PONTIFICIAE
ACADEMIAE
SCIENTIARVM
SCRIPTA VARIA

95

Changing Concepts of Nature at the Turn of the Millennium

PROCEEDINGS

PLENARY SESSION OF THE
PONTIFICAL ACADEMY
OF SCIENCES
26-29 OCTOBER 1998

VATICAN CITY
2000

CHANGING CONCEPTS OF NATURE AT THE TURN OF THE MILLENNIUM

Address:

Pontifical Academy of Sciences
Casina Pio IV, 00120 Vatican City

PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

95

CHANGING CONCEPTS OF NATURE AT THE TURN OF THE MILLENNIUM

PROCEEDINGS

Plenary Session of the Pontifical Academy of Sciences
26-29 October 1998

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

MM

The opinions expressed with absolute freedom during the presentation of the papers and in the subsequent discussions by the participants in the Plenary Session, although published by the Academy, represent only the points of view of the participants and not those of the Academy.

ISBN 88 - 7761 - 070 - 0

The Pontifical Academy of Sciences
Casina Pio IV


PONTIFICIA·ACADEMIA·SCIENTIARVM

CONTENTS

ACKNOWLEDGEMENTS

First of all an expression of gratitude to the Holy Father John Paul II for the enlightening address he made to the Pontifical Academy of Sciences which is printed in these Proceedings. His Holiness has always displayed special solicitude towards the Pontifical Academy of Sciences, as is borne witness to by the provision of our buildings and essential financial support for our activities. I would also like to thank the President of the Pontifical Academy of Sciences, Nicola Cabibbo, who followed the preparations of the plenary session of 1998 with great care and directed its deliberations with great skill. The editors of this publication, Raymond Hide, Juergen Mittelstrass, and Wolf Singer, dedicated great time and energy to producing this volume, and I would like to express to them the gratitude of all our Academicians. All those who participated in this plenary session must also be thanked for their most valuable contributions and energetic input. I would also like to express my gratitude to Dr. Matthew Fforde who revised the texts written in English and performed the task of copy-editor.

Emphasis on the importance of the subject addressed by this publication might appear unnecessary. The research and studies which are presented in the various papers of this volume are a self-evident demonstration of the vital importance of the subject of the concept of nature in the history of Western thought. These papers above all else take into account the contemporary challenges to this concept; however, they fully bear in mind the trajectories and heritage of the past. The method followed in this publication, therefore, encourages looking at what is contemporary with all the benefit of looking at the past, and in particular with reference to the origins and sources of our present systems of understanding. After all, as emerges clearly from these papers, without Aristotle the science of natural physics would not have existed; without medieval metaphysics the innovations promoted by Galileo would not have been possible; and without Galileo the concept of nature embraced by modernity would not have been feasible. As the encyclical 'Fides et

Ratio' stresses with great force, philosophy has the task of bringing out and establishing the horizons of what is, beyond that which merely happens. This includes the great question of what man is, and in addressing ourselves to this question the debate on the concept of nature is of great relevance. We touch here upon the very destiny of man and the earth at a time when scientific and technological progress provides humanity with unprecedented powers of positive and negative intervention.

MARCELO SÁNCHEZ SORONDO

PREFACE

Nature is no longer an easy concept, shared both by the everyday and the scientific understanding. Initially just that part of the world that Man has not made, Nature now includes some of the artificial world built by science and technology. What is the meaning of the concept of Nature at the turn of the millennium for the particle physicist who 'creates' his objects in big machines, or the molecular biologist who rearranges genomes? Is it still Nature that scientists investigate and humanists think of when they speak about Nature and culture and the cultural impact on Nature? Has Nature vanished from our scientific textbooks and understanding? And if so, can we really get along without the concept of Nature in science?

In October 1998 the Pontifical Academy of Sciences held a conference on the 'changing concepts of Nature at the turn of the millennium'. It brought together scientists and humanists from different fields to discuss knowledge and Nature and epistemological questions relating to scientific knowledge and Nature. The topics included changing concepts of Nature (1) in physics, particularly cosmology, particle physics, thermodynamics and complexity theory, (2) in biology, particularly molecular biology, evolutionary biology and the neural sciences (including the nature-nurture distinction and the mind-body problem) and (3) in the humanities in the framework of anthropology (including scientific aspects), linguistics (language as nature and art), ethnology, ethics, and theology. Epistemological questions are raised, for example, by the concepts of complexity, self-organisation, stability/instability and (from a methodological point of view) reductionism versus emergentism involved in modern research on nature.

We are unable to give full details of all the presentations and the discussions they provoked, but this compilation of written accounts by some of the contributors provides a partial record of the proceedings of a most lively and interesting meeting.

Raymond Hide
Juergen Mittelstrass
Wolf J. Singer

THE PONTIFICAL ACADEMY OF SCIENCES

PLENARY SESSION: 26-29 OCTOBER 1998

CHANGING CONCEPTS OF NATURE AT THE TURN OF THE MILLENNIUM

PROGRAMME OF THE PLENARY SESSION

MONDAY 26 OCTOBER

Opening Remarks
Address of President Cabibbo to the Holy Father
Allocution of the Holy Father

Commemoration of Academicians

S. Horstadius – by N. Cabibbo
K. Fukui – by M. Oda
V. Prelog – by A. Eschenmoser
S. Ranzi – by N. Cabibbo
A. Salam – by R. Muradian

Introduction

Historical and Epistemological Aspects of the Concept of Nature
J. MITTELSTRASS

PART I: THE CHANGING CONCEPTS OF NATURE IN PHYSICS

Nature and Particle Physics
N. CABIBBO

Commentator: C. RUBBIA

Cosmology
M. J. REES

LIST OF PARTICIPANTS

Prof. Nicola CABIBBO, President
Rev. Prof. Marcelo SÁNCHEZ SORONDO, Chancellor

THE PONTIFICAL ACADEMY OF SCIENCES
Casina Pio IV
V-00120 Vatican City
Tel.: +39 0669883451 – Fax: +39 0669885218
Telex: (504) 2024 DIRGENTEL VA
e-mail: academy.sciences@acdscience.va

Prof. Vladimir I. ARNOLD
STEKLOV MATHEMATICAL INSTITUTE
Department of Geometry and Topology
8 Gubkina Street
117966 Moscow (Russia)
Tel.: (095) 5958544 – Fax: (095) 1350555
e-mail: arnold@genesis.mi.ras.ru

Rev. Prof. Mariano ARTIGAS
UNIVERSIDAD DE NAVARRA
Facultad Eclesiastica de Filosofia
31080 Pamplona (Spain)
Tel.: (48) 425600 – Fax: (48) 425633
e-mail: martigas@unav.es

Dr. J. Eduardo Athayde
UNIVERSIDADE LIVRE DA MATA ATLANTICA
PO Box 7119
CEP 41811-970 Salvador, Bahia (Brazil)
Tel. and fax: (71) 3362466 – e-mail: uma@fib.br

Rev. F. Rémy BERGERET, O.P.
COUVENT SAINT-THOMAS D'AQUIN
Impasse Lacordaire
F-31078 Toulouse Cedex (France)
Tel.: 62173131 – Fax: 62173117

Dr. Giovanni F. BIGNAMI
AGENZIA SPAZIALE ITALIANA
Via di Villa Patrizi, 13
I-00161 Roma (Italy)
Tel.: 068567413 – Fax: 068567406 – e-mail: bignami@asirom.rm.asi.it

Prof. Dr. Horst BREDEKAMP
HUMBOLDT-UNIVERSITÄT ZU BERLIN
Philosophische Fakultät III
Kunstgeschichtliches Seminar
Unter den Linden 6 – Dorothenenstrasse 28
D-10099 Berlin (Federal Republic of Germany)
Tel.: (30) 20934498 – Fax: (30) 20934209
e-mail: Horst-Bredekamp@rz.hu-berlin.de

Dr. Sydney BRENNER
THE MOLECULAR SCIENCE INSTITUTE
2168 Shattuck Avenue – Second Floor
Berkeley, CA 94704 (U.S.A.)
Tel.: (510) 6470690 – Fax: (510) 6470699

Prof. Dr. Martin CARRIER
UNIVERSITÄT BIELEFELD
Fakultät für Geschichtswissenschaft und Philosophie
Abteilung Philosophie
Postfach 100131
D-33501 Bielefeld (Federal Republic of Germany)
Tel.: (521) 1064596 – Fax: (521) 1065844
e-mail: mcarrier@philosophie.uni-bielefeld.de

Dr. Frank FEHRENBACH
KUNSTHISTORISCHES INSTITUT IN FLORENZ
Via Giusti, 44
I-51121 Firenze (Italy)
Tel.: 0552491152 – Fax: 0552491155

Prof. William D. HAMILTON
UNIVERSITY OF OXFORD
Department of Zoology
South Parks Road
Oxford OX1 3PS (United Kingdom)
Tel.: (1865) 271210 – Fax: 512548
e-mail: william.hamilton@zoology.oxford.ac.uk

Dr. Jeffrey HOFFMAN
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)
U.S. Embassy – NASA European Rapresentative
2, avenue Gabriel
F-75008 Paris (France)
Tel.: (1) 43122100 – Fax: (1) 42658768

Prof. Gerald F. JOYCE
THE SCRIPPS RESEARCH INSTITUTE
Department of Molecular Biology, MB110, MB4B
10550 North Torrey Pines Road
La Jolla, CA 92037 (U.S.A.)
Tel.: (619) 7842017 – Fax: (619) 7842943 – e-mail: lorik@scripps.edu

Prof. Dr. Wolfgang KLEIN
MAX-PLANCK-INSTITUTE FOR PSYCHOLINGUISTICS
PB 310
NL-6500 AH NIJMEGEN (The Netherlands)
Tel.: (24) 3521213 – Fax: (24) 3521213

Prof. Francesca LEVI-SCHAFFER
THE HEBREW UNIVERSITY OF JERUSALEM
Faculty of Medicine – School of Pharmacy
P.O.B. 12065
Jerusalem 91120 (Israel)
Tel.: (2) 6757512 – Fax: (2) 6431094 – e-mail: FLS@CC.HUJI.AC.IL

Prof. Stephen C. LEVINSON
MAX-PLANCK-INSTITUTE FOR PSYCHOLINGUISTICS
Wundtlaan 1 – P.O. Box 310
NL-6225 XD Nijmegen (The Netherlands)
Tel.: (24) 3521911 – fax: 3521300

Prof. Dr. Kuno Lorenz
UNIVERSITÄT DES SAARLANDES
Fachrichtung 5.1 – Philosophie
Postfach 151150
D-66041 Saarbrücken (Federal Republic of Germany)
Tel.: (681) 3022329 – Fax: (681) 3024524 – e-mail: klorenz@rz.uni-sb.de

Rev. Msgr. James T. McHugh, Bishop of Camden
DIOCESE OF CAMDEN
1845 Haddon Avenue – P.O. Box 709
Camden, N.J. 08101-0709 (U.S.A.)
Tel.: (609) 7567900 – Fax: (609) 9632655

Prof. Hubert S. Markl
MAX-PLANCK-GESELLSCHAFT
Hofgartenstrasse 2
D-80539 München (Federal Republic of Germany)
Tel.: (89) 21081211 – Fax: (89) 21081112
e-mail: praesident@mpg-gv.mpg.de

Prof. Jürgen Mittelstrass
UNIVERSITÄT KONSTANZ
Philosophische Fakultät – Fachgruppe Philosophie – Postfach 5560 D 15
D-78434 Konstanz (Federal Republic of Germany)
Tel.: (7531) 882498 – 882745 – Telex: 07 33359 UNIV D – Fax: 882502

Prof. Hannah Monyer
MAX-PLANCK-INSTITUT FÜR MEDIZINISCHE FORSCHUNG
Abteilung Molekulare Neurobiologie
Jahnstrasse 29
D-69120 Heidelberg (Federal Republic of Germany)
Tel.: (6221) 486130 – Fax: (6221) 486110
e-mail: monyer@otto.mpifr-heidelberg.mpg.de

Prof. Giorgio Parisi
UNIVERSITA' DEGLI STUDI DI ROMA "LA SAPIENZA"
Dipartimento di Fisica
Piazzale Aldo Moro, 2
00185 ROMA (Italy)
Tel.: 0649913481 – Fax: 064463158 – e-mail: Giorgio.Parisi@Roma1.infn.it

Prof. Stephen P.R. Rose
THE OPEN UNIVERSITY
Faculty of Science
Department of Biology – Walton Hall
Milton Keynes MK7 6AA (United Kingdom)
Tel.: (1908) 652125 – Fax: (1908) 654167
e-mail: S.P.R.ROSE@OPEN.AC.UK

Rev. don Melchor Sanchez de toca y alameda
PONTIFICIO CONSIGLIO DELLA CULTURA
V-00120 Vatican City
Tel.: 0669887321 – Fax: 0669887368

Prof. Hans G. Schuster
UNIVERSITÄT KIEL
Institut für Theoretische Physik und Astrophysik
Olshausenstrasse 40
D-24098 Kiel (Federal Republic of Germany)
Tel.: (431) 8804127 – Fax: (431) 8804094
e-mail: schuster@teo-physik.uni-kiel.de

Prof. William R. Shea
UNIVERSITÉ LOUIS PASTEUR DE STRASBOURG
International Academy of the History of Science – Institut d'histoire des sciences
7, rue de l'Université
F-67000 Strasbourg (France)
Tel.: (3) 88528029 – Fax: (3) 88528030
e-mail: william.shea@irfest-ulp.u-strasbg.fr

Prof. Petra Stoerig
HEINRICH HEINE UNIVERSITÄT
Institut für Physiologische Psychologie II
Universitätstrasse 1, Bldg. 23.03
D-40225 Düsseldorf (Federal Republic of Germany)
Tel.: (211) 8112265 – Fax: (211) 8114522
e-mail: petra.stoerig@uni-duesseldorf.de

Dr. Axel C. Wiin-Nielsen
NIELS BOHR INSTITUTE OF ASTRONOMY, PHYSICS AND GEOPHYSICS
Department of Geophysics
Juliane Maries Vej 30
DK-2100 Copenhagen (Denmark)
Tel.: (35) 320564 – Fax: 365357 – e-mail: awn@geb.ku.dk
mailing address:
Solbakken 6
DK-3230 Græsted (Denmark)
Tel.: (48) 392384

Prof. Gereon Wolters
UNIVERSITÄT KONSTANZ
FG Philosophie – Fach D15
D-78457 Konstanz
(Federal Republic of Germany)
Tel.: (7531) 882636 – Fax: (7531) 882502
e-mail: gereon.wolters@uni-konstanz.de

Attending Academicians

Arber Werner (Switzerland)
Blanc-Lapierre André (France)
Caffarelli Luis A. (U.S.A.)
Cavalli-Sforza Luigi L. (U.S.A)
Colombo Bernardo M. (Italy)
Coyne George V., S.J. (Vatican City)
Dallaporta Nicola (Italy)
Döbereiner Johanna (Brazil)
Eschenmoser Albert (Switzerland)
Germain Paul (France)
Heller Michal (Poland)
Hide Raymond (United Kingdom)
Jaki Stanley L., O.S.B. (U.S.A.)
Keilis-Borok Vladimir I. (Russia)
Levi-Montalcini Rita (Italy)
Lichnerowicz André (France)
Lojasiewicz Stanislaw (Poland)
Maldamé Jean-Michel (France)

MALU Felix Wa Kalenga (Rep. Dem. Congo)
MANIN Yuri I. (Federal Republic of Germany)
MÖSSBAUER RUDOLF L. (FEDERAL REPUBLIC OF GERMANY)
MOSHINSKY Marcos (Mexico)
MURADIAN Rudolf (Armenia)
ODA Minoru (Japan)
PAVAN Crodowaldo (Brazil)
REES Martin J. (United Kingdom)
RUBBIA Carlo (Switzerland)
SINGER Wolf J. (Federal Republic of Germany)
SZCZEKLIK Andrzej (Poland)
TOWNES Charles H. (U.SA.)
TUPPY Hans (Austria)
WHITE Robert J. (U.S.A.)

ADDRESS OF THE PRESIDENT OF THE PONTIFICAL ACADEMY OF SCIENCES TO THE HOLY FATHER

(27 October 1998)

Holy Father,

for the members of the Academy it is a great honour and very moving to be received in your presence on the occasion of the Plenary Session of the Pontifical Academy of Sciences which is held this week in the Casina Pio IV, the headquarters given to our Academy since its refoundation in 1936 under the pontificate of Pius XI.

I would like to take this opportunity to present you with some of the activities of our Academy over recent years which have been in preparation for the advent of the new millennium. Starting with the Plenary Session held in October 1996, the Academy has engaged in a critical examination of the state of science at the turn of the millennium. At the 1996 meeting the main part of the session was devoted to a review of scientific knowledge pertaining to the important question of the origins of life on earth. The choice of this subject was motivated by the possible detection, during that year, of traces of life, perhaps of fossil micro-organisms, in a meteorite originating from the planet Mars. On that occasion we were able to review the main facts on the possible avenues which might have led to the emergence of life in the hostile environment offered by the earth hundreds of millions of years ago.

These studies, which cannot at the moment be conclusive, illustrate the important progress in the search for life in extraterrestrial bodies, as well as the capability of life to adapt to the hostile environments now present on earth – environments characterised by very high temperatures or extreme chemical conditions.

The present session is devoted to the examination of the concept of 'Nature' and its evolution in the light of the emergence of new scientific concepts: relativity and quantum mechanics in the physical sciences, and the discovery of the molecular basis of heredity and evolution in the biological sciences. The concept of 'Nature' will also be examined in the expressions that it finds in art and in philosophy.

The theme of Nature as opposed to artifice has been present in scientific and philosophical discussion since very ancient times. Nature as observed in our everyday environment is heavily modified by the work of man, by artifice. Artifice is present in man-made structures, in the agricultural modifications of natural habitats, and in the taming of animal species and their adaptation to human needs. Science, however, has identified regions of nature which are not modified and cannot be modified by human activity. These are found in the realm of the very small components of matter revealed by the study of particle physics, which can in certain cases be assembled into useful structures, but never modified, and in the realm of the large structures of the universe which every year reveal new marvels to our constantly improving instruments of investigation.

An important part of the Plenary Session is devoted to the development of scientific ideas concerned with life, in particular the molecular basis of living matter and its evolution. We will than turn our attention to an important area to which the Academy has often returned over the years: the working of the human brain and the mind-brain problem.

In parallel with the investigation of scientific knowledge, the Academy is also engaged in the scientific study of some of the most pressing problems faced by the development of humankind. These will be faced in the course of the year in three workshops devoted to the chemical modification of the environment and its impact on our climate and the biosphere, an ever increasing source of concern; the problems of food production; and the problems of safety in the face of natural violent events. These are themes where the progress of scientific knowledge can lead to important contributions to the well-being of humankind.

Holy Father,

on the occasion of our Plenary sessions we have made available to the Academicians and to the scientists from different regions of the world a copy of your recent encyclical 'Fides et Ratio'. We will study this important document in which you stimulate the search for truth in the field of philosophy and faith. The aim of science is to search for truth in the spirit of honesty which has characterised scientific investigations since very ancient times when these endeavours were considered to be within the scope of the philosopher. We have heard of the emergence of 'weak philosophy' but please rest assured that there is no weak science!

Please accept this expression of our most devoted gratitude to you for having consented to meet us and to illuminate us with your words.

N. CABIBBO

ALLOCUTION OF THE HOLY FATHER TO THE PARTICIPANTS OF THE PLENARY SESSION

Monsieur le Président,

Mesdames et Messieurs les Académiciens,

1. Je suis heureux de vous accueillir ce matin et de vous adresser mes cordiales salutations à l'occasion de l'Assemblée plénière de l'*Académie pontificale des Sciences* sur les changements concernant *le concept de nature*. Je remercie Son Excellence Monsieur Nicola Cabibbo pour les aimables paroles qu'il vient de m'adresser. Je salue cordialement Monseigneur Giuseppe Pittau, ancien Chancelier de votre Académie et je remercie Monseigneur Marcello Sánchez Sorondo, qui a accepté de lui succéder.

Les réflexions que vous entreprenez sont particulièrement opportunes. Dans l'antiquité, Aristote avait façonné certaines expressions, qui ont été reprises et approfondies au Moyen-Age et dont saint Thomas d'Aquin s'est servi pour élaborer sa doctrine théologique. On souhaite que les scientifiques et les philosophes continuent à apporter leur contribution à la recherche théologique et aux différentes formes de la connaissance humaine, pour appréhender toujours plus profondément le mystère de Dieu, de l'homme et de la création. L'interaction des disciplines, dans un dialogue fraternel (cf. Encyclique *Fides et ratio*, n. 33), peut être d'une grande fécondité, car elle élargit notre vision de ce que nous sommes et de ce que nous devenons.

2. Au long des siècles, le concept de nature a été l'objet de multiples enjeux, spécialement en théologie et en philosophie. La conception développée par Ulpien réduisait la nature à l'aspect biologique et instinctif de l'homme (cf. *Inst.*, I, 2). Dans un certain nombre de théories actuelles, on retrouve cette tentation de réduire l'être humain à cette réalité purement matérielle et physique, faisant de l'homme un être qui se comporterait uniquement comme les autres espèces du vivant. L'élargissement du champ scientifique a conduit à multiplier les sens de ce vocable. Dans certaines sciences, il se réfère à l'idée de loi ou de modèle; dans d'autres, il est lié à la notion de régularité et d'universalité; dans d'autres encore il évoque la création prise de manière générale ou selon certains aspects de l'être vivant; dans d'autres enfin, il rend compte de la personne humaine dans son unité singulière, dans ses aspirations humaines. Il est aussi lié au concept de culture pour exprimer l'idée de la formation progressive de la personnalité de l'homme, dans laquelle sont associés des éléments qui lui sont donnés – c'est sa nature – et des éléments qui sont acquis au contact de la société – c'est la dimension culturelle à travers laquelle l'homme se réalise (cf. Aristote, *Le Politique*, I, 2, 11-12). Les découvertes scientifiques et techniques récentes concernant la création et l'homme, dans l'infiniment petit ou dans l'infiniment grand, ont modifié de manière significative le sens du concept de nature, appliqué à l'ordre créé, visible et intelligible.

3. Face à ces différences conceptuelles dans le champ de la recherche scientifique et technique, il est bon de s'interroger sur les acceptions de ce concept, car les répercussions sur l'homme et sur le regard que les scientifiques portent sur lui sont loin d'être négligeables. Le danger principal consiste à réduire un individu à une chose, ou de le considérer au même titre que les autres éléments naturels, relativisant par le fait même l'homme, que Dieu a placé au centre de la création, Dans la mesure où l'on s'intéresse avant tout à des éléments, on est tenté de ne plus saisir la nature d'un être vivant ou de la création, pris dans leur globalité, et de les réduire à des ensembles d'éléments ayant de multiples interactions. De ce fait, l'homme n'est plus perçu dans son unité spirituelle et corporelle, dans son âme, principe spirituel en l'homme qui est comme la forme de son corps (cf. Conc. Vienne, constitution *Fidei catholicæ, DzS*, 902).

4. Dans la philosophie et dans la théologie catholique et dans le Magistère, le concept de nature revêt une importance, qu'il convient de faire apparaître. Il évoque tout d'abord la réalité de Dieu dans son essence même, exprimant ainsi l'unité divine de «la sainte et ineffable Trinité, Père Fils et Saint Esprit, [qui] est un seul Dieu par nature, d'une seule substance, d'une seule nature, ainsi que d'une seule majesté et puissance» (XI^e^ Concile de Tolède, *DzS*, 525). Le même terme rend compte aussi de la création, du monde visible qui doit son existence à Dieu et qui s'enracine dans l'acte créateur par lequel «le monde a commencé quand il a été tiré du néant» (*Catéchisme de l'Eglise catholique*, n. 338). Selon le dessein divin, la création trouve sa finalité dans la glorification de son auteur (cf.

Lumen gentium, n. 36). Nous percevons donc que ce concept exprime également le sens de l'histoire, qui vient de Dieu et qui va vers son terme, le retour de toutes les choses créées en Dieu; l'histoire ne peut donc pas être entendue comme une histoire cyclique, car le Créateur est aussi le Dieu de l'histoire du salut. «Le même et identique Dieu, qui fonde et garantit l'intelligibilité et la justesse de l'ordre naturel des choses sur lesquelles les savants s'appuient en toute confiance, est celui-là même qui se révèle Père de notre Seigneur Jésus-Christ» (Encyclique *Fides et ratio*, n. 34).

Au moyen de sa raison et des différentes opérations intellectives, qui sont proprement la nature de l'homme considéré en tant qu'homme (cf. S. Thomas d'Aquin, *Somme thélogique*, I-II, q. 71, a. 2), l'homme est «capable par nature d'arriver jusqu'au Créateur» (Encyclique *Fides et ratio*, n. 8), en contemplant l'œuvre de la création, car le Créateur se fait reconnaître à travers la grandeur de son œuvre. La beauté de celle-ci et l'interdépendance des réalités créées poussent les savants à l'admiration et au respect des principes propres de la création. «La nature, objet propre de la philosophie, peut contribuer à la compréhension de la révélation divine» (*Ibid.*, n. 43). Cette connaissance rationnelle n'exclut pas cependant une autre forme de connaissance, celle de la foi, fondée sur la vérité révélée et sur le fait que le Seigneur se communique aux hommes.

5. Lorsqu'on l'applique à l'homme, sommet de la création, le concept de nature prend un sens particulier. Le seul être sur la terre que Dieu a voulu pour lui-même a une dignité qui lui vient de sa nature spirituelle dans laquelle se trouve l'empreinte du Créateur, car il a été créé à son image et à sa ressemblance (*Gn* 1, 26), et doté des plus hautes facultés que possède une créature: la raison et la volonté. Celles-ci lui permettent de se déterminer librement et d'entrer en communication avec Dieu, pour répondre à son appel et se réaliser selon sa nature propre. En effet, parce qu'il est de nature spirituelle, l'homme est capable d'accueillir les réalités surnaturelles et de parvenir au bonheur éternel, gratuitement offert par Dieu. Cette communication est rendue possible car Dieu et l'homme sont deux essence de nature spirituelle. C'est ce qu'exprimait Grégoire de Nazianze, lorsqu'il parlait du Seigneur ayant revêtu notre nature humaine: «Le Christ guérit le semblable par le semblable» (*Oratio*, 28, 13). Dans la perspective de ce Père cappadocien, l'approche métaphysique et ontologique nous permet d'appréhender le mystère de l'Incarnation et de la Rédemption, par lequel Jésus, vrai Dieu et vrai homme, a assumé la nature humaine (cf. *Gaudium et spes*, n. 22). Parler de nature humaine rappelle aussi qu'il y a une unité et une solidarité de tout le genre humain. Car

l'homme est à considérer «dans la pleine vérité de son existence, de son être personnel et en même temps de son être communautaire» (Encyclique *Redemptor hominis*, n. 14).

6. Au terme de notre recontre, je vous encourage à poursuivre votre travail scientifique dans un esprit de service rendu au Créateur, à l'homme et à l'ensemble de la création. Ainsi, les êtres humains loueront Dieu car tout vient de lui (*1 Ch* 29, 14); ils respecteront la dignité de tout homme et trouveront la réponse aux questions fondamentales de leur origine et de leur fin ultime (cf. Encyclique *Fides et ratio*, n. 1). Ils prendront soin de la création, «voulue par Dieu comme un don adressé à l'homme, comme un héritage qui lui est destiné et confié» (*Catéchisme de l'Eglise catholique*, n. 299), et qui est bon par nature (cf. Concile de Florence, Bulle *Cantate Domino, DzS*, 1333).

En vous souhaitant des travaux fructueux dans un dialogue riche entre les différentes disciplines que vous représentez, je vous accorde de grand cœur la Bénédiction apostolique.

COMMEMORATION OF ACADEMICIANS

Sven Hörstadius

It is my sad duty to inform the Academy of the death of one of our most valued colleagues, but it is also a great honour for me to commemorate the memory and career of an eminent scientist, learned scholar, and most valuable member of our Academy. Sven Hörstadius passed away on 16 June 1996, and his absence is greatly felt. Sven Hörstadius was a zoologist who specialised in the study of sea urchins and amphibian eggs and larvae. Born in Stockholm in Sweden in 1898, he was not only a distinguished scientist in his own country but also a zoologist of world renown, being among other things member of the Zoological Societies of Great Britain, France and Belgium, and of the Accademia dei Lincei of Rome. His main publications were concerned with his area of specialisation, and perhaps his most famous works was on experimental embryology.

He was appointed a member of the Academy in August 1961 and his active presence at numerous meetings constituted a valuable contribution to the work and deliberations of our institution. Sven Hörstadius was a dedicated scholar who represented the best scholarly and humanitarian traditions of his country. He was a well liked and respected figure who always encouraged and supported his colleagues in their research activities. At a human level, he was known for his sensitivity and human concern. He will be missed by us all, and will be remembered not only as an eminent scientist and leading specialist in his field, but also as a human being of depth, feeling, and commitment.

N. CABIBBO

Professor Fukui: a Quiet but Strong Scientist

Professor Ken-ichi Fukui passed away on 9 January 1998. He was appointed a Pontifical Academician in 1986. His last contribution to the Academy was at the Plenary Meeting of 1996 when he presented a paper on: 'The Possibility of the Chemical Creation of Definite-Sequencepolymers'.

Fukui was born in 1918 in Osaka, Japan, to an old family of the Nara area. After finishing his science (German-major) course at Osaka high school he entered the department of chemistry (chemical engineering course) of Kyoto University. This period of the 1930s to the early 1940s was when quantum mechanics (QM) flourished in physics. This was not so much the case in chemistry, although chemists such as Linas Pauling had introduced QM into chemistry. Relatively little was known about electronic bonds in chemical reactions; indeed, the subject was not much studied.

As a student of Kyoto University, and later as a young member of the University's faculty after serving as a technical officer in the army during the last period of the war, he seemed to have been deeply immersed in the cultural atmosphere of Kyoto. Japan's culture has been well represented by Kyoto since the Heian era of the seventh to eighth centuries and the Muromachi era of the thirteenth to fourteenth centuries. Even now, we recognise intellectuals from Kyoto; we often say that the Kyoto school is unique, being backed as it is by an ancient cultural tradition both in literature and science.

Among physicists I may cite Professor Yukawa as being typical of the scientists deeply influenced by Kyoto culture. Prof. Fukui belonged to this category. Prof. Fukui originally entered the school of chemical engineering of Kyoto University, but his capacities at the level of theory soon led him to study QM. It was not common, then, for chemistry students to do this so he joined the physics course.

After the end of the war, in 1945, he gathered a group of young theoretical chemists around him who developed the concept of the 'frontier orbital in the chemical reaction'.

He and his colleagues expanded their ideas to a wide ranging theory of orbital interaction. With these ideas he met Professor Roald Hoffman of Cornell around 1964, with whom he later shared the Nobel Prize of 1981.

As Japan's first Nobel Laureate in Chemistry, he could not avoid heavy burdens being placed on his shoulders.

This was too much for this quiet, even shy, intelligent gentleman. But, as an ancient Samurai-like gentleman as I call him, he quietly managed his social duties beautifully. He served for a number of committees on scientific policy.

I met this wonderful senior gentleman rather late in his activities, at one of these committee meetings. I immediately noticed the beautiful combination of the Kyoto school spirit and his insights as a scientist. I watched him growing as an important figure in the Japanese university world.

After I was appointed a Pontifical Academician, as a senior Academician he often instructed me when he could not participate at the Plenary Meetings himself.

I now regret that I had not met him earlier and grown to know him more deeply.

M. ODA

Vladimir Prelog

Vlado Prelog, who had been a member of this Academy since 1986, died at the age of 91 in Zurich on the seventh of January of this year, after a brief illness.

The life and career of Vlado Prelog reflects the history of our continent during this century in a quite extraordinary way. Born in Sarajevo (Bosnia) in 1906, the son of Croatian parents, he was among the school children summoned on 28 June 1914 to stand on the street and throw flowers in front of the state carriage of the visiting Austrian Crown Prince, Archduke Franz Ferdinand, and heard the shots that presaged the end of an era. After childhood and adolescence, he studied chemistry at the Institute of Technology in Prague, worked in this city through the years of economic depression as a chemist in a small industrial laboratory, and was finally able to begin an academic career in Zagreb (Croatia) only to be caught up by the Second World War when Yugoslavia became occupied by the German army. Under adventurous circumstances Prelog was lucky to be able to escape from Yugoslavia in 1941 and to reach Switzerland, thanks to the intervention and help of Leopold Ruzicka, who was at that time director of the Organic Chemistry Laboratory of the Swiss Federal Institute of Technology and had been awarded the Nobel prize in 1939. The ETH in Zurich, at the outset for

Prelog only a temporary refuge, became his permanent scientific home with which he was to remain associated for more than fifty years. There he lived and had a splendid professional career, becoming, through his outstanding work and teaching, one of the world's leading stereochemists. He followed in the footsteps of his great fellow countryman Ruzicka, also a former member of this Academy, by becoming director of the Institute of Organic Chemistry at ETH after Ruzicka's retirement, and by receiving the Nobel prize in chemistry in 1975.

Probably the most-lasting contributions of Prelog to science relate to the fundamental phenomenon of chirality, the handedness of things, the property of some idealised objects of NOT being superimposable with their own mirror image. We say of such an object that it is chiral. In observing the material world at sufficiently high structural resolution all material objects of the macroscopic world are structurally different, unique and chiral – no wave that reaches a beach is identical to any other wave that has reached or will ever reach the same beach at any other time, and all these waves are chiral. However, on the level of categorising abstraction, idealised models of material objects may become identical, and many of them may display specific elements of symmetry, as a consequence of which their chirality vanishes. Such models are said to be achiral. The level of abstraction used by the chemist in studying the structure and behaviour of matter is the level of molecules. Molecules – observed at low time resolution – can be achiral or chiral. Complex molecules are chiral at any time resolution and almost all biomolecules, most importantly all proteins and all nucleic acids, are chiral. When chiral molecules interact, their sense of chirality, left-handed or right-handed, is crucial for the interaction. Living systems operate with molecules of only one specific sense of chirality, it is the sense of handedness, which they have evolved to.

Vladimir Prelog was, in his time, perhaps the foremost scientist world-wide in the field of studying, analysing and categorising the consequences of molecular chirality with respect to both the diversity of, and the reactivity between, molecules. Through him and his work, an entire generation of chemists and biochemists was led to a sharpened comprehension of the nature and the consequences of molecular chirality in chemistry and biology. Together with Cahn and Ingold, Prelog created a comprehensive system of categorisation and specification of molecular chirality which today constitutes a basic part of the language by which chemists, biochemists and biologists describe the molecular world.

Prelog's predilection for stereochemistry, the part of chemistry that is concerned with all aspects of the shape of molecules, was intimately connected to his lifelong involvement in natural products chemistry, in the classical tradition in which he had grown up in Prague. It was mainly through studying natural products, mostly produced by plants, that chemistry in its first hundred years gradually uncovered the virtually unlimited diversity of the world of molecular shapes. In this field and early in his career, Prelog made important contributions to the elucidation of the structure of complex alkaloids, the constituents of plants, quite often of great medical interest. In his later years his school was highly successful in determining the structures of a series of chemically as well as therapeutically important antibiotics.

Among the organic chemists of his time, few had such a broad range of interests within their field as Prelog. His ability to bridge in his own work the gap between the classical tradition of natural products chemistry and the post-war developments in physical-organic chemistry was exceptional. Characteristically, of the two influential group of leading figures in organic chemistry of the time, the natural-product-group and the physical-organic-chemistry-group, he managed to be a member of both.

If anything outshone the lustre of Prelog's reputation as a scientist, it was the brilliance of his personality. He was a man who by nature evoked in others love and admiration for him. A great many colleagues from all over the world saw in him a friend. It was not only his charm, his wit and humour, his inexhaustible supply of anecdotes and his great art of telling them, it was also that unique blend of all this with his basically introspective nature, his personal modesty, his smiling at himself, and the warmth with which he would approach other people. Perhaps equally important, Prelog, a scholar and true man of science, was fundamentally uninterested in power. The name of Prelog, the scientist, will live on in the annals of chemistry. For those who are so fortunate to have known him, it is Vlado, the human being, who will be remembered with great affection.

A. ESCHENMOSER

Silvio Ranzi

It is with great regret that I must inform the Academy of the death of our valued and admired honorary Academician, Silvio Ranzi. Yet at the same time it is a great honour for me to remember his many achievements as a scholar and scientist, and his many attributes and high qualities as a human being. Silvio Ranzi was born in Rome, Italy, in 1902, and graduated in natural sciences at the University of Rome in 1924. He became a famous biologist and zoologist both in his home country and abroad, and specialised in comparative embryology and developmental zoology. During the thirties he made important contributions to the study of the natural cycle of the parasite responsible for malaria, then a common disease in Italy, but which remains a world menace today. Later in his career he developed a special interest in ecology and evolution. In this he was somewhat ahead of his times, these being issues and questions of great topical relevance as we move towards the third millennium. He was the author of many important and incisive publications, and received a number of prizes and the memberships of various internationally famous institutions.

Silvio Ranzi was appointed an honorary member of the Pontifical Academy of Sciences in May 1981, and his contributions to our meetings and publications were always valuable, lively, and greatly appreciated by his colleagues. He was a loyal and devoted family man and will be remembered for his warm and cordial spirit which was noticed and felt by all those who came into contact with him. His scientific research was strongly rooted in a committed faith which sustained him and energised him throughout his life. He will remain an example to us all and his presence will be greatly missed.

N. CABIBBO

Abdus Salam

Professor Abdus Salam, Pontifical Academician, Nobel Laureate in Physics (1979), founder and director of the International Centre for Theoretical Physics (ICTP), Trieste, Italy, died in Oxford on 21 November 1996, after a long and heavy illness. He was buried in Pakistan where he was born in 1926, in Jhang, the region of the former British India.

Salam wrote: 'There was no question, I was very fortunate. If I had not been awarded a scholarship by the Indian Government it would have been totally impossible, financially, for me to come to Cambridge.' Salam won the scholarship due to some miracle. During the Second World War India helped the British war effort. To this end, one Indian politician collected a fund of about £15,000. But war ended and he decided to institute five scholarships for foreign education. One of the selected was

Salam. He went to Cambridge in 1946, but the other four students selected never made it because the benefactor died that year and their scholarships were cancelled. In his interview with Dr. Robert Walgate, Salam remembered: 'Now one could call it a set of coincidences; but my father didn't believe this. He had desired and prayed for this and saw this – I think, rightly – as an answer to his prayers.' In 1952 Salam obtained his PhD at the Cavendish Laboratory and was invited by Blackett to guide theoretical particle physics research at Imperial College.

In 1959 he was elected Fellow of the Royal Society. He was elected in all to the membership of 34 Academies and prestigious societies in 24 countries, including the USSR Academy of Sciences. He received 45 Doctor Honoris Causa awards in 28 countries, in addition to many medals for contributions to peace and international collaboration. Professor Salam was widely known for his charismatic nature in international scientific circles. The ICTP has played an important role in providing opportunities for the interaction of physicists of different cultures and different religious and political views. During the Cold War it was almost the only institution where Soviet scientists could establish contacts with Western colleagues. Salam was a legend when it came to his successes on the political front. He had meetings with John F. Kennedy, Zhou En-lai, and François Mitterand to discuss the problems of scientific interaction between developing and developed nations.

Salam had the dream of creating twenty international Centres with ICTP as a model in different areas of science and technology and in different countries. He also had the dream of founding an international 'World University.' He realised a part of these dreams, despite his illness during the last eight years of his life. For example, he created the International Centre for Genetic Engineering and Biotechnology (Trieste, Delhi), and the International Centre for Science and High Technology in Trieste.

He was the founder and first president of the Third World Academy of Sciences. It is interesting to note that Italy, which was by no means the wealthiest country in Europe, permanently and faithfully sponsored the organisational initiatives of Professor Salam.

Professor Salam was one of the main architects of modern physics. In particular, he is famous for his contribution to Electroweak Theory, part of the Standard Model of Particle Physics, one of the greatest intellectual achievements of the twentieth century.

R. Muradian

SCIENTIFIC PAPERS

INTRODUCTION

HISTORICAL AND EPISTEMOLOGICAL ASPECTS OF THE CONCEPT OF NATURE

JUERGEN MITTELSTRASS

Nature is a key word in the history of European thought – in science, philosophy and theology. Even presocratic philosophy, which we take to be the beginnings of scientific thinking, wrote extensively about nature – περὶ φύσεως, *de natura* –, and its expounders wrote about thunder and lightning, solar eclipses, earthquakes and magnetic phenomena, but also about coming to be and passing away and about the essence of things. Philosophy began as philosophy of nature, and the subject matter of this philosophy of nature included both the things of nature and the nature of things. This means in turn that scientific, epistemological, and metaphysical aspects are closely associated in the concept of nature; and this applies not only to the beginnings of science, epistemology, and metaphysics, but also to their later histories.

Nature, according to the original meaning of φύεσθαι as "to take form on its own" or φύσις "the genesis of growing things,"[1] both in everyday language and in the language of science, is that part of the world that Man has not made or that part whose coming to be, whose ("regular" or "lawlike") appearance and effectivity is independent of human intervention, or at least can be thought to be so. The counterpart was technique and culture. By means of technique (τέχνη) – even with the early Greeks – that is, by means of art and skill, natural human abilities are augmented with artisan skills; by means of the law (νόμος) that organizes the cultural reality of Man, natural orientations and activities are restricted or subjected to the rule of law. Plato asserted in this connection a rational correlation of *nomos* and human nature. In other words, scientific and philosophical orientations are joined together in the

[1] Aristoteles, *Met.* Δ4.1014b16-17.

concept of nature, whereby the dominant notion at first is that a knowledge of the nature of things is also developed within the knowledge of the things of nature.

In the following I shall discuss more closely the history of the concept of nature, emphasizing the epistemological aspects. I have chosen the form of thesis plus brief explication, and with this I seek to do justice to both the philosophical and the scientific interest in the concept.[2]

1. *According to an ancient notion, nature is the great "other" of our world, the imperishable being that stands behind all realities. This notion is deceptive. In the transformation of nature into the human world nature loses its naturalness. It becomes itself a product, a work of Man.*

The concept of nature is like the Church Father Augustine's concept of time: If no one asks us about it, we know what nature is; if someone asks us, we don't know. At least not exactly. If we originally conceive of nature as that which Man has not made, we overlook the fact that when Man became Man this was also accompanied by the beginning of nature's becoming culture, that is, the transformation of the "natural" world into the human world. Wherever Man has created a cultural world around him, he has also changed nature and appropriated it. And this holds not only for Man in our times but also for Man in the Stone Age. The Stone Age too was a cultural age that appropriated nature in its own manner. In the human world there has never been an "untouched" nature. Clearing, burning, hunting, plowing furrows, redirecting watercourses, digging up the earth in search of minerals, and producing waste, Man has always appropriated nature, true to the biblical command to subjugate the world. He has made the world his environment and thus a cultural nature.

This means however that such notions of nature are illusory in which nature is conceived as a being beyond our being, over which, though we are joined to it by our own naturalness, we are nonetheless not master and which we basically cannot even understand. The times in which nature was interpreted as an unchanging natural being, as the great being

[2] Some of this material is based on two earlier studies: J. Mittelstrass, 'Das Wirken der Natur: Materialien zur Geschichte des Naturbegriffs,' in F. Rapp (ed.), *Naturverstädndnis und Naturbeherrschung: Philosophiegeschichtliche Entwicklung und gegenwärtiger Kontext* (Munich, 1981), pp. 36-69; R.J. Brown and J. Mittelstrass (ed.), *World Pictures. The World of the History and Philosophy of Science* (Dordrecht, 1989), pp. 319-341.

behind all the beings that belong to our world, have long since passed. This was the notion of an *active* and *acting*, sometimes even divine nature, a nature like an intelligent agent, guided by rational and economical points of view, that nourishes and teaches Man to survive in his world by imitating its abilities and its purported wisdom. Even Galileo at the beginning of the modern age subscribed to this notion at times, for instance when he said "that God and nature are concerned with the government of humans affairs".[3] Even in the context of natural science, as Robert Boyle, a physicist and one of the founders of the Royal Society pointedly phrased it as late as 1686: nature was considered to be "a most wise being, that does nothing in vain; does not miss of her ends; does always that, which (of the things she can do) is best to be done; and this she does by the most direct or compendious ways, neither employing any things superfluous, nor being wanting in things necessary; she teaches and inclines every one of her works to preserve itself".[4]

The further development of natural science soon left little of this notion of nature. For Boyle himself the notion had scarcely more than metaphorical meaning. And this is also true of the philosophy of Jean-Jacques Rousseau and Immanuel Kant. Both of them attempt to rehabilitate, at least with *practical* intent, the older notion of nature that has nothing more to say to the scientific or theoretical understanding. Thus Rousseau measures morality by proximity to the natural, that is, to the state of nature which was replaced by the state of society; according to Kant, it is a plan of nature's that has led Man out of his natural history, in which he was nothing but a natural creature, into a history of freedom, a history of becoming autonomous. Nature changes places here in the human orientational system: It no longer stands for the physical conditions of human existence, but for the idea of Man as an ethical being.

But this notion, too, has become rather forceless today. An appeal to nature strictly speaking creates no legitimating structures at all, neither from a theoretical perspective (as in the history of the original Greek concept of nature) nor from a practical perspective (as in Kant and Rousseau). The same applies to ecological affairs. We have to make it

[3] G. Galilei, 'Dialogi sopra i due massimi sistemi del mondo (1632) III', in *Le Opere di Galileo Galilei, Edizione Nazionale, vols. I-XX* (Florence, 1890-1909), vol. VII, p. 394.

[4] 'A Free Enquiry into the Vulgarly Receiv'd Notion of Nature' (London, 1686), in T. Bird (ed.), *The Works of the Honourable Robert Boyle, vols. I-VI* (London, 1772), vol. V, p. 174.

clear to ourselves that modern Man as a member of a technological culture has increasing difficulty in saying exactly what and where nature is. Nature – what is meant is mainly what we miss: the green world in front of our doors, the ever constant, imperishable source of life, whose perishable part we ourselves are. Where nature is found today, it is a (gradually more scarce) raw material resource or the ground on which technological cultures build and into which they dump their wastes, or a leisure time scenario filled out by the colourful dreams of the tourist industry. Nature, in other words has long since become a part of technological cultures, a part of "Spaceship Earth" – in the fitting language of a technological culture. Wherever we go "in nature" we find that the knowing, building, producing, managing and destroying intellect has long since been there already. Even the climate, for instance, in the form of warm and cold fronts, which has up to now been the paradigm of undisposable naturalness, has turned out to be influenced by technological cultures. Is nature the great "other" of our artificial worlds? This could lead to disappointments along the paths of the modern technological cultures that have become ubiquitous.

2. *In the history of the concept of nature the familiar picture of a natural nature has turned around into an artificial world. In an Aristotle-world, which came down to the modern world in the philosophy of nature of the Renaissance, the work-like has become the essence of nature, too.*

What at first glance might seem to be a trivial relation between nature and a work or product of man proves on closer inspection in historical perspective to be a genuinely immanent and at the same time surprising relation, in as much as the question of the paradigm function of nature for everything work-like is answered by determining that the work-like functions as the paradigm for everything natural. Nature is not originally the opposite of everything work-like but rather itself possesses a "worklike" or, as the Greeks said *poietic* essence (from ποίησις, productive action). The point of departure is given by the Aristotelian concept of nature. Nature, according to Aristotle, can be grasped by viewing it as a system of producing or fabricating activity, as a *poietic* system. The Aristotelian philosophy of nature explained what comes into being and how it comes into being by the way in which it is *brought about* or brings itself about.[5] Nature is a production context and as such, not as a

[5] *Met.* K9.1065b15-16, see also *Met.* K9.1065b21ff., K9.1066a27ff.; *Phys.* Γ1.201a11-12.

"natural" context in our sense, it was the paradigm of *poietic* action. Human poiesis in this sense is an imitation not of "natural" nature but of *poietic* nature, that is, of a nature that itself has a "building" essence. Aristotle expressed this in really *poietic* manner in his *Physics* as follows: "If a house were a thing created by nature, it would have been created in a way similar to that in which it is created by art. So if things by nature were to be created not only by nature but also by art, they would have been created just as they are by nature disposed to be created. Also in nature they would have been created according to the order of means and aims. In general, in some cases art completes what nature cannot carry out to an end, in others, it imitates nature".[6] According to the Greek view, or in an Aristotle-world, Man and nature have the same structure, namely a *poietic* structure.

It is then the later distinction between a *natura naturans*, that is, a creative nature, and a *natura naturata*, or created nature, that makes room for Platonic notions within the conception of Aristotelian philosophy of nature against the background of the concept of *poiesis* that dominated this conception. For Plato the natural world is not the result of the cooperation of "natural things," but the work of a demiurge. *Poiesis* in Aristotle's sense appears here restricted to a "technological" aspect, no longer as the self-organization of natural things (as in Aristotle), but as the activity of an awesome artisan, whom the fledgling Christian tradition soon identified with the creator God: The "order of nature" (*ordo naturae*) owes itself to God's continuing creative power (*potentia fabricatoria*) – according to Augustine.[7] At the same time the "infinite nature" (*natura infinita*) becomes the *mundus archetypus*, that is, the intelligible or archetypal world,[8] after which Plato's sensible world is fashioned, and the "finite nature" (*natura finita*) becomes the *mundus sensibilis*, the sensible world.[9] In other words: In the (Christian interpretation of the) *poiesis* metaphor the Aristotelian and Platonic notions of a natural world come to be joined. At the same time we have here before us – reaching far beyond the natural philosophical context – the origin of the later hermeneutical

[6] *Phys*. B8.199a12-17.

[7] *De civitate Dei* XII 26 (ed. by B. Dombart, vols. I-II, Leipzig 1877/1905), vol. I, p. 553.

[8] A translation of παράδειγμα (Tim. 38c) with '*archetypus*' already appears in the *Timaeus*-translation by Calcidius (*timaeus a Calcidio translatus commentarioque instructus*, ed. by J.A. Waszink, London and Leiden, 1962, p. 30).

[9] See J.S. Eriugena, *De divisione naturae* II 1 (MPL, vol. 122, 523D-526C, also I 1 MPL, vol. 122, 441B-442B).

production metaphor: we can only *understand* what we have *made* ourselves or what can be reconstructed as the result of a production process; in the antique tradition, for instance Lactantius: "Only the author knows his work".[10]

The philosophical tradition discussed this relationship especially under the concepts of art and nature. Thus Cardinal Nicholas of Cusa – alluding to the Aristotelian proposition, often cited in the Middle Ages, that art imitates nature (meaning once again the poietic nature) – pointed out that art not only presupposes nature but also expands it. This again is in accordance with Aristotle's definition, that in some cases art completes what nature leaves incomplete, while in others it imitates nature.[11] Cusanus, however, goes beyond this by dissolving the conceptual opposition between nature and art. He says "that nothing can exist which is either nature or art; all things rather share both nature and art".[12] As examples Cusanus here uses language, because it results from art but rests upon nature, and also (logical) inference, which according to Cusanus "belongs to the nature of Man but relies upon art".[13]

Especially in Renaissance thought, again beginning with Nicholas of Cusa, it becomes clear how strongly the architectonic notions predominate. According to Cusanus, divine art is the paradigm of human art,[14] knowledge of the world without knowledge of (the creating) God is impossible. Hence imitating means imitating God's infinite art (*ars infinita*),[15] which can be studied in nature.[16] "Our mind," Cusanus writes, "understands God analogous to the way we understand a builder exercising his capacity as an artisan".[17] This finally establishes the structural identity of nature and art, already indicated in the Aristotelian concept of *poietic* nature and used in substituting the concept of the

[10] *De opificio Dei* 14,9 (*Opera omnia*, vols. I-II, ed. by S. Brandt, Prague and Vienna and Leipzig, 1890/1893 [CSEL, vols. XIX/XXVII]) vol. II, p. 50.

[11] See footnote 6.

[12] *De coniecturis* II 12 n. 131 (*Werke*, vols. I-II, ed. by P. Wilpert, Berlin, 1967, vol. I, p. 169).

[13] *Ibid.*

[14] *Idiota de sapientia* I 23 (*Werke*, vol. I, p. 224); *De ludo globi* I 45 (Werke, vol. II, pp. 591ff.).

[15] *Idiota de mente* 10 n. 127 (*Werke*, vol. II, p. 263), 2 n. 61 (Werke, vol. I, p. 240).

[16] Nature in this context is preferably called *machina mundi*, see *De docta ignorantia* II 11 n. 156 (*machina mundana, Werke*, vol. I, p. 61), II 12 n. 162 (*machina mundi, Werke*, vol. I, p. 63), II 13 n. 175 (*machina mundi, Werke*, vol. I, p. 67), II 13 n. 179 (*machina mundi, Werke*, vol. I, p. 69); *De venatione sapientiae* 32 n. 95 (Werke, vol. II, p. 563).

[17] *Idiota de mente* 13 n. 146 (*Werke*, vol. I, p. 271).

created thing (τέχνῃ ὄν) for the concept of the natural thing (φύσει ὄν) in the Platonic tradition. And just as the idea of nature in natural philosophy is now basically determined by architectonic metaphors, so thought itself is seen as a *poietic* capacity (*virtus fingendi*). The prime example of this for Cusanus is the art of the potter, the sculptor, the blacksmith and the weaver.[18] Plato's demiurge becomes the paradigm of a *constructing* mind and of the Renaissance builder: "The visible globe", Cusanus writes in *De ludo globi*, "is the image of the invisible globe which exists in the mind of the artisan (*in mente artificis*)".[19]

In the natural philosophy of the Italian Renaissance, this kind of poietic metaphor acquires additional weight, especially in the context of Florentine Platonism. "All parts of the universe," Marsilio Ficino writes in *De amore*, "are the works of one artist and the limbs of a single structure".[20] For Giovanni Pico della Mirandola as well, who along with Ficino was the most important representative of Florentine Platonism, God is the "highest architect"[21] who creates the "cosmic system" in accordance with an archetypal pattern (*mondo intelligibile*).[22] Natural causalities are "instruments" of the divine architect. At the end of the creation, the divine architect determined Man to be the spectator of the universe (*contemplator mundi*) "who is to examine thoughtfully the reason in this sublime work, to love its beauty, and to admire its greatness".[23] As a being without archetype Man is called an *artifex*, an architect: He himself is to determine the "form" in which he wishes to live.[24] Once again it is the concept of the poietic, that connects Man and nature with one another, an architecture-like *poietic*. And precisely this was intended when I spoke of the immanent but surprising relation between nature and work: In the concept of *poietic* nature or of the divine architect, it is architecture or construction that shows itself to be the

[18] *De ludo globi* I 44 (*Werke*, vol. II, p. 591).

[19] *Ibid*.

[20] *Opera omnia*, vols. I-II (Basel 1576), vol. II, 1330. Cf. P.O. Kristeller, *The Philosophy of Marsilio Ficino* (Gloucester Mass. 1964) pp. 111ff.

[21] *Oratio de hominis dignitate*, in G. Pico della Mirandola, *De hominis dignitate, heptaplus, De ente et uno, e scritti vari* (ed. by E. Garin, Florence 1942, *Edizione Nazionale dei Classici del Pensiero Italiano*, vol. I) (quoted in the following as: *Ed. Naz.*, vol. I), p. 104 (= *Opera omnia*, vols. I-II, Basel 1557, vol. I, p. 314).

[22] *Commento alla canzona d'amore* I, 4-6, *Ed. Naz.*, vol. I, pp. 465ff. (*Opera omnia*, vol. I, p. 898ff.).

[23] *Oratio de hominis dignitate*, *Ed. Naz.*, vol. I, p. 104 (*Opera omnia*, vol. I, p. 314). The same conception in Cusanus, *De docta ignorantia* II 13 n. 179 (*Werke*, vol. I, p. 69).

[24] *Oratio de hominis dignitate*, *Ed. Naz.* vol. I, p. 106 (*Opera omnia*, vol. I, p. 314).

paradigm also of all natural processes. Nature has a worklike or architectonic essence.

No one expressed the Greek and Renaissance unity of nature and architecture more vividly than the astronomer Johannes Kepler: "We perceive," he writes in the dedication letter of his *Mysterium cosmographicum* (1596), "how God, like one of our own architects, approached the task of constructing the universe with order and pattern, and laid out the individual parts accordingly, as if it were not art which imitated Nature, but God himself had looked to the mode of building of Man who was to be".[25] Here in an impressive architectonic metaphor the notion of a *poietic* essence of nature in an Aristotle-world is not only once again brought to expression, but also a new paradigm of science and nature, the *technological paradigm* of the modern natural sciences is announced – and with it a new world, which I call the *Leonardo-world*.

By "technological paradigm" I mean that the natural sciences today in the manner of laboratory sciences to a large extent "produce" their objects themselves and study them after or in the course of their production, in other words, that natural scientific "discoveries" are owed essentially to the conditions of technological practice. In the research activity of the natural sciences nature becomes (to a large extent) an artefact. By "Leonardo-world" I mean that the modern world as a whole itself has a *technological form*. It is a world named after the great Renaissance engineer, architect, scientist, and artist, Leonardo da Vinci, a world that is ever less a natural world and ever more a fabricated world, ruled by science and technology and out of which Noah's Ark has become Spaceship Earth. Once again: Wherever we go in our world, the building, constructing, producing, administrating and destroying intellect is always there before us. The Leonardo-world, in which technological cultures live today, is the consistent further development of the Aristotle-world; in it the constructive essence of Man, his essence as *homo faber*, unfolds its full reality. Man makes his own world and his (inner and outer) nature.

[25] *Prodromus dissertationum cosmographicarum continens mysterium cosmographicum, Gesammelte Werke* (ed. by W. v. Dyck/M. Caspar/F. Hammer, Munich 1937ff.), Vol. I, p. 6 (1596), vol. VIII, p. 17 (1620) (engl. by A.M. Duncan, in Johannes Kepler, *Mysterium Cosmographicum/The Secret of the Universe*, Translation by A.M. Duncan, Introduction and Commentary by E.J. Aiton, with a Preface by I. Bernard Cohen, New York, 1981), pp. 53/55.

3. *The history of the philosophical concept of nature is repeated in the history of the scientific concept of the world or nature in the natural sciences. Alongside the Aristotle-world we find the Hermes-world, the Newton-world, the Einstein-world, and the Heisenberg-world.*

What was expressed in the concept of nature in philosophy has a counterpart in the concept of nature in science. Here it is especially the (natural scientific) world pictures that make it clear that nature itself is a cultural concept. This in turn is expressed less in the interpretation of the worklike, artefactual character of nature than in the (apparent or real) relativity of these world pictures. These, too, turn out to be "artefacts," that is, results or presuppositions of scientific theories of nature. To demonstrate this state of affairs, let me adduce the following four examples of natural-scientific world pictures or nature-pictures: the (already mentioned) Aristotle-world, the Hermes-world, the Newton-world, and the Einstein-world. In these worlds, and in a Heisenberg- and a Darwin-world as well, nature begins to dissolve into scientific constructs.

The *Aristotle-world* is a world of natural things that consist of matter and form and have within themselves a source of motion. Motions caused by such a "natural" source are "teleological" motions, that is, they make a thing into what, according to its own nature, it really is (motion as the realization of the form of a being), or they lead it, in the form of a "natural" local motion, to its "natural" place. A theory of natural positions, incorporated in a theory of elements, corresponds in this sense to a theory of simple (natural) bodies (bodies that have a source of motion in themselves) and simple motion (the motion of simple bodies). A perfect order would result in an arrangement (in terms of lightness or heaviness) of the four elements in concentric layers around the center of the world. The inclusion of a fifth element, aether, leads to a conception of finite space, with a theory of (natural) position (as the positional relationships between bodies) taking the place of a theory of space. This is a logical development insofar as the foundation of the Aristotle-world is not a theory of nature (in the sense of the realm of nature in its entirety), but a theory of natural things.

The Aristotle-world is characterized by a high degree of *experiential evidence*. The scientific propositions describing this world are confirmed by the experience acquired in everyday life, or are derived from generalizations made on the basis of experience. Examples of this are (1) the Aristotelian law of gravitation, according to which the velocity of a falling body is proportional to its weight and inversely proportional to the density of the medium, (2) the Aristotelian "law of inertia", which states that all things moved have a mover, and (3) the Aristotelian theory of elements with its familiar concepts derived from the experience of daily life, for example, "above," "below," "natural," and "unnatural" (as in the case of violent motions that run counter to natural motions). The Aristotle-world, moreover, is always in the process of becoming a natural order, embedded in the inner teleology of this world or the teleological nature of all things. This natural order never appears as a perfect state, but it is constantly present in the form of an astronomically ordered, supralunary world. In other words, disorder as well as the tendency to order is the normal state of the (sublunary) world. It is the world of experience and hence – despite physics and natural philosophy which seek to interpret it – a very human world.

As opposed to the Aristotle-world, the *Hermes-world* – by which I mean the hermetic world of alchemy, astrology, and parts of natural philosophy in the Renaissance – is a world of mysterious interactions. Occult powers and living substances take the place of the simple bodies characteristic of the Aristotle-world. Nature consists of different combinations of primary substances that originated in undifferentiated primordial matter. At the same time, these combinations are conceived of as developmental processes that Man can accelerate or retard, though always with methods that "imitate nature", for example, by "refining" metals and other substances (transmutation). Inorganic processes are viewed analogously to organic processes. Explanations of the world take the shape of allegorical interpretations: coming into being and passing away as birth and death, separation and unity as the polarity of the sexes (the *conjunctio* as sexual union or the hermaphrodite as the overcoming of sexual differences).

This conception finds its cosmological expression in the correspondence between macrocosm and microcosm which in antiquity and in the hermetic tradition interprets the world as a great organism mirrored in the microcosm, particularly in Man: "what is below is like what is above; what is above is like what is below: both reveal the miracle of the one".[26] The influence of the macrocosm on the microcosm

[26] The first sentence of an apocryphal text attributed to Hermes Trismegistos. See C. Thiel, 'Makrokosmos', in J. Mittelstrass (ed.), *Enzyklopddie Philosophie und Wissenschaftstheorie*, Vol. II (Mannheim and Vienna and Zurich, 1984; Stuttgart and Weimar, 1995), p. 749.

corresponds to the ever-present assumption in magic thought that it is possible to effect a change in the macrocosm through changes in the microcosm. This conception, as the "sympathetic" relationship among all the parts of the world, is still at work within the context of natural philosophy in the Romantic period: Man as a microcosm "in which the universe looks at itself".[27] In this Hermes-world everything becomes a riddle or a key to solving its secrets. The familiarity of the Aristotle-world gives way to a demonic world that is only accessible through ritual and mystical forms of knowledge. Thus the Hermes-world stands not only in opposition to the familiarity of the Aristotle-world, but also in opposition to the "mechanistic world" that in the modern age begins to supplant both the Aristotle-world, as well as Aristotelian physics.

The foundation for this mechanistic world picture is the *Newton-world*. In this world it is only mass that moves in absolute time, through absolute space. Matter and space are the real elements of this world. The smallest particles of matter, hence the actual atoms, combine to build complex formations or second-order particles. Several of these combine in turn to become third-order particles and so forth. The inner structure of matter is thus characterized by a complex hierarchy of particle formations. These formations are not massive corpuscles, but contain empty space. As the order of the particle hierarchy expands, the amount of empty space in them increases while the extent of solid matter decreases correspondingly. Matter in the world is thus only seemingly solid. In fact, the world is a vacuum for the most part. The actual amount of solid matter in the universe could fit into a nutshell (atomistic nutshell theory).

Characteristic of the Newton-world, moreover, is the assumption that a fundamental dualism exists between passive matter and active immaterial principles. According to this notion, which can be traced back to Cambridge Platonism and hence to hermetic conceptions of the world, matter can be the origin only of mechanical effects, that is, effects mediated by pressure and impulse. Matter itself does not exert force, but only withstands the effects of forces (through its own inertia). Gravitational pull, in particular, is not a property of matter. Gravitation has more the status of an active principle and finds its origin in a non-material aether that exerts an effect on matter. Matter, "inanimate and brute," is not able to guarantee even halfway stable processes of development through its essential characteristics. Since in this world a

[27] J.J. Wagner, *System der Idealphilosophie* (Leipzig, 1804), p. LIII.

general principle for the conservation of energy does not hold, mechanical interactions lead to a steady loss of motion which cannot be fully compensated by the active principles that bring forth new motion. All the regularly functioning causes (material or immaterial) taken together would not be able to impede the movement of the world toward disorder and chaos. The stability of the world, i.e. compensation for the energy loss, is a matter only for God or an occasional divine intervention in this world.

The "mechanism" of the Newton-world, expressed in a mechanics of gravitational motion, in Newtonianism not only determines how anorganic nature is understood but also proliferates in the organic, psychic, and social cosmos. In the theological aspects it still retains, this mechanism documents their fundamental dispensability. The criticism of the effects of occult powers (qualities) in an hermetic world also applies to Newton's theological legitimations. The Newton-world, the quintessential "mechanization of the world picture," becomes a "world of machines" – with God as a "retired engineer".[28]

In contrast to the concept of absolute space in the Newton-world, a concept of relational space is dominant in the *Einstein-world*. While developing the General Theory of Relativity, Einstein was deeply influenced by Mach's forceful critique of absolute space. Discussing again Newton's famous bucket experiment, Mach argued that the centrifugal forces should be explained not as a result of true rotation (rotation against absolute space) but as the effect of the rotation relative to distant masses (that is, the center of gravity in the universe). Einstein transformed this programmatic idea into an elegant physical theory with a rich mathematical structure.

The General Theory of Relativity exhibits an inherently geometric aspect of nature. Gravitation is no longer conceived of as merely a force that diverts bodies from their natural trajectory, but as an entity that is inseparably bound up with the structure of space and time. In fact, once the geometry (the metric field) and initial conditions of a "world" are specified, all dynamic features can be mathematically deduced. Thus, the Einstein-world is, like the Newton-world, deterministic; everything is predetermined from the beginning and takes place necessarily. God does not throw dice. Due to the ineliminable presence of the metric field at

[28] E.J. Dijksterhuis, *De Mechanisering van het Wereldbeeld* (Amsterdam, 1950), p. 539 (= *The Mechanization of the World Picture. Pythagoras to Newton*, Princeton N.J., 1986, p. 491).

every space-time point, the Einstein-world is, however, not virtually empty like the Newton-world, but full like a Cartesian world. The substrate of this world is "curved empty space-time" (J. Wheeler); matter is essentially considered to be a manifestation of a comparably high curvature. Einstein and some of his followers later tried to extend this conceptually intriguing geometrization programme to other branches of physics as well. They succeeded in also providing a geometrical account of electrodynamics. Non-classical aspects of nature were, however, not considered at all.

These are stressed in the *Heisenberg-world*, which differs considerably from the worlds mentioned so far. In contrast to the Newton-world, particles here no longer move on definite trajectories, they are not localized, and their behavior can often only be predicted probabilistically. Although the fundamental equation of motion of non-relativistic quantum mechanics (the Schroedinger equation) guarantees a deterministic evolution of the wave function, an inherently indeterministic element seems to enter into the still poorly understood measurement process. A superposition of several possible outcomes of a measurement here collapses instantaneously into one single *actual* outcome: the measured state of the system in question. Since a causal story of this process cannot be told, the Heisenberg-world exhibits non-causal aspects of nature. Another astonishing new feature of quantum systems is their non-separability. In a famous article in 1935, Einstein, Podolski and Rosen considered a compound ("entangled") quantum system that is divided into two parts which are in turn spatially separated. Applying the standard formalism of quantum mechanics, the authors show that the two systems cannot be considered to be individuals. Instead, the description of each system depends on the other in a subtle way.[29] Once two quantum systems are entangled, they will remain so for all time. In this sense quantum systems are holistic.

This exposition may provoke the impression that a scientific theory (relativity theory, quantum theory, etc.) uniquely determines the world picture that goes with a theory in question. This is not the case. In quantum mechanics, for example, there is a heated debate between the "inhabitants" of a Heisenberg-world and others, who ingeniously try to reconcile the formalism of quantum mechanics with concepts and ideas of classical physics (especially determinism, causality, the existence of

[29] A. Einstein, B. Podolski and N.Rosen, 'Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?', *Physical Review* 47 (1935), pp. 777-780.

particle trajectories, etc.). This is indeed possible, as Bohm's theory demonstrates, if additional nonlocal forces are accepted.[30] Similarly, the recent discussion on the foundations of general relativity concerning Einstein's "hole argument" has led some philosophers of science to argue against relationalism (and for space-time essentialism[31]) and others to argue for a restriction of determinism.[32] Philosophical consequences of science are, to use a term favoured by modern philosophers of science, *underdetermined* by theories, just as theories are underdetermined by data.

But physics is not everything. There is also a vast realm of living things, and here, too, we have left the Aristotle-world. In the field of biology there are developments analogous to those of the Newton-world and the Einstein-world. Charles Darwin, though he did not see nature as acting like a fabricating artisan or architect, did indeed view it from a technological point of view. In the adaptation of organisms to their environment, he saw nature acting like a pigeon breeder moulding his pigeons to fit his ideals. In the bio-diversity of a patch of weeds he saw nature engaged in the "simultaneous rotation" of its crops. Natural selection was, on the one hand, modeled on the breeder's technique of selecting preferred organisms for propagation, and, on the other, it was just one end of a selectional continuum with intentional selection at the opposite end and "unconscious selection" in the middle.[33] In a *Darwin-world* the organic realm becomes part of cultural nature. And in more recent developments, our dispositional knowledge and appropriative actions extend not just to selectional processes but even to the very source of variation, the last bastion of naturalness.

The examples of various worlds mentioned demonstrate the power of science to constitute worlds and generate world pictures. At the same time they emphasize the dependence of the concept of nature, including the philosophical concept of nature, on theoretical conceptions and even

[30] See J. Cushing, *Quantum Mechanics: Historical Contingency and Copenhagen Hegemony* (Chicago, 1996).

[31] A. Bartels, 'Von Einstein zu Aristoteles. Raumzeit-Philosophie und Substanz-Metaphysik', *Philosophia Naturalis* 31 (1994), pp. 293-308.

[32] J. Butterfield, 'The Hole Truth', *The British Journal for the Philosophy of Science* 40 (1989), pp. 1-28.

[33] C. Darwin, *The Origin of Species* (facs. reprint with an Introduction by E. Mayr, Cambridge Mass. 1964), esp. ch. 1 and pp. 114ff. See also H.-J. Rheinberger and P. McLaughlin, 'Darwin's Experimental Natural History', *Journal of the History of Biology* 17 (1984), pp. 247-368.

suggest a certain relativity of our concepts of world and nature. What we see through the history of science, that is, in the historical analysis of science, is not a world that the scientific mind has continually built up, not nature that is ever better revealed to the philosophical mind. We find rather a plurality of worlds that have little to do with one another, a nature whose essence becomes ever less clear. Each of these worlds carries with it its own plausibility with reference to its basic underlying scientific or (philosophical) perspective on things, and each of them is somehow consistent – but they are not mutually compatible as work upon a common world. The same applies to talk about nature. Which world, which nature is the right one, and in which world, in which nature do we want to live?

This question is not easy to answer for the reasons mentioned above, which are both scientific and philosophical. Nature is not only in fact, in the world of technological cultures, that is, in the Leonardo-world, to a large extent an artefact; it is also an artefact in the world of theories, that is, in science and philosophy. The question: "What is nature?" turns out to be much too big; a bit of modesty in dealing with it is called for. This does not mean however that, when the (scientific) concept of the world begins to dissolve, the (philosophical and natural) concept of nature will dissolve too. What the excursion through the history of the concept of nature and world has shown is (once again) only that nature and the world are not the great "other" beyond human culture, but rather are constantly a part of this culture and today part of the culture of a Leonardo-world. I shall conclude with a final thesis on this subject.

4. *In the Leonardo-world nature has definitively become cultural nature. At the same time the Leonardo-world reveals the idealistic essence of the concept of nature.*

An *idealistic* shadow falls on the current discussion of nature in a Leonardo-world, namely the idealistic distinction between nature and mind and the dissolution of this distinction in the concept of mind or spirit. According to Fichte, nature is something posited by Man, that is, by a worldless ego: "There is no nature in itself; my nature, and all other nature that is posited in order to explain my nature, is only a particular way of seeing myself".[34] That means that in Fichte's "idealistic"

[34] *Das System der Sittenlehre nach den Principien der Wissenschaftslehre* (1798), *Sämmtliche Werke*, vols. I-VIII (ed. by I.H. Fichte, Berlin, 1845-1846), vol. IV, p. 133.

perspective, nature, contrary to the Aristotelian concept of an acting nature, becomes the product of subjectivity or a limit posited by the action of subjectivity itself. In Fichte's conception the limits of the *Ich* are the limits of the world. Opposed to this, we find Hegel bemoaning the loss of the Aristotelian concept of nature. Hegel's philosophy of nature is supposed to provide a "reconciliation" of mind with nature, but (in Hegel as well) in a manner advantageous to the mind: "The mind that has grasped itself will want also to know itself in nature, to overcome the loss of itself".[35] Nature appears here as an idea or (in subjective form) as mind in its "externality", but at the same time itself on its way to becoming mind. This, according to Hegel, is what philosophy of nature has to represent. Nature is here not a product, not simply a posit of the mind (as it is with Fichte); rather, as the "other" of the mind, it is itself a *form* of the mind ("externalized" or "alienated" mind) which at the same time loses its actual subject-likeness. And this is what is particular about Hegel's idealism. The *subjectivization* of nature in the form of externalized or alienated mind is compensated by the *desubjectivization* of the mind or of reason. According to Hegel the limits of the mind are the limits of the world.

What does all this have to do with the relatively sober analysis of the concept of nature in the conceptions of philosophy and science? At first glance, certainly very little. Fichte's attempt to pursue philosophy of nature solely within the bounds of an *Ich*-philosophy cannot demonstrate its applicability – much less its intelligibility. Hegel's vision of a subjectless mind, that as "Idea" comprehends nature as well, darkens a philosophy of nature, to which at best the higher dilettantism of philosophy in the affairs of science holds the key.

However, the last word on the idealistic concept of nature, which is of course a very philosophical concept, has yet to be spoken. This concept is in fact more "real" than it seems. It is true that Hegel's endeavour to make nature once again the subject of its own formation process has failed to the extent that nature itself has become part of a Leonardo-world. Nonetheless, the ancient question, which also moved idealistic philosophy, whether nature is capable of reason, has not yet been answered conclusively. Only, today, it is posed and answers are attempted in a different form, for instance, the *ecological* form. Ecological thinking,

[35] *Encyclopädie der philosophischen Wissenschaften im Grundrisse/System der Philosophie, Sämtliche Werke. Jubiläumsausgabe*, vols. I-XX (ed. by H. Glockner, Stuttgart, 1927-1930), vol. IX, p. 721.

too, is characterized by the endeavour to restore to nature a part of the independence that it has lost in a Leonardo-world. Whether one grasps this independence in the terminology of subjectivity or otherwise is of secondary importance.

However, even the loss of the independence of nature, not just the attempt to restore it, (partially) testifies to more "idealism" than one might suspect. One need only recall that nature in a Leonardo-world has become a part of technological culture, a part of the "Spaceship Earth". But this is precisely Fichte; this is Fichte's *Ich* that gives the *non-Ich* its essence. In technological cultures nature becomes the other side of the subject, the "other" of the mind, turned over to it as cultural nature for appropriation and processing. And thus, too, Hegel's notion that the mind recognizes itself in nature has made itself felt. What might seem to be an abstract philosophical, idealist conceptual dream is fulfilled in a strange manner: The Leonardo-world has appropriated nature with the unfortunate consequences that we are all aware of today. But the modern world has begun to look for its own solutions, to roll back the consequences of this appropriation or at least to restrict them to a measure that is tolerable for the human world and for nature. Both of these, appropriating nature and leaving it alone, display elements of the idealistic notion that nature is the "other" of reason or mind – its product or mirror.

This does not mean that I want to conclude with a plea for an idealistic concept of nature, especially since it would probably be more accurate today to see in nature not the "other" of *reason* but the "other" of *unreason*, namely its consequences. The point was merely to show that thinking about nature oscillates in a sometimes easily understandable, sometimes quite peculiar manner between philosophy and science and that the philosophical history of the concept of nature has by no means come to an end with the triumphant progress of science. If I have nonetheless said that in the development of modern science the concept of nature has begun to dissolve, then this is meant in the sense that in the Leonardo-world that science has created, nature is becoming more and more an artefact. Paradoxically, it is precisely under the conditions of a Leonardo-world that it becomes clear how vulnerable nature is. This, too, is a lesson that we should learn from the history of the concept of nature at the turn of our millennium.

PART I

THE CHANGING CONCEPTS OF NATURE IN PHYSICS

COSMOLOGY

MARTIN J. REES

This is not a sermon, but I will start with a text – the famous closing words of the 'Origin of Species': 'Whilst this earth has been cycling on according to the fixed law of gravity, from so simple a beginning forms most wonderful ... have been, and are being, evolved.' Cosmologists aim to probe back before Darwin's 'simple beginning': to set our Earth in a grander evolutionary context, stretching back before the birth of our Solar System – right back, indeed to the primordial event that set our entire cosmos expanding, and triggered the processes that have led from a 'simple' beginning to our present intricately-structured cosmos.

I will try to sketch recent progress in exploring the cosmos, and then mention some current controversies and mysteries, where the specialists are as baffled as everyone else. A century ago, the Sun presented a mystery. Darwin and the geologists had already inferred that the Earth's age was measured in billions of years. On the other hand Lord Kelvin had done a real calculation: he had shown the Sun's age to be little more than 10 million years. That was the timescale on which the Sun would deflate, owing to gravity, as its energy leaked away. Kelvin saw no way round this limit unless – to quote him – there were 'some other power source laid up in the storehouse of creation'. Of course we learnt during the 20th century that there was such a source, within the atomic nucleus. The paradox was resolved, and we now have a convincing picture of the Sun's evolution.

The proto-Sun condensed from a gas cloud. Gravity pulled it together until its centre was squeezed hot enough to trigger nuclear fusion. This energy source supplies power at just the rate needed to balance the heat shining from its surface. Less than half the Sun's central hydrogen has so far been used up, even though it is already 4.5 billion years old. The Sun will keep shining for a further 5 billion years. It will then swell up to become a red giant, large and bright enough to engulf the inner planets, and to vapourise all life on Earth. After this 'red giant' phase, some outer layers are blown off, leaving a white dwarf – a dense star no larger than the Earth, which will shine with a dull glow, no brighter than the full moon today, on whatever remains of the Solar System.

To conceive these vast timespans – future as well as past – a metaphor can help. Suppose you represent the Sun's life by a walk across America, starting in NY when the Sun formed, and reaching California ten billion years later, when the Sun is about to die. To pace yourself on this journey, you would have to take one step every two thousand years. All recorded history would be just a few steps. Moreover, these steps would come just before the half-way stage – somewhere in Kansas, perhaps. Not the high point of the journey. Likewise, we may still be near Darwin's 'simple beginning'. The progression towards diversity has much further to go. Even if life is now unique to the Earth, there is time for it to spread from here through the entire Galaxy, and even beyond.

Astronomers can compute the structure and life cycle for any stars – stars of say 10 solar masses, or 1/2 a solar mass. But how can we check such calculations? Stars live so long compared to astronomers that we are granted just a single 'snapshot' of each one's life. But just as it would not take a newly landed Martian long to infer the life cycle of trees or people, astronomers can test their theories by surveying whole populations of stars.

The best 'test beds' are the globular clusters – swarms of a hundred thousand stars, of different sizes, held together by their mutual gravity, which formed at the same time. There are places where stars seem still to be forming: for instance the spectacular Eagle Nebula, about 7000 light years away. Clouds like these harbour bright young stars; and newly-condensing protostars that have not yet got hot enough to ignite their nuclear fuel.

Not everything happens slowly. Massive stars end their lives violently by exploding as supernovae. The closest supernova of the 20th century, about 150 thousand light years distant, was observed to flare up on 23-24 February 1987. Theorists were given a chance to check the elaborate computer calculations they had developed over the previous decade, and its gradual fading has been studied using all the techniques of modern astronomy. In about 1000 years it will look like the Crab nebula, the expanding debris from an explosion recorded by Chinese astronomers in 1054 AD.

Supernovae fascinate astronomers. But out of every 10,000 people stopped at random on the streets, probably only one would be an astronomer (actually, there are fewer astronomers in the world than astrologers, so you would have more chance of finding an astrologer!). Why should the other 9,999 care about stellar explosions thousands of light years away? One answer is that supernovae made the atoms that we are made of: without them we – and the Earth – would not be here.

On Earth, for every 10 atoms of carbon, there are about 20 of oxygen and 5 each of nitrogen and iron. But gold is a million times rarer than oxygen; platinum and mercury are rarer still. These exploding stars suggest the reason why.

Stars more than ten times heavier than the Sun use up their central hydrogen hundreds of times quicker than the Sun does – they shine much brighter in consequence. Gravity then squeezes them further and the centres get still hotter, until helium atoms can themselves stick together to make the nuclei of heavier atoms. A kind of 'onion skin' structure develops: a layer of carbon surrounds one of oxygen, which in turn surrounds a layer of silicon. The hotter inner layers have been transmuted further up the periodic table and surround a core that is mainly iron.

When their fuel has all been consumed, big stars face a crisis. A catastrophic infall compresses the stellar core to neutron densities, triggering a colossal explosion – a supernova.

The outer layers of a star, by the time a supernova explosion blows them off, contain the outcome of all the nuclear alchemy that kept it shining over its entire lifetime. The calculated 'mix' of atoms is gratifyingly close to the proportions now observed in our Solar System. The creator did not have to turn 92 different knobs.

Our galaxy is like an ecosystem, recycling gas through successive generations of stars, gradually building up the entire periodic table. Before our Sun even formed several generations of fast-burning heavy stars could have been through their entire life cycles, transmuting pristine hydrogen into the basic building blocks of life – carbon, oxygen, iron and the rest. We are literally the ashes of long-dead stars.

One fascinating question, of course, is whether other worlds are orbiting other stars. Astronomers have for a long time suspected planetary systems to be common, because protostars, as they contract from rotating clouds, spin off around them discs of dusty gas. These have now been seen. In these discs, dust particles would stick together to make rocky 'planetesmals', which can in turn merge to make planets.

Evidence for actual planets orbiting other ordinary stars is harder to find, but it came in 1995. In that year, two Swiss astronomers, Michel Mayor and Didier Queloz, found that the Doppler shift of 51 Pegasi, a nearby star resembling our Sun, was varying sinusoidally by 50 m/sec – they inferred that a planet orbiting weighing a thousandth as much was circling it at 50 km/sec, causing the star to pivot around the combined centre of mass.

Marcy and Butler in California have found similar wobbles in several other stars But the inferred planets are all big ones – like Jupiter. They may be the largest members of other planetary systems like our own, but Earth-like planets would a hundred times harder to detect.

Planets on which life could evolve, as it did here on Earth, must be rather special. Their gravity must pull strongly enough to prevent an atmosphere from evaporating into space; they must be neither too hot nor too cold, and therefore the right distance from a long-lived and stable star. Only a small proportion of planets meet these conditions, but planetary systems are (we believe) so common in our Galaxy that Earth-like planets would be numbered in millions

Along with most other European space scientists, I follow NASA's activities with interest. I admire their scale and virtuosity, but am bemused and dismayed by the Space Station. And I am impressed by the commitment of NASA's somewhat messianic chief executive, Dan Goldin, that a search for Earth-like planets should become a main thrust of the programme. This is a long term technical challenge – requiring large telescope arrays in space – but it is far from crazy. Once a candidate has been seen, several things could be learnt about it. Suppose an astronomer forty light years away had detected our Earth – it would be, in Carl Sagan's phrase, a 'pale blue dot', seeming very close to a star (our Sun) that outshines it by many million. If Earth could be seen at all, its light could be analysed, and would reveal that it had been transformed (and oxygenated) by a biosphere. The shade of blue would be slightly different, depending on whether the Pacific ocean or the Eurasian land mass was facing us. Hypothetical distant astronomers could therefore, by repeated observation, infer the Earth was spinning, and learn the length of its day, and even infer something of its topography and climate. Likewise we could learn about other Earths.

But an even more fascinating question – and what of course motivates NASA and the American public – is whether there is life on them. In a propitious environment like that of the young Earth, what is the chance that 'simple' organisms emerge? Even when they do, what is the chance they evolve into something that can be called intelligent? These questions are for biologists – they are too difficult for astronomers. There seems no consensus among the experts. Life, even intelligent life, could be 'natural'; or it could have involved a chain of accidents so surpassingly rare that nothing remotely like it has happened anywhere else in our Galaxy.

The concept of a 'plurality of inhabited worlds' is still the province of speculative thinkers, as it has been through the ages. The year 2000 marks the 4th centenary of the death of Giordano Bruno. He believed that 'There are countless constellations, suns and planets; we see only the suns because they give light; the planets remain invisible, for they are small and dark. There are also numberless earths circling around their suns, no worse and no less than this globe of ours. For no reasonable mind can assume that heavenly bodies which may be far more magnificent than ours would not bear upon them creatures similar or even superior to those upon our human earth.'

I have described how the atoms of the periodic table are made – that we are stardust – or, if you are less romantic, the 'nuclear waste' from the fuel that makes stars shine. But where did the original hydrogen come from? To answer this question, we must extend our horizons to the extragalactic realm. Our Milky Way, with its hundred billion stars, is just one galaxy similar to millions of others visible with large telescopes. Here's Andromeda, the nearest big galaxy to our own – it is about 2 m light years away. The stars are orbiting in a disc, seen obliquely. In others, like the Sombrero galaxy, 10 billion stars are swarming around in more random directions, each feeling the gravitational pull of all the others.

The nearest few thousand galaxies – those out to about 300 million light years – have been mapped out in depth. Galaxies are irregularly distributed – into clusters, and superclusters. Are there, you may ask, clusters of clusters of clusters ad infinitum? There do not seem to be. Deeper surveys show a smoother distribution: our Universe is not a fractal. If it were, we would see equally conspicuous clumps, on ever-larger scales, however deep into space we probed.

Even the biggest superclusters are still small in comparison with the horizon that powerful telescopes can reach. So we can define the average 'smoothed-out' properties of our observable universe. To use another simile, our universe is like an ocean surface, where even the largest waves are small compared to the horizon distance, rather than resembling a mountain landscape, where one feature can dominate the entire scene.

The overall motions in our Universe are simple too. Distant galaxies recede from us with a speed proportional to their distance, as though they all started off packed together 10-15 billion years ago. Light takes a long time to reach us from distant places. As we probe deeper into space, towards our horizon, we see the universe as it was when it was younger and more close-packed. And we can now see very far back. The Hubble Space telescope has given us amazing pictures, which reveal that any small patch of sky, less than a hundredth of the area covered by a full moon is densely covered with smudges of light – each a billion times fainter than any star that can be seen with the unaided eye. But each smudge is an entire galaxy, thousands of lightyears across, which appears so small and faint because of its huge distance.

A huge span of time separates us from these remote galaxies. They are being viewed when they have only recently formed. They have not yet settled down into steadily-spinning 'pinwheels' like Andromeda. Some consist mainly of glowing diffuse gas that has not yet condensed into stars. When we look at Andromeda, we sometimes wonder if there may be other beings looking back at us. Maybe there are. But on these remote galaxies there surely are not. Their stars have not have had time to manufacture the chemical elements. They would not yet harbour planets, and presumably no life.

Astronomers can actually see the remote past. But what about still more remote epochs, before any galaxies had formed?

In these surroundings it is fitting to remember George Lemaître, the great pioneer of the idea that everything began in a dense state – he called it the primeval atom.

To quote from something he wrote: 'The evolution of the universe can be likened to a display of fireworks that has just ended: some few wisps, ashes and smoke. Standing on a well-chilled cinder we see the fading of the suns, and try to recall the vanished brilliance of the origin of the worlds.'

The evidence for Lemaître's 'vanished brilliance' emerged in 1965. Intergalactic space is not completely cold. It is pervaded by weak microwaves, which have been measured by the COBE satellite at many different wavelengths to a precision of a part in 10,000. This spectrum is just what you would expect if these microwaves are indeed an 'afterglow' of a pregalactic era when the entire Universe was hot, dense and opaque. The expansion has cooled and diluted the radiation, and stretched its wavelength. But this primordial heat is still around – it fills the Universe and has nowhere else to go!

Unfortunately, the term 'primeval atom' has dropped from common currency, in favour of 'big bang'. That was actually introduced by Fred

Hoyle, in the 1950s, as a derisive description of a theory he did not like. He still does not like it. But he has come part of the way, and now espouses a kind of 'steady bang' theory.

The flippant name 'big bang' has stuck. But the evidence for it has firmed up. Intergalactic space is not completely cold. It is pervaded by weak microwaves, which have been measured by the COBE satellite at many different wavelengths to a precision of a part in 10,000. This spectrum is just what you would expect if these microwaves are indeed an 'afterglow' of a pregalactic era when the entire Universe was hot, dense and opaque. The expansion has cooled and diluted the radiation, and stretched its wavelength. But this primordial heat is still around – it fills the Universe and has nowhere else to go!

And there is another 'fossil': when the entire universe was squeezed hotter than a star, there would be nuclear reactions. The temperature is only that high for the first three minutes, but that was enough to convert 23 percent of the material into helium – and that is just the fraction of helium we actually find.

I think the extrapolation back to the stage when the Universe had been expanding for a few seconds (when the helium formed) deserves to be taken as seriously as, for instance, what geologists or paleontologists tell us about the early history of our Earth. Their inferences are just as indirect (and less quantitative).

Moreover, there are several discoveries that might have been made, which would have invalidated the hypothesis, and which have not been made – the big bang theory has lived dangerously for decades, and survived.

I will come back later to the first fraction of a second – an era still earlier than when the helium formed – where we cannot yet make such confident claims. You may be thinking: is it not absurdly presumptuous to claim to know anything, with any level of confidence, about cosmology? Not necessarily. It is complexity, and not sheer size, that makes things hard to understand – a star is simpler than an butterfly, for instance. In the fierce heat of a star, and even more in the big bang, everything must have been broken down into its simplest constituents. The early universe really could be less baffling, and more within our grasp, than the smallest organism. It is biologists – trying to understand the marvellous structures and patterns in living things – who face the toughest challenge!

But let us briefly look forward rather than backward – as forecasters rather than fossil hunters.

Futurology

In about 5 billion years the Sun will die;. and the Earth with it. At about the same time (give or take a billion years) the Andromeda Galaxy, already falling towards us, will crash into our own Milky Way. But will the universe go on expanding for ever? Or will the entire firmament eventually recollapse to a 'big crunch'?

The answer depends on how much the cosmic expansion is being decelerated by the gravitational pull that everything exerts on everything else. It is straightforward to calculate that the expansion can eventually be reversed if there is, on average, more than about 5 atoms in each cubic metre. That does not sound much. But if all the galaxies were dismantled, and their constituent stars and gas spread uniformly through space, they would make an even emptier vacuum – 1 atom in every 10 cubic metres – like one snowflake in the entire volume of the Earth.

That is 50 times less than the 'critical density', and at first sight this seems to imply perpetual expansion, by a wide margin. But it is not so straightforward. Astronomers have discovered that galaxies, and even entire clusters of galaxies, would fly apart unless they were held together by the gravitational pull of about 10 times more material than we actually see – this is the famous 'dark matter' mystery.

A pioneer advocate was the Swiss-American professor Fritz Zwicky. He proposed, 60 years ago, that gravitational lensing – bending of light by gravity – could reveal dark matter. He would have been immensely excited by some pictures of clusters of galaxies taken with the Hubble Space Telescope. In these pictures, the brighter-seeming galaxies are members of a big cluster. But there are, as well, numerous faint streaks and arcs: each is a remote galaxy, several times further away than the cluster itself, whose image is, as it were, viewed through a distorting lens. just as a regular pattern on background wallpaper looks distorted when viewed through a curved sheet of glass, the gravity of the cluster of galaxies deflects the light rays passing through it. The visible galaxies in the cluster contain only a tenth as much material as is needed to produce these distorted images evidence that clusters as well as in individual galaxies contain ten times as much mass as we see.

What could this dark matter be? It is embarrassing that 90 percent of the universe is unaccounted for. Most cosmologists believe the dark matter's mainly exotic particles left over from the big bang. If they are right, we have to take our cosmic modesty one stage further. We are used to the post-Copernican idea that we are not in a special place in the cosmos. But now even 'particle chauvinism' has to go. We are not made of the dominant stuff in the universe. We, the stars, and the galaxies we see are just traces of 'sediment' – almost a seeming afterthought – in a cosmos whose large-scale structure is dominated by particles of a quite different (and still unknown) kind. Checking this is perhaps the number-one problem in the whole subject.

Cosmologists denote the ratio of the actual density to the critical density by the Greek letter omega. There is certainly enough dark matter around galaxies to make omega = 0.2 (remember that what we see is only a fiftieth, 0.02). Until recently, we could not rule out several times this amount – comprising the full critical density, omega = 1 – in the space between clusters of galaxies. But it now seems that, *in toto*, atoms and dark matter do not contribute more than about omega of 0.3.

The odds favour perpetual expansion. The galaxies will fade, as their stars all die, and their material gets locked up in old white dwarfs, neutron stars and black holes. They will recede ever further away, at speeds that may diminish, but never drop to zero.

But there is now tantalising evidence for an extra repulsion force that overwhelms gravity on cosmic scales – what Einstein called the cosmological constant, lambda. The American magazine 'Science' rated this the most important discovery of 1998, in any field. The expansion may actually accelerate. If it does, the forecast is an even emptier universe. All galaxies beyond our local group would have accelerated away towards infinite redshift, disappearing completely from view.

So much for the long range forecast. Let us now go back to the beginning. People sometimes wonder how our universe can have started off as a hot amorphous fireball – and ended up intricately differentiated. Temperatures now range from blazing surfaces of stars (and their even hotter centres) to the night sky only 3 degrees above absolute zero. This may seem contrary to the second law of thermodynamics, but it is actually a natural outcome of the workings of gravity.

Gravity renders the expanding universe unstable to the growth of structure, in the sense that even very slight initial irregularities would evolve into conspicuous density contrasts. Theorists can now follow a 'virtual universe' in a computer. Slight fluctuations are 'fed in' at the start of the simulation. The calculations can simulate a box containing a few thousand galaxies – large enough to be a fair sample of our universe. As the box expands, regions slightly denser than average lag further and further behind. Such calculations clearly show the density contrasts growing, the incipient galaxies and larger structures emerging and evolving. Eventually the overdense regions stop expanding and condense into gaseous protogalaxies, each an arena for the emergence of stars, planets and life.

If one had to summarise, in just one sentence, 'What has been happening since the big bang?', the best answer might be to take a deep breath and say 'Ever since the beginning, gravity has been amplifying inhomogeneities, building up structures, and enhancing temperature contrasts – a pre-requisite for emergence of the complexity that lies around us ten billion years later, and of which we are part'.

The way slight initial irregularities in the cosmic fireball evolve into galaxies and clusters is in principle as predictable as the orbits of the planets, which have been understood since Newton's time. But to Newton, some features of the Solar System were a mystery. Why were the planets 'set up' with their orbits almost in the same plane, all circling the sun the same way. In his 'Opticks' he writes: 'blind fate could never make all the planets move one and the same way in orbits concentrick'. Such a wonderful uniformity in the planetary system, he wrote, must be the effect of providence. This coplanarity has only now been understood – it is a natural outcome of the Solar System's origin as a spinning protostellar disc. Indeed, we have pushed the barrier back from the beginning of the solar system to the first second of the big bang.

But – and this is my reason for the flashback to Newton – conceptually we are in no better shape than Newton was. He had to specify the initial trajectories of each planet. We have pushed the causal chain far further back, but we still reach a stage when we're reduced to saying 'things are as they are because they were as they were'.

Our calculations of cosmic structure need to specify, at some early time like 1 second, a few numbers:

(i) The cosmic expansion rate.

(ii) The proportions of ordinary atoms, dark matter and radiation in the universe

(iii) The character of the fluctuations. (iv) And the basic laws of physics

Any explanation for these numbers must lie not just the first second, but the first tiny fraction of a second. What is the chance, then, of pushing the barrier back still further?

The cosmic expansion rate presents a special mystery. The two eschatologies – perpetual expansion or recollapse to a 'crunch' – seem very different. But our Universe is still expanding after 10 billion years. A universe that recollapsed sooner, would not have allowed time for stars to evolve, or even to form. On the other hand, if the expansion were too much faster, gravity would have been overwhelmed by kinetic energy and the clouds that developed into galaxies would have been unable to condense out. In Newtonian terms the initial potential and kinetic energies were very closely matched. How did this come about?

Does the answer lie in the ultra-early universe? I was confident in tracing back to when the universe was a second old. The matter was no denser than air; conventional laboratory physics is applicable and is vindicated by the impressive evidence of the background radiation, helium, and so forth. But for the first trillionth of a second every particle would have more energy than even CERN's new accelerator will reach. The further we extrapolate back, the less foothold we have in experiment.

But most cosmologists suspect that the uniformity and expansion rate is a legacy of something remarkable that happened when everything was compressed in scale by 27 powers of ten (and hotter by a similar factor).

The expansion would then have been exponentially accelerated, so that an embryo universe could have inflated, homogenised, and established the 'fine tuned' balance between gravitational and kinetic energy when it was only 10-36 seconds old. The seeds for galaxies and clusters could then have been tiny quantum fluctuations, imprinted when the entire universe was microscopic, and stretched by inflationary expansion.

This generic idea that our universe inflated from something microscopic is compellingly attractive. It looks like 'something for nothing', but it is not really. That is because our present vast universe may, in a sense, have zero net energy. Every atom has an energy because of its mass – Einstein's Mc2. But it has a negative energy due to gravity – we, for instance, are in a state of lower energy on the Earth's surface than if we were up in space. And if we added up the negative potential energy we possess due to the gravitational field of everything else, it could cancel out our rest mass energy. Thus it does not, as it were, cost anything, to expand the mass and energy in our universe.

Cosmologists sometimes loosely assert that the universe can essentially arise 'from nothing'. But they should watch their language, especially when talking to philosophers. The physicist's vacuum is latent with particles and forces – it is a far richer construct than the philosopher's 'nothing'. Physicists may, some day, be able to write down fundamental equations governing physical reality. But they will never tell us what 'breathes fire' into the equations, and actualises them in a real cosmos. As Wittgenstein famously wrote: 'whereof one cannot speak, one must be silent'!

I am uneasy about how cosmology is sometimes presented. The distinction is often blurred between things that are quite well established and those that are still speculative. I have tried to emphasise that back to one second, I regard cosmology as having as firm a base as other historical sciences. But the ultra-early universe is more speculative, and I must offer a special 'health warning' for what I am going to say in my final five minutes.

As we have seen, our cosmos could not have evolved its present complexity if it were not expanding at a special rate. And there are other prerequisites for a complex cosmos. We can readily imagine other alterations that would preclude complexity. For instance, if nuclear forces were a few percent weaker, no atoms other than hydrogen would be stable. Or the residue of the big bang might be entirely dark matter – no ordinary atoms at all – so that no stars or galaxies could form. Or gravity could be so strong that any large organism got crushed. Or the number of dimensions might even be different.

This apparent 'fine tuning' could be just a brute fact. But I find another interpretation increasingly compelling. It is that many other universes actually exist. Only some would allow creatures like us to emerge. And we obviously find ourselves in one of that particular subset. The seemingly 'designed' features of our universe need then occasion no surprise. If you go to a clothes shop with a large stock, you are not surprised to find one suit that fits.

Some versions of the inflationary universe – espoused by Andrei Linde, and Alex Vilenkin (two ex-Soviet theorists now in the US) and others – suggest that our big bang indeed was not the only one. What we call our universe, a domain probably stretching far beyond the 10 billion light year horizon of present observations, may itself be just one member of an ensemble.

Different domains, quite disjoint from ours, would evolve in distinctive ways, perhaps being governed by different physics. This speculation dramatically enlarges our concept of reality. The entire history of our universe would just an episode, one facet, of the infinite multiverse. Some universes may resemble ours; most would be 'stillborn' because they recollapse after a brief existence, or because the physical laws governing them are not rich enough to permit complex consequences.

The status of this scenario depends on the answers to two questions:

Will a deeper understanding of the physics of the inflationary phase support the ideas of Linde and others that there are many big bangs?

And second, are numbers like omega and the strength of gravity indeed secondary, random outcomes of some still deeper theory applying to a whole ensemble of universes?

This might seem arcane stuff, even by the standards of cosmology. But it affects how we should place our bets in current controversies. I mentioned the debate about the density of the universe, and about whether there is an extra cosmic repulsive force, the so called lambda-term. Some theorists have a strong 'prior preference' in favour of the simplest model, with omega exactly 1: they are unhappy that observations suggest that omega is 0.3, they will be even more so if there were extra complications, for instance a non-zero value for Einstein's cosmical constant lambda. But I am relaxed about this. That is because I draw a lesson from Kepler and Galileo 400 years ago. They were upset to find that planetary orbits were elliptical. Circles were more beautiful – and simpler, with one parameter not two. But Newton later explained all orbits in terms of a universal law with just one parameter, the gravitational constant G. Had Kepler still been alive then, he would surely have been joyfully reconciled to ellipses.

The parallel is obvious. If a universe with low omega, non-zero lambda, and so forth seems ugly, it is maybe through our limited vision. just as Earth follows one of the Keplerian orbits around the Sun that are in the range that allows it to be habitable – but the orbit is no more special than that – so we may realise that our universe is just one of the anthropically-allowed members of a grander ensemble. So I am inclined to go easy with Occam's razor and be wary of arguments that omega=1 and lambda=0 are a priori more natural and less ad hoc.

I end with a quote from Edwin Hubble's famous (1936) book, 'The Realm of the Nebulae', which concludes: 'Only when empirical resources are exhausted do we reach the dreamy realm of speculation'.

We still dream and speculate. There has been astonishing empirical progress since Hubble's time, and the crescendo of discovery seems set to continue. Large telescopes on the ground, and the instrument in space that bears Hubble's name, can now view 90 per cent of cosmic history; other techniques can probe right back to the first few seconds of the 'big bang'.

There are three great frontiers in science: the very big, the very small and the very complex. Cosmology involves them all.

Cosmologists must pin down the basic numbers like omega, and find what the dark matter is – I think there is a good chance of achieving this within 10 years

Second, theorists must elucidate the exotic physics of the very earliest stages, which entails a new synthesis between cosmos and microworld – it would be presumptuous for me to place bets here.

If theorists succeeded in discovering a fundamental theory that unified all the basic forces, it would be the end of a quest that began with Newton and continued with Einstein and the pioneers of quantum mechanics. But it would not be the end of challenging science. Indeed it would have no direct impact on the study of complex phenomena. And cosmology, as well as being a 'fundamental' science, is also the grandest of the environmental science. Its third aim is to understand how a simple fireball evolved, over 12 billion years, into the complex cosmic habitat we find around us – how, on at least one planet around at least one star, creatures evolved able to wonder about it all. And that is a challenge for the new millennium.

THE IMAGE OF THE WORLD: UNIQUE OR ONE OF MANY?

(Comment on Martin Rees's Paper)

MICHAEL HELLER

In modern physics and cosmology the term "nature" is used almost exclusively in two situations: when one speaks, for instance, on the nature of atom, and when one speaks on the laws of nature. The first usage is a remnant of the old Aristotelian meaning, according to which nature is the substance or the essence of a thing as it reveals itself in the way the thing acts. The second usage can be traced back to the beginnings of modern science when "natural philosophy" was a synonym of the new science, and the "laws of nature" meant simply laws discovered by it. The concept of nature had many faces in the Western history of ideas, but it steadily disappears from the present scientific language. The concept which is perhaps the closest one to the intuitive idea of nature, and which seems to replace it in our thinking of the world, is that of the image or vision of the Universe.

Every epoch and every generation has its own vision of the world which is a kind of environment indispensable for the culture of a given epoch to evolve. Usually, it is a mixture of popularized scientific data with common wisdom and prejudices shared by the more educated part of society. In the present world, at the turn of the century, this vision is even more diversified and more dependent on particular views of a given group than it was a hundred years ago. In spite of the great progress in science and its technological applications, science seems to have less and less influence on the cultural profile of our society.

It goes without saying that cosmology, one of the greatest achievements of the twentieth century, should play the principal role in shaping the present, intellectually responsible, global image of the

Universe. In the following, I shall try to filter out of Martin Rees's beautiful exposition those data of contemporary cosmology which can be regarded as its most lasting results and which present the most global features of the Universe. These data, or at least some of them, could in my view serve as a conceptual frame within which other sciences could contribute to composing the vision of the world for the next century. At the end I shall briefly comment on the idea of many universes favoured by Martin Rees.

When presenting these data, I shall equip them with some comments which would go somewhat further beyond the level of a commonly accessible picture of the world. Anyway, even the very popular world image should have its basis in responsible scientific theories.

First, the existence of the Universe. I mean the existence in the physical sense: *the Universe exists as an object which is subject to the investigation with the help of standard methods used in physical sciences* (of course, one should remember that these methods should always be adapted to the investigated object). This is not trivial. At the beginning of our century, the science of the Universe was doomed in paradoxes and inconsistencies. Physical theories known at that time, when applied to the Universe as it was then understood, were unable to explain such seemingly obvious facts as the darkness of the night sky (the Olbers paradox) and the finite force of gravity on the Earth's surface (the Seeliger paradox). The advent of relativistic physics and the discovery of the recession of galaxies not only created a new conceptual framework in which the above difficulties disappeared, but also demonstrated that even the laws of Newtonian physics, when placed in this broader conceptual environment, are, in fact, able to resolve the old paradoxes. Moreover, spectacular achievements of cosmology in the last decades of the twentieth century clearly demonstrate that physical methods of investigating the world on its large scale are not less efficient than they are, for example, on the subnuclear scale.

Second, *the Universe on its large scale is smooth, expanding and evolving*. Smooth – means homogeneous (no points distinguished) and isotropic (no directions distinguished). On its large scale – means that the Universe appears smooth only on the linear scale of the order between 300 and 600 million light years. In the fifties of our century the idea was quite popular that the Universe expands but it does not evolve (the so-called steady state cosmology). This idea had to be abandoned because of several independent testimonies on behalf of the evolutionary view, the most important of them being: the discovery of the microwave background radiation, facts concerning the evolution of chemical elements, in particular the helium and deuterium problems, and the counts of radio sources showing that at larger distances (i.e., more faraway backwards in time) the Universe was more dense than it is to-day. Taking into account the fact that by investigating the microwave background radiation we gain information on the last scattering surface we could claim that we are now able to see about 98% of the history of the Universe. We could truly say that the concepts of the expansion and evolution of the Universe have consistently merged with each other to form what we now mean by the cosmic history.

There exists a dynamic interplay between the smoothness and the expansion of the Universe. In fact, the smoothness of the Universe determines the existence of a global or cosmic time in which the cosmic history evolves, the "spaces of equal time" (or the sets of simultaneous events) being just those "hypersurfaces" which are homogeneous and isotropic. There are strong reasons to believe that the early Universe was smooth on much smaller scales than it is now, and as cosmic time goes on it becomes more and more clumpy.

Third, *the present evolution of the Universe started with the state of a very high density*. We call this state "Big Bang". The same observational evidence, which is quoted on behalf of the evolving Universe, testifies to its superdense initial state. In such extreme conditions physics had to be exotic (from our present point of view). There are many attempts to reconstruct it; all of them are mathematically elaborate and some very elegant. In spite of the fact that they can by no means be regarded as lasting achievements of twentieth-century science (they are still more or less working hypotheses), some of their conclusions (such as ultimate unification of all physical interactions, breaking down of the standard concept of time, quantum creation out of nothing), are already present in the public consciousness (owing to the great proliferation of popular books and articles). Physical scenarios of the "very beginning" strongly depend on new fundamental physical theories, and it could be expected that the next century will be the stage of many developments in this area.

Fourth, *a unification of physics and geometry*. In the first part of the century, cosmology was almost exclusively a geometric theory. The theory of general relativity can roughly be described as a geometry of space-time, and all early relativistic world models were but solutions of Einstein's field equations which, when suitably interpreted, conveyed the information about the global geometry of the Universe. The first attempts to fill in this geometric stage with physical process were rather modest and based on too many unknown parameters. Only the substantial influx of new observational data, starting from the sixties of our century, provided the sufficient foundation for creating the physics of the Universe. To-day we possess the solid knowledge of physical processes leading the cosmic evolution back to a few minutes after the Big Bang. According to the relativistic paradigm, space-time is no longer a passive stage for physical processes, but rather an active partner in the same drama. This unification of geometry and physics (a "geometrisation of physics") has a certain impact on pure geometry in which physics-like methods are now used with great success (a "physicalisation of geometry"). When going back into the "unknown physics" of the first few minutes, and even more so of the first few milliseconds, this unification of physics and geometry becomes – as we believe – more and more radical. The notion itself of geometry broadens so as to satisfy requirements of the "new physics". And *vice versa*, very often the only guidelines for creating "new physics", supposedly reigning in the Big Bang, are pathways along which the hitherto geometries can be generalized.

Fifth, *complex structures in the Universe*, such as molecules, galaxies and their clusters, stars and planets, living cells and human brains, *originate from simpler ones via the complexification processes*. We are only at the beginning of studying these processes, but it is already certain that they can be fully accounted for with the help of physical laws operating in the nonlinear regimes. Nonlinearity is here a key ingredient. A structure or a process modelled by a nonlinear differential equation can, roughly speaking, be something more than the sum of its parts, the surplus being produced by nonlinear interactions between its components. Einstein's field equations are themselves strongly nonlinear equations, and since they are so successfully used to model the Universe, we can truly say that we inhabit the "nonlinear Universe". To its nonlinearity we owe the fact that our Cosmos is not dull and sterile.

Sixth, in the first half of our century cosmology was treated at best as a more or less exotic application of Einstein's general relativity, whereas in its last decades *it has become a branch of physics in its own right*. Moreover, without this branch contemporary physics would loose something of its identity. It is not only that without super-high energies available in the Big Bang particle physicists would be deprived of their "ultimate accelerator" indispensable to check their theoretical speculations (some of them, when combined with cosmological theories might lead to testable astronomical predictions), but also some fundamental physical programs (such as the unification of physics or quantum gravity) would seem meaningless without their natural environment in the very early Universe. On the other hand, cosmology gains from its coalescence with physics an additional support and corroboration. I would risk the statement that for a physical theory there are three criteria with regard to its scientific character and credibility: first of all, agreement with empirical data; second, its conceptual coherence and mathematical elegance; and last but not least, its consonance with the rest of physics. In fact, these three criteria are so intimately interwoven with each other that perhaps it would be more reasonable to treat them as the three aspects of the same criterion.

Seventh, in spite of the great progress we have made in this century, or rather because of it, *we meet some limits in our exploration of the Universe and its deep structure*: singularities in the Big Bang and gravitational collapse, quantum gravity, the beginning of time... In all these domains, and in many others as well, our knowledge of physics is on the verge of breaking down, and sometimes it seems that we are hunting our own shadows. However, all these limits are not absolute barriers to our knowledge, but rather challenging gaps that sooner or later will be filled in. Only a few scientists claim that in several decades nothing will be left for further investigation, but I share the opinion of the majority that this interplay between the already known and still open for being known is rooted in the very structure of the Universe and of ourselves as its part. And here comes my last point.

Eighth, since Copernicus we know that man does not occupy the central position in the Universe, but *he cannot cease to be a kind of reference point as far as the knowledge of the Universe is concerned*. To understand the Universe means for us to place what we see and what we measure within the network of our concepts which, I think, are not given to us *a priori*, but rather are formed in the process of understanding itself. Moreover, in order to see and to measure we must not only extract from the Universe what is *for us* seeable and measurable, but also we must reconstruct the extracted data so that they will be adapted to our senses and our conceptual categories. Nowadays, there are computers (also made by us, more or less on our own image and likeness) which serve us as an intermediary between raw data extracted from the Universe and ourselves. For instance, we convert photons of a radio emission, which are invisible for us but are visible for our instruments, into the set of numbers stored in the memory of our computers, and ask them to compose for us artificially coloured maps which we can contemplate and show to our students. It is true that we could, in principle, proceed without the help of pictures and diagrams, because the essential part of the work is done in terms of abstract mathematical structures, but even the most abstract form of mathematics is but our construct and our invention to cope with what otherwise would have been hidden for our minds for ever. I am far for claiming that all our knowledge of the Universe is subjective and entirely human-made. Our cognitive abilities evolved in the constant interaction with the surrounding world, and there are strong reasons to believe that, as the consequence of this process, the structure of our senses and of our mind is adapted to the structure of the Universe (the effectiveness of the scientific method and its technical applications strongly testify to this), but this does not change the fact that all our science is biased by our human condition and to reach objective knowledge of the world in so much as this possible we must take this into account.

This "human bias" goes much further than the so-called anthropic principles which seek to establish the connection between the structure of the Universe and biological evolution within it. The anthropic reasoning tries to use the results of cosmology to show that such a connection exists, whereas "human bias" underlies both cosmology and all our thinking about it.

The weak anthropic principle emphasises the fact that our own existence imposes strong constraints on the possible place and time we could occupy in the Universe. This is a kind of selection principle: for instance, we could not have evolved in a much younger Universe in which stars had not yet produced carbon. In this sense, there is nothing mysterious in the weak anthropic principle; it simply reminds us that when interpreting cosmological results we should take into account certain selection effects resulting from our specific structure as living beings. It seems, however, that some sort of "selection" worked also in establishing initial conditions for our Universe (this is called the strong anthropic principle). For example, slight variations in the initial rate of expansion or in same numbers characteristic of atomic physics, such as the fine-structure constant, would lead to a universe with no stars and galaxies and none of the chemistry necessary to produce life in the form we know it. Since the initial conditions had to be extremely fine tuned to allow for our existence, it looks to be not an authentic selection effect (for the unique Universe there is nothing to select from), but rather a design or purpose. As far as I understand, precisely to avoid such a "designed Universe", Martin Rees is inclined to subscribe to the idea of many universes (an idea propagated, by among others, Linde and Smolin). The idea is to change design into true selection. If there exist many (possibly: infinitely many) universes, disconnected from each other, with various combinations of initial conditions, we could have evolved in this very special subset of universes in which initial conditions allow for the evolution of life in the form known to us. In this sense, the strong anthropic principle is no longer needed. It is a kind of *generalized weak anthropic principle*, operating now on the level of all universes, that explains the possibility of our own existence.

It seems, therefore, that we have two options: either the unique Universe with "teleological design" or many universes with "natural selection". However, to make the argument convincing, we must take into account the third possibility. We know that the theory of the Universe "before its Planck epoch" had to be a quantum gravity theory but, unfortunately, in spite of many attempts and a few working models such a theory still does not exist. Nevertheless, some partial results obtained so far allow us to believe that such a theory will, when finally discovered, be radical in its explanatory power. If so, we could suspect that it will also explain the role of the initial conditions. There are here several possibilities, for example: (A) no initial conditions are necessary (or the only condition is that there are no conditions), the unique Universe exists because it is the only possibility admitted by the laws of quantum gravity (and of unified physics); (B) there is the spectrum of admissible initial conditions, and all of them are of more or less of equal probability; (C) only a small subset of initial conditions is of significantly higher probability than all the others. Case (B) would be a support for the idea of many universes; cases (A) and (C) would explain (without any design or purpose) the special character of our Universe. I do not think this sample of possibilities is complete. The history of science teaches us that a new physical theory very often surpasses all previous evaluations and hypotheses. The risk of the unforeseeable is always incorporated into the strategy of the scientific adventure. And this is one of the main factors which makes this adventure so exceedingly fascinating.

However, there is still another meaning of "many universes" (or of a "multiverses") which is not only acceptable, but even must be (tacitly) assumed in every cosmological investigation. Cosmology is often accused of being a rather peculiar science since the object of its investigation is unique: the Universe is given to us in a single copy, whereas for the empirical method it seems essential to have many instances of the same type. The point is that this could hardly be understood as an objection against the scientific character of cosmology. Indeed, the laws of physics are usually formulated in terms of differential equations, which by their very nature describe a structure composed of a net of relations between quantitative properties common to phenomena of a given type. Individual characteristics of every phenomenon are accounted for by selecting suitable initial or boundary conditions. In this respect the strategy of cosmology is exactly the same as that of other theoretical-empirical disciplines (some of them also study single objects: a given planet, our Galaxy...). It is assumed that the Universe is described (or better – modelled) by a certain differential equation or a system of differential equations (usually Einstein's field equations). One tries to find all its solutions, and then to identify those initial or boundary conditions which select the subclass of solutions most approximating the Universe we actually observe. Since each solution describes a possible universe, we have, in fact, placed the actual Universe in the environment of many universes. In this conceptual framework, such a set of many universes is usually called the *ensemble of universes*.

Let us observe that the above strategy is implicit in each quantitatively experimental method. Because of unavoidable measurement errors we never select a single theoretical model, as being in agreement with empirical data, but rather a class of such models which fit into the "box of measurement errors".

Moreover, there is now a tendency in theoretical cosmology to explore certain subsets of the ensemble of universes, or even to study it as an interesting mathematical object (see my book: *Theoretical Foundations of Cosmology*, World Scientific, Singapore-London, 1992, chapter 5).

It is evident that the "multiverse" of Martin Rees and the ensemble of universes have totally different methodological significance. The former is a hypothesis with no empirical support (although it might seem philosophically appealing); the latter is presupposed by the empirical method itself. Many universes must, at least potentially, exist (as solutions of certain equations) to render possible our science of the real world.

COMPLEX SYSTEMS: A PHYSICIST'S VIEWPOINT

GIORGIO PARISI

1. *Introduction*

In recent years physicists have been deeply interested in studying the behavior of complex systems. The result of this effort has been a conceptual revolution, a paradigmatic shift that has fax reaching consequences for the very definition of physics.

In the nutshell, physics is an experimental science in which theoretical predictions are compared to experiments. It differs from other sciences of nature in the crucial role of mathematics: physicists describe the phenomena by using a mathematical model and their predictions are obtained by mathematical reasoning.

In this definition of physics the word *prediction* plays a crucial role. Naively one could think that the meaning of the word *prediction* is quite evident and no further explanation is needed. In reality its meaning has changed already in the past and it is still changing now.

Let me recall using modern language what a prediction was at the time physics was born. We assume that the state of the system at the time t is represented by a vector $X(t)$ with N components.

In the case of classical mechanics the state of a point-like particle is described by the three coordinates and by the three components of the velocity. The corresponding vector $X(t)$ has six components. An experiment consists in determining or imposing the position and the velocity of the particle at a given time and measuring it a later time. It is crucial that (at least in principle) the experiment can be done many times by imposing the same initial conditions. If the difference between the initial and the final time is the same, the system is always found in the same final state. When repeated, the experiment always gives the same result. The theoretical task is to predict this unique, reproducible result.

This can be done by using the equations of motion which gives the time evolution of the vector $X(t)$. In the case of classical mechanics, they have the form of Newton's second law

$$\frac{dp}{dt} = F(x), \; \frac{dx}{dt} = \frac{p}{m} \tag{1}$$

where $F(x)$ is the force. Once that the form of the force has been established it is a well posed mathematical problem to compute the final conditions as function of the initial one.

The same perspective applies not only to simple objects but also to much more complicated situations. The description of the system may need more than one position and one velocity. The equations of motion', which are in general of the form

$$\frac{dX}{dt} = G(X(t)), \tag{2}$$

in principle. allow the prediction of the final state for each initial state. The theory (which consists in assuming a particular form of the function $G(X)$) can be tested by measuring X at the initial time, predicting X at the final time and verifying the prediction.

In reality, the mathematical difficulties may be substantial even if the system is apparently simple. To predict the evolution of a three body system (like Sun, Earth and Moon) is a rather difficult task and it can be done only with a lot a work. At the beginning of the nineteenth century Laplace was writing that an infinitely intelligent mathematician would be able to predict with certitude the future by observing the state of the universe now and using his knowledge of the laws of motion.

In this classic, deterministic framework the word prediction has a clear meaning. Unfortunately we are not infinitely intelligent mathematicians and besides an infinitely able experimentalist is needed to measure the state of the system with extremely high accuracy. The Newton-Laplace point of view could be applied only to a restricted class of phenomena. In order to consider other phenomena which could not be studied from this point of view, it was necessary to change the general *philosophy*, by introducing probabilistic concepts and probabilistic predictions.

There have been three revolutions in physics which all went in this direction [1] and as a consequence they have changed the meaning of the word *prediction*. They are:

(1) The introduction of statistical mechanics and of the first probabilistic reasoning by Maxwell, Boltzmann and Gibbs in the second half of the last century.

(2) The discovery of quantum mechanics at the beginning of this century.

(3) The study of complex systems and the related techniques that have been developed in these last years.

As an effect of these revolutions, the word *prediction* acquired a weaker meaning. Predictions in the context of the new paradigm are not acceptable with the old one (and sometimes the supporters of the old point of view try to deny to them a scientific validity). The positive consequence of the process is that the scope of physics becomes much larger and the constructions of physics find many more applications.

My aim is to present point (3). However, it is better to start by discussing point (1) in order to understand in which way the study of complex systems forces us to use the word probability in a wider context. For our purpose we can neglect point (2), because it extends the concept of probability in a different direction. (In quantum mechanics we have to deal with the fact that also in principle the results of a single experiment are not reproducible).

2. *Introducing Probability in Physics*

At the time of Boltzmann [2] and Gibbs, the main motivation for leaving the Newton-Laplace point of view was not that it was wrong, but that it was useless in many cases. Let us consider the following experiments which apparently can be repeated many times with the same result:

We bring water to 100 centigrade: it boils.

We bring water to 0 centigrade: it freezes.

When we study this phenomenon from a microscopic point of view, we face a serious problem. The experiment should be done by measuring the positions and the velocities of all the billions of billions of atoms and we should later use this information to compute the trajectories of all the atoms. This difficulty was bypassed by discovering that for a system composed by many particles, practically all the initial conditions (at fixed total energy) lead to the same macroscopic behavior of the system. The task of measuring everything is not only impossible, it is also useless. If we neglect the possibility of some very special initial configuration – which happens with extremely low probability – the system always behaves in the same way.

The final predictions are the following:

Water practically always boils at 100 degrees. The probability is so high that it is extremely likely that this kind of prediction has never failed in the whole history of the universe.

If we measure the velocity of a single molecule of water we cannot predict anything precise. However we can compute the probability that the molecule has a velocity v ($P(v) \propto \exp(-Av^2)$ where $A = m/(2kT)$). Therefore if we measure the velocity of a molecule M times the observed distribution of velocity should approach the theoretical curve when M goes to infinity.

In general, we could say that for these large systems there are two kinds of quantities:

Some quantities can be predicted with certitude and have always the same value inside a small interval (usually of order $N^{-1/2}$ for a system with N degrees of freedom).

Other quantities do not take always the same value. In this case a probabilistic prediction is possible.

3. *Deterministic Chaos*

In the previous discussion, the main motivation for introducing probability was the large number of particles present. Only in the second half of this century was it realized that there are many systems with a small number of particles, or more generally with a small number of degrees of freedom, for which it is also necessary to use probabilistic arguments [3].

In these systems (which sometimes are called chaotic) the trajectory cannot be predicted for large times, because it is too sensitive to the initial conditions. The difference in the position of the trajectories of two systems which have a very similar initial conditions increases exponentially with time. In other words, even a very small incertitude on the initial condition leads to a total loss of knowledge after a characteristic time τ. More precisely if

$$X_1(0) - X_0(0) \propto \varepsilon \qquad (3)$$

the difference $X_1(t) - X_0(t)$ grows as a function of the time t as $\varepsilon \exp(t/r)$ until it reaches a value of order 1.

Deterministic predictions are possible here on a time scale smaller than r, but they become impossible at later times because we cannot measure the initial conditions with infinite precision.

A very simple example is provided by two (or more) balls on a billiard table without friction. For generic choice of the initial condition the two balls will collide from time to time, and after each collision it becomes more difficult to predict the position of the balls.

Fortunately, in many cases the probability distribution at large times for finding the system in a given configuration is independent on the initial conditions and it can be predicted. So here also we can compute only the probability distribution of some variables, not the exact evolution.

The new framework given by statistical mechanics should now be clear. We have a system, we know the equation of motion. In principle, an exact knowledge of the initial conditions allow us to compute the exact evolution of the systems. In reality this task may be impossible because we do not know the initial conditions with sufficiently high accuracy. It is also possible that the computation is terribly complicated. We can however make progress and get much more insight if we restrict ourselves to the task of predicting the probability distribution of the system at large times (in short its *behavior*). Given the equation of motion G (see eq. 2) we define the probability $P_G(X)$ [3] as

$$\int dX f(X) P_G(X) = \lim_{T \to \infty} \frac{\int_0^T f(X(t))dt}{T}, \tag{4}$$

where $f(x)$ is an arbitrary test function. For ergodic systems the probability $P_G(X)$ does not depend on the choice of the initial point for almost all the choice.

The task of statistical mechanics consists in the computation for given G of the probability $P_G(X)$ and of its properties.

4. *Complex Systems*

It was recently realized that this approach described in the previous section (i.e. to predict the behavior of the system from the knowledge of the equations of motion) fails in the case of complex systems for reasons that are very similar (albeit in a different contest) to those which led to the abandonment of the Newton-Laplace view-point.

There are many possible/definitions of a complex system. I will use the following one. *A system is complex if its behavior crucially depends on the details of the system.* This dependence is often very difficult to understand. (A single complex system may also display different types of behavior and a small peturbation is enough for switch from one behavior to another. For example an animal may: sleep, dream, run, hunt, eat, play...). In other words, the behavior of the system may be extremely sensitive to the form of the equations of motion and a small variation in the equations of motion leads to a large variation in the behavior of the system. More precisely for two systems with N degrees of freedom with equations of motion G_0 and G_1, where

$$G_1(X) - G_0(X) = O(\varepsilon) \tag{5}$$

we could have that for small ε but not large εN,

$$P_{G1}(X) - P_{G0}(X) = O(1). \tag{6}$$

If this happens it is practically impossible to compute the asymptotic probability as function of G.

My aim is to show that although a system is complex, it is still possible to get predictions for its behavior, but these predictions will be now of a probabilistic nature. I will illustrate this point in a particular example. The prototype of a complex system in physics is spin glass. [4] I will choose here something more familiar to most people, a large protein.

A protein is composed by a long chain of a few hundred amino-acids and its chemical composition is specified by the sequence of aminoacids (primary structure). In physiological situations, normally a protein folds in an unique way (tertiary structure). During the folding, the protein goes to the configuration of minimal energy (more precisely, to the configuration of minimal free energy). However, there are many quite different configurations of the protein which have an energy near the minimal one. There are proteins, which are called allosteric, which have two configurations which practically the same energy. Sometimes, if we perturb the protein by a small amount, e.g. changing the pH or changing only one aminoacid in the chain, the folding changes dramatically. We can also select one of the two different configuration by the binding of a ligand.

The variations in the shape of mioglobulin in different conditions are crucial for its respiratory functions. More generally, the possibility of switching from one configuration to another is one of the fundamental mechanisms which allows proteins to work as enzymes. For example the change of configuration of allosteric proteins it is used for doing useful work, e.g. for contracting muscular fibers.

The existence of allosteric proteins implies that a small variation. in the form of the potential among the components of the protein changes the folding of the protein dramatically. It is thus evident that a small error in the form of the interaction among the different components of the protein or of the interaction with the solvent would lead to quite wrong results.

Natural proteins are on the borderline of what can actually be understood; we have not yet computed their folding properties, but-this does not seem completely impossible, especially for the smallest ones. However, to compute the folding properties of much large proteins seems to be a hopeless task.

If an approximate knowledge of the equations of motion does not allow us to compute the behavior of a complex system, we can give up this task and restrict ourselves to compute the probability of a behavior when the equation of motions are chosen randomly inside a given class.

In other words we can study the same problem in two different ways:

In the old approach we consider a given protein (e.g. mioglobulin) and we compute the form of the two foldings with minimal energy and their energy difference as a function of the chemical properties of the solvent.

In the new approach we consider a class of proteins (to which mioglobulin belongs) and we compute the probability distribution of the energy difference among the two foldings with minimal energy. [7]

Of course, this second computation will not tell us the properties of mioglobulin. It will give us predictions that cannot be tested on a single protein (in the same way the probability distribution of the velocities cannot be tested by measuring only one velocity); we need to repeat the experiments on many different proteins.

Taking the new point of view, we often gain insight. The behavior of a given complex system may be obtained only after a very long computation on a computer and often we cannot understand the deep reasons of the final result. The study of the probability distribution of the behavior can sometimes be done analytically and we can follow all the steps that lead to the conclusions.

The advantage of the second point of view is that its results may be easily generalized to other systems. For example long RNA molecules also fold in a characteristic way, in the same way that proteins do. A general explanation which shows that some characteristic of folding are shared by all polymers composed by different monomers may be applied to RNA as well as to protein

There are simple models (e.g. spin glasses [4]) in which this program works. The computation of the behavior of a given system is extremely difficult and sensitive to the minimal detail and can be done only with lengthy computer simulations. The analytic computation of the probability distribution of the behavior for a generic system can be done analytically and these probabilistic predictions have been successfully verified.

The extension of this program to other systems leads to two different types of difficulties.

The generalization of the methods which allow the computation of the probability distribution of the behavior to models which are not as simple as spin glasses, is technically difficult and progress in this direction are rather slow.

This point of view is quite different from the traditional one (mathematically it corresponds to the use of *imprecise probabilities*[5]). The predictions are not made for the properties of a given system, but for the probability distribution of those properties which change with the system. We are not enough familiar with this new point of view to appreciate all its potentialities.

As usual a change in the paradigm leads to a change in the questions posed. We do not have to ask how a particular system behaves. We have to ask which are the general features of the behavior of a system belonging to a given class.

In spite of these difficulties, this new approach seem to be absolutely necessary to get some understanding in really complex systems. We have seen that the arguments are very similar to those described before. In the two cases they can be summarized as follows:

(1) The extreme sensitivity of the trajectory on the initial conditions forces us to study the probability distribution of the systems at large times. This must be done in spite of the fact that an exact knowledge of the initial condition determines the trajectory at all times. The behavior of the system can be computed from the equations of motion.

(2) The extreme sensitivity of the behavior on the detailed form of the equation of motion forces us to study the probability distribution of the behavior of the system. This must be done in spite of the fact that an exact knowledge of the initial conditions determines the behavior. The probability distribution of the behavior of the system can be computed from the probability distribution of the equations of motion. In other terms, given a probability distribution $p(G)$ we can compute the probability $P[P_G(X)]$, which of course depends on p.

The advantage of this new point of view is to expand the range of application of physical reasoning. We shall see now how it puts the relations between physics and biology in a new perspective.

5. *Possible Biological Applications*

In biology problem we face a very difficult of how to use the immense amount of information we gather at the molecular level in order to understand the behavior of the whole organism.

Let us consider an example. One of the simplest organisms is *E. Coli*. Its genome (which is known) codes for about 3000 different proteins which interacts among themselves. Some proteins promote the production of other proteins, while other proteins have a suppressor effect.

In principle we can gather the information on the properties of the proteins, on the interaction among the proteins (for simplicity let us neglect all the other chemical elements of the cell). At the end we can use this information to construct a model of the living cell. The model may lead to a system of few thousand (or more) coupled differential equations which can be studied by a lengthy computations on a computer.

If the information is accurate enough, the model will describe a living cell. However we know that in real life many mutations are lethal, and therefore it is quite likely that imprecision in the form of the interactions among proteins will lead to a non-living cell or to a living cells with a quite different behavior. It is also clear that such a gigantic computation (although welcome) will not capture the essence of life. Indeed it should be repeated nearly from scratch if instead of *E. Coli* we consider a different organism.

The previous discussion suggests that we could give up the aim of deriving the properties of a given organism from its chemical components, and ask different questions, e.g. what are the general properties of a living organism and how they do change from organism to organism.

An example of this last of question has been studied by Kaufmann [6]. There is a dependence of the number different cell types on the number of genes in all kind of living organisms.

$$\#\ \textit{cell types} \propto (\#\ \text{genes})^{1/2} \qquad (7)$$

As Kaufmann points out, this fact must have a general explanation and he proposes one based on mathematical considerations of evolution.

An other empirical law, which calls for a general explanation is

$$\# \textit{ species in an island} \propto (\# \text{ genes})^{1/4} \tag{8}$$

In these two cases we can hope to compute the exponents. However in many other cases this point of view is so different form the traditional one, that it is very hard to find the right questions and also to answer to them.

A field in which this approach seems to be mandatory is the study of the origin of life. Here it is crucial to understand which are the enzymatic capabilities of the prebiotic material (maybe long randomly assembled RNA chains) before evolution starts. We would like to know which of the properties of these long chains had to be selected and which ones Where already present before selection.

This approach is quite different from a reductionistic one, as far as it puts the stress on the behavior of the whole system. For the moment the largest impact of these ideas in biology has been in the field of neural networks, but in the other fields the progress is quite slow. We need to sharpen our theoretical tools in order to be able to predict the typical behavior for different classes of systems. We are seeing now only the beginning of these investigations in mathematical physics.

When the physical instruments become more robust and our theoretical command increases, the interaction with biology will become more easy. I am convinced that in the next century a much more deep understanding of life will come from this approach.

REFERENCES

1. M. d'Eramo, in *Fra ordine e caos: confronti della ricerca*, M. Turno, E. Liotta and F. Orsucci (eds.) (Teda, Catanzaro, 1996).
2. E. Brodda, *Ludwid Boltzmann, Man - Physicist - Philosopher* (Ox Box Press, Woodbrige, 1983).
3. D. Ruelle, *Chance and Chaos* (Princeton University Press, Princeton, 1991).
4. M. Mezard, G. Parisi and M. A. Virasoro, *Spin Glass Theory and Beyond* (World Scientific, Singapore, 1987).
5. P. Walley, *Statistical Reasoning with Imprecise Probabilities* (Chapman and Hall, London, 1991).
6. S.A. Kauffman, *Origins of Order: Self-Organization and Selection in Evolution* (Oxford University Press, Oxford, 1993).
7. E. I. Shakhnovich and A. M. Gutin, *J. Phys.*, 1989, 22A, 1647.
8. G. Parisi, *Physics Words* (1993).

MODELS, PREDICTIONS AND SIMULATIONS

AKSEL C. WIIN-NIELSEN

Preface

The present paper deals with classical physics. In the second half of the present century the field has experienced the design of a large number of models used to simulate various processes in nature. Most of these models have been used to simulate processes in the biological and geophysical fields. In some cases the models have been used to attempt a prediction of a future state by making long numerical integrations of the non-linear model equations.

A major change in the basic foundation of classical physics has been the discovery of chaotic processes. Although the concept was known already in the last decade of the former century, it came to the forefront by investigations of a theoretical or numerical nature in the atmospheric sciences at the beginning of the second half of the present century when it was clearly demonstrated that most non-linear equations show great sensitivity to small changes in the initial state permitting predictions for a limited time only. Chaos is now defined as sensitivity to small changes in the initial state.

The implications of limited predictability is a major topic of the present paper.

1. Introduction

Classical physics has in the present century been considered as an important field for applications in applied and technical sciences. From a research point of view it was a rather uninteresting part of physics since it was assumed to be a fully developed field. At the same time the most important physicists were occupied by the new developments in other parts of physics.

With the design and production of steadily larger and faster computers it became possible to perform numerical integrations of the non-linear model equations. Although the models in the beginning had to be rather simple, due to the limited capacity of the computers and to the inexperience of performing numerical integrations of large systems of equations, it did not take long before the models were expanded to include most, if not all, processes considered relevant for the natural process under investigation. With these models it became possible to describe the averaged state of a natural system with excellent accuracy.

Predictions were performed in a number of fields, but it was soon discovered that the first models did not permit realistic predictions for more than a short time. The limited predictability was explained by the simplicity of the models. It was assumed that the predictions could be extended to cover larger time intervals when it would be possible to include a number of relevant processes. The field of predictions was as a matter of fact governed by a great deal of optimism with promises of extended predictions in the near future.

Models for the simulation of natural processes were developed at the same time as the prediction models. While the first atmospheric predictions for one day into the future were made in 1949, the first simulation of some major aspects of the atmospheric general circulation was produced a few years later by Phillips (1956). In his case he formulated some basic questions concerning major aspects of atmospheric flow. His problem was to account for some, but not all, characteristics of atmospheric flow such as a correct description of the major wind systems with easterlies in the low and the very high latitudes surrounding the westerly winds in the middle latidudes. He wanted also to see if his model could produce the atmospheric waves found in the troposphere and the highs and lows found at the surface of the Earth.

The model was simple. Only two levels were used to describe the vertical variations of the atmosphere. The region of integration was not the spherical Earth, but rather a rectangular region with the proper dimensions. The model contained a fixed driving mechanism consisting of heating at the low and cooling at the high latitudes. In a first attempt he used a model version having only meridional (south-north) variations excluding deliberately any zonal (west-east) variations. He found that while this meridional model did develop strong zonal winds they were not in agreement with nature. Integrating next the full model equations with small random values added in each gridpoint he found as one could expect from theory that the model developed atmospheric waves. These waves interacted with the zonal flow and changed it in such a way that a much better agreement with observations was produced. The primitive simulation of the atmospheric flow contained the waves and the highs and lows. The full model equations were integrated for a simulated time of about 30 days.

2. The impact of limited predictability

The concept of limited predictability was discovered by H. Poincaré (1893 and 1912) by attempting a numerical integration of the proper equations of the astronomical three-body problem to which no analytical solution is known. He describes the large deviations between two integrations starting from slightly different positions of the two planets relative to the sun. As so often happens his discovery was forgotten perhaps because the physicists in the following years were occupied by entirely different problems, or because numerical integrations of problems were considered uninteresting in a time of primitive computing devices.

A rediscovery was done by Thompson (1957) for the atmospheric prediction problem. He showed that atmospheric predictions were sensitive to small changes in the initial state, and he estimated as a matter of fact that the practical limit of predictability was 7.7 days. The impact of his paper outside meteorology was small due to its special nature and the complicated mathematics needed to produce his results. Lorenz (1963) produced a particularly simple example of limited predictability by using a very simplified version of the full equations, containing only the three largest spectral components, applicable to the convection between two horizontal plates each kept at a constant temperature with the higher temperature at the lower plate.

The model equations describe a typical low-order system consisting of only three non-linear equations describing the interaction between the three largest components of the convection between the two plates. For low values of the Rayleigh number ($R<1$), proportional to the temperature difference between the two plates, the necessary heat transport from the lower to the upper plate is carried out by molecular processes. For higher values of the Rayleigh number ($R>1$) convections cells develop, and these cells transport the heat from the lower to the upper plate. Even higher values of the Rayleigh number ($R>24.74$) produce chaotic flows. The limited predictability can be demonstrated in the latter case as shown by Lorenz in his paper.

It can also be demonstrated that the models are sensitive to small changes in the physical parameters entering the model equations. This statement may be understood by noting that a change in one of the parameters initially will result in slightly different fields after the first timestep and thus in limited predictability. Figure 1 shows the RMS-difference between two integrations of the Lorenz-equations when the Rayleigh number is changed from R=28.0 to R=28.0000001. It is seen that the RMS-difference becomes large after an integration of 30 time units whereafter it goes into irregular oscillations. Supercritical values of R correspond to a situation in which all steady states of the model are unstable. The system will thus continue to oscillate and never come to rest.

Subcritical values of the Rayleigh number correspond on the other hand to two stable and one unstable steady state in the Lorenz model. If

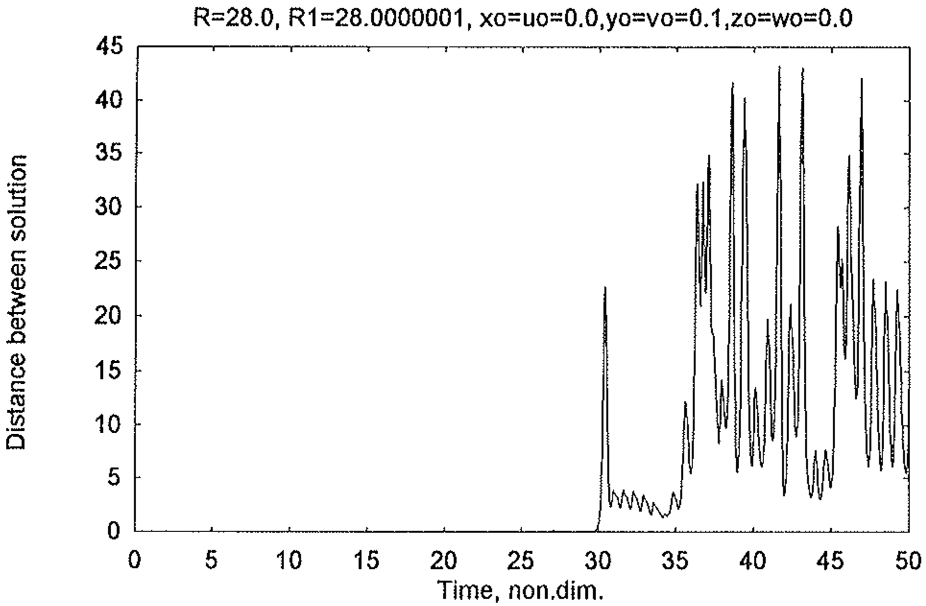


Fig. 1 – A comparison between two integrations of the Lorenz equations for R=28 and R_1=28.0000001 and the common initial state (0,0.1,0). The values of R and R_1 are in the chaotic domain. The ordinate is the distance between the two solutions in the three-dimensional space.

we start very close to one of the stable state the system will end in that steady state. However, if we start an integration from a position far from the two stable states, we may ask if we can predict in advance in which of the two states the system will arrive in the asymptotic case. The answer would be simple if we knew the details of the structure of the attractor basin, but this is not the case. We have thus to find out by numerical experiments. An example is shown in Figure 2 where two integrations start in the same point (1,0,23), but with values of R=23 and R_1=23.0000001. It is seen that the RMS-difference becomes zero after more than 500 time units. The two integrations end thus in the same steady state after a long integration. A small change in R is therefore sufficient to cause that one integration lands in one of the two stable steady states, while the other integrations asymptotically ends in the other stable state. However, another pair of integrations starting in the common initial state (1,-2,23) and with the same values of R and R_1 finish in different steady states after long integrations (400 time units) as demonstrated in Figure 3 showing the two corresponding variables as function of time.

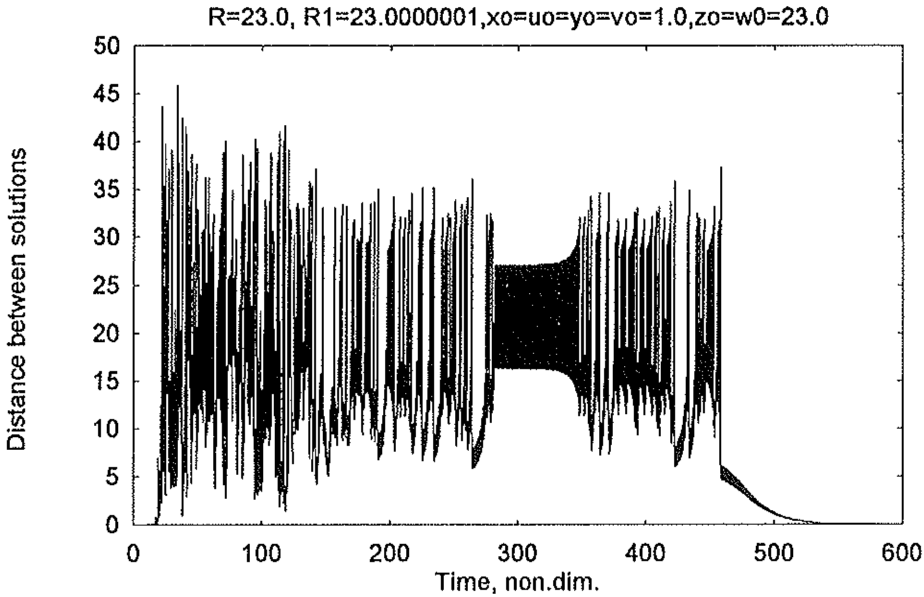


Fig. 2 – The distance between two solutions of the Lorenz-equations for subcritical values of the Rayleigh number: R=23, R_1=23.000001 with the common initial state (1,1,23). The two solutions approach the same stable steady state.

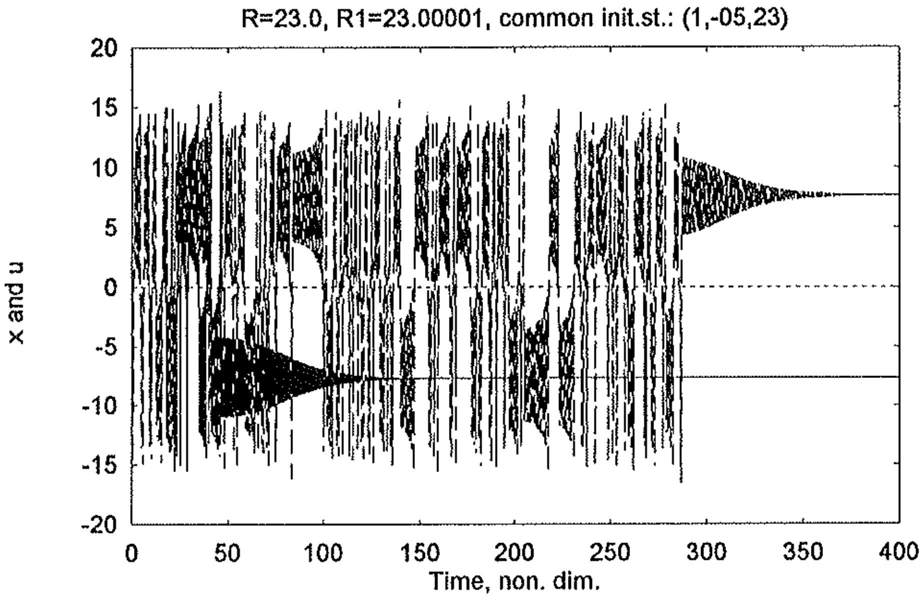


Fig. 3 – The x – and u-values for two solutions with R=23 and R_1=23.00001 and the common initial state $(1,{-}_2,23)$. They arrive in different stable steady states.

Figure 4 shows the fields of the streamfunction for two integrations starting from slightly different initial meridional states. The wavelength is 5000 km, and the vertical wind shear is 20.0 m per s in one case and 20.1 m per s in the other. Waves develop in both cases, but the small change in the initial state results in a large phase difference between the two states. A similar situation is shown in Figure 5 for a wave length of 10000 km, but the same difference in the vertical wind shear.

We shall select the atmospheric prediction case to demonstrate the limited predictability in practice using the best models available at the time of the integrations. Models of the atmosphere has been developed since 1950. They started with a simple model assuming that the atmospheric flow was horizontal and non-divergent. Gradually the major simplifying assumptions were removed. The number of vertical levels were increased. Vertical velocities were incorporated, but for a long time no energy sources and dissipations were present in the models. These were gradually introduced around 1970. Each improvement in the model gave somewhat better results in two ways. The accuracy at a given time became better, and the forecast could be

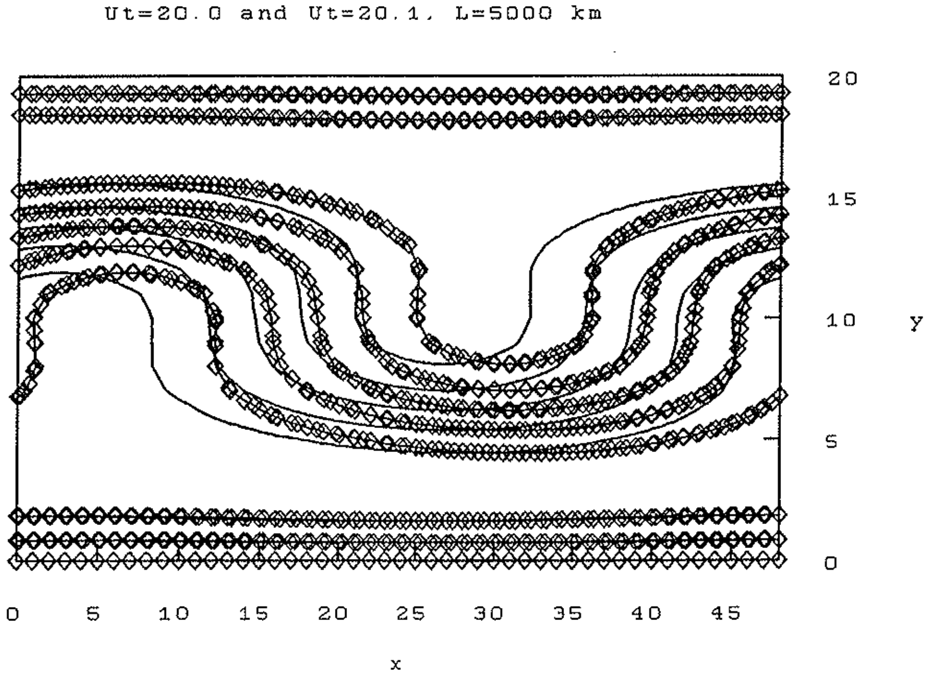


Fig. 4 – The streamfunctions for two integrations, starting from rest, after 2 years. The forcing was a single factor measuring the vertical wind shear: 20.0 m per s and 20.1 m per s. The wavelength is 5000 km. A considerable phase difference is noted.

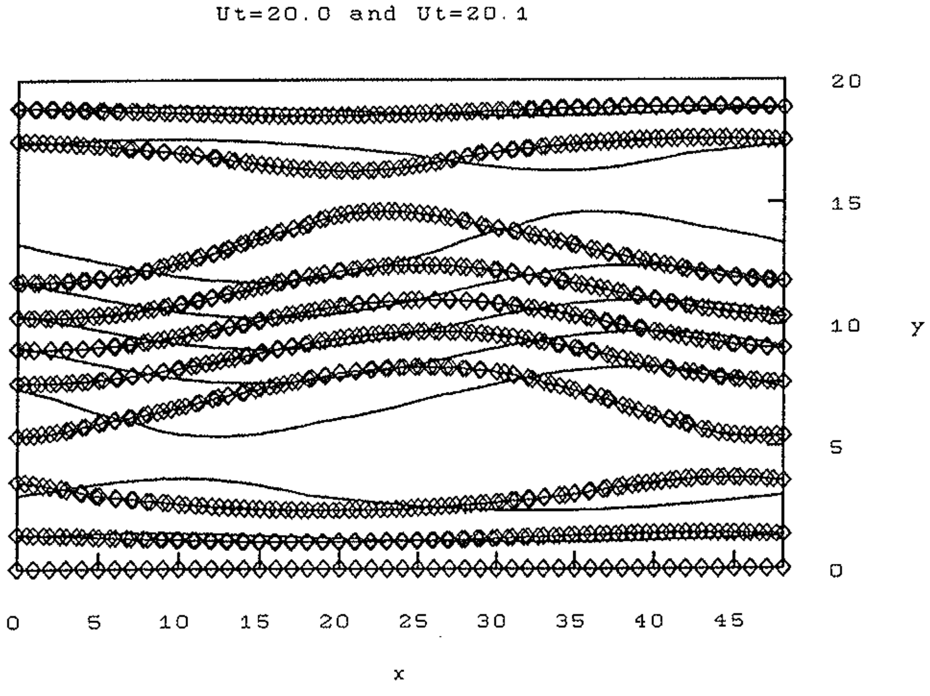


Fig. 5 – Equivalent to Fig. 4, but for a wavelength of 10000 km.

extended with acceptable results slightly longer into the future. The practical limit of predictability was gradually extended from 1-2 days to about a week which is the present limit of *practical* predictablity. Figure 6 illustrates this statement.

The question is if this is also the *theoretical* limit. One may estimate this limit by using the best possible model at a given time and perform two numerical integrations from slightly different, almost infinitesimal, initial states. The two integrations will deviate more and more from eachother. When the difference becomes so large that the two integrations describe totally different states we have reached the theoretical limit of predictability. Integrations of this kind have indicated that the limit is of the order of three to four weeks. We have thus a large difference between the two numbers, and it is still worth-while to attempt to increase the practical limit of predictability. However, this limit has not changed very much over the last few years although a slight increase have been observed. The latest and modest gains in atmospheric predictability

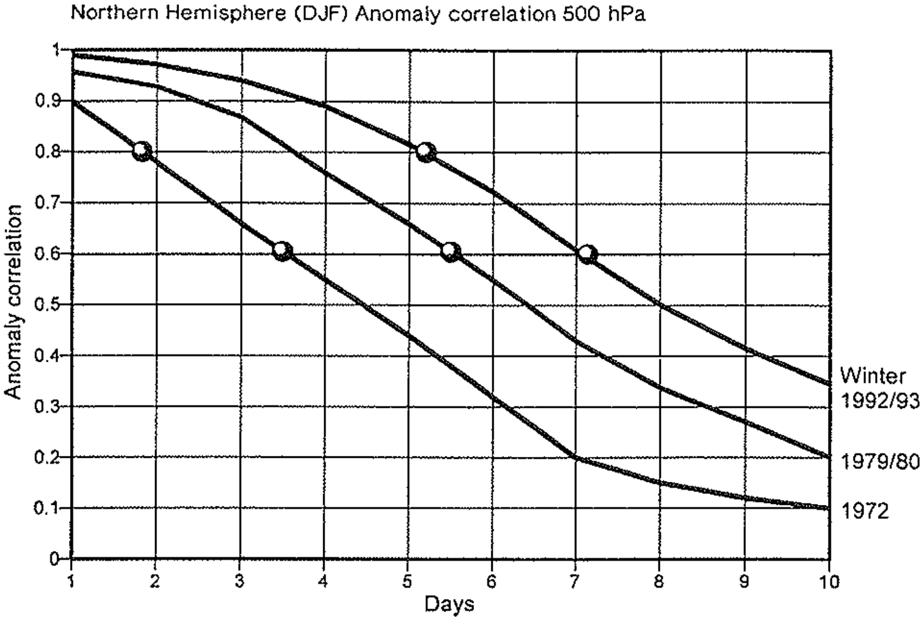


Fig. 6 – The behavior of medium-range atmospheric predictions. The ordinate is a measure of accuracy: the anomaly correlation. Values of of the correlation should be above 0.6 for acceptable predictions. The figure shows the advancement of practical predictability from 3.5 to about 7 days.

have in all likelihood been obtained by a more accurate description of the initial state since the improvement is found already in the shorter ranges (2 to 1 day).

In closing this description of atmospheric predictability as an example of the integration of large systems it should be stressed that the predictions treated here are of the type where the goal is to describe the nature in details including both the size and the position of each individual feature. It is *not* an attempt to predict the averaged state of the medium at some future time.

Similar examples can be found in the fields of economy, chemistry, biology and theoretical ecology. The chosen example is the behavior of a model describing the competition among three species. The model was first formulated by Beltrami (1987) in a somewhat idealized form which we shall use in our example. The variables x, y and z measure the size in each of the three populations. He assumed that the growth rate for each of the three species are the same, and that the rate with which the interaction between x and y influences x is the same as the interactions between y and z influences y and z and x influencing z. The other interaction terms may be interpreted in a similar way.

The model equations have been integrated in a number of cases (Wiin-Nielsen, 1998) where all steady states are unstable. We show a single figure for two integrations with a=0.1 and 0.11, b=4.9 and 4.91, while the common initial state is x=y=z=0.3. Figure 7 shows that the variables y and v after long integrations arrive in two different states characterized by the values 0 and 1. How can this be explained when no stable steady states are present? The fact is that although the figure shows the asymptotic values to be 0 and 1 up to 1500 time units, the two variables are not exactly equal to these values, but very close to them and so close that the graph cannot display the difference. This can be seen by consulting the files containing the numerical values. A further indication is that if an even longer integration than the one shown in Figure 7 is carried out the two values will after a time be the same again. The integrations are threfore never coming to rest in specific states. It just looks that way!

3. Model design problems

We may imagine that the numerical integration of the model equations are carried out using a grid with a certain gridsize which should be determined in such a way that the grid will be capable of

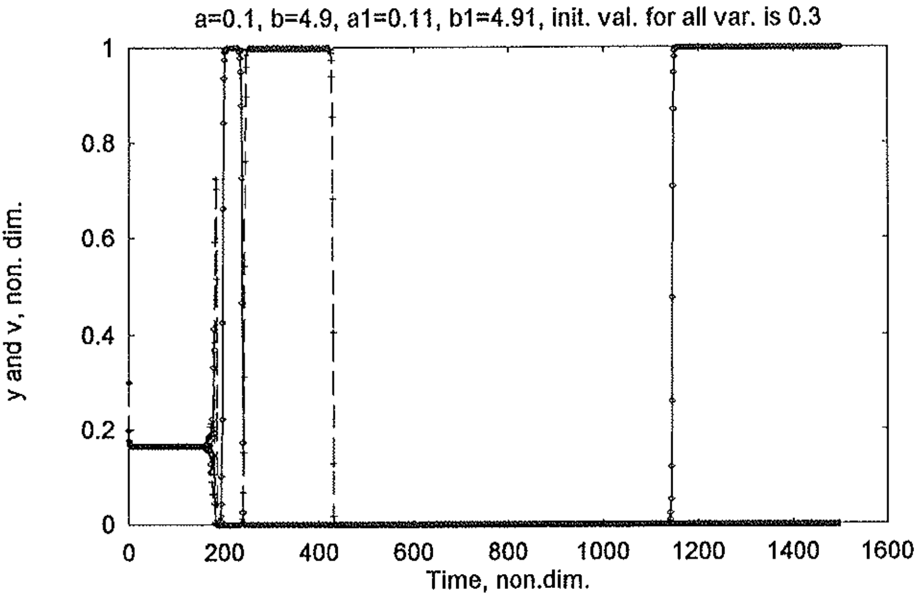


Fig. 7 – The two curves show a comparison between the two variables, y and v, in two integrations of the competition problem for slightly different values of the physical parameters measuring the interaction among the three groups.

describing the major phenomena that we are trying to model. The first gridsizes were large due to the limited capacity of the old computers. Gradually, finer and finer grids have been used, but if the problem under investigation include processes on a very small, perhaps molecular, scale it becomes impossible to describe these processes directly on the grid. Nevertheless, the processes are important, and we then have to find some other way to describe them. Such a description has been named: 'parameterization'. By this word we mean the statistical or empirical description of the influence of a small scale process on the dependent variables entering the model equations. Many processes need to be parameterized.

From the atmospheric case we may mention the whole description of radiative processes due to absorption and scattering in the various frequency bands, the description of the formation and dissipation of clouds, the precipitation process, the interaction between the oceans and the lower part of the atmosphere with respect to evaporation and transfer of heat, the description of the detailed topography of the Earth where it is impossible to account for every little hill or valley and the empirical description of dissipation, since we do not have a valid theory of turbulence.

It goes without saying that a totally accurate description of a parameterized process is impossible. It is largely these processes that the model designers use their time on, and it is the parameterizations they think about when they speak about required improvements of their models. In a sense the parameterization description for a given process is a never ending effort since new parameterizations are always possible. To give an impression of the empirical nature of the description of all the processes it may be mentioned that present atmospheric models include of the order of 200 empirical parameters. The empirical description of all these processes have naturally also an impact on the upper limit for predictability.

4. Predictions of the second kind

By predictions of the second kind we mean a prediction of a future time-averaged state of the system we have under consideration. Such predictions can be of large practical value if they can be produced since for example the agriculteral section would be satisfied by the time-averaged condition over a month or a season. The general public would like predictions of the second kind in planning vacations or other important events.

Various attempts to produce predictions of the second kind have been considered. Since we want the final product to be a time-averaged state, it is natural to think about using the time-averaged equations. However, this approach is impracticable because the time-averaged equations contain the time mean values of the products of the deviations from the averaged dependent variables, the so-called Reynolds stresses, and it has not been possible in any accurate way to relate these stresses to the mean values themselves.

A second very direct approach is to start from an initial state on a given day and integrate the model equations for, say, three months. This day-by-day integration will naturally be influenced by the limited predictability. We know that the prediction for a given day after the first seven days will be unacceptable as an individual prediction. The transient waves will be in incorrect positions and have large deviations in amplitude. If we then average the forecast made for the days of the third month we may hope that the transient waves will be averaged out, and that the remaining very large scale flow will give an essentially correct picture of the time-mean map for the period of the third month. However, this is not the case for the simple reason that when we start from the analysis valid for the day after or the day before the original starting date we get a somewhat different result. This result points in the direction of treating the problem in a stochastic way.

Attempts have been made to formulate stochastic equations from the model equations. However, the approach is cumbersome, and it requires a closing procedure. It has so far not been practical to try a solution in this manner. Nevertheless, we have realized the stochastic nature of the problem, and it can be approached in this way by making a number of integrations from various initial states, obtaining the desired time-mean map for each integration, and then say that the mean of all the time means is the most likely prediction. The deviations from this grand mean will then indicate the uncertainties in the various regions. Some encouraging results have been obtained in this way, but in other meteorological situations the results have been without practical value. We are therefore dealing with a problem that requires more research before the obtained results are satisfactory in all cases. It appears that the best results are obtained in cases where the initial state contains a strong signal as for example a well developed El Niño event.

5. Simulations of climate

The climate is a time-averaged state over a period of many years. The official World Meteorological Organizaton definition says an average over 30 years, but several other averaging intervals have been used depending on the availability of data. A major task of the climate models which are identical to the most advanced prediction models is to reproduce the present climatic state. This has been done by making very long integrations starting from a state of rest and obtaining the 'model climate' as an time average over 30 years. To obtain a good result it is required to select a good set of values for the many empirical parameters. In this way it has been possible to obtain very essential elements of the present climatic state.

To confirm the above statement we consider first Figure 8 giving a comparison between the simulated and the observed zonal winds for

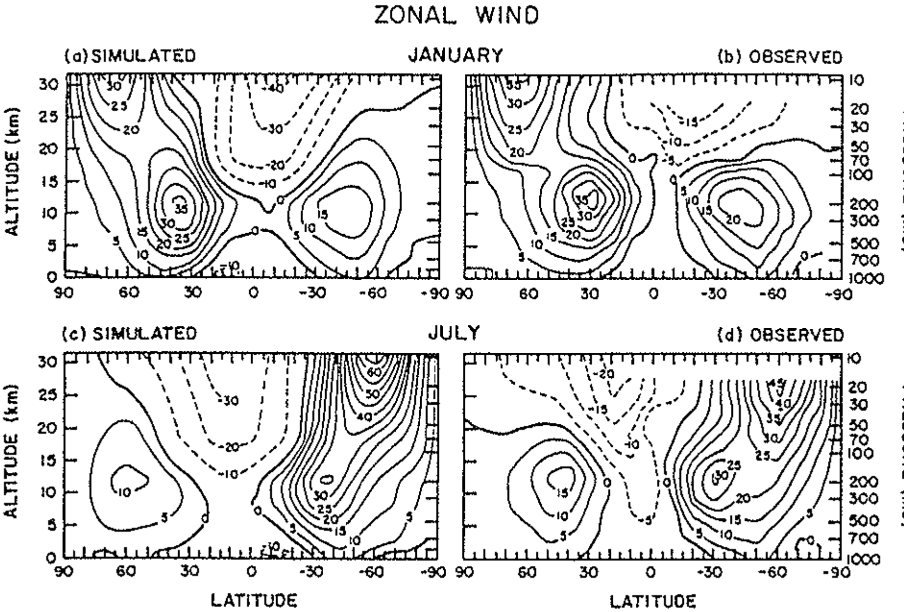


Fig. 8 – A comparison between a simulation of the present climate (left side) and observations (right side) for the zonally averaged winds.

January and for July. We notice the good similarity between the simulated and observed winds in both the winter and the summer hemispheres for January although the winter hemisphere tropospheric jet stream is slightly stronger in the simulation than in the observed case. On the other hand, in the summer hemisphere the observed jet is a little stronger than the simulated jet. However, the main distributions of the winds are in good agreement. In July we notice also that the simulated winds in the Northern Hemisphere are too weak in the tropospheric jet. Figure 9 that compares simulated and observed temperatures shows an equally good agreement although small differences can be found in the minimum temperatures in the lower stratosphere. It appears therefore that the most advanced models can produce results that accounts for the major features of the present climate. Figures 8 and 9 are borrowed from Washington and Parkinson (1986).

The task is naturally to simulate the climate of the atmosphere. It should, however, be stressed that at these long time scales it becomes necessary to simulate the major parts of the interacting climate system

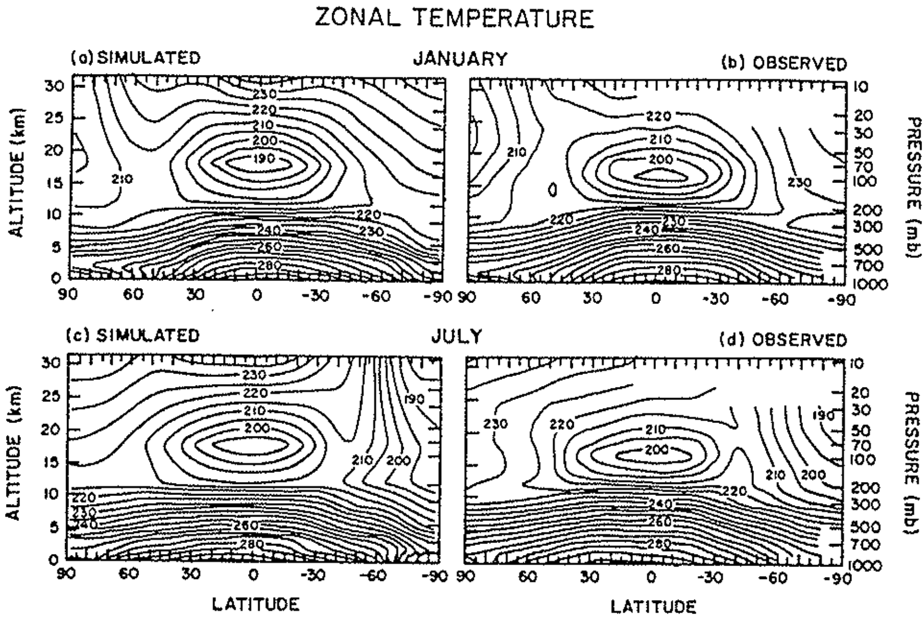


Fig. 9 – As Fig. 8, but for the zonally averaged temperatures.

consisting of the atmosphere, the oceans, the continents, the ice masses and the biomasses. As long as we are concerned with the present climate we may disregard continental drift and assume the present topography. In a similar way we may assume that the ice on the continents is as observed, and the sea ice drift is probably also too slow to be of major importance. The interactions between the atmosphere and the oceans is, however, of major importance. To know these interactions we should consider the motion in the oceans. A coupled model containing all these interactions is very difficult to design. Part of the problem is that motion in the ocean currents is very slow compared to the atmospheric motions. Roughly speaking the currents in the oceans are 1000 times weaker than the winds in the lower atmosphere, while the density of the ocean is about 1000 times larger than the atmospheric density. Considering simulations of the oceans as influenced by ocean processes and interactions with the atmosphere we may note that most of the large-scale oceanic features are simulated in an essentially correct way. This is true for the major currents, for the major regions of upwelling, for regions of bottom water formation and for the poleward transport of heat. However, the comparisons between simulated and observed distributions are not as good as those presented for the atmosphere. One of the reasons could very well be that the oceans contain the so-called mid-ocean eddies that are equivalent to the atmospheric cyclones and anticyclones. However, the ocean eddies are small compared to the atmospheric eddies, and it would require very high resolutions if we were to describe the ocean eddies directly by the equations and not in a parameterized way as it is done in most ocean models. Mid-ocean eddies have been simulated in regional models, but not so far in global models.

Fully coupled models containing all the parts of the climate system have not been design so far. Especially the biomasses are represented in a poor way, if at all. On the other hand, as seen above, we are able to simulate the major parts of the present climatic state of the atmosphere.

With these results one could hope to use the same models to simulate past climates such as the ice ages. This has also been attempted. However, good meteorological observations of a global character are available only for the last two climate periods, 1931-60 and 1961-90. This means that similar detailed comparisons as those displayed in Figure 8 and Figure 9 cannot be made. It is thus impossible to obtain accurate verifications since our knowledge of temperatures in past climate periods, determined in an indirect way from ice cores from Greenland or cores obtained from drilling at the bottem of the oceans, do not give any regional or global temperature distributions.

6. Climate change predictions

It is of considerable interest to investigate if it is possible to predict changes in the present or the past climates. Such a prediction would be of the second kind. In addition, it requires a knowledge of the physical processes that may change the climate. These processes are not known with accuracy although recent research has pointed to a number of such processes.

Any process that may change the driving mechanism, i.e. the net heating of the atmosphere, is of interest. It has been known for some time that the concentration of carbondioxide (CO_2) is increasing in the atmosphere. The increase since 1958 is of the order of 25% according to observations taken at Hawaii and elsewhere. CO_2 is evenly distributed in the atmosphere, and its life time in the atmosphere is quite large.

Considered in isolation the rise in CO_2 will increase the absorption of the long wave outgoing radiation from the surface of the Earth and thus tend to increase the global mean temperature.

The atmospheric increase in the CO_2 concentration is supposed to come from the increase in the burning of fossil fuels, although it is known that a portion of the CO_2 introduced in the atmosphere is dissolved in the oceans, and that another portion may be absorped by the biosphere. The increase of CO_2 in the atmosphere is only about 50% of what it would be if all the CO_2 stayed in the atmosphere. The burning of fossil fuels will also introduce sulphurdioxide (SO_2) in the atmosphere, but it is not distributed evenly. Its atmospheric life time is of the order of one week and thus quite short. Together with water vapour it creates the so-called sulphur aerosols and will thus increase the albedo. The net effect is a tendency to decrease the atmospheric temperatures. With the short life time of SO_2 in the atmosphere we would expect to find the highest concentrations in the middle latitude industrialized regions with small concentrations at the high and low latitudes. In general, the concentrations are smaller in the southern hemisphere than in the northern hemisphere. The CO_2 and the SO_2 effects are supposed to be anthropogenic.

Other processes may influence the atmospheric temperatures. Minor volcanic eruptions where the 'dust' stays in the troposphere have practically no influence because the 'dust' stays in the troposphere for about a week only. However, major eruptions will influence the stratosphere for considerable longer time intervals. Observations show that the influence in these cases is present for 1° to 2 years with atmospheric cooling of 1 to 2 degress and may influence the whole hemisphere.

During the last decade or so it has been shown statistically that the global mean temperature is highly correlated with the deviations from the 11 year cycle in the sunspots (Friis-Christensen and Lassen (1991), Lassen and Friis-Christensen (1995) and Svensmark and Friis-Christensen (1997). A scenario has been made for the physical mechamisms involved in the chain of processes that may explain the influence of the physical processes in the outer layers of the Sun and the global mean temperatures of the Earth. A detailed description of the scenario cannot be made here, but it involves the interaction between the cosmic radiation and the solar wind, the effects on the averaged cloud cover in the troposphere and the influence of the cloud cover on the tropospheric temperatures in the lower layers of the atmosphere. While many details still need to be explained in the scenario, the statistical evidence for the influence of physical processes on the Sun on the cloud cover and the temperatures in the troposphere is quite convincing.

It is naturally very tempting to consider the possiblities for an estimate of the changes in the atmospheric temperatures due to any of the processes mentioned above and due to the combined effect of all the processes. Such an experiment will involve a comparison between two numerical integrations of the selected climate model. One integration will be the standard simulation of the present climate. The other will incorporate the changes in the heating due to one or more of the processes that may change the climate. At this stage we find a logical dilemma. For example, if we want to investigate the effect of a doubling of the CO_2 concentration of the atmosphere we can certainly make the two integrations, and simple, but erroneous, thinking would say that since the only factor that we have changed is the concentration of CO_2, the calculated temperature differences between the two experiments is due to just this effect. However, linear thinking should not be used on nonlinear problems. It cannot be avoided that the small change in the forcing will results in deviating solutions. This fact is not disturbed by the averaging procedure used after the integrations have been performed. The qualitative argument can be substantiated by comparing the computed changes with the observed changes.

The following table compares changes in temperature from the model integration and from observations for a 20 year perios at 8 locations in Western Europe from which we have the longest temperature records. The time interval was carefully selected in such a way that the observations show an increase in the temperatures. It is seen that the computed changes are larger than the observed changes by considerable amounts. Since the model integrations assumed a doubling of the CO_2 concentration, one could try to explain the difference (about 1K) by assuming that a collection of cooling effects, not incorporated in the model, took place in reality. However, an investigation of the actual long temperature records at the 8 locations indicates that a decrease of more than 1K was not found at any of the locations in any 20 year interval. Against this argument one could say that the records are after all limited. Considering the observed spectra it was found that a cooling of 1K is removed more than 3 standard deviations from the mean giving a probability of only 0.27% that it should occur.

TABLE

	MODEL	OBSERVATION	MOD-OBS	MOD/OBS
Centr. Engl.	1.3	0.34	0.96	3.87
De Bilt	1.4	0.50	0.90	2.80
Jena/Berlin	1.6	0.49	1.11	3.27
Paris	1.3	0.25	1.05	5.20
Rome	1.4	0.21	1.19	6.67
Basel	1.6	0.66	0.94	2.42
Trondheim	1.5	0.14	1.36	10.71
Uppsala	1.7	0.41	1.29	4.15
West. Europ.	1.48	0.38	1.10	4.8

The impact of small changes in the forcing appears to tell us that experiments of the nature described above can lead to erroneous estimates of changes in nature. In spite of this conclusion many experiments of this kind have been performed under the auspices of the IPCC (International Panel on Climate Change) and has been used to advice the governments of the world regarding political issues such as a decrease in the output of CO_2 and SO_2 from industrial processes into the atmosphere.

In addition to the arguments stated above it can of course be said that it is erroneous to assume that computed changes resulting from one or two assumed processes should have anything to do with changes in the real climate if these changes are largely controlled by processes on the Sun. Nevertheless, the main points is that any small change in the forcing will lead to diverging solutions. The next question is if realistic estimates could be obtained by employing a different strategy.

Any long term integration with slightly changed forcing, followed by a time average over many years, cannot be used to make realistic estimates of regional climate changes. For this reason the IPCC has limited its estimate of climate change to the increase in the global mean temperature although maps are presented of regional changes. One may therefore ask the question: Can changes in the global mean temperature be estimated without integrations of the full three-dimensional climate model? A clear advantage is that when the governing equations are space-averaged over the whole globe the cumbersome terms containing the main non-linearity will vanish. A equally clear disadvantage is that when we want to apply the space averaged equations we can deal with space-averaged quantities only. We can for example use only the globally averaged concentration of SO_2. Nevertheless, such models have been designed (Wiin Christensen and Wiin-Nielsen, 1996). The model uses the averaged atmospheric temperature and the averaged surface temperature as the dependent variable. The forcing is based on the heat budget for the atmosphere and the surface of the Earth including the effects of clouds and the effects of a changing chemical composition of the atmosphere. The interaction between the atmosphere and the surface of the Earth are also present in the model. In the following examples we have integrated the model equations over 100 years.

Example 1: An increase of the CO_2 by 100% (i.e. 1% per yar) gives a change in the globally averaged surface temperature of 2 K.

Example 2: An increase of the CO_2 by 25% gives a increase of 0.6 K.

Example 3: An increase (decrease) of the cloud cover by 5% will result in a temperature change at the surface by about – 0.2 (0.2) K.

Example 4: An increase of the CO_2 concentration by 25% and an increase in the albedo by 3% results in a decrease at the surface by 0.4 K.

Example 5: An increase of the CO_2 concentration by 100% and a increase in the albedo by 3% gives an increase at the surface by about 1.0 K.

7. Conclusions

Models, predictions and simulations have dominated the quantitative research in many branches of physics in the last half of the present century. Earlier estimates of a qualitative, statistical nature have been replaced by families of models that gradually have increase the realism of predictions and simulations. At the same time it has been realized that in describing nature by more or less idealized models it has become necessary to incorporate sub-grid-scale processes in the models by parameterization procedures. These procedures are invented to measure the influence of the small scale processes on the grid point variables. Model uncertainties are introduced by such unavoidable procedures which in many cases represent an almost impossible task.

The discovery of the sensitivity of a model to minute changes in the initial state and the expansion of the sensitivity to minute changes in the forcing sets an upper limit to the predictability of natural systems. The example of weather predictions is the best documented example of limited predictability.

An estimate of the time-averaged state (i.e the 'climate' of the model) as determined by an extended integration of the model equations followed by time-averaging over large time intervals has turned out to be possible. Nevertheless, small changes in the major parameterizations may change the time-averaged state. A certain amount of 'tuning' has been necessary.

The determination of changes in the time-averaged state (i.e. the prediction of changes in the 'climate') has turned out to be difficult. The reason is once again to be found in the limited predictability. Climate change forecasts turn out to be unrealistic in both the general order of magnitude and in the phase of the systems. In spite of this state of affairs the efforts to produce climte change forecasts continue.

Before closing it is pertinent to mention that the study of any scientific branch ideally goes through a number of stages. They may be listed in the following way:

1. Discovery
2. Description
3. Developmemt of a theory
4. Verification of the theory
5. Improvement of the theory

Some branches of the natural sciences do not contain all the steps, but stop after step 2. However, the most advanced branches contain the complete development. Unfortunately, it has also been experienced that the fourth step of verification cannot be carried out due to technical or economical conditions. An example is the present state of the superstring theory. In the next millenium it will be important to determine what we can or cannot do with reliable results.

REFERENCES

Beltrami, E., 1987: *Mathematics for Dynamic Modelling*, Acad. Press, Inc., 277 pp.

Christensen, C. and A. Wiin-Nielsen, 1996: *Klimaproblemer* (in Danish), *Climate Problems*, Teknisk Forlag, 128 pp.

Friis-Christensen, E. and K. Lassen, 1991: 'Length of the solar cycle: An indicator of solar activity closely associated with the climate', *Science, 254*, 698-700

Lassen, K. and E. Friis-Christensen, 1995: 'Variability of the solar cycle length during the past five centuries and the apparent association with terrestrial climate', *J. of Atm.-Terr. Physics, 57*, 835-845

Lorenz, E.N., 1963: 'Deterministic nonperiodic flow', *J. Atmos. Sci., 20*, 130-141

Phillips, N.A., 1956: 'The general circulation of the atmosphere: A numerical experiment', *J. Roy. Met. Soc., 82*, 123-164

Poincaré, H., 1893: *Les métodes nouvelle de la mecanique celeste*, Paris, Gauthiers-Vilar

Poincaré, H., 1912: *Science et Méthode*, Paris, Flamation

Svensmark, H. and E. Friis-Christensen, 1997: 'Variations of cosmic ray flux and global cloud coverage: A missing link in solar-climatic relationships', *J. Atm.-Terr. Physics, 59*, 1225

Thompson, P. D., 1957: 'Uncertainty of initial state as a factor in the predictability of large-scale atmospheric flow patterns', *Tellus, 9*, 275-295

Washington, W. M. and C. L. Parkinson, 1986: *An Introduction to Three-Dimensional Climate Modelling*, University Science Books, Oxford University Press, 422 pp.

Wiin-Nielsen, A., 1998: *An Example of Limited Predictability in a Model of Competition among three Species*, acc. for publ.

NASA: FINGERPRINTS OF LIFE AND FOOTPRINTS ON MARS

DANIEL S. GOLDIN

It is no longer 1998. It is 2020

We are back on the moon. We are mining asteroids and comets for valuable resources. In part because of the groundbreaking work done on the International Space Station, Earth has just sent its fifth expeditionary team to Mars. The last two missions have already begun building a permanent outpost on the Red Planet's dusty surface. The new team will verify the work of a robotic spacecraft we sent in the first years of the 21st Century, which returned fossilized evidence of microbial life on Mars from ancient riverbeds, thermal hot springs and canyon walls. These kinds of discoveries are not limited to Mars, even to our solar system. Probes and robots are currently taking a census of interstellar space, and a spacecraft now orbiting the Sun at a distance further than Jupiter has just imaged a planet belonging to a nearby G-class star. We look at that star and ask what has become a common and matter-of-fact question: "I wonder what kind of life we'll find there?"

Before this becomes the common question we expect it someday to be, we must first, from our position at the end of the twentieth century, ask and answer three other questions: "Where do we look for life?" "What do we look with?" "What do we look for?" Thanks to discoveries made over just the past few years, in many of which NASA has played a direct role, we have begun to answer the first question. Today, we know where to look.

The Answer to Question # 1 – The Discoveries

The Hubble Space Telescope has observed a planet around another star. A picture it recently took seems to show a planet being kicked-out of a binary star system. If this is confirmed, and there is some controversy, we will have validated a new theory suggesting extremely rapid planet formation.

Interstellar gas clouds are rich in organic material. They contain methane, ammonia, carbon monoxide, and many other long-chain hydrocarbons. All over the universe, we find the elements necessary for life.

Planet-forming processes may be common around young stars. The Hubble Space Telescope has looked at the Orion Nebula and found newborn stars with disks of gas and dust. They look just like what we think our solar system might have looked like before the planets formed. Recently, ground-based astronomers have found evidence of a young solar nebula which is in the very act of creating planets. Never before have we witnessed a solar system being born. We now have confirmed evidence for the existence of 24 planets circling other stars, 13 with masses less than that of Jupiter. Five years ago, we had none.

Comets may have carried the building blocks of life to all the planets in the early solar system. Many comets are 50% water by mass. They are rich in organic materials and volatiles. Even today, cosmic dust from these small planetary bodies rains as much as 30,000 tons of matter on Earth every year.

3.8 billion years ago, Earth and Mars were very much alike. They were warm. They had volcanic activity. They were wet. They appear to have had condensed environments with dense atmospheres consisting mainly of carbon dioxide. Mars Pathfinder roamed the surface of the red planet and returned strong evidence that there once was flowing water. The Mars Global Surveyor, presently in orbit about Mars, has already returned images showing what looks like an ancient river bed. The images look like they could have been taken from an aircraft flying over the western United States. The Mars Global Surveyor also detected a remnant magnetic field on Mars, so we think Mars probably had a protective shield from cosmic radiation early in its evolution, another precondition for life.

The Mars Rock, ALH84001, is controversial, but we are sure of a few things: it came from Mars; it came from a water environment; and it has preserved some reduced carbon from Mars. It could be a fossilized sample of life that is about 3.6 billion years old. That is a few hundred million years after we think water appeared on Mars and a few hundred million years after the earliest fossil microbes so far found on Earth.

On Europa, one of Jupiter's moons, we think we may have found a liquid water ocean underneath a thick ice crust. Because Jupiter is so big, its gravitational pulling could heat up the core of Europa, creating a condition where there is a liquid or slush ocean underneath all the ice. Perhaps there may even be active thermal vents. In fact, the images of Europa's surface look very much like the North Sea does seen from space during the Arctic winter. Icebergs appear to have broken off, only to have become locked in at distorted angles when the surface refroze, once again sealing the interior off from the harshness of space.

Scientists have found that the instant life could exist on Earth ... it did. 3.9 billion years ago, the Earth cooled down to the point where we believe liquid water existed on the surface, one of the conditions we believe are necessary for life. We have recently found fossil carbon in Greenland that was 3.85 billion years old. It looks like in the 4.6 billion year history of the earth, life developed within 50 million years of the time when conditions first permitted it. This is milliseconds – a blink of the eye – on the geological time scale.

We have found that life exists in extreme conditions. Tube worms over 60 centimeters long have been found living near hydrothermal vents in ocean floors. Life has been found in extremely salinic environments, in acid streams in Spain, in ice-covered lakes in Antarctica, and in hot pools in Yellowstone National Park. Microbial life within the Earth's crust itself has been estimated to surpass the accumulated surface biomass of the planet, everything we traditionally thought of as the Earth's biosphere. Today, life seems to exist on Earth wherever four factors are present: liquid water, some source of energy, a nutrient transport vehicle and protection from lethal space radiation.

Here are our preliminary conclusions: we are led to believe that planet formation may be common. Many stars may have planets circling them. Life can exist in extreme conditions. Single-cell life appears to be robust. It arises early and easily. Given just a few parameters, biology may be a natural consequence of physical and chemical evolution in the universe. Life may not be unique to planet Earth.

So where should we look for life? The answer in 1998 is: in more places and planets than we ever thought possible. At NASA, the search is on. And we are beginning to determine and develop the technologies that will answer how that search takes place. This is what we will search with.

The Answer to Question # 2 – The Missions

We are expanding our knowledge of the materials that contributed to the formation of the Earth and the other planets. Starting in 1999, NEAR, the Near Earth Asteroid Rendezvous mission, will conduct a comprehensive scientific survey of the asteroid, Eros. Other spacecraft will do the same with comets, including the Stardust mission scheduled for launch in February, 1999, which will actually fly through the tail of a comet and return material to Earth for analysis.

When the technology is ready, we will complete the close-up survey of our Sun's nine planets with a mission to the enigmatic Pluto and its moon Charon. Then we will continue on into the Kuiper Belt to examine the primordial debris of our Solar System. We are preparing to send a probe to orbit Europa; and we may even send an aquabot to Europa, designed to melt though the ice to the underwater world below and then turn on its camera and sensors so we can see what is there.

In a few years, the Huygens probe, built by the European Space Agency, will break away from NASA's Cassini spacecraft as the pair approach Saturn. Huygens will dive into the rich, chemical soup of the moon Titan's atmosphere. We believe Titan may hold clues about Earth's pre-biotic evolution. Over the next decade, NASA will send ten ever-increasingly sophisticated robotic spacecraft to Mars, including a sample return mission.

Within the next decade we hope to replace the Hubble Telescope and other observatories with even more revolutionary telescopes having significantly better spatial and spectral resolution than their predecessors at a fraction of the weight and cost.

All of these exciting missions are part of NASA's Origins program, a multi-disciplinary effort to understand the beginnings of our universe, our solar system, our planet, and most importantly, ourselves. It is a program that we hope will not only determine if we are alone, but will also determine the challenging questions that will inevitably come next: "What kind of life will we encounter beyond our home planet?" "What kind of life are we looking for?" "Is life elsewhere necessarily like that which arose on Earth?"

The Answer to Question # 3 – The Challenge

When the Galileo spacecraft flew by the Earth several years ago at a distance of 100,000 miles, an experiment was carried out to try to detect life on our own planet using only the instruments on Galileo. The data revealed that Earth's land surface has green pigment, and its atmosphere contains methane and oxygen out of chemical equilibrium. What this experiment showed us is that the traces of life on Earth are actually very subtle. Although lights were visible at night, in the daytime virtually no visible signs of intelligent life could be detected.

If this distance is expanded a billion times, from 100,000 miles to 100 light-years, ozone, water, and carbon dioxide could still be detected with a very large interferometer; but to detect the biologically important methane would require telescopes 100 times larger in area than we think we can build even ten years from now. Detection of nitrous oxides would need an even larger telescope. We need to learn if there are other biological signs that we can look for in the search for life. In the case of Galileo's flyby of the Earth, we knew the solution, and we cribbed the answer. Given the limits of our current observations, we do not know if life could be ubiquitous, or if life on Earth is cosmologically unique.

In other words, it is not enough to know where to look or even to know what we will look with. We need to know what to look for. Do we look for a preponderance of oxygen in the atmosphere as we have today on Earth? Should we search for methane instead? Why should we expect oxygen-driven photosynthesis by green plants to be universal? Maybe a purplish rhodopsin dominates. Maybe photosynthesis is rare. Our own Earth did not have an oxygen atmosphere for its first 2 billion years. A Galileo fly-by two billion years ago would have concluded that Earth was lifeless; but we know that at that time Earth was actually rich in microbial life. The Galileo example (as well as the Viking mission to Mars in the mid 70's) makes it very clear that if we are to search for life, we need to be able to spot the "fingerprints of life."

Right now, where the existence of life is concerned, we have a sample of one: Planet Earth. Clearly a broader approach is needed. On Earth, massive banded iron formations are evidence of a planet undergoing a change-over to an oxygenated world, a victim of photosynthesis. Maybe we should be looking for banded iron or perhaps manganese formations on other planets. We should be looking at the energy sources on different planets and predicting what biology should be doing. What would be the end products of redox reactions that biology could be using? What biominerals would be formed? What would end up in the atmosphere? We should be looking for specific biochemical solutions that biology favors compared to the multiplicity of chemical reactions, like the preponderance of the 20 amino acids routinely used by Earth life compared to an entire family of amino acids found in meteorites. We think that water is the quintessential ingredient for life. What if it is not? What if another solvent were just as suitable given slightly different conditions? Life in another solar system might need ammonia, not water, to survive. How do we know?

To answer these questions, all those interested in the pursuit of life need to be part of the Biological Revolution. We have seen how an explosion in the biological sciences, in areas like health and agriculture, has changed the way we live our lives. We are just now uncovering the natural microbial diversity on the Earth: some scientists have estimated that Earth has 108 times more microorganisms than there are stars in the universe (1022 stars vs. 1030 microbes). The incredible discoveries made in our search for life, at the level of single-cell organisms, has done something perhaps even more profound. They have changed the way we perceive ourselves and our place in the universe.

Understanding this is what NASA is all about. The fact is, biology is essential to everything we do. This is why at NASA there is a new commitment to Astrobiology, which is the study of all aspects of life in the universe, the chemical and physical forces and adaptation that influence life's origins, evolution and destiny. NASA has formed a new, "virtual" Astrobiology Institute, in which scientists from universities and research institutes all over the world, connected by the Next Generation Internet, will search for the fingerprints of life and ask whether or not life is a cosmic imperative.

The Astrobiology Institute is an important start, but we realize that we need to learn a lot more. As recent discoveries make clear, if we are going to search for life beyond our planet, we need a strong intellectual underpinning that tells us what to look for and where to look for it. Also, because the challenges are so great and the questions we seek to answer are so fundamental and so far-reaching, we need to take the intellectual underpinning of biology and apply it not just to our science but to our engineering as well.

The computing capacity of the human brain is estimated to be about a million times more powerful than today's technology, while consuming about a billion times less energy. A single cell can carry ten times as much information as today's most powerful computer. We need to exploit that potential. For instance, a probe that travels to interstellar space needs to be self-thinking, self-validating and self-repairing. It will be so far from Earth that communication at the speed of light will be much too slow to allow real-time control of the system. It must act just like the human biological system, with sensors, with a distributed nervous system, and with correcting mechanisms. It must consume very little electrical power yet have unbelievably high processing capability. In other words, and this is an integral part of NASA's biology vision, biology and the natural world must not only be a resource, but a model for technology.

This is especially true when we exhaust the capacity of machines to gather the information we need, and we must send humans to explore the heavens. Our space science program and our human exploration program are not separate endeavors. They seek to answer the same questions. And often, those answers await in frontiers beyond the limitations of our robotic missions and require the adaptability and dexterity of human beings. The search to explore our physical and biological origins, to understand life, its role in the universe, and its past and present existence deserves no less.

In order to prepare for the day when we are able to send scientists, engineers, and philosophers to study firsthand the incredible discoveries our robotic field teams will surely make, we need to know more about biology, especially how space flight affects humans over long periods of time. When humans leave Earth for Mars, within a few months our planet will appear as no more than a star in the heavens. How will we feel in that isolation? For extended stays and voyages, like those to other planets (right now, a round trip to Mars would take 3 years), we must manage small and extremely intricate ecosystems of spacecraft, surface habitats, and environmental suits. We need to find a way to limit bone loss in astronauts. (Currently, astronauts lose over 1% of their bone mass in certain portions of their skeleton every month they're in space. This is not acceptable for that 3 year trip to Mars.) We need to be able to handle medical emergencies in space flight, since returning to Earth for care will not be an option. What about medical protocols in microgravity or in the 1/3 gravity of Mars? How about immune system response in variable gravity? How do we handle infections when we know that the body's reaction to drugs may be altered in space flight?

Clearly, we have a lot to learn before an astronaut's boot crunches the dusty red surface of Mars. The International Space Station will be our classroom. As has been proven over and over again, the research done in this classroom, this world-class laboratory in the sky, will not only benefit us in space, but will also lead to health care discoveries, new consumer goods, more efficient industrial processes, and a reinvigorated spirit here on Earth. This is NASA's vision; this is NASA's entire mission – exploring the frontiers of space and enriching life on this planet.

The purpose of exploration is to answer fundamental questions, but by its very nature exploration will also raise new ones, some that NASA can not answer at all and many that we will answer only with help: "What if we find life outside Earth?" "Will our beliefs in our unique position in the universe be threatened?" "What if we discover we're not alone in the universe, and we're the baby in the galactic family?" This voyage of exploration is a journey that all of humanity must take together. We need telescopes and microscopes focusing on a common vision. We need religion and philosophy to consider questions that science may not be able to answer. We need curiosity and courage, fortitude and faith. With the collective help of many people, we will discover the fingerprints of life, and we will put our own footprints on the surface of Mars.

PART II

THE CHANGING CONCEPTS OF NATURE IN BIOLOGY

THE CHANGING CONCEPT OF NATURE FROM A NEUROBIOLOGICAL PERSPECTIVE

WOLF SINGER

The common sense definition of Nature to which most members of occidental cultures would probably subscribe, has changed little since Aristoteles: it comprises everything that is not man made artifact. Less clearly defined is our relationship to Nature. The fact that it is us who define Nature implicitly assigns us the role of an observer and opposes us to Nature. Humans have experienced this opposition ever since they became conscious of themselves but what has changed over the centuries and differs among cultures is the degree to which we grant us autonomy and independence from the constraints of nature. In this contribution I shall concentrate on the changes in our relation to Nature and attempt to identify reasons for the changes in our perception of Nature. I shall propose and defend three theses: First, we utilize two complementary cognitive approaches to identify our relation to Nature; second, these approaches lead to conflicting results and, third, it is paradoxically the approach that utilizes the most unnatural tools, the most sophisticated man made artifacts that binds us back to Nature and reduces the opponency between us and Nature with unprecedented and unexpected stringency.

Two cognitive strategies

The first of the two cognitive strategies, the natural approach, relies on our primary experience of the world and of ourselves as it is mediated by our unaided sense organs and our introspection. The second strategy, the scientific approach, relies on the use of tools that extended our natural senses, on experimental manipulations that permit the dissection of perceptual objects into components and on rule based reasoning that analyses the relations among the identified components. The results of both cognitive processes contribute to our perception of Nature but the relative preponderance of the two sources of knowledge has changed dramatically over the centuries. As long as we relied primarily on the first, the natural strategy, we were relatively free to define our relation to Nature – as testified by the very different views proposed by different cultures, philosophical positions and religions.

In the occident we witness a clear historical trend towards an increasing opponency between us and Nature. Members of Western civilisations experienced themselves with growing conviction as autonomous agents that are endowed with the freedom to act, the ability to manipulate Nature and the capacity to set their own moral and ethical agenda. Science, whose impact has been particularly intense in Western cultures is one of the sources nourishing the experience that we are opposed to Nature. It provided us with particularly effective tools to manipulatae what our unaided senses experience as the Nature around us. Thus, primary, unreflected perception of our relation to Nature, the natural cognitive approach, tends to foster the view that human beings are opposed to Nature, and this experience is amplified tremendously by the use of tools that are provided to us by Science.

At the same time, however, science binds us back to Nature and reduces the opponency between us and Nature. Once again, Science shows its "Janus Face". It induces changes in the world and in our perception of the world but these changes have non-concordant consequences. While the tools provided by sience enhance our perception that we are opposed to Nature and independent of its constraints, the knowledge accumulated by science forces us to realize that we are much less opposed to and much more constrained by Nature than primary experience made us believe.

The data collection initiated by Vesalius, continued by the physiologists and nearly completed by modern molecular biology confirms Darwin's hypothesis: our bodies and the functions that keep them alive are like those of animals – if they are Nature we are Nature. The only domaine, it seems, that we have left to defend our autonomy from Nature is our mind, is our psyche, is our culture that we owe to our mental abilities, and these features, we feel, are not shared by the Nature around us.

It is about a century that science started to get seriously interested in the brain and at the end of this millenium we celebrate the decade of the brain, because this enterprise has been so exceedingly successful and continues to be promising with regard to the acquisition of knowledge about the material processes that underly mental phenomena. However, this newly acquired knowledge is in sharp contrast with the intuitions that we have about our relation to Nature. Neurobiological evidence forces us to accept that our cognitive functions, i.e. the instruments that we apply in order to learn about Nature are themselves constrained by Nature. It seems that the processing algorithms according to which we perceive and interprete the world are fully determined by the functional architecture of our brain, by the way in which the nerve cells in our brain are wired together. These architectural features, in turn, are to a large extent determined by genetic programs and hence by our evolutionary past, i.e. by Nature. In addition, the functional architecture of our brains undergoes substantial, experience-dependent modifications during postnatal life and thereby gets adapted to the specific natural, social and cultural environment, within which the individual develops. Thus, we are by no means independent observers capable of providing unbiased descriptions of Nature. Rather, the tools with which we observe and reason are themselves a product of Nature and therefore an integral part of Nature. We are trapped in a self-referential loop when we study Nature and in particular, when we study our own brain. And this should be kept in mind when I now discuss in more detail the biological constraints of our cognitive abilities and the conflicts that arise between our complementary strategies of knowledge acquistion – our intuition and self-perception on the one hand and our instrument based scientific approach on the other.

Nature reflects itself

Psychophysical and neurobiological evidence demonstrates clearly that our perceptions are the result of a highly constructive process. Our brain does not function like a camera lucida that generates isomorphic representations of our environment. The behaviourist position that brain-processes, – including perception – can be reduced to simple stimulus-response cascades is no longer tenable. Rather, our brains are born with a large set of very precise hypotheses about regularities of the world and use these preconceptions in an active search process in order to organize the signals provided by the sense organs. Cognition, thus, appears as an active, expectancy-guided process of hypothesis testing. This implies that we cannot perceive what we do not expect and hence, that our perceptions are constrained by preconceptions. All we can say with confidence about the nature of these preconceptions is that they are adapted to yield interpretations of the world and of ourselves that are useful for survival and reproduction. This follows from the fact that our brains are the product of evolutionary selection and ontogenetic adaptation. There is thus no guarantee that the cognitive functions of our brains are optimized to design a true picture of the world – in the sense of epistemological truth – on the contrary, we have all reasons to doubt that this is not the case, as will become clear in a moment.

In the following chapter, I shall briefly illustrate how crucially perception depends on a priori knowledge, then I shall discuss the question how this knowledge is stored in the brain, to which extent it is derived from evolutionary selection or individual experience, and then I shall review hypotheses concerning the neuronal basis of cognitive processes.

If one analyses in detail the operations which the visual system has to accomplish in order to identify figures in a complex scene it becomes immediately obvious that even simple and seemingly effortless perception of our environment requires a considerable amount of a priori knowledge about the properties of perceptual objects. The image on the retina consists merely of a two-dimensional distribution of brightness and hue values. In order to extract from the neuronal signals evoked by this distribution the information necessary for the identification of individual figures, responses generated by individual objects need to be grouped together and evaluated jointly, and they have to be segregated from signals originating from the embedding background or from other unrelated figures. This process of scene segmentation must occur at rather peripheral levels of visual processing because it has to precede the computations which lead to object identification. Accordingly, this segmentation process usually does not require attention, remains unconscious, and is automatic. For the same reason, the grouping rules must be of a general nature and applicable to all possible scenes. Grouping has to be achieved before one knows what one is going to see. Without a priori knowledge about the rules according to which the visual world is structured it would be impossible to appropriately segment complex scenes and to group together signals from contours that are constitutive for individual figures. The same applies of course to other modalities. Segregation of a speaker's voice from other sound sources and appropriate segmentation of the continuous stream of sounds generated by the speaker are an indispensable prerequisite for language comprehension. The rules according to which perceptual grouping is accomplished have been explored and identified by the Gestaltpsychologists around Max Wertheimer in the early thirties. Such grouping criteria are, for example, the contiguity of signals in space and time, and the similarity of features such as contrast, texture, or colour in vision or a particular mix of frequencies in audition. A particularly efficient grouping criterion that is with all likelihood genetically determined and inborn is the criterion of common fate. Our visual system has a virtually compulsive tendency to group together contours that move with the same speed in the same direction. In addition to these basic grouping criteria which exploit rather elementary relations among features there is a set of more complex rules which take into account Gestalt-principles such as closedness, good continuation and symmetry. Since these grouping criteria are shared by all species endowed with evolved cognitive systems, it is likely that they are the result of evolutionary selection, and hence do reflect basic properties of perceptual objects.

Evolution as a cognitive process

It is now possible to formulate educated hypothesis about the mechanisms by which a priori knowledge about the environment is acquired during evolution, stored in the genes and expressed during ontogeny in the architecture of the developing brains. The highly specific architecture of brains, i.e. the specific blueprint according to which neurons are interconnected, is a result of evolutionary selection and adaptation, and for this reason exhibits striking similarities between individuals of the same species. The instructions that lead to the development of these architectures during ontogeny are stored in the genes and transmitted with only minor variations from generation to generation. Unlike in von Neumann computers which are often cited as a metaphor of natural nervous systems, the latter permit no distinction between program and architecture, between soft – and hardware. In nervous systems, the program is fully determined by and resident in the blueprint of the neuronal connections. Accordingly, all the a priori knowledge, all the rules according to which the nervous system processes information, must reside in its functional architecture. Thus, evolution can be regarded as a cognitive process. Knowledge about the world is acquired through trial and error, is stored in the genes and then translated into the functional architecture of nervous systems. Once development is completed this knowledge is in turn utilized to interpret the signals provided by the sense organs. The complex structural differentiation of evolved brains can thus be considered as the material correlate of knowledge acquired during evolution.

Ontogeny as a cognitive process

A second important source of information for the programming of brain functions is the experience gathered during postnatal development. Human brains, and this is true for all mammalian brains, continue their development way beyond the time of birth. When born, the brain does possess by and large the full set of nerve cells – but in many structures, particularly in the neocortex, outgrowth of nerve fibres and contact formation are still in progress and come to an end only towards puberty. The remarkable feature of this late differentiation of circuitry is that it depends on neuronal activity. This activity is partially of internal origin – but it is also substantially modulated by signals arriving from the sense organs. Hence, sensory experience influences the development of neuronal architectures. It is used to validate functionally the newly formed connections, consolidating those identified as appropriate and disrupting those which are functionally maladapted. Until the end of this developmental process the brain generates 30 to 40% more connections than actually remain in the fully mature brain. There is, thus, a remarkably high turnover of newly formed and subsequently destroyed connections, a process that leads to substantial modifications of the genetically specified blueprint. These structural modifications are sufficiently prominent to be identified with a light-microscope.

What makes this postnatal developmental phase so extremely important is the fact that the process of use-dependent circuit selection comes to an end after a critical period. Beyond puberty there is no further outgrowth of connections nor is there activity-dependent disruption. Once the basic layout of circuitry is accomplished, there is no possibility for further modifications. Individuals have to live with the brains which they have developed by the time of puberty.

This epigenetic modifiability of brain architecture is, of course, constrained. Late outgrowth and experience-dependent modification of connections are restricted mainly to short-range circuits that associate neurons within particular areas of the cerebral cortex. The long-range connections which link remote areas of the brain are much less adaptive, their layout being determined mainly by genetic instructions. It is, thus, mainly the fine tuning that is left to experience and not the basic layout of the architecture. Furthermore, there is ample evidence that these experience-dependent modifications of circuitry are gated by central systems which evaluate the behavioural relevance of the respective sensory input and permit changes to occur only if these signals have been identified as appropriate in a broader behavioural context. Only if joint evaluation of distributed response patterns has identified the respective input signals as functionally meaningful and behaviourally relevant are permissive chemical substances liberated which enable activity dependent modifications of circuitry.

The rules governing these activity-dependent modifications of synaptic connections are known, at least in principle, and the molecular mechanisms underlying the translation of electrical activity into functional and structural long-term modifications have also been well characterized over the past years. The simple formula is: "Neurons wire together if they fire together". Connections between neurons which have a high probability of discharging in synchrony tend to consolidate while connections between neurons exhibiting uncorrelated activity tend to be weakened and removed. For neurons in sensory systems this implies that cells tuned to features which have a high probability of co-occurring in the natural environment tend to strengthen their connections while cells tuned to features which rarely occur together tend to be less firmly associated. Thus, the statistical probability of co-occurrence of particular features can be translated through this experience-dependent developmental process into modifications of neuronal coupling that reflects the contiguity of events in the outside world. Since strong coupling among neurons favours the joint processing of the activity relayed by these neurons, features encoded by well coupled neurons tend to be processed together, i.e. they tend to be treated as related and are bound perceptually. Thus, experience-dependent circuit changes can be used to bias the operations required for perceptual grouping. Genetically predetermined grouping rules can be modified and entirely new rules can be installed. [For a detailed discussion of these developmental processes the reader is referred to Singer, 1990 and Singer, 1995].

But how then do we learn as adults when modifications of neuronal circuitry are no longer possible? A large body of evidence indicates that adult learning is due to activity-dependent modifications of the efficiency of existing synaptic connections. The efficiency of synaptic transmission can be enhanced or reduced in an activity-dependent way. These changes, too, can be long-lasting and then result not only in modifications of the molecular composition of the synaptic contacts but also in local growth of new contacts or in the retraction of existing synapses. The rules governing these modifications resemble those described above for circuit changes during early development. The gain of connections increases if the interconnected neurons often discharge in synchrony and it gets reduced if the neurons exhibit uncorrelated activity. Moreover, these use-dependent modifications of neuronal coupling are also controlled by central gating mechanisms that permit changes to occur only if activity patterns have been identified as meaningful. This evaluation is with all likelihood accomplished by centers in the limbic system, and the result of this evaluation is conveyed to the cortical processing circuits via highly distributed projection systems that use specific chemical transmitter substances known as neuromodulators. For further literature on these adaptive processes see Singer (1990) and Singer (1995).

There are, thus, three mechanisms through which the brain acquires the knowledge about the world that it needs in order to group and evaluate sensory signals in a rulebased way and to reconstruct distinct perceptual objects from the continuous stream of signals arriving from the sensory surfaces: Evolution which gathers knowledge about the world by trial and error, stores this knowledge in the genes and expresses it in the phenotype of the developing brain, ontogeny of individual organisms which permits acquisition of knowledge through experience and direct storage of this knowledge in the architecture of tardively developing neuronal connections, and finally, adult learning which leads to a more subtle modification of neuronal communication by inducing long-term changes of synaptic efficacy. Together, these three processes of knowledge acquisition fully determine the functional architecture of the brain, and hence the program according to which the brain processes signals from its environment, creates representations of perceptual objects, arrives at coherent interpretations of the world and decides on future actions.

The question arises then how knowledge, that resides in the functional architecture of the brain can be read out and made available to support cognitive processes. This question is in turn intimately related to the problem of how the brain creates representations of its environment and ultimately also of its own cognitive processes.

NEURONAL REPRESENTATIONS, DISTRIBUTED PROCESSING AND THE BINDING PROBLEM

There is growing evidence that both perceptual and motor functions of the neocortex are based on distributed processes. These occur in parallel at different sites and always involve vast numbers of neurons that, depending on the complexity of the task, may be disseminated throughout the whole cortical sheath. In the visual system, for example, even simple sensory stimuli evoke highly fragmented and widely distributed activity patterns. Neurons preferring the same features or coding for adjacent points in visual space are often segregated from one another by groups of cells preferring different features. Moreover, different aspects of visual objects such as their shape, spectral composition, location in space and motion are processed in separate, non-contiguous cortical areas (Desimone *et al.*, 1985; Felleman and van Essen, 1991; Zeki, 1973). Thus, a particular visual object elicits responses in a large number of spatially distributed neurons each of which responds only to a partial aspect of the object. This raises the intriguing question, commonly addressed as the binding problem, of how these distributed activities are reintegrated in order to generate unambiguous representations of objects in the brain.

Such binding problems arise already at very early stages of sensory processing where simple properties of visual objects are represented such as the precise location and orientation of contours. The reason is that even at levels as peripheral as the primary visual cortex responses of feature selective neurons are only poor descriptors of these properties. The ambiguity results from the broad tuning of individual feature sensitive neurons. The amplitudes of their responses depend on a number of different properties of a contour such as its position relative to the center of the receptive field, its orientation relative to the preferred orientation of the neuron, its curvature, length and luminance contrast. Thus, in a particular cell stimuli differing along these various feature dimensions may all evoke responses of similar amplitude. This ambiguity can only be resolved by evaluating together the responses of the large number of different neurons that are coactivated by a particular contour. This, however, requires to establish selective relations among neurons that respond to the same contour and to distinguish these responses from those to other nearby contours. As the number of possible combinations between locations and orientations of contours is nearly infinite, a flexible binding mechanism is required for the non-ambiguous association of responses to the same contour.

Similar binding problems have to be resolved at processing stages which accomplish scene segmentation and perceptual grouping. Irrespective of the sensory modality, the first step towards the identification of perceptual objects consists of a grouping operation whereby the features of a particular sensory object need to be related to one another and become segregated from features of other objects and from features of the embedding background. This requires again to establish highly selective relations among the responses of large populations of neurons that will often be distributed across various cortical areas. Because different objects lead to activation of different constellations of neurons whereby subsets of such populations may be the same for different objects, again a versatile binding mechanism is required that can cope with the very large number of possible combinations.

Finally, binding problems arise also at the level where perceptual objects get eventually represented. Just as elementary features appear to be represented by a population code rather than by the responses of individual neurons, complex perceptual objects also seem to be represented by populations of neurons each of which codes for a particular sub-constellation of features. This has to be inferred from the fact that search for individual neurons responding with high selectivity only to particular perceptual objects revealed specificity only for faces and for a limited set of objects with which the animal had been familiarized extensively before (Gross *et al.*, 1972; Baylis *et al.*, 1985; Desimone *et al.*, 1984; Perret *et al.*, 1987; Sheinberg and Logothetis, 1997). But even in these cases a particular face or object evokes responses in a very large number of neurons and any particular cell can be activated by numerous, often only loosely related patterns.

Binding through convergence

The most widely accepted proposal for the solution of binding problems in sensory processing implies that there are special "binding units" which "collect" the responses of cells that need to be bound together by means of converging input connections. The idea is that the thresholds of these binding units are adjusted so that they respond only if the full set of the respective driving units is activated. A particular constellation of responses in the input layer would thus be signaled by the activation of the respective binding unit. In order to analyse the population responses which signal the presence of a particular perceptual object, a binding unit would be required which receives its input connections from exactly the set of feature selective units that respond to the various features constituting that particular object. This is clearly not an attractive solution: If coarse codes are disambiguated by creating individual sharply tuned cells, an exceedingly large number of units is required to represent the virtually infinite number of distinguishable perceptual objects. Introducing binding units is thus extremely expensive in terms of hardware because the number of required binding units scales very unfavourably with the number of different input constellations that can be bound. Despite of this it is commonly held that the binding of the component features which define perceptual objects is achieved by such convergence onto higher order "binding units". While such a solution to the binding problem may be exploited by simple nervous systems and is perhaps also implemented in vertebrate brains to bind frequently occurring, stereotyped constellations of features, it seems highly unlikely that it is used as a general binding mechanism because it would require too many binding units. In essence, one would need at least one binding unit for each of the nearly infinite feature constellations characterizing the vast number of distinguishable objects. Moreover, at least 4 or 5 additional units are needed per distinguishable object to bind the different response configurations that are caused by different views of the same object. Even if objects and their different views are represented in a more economical way by interpolation in small groups of neurons (Poggio, 1990), no single area in the visual processing stream has been identified so far that could serve as the ultimate site of convergence and that would be large enough to accommodate the still exceedingly large number of required neurons. Also, one would have to postulate a large reservoir of uncommitted cells in order to allow for the binding of features of new, hitherto unknown objects. These neurons would have to maintain latent input connections from all feature-selective neurons at lower processing stages. For the representation of new objects, the subsets of these connections, which are activated by the unique feature constellation of the new object, would have to be selected and consolidated instantaneously.

Binding through assembly formation

Alternative solutions to the binding problem have therefore been proposed. These are all based on the assumption that binding is achieved by cooperative interactions among the neurons whose responses need to be bound together. The idea is that at each level of processing cells interact through a dense network of reciprocal, highly tuned connections, the functional architecture of which reflects the criteria according to which active cells should be grouped or bound together. Thus, once input activity becomes available and cells begin responding, a self-organizing process is initiated by which subsets of responses get bound together according to the joint probabilities set by the specific input pattern, the functional architecture of the coupling network *and* the signals arriving through reentry loops from higher processing stages. The essential advantage of such a dynamic, self-organizing binding process is, that individual cells can bind at different times, e.g. when input constellations change, with different partners. This greatly economizes the number of required cells. Binding units are no longer necessary as the respective ensemble of ad hoc bound units would be functionally equivalent with a "binding unit". Moreover, and most importantly, a particular cell can now be used in representations of many different feature constellations as it can be bound in a flexible way to changing partners. This makes it possible to create with a limited set of neurons a nearly infinite number of different binding constellations. The only constraint is the dynamical range of the neurons which limits the number of inputs a cell can receive but this problem can be overcome by iteration and parcellation (see below). This solution to the binding problem resembles closely previously formulated concepts on sensory representations which assume that perceptual objects are represented in the brain by *assemblies* of interacting neurons rather than by individual, highly selective cardinal cells as proposed by Barlow (1972) and recently again by Martin (1994). The assembly-hypothesis has been made explicit in Hebb's (1949) seminal book "On the organisation of behaviour" and has since then become considerably more elaborate and adapted to recent neurobiological evidence. (Abeles, 1991; Braitenberg, 1978; Crick, 1984; Edelman, 1987, 1989; Grossberg, 1980; Hebb, 1949; Palm, 1982, 1990; Singer, 1985; Singer, 1990; v.d. Malsburg, 1985).

Neuronal signatures of relatedness

However, relatively little attention has been paid until recently to the question, how responses of neurons in a Hebbian assembly can be labelled so that they are distinguished unambiguously as belonging to the same assembly or, in the context of our binding problem, how responses that get bound together become distinguished as being bound and can be segregated from other, often simultaneous responses to which they should not be bound. To ascertain that the responses of neurons that constitute an assembly are interpreted by the rest of the brain as a coherent, not further reduceable representation of a particular content, the responses of such an assembly must be processed jointly by subsequent processing stages.

The only way to select responses for further joint processing is to enhance their saliency, i.e. to increase their impact on neurons at subsequent processing stages. The simplest strategy to achieve this is to raise their discharge rate jointly. Accordingly, most proponents of the assembly hypothesis, including Hebb, have proposed that cells which have joined an assembly are distinguished because they increase their discharge rates due to reciprocal excitation and reverberation. The problem with this idea is that follower cells need to integrate over some tens of msec to find out whether a feeding cell has increased its discharge rate. Thus, discharge rates have to be maintained elevated over some time to allow for effective temporal summation. If within this integration time another assembly becomes organized a superposition problem arises as it becomes impossible to know which of the many simultaneous, enhanced responses belong to which assembly. This limits the number of populations that can be enhanced simultaneously without becoming confounded. Only those populations would remain segregatable which are clearly defined by a place code. But place codes are again expensive with respect to the number of required neurons and they suffer from low combinatorial flexibility. Another disadvantage of selecting neurons solely on the basis of enhanced discharge rates is that it precludes the option to encode information about features or constellations of features in the graded responses of distributed populations of neurons because rate is no longer available as a coding space for stimulus qualities.

It has been proposed, therefore, that the synchronization of responses on a time scale of milliseconds is a more efficient mechanism for response selection (for review see Singer and Gray, 1995). Synchronization also increases the saliency of responses because it allows for effective spatial summation in the population of neurons receiving convergent input from synchronized input cells. In addition, synchronization expresses relations among input neurons with much higher temporal resolution than joint enhancement of discharge rate because synchronization raises the saliency of individual discharges. In principle, a particular assembly can be defined by a single barrage of synchronously emitted action potentials whereby each individual cell would have to contribute only a few discharges. Predictably, such synchronous events are very effective in eliciting responses in target populations and because synchronous discharges of large numbers of neurons are statistically very improbable their information content is high. Thus, with synchronization, response selection can be highly specific and different assemblies can become organized in rapid temporal succession by using a multiplexing strategy.

For these reasons it has been proposed that binding of cells into functionally coherent assemblies should be achieved by synchronization (von der Malsburg 1985; von der Malsburg and Schneider, 1986; see also Milner, 1974, for a related proposal). The assumption is that during the formation of assemblies the discharges of neurons undergo a specific temporal patterning so that cells participating in the encoding of related contents eventually come to discharge in synchrony. This patterning is thought to be based on a self-organizing process that is mediated by a highly selective network of reentrant connections. Thus, neurons having joined into an assembly coding for the same feature or at higher levels, for the same perceptual object, would be identifiable as members of the assembly because their responses would contain episodes during which their discharges are synchronous.

During the last decade predictions derived from this hypothesis have been subjected to experimental testing and many of them could be confirmed (for review see Singer and Gray, 1995; Singer *et al.*, 1997; Singer, 1999,a,b) whereby most of the data have been obtained in the mammalian visual cortex.

The results indicate clearly that synchronization probability depends not only on the fixed anatomical connections between neurons but also and to a crucial extent on the configuration of the stimuli. So far, synchronization probability appears to reflect rather well the Gestaltcriteria for perceptual grouping and the occurrence of synchronous events is well correlated with cognitive processes and motor performance. However, most of the evidence available to date is correlative in nature and there is a lively debate in the scientific community as to whether the observed synchronization of neuronal activity is actually serving as signature of relatedness.

Whatever the final solution to the binding problem will be, available anatomical and functional data indicate clearly that the distributed organization of our brains differs radically from what our introspection made us believe. There is no single convergence center in the brain where all sensory signals could come together to permit a coherent interpretation of the world, where decisions could be reached and plans for future actions elaborated, there is no Cartesian theatre where the homunculus endowed with mental capacities, the mind; could be seated that evaluates and at the same time controls the results of the material processes in the brain.

The conflict

Here is not the place to discuss in detail the far reaching and dramatic consequences which these notions have for our self-understanding. If, as science suggests, mental and psychological processes – including sensations and consciousness – are indeed emergent qualities of neuronal processes, if there is no need to postulate an ontologically segregated mind that interprets and controls the material processes in the brain, if what we do next is entirely determined by the status quo ante and the dynamic trajectories of self-organizing processes in our brain, if our brains can be as readily described in neurobiological terms as the brains of animals, then there is a severe incompatibility between the results of our two cognitive strategies: introspection on the one hand and scientific analysis on the other. The evidence derived from introspection and mere observation of others is incompatible with evidence derived from scientific analysis. The latter insists that what we experience as our conscious mind is nothing more than a rapporteur that has access to certain but by far not to all brain processes and summarizes a posteriori the causes for decisions and actions to the extent that these are accessible. If so, free will has to be considered as an illusion, as a cultural construct that is passed on from generation to generation by education and learning. Intuition, by contrast, insists that it is our conscious self that has the initiative and triggers processes in the brain in order to instantiate action (for a more extensive discussion of putative neuronal correlates of consciousness see Singer, 1999c).

Here is a worrying example: If one presents a pictogram containing an instruction for a particular action in the left visual hemifield of a split-brain patient whose commissures between the two hemispheres have been severed, the patient has no conscious recollection of the stimulus because the visual signals from the left hemifield are processed exclusively in the right hemisphere and have no access to the speech competent left hemisphere. Still, however, the patient may execute the requested action. When asked why he/she just executed that particular action the patient will typically answer "I wanted ...". or "I intended...". or "Because this or that had to be changed", etc. The real cause, the instruction that had remained excluded from conscious recollection is swiftly replaced by an explanation that attributes the initiative to the acting self; and the patient is actually convinced that he/she had initiated the action following a volontary decision.

So, our conscious self is highly susceptible to dillusions and in its search for coherence offers interpretations which are inconsistent with the reality defined by the scientific observer. We interpret actions, i.e. neuronal activity, whose cause is not identifiable by conscious experience as the result of an intentional act of our self and invent the required motivation a posteriori. And, conversely, as suggestesd by the existence of dreams, halluzinations and déjà vue experiences, our brains are in principle capable to self-generate activity patterns that are identical to those that would have resulted from external stimulation and they can experience this self-generated activity as if it were caused by a real event.

What then should we trust? Our intuitions and primary experiences or our scientific descriptions? The way in which we perceive ourselves and our relation to Nature will depend critically on the relative weight that we grant the two cognitive strategies. If we give priority to the traditional cognitive approach that is based on primary experience, intuition and reasoning – the approach that has deeply impregnated our culture and is the basic approach of the humanities – then we perceive ourselves as opposed to Nature and our distance to Nature increases steadily due to the spin off of science, i.e. technology.

In contrast, if we give priority to the knowledge provided by the scientific approach, we are forced to perceive ourselves as an integral part of Nature, and then also our cultural and technological achievements ought to be considered as natural, as products of an evolutionary process in which we simply play the role of mediators.

The question then is, what our preferences are and whether we are actually free to choose between the two options. Should we keep the two sources of knowledge strictly apart as still advocated by many proponents of the humanities and simply ignore scientific description systems when it comes to define our place in the world? And would such an attitude be compatible on the long run with our longing for a coherent interpretation of the world?

Or will we simply get used to the scientific interpretations of our conditio as we got used to the interpretations given by Copernicus and Darwin? – in which case our self-perception will have to change once again and more drastically than ever before.

Or shall we have to change our attitude towards science and follow those who declare that scientific descriptions are valid for only a limited class of phenomena, and if we opt for this, how are we going to decide where the limits are? How are we going to deal with the recent surge of esoterism and pseudoscientific interpretation of the world and how can we distinguish their claim for truth from that of the old religions and their great mystics?

REFERENCES

Abeles, M., 1991, *Corticonics* (Cambridge: Cambridge University Press)

Barlow, H. B., 1972, "Single units and cognition: A neurone doctrine for perceptual psychology", *Perception* 1, 371-394

Baylis, G. C., Rolls, E. T. and Leonard, C. M., 1985, "Selectivity between faces in the responses of a population of neurons in the cortex in the superior temporal sulcus of the monkey", *Brain Research* 342, 91-102

Braitenberg, V., 1978, "Cell assemblies in the cerebral cortex" *Architectonics of the cerebral cortex. Lecture notes in biomathematics 21. Theoretical approaches in complex*, eds. R. Heim, G. Palm (Berlin: Springer Verlag), 171-188

Crick, F., 1984, "Function of the thalamatic reticular complex: The searchlight hypothesis", *Proceedings of the National Academy of Sciences USA* 81, 4586-4590

Desimone, R., Albright, T. D., Gross, D. G. and Bruce, C. (1984) "Stimulus-selective properties of inferior temporal neurons in the macaque", *Journal of Neuroscience* 4, 2051-2062

Desimone, R., Schein, S. J., Moran, J. and Ungerleider, L. G., 1985, "Contour, color and shape analysis beyond the striate cortex", *Vision Research* 24, 441-452

Edelman, G. M., 1987, *Neural Darwinism: The theory of neuronal group selection* (New York: Basic Books)

Edelman, C. M., 1989, *The remembered present* (New York: Basic Books)

Felleman, D. J., van Essen, D. C., 1991, "Distributed hierarchical processing in the primate cerebral cortex", *Cerebral Cortex* 1, 1-47

Gross, C. G., Rocha-Miranda, C. E. and Bender, D. B., 1972, "Visual properties of neurons in inferotemporal cortex of the macaque", *Journal of Neurophysiology* 35, 96-111

Grossberg, S., 1980, "How does a brain build a cognitive code?", *Psychological Review* 87, 1-51

Hebb, D. O., 1949, *The organization of behavior* (New York: John Wiley & Sons)

Martin, K. A. C., 1994, "Brief history of the 'feature detector'", *Cerebral Cortex* 4, 1-7

Milner, P. M., 1974, "A model for visual shape recognition", *Psychological Review*, 81, 521-535

Palm, G., 1982, *Neural assemblies* (Heidelberg: Springer Verlag)

Palm, G., 1990, "Cell assemblies as a guildeline for brain research", *Concepts in Neuroscience* 1, 133-147

Perrett, D. I., Mistlin, A. J. and Chitty, A. J., 1987, "Visual neurones responsive to faces", *Trends in Neuroscience* 10, 358-364

Poggio, T., 1990, "A theory of how the brain might work", *Cold Spring Harbor symposia on quantitative biology* (Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press), 899-910

Sheinberg, D. L. and Logothetis, N. K., 1997, "The role of temporal cortical areas in perceptual organization", *Proceedings of the National Academy of Sciences USA* 94, 3408-3413

Singer, W., 1985, "Activity dependent self-organization of the mammalian visual cortex", *Models of the visual cortex,* eds. D. Rose, V. G. Dobson (New York: John Wiley & Sons), 123-136

Singer, W., 1990, "The formation of cooperative cell assemblies in the visual cortex", *Journal of Experimental Biology* 153, 177-197

Singer, W., 1995, "Development and plasticity of cortical processing architectures", *Science* 270, 758-764

Singer, W., 1999a, "Response synchronization: A universal coding strategy for the definition of relations", *The Cognitive Neurosciences*, Second Edition, ed. M. S. Gazzaniga (MIT Press), in print

Singer, W., 1999b, "Time as a coding space", *Cognitive Neuroscience. Current Opinion in Neurobiology,* ed. D. L. Schacter, 189-194

Singer, W., 1999c, "Phenomenal awareness and consciousness from a neurobiological perspective" *Neural correlates of consciousness – Empirical and conceptual questions*, ed. T. Metzinger (MIT Press), in print

Singer, W. and C. Gray, 1995, "Visual feature integration and the temporal correlation hypothesis", *Annual Review of Neuroscience*, 18, 555-586

Singer, W., Engel, A. K., Kreiter, A. K., Munk, M. H. J., Neuenschwander, S. and Roelfsema, P. R., 1997, "Neuronal assemblies: necessity, signature and detectability", *Trends in Cognitive Sciences* 1, 252-261

von der Malsburg, C., 1985, "Nervous structures with dynamical links", *Berichte Bunsengesellschaft für Physik und Chemie* 89, 703-710

von der Malsburg, C. and C. Schneider, 1986, "A neural cocktail-party processor", *Biological Cybernetics* 54, 29-40

Zeki, S. M., 1973, "Colour coding in the rhesus monkey cortex", *Brain Research* 53, 422-427

NEW MILLENNIUM: NEW BIOLOGY?

STEVEN P. R. ROSE

Constraints on Knowing Nature

As Wolf Singer (this volume) reminds us, we view and interpret the world around us, both natural and cultural, through perceptual and cognitive spectacles of our own construction. The natural sciences claim that their methods, of hypothesis, observation and experiment, permit something approximating to a true representation of the material reality that surrounds us to be achieved. However, for several decades now, philosophers, historians and sociologists of science have been pointing to the ways in which our scientific knowledge is socially, culturally and historically constructed – that is, it offers at best a constrained interpretation of the material world. A first such constraint is provided, as Singer argues, by the very construction of our brain and the biology of our perceptual processes. To this I would add that brains do not exist in isolation from bodies: how we perceive the world is affected by our hormonal, immunological and general physiological state. And we perceive the world in the way that we do because our visual system is capable of sensing only a limited range of wavelengths, our mass and volume give us a particular relationship to gravitational forces not shared for instance by bacteria or beetles, or by whales or elephants. Our sense of the temporality of events is shaped by the fact that we may live for anything up to and now even beyond a century. Bacteria divide every twenty minutes or so, mayflies live for a day, redwood trees for thousands of years. Human technologies can and do enable us to escape these structural and temporal limitations, to observe in the infrared or ultraviolet, weigh atoms and measure time in anything from nanoseconds to light years. Yet even when considering the inconceivably small or distant, we do so by scales that relate to our human condition: the measure of man is man.

But there are other constraints that transcend our mere biology. One – which is where the sciences differ most from the arts and humanities – is that we are not free to offer interpretations which our observations of, and experiments on, the external world disconfirm. A second is defined by the limits of our available technologies.[1] Until the means of circumnavigating the earth were available it was a legitimate approximation to the truth to maintain that the earth was flat. Until Lavoisier weighed the products of combustion, phlogiston theory was as good as oxygen theory. Until microscopes revealed the internal constituents of living tissue it was legitimate to regard cells as composed of homogeneous protoplasm.

But a third and equally important constraint is that resulting from the very social and historical nature of the scientific enterprise itself. The ways in which we view the world, the types of experiments we conceive and evidence we accept, the theories we construct, are far from being culturally free. This means that we cannot understand the current shape of biological thinking without reference to the history of our own discipline. This should not surprise us. After all in a famous aphorism, known to all biologists, the great evolutionist Theodosius Dobzhansky pointed out that nothing in biology made sense except in the context of evolution. I would want merely to broaden that statement, in ways that will become apparent in the course of this paper, to read 'nothing in biology makes sense except in the context of history – by which I mean evolutionary history, developmental history, and the history of our own subject (Rose, 1997). This does not imply a simple progressivism; new knowledge claims may well be, but are not necessarily, 'better' representations of the material world than prior ones.

[1] Note that, unlike many commentators, I do not regard technology as fundamentally distinct from science. Whether knowledge and practice are scientific or technological depends on the use for which they are employed, not something intrinsically different. For discussion of this argument see eg: Rose, H and Rose, S.P.R. (1969) *Science and Society* (Harmondsworth, Penguin); Rose, S.P.R. (1993) *The Making of Memory*, (Uxbridge, Transworld/Bantam); Rose, S.P.R. (1997) *Lifelines: Biology, Freedom, Determinism* (London, Allen Lane The Penguin Press).

The Power of Reductionist Thinking and the Plurality of Biological Explanation

For reasons that it would take me too far outside my theme to explore here, throughout its post-Cartesian and Newtonian history western science has seen physics as its explanatory model. The more pluralistic, pre-scientific world gave way to one in which all our day-to-day experiential richness of colour, and sound, of love and anger, came to be seen as secondary qualities underlying which there were the changeless particles, waves and forces of the physicists' world. The task of other sciences, chemistry, biology and later psychology, sociology and economics, was to make themselves as like physics as possible. Their qualities needed to be reduced to the true, quantitative 'hard science' of physics. As the philosopher Thomas Nagel claims (Nagel, 1998), other sciences describe things, reductionism explains them. The molecular biologist James Watson, following Rutherford, put it more bluntly: "there is only one science, physics; everything else is social work."[2]

A further problem for biology, perhaps because its subject matter is so complex, is that there has been a continuing tendency to understand living processes and systems by metaphorising them to the most advanced forms of current human artefact. Many origin myths, including the Judaeo-Christian one, refer to humankind having been created from the dust or clay of the earth, like a potter's wheel. The Greek Hero was said to have created lifelike robots using steam and water power. Hydraulic imagery persisted through the Renaissance (e.g. hearts as pumps; nerves as tubes for conveying vital forces) to give way to electrical and magnetic ones in the eighteenth and nineteenth centuries. Brains became telegraph systems, then telephones and now computers. Such metaphors are powerful, and may be helpful. But too often their seductive powers blinker our capacity to see the world. As I will argue, brains are not computers, and genes are not selfish.

Let me offer a fable to demonstrate the limits of reductionism in biology. Five biologists are on a picnic, when they see a frog jump into a pond. They fall to discussing why the frog has jumped. The first, a physiologist, describes the frog's leg muscles and nervous system. The frog jumps because impulses have travelled from the frog's retina to its brain and thence down motor nerves to the muscle. The second, a biochemist, points out that the muscles are composed of actin and

[2] In a debate with me at the Cheltenham book festival in 1996.

myosin proteins – the frog jumps because of the properties of these fibrous proteins that enable them, driven by the energy of ATP, to slide past one another. The third, a developmental biologist, describes the ontogenetic processes whereby the fertilised ovum divides, in due course forming the nervous system and musculature. The fourth, a student of animal behaviour, points to a snake in a tree above where the frog was sitting: the frog jumps to escape the snake. The fifth, an evolutionist, explains the processes of natural selection that ensured that only those frog ancestors able both to detect snakes and jump fast enough to escape them had a chance to survive and breed.

Five biologists, five very different types of explanation. Which is the right one? Answer: all of them are right, just different. The biochemist's explanation is the reductionist one, but it in no way eliminates the need for the others. Nor can we envisage a research programme in which the other types of explanation would in due course all be subsumed by either the biochemical, or the evolutionary one – despite the often quoted claim in the opening sentences of Wilson's book on sociobiology (Wilson, 1975), reiterated most recently in his demand for 'consilience' (Wilson, 1998). The most that we can insist is that explanations in the different discourses should not contradict one another. As a materialist, as all biologists must be, I am committed to the view that we live in a world that is an ontological unity, but I must also accept an epistemological pluralism. As the philosopher Mary Midgley puts it, neither the value of money, nor the rules of football, are collapsible into physics; there is one world, but it is a big one (Midgley, 1998).

The Shifting Boundaries Between Nature and Culture

Which type of explanation we prefer depends on the purposes for which it is required. If we are concerned with diagnosing and treating diseases like muscular dystrophy or myasthenia gravis, genetic and biochemical approaches may point the way. For others, like understanding why a person chooses to take a swim or a baby learns to walk, they are almost entirely useless. Far from such 'lower level' accounts explaining, as Nagel would have it, they at best merely describe, whilst the higher and strictly irreducible accounts have the most explanatory power. Yet over the hundred and forty years since the publication of Darwin's *Origin*, biology's pluralism has steadily been restricted. Physiology has been collapsed into biochemistry and biochemistry into chemistry and physics. Skinner's behaviouristic attempt to reduce psychology to physics and skip the intervening biological level may have been rejected, but a new school of 'neurophilosophers' seeks to dismiss what they call 'folk psychology' in favour of neurocomputation, in which brains are indeed replaced by computers (Churchland, 1986; Dennett, 1991). Evolutionary biology has replaced study of the living world by abstract mathematical calculations about changes in the population frequencies of individual selfish genes (Dawkins, 1976). Indeed, the very phenotype, the living organism itself, has been emptied of any function other than that of being the 'lumbering robot' serving for the replication of its genes, to quote Dawkins. Molecular geneticists now see organisms as mere tools with which to probe gene function. They offer to predict our entire lifeline, our trajectory from birth to death, from the diseases we will die of to the political parties we will vote for, the drugs we will enjoy, our degree of job satisfaction and tendency to mid-life divorce (see Rose, 1997 for references). It would seem that reductionism has triumphed.

What is clear is that developments in the sciences in general, and biology perhaps in particular, have profoundly changed our concept both of nature and of the boundaries between nature and culture. Take the concept of motherhood. That here are both biolgical and social mothers has long been recognised. But as feminists (eg Hilary Rose;1994) have emphasised, the new reproductive technologies have changed our understanding of what it is to be 'a mother,' so that there are now genetic mothers, surrogate (carry) mothers, social mothers...If human cloning becomes a reality, the concept of a mother will change yet again.

This reconceptualisation of what is 'nature' is moving forward with great speed on the heels of new developments in genetics. Thus the neurosciences in collaboration with genetics are offering to transform our understanding of human nature, turning what were once regarded as the results either of individual free will (or humanity's sinful nature – see for instance Milton's *Paradise Lost* for an earlier orthodox theological account) into biomedical matters. Adultery and cheating were once sins; now evolutionary psychology tells us that these activities are the consequences of adaptations during humanity's palaeolithic past (see Barkow, Cosmides and Tooby, 1992 for an exposition of this argument; Rose and Rose, 2000, for a critique). Alcoholism and violence were social problems; now they are supposed to be caused by abnormal genes. As an example, the late John Kennedy explained that he didn't 'become' an alcoholic, it was something he was 'born with.' Same-sex love was once a sin, then a social problem; today there are claims that it is genetically caused (see Rose, 1995, 1997 and references therein). Personal responsibility for our actions, a given for both religious and humanist thinkers, is dissolved into DNA's double helix. Culture becomes nature, whilst simultaneously biomedicine holds out the promise of transforming nature by genetic manipulation. Biology is Janus-faced. It is determinist, as much predestinationist as any religious sect. But it is simultaneously Promethean, offering technology to conquer destiny. Thus I differ from Singer in his assertion that there is an unchanging nature out there constituted of 'everything that is not man made artefact.' The boundaries are not stable.

Yet there are limits to reductionism's onward march. Try as we may to collapse our sciences into grand physical theories of everything (the physicists' TOES and GUTS), such attempts must fail. The dream of writing a single equation which will embrace the world resembles more the search for an alchemical philosopher's stone which will transmute base metal into gold and grant perpetual youthful life to its possessor, or the cabbalistic belief that there can be found a single mystical sentence which will give its utterer almost god-like power over people and things, The Vienna School's philosophical attempt in the 1930s to impose a unity on the sciences – a unity built upon physics – was doomed to failure, and Wilson's latest evocation of it is unlikely to succeed.

Let me draw briefly on three areas of current biology to demonstrate the limits to reductionism's dream and use these to point in the directions in which I believe that biology must move in its concept of nature in the new millennium: neuroscience, developmental and evolutionary biology.

Brains, Minds and Meaning

First, the brain. Singer's paper makes clear that in order to understand how the human brain functions it is not sufficient to simply extrapolate upward from the firing properties of its hundred billion neurons or the 10^{15} or so synaptic connections between them. Even a wiring diagram of their anatomical connections is insufficient. The temporal relationships between activity in distant brain regions, coherent oscillatory processes, binding mechanisms and doubtless as yet undiscovered interactions all make it necessary to consider the brain as a system, not a mere assemblage of parts, perhaps to be understood using chaotic dynamic theory (Freeman, 1999). I want to add one further point, and that is to challenge the popular view that brains are computational, information processing devices, a claim most forcefully made recently by Pinker (1997).

In Pinker's view, following other evolutionary psychologists, the brain/mind is not a general-purpose computer; rather it is composed of a number of specific modules (for instance, a speech module, a number sense module, a face-recognition module, a cheat-detector module, and so forth). These modules have, it is argued, evolved quasi-independently during the evolution of early humanity, and have persisted unmodified throughout historical time, underlying the proximal mechanisms that traditional psychology describes in terms of motivation, drive, attention and so forth. Whether such modules are more than theoretical entities is unclear, at least to neuroscientists. Indeed EP theorists such as Pinker go to some lengths to make it clear that the 'mental modules' they invent do not, or at least do not necessarily, map onto specific brain structures. But as Ellman *et al.* (1996) shows, even if mental modules do exist they can as well be acquired as innate.

Modules or no, it is not adequate to reduce the mind/brain to nothing more than a cognitive, 'architectural' information processing machine. Brains/minds do not just deal with information. They are concerned with living meaning. In *How the Mind Works* Pinker offers the example of a footprint as conveying information. My response is to imagine Robinson Crusoe on his island, finding a footprint in the sand. First he has to interpret the mark in the sand as that of a foot, and recognise that it is not his own. But what does it mean to him? Pleasure at the prospect of at last another human being to talk and interact with? Fear that this human may be dangerous? Memories of the social life of which he has been deprived for many years? A turmoil of thoughts and emotions within which the visual information conveyed by the footprint is embedded. The key here is emotion, for the key feature which distinguishes brains/minds from computers is their/our capacity to experience emotion. Indeed, emotion is primary; affect as much as cognition is inextricably engaged in all brain and mind processes, creating meaning out of information – just one reason why brains aren't computers. What is particularly egregious in this context is Pinker's oft-repeated phrase, 'the architecture of the mind.' Architecture, which implies static structure, built to blueprints and thereafter stable, could not be a more inappropriate way to view the fluid dynamic processes whereby our minds/brain develop and create order out of the blooming buzzing confusion of the world which confronts us moment by moment.

DNA and the Cellular Orchestra

Within the reductionist paradigm, development is the reading out of genetically encoded instructions, present within the 'master molecule,' DNA. Hence the popular references to DNA as being the blueprint of life, the code of codes, and so forth. The organism, the phenotype, is simply the vessel constructed by the DNA in order to ensure its safe replication. This model misspeaks both the relationship of DNA to cellular processes in general and the nature of development.

DNA itself is rather an inert molecule (hence the possibility of recovering it intact from amber many tens of thousands of years old – and the plot of Jurassic Park). What brings it to life is the cell in which it is embedded. DNA cannot simply and unaided make copies of itself; it cannot therefore 'replicate' in the sense that this term is usually understood.. Replication – using one strand of the double helix of DNA to provide the template on which another can be constructed – requires an appropriately protected environment, the presence of a wide variety of complex molecular precursors, a set of protein enzymes, and a supply of chemical energy. And even when DNA has been copied faithfully, the 'read-out' into RNA and thence into protein, once though to be linear, is far from being so. Individual coding sequences of DNA are distributed along chromosomes, punctuated by long sequences (introns) of no known coding function. In humans some 98% of the DNA in the genome comes into this non-coding category. Coding sequences are 'read' by cellular mechanisms, snipped out from the rest, spliced together, transcribed into RNA, edited.

The proteins they code for are then further processed and tailored by temporal and state regulated cellular mechanisms quite distal to DNA itself. All these are provided in the complex metabolic web within which the myriad biochemical and biophysical interactions occurring in each individual cell are stabilised (Kauffman, 1995). The famous 'central dogma' enunciated by Crick and on which generations of biologists have been brought up, that there is a one way flow of information by which 'DNA makes RNA makes protein' and that 'once information gets into the protein it can't flow back again,' was a superb simplification in the early days of molecular biology. But it simply is not true any more. Dogma in science is as unstable as that in religion. What is certain is that there are no master molecules in cellular processes. Even the metaphor of the cellular orchestra, which I have used previously, is not adequate, as orchestras require conductors. Better to see cells as marvellously complex versions of string quartets or jazz groups, whose harmonies arise in a self-organised way through mutual interactions. This is why the answer to the chicken and egg question in the origin of (see eg the SETI discussions in this volume) is not that life began with DNA and RNA but that it must have begun with primitive cells which provided the environment within which nucleic acids could be synthesised and serve as copying templates.

The Paradox of Development

It is a commonplace that despite the near identity of our genes, no-one would mistake a human for a chimpanzee. For that matter we share some 35% of our genes with daffodils. What distinguishes even closely related species are the developmental processes that build on the genes, the ontogenetic mechanisms that transform the single fused cell of a fertilised ovum into the thousand trillion cells of the human body, hierarchically and functionally organised into tissues and organs. Developmental processes have trajectories which constitute the individual lifeline of any organism, trajectories which are neither instructed by the genes, nor selected by the environment, but constructed by the organism out of the raw materials provided by both genes and environment, This is the process described by Maturana and Varela (1980) as autopoiesis and by Oyama (1985) as 'the ontogeny of information).

One of the problems for twentieth century biology, a problem resulting partly from contingent features of the history of our science, is that whereas at the beginning of the century developmental biology and genetics were seen as a single scientific endeavour (a splendid exemplar being TR Morgan, the founder of the famous 'fly school' which introduced Drosophila as 'god's organism' for genetic and chromosomal analysis), by the 1930s they had become quite distinct. Thus development became the science of similarities, genetics the science of differences. Explaining how it is that virtually all humans are between 1.5 and 2.5 metres in height, are more or less bilaterally symmetrical and have pentadactyl limbs was a subject for developmental study. Why some of us have differently coloured eyes, hair or skin became part of genetics. Only in the closing years of the century does there seem to be a chance to bring the two together once more (Maynard Smith, 1998).

The unity of an organism is a process unity, not a structural one. All its molecules, and virtually all its cells, are continuously being transformed in a cycle of life and death which goes on from the moment of conception until the final death of the organism as a whole. This means that living systems are open, never in thermodynamic equilibrium and constantly choosing, absorbing and transforming their environment. They are in constant flux, always at the same time both *being* and *becoming*. To build on an example I owe to Pat Bateson, a newborn infant has a suckling reflex; within a matter of months the developing infant begins to chew her food. Chewing is not simply a modified form of suckling, but involves different sets of muscles and physiological mechanisms. The paradox of development is that a baby has to be at the same time a competent suckler, and to transform herself into a competent chewer. To be, therefore, and to become.

Being and becoming are not to be partitioned into that tired dichotomy of nature versus nurture. Rather they are defined by a different dichotomy, that of specificity and plasticity. Let me expand on Singer's account of the constructive nature of visual and perceptual processes in a developmental, epigenetic context. The retina of the eye is connected via a series of neural staging posts to the visual cortex at the back of the brain. A baby is born with most of these connections in place, but during the first years of life, the eye and the brain both grow, at different rates. This means that the connections between eye and brain have continually to be broken and remade. If the developing child is to be able to retain a coherent visual perception of the world this breaking and remaking must be orderly and relatively unmodifiable by experience. This is specificity. However, as both laboratory animal experiments and our own human experience show, and as Singer discusses, both the fine details of the 'wiring' of the visual cortex, and how and what we perceive of the world are both directly and subtly shaped by early experience. This is plasticity. All living organisms and perhaps especially humans with our large brains show both specificity and plasticity in development, and both properties are enabled by our genes and shaped by our experience and contingency. Neither genes nor environment are in this sense determinant of normal development; they are the raw materials out of which we autopoietically construct ourselves.

Thus the four dimensions of living processes – three of space and one of time – cannot be read off from the one dimensional strand of DNA. A living organism is an active player in its own destiny, not a lumbering robot responding to genetic imperatives whilst passively waiting to discover whether it has passed what Darwin described as the continuous scrutiny of natural selection.

Evolution and Levels of Selection

Within the reductionist paradigm within which much of contemporary biological theorising is located, the processes of evolutionary change have also become simplified. By contrast for instance with Darwin's own pluralism, which saw natural selection as a main but not the only mechanism of change, a dominant orthodoxy, described as fundamentalist or ultra-Darwinian has emerged, as evidence in the popular writings of Dawkins. Three main theses characterise this new fundamentalism. First, most phenotypic features we can observe are adaptive; second, they are generated by natural selection; and third, natural selection acts solely or primarily at the level of individual genes. A new biology for the new millennium must transcend each of these propositions, in part by reverting to Darwin's own more pluralistic understanding. I will consider the counter-arguments to these propositions in reverse order.

The present-day understanding of the fluid genome in which segments of DNA responsible for coding for subsections of proteins, or for regulating these gene functions, are distributed across many regions of the chromosomes in which the DNA is embedded, and are not fixed in any one location but may be mobile, makes the view that individual genes are the only level of selection untenable. But it always was. To play their part in the creation of a functioning organism many genes are involved – in the human, some hundred thousand. For the organism to survive and replicate, the genes are required to work in concert – that is, to co-operate. Antelopes which can outrun lions are more likely to survive and breed than those that cannot. Therefore a mutation in a gene which improves muscle efficacy, for instance, might be regarded as fitter and therefore likely to spread in the population. However, as enhanced muscle use requires other physiological adaptations – such as increased blood flow to the muscles, without this concerted change in other genes, the individual mutation is scarcely likely to prove very advantageous. And as many genes have multiple phenotypic effects (pleiotropy) the likelihood of a unidirectional phenotypic change is complex – increased muscle efficacy might diminish the longevity of the heart for example. Thus it is not just single genes which get selected, but also genomes. Selection operates at the level of gene, genome and organism.

Nor does it stop there. Organisms exist in populations (groups, demes). Three decades ago, Wynne-Edwards (1962) argued that selection occurred at the level of the group as well as the individual. He based this claim on a study of a breeding population of red grouse on Scottish moors, and argued that they distributed themselves across the moor, and regulated their breeding practices, in a way which was optimum for the group as a whole rather than any individual member within it. It may be in the individual's interest to produce lots of offspring; but this might overcrowd the moor, which could only sustain a smaller number of birds; hence it is in the *group's* interest that none of its members over-breed. Orthodox Darwinians, led by George Williams, treated this claim with as much derision as they did Lamarck's view that acquired characteristics could be inherited, and group selection disappeared from the literature.

Today however it is clear that the attack was misjudged. In part it was always in part semantic. Maynard Smith's work, for instance, indicated that stable populations require the mutual interactions and ratios of members with very different types of behaviours (hawks and doves, for instance, to use his model) – so called evolutionary stable strategies. But there are an increasing number of examples of populations of organisms whose behaviours can most economically be described by group selectionist equations. Recently Sober and Wilson (1999) have published a major reassessment of group selectionist models and shown mathematically how even such famously counter-intuitive (for ultra-Darwinians) phenomena as altruism can occur, in which an individual sacrifices its own individual fitness, not merely for the inclusive fitness of its kin but for the benefit of the group as a whole.

Finally, there is selection at even higher levels – that of the species for example (Gould, 1998). Natural selection may be constantly scrutinising and honing the adaptiveness of a particular species to its environment, but cannot predict the consequences of dramatic changes in that environment, as for example the meteor crash into the Yucatan believed to have precipitated the demise of the dinosaurs. Selection also operates at the level of entire ecosystems. Consider, for example, a beaver dam. Dawkins (1986) uses this example to claim that the dam may be regarded as part of the beaver's phenotype – thus swallowing an entire small universe into the single strand of DNA. But if it is a phenotype, it is the phenotype of many beavers working in concert, and indeed of the many commensal and symbiotic organisms which also live on and modify for their needs the structure of the dam. As Sober and Wilson point out, selection may indeed occur at the level of the individual, but what constitutes an individual is very much in the eye of the beholder. Genes are distributed across genomes within an organism, and they are also distributed across groups of organisms within a population. There is no overriding reason why we should consider 'the organism' as an individual rather than 'the group' or even 'the ecosystem.'

Nor is natural selection the only mode of evolutionary change. We need not be Lamarckian to accept that other processes are at work. Sexual selection is one well-accepted mechanism. The existence of neutral mutations, founder effects, genetic drift, and molecular drive (Dover, 1982), all enrich the picture. Gould (1989) argues that much evolutionary change is contingent, accidental, and that, as he puts it, if one were to wind the tape of history backward and replay it, it is in the highest degree unlikely that mammals, let alone humans would evolve.

Finally, not all phenotypic characters are adaptive. A core assumption of ultra-Darwinism is that observed characters must be adaptive, so as to provide the phenotypic material upon which natural selection can act. However, what constitutes a character – and what constitutes an adaptation – is as much in the eye of the beholder as in the organism to which the 'character' belongs. The problem lies in part in the ambiguity of the term phenotype which can refer to anything from a piece of DNA (strictly the gene's phenotype) through the cellular expression of a protein to a property of the organism as a whole, like height, or 'behaviour' such as gait. At which level of phenotype a character is 'adaptive,' if at all, and at which its properties are epiphenomenal is always going to be a matter for debate. A not entirely apocryphal example is provided by the American artist Thayer, who suggested, early in this century, that the pink coloration of flamingos is an adaptation to make them less visible to predators against the pink evening sky. But the coloration is a consequence of the flamingo's shrimp diet and fades if the diet changes. Thus even if we were to assume that the coloration was indeed protective, it is an epiphenomenal consequence of a physiological – dietary – adaptation, rather than a selected property in its own right.

Natural selection's continual scrutiny does not give it an *à la carte* freedom to accept or reject genotypic or phenotypic variation. Structural constraints insist that evolutionary, genetic mechanisms are not infinitely flexible but must work within the limits of what is physically or chemically possible. For instance, the limits to the size of a single cell are set by the physics of diffusion processes, the size of a crustacean like a lobster or crab by the constraints of its exoskeleton. The limits to the possible lift of any conceivable wing structure make it impossible to genetically engineering humans to sprout wings and fly; there are good reasons why we cannot become angels. Webster and Goodwin (1996) have extended this argument further, arguing that there are exact 'laws of form' which ensure, for instance the generation of pentadactyl (five-fingered) limbs.

A Biological Decalogue for the Millennium

If we are to transcend biology's reductionist view of nature for the new millennium, and to create what I would regard as an understanding of living processes more in accord with the material reality of the world than our present, rather one-eyed view, we need some principles with which to work. These principles will of course not reject the explanatory power of reductionism, but will recognise its limitations. They should accept, too, Goodwin's (1994) call for the return to a science of qualities, to complement reductionist quantitation. Such a science will rejoice in complexity, in dynamics, and in an emphasis as much on process as on objects. In *Lifelines* (Rose, 1997) I enumerate a set of such principles; by chance rather than design, there are ten in all. In brief, here is my decalogue. To exemplify all its principles would extend this essay beyond reasonable length, but enough has I trust been said to give a feel for the conceptual approach I am arguing for:

- Scientific knowledge is not absolute, but provisional, being socially, culturally, technologically and historically constrained.
- We live in a world that is ontologically unitary, but our knowledge of it is epistemologically diverse. There are multiple legitimate ways of describing and explaining any living process.
- Different sciences deal with different levels of organisation of matter of increasing complexity. Terms and concepts applicable at one level are not necessarily applicable at others. Thus genes cannot be selfish; it is people, not neurons nor yet brains or mind, who think, remember and show emotion.
- Causes are multiple, and phenomena richly interconnected. Adequate explanation demands finding the determining level. To take an example, the high levels of murder in the US by comparison with say Europe or Japan are best explained not by some special feature of the US genotype, abnormal genes or biochemistry which predispose to violence (despite a major research programme dedicated to identifying such biological predispositions), but by the high number of personal handguns in society, and a culture and history of their use.
- Living organisms exist in four dimensions, three of space and one of time, a developmental trajectory or lifeline, always autopoietic, both being and becoming. Lifelines are stabilised through dynamic processes. The traditional biological concept of homeostasis as a

regulatory mechanism needs transforming by that of homeodynamics, to emphasise that indeed stasis for any living organism means death.

- Organism and environment interpenetrate; environments select organisms (the process of natural selection); but organisms choose and transform environments. Organisms are thus active players in their own destiny.
- Living organisms are open systems far from thermodynamic equilibrium; continuity is maintained by a constant flow of energy and information. All is flux; stability emerges through process, not structure.
- Evolutionary change occurs at the intersection of lifeline trajectories with changing environments.
- Organisms cannot predict patterns of change, and selection therefore always tracks environmental change. Nothing in biology makes sense except in the context of history.
- Thus the future, for humans and other living organisms, is radically unpredictable; we make our own history, though in circumstances not of our own choosing.

REFERENCES

Barkow, J.H., Cosmides, L., and Tooby, J. (eds.) (1992) *The Adapted Mind: Evolutionary Psychology and the Generation of Culture* (New York, Oxford University Press)

Churchland, P. (1986) *Neurophilosophy: Towards a Unified Science of the Mind/Brain* (Cambridge, MA, MIT Press)

Dawkins, R.(1976) *The Selfish Gene* (Oxford, Oxford University Press)

Dawkins, R. (1982) *The Extended Phenotype* (Freeman)

Dennett, D. (1991) *Consciousness Explained* (Boston, Little Brown)

Dover, G. (1982) 'Molecular drive: a cohesive model of species evolution', *Nature* 299, 111-117

Ellman, J.C., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., and Plunkett, K. (1996) *Rethinking Innateness: a Developmental Perspective on Connectionism* (Cambridge, Ma, MIT Press)

Freeman, W. (1999) *How Brains Make up Their Minds* (London, Weidenfeld and Nicolson)

Goodwin, B. (1994) *How the Leopard Changed its Spots* (London, Weidenfeld and Nicolson)

Gould, S.J., (1989) *Wonderful Life: the Burgess Shale and the Nature of History* (Harmondsworth, Penguin)

Gould, S.J. (1998) 'Gulliver's Further Travels: the Necessity and Difficulty of a

Hierarchical Theory of Selection', *Philosophical Transactions of the Royal Society B*, 353, 308-314

Kauffman, S. (1995) *At Home in the Universe: the Search for Laws of Complexity* (London, Allen Lane The Penguin Press)

Maturana, H.R. and Varela, F.J. (1980) 'Autopoiesis and Cognition: the Realisation of the Living', *Boston Studies in the Philosophy of Science*, Vol 42, Dordrecht, Reidel

Maynard Smith, J. (1998) *Shaping Life: Genes, Embryos and Organisms* (London, Weidenfeld and Nicolson)

Midgley, M. (1998) 'One World, but a Big One', in Rose, S.P.R. (ed.) *Brains to Consciousness? Essays on the New Sciences of the Mind* (London, Allen Lane The Penguin Press) pp. 246-270

Nagel, T. (1998) 'Reductionism and Antireductionism' in Novartis Symposium: *The Limits of Reductionism in Biology* (Chichester, Wiley), pp. 3-14

Oyama, S. (1985) *The Ontogeny of Information* (Cambridge, Cambridge University Press)

Pinker, S. (1997) *How The Mind Works* (London, Allen Lane The Penguin Press)

Rose, H.A. (1994) *Love, Power and Knowledge* (Oxford, Polity Press)

Rose, H.A. and Rose, S.P.R. (eds.) (2000) *Coming to Life*, (London, Cape and New York, Crown)

Rose, S.P.R. (1995) 'The Rise of Neurogenetic Determinism', *Nature*, 373, 380-382

Rose, S.P.R. (1997) *Lifelines: Biology, Freedom, Determinism* (London, Allen Lane The Penguin Press)

Sober, E. and Wilson, D.S (1998) *Unto Others: the Evolution and Psychology of Unselfish Behavior* (Cambridge, Ma, Harvard University Press)

Webster, G. and Goodwin, B. (1996) *Form and Transformation: Generative and Relational Principles in Biology* (Cambridge, Cambridge University Press)

Wilson E.O. (1998) *Consilience: the Unity of Knowledge*, (London, Little Brown)

Wilson, E.O. (1975) *Sociobiology: the New Synthesis* (Cambridge, Harvard University Press)

Wynne-Edwards, V.C. (1962) *Animal Dispersion in Relation to Social Behaviour* (Edinburgh, Oliver and Boyd)

MIND AND BODY

The Properties of Living Organisms

PETRA STOERIG

The Mind-Body-Problem

The venerable mind body problem can be exemplified with questions like: How is it possible that my hand moves when I want it to? How is it possible that I feel pain when my fingers are burnt? Or, put in more general terms, how does the mental, like an act of will, pain, pleasure, sorrow, affect the body and via the body the environment, and how can the mental in its turn be affected by the body, and, again via the body, by the environment?

Why this relationship between the mind and the body should be problematic is not immediately obvious. After all, we all know that things work this way in ourselves, and obviously work this way in others as well, and are not a problem unless something goes wrong and for instance one cannot bring one's hand to move, or even bring oneself to want to make it move. The problem thus does not arise from our experience, but from reflections on the possibility of the experience; it is in this sense a metaphysical problem. Man asked himself how it is possible that mental and bodily entities affect each other, difficulties arising when ideas of what minds and bodies are and what was required for any causation or interaction between them rendered the obvious unintelligible.

The problem thus hinges much on the way the partners – mind and body – have been implicitly or explicitly defined. René Descartes was the one to finalize a development of continuous estrangement between the one and the other: He classified the mind as spiritual intellect ('res cogitans'), and as such as unextended in space, undividable, unquantifiable, unmathematizable, and immortal. In contrast, the body ('res extensa') was classified with all other forms of material things, which share properties such as extended in space, dividable, quantifiable, mathematizable, and perishable (Descartes, 1904). The straightforward opposition of all properties rendered an understanding of the intimate interaction of mind and matter impossible.

About 200 years after Descartes' death, Herbert Feigl published his essay on 'The Mental and the Physical' (1958), where he tackled the problem of the incommensurable properties of the interacting partners on the basis of their changed scientific descriptions. He listed a number of opposite properties – subjective: objective; qualitative: quantitative; purposive: mechanistic; holistic: atomistic; mnemic: non-mnemic; emergent: compositional; intentional: blind – and declared them to be untenable in every instance. For example, regarding the spatial/non-spatial distinction he wrote To put it very strongly, mental events as directly experienced and phenomenally described *are* spatial. Physical bodies geometrically characterized in their measurable positions, orientations, shapes, and sizes are not spatial (in the *visual*, or generally, *phenomenal*) sense at all. 'Space' in the physical sense is an abstract theoretical ordering system' (p. 408).

The arguments Feigl used to point out that the attributes of the mental and the physical were inadaequate and needed changing were highly controversial. In my view, he was right to argue that definitions of mind and body are subject to revisions, and should reflect the current state of the empirical sciences. It was also a good move to replace Descartes' *res cogitans* with the *mental*, dodging questions of immortality and substantiality by using a term that can equally well refer to a conglomerate of mental functions as to a substance. But it causes unnecessary problems to treat the *physical* on the other side of the problem, as both Descartes and Feigl did. To talk about the physical puts the body with all other physical entitites, when in fact the bodies in question are a separate and special class, are biological entities, bodies of living organisms which have properties not common to all matters physical. They are the only entities we know to have mental functions, a fact that is astonishingly often overlooked.

Living Organisms

Metabolism, Reproduction, and Mutation

Living organisms are a special part of the physical world. They are often characterized by three distinct functions, namely metabolism, reproduction, and mutation (e.g. Gierer, 1985). Even in very simple organisms, the different functions are excuted by specialized parts of the organism. Single-cell organisms such as paramecia have DNA, organelles, contractile vacuoles, have an ectoplasm that separates them from the environment, and fibrillae used for self-propellation (Scott, 1963; Wells, 1968). Such equipment as already present in single-cell organisms is increasingly distributed and elaborated in more complex organisms. In fish, birds, reptiles, mammals, cells of one kind aggregate to form muscle tissue, cells of another kind form the skin that now marks the boundary to the environment, cells form organs devoted to metabolic functions, to procreation, to self-recognition and defense, and cells form a steering committee that orchestrates the ensemble, a nervous system. Which functions the organs perform and how precisely they do it has been studied in the biosciences whose central concept is that of 'function'.

Philosophers, physicists, and biologists have pointed out that the existence of functions is contradictory to a concept of nature as a lawful deterministic physico-chemical mechanism, mechanic or quantum-mechanic causation and interaction, because it implies a goal, a telos, purposes, something that ought to be achieved. According to the evolutionary biologist Ernst Mayr, the teleological or teleonomic processes may be the most characteristic feature of the domain of living organisms (1988), and indeed a description of its every molecule will yield no complete understanding of a living organism as long as the 'What does it do that for?' question is not addressed.

To say that 'function' is what biology is about is to say that purposes are an indispensable part of life. Because living beings are open systems, in order to survive they need to maintain their energetic balance, their homeostasis. Because of this, the organism is always 'about something', is intentional in this sense of the term, because it cannot stay alive unless it manages to keep his homeostasis within physiological viable limits. A great many functions of organisms, or systems within organisms, are devoted to homeostasis. Metabolism, one of the three most commonly mentioned properties of life, serves homeostasis, and it requires drinking, feeding, breathing as behaviours of the organism, blood pumping, ovulation, bowel peristalsis as functions of its organs, and oxygenation, break-down of carbohydrates into glucose, and enzyme synthesis as functions of its biochemical components.

Metabolism is indispensable for the survival of the individual organism. Its necessity derives from the fact that living beings are open systems which in turn implies that they are 'needy'. In contrast, procreation, although important for the survival of the species, is of secondary importance to the individual for which it is not indispensable because one can certainly be alive and not procreate. Mutation, the third of the acceptedly major functions of life operates via one's genome on one's offspring. Inducing variation in the species, it promotes adaptation to changes in its environment (see Arber – same volume?). While playing a dominant role for the survival of the species, like procreation it appears less important for the individual organism than metabolism.

Self/Non-Self Distinction

As open systems, living organisms are in constant need of energy to replace the one.they have used. This neediness applies to every species, and is complemented by a principle of vulnerability. One is vulnerable if one is needy because if one cannot satisfy one's metabolic needs, one's fitness suffers to the point of death. One is vulnerable if one can survive only if the temperature is bearable, if one is sheltered against the elements and against other organisms that are similarly needy and may regard one as a source of food, or as competing for the same source.

In order to successfully deal with these facts of life, the organism has to distinguish itself from everything that is non-self, to distinguish what belongs to itself and what does not. Dennett (1991) formulated this by saying. "As soon as something gets into the business of self-preservation, boundaries become important, for if you are setting out to preserve yourself, you don't want to squander effort trying to preserve the whole world: you draw the line. You become, in a word, *selfish*" (p. 174). This is the first step, the basis of any episteme or recognition. As this is a distinction, you can know a lot more about one or the other, but you cannot have one without the other.

The processes by which self-recognition is mediated are complex and stem from several sources. Without attempting completeness, I'll name three examples. The first regards digestion. In order to survive and not to digest itself, the organism needs to distinguish food from its own digestive organs. The second example regards immune function. In order to recognize bacteria and viruses, the organism needs to tell them from its own cells, and in a second step, to determine whether they are harmful or helpful. The immune system, entrusted with this task, is one of the most complicated physiological systems we know. It can fail, not only by being unable to deal with an intruder, or by recognizing an intruder as such, but by attacking the organism's own cells. The consequence of such failure are auto-immune diseases which, while increasingly recognized, are difficult to heal. Both self-digestion and self-attack demonstrate the necessity of self-recognition.

The third process involved in self-recognition is a mixture of sentience and proprioception, which is very broadly speaking the ability to know one's own boundaries in one's position in space. Paramecia, when trying to paddle away from a harmful substance in their medium, require information regarding themselves in relation to the substance in order to know how and where to move. Complex organisms also require this information, and their/our children spend a long time in tactlie-kinesthic exploration, investigating what they can move, and whether things they touch are parts of themselves or not (Bruner, 1990; Stern, 1985).

Without self-recognition, an organism cannot prevent itself from digesting itself, and it cannot recognize that the damage that occurred in its skin requires repair, it will attack instead of defend itself, it does not know where it stands. In contrast to its genes (that Steven Rose rightly pointed out can not be selfish), the organism is necessarily *self-ish* and *selfish*: It is not viable if it cannot distinguish itself from non-self, and it is selfish because as an open system it is needy. It may also be selfish in the sense that it attempts to claim time and space beyond its own existence, by procreating and thus claiming the future for its descendants. Athough this is important in the context of the species and the discussions of human biomass and over-population raised at the meeting, it is not a necessity for each individual organism.

The self-recognition which entails a self/non-self distinction is a *sine qua non* for any living organism. Before turning to some of the finer points of both self – and non-self-directed recognition, I want to point out that the properties treated so far – needy, vulnerable, and self/non-self-distinguishing – presuppose an interest in one's own survival and well-being, and a viewpoint and thus subjectivity. If you are – and every organism is – needy and vulnerable to start with, you have to take an interest in your survival and well-being because you cannot survive and be well otherwise. Parental (or other) care can take you through to a certain point, and is common in many species (e.g. in bats (Wilkison, 1984), but only a full life-support system can keep you alive if you don't eat and drink and breathe. Where helpless conspecifics such as babies or severely ill people are concerned, survival is possible only if the interest in preservation is partially externalized, handed over to relatives or to other helpers.

Under normal circumstances, a living organism is interested in its own well-being, and the interest is defined by its own point of view. An apple are interesting because I am hungry and a wolf is interesting because I am vulnerable, and subjectivity is there as soon as there are individualm organisms who need to fend for themselves.

INFORMATION

As essential as the self/non-self distinction is for survival, it is only a first step. Living organisms need to make finer distinctions, the finer the more complex the needs and threats they are exposed to: It is very useful to know whether a change in homeostasis is due to lack of water or lack of oxygen if different interventions are needed to reestablish the balance. Similarly, regarding one's environment, it is helpful to know whether the non-self is edible or threatening, poisonous, neutral, or useful. Information of this kind is necessary for survival and already processed in paramecia who try to propel themselves away from damaging chemicals. The basic feature of information processing is present in a single-cell organism: to discriminate what is good for yourself, and what is not. This distinction already entails an evaluation on the part of a self from whose point of view an event is good or bad, is something to seek or something to avoid. From early on, information-processing is evaluative and requires an interest, first in survival and then in a good life (Whitehead's function of reason (1929)), and it requires a subject, a self-ish organism who is interested in its survival, in its living well.

Organisms continuously process information. Changes in blood sugar level, in blood oxygenation and viscosity, damage to vessels or the skin, are very few examples of the many processes that need to be monitored. The sympathetic and parasympathetic nervous systems transmit this information to the central nervous system, where nervous, endocrine, and immune functions are masterminded. Information about the environment similarly needs to be monitored, with the amount and detail depending on the ecological niche in which the organism lives, the sensory organs it has developed, the variety of activities it can perform, and its internal state which changes continuously. The interest the organism takes in the information depends on its present state, with food and drink and air becoming more and more important the greater the present need. Information processing is a function of interest and thus of need, and although it can and in complex organisms does transcend its narrow physiological basis and turn into information sought for pleasure's or it's own sake, the having-of-interests is at the basis of information processing. The potential weath of data in one's environment becomes information when it is processed by an organism who does so because it is interested in self-preservation.

Consciousness

It is *logically* possible that the biological functions that I have listed are all unconsciously performed. Indeed, in organisms such as ourselves, we know that the majority of biological functions are performed without our becoming conscious of them: Introspectively, we don't know the first thing about protein synthesis, digestive enzymes, blood fat values, nervous transmission. Our conscious access to our physiological states is extremely limited and global. We consciously know whether we are hungry, thirsty, tired, in danger of suffocating, dizzy, hot, cold, or in pain, whether we are feeling well and active. We don't have any direct knowledge or insight into the processes that keep us alive, into the way the air we breathe is used, or the temperature kept at the right level. This kind of information is accessible only through empirical study.

Information about the non-self, the environment and its inhabitants, is gleaned through the senses, its nature and amount depending on the individual's sensorium. In man, sensory information from eyes, ears, body, nose and tongue may be consciously represented and thus be directly accessible. Still, information about the external world, about light and sound and smell is also processed implicitly, without attaining conscious status. This can be demonstrated in healthy subjects who convincingly claim to be entirely unaware of e.g. a visually presented word hidden in a rapid sequence of non-words. Nevertheless, the brain potential evoked when the 'unseen' word is then presented again differs significantly from that elicited by a new word, showing that the subject implicitly recognizes the repeated word (see Fig. 1). Social psychology provides other examples of implicit processing, for instance when the stressfulness of a situation is registered physiologically, leading to glucocorticoid discharge, changes in heart rate, blood pressure, while the person claims not to have experienced any stress.

Implicit information processing can also be demonstrated in neurological patients with lesions in the central part of a sensory system. If the lesion is in the intermediary net, sufficiently remote from the

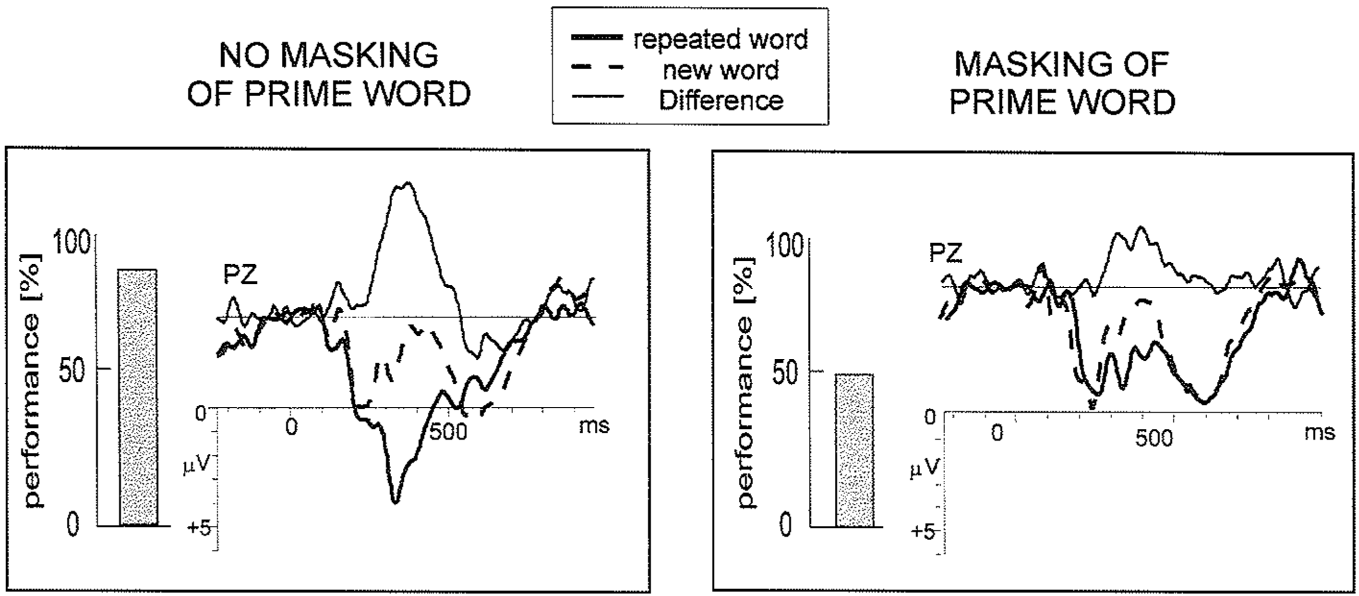
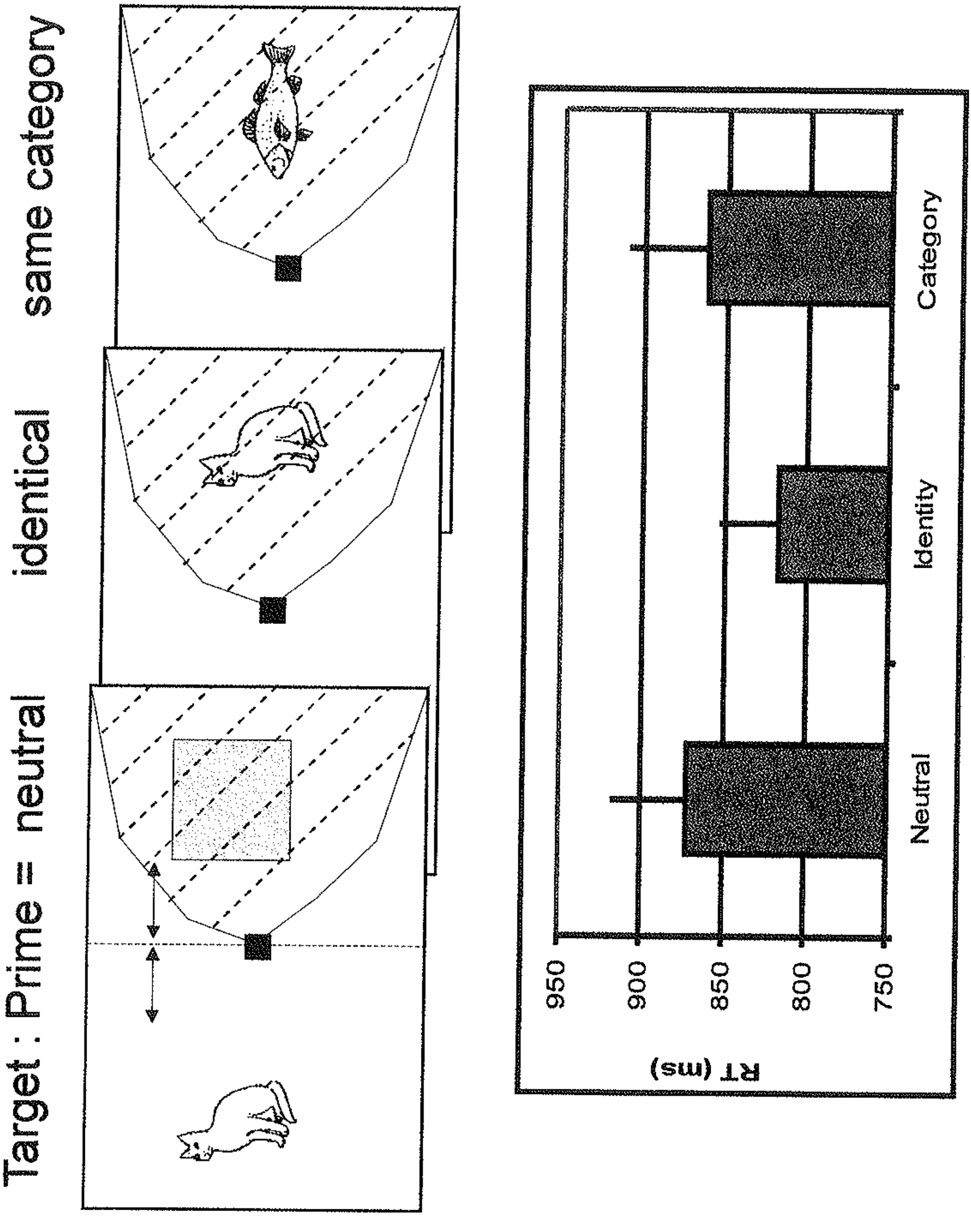


Fig. 1. Event-related potentials, recorded from the scalp of a normal observer, show that explicit recognition of a previously presented word is accompanied by a pronounced positivity (A). When the previously presented word was masked by presenting it in rapid succession with non-targets, and explicit recognition is at chance level (B), the potential still differs from that elicited by presenting a new word.

sensory organ to allow information to be processed but disallowing its conscious representation, the sensory information can be still be used for navigation, prehension, detection, and localization. In the visual domain, patients with cortical blindness following lesions in the primary visual cortex are not directly aware of the fact that they can use 'blind', unconscious visual information, but they may nevertheless respond to the same information, directing their eyes or hands toward a stimulus, or discriminating it from another one ('Blindsight' (Weiskrantz et al., 1974; Stoerig and Cowey, 1997)). A striking example of this implicit visual processing is the decrease in the response time blindsight patients take to categorize visual objects presented in their normal visual field as a function of similar or dissimilar objects being presented, unbeknown to them, in their cortically blind visual field (Fig. 2). This is noteworthy because in order to selectively influence categorization, the unseen, only implicitly processed stimuli need to be semantically encoded. Examples of implicit processes have also been described in other domains, and include unfeeling touch and deaf hearing as well as unconscious memories that nevertheless shape the behaviour of amnesic patients (see Schacter et al. (1988) for more examples from neuropsychological syndromes). A classic example stems from Claparéde (1911) who described an amnesic woman who after 5 years in an asylum could not recognize the doctors or the nurse, or recollect at will her recent memories. However, when Claparède pricked her hand hard with a hidden pin, although she quickly forgot the pain, she nevertheless spontaneously withdrew her hand when, even days later, he again approached his hand to hers. When asked to explain her behaviour, 'she answered with astonishment: – why, is it not perhaps my right to withdraw my hand? – and if I insisted she would say: – is there perhaps a pin hidden in your hand? – and to my question: – who has made you think that I want to prick you? – she would answer with a refrain: – it's an idea that crossed my mind – or sometimes she would try to justify herself saying: – sometimes there are pins hidden in hands' (pp. 84-85).

In addition to unconscious or implicit information processing, we have conscious perceptions and memories and intentions, and it is the conscious ones that come to the conscious mind because the unconscious ones need to be uncovered, revealed by observation and experimentation; they are not directly accessible to the subject. The conscious processes are important in the context of the mind body problem, because 'conscious' is an attribute of emotions, perceptions, memories, thoughts, and thus of mental experiences and functions. It may therefore appear as if at this


Target : Prime = neutral
identical
same category
RT (ms)
950
900
850
800
750
Neutral
Identity
Category

point, when living organisms have been described as open systems who are needy, self/non-self-distinguishing, subjective, information-processing, and evaluative, and thus have attributes which can be applied to mental functions as well as to the organism but cannot be used for the material physical world as such, a property turns up which is exclusively mental and not applicable to the organism. But this is not so, because conscious is also an attribute of living organisms. Indeed, in order to have any conscious representations of information, the organism needs to be conscious.

Conscious and Unconscious States

Conscious processes occur exclusively in conscious organisms. Unconsciousness, as the counterpart of consciousness, ranges from deep coma to persistent vegetative state (PVS), from the rare transient loss when one faints or is anaesthetized to the regular transient loss in dreamless sleep. Consciousness is also graded and ranges from drowsiness to alert. In organisms that have a nervous system, the state of consciousness is mediated by a part of this system. What parts are involved in the mediation has been studied by observing the lesions that abolish consciousness (Plum and Posner, 1980), the processes that regulate sleep (Hobson et al., 1998), and the effects of anaesthesia (Flohr, 1995). Sleep and arousal involve functional interactions of rhomb – and mesencephalic structures including pontine nuclei and the locus coeruleus. These brainstem nuclei contribute to an 'activating system' that via the thalamus (a major complex of nuclei of the diencephalon) influences the entire cerebral cortex (Moruzzi and Magoun, 1949; Kahn et al., 1997). The pathology of coma with the lack of awakability that distinguishes it from sleep, and of PVS with its preserved arousal mechanisms but (to all appearance) loss of consciousness, is commonly diffuse, the lesions affecting cortical, thalamic, and brainstem structures. The role the thalamus plays in this concerted action has been highlighted by the case of Karen Ann Quinlan who spent 10 years in a PVS. Her postmortem showed 'disproportionately severe damage in the thalamus as compared with the cerebral cortex', suggesting 'that the thalamus is critical for cognition and awareness and may be less essential for arousal' (Kinney et al., 1994, p. 1469).

A central role for the thalamus in mediating the state or degree of consciousness has previously been hypothesized by Penfield (1969) who recorded from the awake human brain during neurosurgical interventions. In particular the intralaminar nuclei of the thalamus have been his focus, and are also that of Bogen who is currently a prominent defender of their central role in the regulation of conscious states (1995). In a slightly modified version this hypothesis is held by E. G. Jones (1998). His anatomical work has demonstrated that the specific thalamic nuclei (which are part of a well-defined functional (e.g. sensory) system) have more neurons projecting to the middle layers of cortex (layers III and IV), while the unspecific nuclei, such as the intralaminar ones, project predominantly to the upper layers of the cortex (layers I and II). In contrast to the former, the latter do so in a widespread fashion that does not respect the particular domains of cortex devoted to individual sensory or motor systems. Instead of distinguishing the thalamic nuclei per se, Jones thus distinguishes these two classes of cortico-projecting neurons with their differential distribution in specific and non-specific thalamic nuclei.

Of course, the distributed non-specific centrencephalic system that has been the focus of research into the neurobiological basis of conscious states is not only present in humans but also in other mammals; in fact, its properties are extensively studied in cat and monkey. While its presence, along with the spontaneous behaviour of the animal, indicates that these animals have conscious and unconscious states similar to ours, it is impossible to conclude that its absence in species who do not have this (or any) type of nervous system indicates an absence of conscious states. The basic functions of life that were already discussed are common to all living organisms, and only become more elaborate with increasing organic complexity. Self/non-self distinction involves the nervous system, the immune and the digestive system in mammals, but it is also achieved in organisms who have no such specialization. Similarly, information is processed both in animals with nervous systems devoted to that task and in organisms without a nervous system. Although the amount and the kind of information will differ between the different organisms, and qualitative discontinuities ('Qualitätssprünge') are likely, it is nevertheless possible that conscious states are present even in very simple organisms.

In man and other animals of whose consciousness we can be certain not only because of similar neuronal and neurochemical organization, because of their sleep-wake cycles, their capacity to lose consciousness, and their complex non-reflexive behaviour, we can observe that in unconscious states the organism is incapable to maintain itself. A patient in a coma or in a PVS, a cat under anaesthesia, a Snow White in perpetual sleep may at best be able to breathe and show some reflexive motor activity, but they are unable to get themselves anything to drink or eat, and will certainly die if oxygen runs out, and their life is not supported. In these organisms which we find capable of conscious and unconscious states, consciousness thus appears to be a prerequisite for spontaneous goal-directed activity. As such it may well be *biologically* necessary for survival in all organisms who depend on self-generated activity to maintain homeostasis.

Consciousness is a state of an organism. We do not know whether there are organisms who do not have this state. Note that this is different from saying that we do not know whether other organisms are conscious. The latter question – 'Might they even be conscious beings?' (Pennesi, 1999) – put again and again and answered in the affirmative by scientists who do, and in the negative by scientists who do not own dogs (Schrödinger, 1969), has factually long been answered affirmatively. Scientists when studying the neuronal basis of conscious states in non-human animals assume that they have these states, and have thus revealed a vast amount of data showing similar neuronal and neurochemical organization in the sleep and arousal systems of different species. And more importantly, the consciousness of the animal is recognized whenever he or she is anaesthetized before undergoing an invasive operation, a procedure demanded by law in many countries.

But 'conscious' is also an attribute of certain mental operations and representations if they are operations and representations of a conscious organism. Whether or not representations are conscious may be difficult to find out, espcially in view of the variety of implicit processing mentioned above.

Conscious Representations: Who Has Them?

What organisms are conscious *of* must depend on what kind of information they can process. This in turn depends on the organism's sensorium: you don't have visual experiences if you don't have eyes, and you cannot imagine the 'feel' of the information coming from an echolocating or sideline organ if you don't have that organ. It will probably also depend on the development of the intermediary net that links input and output in an increasingly indirect way the higher (the more differentiated) the animal, and that takes up a larger and larger proportion of the available neurons, and assumedly is responsible for the amount of cognition the organism is capable of. But these are necessary, not sufficient conditions for conscious representations.

What would be incontrovertible proof of an organism's conscious perception, thinking, planning, acting? The suggestions that have been made include language, non-reflexive and non-instinctive behaviour, awareness of self and others, and theory of mind. Ethologists and experimental psychologists have provided evidence for all of these. Parrotts learn to speak and appropriately use English (Pepperberg, 1991); Bonobos communicate with each other and experimenters purposefully using a keyboard (Savage-Rumbaugh and Lewin, 1994); Machiavellian intelligence, tactile deception (Bryne and Whiten, 1988; Ristau, 1996) have been observed in primates and birds; tool-use has been described in primates (McGrew, 1992); rats do not eat poisoned food when they are able to smell it on an affected partner (Galef jr., 1986); apes learn to use mirrors (Gallup, 1970); socially living cats check on each other and their human when these emit noises of distress (own observation); bats feed other bats if they have enough and the other are hungry (Wilkison, 1984). All of these examples have been observed in conscious (as opposed to unconscious) animals, but sceptics say thay can also be interpreted not as evidence of conscious cognition but of sophisticated implicit processing.

A pragmatic (but not conclusive) approach is to ask whether humans can perform the suggested activities without having conscious representations. We sometimes talk without knowing what we say; we sometimes communicate without knowing what we communicate, and what we communicate is sometimes different from what we intend. We exhibit non-reflexive and non-instinctive behaviour without knowing how; although procedural learning can require a lot of conscious attention, procedural knowledge is not consciously accessed (Halsband and Freund, 1993); it is learning and knowing, not knowing how that requires consciousness (Schrödinger, 1969). Neurological patients as well as monkeys with blindsight respond non-reflexively to unseen visual information (Stoerig and Cowey, 1997), and amnesic patients can learn to adjust their behaviour through experiences they cannot remember (Claparède, 1911; Damasio, 1994). But awareness of oneself and others as well as evidence of a theory of mind from pretending, lying, hiding of desirables, helping, are things and acts we usually are conscious of.

It thus remains likely but unproven that at least the mammals and birds who engage in such behaviours are conscious of their own intentions and capable of presuming those of others. But all of the behaviours in question are very complex, suggested as proof of conscious representations in he hope that they can provide incontrovertible affirmation precisely because it is difficult to imagine them performed in an implicit mode. However, it may be unnecessary to aim so high because we know from our own experience that conscious representations occur in much simpler situations as well. We consciously enjoy food or being groomed, we consciously suffer when hurt or abandoned, we consciously perceive long before we are able to engage in any such complex social behaviour. 'Consciousness of' begins with qualia – brightness and darkness, pleasure and pain, colour and pitch and texture, tactile-kinesthetic experience. It ontogentically begins this way; for all we know, babies consciously feel pleasure and discomfort, see colours, hear sounds long before they are able to identify the object or person let alone engange in complex planning and interpretation. Similarly, neurological patients may lose the ability to consciously recognize other people or objects while retaining phenomenal (= conscious) visual experiences – the qualia (red, blue, dark, bright). The agnosias are precisely this – a loss of conscious recognition with preserved phenomenal vision or hearing. But once phenomenal vision or hearing is lost, the ability to consciously recognize visual or auditory objects is lost as well. As all reports on neurological disorders concur with this order of loss – the higher cognitive abilities can be lost without the qualia but not the other way round, I have suggested that qualia are the first level of conscious representations (Stoerig, 1996). As conscious states without conscious content are rare to non-existent (e.g. Schrödinger, 1969), I am convinced that other animals have qualia and know what it is like to be themselves (Nagel, 1974) even if they do not exhibit the complex behaviours that have been observed. Qualia are ontogentically prior to the complex forms of cognition used to test consciousness in animals, and they will be phylogentically prior as well.

The neuronal correlate of conscious representations

How conscious representations – what one is conscious of – are neuronally implemented is an exciting empirical question, just like that regarding the processes allowing the self/non-self distinction. The answer is not yet known, and indeed the proper level of investigation – sub-cellular, neuronal, systems, brain – is still debated (Arendes, 1996). How information comes to be consciously represented, how neuronal processes that code for chromaticity, luminance, orientation, depth can produce the red rose I see before me, is extensively investigated. In view of the endlessly varied conscious experiences each individual is capable of, it appears that very many neuronal networks should in principle be able to produce different conscious representations, but what the features are that distinguish networks that can from those that cannot produce them is still open. Similarly, the question of how it is determined which individual network (or assembly) gains conscious access at any particular point in time – a question that has been addressed with approaches using ambivalent stimulation (e.g. binocular rivalry (Logothetis and Schall, 1989)) – is still open. One possibility that could link the conscious content with the organism's state of consciousness on which it depends (unfortunately consciousness as a state of an organism and consciousness of are commonly studied independently) are the oscillatory neuronal responses in the high frequency (γ-band) range: Temporal synchronization of neuronal responses in this range is regarded as servicing the binding of visual features (brightness, colour, motion) in a normally complex visual environment (e.g. Singer and Gray, 1995; Rodriguez et al., 1999). It has recently been found that increased synchronicity and regularity of such oscillations also differentiates between the perceived and non-perceived stimulus in binocular rivalry (Fries et al., 1997). The state of consciousness (e.g. alertness) has similarly been suggested to make use of coherent rapid oscillatory activity: When awake or REM-sleeping, subjects show widespread *-band activity which is reduced during non-REM-sleep (Kahn et al., 1997; Llínas and Ribary, 1993; 1998) and anaesthesia (Munk et al., 1996).

A link between the content and the state of consciousness could also be formed through the dominant projections of the nonspecific thalamic nuclei (which are part of the activating system assumedly involved in mediating the state of consciousness) to the uppermost cortical layers (Jones, 1998). Results on monkeys whose conscious decisions in difficult tactile discriminations were found to be reflected in early negative potentials attributed to the upper cortical layers and attenuated during slow-wave sleep (Cauller and Kulics, 1981; Cauller, 1995). This points to a special role for the upper cortical layers where the back-projecting axons travel that transmit information from neurons in higher cortical areas back to the earlier stages. Functional reverberations that integrate impulses from the non-specific system may thus be one essential feature of neuronal networks whose informational content is consciously represented.

The neuronal correlate of conscious states (consciousness) and conscious representations (consciousness of) is very much investigated, and promising hypotheses become testable as methods and paradigms develop. They will help our understanding of the nervous system, and open routes to new treatments of its disorders, but by themselves they will not yield an understanding of whether, why and how conscious representations are more effective than unconscious ones in generating adaptive behaviour, adaptive in that the organisms adapts itself to its environment and adapts the environment to its requirements. To this end we will need to study animate behaving organisms.

Shared properties

The properties of living organisms are properties that do not belong to the physical world *in toto* but to its biological inhabitants. They derive from the fact that an organism is an open system which needs to maintain homeostasis in order to survive. Needy, self/non-self distinguishing, subjective, interested, intentional, information-processing, evaluative, and conscious are all attributes of living organisms. They are also attributes of the mental: Perception distinguishes between self and non-self; mentation is always subjective and from a point of view; information is sought, processed, evaluated, and often consciously represented. The mind is not a unitary entity, but an ensemble of processes and functions that change constantly over time and whose unity is dependent on neuronal (e.g. Stoerig and Brandt, 1993) and bodily (Damasio, 1994) interactions.

Conclusion

The biological properties of living beings listed above differ from the attributes of the physical that Descartes listed. Organisms are still extended and perishable, and certain biological functions can be described quantitatively in the form of laws. But in addition to the properties they share with other physical entities, they have numerous attributes pertaining only to living beings. These derive from the open system – function – homeostasis core, and instead of being diametrically opposite to the attributes of the mental they apply to it in many instances. Instead of forcing us to stay 'stuck with the mind-body problem as Descrates created it' (Burnyeat, 1992), they allow the mental to be understood as a composite set of functions that form part of the intricate and wondrous multitude of biological functions.

SUMMARY:

The following hypotheses are put forward in this article. 1. The living organism has many attributes which similarly apply to the mental: It is composite, needy, vulnerable, intentional, distinguishes self and non-self, processes and evaluates information, has a point of view. 2. The organism needs to be in a conscious state in order to have conscious mental representations. 3. Consciousness is not a property of the brain or a sub-population of its neurons but a property both of the organism and of its mental representations. 4. It may be biologically necessary for organisms who need to engange in self-generated, goal-directed motor activity to maintain their homeostasis. 5. Qualia provide the first level of conscious processes. The higher order thoughts and reflections that increasingly characterize conscious cognition in higher animals and humans build and depend upon them.

ACKNOWLEDGEMENTS:

My thanks for helpful comments on the article go to H.-J. Freund and L. Arendes. M. Niedeggen kindly prepared the figures.

REFERENCES

Arendes, L., 1996, "Ansätze zur physikalischen Untersuchung des Leib-Seele-Problems", *Philosophia Naturalis* 33, 55-81

Bogen, J. E., 1995, "On the neurophysiology of consciousness: I. An overview", *Consciousness and Cognition* 4, 52-62

Bruner, J., 1990, *Acts of Meaning* (Cambridge MA: Harvard University Press)

Bryne, R. W., Whiten, A., 1988, *Machiavellian Intelligence* (Oxford: Clarendon Press)

Burnyeat, M., 1992, "Is an Aristotelian Philosophy of Mind still Credible?" *Essays on Aristotle's 'De Anima'*, eds. M. C. Nussbaum and A. Oksenberg Rorty (Oxford: Clarendon Press) 15-26

Cauller, L., 1995, "Layer 1 of Primary Sensory Neocortex: Where Top-Down Meets Bottom-Up", *Behavioral Brain Research* 71, 163-170

Cauller, L., Kulics, A. T., 1991 "The Neuronal Basis of the Behaviorally Relevant N1 Component of the Somatosensory-Evoked Potential in SI Cortex of Awake Monkeys: Evidence that Backward Cortical Projections Signal Conscious Touch Sensation" *Experimental Brain Research* 84, 607-619

Claparède, E., 1911, "Recognition et moité" *Archives de Psychologie* 11, 79-90

Damasio, A.R., 1994, *Descartes Error. Emotion, Reason, and the Human Brain* (New York: G. P. Putnam's Son)

Descartes, R., 1904, *Les Meditations Metaphysiques*. Adam Ch, Tannery P (eds): Oeuvres de Descartes (Paris: Paul Cerf) Vol. IX

Feigl, H., 1958, "The 'Mental' and the 'Physical'" *Concepts, Theories, and the Mind-Body Problem*, Minnesota Studies in the Philosophy of Science II, eds. H. Feigl, G. Maxwell, and M. Scriven (New York: Applteton-Century-Crofts) 370-497

Flohr, H., 1995, "An Information Processing Theory of Anaesthesia", *Neuropsychologia* 33, 1169-1180

Fries, P., Roelfsema, P. R., Engel, A. K., König, P., Singer, W., 1997, "Synchronization of Oscillatory Responses in Visual Cortex Correlates with Perception in Interocular Rivalry", *Proceedings of the National Academy of Science, USA*, 94, 12699-12704

Galef jr., B. G., 1986, "Social Identification of Toxic Diets by Norway Rats (Rattus Norvegicus)", *Journal of Comparative and Physiological Psychology* 100, 331-334

Gallup, G., 1970, "Chimpanzees: Self-Recognition" *Science* 167, 86-87

Gierer, A., 1985 *Die Physik, das Leben und die Seele* (Munich, Zurich: Pieper)

Halsband, U., Freund. H,-J,. 1993 "Motor Learning", *Current Opinion in Neurobiology* 3, 940-949

Hobson, J. A., Stickgold, R., Pace-Schott, E. F., 1998 "The Neuropsychology of REM Sleep Dreaming", *NeuroReport* 9, R1-R14

Jones, E. G., 1998 "A New View of Specific and Nonspecific Thalamocortical Connections", in: *Consciousness. at the Frontiers of Neuroscience* eds. H. H. Jasper, L. Descarries, V. F. Castellucci and S. Rossignol, Advances in Neurology, Vol. 77 (Lippincott – Raven: Philadephia, New York) 49-71

Kahn, D., Pace-Schott, E. F., Hobson, J. A., 1997 "Consciousness in Waking and Dreaming: The Roles of Neuronal Oscillation and Neuromodulation in Determining Similarities and Differences", *Neuroscience* 78, 13-38

Kinney, H. C., Korein, J., Panigrahy, A., Dikkes, P., Goode, R., 1994 "Neuropathological Findings in the Brain of Karen Ann Quinlan", *New England Journal of Medicine* 330, 1469-1475

Llínas, R., Ribary, U., 1993 "Coherent 40Hz-Oscillation Characterizes Dream-State in Humans", *Proceedings of the National Academy of Science, USA* 90, 2078-2081

Llínas, R., Ribary, U., 1998 "Temporal Conjunction in Thalamocortical Transactions", *Consciousness. at the Frontiers of Neuroscience*, eds. H. H. Jasper, L. Descarries, V.F. Castellucci and S. Rossignol, Advances in Neurology, Vol. 77 (Lippincott – Raven: Philadephia, New York) 95-103

Logothetis, N.K., Schall, J.D., 1989 "Neuronal Correlates of Subjective Visual Perception" *Science* 245, 761-763

Mayr, E., 1988 *Toward a New Philosophy of Biology* (Cambridge: Cambridge University Press)

McGrew, W. C., 1992 *Chimpanzee Material Culture* (Cambridge: Cambridge University Press)

Moruzzi, G., Magoun, H. W., 1949 "Brain Stem Reticular Formation and Activation of the EEG", *Electroencephalography and Clinical Neurophysiology* 1, 455-473

Munk, M. H. J., Roelfsema, P. R., König, P., Engel, A. K., Singer, W., 1996 "Role of

Reticular Activation in the Modulation of Intracortical Synchronization", *Science* 272, 271-274

Nagel, T., 1974 "What is it Like to be a Bat?", *Philosophical Review* 4, 435-450

Penfield, W. G., 1969 "Epilepsy, Neurophysiology and Some Brain Mechanisms Related to Consciousness", *Basic Mechanisms of the Epilepsies* eds. H. H. Jasper, A. Ward Jr., A. Pope (Boston: Little, Brown) 791-814

Pennisi, E., 1999 "Are our Primate Cousins 'Conscious'?" *Science* 284, 2073-2076

Pepperberg, I. M., 1991 "A Communicative Approach to Animal Cognition: a Study of Conceptual Abilities of an African Gray Parrot", *Cognitive Ethology – The Minds of Other Animals*. ed. C. A. Ristau (Hillsdale, N. J.: Erlbaum)

Plum, F., Posner, J. B., 1980 *The Diagnosis of Stupor and Coma*, (Philadelphia: F. A. Davies Company)

Ristau, C. A., 1996 "Aspects of the Cognitive Ethology of an Injury – Feigning Bird, the Piping Plover", *Readings in Animal Cognition* eds. M. Bekoff and D. Jamieson (Cambridge MA: Bradford Books/MIT-Press) 79-89

Rodriguez, E., George, N., Lachaux, J.-L., Martinerie, J., Renault, B., Varela, F. J., 1999 "Perception's Shadow: Long-Distance Synchronization of Human Brain Activity", *Nature* 397, 430-433

Savage-Rumbaugh, S., Lewin, R., 1994 *Kanzi. The Ape at the Brink of the Human Mind* (New York: John Wiley & Sons)

Schacter, D. L., McAndrews, M. P., Moscovitch, M., 1988 "Access to Consciousness: Dissociations between Implicit and Explicit Knowledge in Neuropsychological Syndromes, *Thought without Language* ed. L. Weiskrantz (Oxford: Clarendon Press) 242-278

Schrödinger, E., 1969 *What is Life? & Mind and Matter* (Cambridge: Cambridge University Press)

Scott, J. P., 1963 *Animal Behavior* (New York: Doubleday Anchor/American Museum of Natral History)

Singer, W., Gray, C. M., 1995 "Visual Feature Integration and the Temporal Correlation Hypothesis", *Annual Review of Neuroscience* 18, 555-586

Stern, D. N., 1985 *The Interpersonal World of the Infant: A View from Psychoanalysis and Developmental Psychology*. (New York: Basic Books)

Stoerig, P., 1996, "Varieties of Vision: from Blind Processing to Conscious Recognition", *Trends in Neuroscience* 19, 401-406

Stoerig, P., Brandt, S., 1993 "The visual system and levels of perception. An essay on neuromental organization", *Theoretical Medicine 14*, 117-135

Stoerig, P., Cowey, A., 1997 "Blindsight in Man and Monkey", *Brain* 120, 535-559

Weiskrantz, L., Warrington, E. K., Sanders, M. D., Marshall, J., 1974 "Visual Capacity In the Hemianopic Field Following a Restricted Cortical Ablation", *Brain* 97, 709-728

Whitehead, A. N., 1929 *The Function of Reason* (Princeton: Princeton University Press)

Wilkison, G. S., 1984 "Reciprocal Food-Sharing in the Vampire Bat", *Nature* 308, 181-184

MATTER AND CONSCIOUSNESS: ON THE CAUSAL RELEVANCE AND THE IDENTIFICATION OF KINDS AMONG CONSCIOUS STATES

MARTIN CARRIER

1. *The Biological Mind: Stoerig's Argument*

In her paper on the mind-body relationship Professor Stoerig pursues an anti-functionalist path. Underlying her argument is the claim that conscious mental activity is essentially connected to certain types of neuronal processes. Regarding the mind, matter indeed matters. The mind is an essentially biological phenomenon. It's a feature displayed by certain arrays of living cells. A functionalist approach to the mind considers particular patterns of interaction as the crucial feature of mentality; regardless of which kind of organized matter actually realizes these patterns. Stoerig, by contrast, shifts neurophysiology to center stage. Mental processes are essentially implemented by neuronal processes. Within this framework, the salient question is: which neuronal processes correspond to mental events.

Stoerig places heavy emphasis on conscious states. One of the issues specifically addressed by her concerns the question of which neuronal processes correspond to such conscious mental states. In her understanding, conscious states are distinguished by two features, content and subjective accessibility. Conscious states are supposed to possess content; they represent something. Humans are aware of events or situations. Moreover, conscious states are liable to introspective experience. They are accessible to a person's focus of attention, and they are subjective and private for this reason. Fourth, in keeping with her emphasis on neurophysiological processes, Stoerig assumes that the critical features of consciousness should appear wherever the relevant neuronal structures are realized. This approach implies that, in contrast to the Cartesian tradition, animals are considered conscious creatures.

On the whole, then, Stoerig underlines the significance of conscious states for explaining behavior and she stresses the connection between such states and neurophysiological processes. I am prepared to grant that both claims are essentially correct. On the other hand, they are subject to certain restrictions; and it is part of my duty as a commentator to bring these restrictions into focus. First, while it is certainly true that conscious states are chiefly relevant for human behavior, I would like to enlarge the framework and to integrate unconscious processes more intimately in the picture of the mind. In particular, such processes play a significant role in producing behavior. Second, given a tight correlation between mental and neuronal token states, it is by no means a matter of course that the explanatory burden of the former can also be borne by the latter. Assume that human behavior is accounted for by recourse to conscious states, and assume further that instances of these states are strictly correlated to certain neurophysiological patterns, it still does not follow that these patterns can replace the explanatory role of conscious states. This would require a match between the relations of similarity among mental and neuronal states.

2. *The Possible Irrelevance of Conscious States*

At first sight, it appears quite obvious that conscious states are the chief causal factors in producing behavior. As Stoerig rightly stresses, my hand moves when I want it to. Bodily motions are produced at will, and their mental causes are amenable to introspection. But she herself goes on to explain that things aren't always that easy. She mentions blindsight or unconscious vision which enables cortically blind persons to respond appropriately to visual stimuli without any conscious optical perception. Blindsight and analogous phenomena are generically called "implicit knowledge"; their import for the present context is that they circumscribe a class of voluntary actions that are not produced by introspectively accessible mental states. The relevant persons receive visual information and act accordingly (e.g., they avoid obstacles) without realizing that they are perceiving anything. This means that these persons are not aware of the mental states that are actually influential in the production of their behavior. If asked for their reasons for pursuing certain pathways, these persons gave answers to the effect that they were merely guessing. This shows that the mental states, introspectively perceived as being causally responsible for their own behavior, were actually irrelevant.

Stoerig rightly points out that the behavior produced under these admittedly pathological conditions is severely restricted. Visually guided navigation is possible but recollection is not. So I take her as claiming that if the behavioral spectrum is broadened appropriately, cases of unconscious causation considerably lose in importance. And it seems to be true, at first sight at least, that integrated and flexible behavior of humans can only be produced by conscious states. However, this picture flies in the face of four decades of empirical cognitive psychology. Within this field, many theories have been formulated which have significantly contributed to accounting for human behavior. To give just one example, it is assumed within the theory of cognitive dissonance that humans are endowed with a system of persistent motives which is influenced by a general tendency toward harmony. Disparate motives strive toward an accordance with one another. If discordant motivations are created by external interference, a drive to restore harmony occurs. Cognitive dissonance of this sort is generated, for instance, when a person acts contrary to her beliefs. The theory predicts that the beliefs or the behavior is adjusted such that harmony is regained. The tendency to alleviate dissonance is dependent on one more factor, namely, on the availability of justification. If good external reasons can be given for behavior that contradict one's own beliefs, the tendency to change the beliefs so as to suit the behavior is diminished. This central tenet of the theory was confirmed experimentally by the successful prediction of the phenomenon now called "forced compliance." Consider the following experiment. Test subjects were asked to defend a position they did not actually hold. Thus, a dissonance was created and the adaptation of the behavior to the belief was made impossible by the constraints of the situation. The only way to reduce the dissonance was to adjust the belief to the behavior. Afterward the test subjects were rewarded for their efforts with money in varying amounts, and the sum received was the only excuse people had for supporting views opposed to their own beliefs. Clearly, the larger the amount the better the excuse. Consequently, test subjects getting a more generous reward felt less urged to adjust their views to the behavior and remained more faithful to their original opinion after the experiment. A stronger reinforcement goes along with a less marked response (Carrier and Mittelstrass 1989, 136; Carrier 1998).

The theory of cognitive dissonance successfully accounts for a wide variety of human behavior. One thus plausibly assumes that it gets some sort of grip on the mental factors that are causally relevant in the production of behavior. However, none of the mechanisms attributed by the theory are reported by the corresponding persons on request. They relate a lot about their reasons, considerations and deliberations, but nothing about what was really going on in their heads – given the correctness of the theory. Generally speaking, no part of the complex machinery of weighting, comparing, compensating, regaining equilibrium and the like that is constitutive of a typical psychological theory finds its way into the verbal reports of the subjects. And yet this machinery appears to be efficacious in bringing about behavior.

I take this as supporting the conclusion that not alone in physiologically pathological cases but also for the common everyday behavior of normal people the true mental causes of actions are hard to detect introspectively. What we suppose to have identified consciously as the mental causes of our own behavior need not coincide with the actually efficacious factors. Introspection might be deceptive. Accordingly, given the adequacy of this general approach to explaining human actions, part of the mental causes of everyday behavior is not amenable to subjective experience. And this behavior can in no way be regarded as ephemeral and negligible. The threat posed by cognitive psychology to the causal relevance of conscious states is thus far more serious than the challenge by implicit knowledge (Carrier 1997, 199-201).

Of course, Stoerig is well aware of the existence and possible relevance of unconscious processes. She explicitly mentions neuronal subsystems whose functions are in principle inaccessible to subjective awareness (p. 8). So I assume there is agreement among us as to the significance of unconscious processes for the production of behavior. My point is that this insight should be taken into consideration more thoroughly. As I tried to make plausible, psychological theories tend to account for overt and seemingly conscious behavior by recourse to covert mental events. A subset of the efficacious mental processes involved in the production of behavior may be inaccessible to conscious inspection. This picture, as suggested by psychological theorizing, is also supported by neurobiological views (Gazzaniga and LeDoux 1978). According to these views, consciousness, like the screen of a word processing program, provides a heavily processed and multiply enhanced perspective which hides the causally influential processes from our view. The latter act in the background, veiled yet highly relevant.

Provided that this scenario roughly captures the operation of the mental machinery, Stoerig's correlational approach to what makes a hand move might fail to identify the real neuronal causes. This approach focuses on the neuronal correlates of conscious states. But if, as suggested, the mental causes of behavior are not always reflected consciously, their neuronal correlates might be as causally inert as their mental counterparts. My point is that it is not sufficient for clarifying the mental production of action to establish empirical correlations between subjective, experienced states, and kinds of behavior. The causally relevant mental states are also in need of identification. For this latter task, consciousness is not enough; psychological theorizing is requisite as well. We are faced with a two-fold challenge, namely, to discover the causally efficacious states on the neuronal and on the psychological level. None of these tasks is easy, and none of them can be considered settled.

3. *Natural Kinds in Psychology and Neurophysiology*

If it is granted that the neuronal events identified on the basis of empirical correlations of subjective experiences with behavior are, in fact, causally relevant, it does not follow automatically that they can take over all the explanatory burden of mental states. So, I turn to explanation now – as it befits a philosopher. After all, according to the usual academic division of labor, scientists explain the facts, and philosophers explain what scientists are doing. An important explanatory task fulfilled by mental states is that appeal to them induces the right relations of similarity. This is where mental content comes into play. Content is rightly recognized by Stoerig as one of the outstanding features of mental states. In the same vein, I argued in the preceding section that representational states play an important role in accounting for human behavior. After all, the theory of cognitive dissonance turns on the assumption that behavior is affected by the agreement or conflict between the content of the mental states involved. Belief states of equal or similar content are psychological states of the same kind.

But neurophysiology has a hard time reproducing such relations of similarity. Think of the distinct neurophysiological channels through which a given belief state may be acquired. The expectation that it will be raining may be gained, for instance, by watching the weather forecast on TV or by listening to the radio. Or one might come to believe it by feeling a characteristic pain in one's limbs. The point is that the difference in the physiological channels suggests that the physiological processes involved in the formation of the belief states are not of the same kind. It certainly makes a physiological difference whether one sees, hears, or feels something. Likewise, mental states representing the same content may be stored in short-term or long-term memory, respectively. But the neurophysiological organization of both types of memory is different. Moreover, the process of recovery after a stroke involves a physiological restructuring which amounts to a different implementation of the same psychological states. That is, states of the same content may be realized disparately before and after the disease. In sum, a plethora of neurophysiologically heterogeneous states appears to be associated with one and the same belief state, and it is hard to find a physiological justification for considering them as realizations of the *same* mental state (Carrier 1991, 42-45).

A closer look at psychological and physical relations of similarity brings out the point more distinctly. A regularity establishes a relation of similarity among the entities it covers. To make the general claim that scientists pile up discoveries and that philosophers poke holes in one another's theories is to establish a relation of similarity among scientists and philosophers, respectively. A true generalization entails that its instantiations are similar in certain respect. Consequently, psychological generalizations induce relations of similarity among mental states. These relations may fail to be captured by laws of physics because the relevant mental states are linked with physically disparate situations. Conversely, psychological generalizations may set apart mental states whose situational counterparts are physically alike. To begin with the latter, physical states linked to one another by physical laws need not have anything in common psychologically. Consider the slamming of a door when the windows are open and the lifting of an airplane. Both processes are governed by the same physical law (namely, Bernoulli's principle), but their mental representation is vastly different in almost all humans. Regarding their psychological effects, both processes are quite distinct. That is, physically similar entities can be connected to psychologically dissimilar states. It follows that one learns nothing about human behavior if one recognizes the physical similarity of the various phenomena involved.

Conversely, physically disparate states of affairs may be conjoined to a unified psychological kind. One of the consequences of the theory of cognitive dissonance is the heightening of contrast between equally attractive alternatives after a choice was made among them. Consider a person who is forced to choose from among a set of physically distinct but similarly appreciated alternatives such as different cars, apartments, or candidates for a position. These alternatives are contrived such that they differ in their physical characteristics but approximately coincide in their overall quality. The situational circumstances generate a conflict among the various relevant criteria and preferences which is then mitigated by intensifying the perceived contrast among the alternatives. After the decision was made the selected item is taken to be much more superior to the discarded options than it was in advance. That is, the psychological conflict engendered by dissonance is reduced by increasing the perceived divergence among the options (Heckhausen 1980, 160-161).

A class of situations of comparable attractiveness does certainly not constitute a physically uniform set of entities. "Comparable attractiveness" is not a physically relevant property; there is no law of physics that ties together such a configuration of situations. But there is a law of psychology to this effect. The theory of cognitive dissonance links precisely this configuration with the follow-up state of increased perceived difference in attractiveness. Physically disparate situations are connected to the same psychological state. A relation of similarity is induced among these physical states and this relation is of explanatory relevance.

Psychological explanations are given by applying psychological generalizations to mental states exhibiting content. These generalizations latch on to mental content and they induce relations of being equal in psychological kind. Neurophysiological accounts of human behavior either have to replace or to keep up with these explanations, and the latter option requires reproduction of the similarity relations. Even provided a strict correlation between neurophysiologically characterized perception states and the physical states represented by them (so that no additional complications emerge at this juncture), the just-mentioned problems suggests that the neurophysiological reproduction of content-based similarity relations is difficult to achieve. And a mere relation between token events (such as hearing a symphony and the pertinent neurophysiological activation pattern) falls short of providing an appropriate explanatory basis. Correlations of this sort are too fine-grained to play a significant role in psychological explanations. It would be like invoking regularities of the sort that coffee and milk usually intermingle rather than appealing to the law that the entropy of closed systems increases. Significant explanations need generalizations with a wide scope. Such overarching generalizations typically establish relations of similarity among systems that appeared to be disparate before. Piecemeal correlations between token events fail to furnish unifying explanations.

The upshot is that the role of psychological processes and generalizations in explaining human behavior is tied up with binding states or situations together as being equal in kind. A law of science induces a connection among the relevant entities in that they appear as instances of the same law. For instance, it's a law that all protons possess the electron charge and a half-integer spin value. Consequently, all protons are of the same kind in that they equally display these properties. The law generates a natural kind (Fodor 1974, 101-102). On the other hand, the class of battered cars is not a natural kind. There are no laws that specifically apply to battered cars. It is true, such objects also have a lot in common. For instance, all battered cars attract every other body by the force of gravitation. But they don't exert this force in virtue of being battered cars but in virtue of being massive bodies. Battered cars constitute a subset of a natural kind but not a natural kind in themselves.

The point is that adequate explanations need to get the equivalence classes right. When Mary's automobile is found rolling down the hill, the appropriate explanation does not appeal to its property of being a battered car but rather being a massive body – in spite of the fact that all battered cars are actually massive bodies. The property of being a battered car is too fine-grained to provide an appropriate explanation; there are no laws that specifically hold for this class of objects. That is, in spite of the fact that a perfect – if one-sided – correlation occurs between the properties of being a battered car and being a massive body, the former fails to bear the explanatory burden of the latter. Recourse to battered cars falls short of providing a unifying explanation of the sort the appeal to massive bodies does. Analogously, if mental states of the same content turn out to be connected with different neuronal processes, depending, e.g., on the physiological channels through which the relevant information is gained, reference to the particular neuronal realization only accounts for a subset of what appeal to the mental state explains. Within the neurophysiological framework, the unifying psychological generalization is likely to disintegrate into a multitude of heterogeneous correlations of poor explanatory import.

At a second glance, matters look even worse. As far as I can see, the neurophysiology-based individuation of states is not only too fine-grained, it is too coarse-grained at the same time. No neurophysiological method appears to allow for a differentiation among mental states of unequal content. Perceiving a tree cannot be set apart neurophysiologically from seeing a car. The neurophysiological individuation of conscious mental states seems insensitive to the representational nature of these states. This means that neurophysiological means not only introduce irrelevant distinctions among states of equal content, they also lump together mental states of dissimilar content. Neurophysiology fails to yield the right relations of similarity, and this is why empiricial correlations between instances of neuronal activity and mental token events may fall short of contributing to a substantial explanation of behavior.

There is no need to convince me of the fact that a large number of important features of the mind are accessible through the study of psychophysical correlations. But it would surprise me if mental content and the similarity relations among mental states induced by it were reflected in such correlations. Given the failure to reproduce neurophysiologically the structure of psychologically relevant kinds of states, neurophysiology has still a long way to go until a satisfactory explanation of human behavior is in sight. There is no need to emphasize that empirical connections of the sort Professor Stoerig is about to disclose are highly relevant and constitute an important aspect of the empirical basis of any attempt to come to terms with the mind-body relationship. My point merely is that Stoerig's approach, worthwhile or even indispensable as it is, is not sufficient for a comprehensive analysis of the ties between the mental and the physical. It has to be supplemented with considerations of a different sort. I trust there is no disagreement between Professor Stoerig and myself in this respect.

REFERENCES

Carrier, M., 1991, "On the Disunity of Science, or Why Psychology is not a Branch of Physics," in: The Academy of Sciences and Technology in Berlin (ed.), *Einheit der Wissenschaften*, Berlin: de Gruyter, 39-59

Carrier, M., 1997, "On the Difficulty of Keeping Consciousness Intact", in: M. Carrier and P. Machamer (eds.), *Mindscapes: Philosophy, Science, and the Mind*, Pittsburgh: University of Pittsburgh Press/Konstanz: Universitätsverlag, 195-206

Carrier, M., 1998, "In Defense of Psychological Laws", *International Studies in the Philosophy of Science* 12, 217-232

Carrier, M. and Mittelstrass, J., 1989, *Mind, Brain, Behavior. The Mind-Body Problem and the Philosophy of Psychology*, New York: de Gruyter, 1991

Fodor, J.A., 1974, "Special Sciences (or: The Disunity of Science as a Working Hypothesis)", *Synthese* 28, 97-115

Gazzaniga, M. and LeDoux, J.E., 1978, *The Integrated Mind*, New York: Plenum Press

Heckhausen, H., 1980, *Motivation und Handeln*, Berlin: Springer

GLOBAL SUSTAINABILITY, BIODIVERSITY, AND THE FUTURE

PETER RAVEN

I will take the privilege of speaking now outside of the general theme, simply on my behalf, and I am sure on the behalf of many of the people here, to thank all of the speakers who came here to be with us at this assembly. No doubt that will be done comprehensively at the end of the session, but I have been very, very delighted myself with the presentations that have been made by so many of you. Knowing the difficulty of coming and going to meetings and so forth, I just want to say how much we appreciate your wonderful participation.

As kind of a text for my talk, I want to read some words that were said by the Holy Father John Paul II on the occasion of his general audience on August 19, 1998. He said: 'Thus, creation made alive by the presence of the Creator's spirit is called to become a dwelling of peace for the whole human family. Creation realizes this objective through the mediation of freedom of man whom God has placed as his custodian. If man becomes egotistical about himself through a false conception of liberty, he becomes fatally involved in this perversion of creation itself. The created world receives its true meaning in man and through man. Man certainly cannot use the cosmos in which he lives as he pleases but, rather, with his intelligence and will, he should raise the work of the Creator to its fullness'. That expresses perfectly well the theme that I want to address today, which, as you will soon see, is more of an exhortation about ways in which we can and, I would say, must use science rather than a contribution to the understanding of where science is at the end of this century. In some sense, it is related to the three working groups that will be meeting here over the next months: the one on global change, in a couple of weeks; the one on food security in February; and the one that some of us are organizing in March on basic science for survival and sustainable development.

Perhaps one of the important scientific things to say, which relates to several of the talks given earlier, is that we tend to view the 21st Century (the coming century) as the age of biology, or as a time when we are going to have or experience the fruits of a biological revolution. It is impressive to recognize that molecular biology began, I would say, at Cambridge University as recently as the beginning of the last half century with the first postulate of what turned out to be a satisfactory model for the functioning of DNA in 1953; the first preparation of a transgenic organism as recently as 1973; and the first transgenic plants in the early 1980s. If one really begins to think about that and begins to think seriously about the ways in which the understanding of the whole genomes of eukaryotic organisms will enlighten what we do and how we think about all of these matters in the future, then one begins to understand, on the one hand, how it is that biological complexity and biological diversity, in all of its abundance and all of its splendidness, give meaning to all of these basic principles that we have been learning, and, at the same time, provide/point the ways in which we can use them to make the 21st Century truly an age of biology.

What I would like to suggest is that we are neither paying attention to the Holy Father's very appropriate words, nor are we behaving in a way that is even remotely or imaginably suitable if we are trying to make preparations for an age of biology: an age when the properties of organisms will give us the opportunity to achieve a kind of sustainability on which human futures can be appropriately based. I will suggest that in the following way.

A little bit about the history of the earth, which we have heard a good deal about in earlier papers: our planet is about 4.5 billion years old; life on earth is at least 3.5, or perhaps at least 3.85 billion years old, or possibly a little older than that; but life on land is only about 430 million years old. Life did not come on to land until about 90 percent of the way through the history of life on earth. Forests, which we take for granted in looking at the world at the present day, are only about 300 million years old, which is really yesterday in the whole 4.5 billion year history of the earth. The petroleum and the natural gas deposits on which we base the Industrial Revolution, which I am coming to in a minute, were formed largely by the activities of cyanobacteria functioning for billions of years before the appearance of multicellular life. The coal deposits, which are the third part of our great energy supplies, of course, are a product of those forests.

At the end of the Cretaceous Period, 65-66 million years ago, and the Mesozoic era, what seems clearly to have been the collision of an asteroid with the earth in the Gulf of Mexico, sent up an opaque cloud and drove what are estimated to be about two-thirds of the species of organisms that were then in existence to extinction in a very short period of time, leaving what I would vaguely estimate as something like 500,000 kinds of organisms. In the 10 million years that it took for life on earth to recover, the whole character of life on earth changed profoundly. One of the easiest ways in which we can show how profound that change was is to point out that at the end of the Cretaceous Period, the largest mammal on earth was about the size of a house cat and all of the diversity that we see in mammals now from giraffes to mastodons, to elephants to all the grazing mammals on the plains of Africa; to the kangaroos, the whales, the bats, and the lot, have all evolved from the occurrence of mammalian evolution, which have taken place during the last 65 million years. That is why we say the character of life on earth has changed completely.

In addition, the numbers of species on earth have gone up steadily for the past 65 million years with about 500,000 species; notionally, something like that 65 million years ago – terrestrial species, if you want; it does not make much difference. The total number of species has gone up to what Robert May, who is perhaps the best qualified and most serious of the estimators of the number of species on earth, estimated in a forum that we held on biological diversity in Washington last October, is about 5 to 7 million species of eukaryotic organisms. That is a conservative estimate, but 10 million would be a high estimate in view of the emerging picture.

So, there have been between a ten-fold and a twenty-fold increase in the number of species on earth over the past 66 million years.

Our genus, the genus *Homo*, the group to which we all belong, appeared about 2 million years ago. Exactly when is a little doubtful because of the way in which we relate to *Australopithecus*, the immediately preceding genus, and in Africa, and our species, so I would think we would say human beings appeared about 2 millions years ago. Our particular species, *Homo sapiens*, which we hope is not an ironic designation, appeared several hundred thousand years ago.

The most significant event in the presence of our species on earth in terms of what I am talking about now was clearly the invention of agriculture at several widely scattered centers, both in the new world and in the old world and on every continent independently, except Australia, and, of course, Antarctica. The invention of agriculture by our ancestors occurred about 10,000 years ago. In other words, relatively close before the beginning of written history.

The first point to note about this is that, at the time when agriculture was developed, the total number of people in the entire world was about 3 to 4 million people. In other words, a very, very tiny number of people – 3 to 4 million people, which would be a small city if it were around at the present time and if all those people were concentrated in one place. Think of the density of people in pre-agricultural days as being like the density of aborigines in Australia before European contact, because they had no agriculture; or think of the density of bushmen in southern Africa before African groups, which had agriculture, or before Europeans arrived there a very low density, a very small impact, on the earth 10,000 years ago, in a 4.5 billion year earth history.

With the invention of agriculture, villages and towns and, ultimately, cities began to be formed and people could specialize and become lawyers, professors, scientists, teachers, and all of the other things that we value. But this is a 10,000 year period – a much smaller period than we think about unless we dwell on that a lot. Another way of looking at it is, when the pyramids were built, about 5,300 years ago, the entire population of the world was something like 20 million people: much, much smaller than the population of Italy at the present time. And yet, if we look back at those days, at biblical days, or days when things were first being written, we tend to think of it as being a densely populated world with lots of people around doing the sorts of things that we are now. And, of course, there were cities, but it was not a densely populated world.

By the time of Christ, we were up to about 150 million people; in the Renaissance, we were up to about 500 million people – about the current population of Europe. By 1800, when Thomas Malthus was saying that food production could not keep pace with human population growth, we reached a billion people for the first time. The human population has gone shooting on upward since then, spurred over the period from the mid-18th century to the present by the Industrial Revolution and by the discovery of those terrific sources of energy, which produced the engines and the possibilities that drove on human opportunity, to 2 billion people in 1930 and 2.5 billion in 1950. In other words, when the first satisfactory model for the structure of DNA was proposed, or when we were enjoying the first years after the end of World War II, there were about 2.5 billion people in the world. And now, there is 6 billion people in the world – 3.5 billion people added over the last 50 years.

We think that we are in a world that is somewhat sustainable, but we are not in a world that is being operated in a sustainable way, not even remotely. We think that those 6 billion people have kind of come about, we have them, and it is all right, but what we have to worry about is the future. Let me mention a few things that have happened during the last 50 years.

Over the last 50 years, about 25 percent of the world's topsoil has been lost, and now we are losing about 26 billion tons of topsoil a year. We are losing an amount of topsoil equal to all the topsoil on all the wheat lands of Australia, for example, which is a highly productive area, every year. We have lost about 15 to 20 percent of the land that was under cultivation in 1950. In other words, we are feeding 3.5 billion extra people with 80 to 85 percent of the land that we had 50 years ago. That is marvellous and is quite an accomplishment; but, at the same time, I think you will recognize from what I have just said that we are in the position of a family who inherited $1 million and said, 'Isn't that marvellous; now we are going to spend $200,000 a year and have a really great way of living; it is all super and wonderful'. Then, at the end of 5 or 6 years, they go back and look at their bank account and it is empty. We are not spending the interest, and we are not using the natural productivity of the world, which is something that is sustainable, but we are using the ecological capital of the world, which is what has to sustain us in the future, and that is the problem.

Are we really feeding people? Is this really all so wonderful? Of the 6 billion people in the world, 2 billion of them (one-third of the people in the world), subsist on less than $1 a day. They are living in a condition that the World Bank defines as extreme poverty. About 700 million people are getting less than 80 percent of the UN recommended minimum caloric input, which means that their bodies are wasting away, and their brains, which we have talked about, cannot develop properly when they are children.

In the 700 million people who are literally starving in the world at the present day, about 1 out of 8 people in the world – and what that means very simply is that the women and the children in that huge part of the human race – have to spend all day every day going out and getting fresh, dependable supplies of water or dependable supplies of fuel (firewood), which are often 20 kilometers or more away, and then bringing it back and cooking their food in highly carcinogenic, smoke-filled places that they live causing further health problems. There are 250 million people in the world afflicted by malaria, to name just one example, every year, and tens of millions die of it. About 15 million children under the age of 4 starve to death or die of diseases related to starvation every year – about 35,000 children a day – and yet we act as if, in our papers, magazines, and things, would generally make us feel, that there is no world food problem: there is no kind of general problem in the world or, if we do pay attention to it, we say, "well, it is political; or, there are other reasons, and it is really okay or it would be okay if only people were better, but let's forget about that and go back to our work". In other words, we do not live in a world that is really operating very well.

If you add to that the fact that the properties of the atmosphere have been changed substantially over the past 50 years, with something like a 15 percent addition to carbon dioxide, the major greenhouse gas, and something like a 7 to 8 percent decline in the stratospheric ozone layer that shields us from ultraviolet b, the ozone being in equilibrium with oxygen, which is probably the protection of that layer, may well have been the thing that allowed life to come on land in the first place. Consequently, since UVB radiation is very unfriendly to biological molecules, the incidence of malignant skin cancer in places like here has gone up about 20 percent over the past 50 years and much more than that in very high latitudes.

Worst of all, the crime, the sin that people who come after will not be able to forgive us for is the fact that we have driven the extinction rate of the organisms that we share the world with up to levels that have been unprecedented for the past 66 million years. That is a real denial of a responsible attitude towards creation.

For every species that evolves now, about 1,000 become extinct. Soon, the rate will be about 10,000. Species are becoming extinct extremely rapidly, so rapidly. I will show some relationships about this in the slides that Stuart Pimm and his colleagues. They made a new and very careful estimate of extinction rates for the Forum on Biodiversity that I mentioned earlier and have calculated that about 25 percent of all species of plants, animals, and microorganisms are likely to be either extinct or on the way to extinction, by which I mean in populations so small that they cannot be salvaged, within another 25 years. By the end of the next century, the so-called age of biology, which begins to take on an ironic sound in the face of these facts, as many as three-quarters of all the species on earth could disappear permanently or be on the way to extinction as this continues. That would be a level of extinction much higher than the rate of extinction that occurred at the end of the Cretaceous Period, which profoundly changed the character of life on earth for 10 million years before it began to recover. That rate of extinction is something which is completely intolerable in the face of what we hope to do with biological diversity, and yet we are not really addressing that problem at all, neither by our passivity, neither by the way in which we affect those organisms in the communities in which they exist, nor by taking any particularly well organized action to save them or any subsample of them for any purpose that we might want to put them to.

I would like to say very clearly, because I may have given the erroneous impression by not bringing it to the surface, that I think population is the problem and the only problem, and that is not in the slightest the case. The problem is a combination of population and affluence, which is level of consumption; affluence – the way in which we use natural goods for our own well-being. For example, my friend Ed Wilson points out that if everyone were living at the level of the industrialized countries at the present time, we would need two other extra planets to support us all. And yet the Brundtland Report, the report of the World Commission on the Environment and Development, sort of implies – and this is the kind of dream that we would like to have – that somehow everybody in the industrialized countries is doing it right, and if we were all just a bit leaver, people in developing countries could come up to that level; and as they came up to that level, then everybody would be living that way. Whereas, that is really a myth. It simply cannot be done by any kind of technology or way of living that we have now.

In addition, the third item is the kind of use technology that we choose to accomplish what we want. The easiest example that I have to point out something about that is: big car manufacturers in the world regard East Asia as their best target – the best place that they can manufacture and sell cars/automobiles – China, Indonesia, and so forth. Here is the point about that: if people in either China or India owned the same number of cars per person that we shamefully do in the United States, China by itself would need the entire world petroleum production in order to be able to provide gasoline to fuel the cars that they would own. They would need every bit of petroleum produced in the entire world. In other words, it is an impossibility. It is the propagation of the wrong technology in the wrong place for the wrong reasons, just as the use of that technology in the United States or in Italy, to the extent that we do, is wrong. The problem that we are trying to solve is the problem of how people can get from place to place easily or how they can live in such a way that they don't need to get from place to place in that way, and we are solving it just by producing more automobiles, which is no solution at all. The world dilemma that we face as we enter the 21st Century is the product of population, affluence, and technology and that can be resolved only by addressing all three of those points simultaneously, and something that is very important if we want to address it on a world scale.

As Mr. Hoffman pointed out in his lecture earlier, the distinctive thing about our planet is that it is a living planet, and although we may find other planets that are living planets later, this planet is, as far as we know, the only one in the universe – it is the only one we know about that has this wonderful complement of living organisms. It is logical and proper for us to be excited about the possibility that maybe there were some bacteria on Mars that became extinct 3 billion years ago, or the possibility that maybe there is some bacteria living five kilometers deep under the Martian soil. Is it not a little fantastic that we really do not care about the 5 to 10 million species of organisms that occur on this earth, that make this earth what it is, that provide our entire livelihood on this earth, and that provide the unique tools by which we may be able to build a sustainable future?

A single expedition to Mars – the latest and least expensive one – costs as much as the total worldwide expenditure for dealing with biodiversity and ecosystems and everything about them in a year on earth. Imagine if we were on Mars with nothing alive around, and we sent an expedition down here to earth and saw what we have here. What would our reaction be and how many billions of dollars would we be willing to spend to learn about it? As it is, we are not.

Biodiversity can be thought about in three different ways. The first way is the way in which biodiversity functions in communities and ecosystems, like this scene here on the island of Madagascar off the east coast of Africa, where the organisms together regulate a certain proportion of the energy from the sun and regulate the expenditure of that energy by different tropic levels of living organisms; regulate the cycling of nutrients in that ecosystem; regulate watersheds; the purity of water and the air; and have a wonderful capacity for absorbing toxics and so forth, and make the world what it really is to providing what are increasingly called ecosystem services.

Some of the linkages in such an ecosystem are pretty obvious and well known, although often bizarre. For example, leaf cutter ants in the tropics, which have been practicing a form of agriculture, so to speak, for 40 million years, gather leaves, take them back into their nests, chew them up, inoculate them with fungal spores, and grow a species of fungus on them, which, by doing that, provides the food for themselves and their larvae. And that is kind of a linkage of energy levels in an ecosystem.

Another kind of a linkage is that shown by a species of bat in a Costa Rican forest, which eats a fig and spreads the seeds of that fig. Actually, the relationship between bats in the new world and in the old world and the fruits and the forest is so close that the forest will not become reestablished unless the bats are there to carry the seeds out beyond the shadow of the existing forest. When you look at an ecosystem like that on the coast of British Columbia, and you see those magnificent coniferous trees, you need to think also of the fact that the nitrogen that enters that system is entering that system as a result of nitrogen fixation by cyanobacteria that are the photosynthetic component in lichens living on the tops of the trees and then washed out down to the forest floor and that all of those coniferous trees have, associated with their roots, ectomycorrhizal associations with fungi, which are responsible for the transfer of phosphorous into the trees and indispensable for their life. The spores of some fungi are scattered by mice burrowing through the floor of the forest. In other words, an ecosystem is an incredibly complicated thing, and we have just barely, while we are dissecting and destroying the world's ecosystems, come into possession of the simplest and fewest facts about how those ecosystems really function at a time when we are destroying them and at a time when we have no substitute for their literally priceless ecosystem services.

A second way of thinking about organisms is in terms of the individual products that they provide. There is a small tree native to the Central American region cacao which is widely cultivated in West Africa and elsewhere. It is the major ingredient in chocolate, and it is an example of the way in which commodities are brought all over the earth and are used and grown in different places. An even more cogent example: here is a picture of cobs of maize from a corn crib in the state of Puebla in Central Mexico. What they remind of us are, first of all, the genetic diversity of crops near the places where they were first brought into cultivation, and, secondly, the international nature of agriculture. Very few of the world's crops are cultivated in the areas where they were first brought into cultivation are not entirely so; for example, tomatoes, potatoes, and maize from the new world. It is hard to imagine Italians cooking without tomatoes, but before Columbus, it was no tomatoes; they were all in Peru, where they were first domesticated and elsewhere in the new world. So, we share a common world heritage (a genetic heritage) of the wild relatives of crops, and we need to go beyond our own countries in order to find additional genes regardless of how adept we may be in understanding what we want to do to improve them.

There is a diploid-like, two and ten, form of maize like cultivated maize – *Ziadiploperentis*. It has a single row of kernels. What I want to point out is that it was discovered in 1989. It is interfertile with cultivated maize. It has genes in it that make that maize resistant to 7 of the 9 viral diseases that are the most important factors in lowering the yield of maize all over the world. It is a perennial; it is being used in northern Argentina and some places where there is some experimentation with perennial maize. Maybe, in order to win sustainable agriculture, which is one of the great things that we need to do sooner rather than later, that perenniality will be important too, but the point I want to make is that this plant was discovered only in 1989 and its total native area is a tiny fraction of the area of Vatican City, and it is a pasture that is full of cows. It could easily have been made extinct without ever, ever, ever being known. It is just sort of a cartoon, if you will, of the kind of losses that we are looking at as species are going out of the picture.

Medicines. In Suriname in South America people use plants to combat illness, but this a reminder, even if an unusual one, of the fact that about 80 percent of the people in the world depend directly on plants for their medicines. Even for those of us who do not depend directly on plants, the majority of the big selling ones are natural products, which may now be manufactured. For example, aspirin, which was discovered because Europeans were chewing the bark of willows. It was discovered and then slightly modified chemically so it would not burn the lining out of your stomach; or, steroids, which are grown in plants and then used as the basis for cortisone and other similar kinds of medicines; or, things like vinblastine and vincristine, which are taken directly from plants and then used in cancer treatment; or, improved by the use of natural products. In other words, our whole source of medicines is very, very effective by natural products. For example, tubocurarine is something that is used to relax muscles and the diaphragm if you perform thorax surgery. Tubocurarine is a modified natural product made from curare, which this man is using to hunt with as a powerful muscle relaxant. We would not have even known of the existence of such a molecule or such a possibility if we had not studied his activities.

There is a plant that we discovered in Missouri Botanical Garden in Cameroon in West Africa. It has an ingredient in it that is effective against all four of the major kinds of HIV virus. But, unfortunately, it is a powerful neurotoxin, so not the sort of thing that you would give a patient. But, on the other hand, and this is the point I made a minute ago, its way of affecting the HIV virus is different from that of all the other chemicals that are used to affect the HIV virus so we learned something new about the action of the virus and what we might be able to do to control it by understanding what that molecule does to them, even though we cannot use it directly as a medicine.

This is genetic engineering. This is the use of genes from one unrelated kind of organism. *Bacillus thorengiensis* defends cotton bolls. When you learn that over half of all the pesticides in the world are sprayed on cotton (22 separate springs of insecticide in order to get a cotton crop) in most areas of the world where it is grown, and when you recognize that several hundred people in Central America alone are killed by wrong exposure to pesticides that are used on cotton, then you can understand, without going into the details, why the ability to transfer new kinds of genes into cultivated plants is going to be – when we work out problems that are going on now (many kinds of problems, which I do not have time to go into), that it will be a powerful assistance towards building sustainable agriculture in the future; and it is something that we need to get on with.

Then there is the shear beauty of organisms. Ed Wilson has pointed out in his book, 'Biophilia', and in other writings, how it is that we enjoy organisms. And when you think about it, going back to the theme of the human mind and brain, our mind, our way of dealing with things, our linguistic systems, must necessarily have been built up in settings where biodiversity was what we mainly had to communicate about. Whether it was the peaceful kind of biodiversity that we were going to dig up to eat, or whether it was the kind of biodiversity represented by a saber tooth cat that was going to come and eat us, what we wanted to talk about and communicate about would have to have been largely biodiversity when we were living in a world with 3 million of us very widely scattered. When you think about that, it is no wonder that plants are so pleasant to us. We have them in almost every room that we can; we love to garden; we love pets, cats, dogs, and fish, or whatever; we love to see them around us; we love to go to the zoos; we love to go to places where we can see it. And when you think about our very recent history, it is very easy to see why they have been an inspiration of so much of our art.

Then, when we think about how an extinct bird – the Carolina parakeet; a parrot that was native in the United States – used to exist in flocks of tens of thousands, which unfortunately used to come through and eat all of the fruit out of orchids; but when you see what a beautiful thing that is, you can realize simply, on aesthetic grounds, that it should cause a great pain to us to think about them not being in the world anymore, but just simply being gone permanently. Biodiversity is really fantastic.

There is a species of bee in the new world: its tongue comes all the way back to here and it takes nectar out of flowers; it goes to other kinds of flowers and gathers scent in these big hollow hind legs and then marks mating sites in the forest with them; then look at it, it is beautiful!

There is the poison arrow frog from South America – the male carries its tadpole around from place to place and advertises with this warning coloration so as to avoid predators; too dangerous to get into the water in the tropics; the same poison that the natives dip their darts with in a part of the northwestern Amazon.

Rafflesia is the largest flower in the world of nearly a meter across in South Asia, all of the species of which are threatened with extinction at the present time; leafless; parasitic on the roots of plants in the grape family.

We know a lot about some groups of organisms, like vertebrates. There are about 45,000 species. Or, flowering plants – we know probably seven-eighths of them. There are about 300,000 species. We know very, very little about some other groups of organisms. For example, this is a ground beetle. The tops of trees in America have tens of thousands of undescribed species of this group of ground beetles in them. When you begin to sample them, then you realize that the total number of species of insects must be much larger than the 750,000 or so forth that we have described.

Even in well known groups, this is a subfamily of mammals. There is an 80 kilogram animal with horns about 70 centimeters long that was discovered in central Vietnam in 1983. It is a whole distinct subtribe. It is now known from about 30 localities and there it was, and no scientist had ever seen it; it was not in any museum; it was not anything anywhere at all. About a dozen new species of monkeys have been discovered in the Amazon Basin during the 1990s alone. And when you consider that there are only about 200 species of primates all together, that is a huge addition to a group that we would have thought that was really well known. And so it goes on.

Some groups like fungi, where estimates go up to a million species and which are extremely important, both environmentally and economically as disease-causing organisms for humans, other animals, plants, and the like, are very poorly known and with very few people trying to study them.

The causes, as I outlined at the beginning, of the extinction of biodiversity are, of course, to reiterate it, a combination of population, which is simply too high to be supported in many places. As the Holy Father has pointed out many times, the combination of too many people with too much poverty, is something that ought to make people look to responsible parenthood in a way that they sometimes neglect to do. It just does not work, and the environment cannot be supported under those circumstances. One of the most morally reprehensible things about the world is that those of us who live in industrialized countries, although we draw a high proportion of our wealth and our activities from developing countries, simply do not take that relationship seriously in our activities. We simply like to go on assuming that our economies are entirely internal.

I have here a picture of a large portion of the Central Amazon in Brazil during the dry season. It is a couple of hundred kilometers in each direction, showing the major fires burning. Why is the forest being cleared? The mythology is that the forest is being cleared because there are so many people using the forest. There are so many people using the forest, but, just as in the United States, the people using the forest are mainly people living in cities who are developing big cattle ranches there or developing it in some economically suitable way. In fact, although the population of Brazil is growing, although more slowly than it was 20 years ago by far, it is growing in the cities. The rural population is not really growing at all. The people are coming into the cities as people move out.

There is a transettlement in Indonesia where people are being taken from good farmlands in Java to other parts of Indonesia and put on poor soils. And, of course, when they are, they use them up right away. But the good farmlands in Java, like the good farmlands everywhere else, are being used up by urban sprawl, factories, and other things that seem to be more high yield. Then we seem to become disconnected from the agriculture that is still necessary to support us. So, the natural areas in the world are getting reduced to small patches, usually on places that are too steep or too wet to cultivate. Here is an example. The relationship between species number and area is basically a logarithmic one. These are islands in the West Indies and species of reptiles and amphibians. A reduction to one-tenth of the former size of an area will cause the extinction sooner or later of about half the species that were in the area. You cannot just save it by saving a small chunk of the area. There is an experiment on the same subject conducted by Tom Lovejoy in the Central Amazon.

The relationship between poverty and preservation is obviously a direct one, just as the relationship between population, affluence, and technology is. This is a national park in western Ecuador during the harvesting of bamboo season.

There is a plant from western Ecuador that was found only once on a fallen tree trunk in a pasture and then fortunately brought into cultivation.

There is a field station in western Ecuador built of a tree in the Laurel family that was the major source of wood in western Ecuador when it was 80 percent forested in 1950, but now that forest cover has been reduced to 2 percent, this tree is now represented by 8 individuals, all of which are on the grounds of this field station, which means that it is no longer a source of wood.

In Madagascar, very briefly to give you a single concrete example, live about 45 species of non-human primates (lemurs), and every one of them is threatened or endangered, as are the sort of 80 percent of the plants and animals of Madagascar generally, which are nearly half of the total number of species found in all of tropical Africa; so it is a very rich and very highly endemic area. This is a picture of an area of northeastern Madagascar, and it shows the reduction in forest cover before people were there about 1950, about 1984, and now it is less than half of that. That is why most of Madagascar now looks like this. See the soil running off there and the colour of the stream? This is a picture of what a lot of Madagascar looks like now. Those are introduced African grasses, and the only native plants or animals would be hanging on down along here, so naturally they are highly threatened. Why does it matter?

The rosy periwinkle, *Catharanthus roseus*, which is a common garden plant, is the source of vinblastine and vincristine, which were put on the market in 1971 by Eli Lilly and are about a $130 million a year commodity because they raise the chance of survival for childhood leukaemia from about 1 in 20 to about 19 in 20. So the question you would ask is: how many of those can be hanging on in a place like that? And, does it really matter for us? How many other things are there about which we know nothing and have not appreciated at all, with only about a quarter of the species in the world even put into the books?

In order to solve the problem, and I will conclude on solutions or some of the ways we can think about solutions, we need to think about poverty and people around the world with an intensity that we are not used to doing.

This picture of girls on the island of Mindanao in the Philippines shows them gathering water about a 100 meters below a gold mine where mercury is being used to separate gold from the ore. You can imagine the effects of the water that they are bringing back to their families, and yet what most of us think about the Philippines, which is a very important country of about 90 million people, are the excesses of Ferdinand Marcos, or what kind of an election they just had, or some kind of superficial function, and not the fact that about two-thirds of the people there are living in extreme poverty and under conditions where they cannot possibly stabilize the country. Knowledge is very important. Abdus Salam, whose passing we noted at the beginning of this meeting and who was such a wonderfully creative person in this area, estimated that about 6 percent of the world's scientists and engineers live in developing countries and about 94 percent live in industrialized countries. What that means very simply is that 80 percent of the people in the world with 80 percent of the world's biological diversity and 15 percent of the world's money have 6 percent of the world's scientists to make decisions about what to do about this biodiversity or any other aspect of sustainability based on their own knowledge. If you discount a few countries like Brazil, Mexico, China, India – developing countries that have relatively many scientists – then you can realize that for most of the developing countries there is basically no wherewithal to make those decisions credibly.

Sustainable agriculture: whether it be the kind of polyculture on the background there in Sri Lanka or tea culture in the front needs to be built up worldwide.

Captive breeding: something which, if Sydney Brenner is right in proposing a model where we take DNA and store it, would certainly be better than nothing. Perhaps, however, there are other modes of preserving organisms. The important point that I want to make now is not to suggest solutions, but rather to point out that we have no general operational plan for dealing with these problems at all, and we need a general operational plan. In a world like the world I am describing, there must be a clever and intelligent response. We do not need to be incredibly ignorant and careless with this wealth of biological diversity that we have. We could decide at least which parts of it we would like to save and what we would like to do about it. Preserving organisms is the most efficient way of saving the large numbers of them, particularly given the situation where we do not know about most of them and couldn't choose to protect them individually. But that again would take a worldwide will that has not yet been expressed. At the Earth Summit in Rio de Janeiro, lots of nations came and said what a wonderful job they individually were doing, but no nation came and said that this is a critical worldwide problem and we are willing to cooperate profoundly with other nations in solving it, which is really what we need. And, unfortunately, things seem to have run a bit downhill from there.

The choice that we have to make as we go into the next century and the next millennium is whether we want simply to use the natural capital on which we could base long-term sustainability and a kind of a society that would keep all of the things about civilization that we prize together, or whether we will condone the kind of activity that leads to scenes like this without any particular plan because we prize so much individual enterprise, or whether we would prefer scenes like this, or at least some of them in the world that we are going to leave to our children and grandchildren. In other words, we have to work together with all the people in the world to accept the responsibility for competent management of what we have.

In some sense, though, both Dawkins and Seitz were right: we are programmed to do certain things based on our very long history of not needing to care about these issues; and, on the other hand, we can make choices. All we really have to do is think about the fact that human beings are not, thank goodness, computers but human beings that can make creative choices and change their styles of living, to realize that if we are willing to deal with the situation individually and positively that there is great opportunity to make changes. In that vein, we might also think of the examples of wonderful leaders like Francis of Assisi or Gandhi, who made an enormous difference during their own lifetimes and convinced many people to follow and adopt better ways of doing things as we learn about life on earth, exploring it, saving it, and deploying it in ways that are really intelligent.

I hope that this has presented some challenges. I would like to conclude with some words from Patriarch Bartholomew of the Greek Orthodox Church in a speech that he made about a year ago, just as something to think about. He said that if human beings treated one another's personal property the way they treat their environment, we would view that behavior as antisocial. We would impose the judicial measures necessary to restore wrongly appropriated personal possessions. It is, therefore, appropriate for us to seek ethical legal recourse where possible in matters of ecological crimes. It follows that to commit a crime against the natural world is a sin – it is a sin for humans to cause species to become extinct and to destroy the biological diversity of God's creation; for humans to degrade the integrity of earth by causing changes in its climate by stripping the earth of its natural forests or destroying its wetlands; for humans to injure other humans with disease;

for humans to contaminate the earth's waters, its land, its air, and its life with poisonous substances. These are sins. In prayer, we ask for the forgiveness of sins committed both willingly and unwillingly, and it is certainly God's forgiveness which we must ask for causing harm to his own creation. Thus, we begin the process of healing our worldly environment, which was blessed with beauty and created by God. Then we may also begin to participate responsibly as persons making informed choices in both the integrated whole of creation and within our own souls.

With those inspirational words, I would like to conclude these remarks and say that it has been a pleasure to be able to address you, and I hope very much that we as a group and all of us in our own groups, and that we individually, may find ways to responsibly contribute towards the creation of a world that we really would want to leave to our children and grandchildren in the full spirit of the enlightenment, in the full spirit of what we have accomplished together over the last 500 years and earlier, because surely the kinds of things that we are talking about here represent extraordinary serious challenges to the nature of the world that we are preparing as we move forward in the 21st century and into the third millennium. Thank you.

EVOLVING CONCEPTS OF NATURE[1]

GEREON WOLTERS

0. Introductory Remarks

"Nature" is not a technical term in any of the "natural" sciences. Check the index of any textbook of physics, chemistry or biology – you won't find "nature". It seems that in the sciences of nature their very object has gone out of focus: "Nature" is not an object of scientific research like solid bodies, Alzheimer genes or nitrogen oxide (NO) molecules. Nonetheless we use "nature" in scientific discourse. What do we mean by it?

The concept of nature in modern science is what I would like to call a dialectical concept. On the one hand "nature" constitutes what the philosopher Edmund Husserl has called the "horizon" (*Horizont*) of special scientific knowledge. This means that both in every day cognition as well as in the sciences we never experience an object in isolation. Rather, each and every object is perceived both in the context of other objects, as well as personal experiences and the cultural premises it contains. Needless to say, we are not normally explicitly aware of the constituents of the horizon of our knowledge. Rather, it has to be revealed through historical and philosophical investigation. On the other hand the "horizon" of knowledge is not immutable. It can be changed and indeed is, changed by the very cognition that arises within it.

In the sense just specified, the – or better – *a* concept of nature has always been part of the "horizon" of knowledge in the natural sciences. This horizon both shapes scientific knowledge in some sense, and is at the same time itself changed and shaped by scientific progress. Here, I would

[1] Acknowledgement: this paper owes much to Ringan E. Douglas' linguistic help and philosophical critique.

like to concentrate on the shaping of the concept of nature by evolutionary theory and *vice versa*.

In the first section, I will present a quick look into the history of ideas for those components of the concept of nature that are relevant in this respect. As we shall see, distinctions and definitions made long ago will help us to understand the changes of the concept of nature effected by evolutionary theory. In section II, I turn to a special case of nature: i.e., *human* nature. Here I will report changes that have been claimed during the last two decades by some evolutionists. Finally in the section III, I will evaluate these claims.

I. The Concept of Nature in the History of Science

In those parts that are of interest in our present context the history of the concept of nature up to the eighteenth century consists basically in slight variations of Aristotelian themes,[2] footnotes to Aristotle as it were.

Aristotle distinguishes between (1) "nature" as the collection of all natural bodies, and (2) "nature" as the essence of a singular natural body, an essence that is immutable despite all change that might occur around it.

A natural body – so goes Aristotle's definition – is a thing that has "*within itself* a principle of motion and stationaryness (in respect of place, or growth and decrease, or by way of alteration)".[3]

Note that "motion" in Aristotle's terminology has a wider meaning than today. It is synonymous with every kind of change. "Motion" in the modern sense, i.e. locomotion, is just one of the various "motions" in the Aristotelian conception, just as animals, plants and the four elements all qualify as natural entities.[4]

We may consider two axioms that formulate these distinctions. These axioms functioned as a sort of horizon of concrete observation and research for about two thousand years:

[2] I can restrict myself to just a few remarks given the rich presentation of Mittelstraß in this volume. See also his account of the history of the concept of nature in Mittelstraß (1981); see furthermore the entry "Natur" in Ritter/Gründer (eds.) 1984.

[3] *Physics* 192b14f., quotation from Aristotle (1941), p. 236

[4] Note, for example, that stones are also natural entities, insofar that within Aristotle's theory they have an intrinsic tendency to move to their "natural place".

Axiom A_1: Natural bodies possess an *immutable essence*, and thus nature as the collection of all natural bodies consists of a family of fixed, immutable essence classes.

Axiom A_2: Changes that occur to a natural body, and which originate from within that body, never transgress the limitations of the immutable essence class that body belongs to.

Note that change ("motion") is only imaginable as a development *within* the limits of its essence, what is also called its "form". Within the realm of living things, this means that a worm can never become or generate anything other than a worm, and a man nothing other than a man.

Needless to say, such a conception leaves no room for the evolutionary idea of new species originating from existing ones.

There is, however, a heterodox tradition in the history of post-Aristotelian science.[5] I am referring to alchemy, where these Aristotelian axioms of natural philosophy were disavowed for the first time, albeit only for what we would regard as the inanimate part of nature. Claiming godlike powers for themselves, alchemists like Paracelsus (1493-1541) thought it possible in a first destructive step to dissolve natural bodies into formless matter lacking essence – thereby violating A_1 – and becoming what Paracelsus called "slyva"[6], and then in a second constructive step, to rearrange it thereby possibly creating new forms and properties from structureless matter – in violation of A_2. By creating new forms and properties better suited to human needs and desires, particularly for healing, than what the original constitution of the world made available, alchemists were convinced that they would do a better job than the Creator himself had managed.[7] As we know, alchemy, despite its remarkable successes in dissolving and synthesizing substances, basically turned out to be a failure and remains merely a remnant of the

[5] Note that much of pre-Aristolelian, or better, Presocratic science did not hold the Aristotelian idea of fixed essences, e.g. Heraclitus.

[6] thus translating Aristotle's ulh. For brief information on Paracelsus see the entry "Natur" in Ritter/Gründer (1984), p. 459f.

[7] "Nature is so subtle and sharp in Her workings that one cannot make use of Her without great art. For she does not give anything to the light of the day that is perfect the way it is. Rather man has to make it perfect. This perfection is called alchemy" ("[...] die natur ist so subtil und so scharpf in ihren dingen, das sie on große kunst nicht wil gebrauchet werden; dan sie gibt nichts an tag, das auf sein stat vollendet sei, sondern der mensch muß es vollenden. dise vollendung heißet alchimia" (Paracelsus (1924), p. 181)).

past, an episode in the history of science. Nonetheless for the first time in the history of science, the idea and the possibility of creating new essences or forms was entertained, albeit only in the mineral realm, i.e. concerning forms that nature in its regular course would never produce.[8]

The alchemical conception of the creation of new essences or forms in nature has returned in a twofold way to the realm of the living: (1) in its full sense, as it were, as in our contemporary conception of genetic engineering. Here, human ingenuity would has created creates new forms by inserting the genetic material of one species into the genome of another. However, I am not concerned here with this particular sort of development of the concept of nature as effected by the creativity of man. Rather, I am interested in (2) the somewhat indirect return of the alchemical *alter deus* (second God) in the theory of evolution. In evolutionary theory, though, it is not man who perfects the Great Work, but Mother Nature herself. Contrary to the Aristotelian Axiom A_I, the essence of (living) nature here consists, in a sense, in simply having no essence. There is still (3) another way to créate new forms, though again not essentially, that has been with humanity almost 20.000: the creation of domestic animals through the breeding of wild forms and by selecting useful variations. Francis Galton in the last century, inspired by the theory of evolution of his cousin Charles Darwin, applied the idea of breeding to humans, thus inventing modern eugenics.[9] I shall come back to eugenics later.

Until the mid-eighteenth century, scholars were convinced that development in nature was possible only *within* fixed and immutable species forms, thus remaining faithful to the two Aristotelian Axioms. Then, suddenly, in the eighteenth century, based particularly on new evidence of the age of the earth and on findings that were identified as remnants of extinct living forms, the idea gained ground that there had been in the vast history of the earth a more or less continuous transformation of species forms. Thus, the idea of evolution as a *fact* about the history of the earth was born. What was missing was a *theory* explaining this fact by exhibiting the mechanisms that brought about the transformation of species.

[8] Common lore has the alchemists rather drawn to change forms already abundantly existing in nature (e.g. lead) to those in scarce supply (e.g. gold) than to creating forms never made by Nature herself.

[9] The founding document of modern eugenics is Galton (1865). The very idea of eugenics is much older. Its first known advocate was Plato in his *State*.

It was Darwin's theory of natural selection, published in 1859, that marks the first successful attempt at such a theory and in its basic outlines. Especially important was the role natural selection played as primary evolutionary mechanism, which has remained successful up to the present day.

The theory of natural selection both implies and has been made possible through a significant change of the concept of nature in what are now the biological sciences: The two axioms mentioned above are no longer valid, they have been replaced by a new one:

Axiom *D*: Living nature is not compartmentalized into immutable essences, i.e. species. Throughout the history of the earth, species have evolved and continue to evolve into other, new species.

The relative compartmentalization of nature into the species that we actually observe reveals nothing but an insignificant temporal micro-slice in the vastness of geological time. The overall picture of nature from the evolutionary perspective is one of eternal, although not necessarily continuous, undirected change. Nature Herself, thus, has become the creative force *par excellence*.

II. Human Evolutionary Nature

Darwin was already explicit about the consequences of his theory for man. Still somewhat hesitatingly, he notes in the "Conclusion" of the *Origin of Species*:

> "In the distant future I see open fields for far more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation. Light will be thrown on the origin of man and his history."[10]

Twelve years later, in 1871, Darwin himself first attempted to draw consequences from his theory for man [in his book *The Descent of Man, and Selection in Relation to Sex*[11]]. There are basically two such consequences, the second in some sense implied by the first:

(DC_1) The human species originates from primate species.

[10] Darwin (1959), p. 488. The prospects envisaged by Darwin in this passage were so offensive to Darwin's first German translator, the eminent paleontologist Heinrich Georg Bronn (1800-1862), that he simply left it out of his translation (cf. Junker (1991), 200).

[11] Darwin (1871).

(DC_2) There is a continuity between animals and humans with respect to physical structure and physiological function as well as to the cognitive, emotive and social capacities and their corresponding behaviors. Added to this ontological consequence is a methodological correspondent: methods successfully applied to the evolutionary study of the animal kingdom should also be exercised with humans.

Since the time of Darwin, (DC_1) has become common lore all over the world with the exception of large parts of the population of the United States. Ironically enough, the most radical contenders of (DC_2) are also found in that part of the world.

In its methodological sense, (*DC*2) can be simply understood as a "naturalistic" research program that aims at evolutionary explanations both of human cognition, emotions, social behavior on the one hand and of the whole of culture on the other. "Naturalistic" here means that these fields are no longer the domain of disciplines like philosophy, theology, sociology, cultural studies, and so on; rather, it should be studied with the methods of the natural sciences, particularly of biology and evolutionary theory. Such a program is, of course, useful, but only in so far as it goes. That is not to say it should be criticized *a priori*; but there are "radical" versions of the program that transgress the boundaries of science and, finally aim at a sort of *Weltanschauung*, what Edward O. Wilson, as one of the most radical contenders of that program has called "scientific materialism". Advocates such as Wilson, i.e. radical contenders of (DC_2), will be called ultra-Darwinists or ultra-evolutionists from here on. Ultra-Darwinists do not see many limitations to the power of the naturalistic methodological approach. Daniel Dennett, for example, in his book *Darwin's Dangerous Idea*, applies the metaphor of a "universal acid" to what he takes to be Darwinism; a universal acid is understood to be a liquid that has dissolved and will dissolve everything with which it gets into contact:[12] society, ethics, religion, and what have you.

One can say without exaggeration that one of the most deadly intellectual battles at the millennium is being fought here. This is not at all astonishing, because acceptance of the radical versions of (DC_2) necessitates a complete change in the traditional dualistic concept of human nature; in the ultra-evolutionist perspective, human nature no longer exists in the sense that Descartes, other dualists, as well as the teachings of the Church, have claimed: that there is a *compositum* of two ontologically somehow independent "substances", i.e. matter and mind

[12] Dennett (1995), p. 61ff.

(or soul). Rather, there is only matter. Mental phenomena in the broadest sense of the word are just properties of living matter that emerge at sufficiently complex levels of organization and are shaped by natural selection.[13]

This means for the ultra-evolutionists I am talking about that cognitive, psychological, social, ethical and other aspects of human culture, religion included, are just evolutionary adaptations. Accordingly, they are to be studied by the natural sciences. Theology as well as philosophy and other *Geisteswissenschaften* are still of some value in exhibiting the history of ideas, but they are not able to contribute in a systematical and causally meaningful way to our understanding of cultural phenomena. This view has been contended, for example, for some 25 years now, by Wilson, who probably knows more about ants than anybody else in this world. In the next century, Wilson expects that "the humanities, ranging from philosophy, and history to moral reasoning, comparative religion, and interpretation of the arts, will draw closer to the sciences and partly fuse with them".[14]

IV. Critique of Ultra-Evolutionism

The ultra-evolutionist approach with respect to man has been harshly criticized in the address Pope John Paul II made to the Papal Academy on October 22, 1995. In the "Christian Image of Man and Modern Evolutionary Theories" he states:

> Those evolutionary theories are not compatible with the truth about man that [...] take the mind to be a development of the forces of living matter or a simply an epiphenomenon only of this matter. [15]

This incompatibility is quite obvious, even if one does not share the claim made here and even more elaborately in the Encyclica *Fides et Ratio,* promulgated on October 15, 1998, that the Bible reveals truth in the

[13] In a sense the present battles are a reprise of the bitter fights that at the end of the last century were fought under the banner of "monism" by people like Ernst Haeckel and Wilhelm Ostwald. The difference is that contemporary proponents of monism, or "naturalism" as it is typically referred today, claim to have better arguments than their predecessors a century ago.

[14] Wilson (1998), 12. What Wilson has to say in his book in detail is far less cautious, however. Namely, "Drawing closer" to the natural sciences is clearly meant as replacement by those sciences.

[15] John Paul II (1996), Nr. 5.

same understanding of the word as in the methodology of the natural sciences, or in philosophy. For, in this case, a possible incompatibility of faith and reason amounts to the falsehood of the scientific statement in question, because faith allegedly reveals "ultimate" truth.[16] In the case of Galileo, the Church has made – as we know – disastrous experiences by drawing this conclusion from the contradiction of reason and faith as it was regarded at that time. In my view, it seems advisable to regard "truths of faith" about human nature as categorically different from all possible truths about the same object that might be produced in natural science.[17] This would require that the church abandon any assertions about nature (and the course of history) based on the authority of revelation. Such statements need to be left to the natural sciences, or to history, for that matter, using their established and accepted methods of empirical research. If the church adopted this view, there could not arise an incompatibility between reason and faith, and, hence, there would be no need for rejecting scientifically confirmed "truths".

On the other hand, in my view, there is not much to fear from ultra-Darwinism. As has been convincingly shown by several scholars,[18] both in philosophy and in biology, ultra-Darwinism, particularly insofar as humans are concerned, suffers from serious methodological flaws. In other words: ultra-Darwinist "truths" are in part just poor science.

We many consider a few reasons for this contention[19]: (1) While evolution by natural selection is – as already Darwin himself modestly recognized – the most important principle of evolution, it is not the only one, as assume ultra-Darwinists at least in practice. For example, there is strong evidence that "the great majority of evolutionary changes on the molecular level [...] are caused not by Darwinian selection but by random drift of selectively neutral or nearly neutral mutants" – quoting Motoo Kimura, the founder of the so called neutral theory.[20] (2) Ultra-Evolutionism is based on genetic determinism, i.e. the idea that

[16] Interestingly enough, the two documents do not arrive explicitly at this conclusion, but suggest it only as self-understanding. See esp. Nr. 49-52 of "Fides et Ratio".

[17] I suggest, in other words, a homonymous understanding of "truth" in religion/theology on the one hand and the sciences and philosophy on the other.

[18] To name just two: Stephen J. Gould in his many books puts forward the line of criticism I am here referring to. Particularly instructive in our context are Gould (1997a,b). The second I would like to name is Steven Rose who deals with related questions in Rose (1997).

[19] Cf. Gould (1997a), (1997b).

[20] Kimura (1983), p. xi.

phenotypic traits, complex behavior included, "may be traced solely to genetic agents and their surrogate proteins without recourse to the properties from the complex and nonlinear interactions of these agents" (Strohman (1997), 194). Contrary to this belief, among other things, developmental mechanisms play a particularly decisive role on the causal route from genotype to phenotype, especially going from genes to behavior. Identical genomes, can thus be expressed in widely different ways. We humans share more than 98% of our genome with chimpanzees. Nonetheless, the respective organisms "manage to construct very different results from their nearly identical genes" (Strohman (1997), 195). (3) As has been particularly emphasized by Gould, not every feature that does adaptive service at present has evolved for this service. Environmental conditions that favoured the selection of some characteristic in the first place might change and render this characteristic not useful any more. Yet, the organism might find another use for this characteristic. In any case, evolutionary explanations do not then hold for those features; they are no evolutionary adaptations any more. (4) There is such a great cognitive and social plasticity and general problem solving capacity among humans that it is hardly possible to arrive at *adaptive* explanations for a significant number of significant cultural features.[21] Because of the general intelligence of humans, the universality of a behavioral trait is by no means a sufficient criterion to be an adaptation. It might well be that such a universality results from the general human cleverness in solving problems, complex problems in particular. General human smartness may lead to just one optimal solution of a problem that has been independently found and adopted (almost) everywhere. In sum, the most important and interesting features of our culture, I mean the complex ones, are those that are far away from the rather simple biological adaptations of human evolution and in principle not accessible to adaptive explanations. This is particularly true for the evolutionary explanation of religion. Wilson (1978), for example, has given such an explanation.[22] According to Wilson, religious societies possessed a selective advantage with respect to non-religious ones. In this view, religion served to fence off social groups from one another and to forge them together in unconditional faithfulness. Non-religious groups

[21] One of the rare exceptions might be the almost universal human aversion towards incest. Cf. Bischof (1985).

[22] Wilson (1978), Ch. 8. Wilson (1998) is less explicit on this point, but still holds the same view.

did not have this advantagous disposition and died out. In short, according to Wilson, religion furthers tribalism, and tribalism is good for the survival of a group. Unfortunately, Wilson does not give any evidence for this contention, and to me it seems far from obvious. In particular, two points are very suspicious about Wilson's position. First, it implies the concept of group selection that is notoriously difficult to uphold in evolutionary theory and is rejected by most evolutionary biologists. Second, it is surprising that perhaps the majority of the major religions are explicitly non-tribal or even anti-tribal. Consider, for example, Christianity[23] with the mission command of Jesus (Matth. 28, 19-20): "Go therefore and make disciples of all nations, baptizing them in the name of the Father-Mother and of the beloved Child and of the Holy Spirit, and teaching them to obey everything that I have commanded you."[24]

In concluding my critique of ultra-evolutionism, I would like to briefly consider the notion of changing, or more exactly, bettering human nature by eugenics.[25] Strangely enough, it looks as if the idea of eugenic improvement of human nature cannot be eradicated, although it has been repeatedly compromised in theory and in practice. In failed in *theory*, because the questions of (i) who decides (ii) with which authority and (iii) by what justification (iv) which traits are worth being propagated in the brave new world of eugenics have not yet been answered in a satisfactory way. It seems that a satisfactory answer cannot, in principle, be given. In *practice*, eugenics has failed because eugenic legislation in the first half of the 20th century in the United States and in European countries, not to mention Nazi Germany, has lead to atrocities and violations of human rights that today seem incredible, but were at that time the societal consensus. Nonetheless, eugenics also appear every now and then these days, and even at unlikely places like the Vatican. At the plenary session 1998 of the Papal Academy – which is documented in this volume – William Hamilton, an eminent biologist from Oxford and founder of what

[23] This also applies to Islam. Buddhism, as far as I know, also does not contain tribal restrictions. Judaism, on the other hand, seems to be a tribal religion. – For a more comprehensive critique of Wilson's stand on religion cf. Wolters (1997a).

[24] The wording of this quotation may sound somewhat unfamiliar to most of you. I have taken it from Victor Gold (et al.) (eds.): *The New Testament and Psalms: An Inclusive Version*, New York 1995 (Oxford University Press), one of the oddest products of the collective US-American insanity called "political correctness".

[25] This idea reflects in a sense the (mistaken) idea of evolution as being "progressive".

is called "sociobiology"[26], gave a talk that, unfortunately, has not been included in this volume. Happily enough, Hamilton distributed a written version of his paper. Among other things, he is obsessed by the idea that because of the progress and the effects of medicine, humankind will degenerate more and more. Finally, according to Hamilton, we will end in a state that Hamilton terms a "Planetary Hospital" (Hamilton (1998), *p.* 29). To avoid this state that he deeply abhors[27] he recommends both abortion for genetic reasons and infanticide of individuals born with genetic defects. This is not an unusual position in philosophy these days, not to mention the practice in many countries. In what follows, I am not entering the discussion about infanticide or abortion for genetic reasons to take side with one party or the other. Rather, I would like to analyze Hamilton's arguments for his position. For reasons of simplicity, I restrict myself to the case of killing newborn children with genetic defects. Hamilton's thesis is:

(*HT*) One should kill newborn children with severe genetic defects.[28]

His arguments are as follows:

(H_1) It is the evolved function of the sexual process to eliminate genetically defective embryos. In this sense "Nature" normally aborts genetically defective fetuses, or malformed newborn children are let to die by the "natural" instinct of mothers, respectively.[29]

(H_2) One should not fight Nature (or natural selection, respectively).[30]

(H_3) For parents and siblings, the death of defective fetuses and neonates is best.[31]

[26] The term "sociobiology" was created 1975 by E. O. Wilson, several years after Hamilton's seminal work.

[27] Hamilton confesses: "I have been over the years of my working life slowly developing a paranoia for hospitals" (*op. cit.*, p. 31)

[28] "If early signs of a severe handicap can be detected during that early post-natal period, I hold that the kindest thing for the family on which the defective child is dependant may well be to kill it." (*op. cit.*, p. 23). The following pages of his paper give examples that – in Hamilton's view – it *is*, in fact, the kindest thing to kill it.

[29] "In the state of nature from which we come, before the great religions took hold on us with their theories, the naturally aborted fetus and the malformed neonate which the mother's instinct was undoubtedly to let to die, would have far higher than average probability to be 'mine-shaft' victims. These I insist *it is the evolved function of the sexual process to eliminate.*" (Hamilton, *loc. cit.*, p. 21).

[30] "We are going to have to struggle almost impossibly hard against Nature if we seek long-continued preservation of such [scl. genetically defective] individuals." (Hamilton, *ibid.*).

[31] "While various sophistries are possible concerning how it is not in the best inter-

(H_4) The death of defective fetuses and neonates is also best for the genetic future of mankind.[32]

A closer look at Hamilton's arguments shows that he relies exclusively on (alleged) *facts*, or for that matter the propositions expressing them, in order to justify (*HT*) which is a *norm*. Facts and norms belong respectively to different categories of logical grammar. For example, statements about facts can and must be true or false, whereas norms cannot be true or false. Rather they are adequate or inadequate, good or bad, right or wrong, desirable or undesirable, or what have you. Norms, in short, do not express a state of affairs, but rather require the realization or avoidance of such a state. Any argument that tries to infer norms from facts is logically flawed. Since the Cambridge philosopher George E. Moore coined the term in 1903, this flaw has been called the "naturalistic fallacy".[33]

On the other hand, norms are often related to facts. This relation, though, can be validly deductive only if the argument contains at least one norm, thus (possibly) securing the normative character of the conclusion. Hamilton's deduction of (*HT*) is in need of several such norms.[34] For example:

ests of mutation-burdened embryos or fetuses to be let die, *surely* [emphasis added] for parents and siblings it *is* quite obviously the best thing that can be done." (Hamilton, *ibid.*).

[32] "By seeming to ourselves to be kind to embryos, neonates and the like now, we are actually being *unkind*, firstly to families, secondly to every one in the future." (Hamilton, *loc. cit.*, p. 23).

[33] Also Luigi Cavalli-Sforza's argument in favor of abortion for genetic reasons in this volume suffers from the same logical flaw.

[34] I do not wish to deal here more extensively with the other flaws in Hamilton's arguments, e.g. his explicit racism. So he remarks rightly on the first page of his paper that "he even would gladly sacrifice a hundred unknown Chinese to save a last pair of pandas". Apart from the questionable biological sense of such a "sacrifice" I would like to ask: why just Chinese? Why not "sacrifice" a hundred Oxford professors (Hamilton included), all of them (despite possible expectations to the contrary) probably unknown to "the" Chinese. – Hamilton pretends to be so concerned about the "extinction [because of genetic decline] of Homo" and "the whole of humankind" (*loc. cit.*, p. 9, 10). Contrary to this his concern seems to be mainly about the genetic future of *Homo Britannicus* and its Caucasian kin. For, he is afraid of the possibility that East Asians do not have the "scruples" that prevent "the so-called West of the world" from adopting his eugenic regime. "If we [i.e. Brits and the like] don't, while they [i.e. East Asians] do adopt such policies, we are going to see eastern cultures pull increasingly ahead of the rest of the world in many ways that we all value. And in my opinion easterners will deserve all the health, intellect, and happiness that they get. (Hamilton, *loc. cit.* p. 34f.). –

(HN_1) It is morally imperative to make up with human action for what Nature does effect in Her regular course, but has failed to do in a particular case.

(HN_2) One should not act contrary to natural selection.

(HN_3) The right to life of embryos and newborn children is dependant on the interests of their respective families.

(HN_4) It is morally imperative to care for a "good" genetic future.

The justification of such norms cannot be gained from biology or from any other natural science. Natural science can exhibit only facts. Norms have to be justified in a philosophical discourse that follows its own rules, among them in particular, the idea of universalization that (in practically all cultures) has found its simplest expression in the Golden Rule: "As ye would that men should do onto you, do ye them likewise!".[35]

I would like to conclude by stating that what evolutionary biology has told us so far about human nature in its cultural dimensions is to a large degree just badly founded speculation that would nonetheless claim a respect reserved for objective scientific results. I doubt if anyone of us would step on or drive over a bridge that was constructed with scientific evidence as weak as we find it with ultra-evolutionism.

REFERENCES:

Aristotle (1941): *The Basic Works of Aristotle*, ed. Richard McKeon (New York, Random House)

Bischof, Norbert (1985): *Das Rätsel Ödipus. Die biologischen Wurzeln des Urkonflikts von Intimität und Autonomie* (Munich, Piper)

Darwin, Charles (1859): *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, London (Facsimile edition, introduction Ernst Mayr (Cambridge Mass., Harvard University Press, 1964)

Darwin, Charles (1871): *The Descent of Man, and Selection in Relation to Sex*, (London)

Well, I find it difficult to understand these embittered lines if Hamilton really means what he says elsewhere: "For me extinction of Homo is worse even than an extinction of my known circle of family and friends." (*loc. cit.*, p. 9). When easterners thrive, this seems good for *Homo* to me.

[35] Among philosophers the Golden Rule has always suffered from some condescension. It is just too simple. Philosophical refinements include Kant's categorical imperative. For the philosophical justification of norms and its relation to scientific procedures of validation cf. Wolters (1997b).

Dennett, Daniel (1995): *Darwin's Dangerous Idea: Evolution and the Meanings of Life*, (London Allan Lane The Penguin Press)

Galton, Francis (1965): "Hereditary Talent and Character", *MacMillan's Magazine* 12, 157-166, 218-227

Gould, Stephen J. (1997a): "Darwinian Fundamentalism", *The New York Review of Books*, June 12, 1997, 34-37

Gould, Stephen J. (1997b): "Evolution: The Pleasures of Pluralism", *The New York Review of Books*, June 26, 1997, 47-52

Hamilton, William D. (1998): "Changing and Evolving Nature: The Human and the Rest", typescript distributed by the author at the Plenary Session 1998 of the Pontifical Academy ("Changing Concepts of Nature at the Turn of the Millenium", October 26-29, 1998)

John Paul II. (1996): "Truth Cannot contradict Truth" [Address to the Pontifical Academy on October 22, 1996], *Osservatore Romano*, English Edition, October 30, 1996

John Paul II. (1998): "Encyclical Letter "Fides et Ratio"", promulgated October 15, 1998

Junker, Thomas (1991): "Heinrich Georg Bronn und die Entstehung der Arten", *Sudhoffs Archiv* 75, 180-208

Kimura, Motoo (1983): *The Neutral Theory of Molecular Evolution* (Cambride University Press)

Mittelstraß, Jürgen (1981): "Das Wirken der Natur. Materialien zur Geschichte des Naturbegriffs", in: Friedrich Rapp (ed.): *Naturverständnis und Naturbeherrschung. Philosophiegeschichtliche Entwicklung und gegenwärtiger Kontext* (Munich, W. Fink), pp. 36-69

Paracelsus (= Theophrast von Hohenheim) (1924): *Das Buch Paragranum*, in: Karl Sudhoff (ed.): *Theophrast von Hohenheim, gen. Paracelsus: Medizinische, naturwissenschaftliche und philosophische Schriften*, Bd. 8 (Munich/Berlin, Barth), 133-224 (repr. Hildesheim Olms, 1996)

Ritter, Joachim/Gründer Karlfried (eds.) (1984): "Natur" [authors: F.P. Hager, A. Maierù, G. Stabile, F. Kaulbach], in: *Historisches Wörterbuch der Philosophie*, vol. 6, Basel (Schwabe), 421-478; "Natura naturans/naturata" [author: K. Hedwig], *ibid.*, 504-509

Rose, Steven (1997): *Lifelines: Biology, Freedom, Determinism* (London, Allen Lane The Penguin Press)

Strohman, Richard C. (1997), "The Coming Kuhnian Revolution in Biology", *Nature Biotechnology* 15, March 1997, 194-200

Wilson, Edward O. (1978): *On Human Nature* (Cambridge Mass., Harvard University Press)

Wilson, Edward O. (1998): *Consilience: The Unity of Knowledge* (New York, Knopf)

Wolters, Gereon (1997a) "Evolution als Religion?", in: Fritz Stolz (ed.), *Homo naturaliter religiosus – Gehört Religion notwendig zum Menschsein?* (Bern, Peter Lang), pp. 137-166

Wolters, Gereon (1997b): "Orientierungswissen als Humanressource", in Günter Clar/Julia Doré/Hans Mohr (eds.): *Humankapital und Wissen. Grundlagen einer nachhaltigen Entwicklung* (Berlin, Springer), pp. 33-51

THE ENVIRONMENT AND CHANGING CONCEPTS OF NATURE

WILLIAM R. SHEA

At the end of this millennium, a banner is increasingly unfurled. It reads: "Nature knows best", and its followers insist that the solution to the depletion and waste of natural resources lies in listening to Nature and what she has has to say. Since Nature does not write her own reports, this means attending to her behaviour, learning to share her thoughts and espouse her aspirations. But to whom is the description of Nature to be entrusted and in what language should it be couched? One answer is to call on environmentalists and to recommend the idiom that contemporary society considers most persuasive: quantitative measurement. But what kind of environmentalists? Nature lovers or professional ecologists? The descriptions offered by these two groups will not necessarily tally. Members of Greenpeace, for instance, focus on offenses against Nature and often describe them as cases of "abuse" or "rape". The implication, sometimes explicit but normally tacit, is that Nature in its undisturbed "natural" state is a haven of *stability* and *diversity*, two characteristics that are elevated to the status not merely of facts but of moral values. Nature is good and, uncorrupted by humans, fundamentally benign. A society attuned to Nature would become an integral part of the harmonious equilibrium between all forms of life. By contrast, scientists are less prone to enshrine the concept of the balance of Nature and more willing to mention such words as rivalry, exclusion and exploitation.

But surely the quantitative language of ecology, on which all parties agree, is not open to biased interpretation? The measurements themselves may not be problematic but their significance is a matter of disagreement, sometimes of heated argument. We can see this in profound divergences over environmental risks by groups that have access to the same quantitative data. Green activists perceive considerably more risk than industrialists, and yet industrialists cannot be said to be acting in an irresponsible or unfeeling way. After all they pay handsomely for independent risk assessments from outside firms and universities! How many parts per billion of a toxic materials is "acceptable" is not a question that can be answered by epidemiological studies alone. For many, zero pollution is a goal that requires zero tolerance of any environmental contamination. What is crucial in the discussion is not the percentage number but the word *pollution* that has acquired an unprecedended popularity and ubiquity in recent years. The Oxford dictionary gives as the three main definitions of *pollute*: 1. contaminate or defile (the environment); 2. make foul of filthy; 3. destroy the purity or sanctity of. These three usages are not mutually exclusive since the second and the third resonate when the first is heard. Indeed, debates on physical pollution are often thinly disguised debates on the purity and sanctity of the environment. This is why there is so much opposition to expert opinion that a minute quantity of a pollutant poses no risk to human health and no threat to Nature. There is something foul in the notion of allowing pollution, however insignificant. What is objectionable is not only the danger to human beings but the implied affront to Mother Nature.

Pure Nature

The fear of pollution is a universal constant of individual and societal consciousness. It is as common among "advanced" societies as among those that were once described as primitive. Whether a community uses high technology or relies on traditional crafts, it is always the case that some things are identified as contaminants and considered a menace to the security and well-being of individuals or society. The use of soap before eating is a modern way of warding off the evil consequences of dirt. Those who forgo this practice are perceived as potential threats and are either reprimanded or shunned. But what is dirt? It is not merely matter, but matter out of place, matter violating a system of organization. As the anthropologist Mary Douglas puts it in *Purity and Danger*:

> Where there is dirt, there is system. Dirt is the by-product of a systematic ordering and classification of matter, in so far as ordering involves rejecting inappropriate elements. This idea of dirt takes us straight into the field of symbolism and promises a link-up with more obviously symbolic systems of purity (Douglas, 1996a).

Pollution not only casts a shadow over our health, it violates our sentiment of what is right and fitting. This is why, Mary Douglas explains, "dangers-beliefs are as much threats which one man uses to coerce another as dangers which he himself fears to incur by his own lapses from righteousness. They are a strong language of mutual exhortation. At this level the laws of Nature are dragged in to sanction the moral code" (Douglas, 1996b). When we hear that such-and-such an individual or a company has committed an act that pollutes the environment, we point an accusing finger at the perpetrator not only for sullying the physical environmental but the order of things that the environment represents. Although we may not always realize the real cause of our indignation, it is the attack on our idea of Nature that we resent most. Neil Evernden goes to the root of our malaise when he writes, "the debate is not simply about the physical contamination of Nature but about the moral contamination of an ideal" (Everden, 1992). Environmental confrontations about the use of water (say to flood a wooded area to generate hydroelectric power) are really about what constitutes proper behaviour. In a society that is sufficiently homogeneous the environmental ideal will be broadly shared and conflict will be rare. In our pluralistic society, where there is no common conception of proper behaviour and no authority to guide us, we cannot expect a spontaneous consensus on environmental issues. We find, however, that participants in the environmental debate, unlike in politics or moral philosophy, often assume that there is an authority that could settle all disputes if we would but listen to its voice. This is Nature who declares "unnatural" whatever violates her integrity and the "right" order of things. Since physical pollution is both the consequence and the sign of moral turpitude, we should not be surprised that emotions run high when Nature is believed to be at risk. What opposing parties do not realize is the plasticity of the concept of Nature. Even works that purport to offer an historical account of the genesis of our ideas about the environment assume that the notion of Nature is obvious. For instance, in his deservedly popular *The Rights of Nature: A History of Environmental Ethics*, Roderick Frazier Nash declares:

> This book concerns the history and implications of the idea that morality ought to include the relationship of humans to Nature. Focusing on American intellectual history, it traces the relatively recent emergence of the belief that ethics should expand from a preoccupation with humans (or their gods) to a concern for animals, plants, rocks, and even Nature, or the environment, in general. One way to think of this is as an evolution of ethics from

> the natural rights of a limited group of humans to the rights of part, or, in some theories, all of Nature. ... From this perspective one can regard environmental ethics as marking out the farthest limits of American liberalism (Nash, 1989).

On this view, the extension of "natural rights" to "Nature" itself is the next "natural" step in the movement to liberate oppressed minorities. Nature, or the natural environment, must be freed from human domination.

The Nature as the Normative

Leaving aside for the time being the ambiguities built into the word Nature, we can ask the simple question. How do we know what Nature wants? Let us examine a hypothetical situation in order to give our question a more concrete turn. Suppose a large firm decides to develop a ski resort on a mountain top in a national park. The advantage to the inhabitants of the neighbouring city, which is increasingly polluted, are obvious, and the citizens, in sore need of fresh air and exercise, vote overwhelmingly to allow an access highway to be cut across the virgin forest and for trees to be felled to make room for downhill runs and cross-country trails. Environmentalists raise their voice and object that we cannot sacrifice the integrity of the mountains and that we have no right to deprive animals of their freedom. Now freedom and autonomy are moral values that humans hold dear, but what reason have we to believe that animals see them, if not in the same, at least in an analogous light? Wild animals frequently show their preference for the sanctuary of a controlled environment. The deer is for us a symbol of freedom but a fawn might be happier being fed in a park rather than risking starvation in the wilderness. The interests of trees and plants are more difficult to imagine but we could argue that maple trees would feel more secure in neat rows where they could grow naturally without choking one another, and without having to gasp for air, water and light.

If we leave our hypothetical mountain for a real natural environment, we find that the problems are not lessened. Take one of the world's most breath-taking sites: Niagara Falls. The process of erosion that began several thousand years ago is decreasing the height of the Falls and piling up a very considerable amount of talus at the bottom. The flow of water and hence the majesty of the Falls is changing. Most people feel that it would be better in the Falls were restored to their pristine glory or, at least, if the deleterious effects of erosion were stopped. Left to itself, the

Falls would wear away. There is nothing pernicious about changes wrought by Nature, but there is a widespread consensus that the Falls should be as close as possible to the ideal waterfall that they represent. Niagara Falls is much more than millions of litres of water pouring over an enormous cliff. It is a symbol of the grandeur and beauty of Nature. It is also, by the way, the reason for a multi-million-dollar-per-year tourist industry. The Canadian and American governments, who are responsible for the river through which the water flows, saw the need to create an international Committee to study what could be done to save Niagara Falls from a further reduction of its height and, hence, of its grandeur.

The members of the Committee soon realized that no intervention could be justified until a decision was taken on how to treat the Falls, and they proposed three ways of doing this (Krieger, 1972). First, the Falls could be frozen in its present state by strengthening the structure of the walls and preventing rockfall. Debris at the bottom could also be removed. This would turn the Falls into an international monument. Second, the Falls could be treated as an event. Some of the larger boulders at the base could be removed but the rockfall would not be arrested. Sophisticated computerized sensors could be installed to monitor the impending fall of rock, and visitors would come to Niagara to see a dramatic instance of the natural process of erosion. Third, the Falls could become a show, a grandiose *son et lumière*, controlled by engineers who would alter the flow of the water to produce a number of spectacles to illustrate the wonder and power of natural forces.

What is the proper environment of the Falls? If the forces of Nature are to be totally liberated and allowed to do their work, then they should be allowed to fall. Our reluctance to let Nature have its way emphasizes the ambiguity of the concept of Nature and the role society and culture play in defining the natural environment.

One particular aspect of the environment that has been socially constructed in recent years, especially in America, is the idea of wilderness as the embodiment of what is healthy and good. For the early settlers, the wildness was something quite different. The harsh and cold climate, especially in January and February, and the constant fear of Indian incursions, made the environment unfriendly and threatening. Michael Wigglesworth described it in 1662 as:

> A waste and howling wilderness
> Where none inhabited
> But hellish fiends and brutish men
> That devils worshiped.

When Alexis de Tocqueville visited America in 1831 he was struck by the general indifference of Americans to the wilderness that had awed his contemporary Chateaubriand. He writes in *De la démocratie en Amérique*,

> On s'occupe beaucoup en Europe des déserts de l'Amérique, mais les Américains eux-mêmes n'y songent guère. Les merveilles de la nature inanimée les trouvent insensibles et ils n'aperçoivent pour ainsi dire les admirables forêts qui les environnent qu'au moment où elles tombent sous leurs coups. Leur œil est rempli d'un autre spectacle. Le peuple américain se voit marcher lui-même à travers ces déserts, desséchant les marais, redressant les fleuves, peuplant la solitude et domptant la nature. Cette image magnifique d'eux-mêmes ne s'offre pas seulement de loin en loin à l'imagination des Américains; on peut dire qu'elle suit chacun d'entre eux dans les moindres de ses actions comme dans les principales, et qu'elle reste toujours suspendue devant son intelligence (Tocqueville, 1981).

Nature had to be conquered and subdued, turned into a more hospitable and comfortable place. Above all it was to be covered with the great American symbols of freedom and power, the railroad in the nineteenth century and the car in our own. Even Thoreau felt this excitement. "When I hear the iron horse make the hills echo with its snort like thunder", he wrote, "it seems as if the earth has got a race now worthy to inhabit it" (Thoreau, 1971).

The subjection of Nature by man was not an unqualified success, especially for those people who were driven from the countryside to inhabit cities rendered squalid by industrial pollution. This is why Nature in the Romantic poetry of the eighteenth and nineteenth century often means rural as opposed to urban. There is nothing very startling in the discovery that one can find peace and contentment in the countryside. Since Horace there had seldom lacked poets to recommend the virtues of life away from the din of the city. What is different in writers like Wordsworth and Coleridge is the intensity of the sense of relief and restoration that they experience on getting out into the country. The emotion seems the outcome of the rapid growth of towns and the development of a way of life very different from the rural. It is the city-dweller that began to feel the need of Nature and the importance of preserving the natural environment. The environmental movement was not born on farms where the call was rather for electricity and increased mechanization.

The maxim that God made the country and man made the town is at least as old as the Latin poet Varro. The novelty is the fear that Nature is somehow running out. When Wordsworth "escaped from the vast city" in which he had long "pined a discontented sojourner", there was no doubt in his mind that Nature was plentiful, easy of access and indestructible. It was a living presence, which he hailed in his famous poem, *Lines composed a Few Miles Above Tintern Abbey*, as

The anchor of my purest thoughts, the nurse
The guide, the guardian of my heart, and soul
Of all my moral being.

This is not a description of the natural environment, but a metaphysical statement about the relationship between Nature and man, her "worshipper", whom she leads "from joy to joy". What the Bible was to an earlier generation, Nature became for the Romantics: an authoritative voice and the norm of moral excellence. The appeal to Nature certified the legitimacy of a particular belief. Once it was declared "natural", it needed no further credentials. This is why an "environmental ethic" is treated by those who favour such a notion as the first step towards a recognition of the sovereignty of a permanent natural law that constitutes the given as opposed to the contrived or civil law. In spite of occasional lip-service to Darwin, environmentalists regard Nature as a fixed state rather than a dynamic process. Eagerness to reform may look back, as it did in the case of Jean-Jacques Rousseau, to some earlier, simpler and happier mode of existence. Although modern man is less inclined to believe that progress means shaping the future like the primeval past, he is deeply concerned about the relentless harnessing of the forces of Nature. Without knowing it he is reacting against the mechanization of Nature that was until recently hailed as the greatest achievement of the Scientific Revolution. He is increasingly uncomfortable with the assumption that the universe of Nature should be understood, as in all our scientific textbooks, on the analogy of a machine rather than on the analogy of an organism as it was prior to the seventeenth century.

The Womb of Nature

The analogy that is uppermost in the consciousness of an age is not merely a matter of convenience; it determines our attitude towards Nature. For instance, because the earth was considered a living being in Antiquity, the formation of metals was seen as the result of a long gestation in womblike matrices deep below the surface. This idea carried ethical implications for mining. In his *Natural History*, Pliny (23-79) warned against invading the womb of mother earth and conjectured that earthquakes were her way of expressing her indignation at this violation. "Quam innocens", he added, "qua beata, immo vero etiam delicata esset vita, si nihil aliunde quam supra terras concupisceret, breviterque, nisi quod secum est" (Pliny, 1979) Ovid, in the *Metamorphoses*, contrasts the happy state of mankind before mining was practised with the evil let loose in the form of greed and trickery as men dug into the earth's entrails in the age of iron. Seneca also lamented the greed that made men pry into the veins of the earth: "Quae tanta necessitas hominem ad sidera erectum incurvavit et defodit et in fundum telluris intimae mersit, ut erueret aurum non minore periculo quaerendum quam possidendum?" (Seneca, 1972). These texts were quoted well into the sixteenth and the seventeenth century. The Ovidian theme is echoed in the two greatest epic poems in English: Edmund Spencer's *Faerie Queene* (1595) and John Milton's *Paradise Lost* (1667). Spencer laments the day when mining began:

> Then gan a cursed hand the quiet wombe
> Of his great Grandmother with steele to wound,
> And the hid treasures in her sacred tombe
> With Sacrilege to dig...

Milton describes "bands of pioners with Spade and Pickaxe" who, led on by Mammon,

> Ransacked the Center, and with impious hands
> Rifled the bowels of their mother Earth
> For Treasures better hid. Soon had his crew
> Opened into the Hill a spacious wound
> And diged out ribs of Gold.

The large-scale development of mining in the sixteenth century, especially in Germany, led to a shift in the appraisal of the extraction of ore from the bosom of the earth. Vannoccio Biringuccio and Agricola (Georg Bauer) argued that minerals and metals are blessings from heaven and that those who did not avail themselves of them wronged themselves and their fatherland. Just as man catches fish out of the deep blue sea, so he hauls up bounty from the deepest recesses of the Earth. Although Biringuccio and Agricola did not make a frontal attack on the metaphor of the Earth as a nurturing mother, their vindication of mining and their praise of machinery contributed to the demise of the organic model and prepared the rise of the mechanistic image that replaced it.

The growing interest in machinery is illustrated in the writings of

Renaissance engineers such as Leonardo da Vinci (1452-1519) and Francesco di Giorgio Martini (1439-1501). By the time Montaigne went on an extended tour of Switzerland, Southern Germany and Italy in 1580-1581, it had become fashionable to be on the look-out for technological innovations, especially if they had entertainment value. In his *Journal de voyage*, Montaigne notes practical devices for hoisting and distributing water, and he particularly admired the fine display of fountains and waterfalls at the Villa d'Este in Tivoli. He comments enthusiastically on the hydraulic organs that played music to the accompaniment of the fall of water, and devices that imitated the sound of trumpets. He relates how birds began to sing and how, when an owl appeared on a rock, the bird-song ceased abruptly. The rest of Europe sought to emulate Italian achievements and Henri IV borrowed from the Granduke Ferdinand I (1551-1609) the services of Tommaso Francini and his brother, Alessandro, to design the water-works at Saint-Germain-en-Laye. Their creations were to inspire Descartes who either saw them personnaly or read about them in Salomon de Caus' illustrated *La raison des forces mouvantes avec diverses machines tant utiles que plaisantes auxquelles sont adjoints plusieurs dessins de grottes et fontaines* (Frankfurt, 1615).

Closely related to the growing interest in machines was the fascination with automata based on models found in antiquity When the Emperor Charles V abdicated in 1555 and retired to the convent of San Yuste he was accompanied by a staff of retainers, among whom was Gianello Torriano of Cremona (ca. 1515-1585), who distracted the monarch with mechanical figures that simulated the actions of human beings, for instance, lute players. The singing bird of Philo and Hero were motivated by compressed air or steam. An important innovation of the sixteenth century that made possible the reproduction of sound within a self-contained unit was the revolving pinned barrel or cylinder. The action of pins or pegs attached to the circumference of the cylinder or barrel at right angles to the axis could be transmitted some distance by means of simple levers as the cylinder revolved. If these levers were placed in contact with valves of organ pipes, the pipes would sound for as long as the pins continued to make contact with the levers. The device made possible the completely mechanical performance of automatic sounding instruments. One of the earliest applications of this invention was made in an organ clock and presented as a gift Queen Elizabeth to the Sultan of Turkey in 1599.

Nature as the Grand Machine

These technological innovations provided an environment where natural philosophers had their attention directed to mechanical processes they might otherwise have overlooked. Technological progress hastened the recognition of a new purpose for natural philosophy. The spokesmen of the new school of thought were numerous but none was more eloquent than the Lord Chancellor, Francis Bacon. In the opening lines of the *Novum Organum* he wrote: "Homo, Naturae minister et interpres, tantum facit et intelligit quantum de Naturae ordine re vel mente observaverit, nec amplius scit aut potest. ... Scientia et potentia humana in idem coincidunt". Bacon stressed that Nature was not only to be contemplated but modified and improved. Knowledge confers power and for the Lord Chancellor power was to be used for the establishment of the kingdom of man over Nature.

Descartes was equally insistent on the domination of Nature as the goal of the "practical" philosophy which he opposed to the "Philosophie spéculative" of the Schoolmen in his *Discours de la méthode*:

> Au lieu de cette philosophie spéculative, qu'on enseigne dans les écoles, on en peut trouver une pratique, par laquelle connaissant la force et les actions du feu, de l'eau, de l'air, des astres, des cieux, et de tous les autres corps qui nous environnent, aussi distinctement que nous connaissons les divers métiers de nos artisans, nous les pourrions employer en même façon à tous les usages auxquels ils sont propres, et ainsi nous rendre comme *maîtres et possesseurs de la Nature* (Descartes, 1897-1913a).

For Descartes, the material world, all the material world, is made up of cogs and wheels, of cranks and shafts. The component parts of Nature are bits and pieces of machinery, and machines, regardless of their size or complexity, have no end of their own. They are to be used to promote human welfare. The world is a machine in the literal sense of an arrangement of material parts designed, assembled and set in motion for a purpose by an intelligent mind outside itself, the supreme Watchmaker and Ruler of Nature. This view depends on the Christian notion of a creative and omnipotent God but it is also based on the experience of designing and building machines. In his *Traité de l'homme*, Descartes refers to water-powered automata in the royal gardens to explain the operations of the human body which, he writes:

> n'est autre chose qu'une statue ou machine de terre. Et véritablement, l'on peut fort bien comparer les nerfs de la macine que je vous décris, aux tuyaux des machines de ces fontaines; ses muscles et ses tendons, aux autres divers engins et ressorts qui servent à les mouvoir; ses esprits animaux, à l'eau qui les remue, dont le cœur est la source ... la respiration et autres telles actions ... sont comme les mouvements d'une horloge, ou d'un moulin, que le cours ordinaire de l'eau peut rendre continus (Descartes, 1897-1913b).

Descartes' idealized hydraulic automata are more perfect than human beings. He marvelled at their regularity, consistency and reliability, all explainable in terms of the shape, size and motions of their parts. If Descartes had never seen automata it is unlikely that he would have pinned such faith on the possibility of a mechanical explanation of Nature.

Descartes was not alone in his fascination with watchmaking. As early as 1541, Joachim Rheticus asked in the *Narratio Prima*, one of the first accounts of Copernicanism, "Deo naturae conditori eam industriam non tribueremus, quam communes horologiorum Artifices habere cernimus?" (Rheticus, 1938). A younger contemporary of Descartes, Robert Boyle, repeatedly referred to the world as a "great automaton" on the analogy of the cathedral clock in Strasbourg. Man, created in God's image, transcends Nature and, in a clockwork universe, exercises his stewardship as a mechanic rather than a shepherd. When the world was conceived as an organism, to intervene in Nature was to act upon entities endowed with their own vital forces. Now Nature could be wound up, regulated and oiled like a machine.

Put in this stark way, it is clear that the conception of Nature that underlies much of science is an intellectual and social construct. The mechanical philosophy is as much a mirror of ourselves as it is a reflection of *what is really out there*. Our ideas about Nature contain a remarkable amount of history and are in need of social validation. Natural processes, said to be described on their own terms without any prior assumption of purpose or design, are really cobbled together out of mechanical principles. When we describe Nature we are always looking at an image we have constructed. It is important to remember this at a time when we are groping for a better one. To forget history is to run the risk of turning a new symbol into a graven image.

REFERENCES

Douglas, Mary, 1966a, *Purity and Danger* (London: Routledge and Kegan Paul), p. 35

Douglas, Mary, 1966b, *Purity and Danger* (London: Routledge and Kegan Paul), p. 3

Everden, Paul, 1992, *The Social Creation of Nature* (Baltimore: Johns Hopkins University Press), p. 6

Descartes, René, 1897-1913a, *Oeuvres*, eds. C. Adam and P. Tannery (Paris: Léopold Cerf), VI, pp. 61-62

Descartes, René, 1897-1913b, *Oeuvres*, eds. C. Adam and P. Tannery (Paris: Léopold Cerf), XI, pp. 130-131

Nash, Roderick Frazier, 1989, *The Rights of Nature: A History of Environmental Ethics* (Madison: University of Wisconsin Press), p. 4

Ovid, 1977, *Metamorphoses* (London: Heineman), bk I, lines 137-150

Pliny, 1979, *Historia Naturalis* (London: Heineman), bk XXIII, pp. 1-3

Rheticus, Joachim, 1938, *Narratio Prima* in Kepler, *Gesammelte Werke*, eds. M. Caspar (Munich: Beck) I, p. 100

Krieger, Martin H., 1972, "What's Wrong with Plastic Trees", *Science* 179 (February), pp. 447-448

Seneca, 1972, *Naturales Quaestiones* (London: Heineman), bk. V, p. 3

Thoreau, Henry David, 1971 (Princeton: Princeton University Press), p. 116

Tocqueville, Alexis de, 1981, *De la démocratie en Amérique* (Paris: Garnier Flammarion) II, pp. 94-95

THE MEANING OF NATURE

LUCA CAVALLI-SFORZA

I feel greatly honored at having been invited to illustrate what I mean by the word 'Nature' and to have a chance to compare notes with my colleagues. When I was asked if I wanted to become a member of the Pontifical Academy, I was glad to accept because I was assured that my beliefs were no limitation and that the purpose of the Academy is the search for truth. Both the religious and the scientific person cherish truth, but there is a radical difference in their approach: the first searches for truth through faith and the second through doubt. They remain united by the persuasion that there is only one truth. The Church has recently taken important steps to open up discussion with science, for instance in relation to evolutionary theory. Of course, what seems to me one of the greatest achievements of this Pontificate was the recognition that it was an error to force Galileo to deny his scientific theories publicly. The original condemnation was wrong whether or not Galileo was right in his astronomical statements and beliefs because it condemned not a particular result but the scientific method as a whole.

The request made to me to speak on the meaning of Nature added 'in the light of anthropology'. My credentials to speak for anthropology may be questioned, as I have taught genetics, and not anthropology, for most of my life. It is true, however, that my research has almost always been on human population genetics and evolution, which is part of any course of general anthropology. I was formally a professor of anthropology at the University of Florence, but this could be hardly considered a serious credential as after an extremely short time I resigned for personal reasons. Somewhat earlier, I had been offered the chair of the Anthropology Department at Harvard. I did not accept, in spite of the exceptional opportunity it might have given me to influence American anthropology, because I had better chances of continuing my research in the Stanford environment.

It is difficult, however, to summarise the present ideas of anthropologists. American anthropology is undergoing a severe schism. A separation into what were called Biological or Physical Anthropology on the one side, and Cultural Anthropology on the other, has already taken place at Stanford and is brewing in other universities. As is often the case, the example set in California, which usually still acts as the pioneer state, may well be followed in other parts of the United States. Many American cultural anthropologists have been strongly influenced by the anti-scientific stance of some French post-modern philosophers and have chosen to narrow enormously the width of their subject, turning their interests to a subset of social sciences distinguished from sociology only because they usually do not employ a quantitative approach. I do not believe that this approach to anthropology can offer much insight into the meaning of Nature – it is not interested in Nature but only in some behavioral aspects of just one living organism.

This long preamble may help to explain the anthropological angle from which I approach the problem of what Nature is. I also want to clarify at the outset some potential misunderstandings. My special research interests brought me occasionally to use the word 'Nature' in a narrow sense, as the opposite of 'Nurture'. In fact, genetics was concerned for a long time with distinguishing the genotype, that is to say what is inherited, from the phenotype, that is to say what is observed, in living beings, and this includes potentially the whole anatomy, physiology and psychology of an individual. The phenotype typically arises from the development of an individual genotype, with all its inborn tendencies, within a particular environment, both physical and social. The phenotype is, in other words, the realization of the genotype; it inevitably includes the genotype, but is also the product of what is usually called the 'environment', that is to say the conditions, ranging from physical to social ones, in which individual development takes place.

When I started research in genetics one had to infer the genotype of an individual on the basis of its ancestors and descendants, that is to say its genealogy, and information on gene function, e.g. dominance, interactions between genes etc. Inference of the genotype was an important part of the geneticist's art and science. Today we have witnessed an enormous simplification: one can say, without fear of excessive reductionism, that the genotype is nothing but DNA, and is accessible by straightforward chemical analysis.

Replacing the word 'genotype' with the word 'DNA' is a very substantial progress. It does give us the feeling that we have the power to know everything that is genetically determined, and that all we have to do is to wait for the end of the sequencing of the genome for this to be true. This feeling is basically correct, but has three serious limitations, at least today and for an unknown length of time. One: the real interest for practical purposes is the phenotype, which is also controlled by the individual 'environment' in ways which are sometimes difficult to understand completely. The second is that the DNA of every individual is different. Technology will give us the chance to discover the DNA of each individual more easily than is presently the case, but the third difficulty is that we still do not have the keys by which to understand how far knowledge of DNA can take us in predicting the phenotype, except in a few instances. We know how painful and difficult it is to learn in full the functions of a gene. The significance of many small, superficially trivial, but sometimes important details of DNA structure still escapes us. We will certainly learn general rules which will make the procedure less slow and difficult, but the task ahead includes the function of almost a hundred thousand genes, and their interactions with, and reactions to, environmental conditions. To understand Nature, including the effects of Nurture, knowledge of DNA is not enough. We must also learn about Nurture.

I became personally interested in another dichotomy: that between Nature and Culture. Culture is a very special part of Nurture: I view culture as the accumulation of knowledge over generations; or one can also call it everything that we learn from others. It is obviously a product of communication. It is important to remember that culture is not at all limited only to humans; it is clear that most animals have knowledge which is acquired culturally. But humans are by far the most highly cultural animals. This does not come as a surprise because humans are also the animals which have the most highly developed language – so much so that many prefer to reserve the term 'language' exclusively to human communication. There is undoubtedly a difference of orders of magnitude between the wealth of words or concepts that are communicated by human language compared with the best that animals achieve, at least judging on the basis of what we have learnt about their 'language' and the communication with them we have been able to establish through the artificial languages designed to this aim. But perhaps the sharpest differences between the languages of animals and humans are in the wealth of structure found in human language, the wealth of neural structures connected with the production and perception of language in the human brain, and the strength of the innate predisposition which makes the learning of language the most natural and important activity of children of very young ages. The rich biological predisposition to acquire language makes human communication quite distinct from all the examples we observe in animals.

Anthropologists have long been searching for differences between humans and non-humans. For a long time they stopped at differences in the structure of the hand, important for tool development, and the erect posture, which freed hands for tool making.

More recently, there has been enthusiasm for 'symbolizing'. This is in my view the wrong approach. It is very difficult, if not impossible, to evaluate the level of abstract and rational thinking in animals, but I believe that if it were totally absent it would be practically impossible for them to reach the accuracy of decision-making which is shown by their living strategies. It is also incorrect that animal behavior is entirely achieved by instinct, that is by genetic predisposition. It seems to me that the amount of teaching and learning that is observed in many animals, especially but not exclusively birds and mammals, does of necessity involve some degree of 'symbolizing'. In any case, these words seem meaningless to me until we can give to them some basis in terms of neurological structure. In its absence, this kind of discussion is a waste of time, but I would not be surprised if the difference in 'symbolizing' between humans and animals turned out to be, like everything else, a matter of degree, even if in some domains it may involve differences of order of magnitude on a quantitative scale.

I am persuaded that human language has contributed enormously to the capacity for abstract and rational thinking in humans and to cultural learning by communication. Naturally, it is difficult to establish rigorous criteria for saying which of the various differences observed among humans and animals was the most important in enabling us develop the enormous control over nature that we have achieved. My own view is that culture, and the major factor behind it, language, hold many, if not most, of the keys to understanding abstract and logical reasoning. It would be impossible to have speech such as we do without a strong understanding of logical relationships. Many tend to view God as a logician, or a mathematician, which is almost the same thing. Neither logics nor mathematics are the absolute privilege of humans, as animals can to some extent reason or count, but I believe they are certainly much more developed in humans than in animals.

I have mentioned the dichotomies of Nature and Nurture, Nature and Culture, essentially in order to affirm that the real Nature I would like to consider through this word must also include Nurture and Culture, especially the latter. In the definition I use, Culture is essentially accumulated learning derived from interaction with other human beings, in part by simple observation of the actions of other humans (or animals), in part by direct and voluntary teaching by others. The word 'Nurture' tends to include mostly aspects of the environment which are largely inanimate, as well as living beings other than humans. But humans have adapted to many different environments, in part by biological mechanisms, but even more by cultural ones. Thus, much of Nurture is derived by cultural means, that is to say by some form of communication with others, making the distinction between Nurture and Culture occasionally difficult but unnecessary at this moment if we include them both in the more general definition of Nature. Simple Nature, bared of all the products or interactions of living organisms with themselves and the physical environment through Nurture or Culture, would be essentially just DNA, which is only one ingredient, even if an absolutely essential one, of life.

In the era of prions and their capacity for autocatalytic growth one might want to add them to DNA in thinking of the genotype. But the basic importance of prions in the economy of development and that of living beings is still to be verified, and there is still the possibility that it is quite limited. We have to be careful, however. There was in the forties a similar situation with regard to DNA. At the time of the first discovery of the chemical nature of the pneumococcus transforming principle, it was still possible to think that DNA might have had limited importance. But today we have replaced the idea of the genotype with that of DNA. It is too early to say whether one should give small or great importance to prions in biology, at least at the present time.

How has the modem world of Nature, meant in this wide sense, come about? It is the product of an evolutionary process in which the self-reproduction of DNA is governed by natural selection. For life to exist, organisms must be able to reproduce themselves. We know DNA makes this possible. We know DNA is the structure whose reproduction makes life possible. It is of course possible, and even likely, that at the very beginning self-reproduction was carried out by RNA, and that the transition to the era in which DNA was mostly, if not alone, responsible for the self-duplication of hereditary structure was a later step. But it was certainly a fundamental one, and today it clearly has overwhelming importance.

We also know that, as is the case with all reproduction, there are unavoidable mistakes in the process of copying DNA. They are called mutations. Mistakes in the reproduction of DNA are always carried forward to later generations, at least potentially, because the DNA changed by a mutation becomes like all other unchanged DNAs, the model or master copy used to produce the next generation. In the generation after a mutation has occurred, there are likely to be produced one or more copies not only of all the original types, but also of the mutant DNA. The mutation will be lost only if the individual whose gametes carry a new mutant has zero progeny.

Reproduction accompanied by mutation generates evolution, but our explanation would be pitifully unsatisfactory without one more fundamental ingredient: Natural Selection. Mutated and unmutated DNAs are likely to reproduce at different rates. This is sometimes summarised by the expressions: 'survival of the fittest', 'struggle for existence', or the more extreme: 'nature red in claws and teeth'. Each of these covers approximately some aspects, albeit never accurately, of the whole meaning of natural selection. It looks as if they were all generated in order for newspapers to catch people's attention rather than to engender sympathy with the concept. Natural selection conquered the minds of many nineteenth-century scientists and laymen, but also made many enemies. A more correct statement is that natural selection is an automatic process of evolution whenever two or more different inherited types reproduce at different rates. It is simply the outcome of a normal, unavoidable demographic process. None of the above famous expressions includes the fact that natural selection may favor, for instance, altruism, or cooperation. It often does. Or the fact that some mutants reproduce at the same rate as their parental types ('selectively neutral' mutants). This phenomenon is not strictly part of natural selection, but some mutants may be selectively neutral in certain environments and not in others. There is still evolution even if there are no differences in the reproductive rates of heritable types, and this because of the unavoidable effects of chance ('random genetic drift'). This prompted Motoo Kimura, the scientist who was most effective in foreseeing the consequences of this process, to employ the phrase 'survival of the luckiest', an expression, which, when opposed to that of 'the survival of the fittest', has also appeared in newspaper headlines.

Natural selection can unquestionably cause increased adaptation, but the history of most adaptations is full of side steps and complicated or obscure bypasses.To explain the evolution of flying it was found useful to introduce a new concept, the existence of a preliminary step which did not come about for the specific purpose of flying but was already present for other reasons and made the evolution of wings possible (Gould). Another example is the origin of human language, which uses the pharynx and the larynx, the upper parts of two adjacent, nearly parallel tubes developed originally for other purposes, namely eating and breathing. The development of language required the evolution of special parts that had to evolve further, such as the vocal chords. The tongue and palate also had to change, and the development of the tongue musculature required in turn a greater development of the XII cranial nerve, the hypoglossus, and the neural structures controlling it, not to mention the development of the auditory system.

The process of achieving greater adaptation by the acquisition of new organs, or skills, is usually so complicated that to describe it as the survival of the fittest, as often happens, is only a very poor approximation. It is a process that has lasted billions of years, and has involved new uses of existing genes originally dedicated to entirely different purposes which acquired dual or multiple functions. The ways of Nature in achieving greater adaptation by natural selection are sometimes so complicated and devious that Francois Jacob described them very accurately with the word 'tinkering' ('*bricolage*' in French). An eye or an ear may seem exceedingly complicated organs to have been generated by a trial and error process, like the process of mutation and selection. Mutation is a random process, and most of its products are useless or, more often, counterproductive. This is what must be expected of random changes in delicate and complex mechanisms which evolved over more than three billion years to meet the most disparate challenges. Clearly deleterious mutations are rapidly eliminated by natural selection, which keeps purging them automatically as soon as their mischiefs become manifest. The so-called 'selectively neutral' mutants, or trivial changes according to Darwin, are left to fend for themselves and evolve entirely under the mechanism of the survival of the luckiest. The rare advantageous ones have a high chance of becoming part of the species gene pool. They are the most important in transforming and differentiating living beings, and by following the whole process over billions of years one can understand how end products such as eyes and ears are possible.

There have been attempts to prove that mutation is not, or not entirely, random, but attempts to provide truly rigorous proof of this have failed. Thus, biological evolution remains largely a trial and error mechanism. Even so, there is no doubt that when a mutation under trial shows some advantage to the individuals which carry it, increased adaptation will take place almost of necessity, unless it is barred by random events, such as the random loss of a unique favorable mutation. But some time, perhaps elsewhere, the same mutation will arise again.

Thus in genetic evolution, mutation is a practically random change in DNA, a biological substrate very resistant to mutation. But other evolutionary mechanisms help to improve the odds. It seems likely, and recent experiments on bacteria seem to support this idea, that under conditions of stress mutation rates may increase. Mutation is most probably always random, but given the great variety of possible challenges to be met, increasing its rate can be adaptive under certain conditions, especially when the challenges are so great that it is worth sustaining the increased cost of natural selection due to an increase of the mutation rate. Higher mutation rates are caused by random, though relatively rare, mutations, and are also subject to natural selection.

However, one evolutionary mechanism has been generated – and natural selection must have fostered it – in which mutation is not necessarily random, and that is cultural evolution. The units of cultural evolution are not genes but products of our brain, ideas. They are copied when they are transmitted to other fellow human beings, most often with the help of language, but at other times by sheer observation and the imitation of others. Ideas can change in the process if there happens to be a mistake in the copy process. This change can be random, but it can also be voluntary. Moreover, new ideas arise as innovations, inventions, and these usually have the purpose of solving some specific practical problem.

There is also a somewhat similar process in biological evolution: the production of new genes. But they often have no special purpose, unless they duplicate the factory of an important protein, and help to produce a larger amount of it. Another major advantage of duplicate genes is that if the duplicate is not necessary for the purpose of simply increasing the amount of the gene product, it can be used for making, by later mutations, a product similar but not identical to that of the old gene, which can be specialised for other purposes. A well known example is the genesis of myoglobin from hemoglobin, or viceversa. There are many similar gene families which have arisen by successive duplication and functional differentiation. Gene duplication is very important because it is a key to the increased complexity of organisms and the further specialisation of their functions. But the process remains one of trial and error. The arbiter for deciding what is an error and what is not an error but a useful addition remains natural selection.

So there is reproduction, i.e. copying, and potentially, mutation, in cultural evolution. The reason for mentioning it at this stage is that it has introduced a new mechanism of mutation and selection. Some of the mutation produced in cultural variation is certainly random. Ethnography, the study of different cultures, shows the extreme variety of customs of different tribes, populations, or groups however defined, and many of these differences in customs appear totally absurd to individuals from other ethnic groups. In large part this is due to our inability to accept difference, and to a perhaps innate sense of superiority which makes us look down upon customs different from ours. But there are customs which are very difficult to understand even with the best of intentions. In principle, innovations are directed towards some aim. But the solution of practical problems is rarely easy, and many proposals are simply mistaken. Often the solution is directed to please the inventor rather than the rest of the people, as happens in particular when the inventor is in a position of power, a king for example, or hopes to achieve prestige through suggesting an innovation. Moreover, any invention has advantages and disadvantages. There is always a cost along with a benefit in each change ('there is no free lunch'), as we have painfully learnt with all technological innovations.

Even so, it seems clear that most cultural innovations are directed towards the solution of some practical problem. Thus here mutation is not entirely random, although there always remains some element of randomness. Cultural evolution is usually meant to improve our living conditions, and to some degree it is successful. The simplest proof is the difficulty we encounter in doing without a new gadget of some importance, such as cars, washing machines, telephones, radios, TVs, and personal computers, as soon as we have had the time to get used to one of them. Most innovations are highly addictive. The balance of advantage and disadvantage of each is difficult to evaluate but it would seem that most of the gadgets just listed are here to stay in one form or other, unless the world experiences a major disaster that makes them unusable.

Cultural transmission is an adaptation mechanism made possible by communication of high quality, such as human language. In genetic evolution the Mendelian transmission of randomly occurring DNA mutations is the rule, but in cultural evolution transmission is Lamarckian, that is to say characters acquired during life by the voluntary or random change of customs can be trasmitted to children, and also to anybody else, without waiting for the next generations. This mechanism of transmission makes cultural evolution potentially very fast, but in certain circumstances it nevertheless remains rather stable in time. In fact, cultural characters transmitted by parents to children have dynamics of evolutionary change which are similar to those of genetic evolution, and are therefore usually very slow. This is called vertical cultural transmission. It is especially powerful when it takes advantage of sensitive periods (sometimes called critical periods) to learn special skills. Language is one of these.

As described in a book with Marc Feldman ('Cultural Transmission and Evolution', published in 1981 by Princeton University Press), we called horizontal cultural transmission that where transmission is between unrelated individuals.The dynamics of horizontal transmission are more like that of the more common infectious diseases, and are independent of special time units (like generation, for vertical transmission) or of the genetic relationship between transmitter and transmittee. It can be as fast as communication channels permit, and its success will be proportionate to the degree to which the suggested cultural change looks acceptable to transmittees.

Even if cultural evolution seems quite distinct from other mechanisms of biological evolution, it is undoubtedly a biological mechanism which can increase biological adaptation. It shares the general evolutionary mechanism of biological evolution, by mutation and selection, except that the physical substrate of the mutational change or of transmission is the brain and not DNA. In addition, the basic unit is the idea and not the gene. The rest – mutation, natural selection, and other evolutionary mechanisms which I shall not discuss, such as drift or migration – are formally similar to those of biological evolution.

To the extent that cultural changes can be transmitted to other living individuals, they are inevitably subject to natural selection, which is an unavoidable evolutionary mechanism of all inherited traits, independently of whether they are transmitted by Mendelian or by Lamarckian mechanisms. The evolutionary dynamics are different because they are dictated by the mechanism of transmission. As we have just said, in cultural transmission they can vary from the Lamarckian one to a model similar (but not identical) to the Mendelian one, and their speed can be very fast or very slow.

Cultural evolution contributes together with that of genes to making up, and changing, the individual phenotype. It may seem that it is only one part of the overall phenotype, which is mostly behavioral, that is changed, but behavior can affect almost every physical trait. It is the phenotype which is subject to natural selection. We may accept or refuse an idea because of a process of choice going on in our brain, called cultural selection. But the fate of an individual who accepts and practices a good or bad idea on the basis of what is a personal decision is still determined by natural selection, something true of every other aspect of the individual's phenotype. We may choose one or the other behavior suggested to us by our cultural environment. Using negative examples which have more dramatic effects, one may take up drugs, yield to sexual impulse and have sex with a person who may have AIDS, or cross the road in London thinking the rules directing traffic are the same in England and in the rest of the world. All of these culturally influenced decisions may lead to the early death of the individual, and his/her exclusion from later generations. Thus cultural evolution, too, like any other influence on our phenotype, is ultimately under the control of natural selection, and bad cultural decisions may mean the end of individuals or people as easily as purely genetic changes. Or they may mean their success. Bad ideas may eventually die with the individuals who practice them but, as we know, it may take a long time before they do. As they can be reinvented they may unfortunately be there for ever.

We are justified, therefore, in making natural selection the real and general force behind the Nature of living things – in fact, the nearest thing we can think of when we try to reduce Nature to its most pervasive force. It will therefore be useful to try and give a definition of natural selection which is as accurate and synthetic as possible.

I well realize that I did not understand the real definition of natural selection until I read a classic book by my Cambridge professor, R. A. Fisher. The book, first published in 1930, is called 'The Genetical Theory of Natural Selection' and has been reprinted by Dover Publications. It defines the measure of a quantity called 'Darwinian fitness' which allows us to predict the fate of an individual on the basis of its phenotype. I should insist on the word 'phenotype'. Geneticists, of course, like to think in terms of genotype, which would make computations of the fate of genes easier. But the performance of an individual in terms of natural selection is determined by the phenotype. Dawkins erred in making genes immediately sensitive to natural selection in his famous, and otherwise excellent, book 'The Selfish Gene' and went to great lengths to correct his error in his subsequent works.

Unfortunately, the Darwinian fitness of a phenotype (or, when information is available, genotype) is calculated with an equation which is not elementary and may not even have an explicit solution. It was first given in demography by Lotka and describes the fate (the expected rate of increase or decrease) of a population, of an individual or group whose fertility and mortality by age are known. It can be simplified, at the cost of some imprecision, by saying that the Darwinian fitness is the product of the probability of surviving to the average age at which children are born, times the average number of children born to an individual (or to a couple). Death before the beginning of reproductive age, or total sterility, are equivalent to a Darwinian fitness of zero. In general, Darwinian fitness is used as a relative value for comparing the average fitness of different types, averaging over individuals of each type.

The important thing is that the measurement of natural selection is an entirely demographic affair, aimed at calculating the number of children which specific types of individuals (or pairs) will have in the next generation. The types who will have relatively more children (taking account also of their probability of surviving to the age of having children) will prevail in the long run, at a rate which depends on the difference between the fitnesses of the types. There is no need here to think in terms of adaptation to specific challenges: the reality of adaptation is measured by the capacity to survive and have children. It may be very difficult to measure adaptation to a given challenge, say resistance to an infectious disease, or to hunger, or to a physical effort, or to all of these things together, but all that matters is the probability of survival to reproductive age and fertility in terms of the expected number of children who will be born.

This may also help us to understand that natural selection is not a hypothesis, nor a possibility, but just a fact of life, an unavoidable contingency, which fully determines the chance that a phenotype will be represented in the future generations, and predicts the direction of evolution. It also shows that evolution is not a hypothesis, nor even a theory: it is a genetic change bound to happen. It affects every transmitted trait however it is transmitted – as a Mendelian or a Lamarckian trait, biologically or culturally. Natural selection has the strength of a theorem, and because of this the same is true of the reality of evolution.

Humans are not the organisms in relation to which it is easiest to prove the reality of evolution. Their generation time is too long and their evolution too slow.

Nevertheless, things do happen during our lifetime and simple demographic considerations prove that evolutionary changes will be slow but unavoidable. For instance, the difference in the growth rate of people from different continents or countries will undoubtedly cause a change over the next centuries in average skin color and other morphological traits affecting superficially visible, transmissible differences among people. Europe, and other parts of the world in which white people are prevalent, are now reproducing at very low rates, while Africa and parts of Asia are reproducing at a high rate and their peoples have a darker skin. Given that much of our superficial morphology is determined genetically, substantial genetic changes must be going on. The frequency of white skin, blonde hair and light eyes will decrease at a rate that can be calculated as long as net growth rates will remain the same or change predictably.

The increase in population sizes is one of the major worries of the responsible world, and some of the areas which are more at risk such as China have taken serious steps towards decreasing birth rates. Other developing countries have not been as effective, and mostly they have been totally ineffective. Nature reacts by classic mechanisms to excessive growth above the threshold of tolerated population densities: epidemics, wars and famine. All of Nature's brakes are on at this time. AIDS is assuming scary proportions, especially in Africa which is where it started, and hence the epidemic had longer time to spread. The expected increase in the number of people in Africa is roughly 20 million per year (or about 3% per year). If the growth of the epidemic continues unabated and no measures of prophylaxis or therapy become available, the African population will start going down. There is, both in Africa and Europe, a relatively small proportion of individuals who are genetically resistant to the infection, and at worst it is they who will survive. If only highly resistant individuals survive, the African population may fall to perhaps 10% of what it is today. It is more difficult to make predictions about the degree of thinning of populations expected because of the two other factors of war and famine.

It is of course absurd to let the world continue to go closer and closer to disasters due to excessive population growth because we are unable to apply an effective brake. But the inability of most governments to take action, the difficulty of influencing individuals on such a private matter as procreation, the great ignorance of vast layers of the world population, and the large number of political interests favourable to maintaining lively population growth in religious or ethnic or political partitions, and especially in less advanced countries, make the task very difficult.

There are other causes for concern when we consider the future of populations. Medical innovation has been very effective in reducing mortality. As is well known, in advanced countries pre-reproductive mortality has been reduced to very low figures, and life expectancy has grown for older people in ways that have suggested to some that we may be directed towards a sort of immortality. These results are not without negative aspects – the substantial increase in the cost of medical assistance, due especially to the creation of forms of treatment which are extremely expensive. The greatest fraction of medical progress in the last 100 years or more has been in the treatment of infectious diseases. But here is where evolution is fast enough for it to be observed in action. A bacterial generation is half a million times shorter than a human one, but bacteria have almost the same mutation rate per generation as humans. One can expect bacteria to have an evolutionary rate such that in a hundred years, the time since the beginning of the very first sera, vaccines, and the first chemotherapeutic, they might have had the same amount of evolution in mammals since dinosaurs disappeared. This is a very approximate calculation, not least because bacteria are most probably subject to stronger natural selection than humans, which will make their evolution even faster. The first widely used antibiotic, penicillin, started becoming widely used after the end of the Second World War. Since then, many bacteria, fortunately not all, have developed considerable resistance to penicillin, and they had to be fought with other, newly discovered antibiotics. Staphylococci are responsible for a number of serious skin and other infections; they in particular have become resistant to very many antibiotics. Genes for resistance are being passed from bacterium to bacterium, even to species remote from the one of origin, in DNA packages containing genes for resistance to several antibiotics. A new antibiotic, vancomycin, is widely used for the treatment of resistant staphylococci, but the first strains resistant to vancomycin have started appearing.

We may progressively lose the current advantage in the struggle against infectious diseases unless we keep finding new antibiotics. This is being done by using substances toxic to bacteria produced by other bacteria and fungi. For how long can we continue to find new ones? Fortunately, the study of bacterial genomes has progressed to the point that the DNA of several pathogenic bacteria is fully known. It becomes possible to invent entirely new methods of warfare against bacteria without having to rely entirely on the past ingenuity of nature. But how long can we go on keeping ahead of bacterial resistance to antibiotics? The time may come in which we will need to go around with special antibacterial dresses or masks, or disperse in colonies on satellites in the cosmos, imposing strict quarantines on visitors from other colonies.

Thanks to the high rate of evolution of bacteria, when we look carefully at them evolution is no longer a hypothesis but just a fact. Bacteria have, in spite of their capacity to evolve rapidly, a certain number of genes which are extremely similar to genes of equal or similar function which we and other higher organisms like us also have. Certain functions cannot be easily replaced, and even Nature does not have an infinite ability to generate new solutions. Genes which have fundamental functions have reached a structure which could not be easily changed further without serious loss. Only the future can tell us whether this fact will help us in our struggle against parasites or if it will work against us.

Medical progress has not been limited to the fight against parasites, but today we can treat successfully a number of conditions which were lethal until recently, causing some increase in the expectation of life at higher ages – though not yet a really satisfactory one. Many of these are of genetic origin, and the cost of treatment is very high. Among them are some that need organ transplantations, which have the additional restriction that organs are difficult to find.The cost of medicine has reached a level at which it is becoming incompatible with providing good social services for all, unless the political establishment decides on radical changes in the financial support of health. One can always hope that the increasing cost of health will be absorbed by society if it becomes possible to decrease military expenditure, but the immediate future does not look promising. Whatever the case, medical costs will probably soar so high that some other solutions will have to be accepted.

NATURE AND CULTURE – AN OBSOLETE DISTINCTION?

KUNO LORENZ

The question to be dealt with at this meeting is based on a very elementary distinction. And this distinction is connected with quite a few dualisms which haunt our intellectual tradition.

We are accustomed to contrast that which is given with that which is made, fact with artefact. The given as that which exists independently of any intentional human interference, yet bounded by space-time, belongs to nature; the made as that which owes its existence in its particular shape to human activity belongs to culture. As nowadays hardly anything exhibits only natural features in the sense just defined, nature seems to have receded beyond direct access.

But, we should take note of another inheritance from antiquity which is closely allied with the distinction of nature and culture. It is the conviction that nature is governed by regularities, in fact causal ones, which guarantee that the particulars of nature may be characterized by their essential features, e.g., natural laws, whereas culture is something arbitrary because artefacts owe their existence to human activity which varies irregularly with time and place.

This picture is still far too simple. We have to add at least two additional features. The one is concerned with a closer look at the realm of human activities. Rather than separating the activity from its object such that something is *made out of* something, e.g., making bread out of the usual ingredients, one may treat such an activity as an undivided whole where nothing relevant for its execution is left outside as something external, neither the agent nor the various objects or circumstances. Consequently, one avoids the widely adopted modern strategy of treating actions as functions on states, e.g., as a transformation of the no-bread-there-state into the bread-there-state.

If one follows this more radical path, a poietical activity gets turned into a practical activity. In the terminology of Aristotle who introduced the systematic distinction between *poiesis* and *praxis*, you may say that instead of making something for the sake of this something you do a making-something for the sake of making-something, i.e., you do it for its own sake. Of course, in antiquity as well as nowadays, usually actions are classified as either poietical or practical ones – thereby making it easy to keep the areas of technological and political activity distinct – thus overlooking the fact that this classification is itself an artefact which depends on the perspective taken towards the action in question. In fact, it is even possible to suggest that primacy of *poiesis* over *praxis* is a characteristic feature of modernity from the Renaissance onwards, whereas in antiquity *praxis* was usually held to be nobler than *poiesis*. In both cases, however, it was never doubted that beyond the areas of *poiesis* and *praxis* which fall under the category of doing there is an area of what can be known, the objects of *theoria*, which fall under the category of suffering. This is the area of the given which is identified as nature, i.e., the particulars as instantiations of universals. Within this context it is of minor importance that with the advent of modern science, due to certain misapprehensions, functional universals had to take the place of substantial universals (cf. my paper: Versionen des methodologischen Dualismus. Bemerkungen zu den historischen Wurzeln des Streits um kausale und finale Erklärungen, *Internationale Zeitschrift für Philosophie* 1/1999, 5-23).

But, encouraged by a religious belief through the ages that nature itself is something made, though not by humans but by God – in fact, for God *poiesis* and *praxis* are indistinguishable – we are facing now, at the turn of the millenium, its secularized version: Everything will eventually turn out to be matched by an artefact, i.e. to each "natural" particular there is or will be a corresponding "cultural" particular of the same type. Theories as well as their objects, i.e., those which theories are about, are alike considered to be artefacts. Thus, it seems, we are faced with the prospect that the category of suffering, and with it the concept of nature, are losing their applicability.

At this juncture, the other feature I wanted to add to my picture, enters the scene. It is the outcome of the attempts either to treat culture as a particular subsection of nature – man's activity should itself be considered as something given – or to treat nature as a particular cultural achievement – only by learning how to proceed in a purely scientific manner, i.e., to lead a "theoretical" life (*bios theoretikos*), will we experience reality "as it is", without active human interference. In this latter case, theoretical activity, be it perceptual as in observation or conceptual as in articulation, is by definition something you "do" and, hence, theoretical activity is conceptually different from the object[s] to which it refers and which you "suffer".

Making bread, for example, is different in kind from observing bread-making. In the case of making bread, you execute a special action schema or action type by producing an action token which occupies a particular area of space-time; in the case of observing bread-making you observe such a token by identifying it perceptually as a token of the action type bread-making. It is common, however, to treat 'observing something' on a par with 'making something'. Therefore, the use of 'observe' as a designation of the theoretical activity of identification alongside with its use as a term for an ordinary activity is tantamount to the introduction of a systematic semantic ambiguity. In the theoretical case you use 'observe' semiotically, as a kind of prefix to 'bread-making' in order to indicate that a token of bread-making is used as a representative of the action type bread-making, and 'observe' is *not* used pragmatically, for interfering with making bread. In such a case where 'observe' functions as an ordinary action term, it refers to an action type which is different from the action type bread-making in our example. In fact, it acts as a *carrier action* for the semiotic function of "understanding" the observed token as a representative of the corresponding type. In this case, there may exist "external" causal relations between the token of the carrier action of observation on the one hand, and the observed token, on the other hand. Care has to be taken to distinguish these external relations from the "internal" semiotic relation between a sign and what it refers to. In the example, the semiotic relation holds between the sign, being the carrier action of observing bread-making *in its function* to understand, when executed, the token of making bread as an instance of its type, and the corresponding type bread-making as its reference. If taken as a theoretical activity and not as an ordinary one, observation functions as a piece of non-verbal language quite similar to its verbal counterpart articulation: one refers to something.

In either alternative the ancient categories of doing and suffering (*poiein* and *paschein*) which govern the distinction between that which is made and that which is given are fully vindicated. Consequently, with respect to the corresponding notions of culture and nature two things may happen. On the one hand, culture may indeed turn out to be a piece of nature – *if* that which is made has become an object of *theoria* by being observed or articulated; on the other hand, nature is incorporated into culture, *if* that which is given becomes part of my activity which is th case when I deal with it (Plato would have switched from the term '*ont* to the term '*pragmata*').

The consequences for the self-characterization of man are crucial. W have to face a basic ambiguity of human nature. As a natural being ma may describe himself as a specific part of the given, whereas, as a cultura being, man may construct himself as a particular artefact. It is in th context of this alternative that the distinction between Self and Other lies I am something given with respect to being an object of *theoria*, i.e., a Other, and I will be something made while being engaged in activities i.e., as Self. The dialogical character of human nature has to be explicate in order to arrive at a proper understanding as well as determination o what it is to be human.

For getting a better perspective on the various questions involved le me first turn to a short historical retrospection. There exists a documen in which the idea of becoming human is spelled out in terms of a cultura process which starts from a state of nature. In fact, it is a myth, attribute by Plato to the sophist Protagoras and contained in Plato's dialogu *Protagoras* (320c8 – 323c2). There we find a tale in which human being come into existence by two distinct steps. With the first step technica abilities are acquired to compensate for natural deficiencies. Thes abilities appear individually as a character of the species and make it members able to survive collectively as natural beings. The whole real of *technai*, which includes the arts and religious rites as well, is availabl on this level. After that, it is the second step which leads to rationality i its full sense of having practical abilities at one's disposal. They provid for political units of self-government: honesty or justness (*dike*) an modesty or respect (*aidos*) lead to solidarity (*philia*).

The language-dependent abilities on the second level which aris from mutual recognition cannot be exercised except through individua distinction and social coherence – any such social individual leads a lif governed by reason, it is a rational being. Here, we have found th backbone necessary for guaranteeing the original equivalence of the tw ancient "definitions" of man: a rational animal (*zoon logon echon*) and social animal (*zoon politikon*). Two additional remarks may be helpfu here.

Plato, elaborating on Protagoras, or rather commenting on the myth relegates every action which belongs to the sphere of the first step, that is poietical action and therefore something non – or not-yet-rational to sphere of merely natural or cultural exigencies; it is not specificall human. The move from the first to the second step of the ancient myth has been interpreted as a move from "amoral" competitive behavior to the more developped stage of "moral" cooperative behavior, even in cases where the notion of rationality is not limited to the area of moral legislation but includes means-end-rationality as well.

My second remark concerns an additional distinction which is due to Aristotle. It is the distinction between rationality as the ability to theorize and sociality as the ability to lead a good life which merges with the previous Platonic classification, thus yielding a related developmental bifurcation with an intermediate step. We have a primary level of mere acting which should rather be called behavior, and a secondary level of deliberate activity, that is, actions guided or at least accompanied by thinking where theory serves practice. And, in addition, there exists a level in between the other two where poietical activity serves particular cultural needs above behavior necessary for natural survival and below action guided by reason peculiar to man. And it is the stage arrived at in this intermediate level where both the competitive activity of the primary level and the cooperative activity of the secondary level interact and keep the cultural process going.

In order to appreciate the significance of this, we should note the existence of two conflicting pictures of the cultural process throughout our history. On the one hand, we have a progress-theory of the cultural process where the progress is measured in terms of complexity of (group-) organisation with Hobbes' assumption of a *bellum omnium contra omnes* as the characterizing feature of the initial state of nature. The individuals count as members of a species which will eventually be fully governed by reason. Privileged documents for a development along this line are the constitutions designed to elicit potentially universal acceptance. Political universalism, the idea of enlightenment, takes national states to be constitutional states, and unpeaceful fights among them count as signs of the initial barbaric stage which has not yet been overcome.

Yet, on the other hand, we observe the growing influence of an alternative picture of the cultural process. It is described in terms of a decline-theory rather than a progress-theory. On the basis of an *aetas aurea*, a natural state of paradisaic existence for each individual – it is well known from Rousseau's forceful descriptions –, an ever increasing consciousness develops and spoils the ability to act spontaneously. Natural individual creativity is hampered by social pressures which derive from conscious activity for and against others, and the decline can be measured by the losses in (self-)production. Only the free association of individuals as given in natural ethnic groups defined by a common frame of world views and of ways of life, that is, a culture, allows for uninhibited self-expression. Cultural particularism, the idea of romanticism, argues for national states to be ethnic states designed to fight for their cultural survival. Rather than moving from "barbaric" competition to "civilized" cooperation, as the cultural process is viewed in progress-theories, we have in this case the call to reverse the cultural process which leads, according to decline-theorists, from natural cooperation, possibly including cooperation with non-human nature as well, to cultural competition.

Underlying these two theories of the cultural process we find two competing notions of culture – or rather two competing attempts to define the boundaries between natural and cultural aspects of being human. In the progress-theory, the claim is made that universalizing reason is the final destiny of man; in the decline-theory, the claim is made that particularizing nature is the primordial ruling force. In order to mediate between these two views regarding human nature a thorough scrutiny of the dialogic nature of man is called for. As Self, man is subject to "doing", as Other to "suffering". But, before embarking on this scrutiny which I have done in detail in my *Einführung in die philosophische Anthropologie* (Darmstadt ²1992), it is worth taking a further look at the historical setting of the two notions of culture.

According to enlightenment, the prospect of cultural development defines the proper "second nature" of man, whereas, according to romanticism, a natural potential acts as the cause of the true culture within the one and first nature of man. It seems as if among the premisses of enlightenment we have to include the belief in reason within history as "*ultima ratio*", usually called the belief in historical progress, and, correspondingly, in romanticism there seems to exist a belief in God in nature as "*prima causa*", usually called the belief in natural evolution – up to evolutionary epistemology as promoted by some scholars nowadays.

These remarks should not be read as an attempt to initiate a discussion of the relative merits of romantic individualism and of enlightened universalism. With these latter characterizations one misses the point. We, rather, should take note of the following awkward turns. The romantic slogan 'back to nature' – in fact already en vogue in antiquity with the Stoics: *secundum naturam vivere* – works as a kind of universal norm asking everybody for his or her respective engagement, and the enlightened call for a self-determined way of life gives rise to a multitude of essentially dissociated life-plans. Romantic individualism tends to become a version of communitarianism with its pledge that the community should have primacy over the individual, whereas enlightened universalism shows up as a kind of liberalism dependent on the primacy of the individual over the community. Both approaches suffer from intrinsic inconsistencies, and it is this ambiguous setting, I believe, which feeds contemporary debates like, e.g., the debate on communitarianism versus liberalism with its focus on how to defend or to attack ethnocentrism, i.e., the particularity of value-systems, or the debate on the content and scope of human rights with its focus on how to identify universal values, if there is such a thing, with an identity across cultures.

We seem to be caught in an age-old dispute of our own Western tradition with its roots in antiquity on how to define the relation between individual and society. What is the difference between juxtaposing an individual human being with its "membership" in the species man on the one hand, and with its being a "part" of mankind on the other hand? Does it make a difference when in the first case an individual is understood to be endowed with the faculty to act and speak as a representative of any other individual, i.e., to act and speak "transsubjectively" – this is the precise meaning of the traditional notion of 'having reason' or 'to be able to reason' –, and when in the second case an individual is taken to be a particular contribution, by his or her share in verbal and non-verbal activity, to the subsistence of mankind as a whole – this may be taken to be the meaning of the traditional notion of man as a social animal?

Of course, in both cases, when acting as a universal representative and when participating in mankind's subsistence, actual activities will fulfill their aims only with respect to particular groups, though in the first case this limitation is judged negatively – real objectivity has not yet been achieved –, whereas in the second case the limitation is judged positively – participation can work only within the groups to which an individual actually belongs.

In the first case we are faced with the opposition 'individual-universal', in the second case with the opposition 'individual-social', in both cases, however, it is obvious that competitive behavior is judged to be inferior to cooperative behavior. In fact, both these cases can be treated as consequences, respectively, of two basic traditional assumptions which contradict each other. The first assumption amounts to the simple claim that man is by nature bad. It acts as a presupposition for progress-theories of the cultural process, whence the negative judgment on any limitation with respect to acting as a universal representative. The second assumption may be abbreviated to the opposite claim that man is by nature good. This is the basic presupposition of decline-theories of the cultural process, whence the positive judgment on the limitations of participating in mankind's subsistence. Entering into a debate on the acceptability of either presupposition forces us to engage in moral preoccupations and convictions. Instead, looking at basic human needs first, appears to be a more promising approach.

One who tries to reach a better understanding of how human beings relate to each other, will have to face two incompatible basic needs, the one to be close to one another and the other to keep distance from each other. In order to elucidate this phenomenon I propose to take a closer look at the work of an author who discusses the content, scope, the mutual relations and presuppoitions of the two competing theories of the cultural process. He does this with an explicit awareness that both the predicates 'good' and 'bad' and their theoretical analogues 'true' and 'false' should not be used descriptively but reflexively. They do not refer to properties of empirical sentences about given objects, but act as reflexive terms for passing (philosophical) judgments while reconstructing, i.e., delineating conceptually, the objects in question. The author I am referring to is Herder. He seems to have been the first in history to have become aware of the conceptual rather than empirical relation which holds between the two characterizations of human beings occurring in Protagoras' myth. Human beings are on the one hand deficient beings insofar as they lack sufficient protection against inanimate nature and do not possess effective weapons against animals, and, on the other hand, this *means* that they are proficient beings insofar as they have both poietical and practical abilities which are acquired consecutively by the two steps in the myth. The terms Herder uses to refer to poietical and practical abilities, respectively, are 'freedom' and 'reason'. You "possess" freedom which will eventually yield peace, and you "possess" reason which will eventually yield justice. Both have to be acquired and should not be treated as "just there".

It is by exercising these abilities that humans define their deficiencies, and, therefore, it is wrong to treat the relation between proficiency and deficiency as an empirical one of compensation. The point becomes still clearer, if we turn to the details of the interdependence between being proficient and being deficient.

Herder defines the cultural process neither by progress nor by decline but by a process of education. He uses a dialogue model of teaching and learning – for example, in his *Ideen zur Geschichte der Menschheit* – where teaching includes construction of representations and learning correspondingly includes deconstructions by means of interpretations up to concrete activity. The dialogue model is used as a means to identify items of a cultural process in as much as both doing and suffering, terms to characterize the two roles in a teaching and learning process, always occur together. The categories of doing and suffering govern not only the realm of verbal activity but also the realm of non-verbal activity. Now, as every individual plays both roles – he or she is learning as well as teaching, possibly at different moments in his or her lifetime –, it is individual distinction together with social coherence, that is, competitiveness against a common background and cooperativeness split up into different approaches, which defines the process of education.

Reason, being basically the ability to organize and therefore to handle problems of presentation, and freedom, being basically the ability to produce which includes being able to tackle problems of representation, appear, when exercised, on the side of "doing" as proficiency and on the side of "suffering" as deficiency. On the basis of this, Herder is able to explain why tradition may include errors – a deficiency of reason – and why something evil may occur among the items somebody chooses – a deficiency of freedom. The difference to an understanding of competition merely as fixing and pursuing individual interests and of cooperation merely as establishing and pursuing common interests is obvious. Such an understanding of sociality and rationality in terms of individual and common interests, respectively, has turned the reflexive use of sociality and rationality, which up to Aristotle was the outcome of a self-characterization of humans, into the ordinary positive use of describing pre-existing properties of humans.

It was Hannah Arendt in chapter 4 of her book on *The Human Condition* (Chicago 1958) who clearly demonstrated how by translating the Greek term *'politikon'* into the Latin term *'sociale'* such a change of meaning has led to a conceptual confusion throughout our tradition up until now. But, it was not this fact alone which had such an effect. In addition to it, one has to take into account another important feature due to the Stoic replacement of *'politikon'* by *'koinon'*: sociality was no longer restricted to the second Protagorean level of reason-guided ways of living but is understood as pervading the first level of "natural" abilities, too.

It is this accidental insight brought about by a conceptual confusion during *translatio studii* together with the complementary recognition that rationality – in its full sense and not in the confined sense of means-end-rationality – is required for exercising first-level poietical activities which made Herder confident of being right in reestablishing the reflexive use of sociality and rationality, but now throughout the whole range of human activities.

Hence, 'sociality' – Herder's 'freedom' – does not refer to the struggle among individual interests whether understood in the intentional setting of a (cultural) "struggle for power" or confined to explanations by a causal theory of behavior to account for the Darwinian "struggle for survival", but it refers to social coherence both in acting and speaking which is cooperation *by means of* individual contributions. Realizing that everyone must invent his own way of life and his own world view provides for the possibility of gradual development of sociality which may also be called solidarity in case one wants to use a term more akin to the Greek term *'philia'* (friendship) which had served the same purpose in antiquity as mentioned above.

Likewise, 'rationality' – Herder's 'reason' – no longer refers to the ability to act along common interests even if 'common' is not restricted to some group interests but refers to fullfledged moral generality. Instead, it signifies individual distinction at all levels which is competition *grounded* in a community of acting and speaking. In fact, it is a paradigm case of rational behavior to compete by argumentation. By successful refutation, for example, you earn a reputation in the scientific community. Realizing how one's own way of living and one's own world view is found amidst shared activities is an accomplishment of another step on the way to individuality.

Traditionally in this context, from antiquity through Kant up to the present, we are accustomed to speak of self-determination as the task of reason; but, as reason is said to be concerned with the universal and not with the particular, self-determination is usually understood as deliberate submission to universal laws and, therefore, as an obligation to create the universal human being – the transcendental Ego in Kant – and not as a universal task to be carried out individually.

It is not difficult to understand why such confusions have occurred. They are an outcome of neglecting the insight that individuality and sociality are but stages in a process which is simultaneously a process of individuation *and* of socialization. This process is the one which had been conceptualized by Herder as the education process (in German: "*Bildungsprozeá*"). Self and Other are bound together and constitute what may be called a "dialogical dyad", an entity well known for quite some time in psychoanalysis, for example.

An account of self-determination which starts with a set of ready made individuals has to postulate preferences and beliefs as additional entities to be possessed by individuals, because otherwise there is no chance either to determine or to explain any of the different competitive and cooperative relations among individuals let alone those of deliberation, negotiation, or arbitration or the like – yet, the burden of proving the existence of those additional entities above and beyond my own preferences and beliefs is shirked.

Among individuals, within an approach where the existence of individuals is not traced back to a mutually dependent genesis in a process that is simultaneously one of individuation and of socialisation, there are only external – natural or cultural – relations between individuals, relations of the exertion of influence upon one another. This violates the basic condition connected with the concept of self-determination or autonomy of an individual. Exerting influence upon one another results in heteronomy. The chance of learning from each other and in this sense of being engaged in a process of mutual, and therefore, truly autonomous education does not even appear.

Of course, the process of education I referred to as an alternative to the process of exerting influence upon one another must not be understood in the descriptive sense of education which is current at present. Neither education in the intentional framework of given educational aims, nor education in the causal framework of social engineering will be mutual education. Mutual education is a process of *self*-education in which both sides in the process of teaching and learning change their ways of life and their world views by a further step of both individuation and socialization. Self-education concerns Self with respect to Other, it is not an individualistic notion but a dialogical one.

Ways of life and world views can be apprehended only if seen in both their individual and in their social aspects; they show individual distinction and social coherence. Self-education is not striving for a balance between guiding and letting grow, the educational equivalents to the characterizing activities of the two theories of the cultural process discussed earlier: striving for universal culture as the second nature of man and obeying the natural evolution of cultural features within the first and only nature of man. Self-education which is mutual education of Self and Other, and by that very feature an attempt to balance the relation of Self and Other with respect to acting and being acted upon (= suffering) consists in setting up limits against being influenced.

Setting up such limits proceeds both by standing up against submission to cultural conditioning and by inventing ways of compensation for natural dependencies. In terms of an educational process we may say that being guided is countered by individual acting in making use of individual knowledge or know-how already acquired, whereas growing is countered by invoking social knowledge which is an already acquired knowledge of social norms, the common aspect of activity.

Learning from one another establishes bonds as well as demarcations, and it exhibits such a kind of relation even with respect to two empirical persons each individually: the Other – a not yet known or alien part – within oneself, and the Self – a well known part of oneself – appearing opposite to oneself. It is exactly this kind of radical extension of the concept of Self-Other-dependency to include Self-Other-relations within one empirical person that lends itself to perceptual representation as showing both self-expression (for Self and for Other) and other-description (again for Self and for Other). In such a way the self-characterization of human beings as belonging to both nature and culture is fully validated. It, even, becomes clear that the very distinction of nature and culture rests on the process of self-discovery which we have identified as a process of mutual education of the dialogical dyad: Self and Other.

Individuality, a differentia of individuals on the level of reflection, can be recognized only within some common activity; sociality, an equality of individuals on the level of reflection, can be performed only if we are conscious of the different approaches within the same common activity. Mutual dependency of Self and Other is by far stronger than it is often thought to be. It is a consequence of the dialogical polarity underlying both human self-understanding in knowing that we belong to nature – a case of suffering – and human self-determination by acting which defines us as cultural beings – a case of doing.

PART III

THE CHANGING CONCEPTS OF NATURE IN THE HUMANITIES

NATURE AS MOTHER AND STEPMOTHER

The Personification of *Natura* in Art History

HORST BREDEKAMP

I. The Question of an Epochal Shift

The relation of art to nature constitutes the most important element in all of art theory. It encompasses two poles: the imitation of the created *natura naturata*, and *natura naturans*, the creative impetus of nature. One of the singular achievements of art is that it has not only used both of these principles, but has also allegorized them in the form of personifications. In art nature occurs not only as an object, but also as a person, whose changing forms and actions vividly illustrate changing concepts of nature. In the following, the history of the goddess Natura will be traced in six broad strokes in the hope of shedding light on areas of both continuity and evolution as well as of drawing attention to the potential political dimension of concepts of Nature and Art.

The history of the goddess Natura is longer than has often been assumed. Representations such as the Natura Lactans from a Pliny manuscript of ca. 1485, showing nature as a giant woman holding the cosmos like a fruit in front of her body and spraying it with her breasts, have typically been seen as an innovation (Fig. 1).[1] The many-breasted Ephesian Diana as an allegory of nature has been viewed in a similar way. In a woodcut of ca. 1588, for example, Hendrik Goltzius shows her splashing plants and animals from a vitreous matrix (Fig. 2).[2] Images of

[1] Hermann Walter, "An Illustrated Incunable of Pliny's Natural History in the Biblioteca Palatina, Parma," *Journal of the Warburg and Courtauld Institutes*, vol. 53 (1990), pp. 208-216: 214f., ill. 21a.

[2] Wolfgang Kemp, "Die Höhle der Ewigkeit," in *Zeitschrift für Kunstgeschichte*,

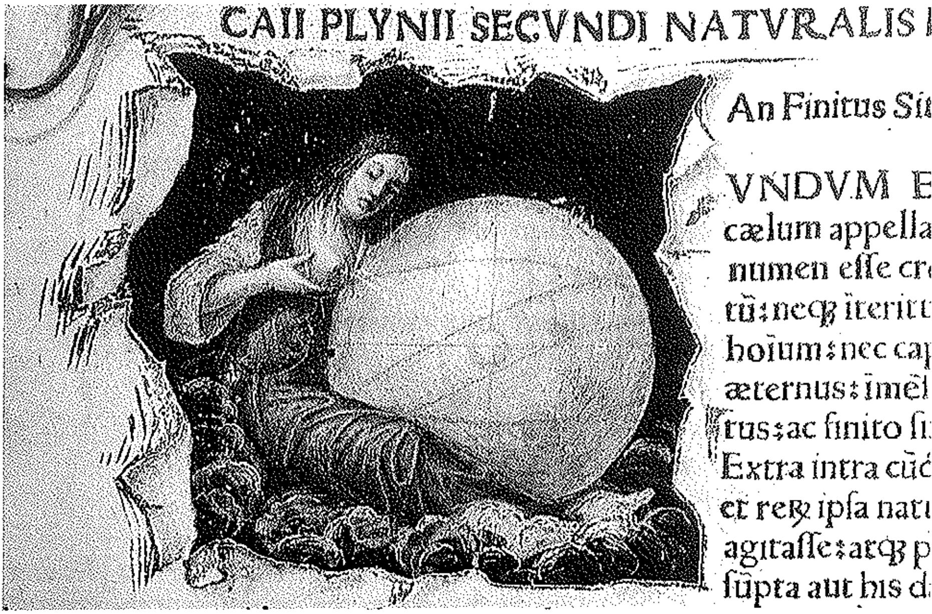


Fig. 1. Nature as nutrex of the cosmos, Ill. to Pliny, *Naturalis historia*, ca. 1485, Parma, Biblioteca Palatina, MS Inc. Pal. 1158.

Fig. 2. Hendrik Goltzius, The *Cave of Eternity*, woodcut, ca. 1588.

this goddess were also familiar to the Renaissance, the best known and most often reproduced of which was held in Rome, in the possession of the Rossi in Rome.[3]

Precursors of both types from before the Renaissance have been dismissed as indefinite solutions that testify rather to the pictorial non-existence of the goddess.[4] Only last year, however, a ground-breaking study succeeded in showing that the Renaissance iconography has obscured the pictorial history of a goddess who stands in a relationship of conflict with man and encounters him not in the matriarchal gesture of a bearing and nurturing mother, but rather as an antagonistic stepmother.[5]

II. The Complaining Stepmother

The idea of nature as a stepmother originates in antiquity. In Book VII of his *Natural History*, Pliny affirms that while nature has ostensibly created all things for the sake of man, he is forced to pay a "terrible price" for it: thrown naked into the world, he must laboriously acquire the ability to survive in nature, "so that one cannot clearly decide whether she is a kind mother to man or a harsh stepmother (noverca)".[6] Similarly, around the year 300, Lactantius emphasized that nature was to be viewed as a noverca, the "stepmother" of man.[7] A hundred years later, however, Claudian construed nature's transformation from a mother into a

vol. 32 (1969), pp. 133-152, p. 137f.; Horst Bredekamp, "Die Erde als Lebewesen," *Kritische Berichte*, vol. 9/4-5 (1981), pp. 5-37: 19f.

[3] Klaus Lankheit, *Der Tempel der Vernunft. Unveröffentlichte Zeichnungen von Etienne-Louis Boullée*, 2 ed. (Basel and Stuttgart, 1973), pp. 30ff.; Phyllis Pray Bober and Ruth Rubinstein, *Renaissance Artists & Antique Sculpture* (London, 1986), p. 87.

[4] Wolfgang Kemp, *Natura. Ikonographische Studien zur Geschichte und Verbreitung einer Allegorie* (Frankfurt/Main, 1973), pp. 17ff. Cf. the opposite votum: Hans Robert Jauss, "Allegorese, Remythisierung und neuer Mythos. Bemerkungen zur christlichen Gefangenschaft der Mythologie im Mittelalter," in *Terror und Spiel. Probleme der Mythenrezeption* (ed. by M. Fuhrmann) (Munich, 1971), pp. 187-210.

[5] Mechthild Modersohn, *Natura als Göttin im Mittelalter. Ikonographische Studien zu Darstellungen der personifizierten Natur* (Berlin, 1997).

[6] "Principium iure tribuetur homini, cuius causa videtur cuncta alia genuisse natura magna, saeva mercede contra tanta sua munera, non ut sit satis aestimare, parens melior homini an tristior noverca fuerit" (Gaius Plinius Caecilius Secundus, *Naturalis Historia*, Liber VII, 1, 1).

[7] Laktanz, *Op. Dei*, III, 1; cf. Klaus Saalmann, "Studien zum philosophischen Naturbegriff der Römer mit besonderer Berücksichtigung des Lukrez," in *Archiv für Begriffsgeschichte*, vol. 7 (1962), pp. 140-325: 221.

stepmother as the result of man's own devastation; nature, "erstwhile the mother of all living beings, had suddenly taken upon her the hated guise of a stepmother".[8] These two fundamental positions, revolving around the question of whether nature should be viewed as a mother or a stepmother, formed the basis for a conflict that would present man and nature as two opposing forces.

In the 12th century, it was above all Alain de Lille who adopted and expanded this pattern from late antiquity. In his works the figure of a complaining nature appears again and again in the variable features of a personified goddess. In a 13th-century manuscript, the figure of nature appears in the guise of an ecclesiastical virtue (Fig. 3).[9] Elevated on a pedestal like a cathedral sculpture, full of dignity and majesty but with a threateningly furrowed brow and a turned-down mouth, she expresses her wrath against man with the authoritative gesture of a monumental apparition.

In Guillaume de Lorris and Jean de Meun's *Roman de la Rose*, the figure of complaining nature attains prominence above all when she accuses man of sexual abstinence and thus of betraying the duty of nature. Absolution will be given to all who strictly follow the rules "that are written in my book, / and make great efforts / to increase their families, / and remember to love well".[10] Yet the Genius of the *Roman de la Rose* in turn imposes upon nature what she herself had dictated to man. In a manner recalling Aristotle's comparison of the sexual act with technical creation, he develops a comprehensive concept that makes no distinction between the act of procreation and technological production.[11] A Paris manuscript of the *Roman* from the 14th century illustrates how nature as a smith unceasingly counters the destructive force of death (Fig. 4)[12]: "she hammers, she forges again and again / and untiringly renews her individual creatures / through new generation".[13]

A more sublimated form of nature's activity as a smith appears in numerous other illustrations. In an early 15th-century manuscript in the

[8] Claudian, *De Raptu Proserpina*, 3, 39f., in *Claudian* (ed. by Maurice Platnauer), (London and Cambridge, 1972), vol. II, pp. 348ff.

[9] *Anticlaudian*, Oxford, Corpus Christi College, MS 59, fol. 7; Modersohn (note 5), p. 27.

[10] Guillaume de Lorris and Jean de Meun, *Der Rosenroman* (ed. and transl. by Karl August Ott), 3 vols., (Munich, 1976-79), vs. 1384-7.

[11] Aristoteles, *Metaphys.*, Z 7-9, 1033a; cf. Modersohn (note 5), p. 157.

[12] Paris, Bibl. Nat. fr. 1565, fol. 104v; Modersohn (note 5), p. 157, ill. 142.

[13] De Lorris and De Meun (note 10), v. 16005.

Fig. 3. Nature as a monument, Ill. to Alain de Lille, *Anticlaudian*, 13th. century, Oxford, Corpus Christi College, MS 59.

Fig. 4. Nature in her forge, Ill. to the *Roman de la Rose*, 14th. century, Paris, Bibl. Nat. fr. 1565.

Getty Museum, Natura appears in an open landscape, creating the animals on an anvil; in the upper right, God offers his blessing, the orb of the earth hovering before him (Fig. 5).[14] Man himself is a part of this technological creation. In a 14th century manuscript from Paris, a finished and already animated human figure lies on the anvil; above it, apparently as a test to see if it is alive, a hammer is threateningly raised (Fig. 6).[15] And in fact the figure seems to make efforts to arise. Creation is portrayed as the artisan's technology, exercised parallel to the natural process of procreation; as such, it enjoys the blessing of God, since He himself as an architect created the world.

The creation of man and of a new human race thus represents the highest goal of nature's activity as an artisan. In view of her elementary mistake in the creation of man, her task is to produce a new race, the *homo novus et perfectus*.[16] *Hic loquitur Natura*: in an illustration from the mid-13th century, we do not see Judith holding the head of Holofernes, but Natura inspecting a specimen of the head of the new and perfect man (Fig. 7).[17]

III. The Judgment of Jove

The figure of complaining nature occurs as late as a text published shortly before 1500, the *Iudicium Iovis* of the German humanist Paulus Niavis.[18] In this didactic play, the pendulum swings of complaints against nature as a stepmother and against man, who makes her what she is, are taken to an almost unparalleled extreme.

[14] Getty Museum, MS Ludwig XV 7, f. 124v; De Lorris and De Meun (note 10), vs. 19895-906; Modersohn (note 5), pp. 133ff., 144, ill. 118.

[15] London, Br. Libr., Egerton 881, fol. 124r; De Lorris and De Meun (note 10), v. 15893; Modersohn (note 5), ill. 108.

[16] Ernst Robert Curtius, *Europäische Literatur und Lateinisches Mittelalter* (Bern, 1948), pp. 130ff.

[17] Verona, Bibl. Capitolare, Mc CCL, fol. 4; Modersohn (note 5), pp. 27ff., ill. 9.

[18] Paulus Niavis, *Iudicium Iovis in valle amenitatis habitum ad quod mortalis homo a terra tractus propter montifodinas in monte Niveo aliisque multis perfectas ac demum parricidii accusatus* (s.l., s.t.); Paulus Niavis, "Iudicium Iovis oder Das Gericht der Goetter über den Bergbau. Ein literarisches Dokument aus der Fühzeit des deutschen Bergbaus" (ed. by Paul Krenkel), in *Freiberger Forschungshefte. Kultur und Technik*, vol. D 3 (Berlin, 1953). Cf. Horst Bredekamp, "Der Mensch als Mörder der Natur. Das "Iudicium Iovis" von Paulus Niavis und die Leibmetaphorik," in *Vestigia Bibliae* (vol. 6, 1984), pp. 261-283.

Fig. 5. Nature as smith and God, Ill. to the *Roman de la Rose*, 15th. century, Los Angeles, Getty Museum, MS Ludwig XV 7.

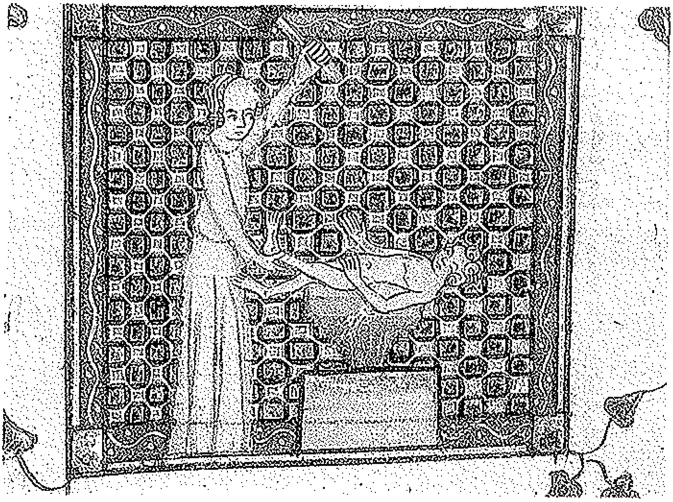


Fig. 6. Nature as smith, Ill. to the *Roman de la Rose*, 14th. century, London, Br. Libr., Egerton 881.

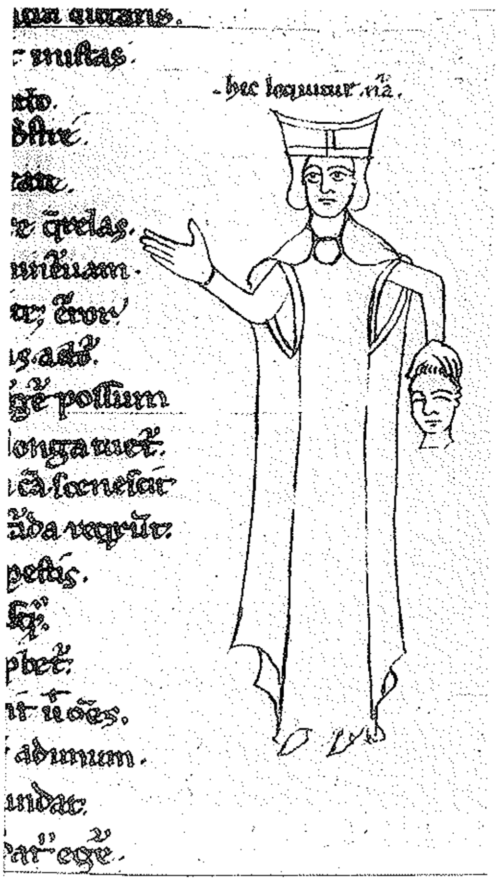


Fig. 7. Nature with head of the new man, Ill. to Alain de Lille, *Anticlaudian*, 14th. century, Verona, Bibl. Capitolare MS CCL.

The woodcut shows a hilly landscape with a garden-like area enclosed by a wall in the foreground (Fig. 8). The scene of the interior is dominated by an enthroned figure, distinguished as a king by his crown, imperial orb, and scepter. The attention of the figures on the left is focused on a man with a hood, mallet, and iron tool who, along with his dwarf-like companions, stands behind the enthroned figure: he is obviously the accused. A hermit, who comes upon the enclosed garden after losing his way in a strange forest, witnesses the trial of a miner.

The earth appears as a weeping woman, her green dress torn and her body injured in many places. Behind her, a number of gods, including Mercury and Minerva, appear as accusers. Man, argues Mercury, prepares his own destruction with this strategy, all the more absurd in view of the fact that nature does everything for him: "Year after year the earth bears fruit for the nourishment and preservation of all living things. In the end, it is all for one purpose alone: only for the sake of man does she bring forth all these things. Dissatisfied with this goodness, however, man pierces the entrails of his mother, ransacks her body, injures and ravages all its inner parts. Thus in the end, he mutilates the entire body and fully cripples its powers".[19] Man is a criminal of the worst sort, a matricide, who without pity or even a spark of affection observes the torments and infirmity of the mother who bore him and nourishes him and after death receives him back into her womb. He must be given the harshest of punishments: to be bound in a sack with a dog, a snake, and an ape and thrown into a pond.

Full of irony, the man answers that at most, he should be accused of murdering his stepmother, for the earth, "who claims for herself the name of the mother of man and continually invokes her maternal love, hides and conceals it deep inside, so that she clearly deserves the name of a stepmother rather than a real mother".[20] And further: "If your love for me were truly so great as you claim here before this court and the face of almighty Jove, you would not conceal the veins of ore in the deepest haunts, near the very center of the earth, thus driving me into the arms of

[19] Niavis (note 18), 1953, p. 16. "Terra etenim annuos ferens fructus! equibus alit atque sustenat que que animancia et que omnia certe in unum referuntur hominis causa solius procreantur nec ea contentus bonitate / matris aperit viscera: perforat ventrem eius ledit tandem: atque offendit singula intestina. totum lacerat corpus. omnes denique vires: et corporis: et membrorum debilitat" (Niavis, [note 18], s.l.).

[20] Niavis (note 18), 1953, p. 20. "Terra autem que parentis nomen hominis usupat / et matris amorem in ipsum predicat abdit: atque occultat in intima sua / ut noverce officium pocius quam genitricis habere videatur" (Niavis, [note 18], s.l.).

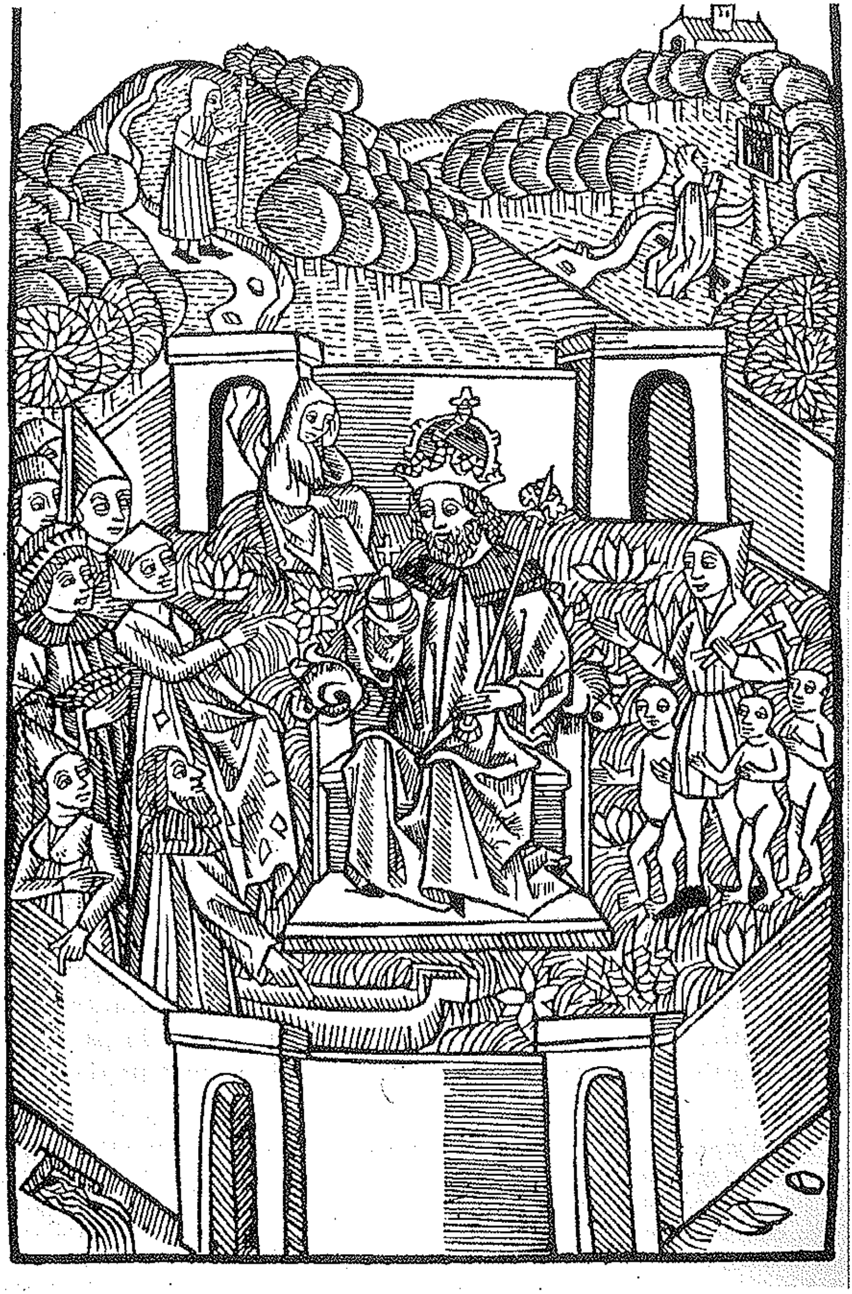


Fig. 8. The Judgement of Jove, Ill. to Paulus Niavis, *Iudicium Iovis*, woodcut before 1500.

death. I feel nothing of a mother's love from you, but rather the mind of a stepmother, far removed from any love and affection for the children she must raise".[21]

In the end, the judgment favors man: "It is man's destiny to ransack the mountains; he must dig mines, till the fields, and pursue trade. In so doing, he must offend the earth; he must leave the regular paths of science, disturb Pluto, and search for ore even in the watercourses. Yet his body is swallowed by the earth and stifled by bad weather; it is drunk with wine, it suffers from hunger, and it is a very good thing that no one knows the many dangers of other kinds that are inseparable from man".[22] After a defense of the undamaged earth, the "Judgment of Jove" thus ends with a considered decision in favor of intervention in nature, i.e., technology, whose price is the vulnerability and mortality of man.

When Niavis argues that in destroying Nature, man kills himself, and that he is forced to hurt his mother at the risk of his own injury and death, nature and man are conceived as antagonistic, and at the same time connected, as a single entity. Even or perhaps especially as the opponent of nature, man continues to be a part of it.

IV. The Technique of Natura

This grandiose poetry is the culmination of more than three centuries of a discussion which, from a present-day perspective, has an ecological character. Against this background, the invention of the figure of Natura Lactans mentioned at the beginning appears as a defusing, holistic neutralization of the problem (Fig. 1). While the story of the conflict between man and nature advances the justifiable positions of both sides,

[21] Niavis (note 18), 1953, p. 33. "Namque ut alia obmittam cerne manus meas callis affectas propter durum laborem: et prope inhumanum, ad quem me applicare tuum in me odium cogit, quod si tanta esset erga me dilectio tua quantam hic in strennuo inditio! inque conspectu iovis optimi: et maximi predicas / non abderes in intimis latibolis et in medio feme terre metallorum venas et quodammodo cogeres mortis vincula. Non parentis te cognosco affectam charitate / pocius noverce a qua perfecto omnis amor est atque favor in educandos liberos semotus" (Niavis, [note 18], s.l.).

[22] Niavis (note 18), 1953, p. 38. "Homines debere montes transfodere: metallifodinas perficere: agros colere studere mercature terramque offendere, scientiam abicere: plutonem inquietare. ac demum in rivulis aquarum venas metalli inquirere corpus vero eius a terra conglutiri: per vapores suffocari. vino inebriari: fame subici et quid optimum sit ignorare multa preterea alia pericula hominibus esse propria" (Niavis, [note 18], s.l.).

the harmonious conception of a nurturing nature, as it appears in the title page of a manuscript of Aristotle's Physics created shortly after Niavis' *Judgment of Jove*, serves rather to efface the soul of obstinate nature.

From now on, nature is portrayed as producing even the technical means by which man can impress his own image onto her. Benvenuto Cellini's *Natura*, for example, created as a design for the Art Academy in Florence, shows technique as a gift of Natura Artifex (Fig. 9). His drawing of 1562-63 shows the many-breasted Ephesian Diana as *natura naturans*. Cellini showed not only the trumpets of fame, the lion, and the snake as a sign for her strength and prudence, but also, as her basis, the alphabet of

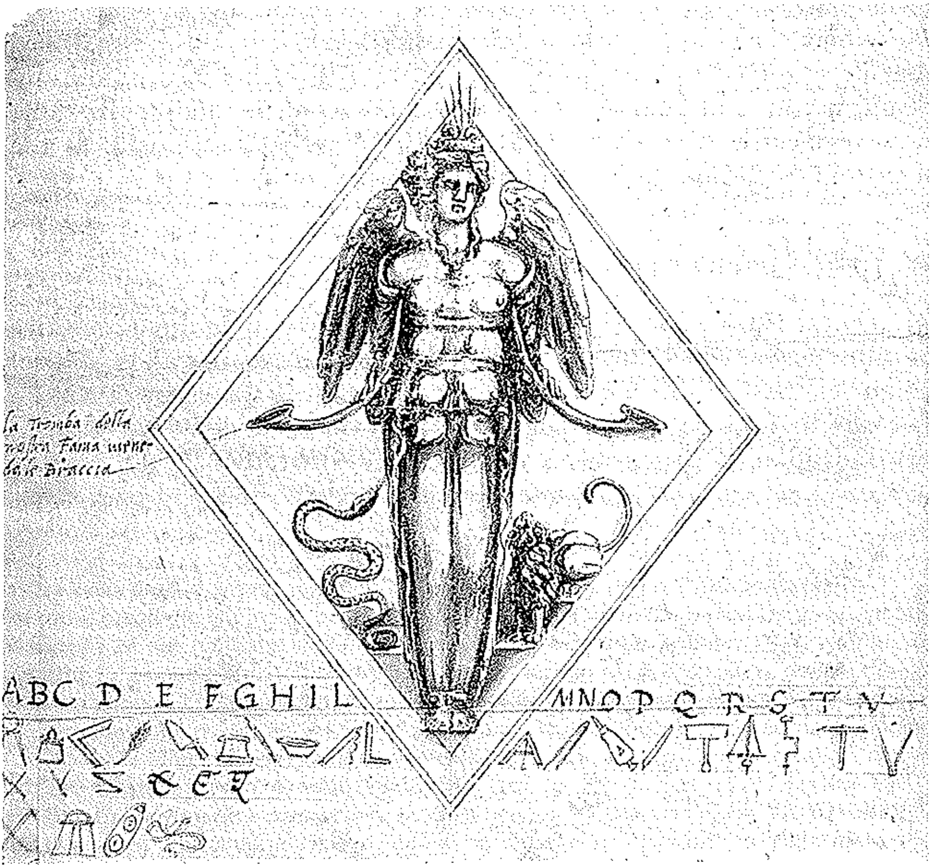


Fig. 9. Benvenuto Cellini, Seal of the Florentine Academy, Drawing, 1562/63, Florence, Uffizi.

technique at her feet.[23] Decades before Galileo's *Saggiatore* would attempt to read "the book of nature" according to the letters of geometry and stereometry, Cellini presented the natural alphabet of technique. Here Natura's nutritive function as a mother is embodied in her role as provider of the means for her own technological utilization, producing a mnemotechnical alphabet ranging from the pincers to the pulley.

Maarten van Heemskerck's grandiose image of Natura from the year 1671 represents a further development of this idea (Fig. 10).[24] Here, the cosmos hovers over the earth like a planet, the zodiac encircling it at a slant like a sash. Adorned with the instruments of technology, it is an attribute of the Ephesian Natura, who nourishes man not only as *natura lactans*, but also provides him with tools suitable for his work. While this cosmos of technique is a product of nature, it is at the same time distinguished from her in its artificiality. In this way, the many-breasted Natura bestows upon man the means of her own utilization in a truly sovereign fashion.

Finally, Matthäus Merian's frontispiece for Robert Fludd's gigantic work on the structure of the world and the human arts from 1617-18 shows both technique and art springing from a personified nature (Fig. 12).[25] From outside and inside, the Empyreum with the hierarchy of angels and ideas is followed by the spheres of the fixed stars and planets, the elements of fire and water and the three realms of nature: the animal kingdom, crowned by man, along with the vegetable and mineral kingdoms. The realm of the "more liberal arts" follows, remarkable for the dominant role played by the mechanical arts. On the surface of the earth sits an ape which, in accord with the traditional model of the world-architect, measures a globe.[26] As in Heemskerck, a second world of technological arts hovers over the earth. The ape personifies art, supported and directed by nature: *Ars Simia Naturae*.[27]

[23] Wolfgang Kemp, "Disegno. Beiträge zur Geschichte des Begriffs zwischen 1547 und 1607," *Marburger Jahrbuch für Kunstwissenschaft*, vol. 19 (1974), pp. 219-240: 223.

[24] Hans-Martin Kaulbach and Reinhart Schleier, *"Der Welt Lauf". Allegorische Graphikserien des Manierismus* (exhibition catalogue, Stuttgart, 1997), pp. 59ff.

[25] Matthäus Merian, frontispiz, in Robert Fludd, *Utriusque Cosmi, maioris scilicet et minoris, metaphysica, physica atque technica historia* (Oppenheim, 1617). Cf. Kemp, *Natura* (note 4), pp. 88ff.

[26] Johannes Zahlten, *Creatio mundi. Darstellungen der sechs Schoepfungstage und naturwissenschaftliches Weltbild im Mittelalter* (Stuttgart, 1979), pp. 153ff.

[27] Horst Woldemar Janson, *Apes and Apes Lore in the Middle Ages and the Renaissance* (London, 1952), pp. 30ff.; Horst Bredekamp, *The Lure of Antiquity and the*

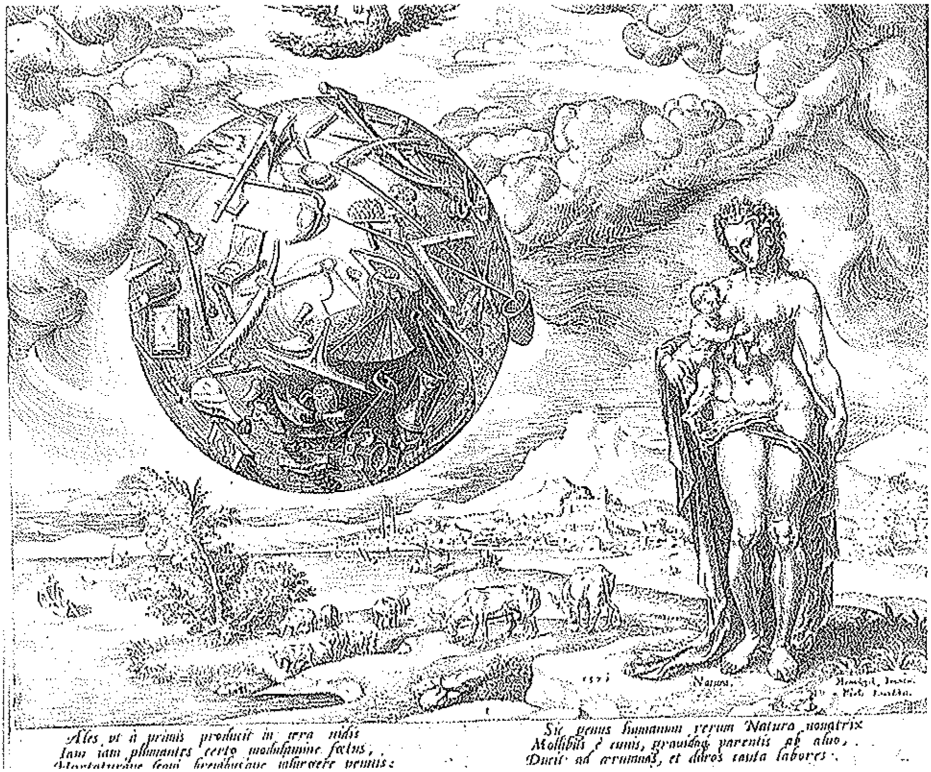


Fig. 10. Maarten van Heemskerck, *Nature*, engraving, 1571.

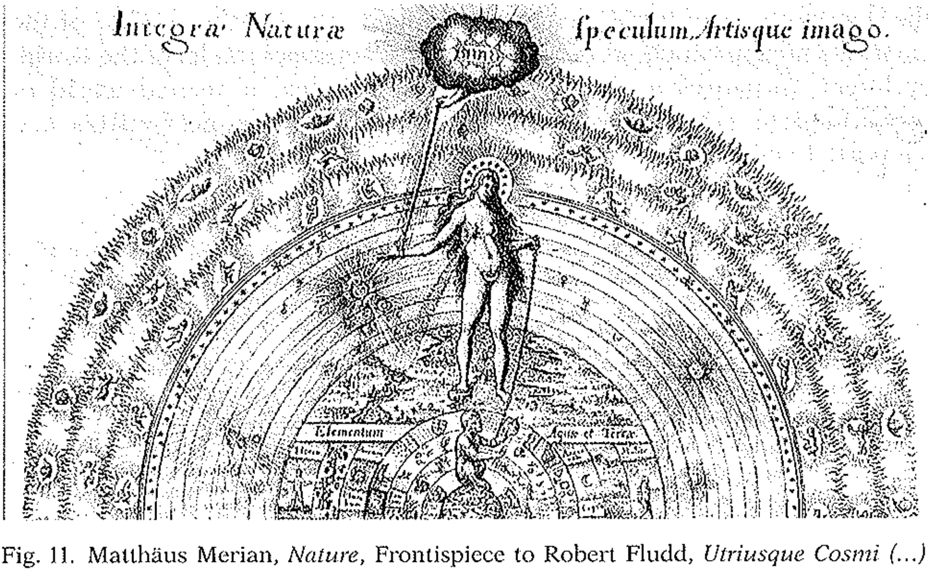


Fig. 11. Matthäus Merian, *Nature*, Frontispiece to Robert Fludd, *Utriusque Cosmi (...) historia*, 1617.

V. The Counter-Nature of the State

The ape of God is chained to nature, just as nature is guided by God. This chain, along with other borrowed motifs, was employed by Thomas Hobbes in his Leviathan of 1651 in the same way Merian had used it. In his discussion of the fact that all human actions can be traced back through long sequences to the origin of all causes, Hobbes speaks of "a continuall chain, whose first link is in the hand of God,"[28] as if imagining a left hand extending out from a heavenly cloud, holding the right arm of nature on a chain at a strangely splayed angle.

Hobbes likewise makes reference to this iconography of nature in his characterization of the natural goods of the earth: "As for the Plenty of Matter, it is a thing limited by Nature, to those commodities, which from (the two breasts of our common Mother) Land, and Sea, God usually either freely giveth, or for labour selleth to man-kind".[29] Though affirming Mother Nature's beneficence, Hobbes' characterization of the relation between man and nature is unique in its reformulation of the medieval complaint of nature against man.

For Hobbes, however, the question of guilt has two sides. To be sure, nature is mother and by no means a stepmother, but she made the mistake of bearing man as a wolf. As compensation, man is given the task of applying technology and the recreation of nature to himself, in order to create a new man, one who will transcend the boundaries of the organic (Fig. 12). The giant android of the State, the earthly god created by man whose task it is to suppress continual civil war by installing fear, results from the attempt to imitate nature. The *Leviathan* opens by stating that "Nature, the Art whereby God hath made and governs the World is by the Art of man (...) imitated, that it can make an Artificial Animal (...). Art goes further, imitating that Rationall and most excellent

Cult of the Machine. The Kunstkammer and the Evolution of Nature, Art and Technology (Princeton, 1995), pp. 70ff.

[28] "Liberty and necessity are consistent: as in the water, that hath not only *liberty*, but a *necessity* of descending by the Channel; so likewise in the Actions which men voluntarily doe: which, because they proceed their will, proceed from *liberty*, and yet, because every act of mans will, and every desire, and inclination proceedeth from some cause, and that from another cause, in a continuall chain, (whose first link is in the hand of God the first of all causes,) they proceed from *necessity*" (Thomas Hobbes, *Leviathan* [ed.: Richard Tuck], [Cambridge etc., 1991], chap. 21, pp. 146ff.).

[29] Hobbes (note 28), chap. 24, p. 170.

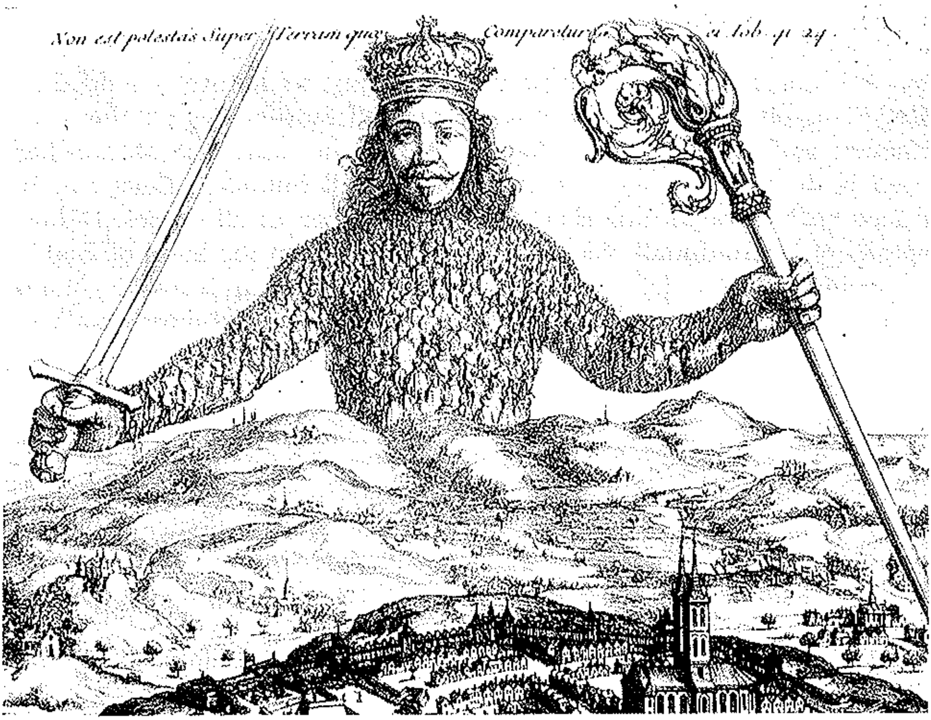


Fig. 12. Abraham Bosse, Frontispiece to Thomas Hobbes, *Leviathan*, 1651.

work of Nature, Man. For by Art is created that great LEVIATHAN called a COMMON-WEALTH, or STATE (in latine CIVITAS) which is but an Artificiall Man".[30]

With this usurpation of nature's creative function and the engendering of the modern state as a mortal god in response to the imperfection of man's own nature, the problem shifts its focus. Hobbes' *Leviathan* describes the technical rearmament of the second nature of man, and in so doing finally gives nature her Genius as a male counterpart: Father State, in relation to whom the parallel question – whether he relates to us as a father or a stepfather – will from now on be posed.

[30] Hobbes (note 28), p. 9.

VI. Nature and Reason

In order to avoid this very question, the French Revolution used an argument diametrically opposed to that of Hobbes, appealing to personified nature as the founder of a new political order. The Uffizi contain two designs by Etienne-Louis Boulée envisioning a project for a Temple of Reason in the sublime megalomania of revolutionary architecture. On the interior, above a colossal hemisphere, a smaller but still gigantic opposing shell sinks into the earth (Fig. 13). At the bottom it opens into a black fissure, behind which a tunnel continues downward.

On the arch covering this opening stands the image of the Ephesian Diana, the embodiment of a nature that Boulée had celebrated as a "universal science" in his architectural treatise (Fig. 14). His design was created at the time of the Terreur, when Christianity was to be replaced with the cult of reason and nature.[31] In contrast to Hobbes, for whom the State must be erected as a bulwark against the natural condition of man, here the community born of reason is defined as the product of personified nature.

In spite of a variety of opposing forces – the counter-reaction of Romanticism, the victory march of the steam engine, which established Prometheus as the new mythological hero,[32] Darwin's leveling of the barriers between the human and the non-human in nature, the dissolution of man into biomechanical or neuronal entities, making him appear so internally differentiated that he could no longer be conceived as nature's counterpart, and finally the attacks on concepts of three-dimensional space – the personification of nature nonetheless enjoyed an afterlife, as the adaptation of the Ephesian image of nature as a new Mary of technology in 1872 seems to show (Fig. 15).[33]

The process of alienation between *natura naturata* and the arts continued throughout the twentieth century, and artists, at least since

[31] Lankheit (note 3), pp. 27-35: p. 34. Cf.: Monika Steinhauser, "Étienne-Lous Boullées Architecture. Essai sur l'art. Zur theoretischen Begründung einer autonomen Architektur," in *Idea*, vol. II (1983), pp. 7-47: 32 and Gottfried Fliedl, "Architektur als Zweite Natur. Bemerkungen zur Architektur von C. N. Ledoux und E. L. Boullée," *Wiener Jahrbuch für Kunstgeschichte*, vol. XXX/XXXI (1977/78), pp. 239-258.

[32] Reinhard Steiner, *Prometheus. Ikonologische und anthropologische Aspekte der bildenden Kunst* (Munich, 1991).

[33] Joachim Radkau, "Natur und Technik – eine dialektische Beziehung?," in *Erfindung des Menschen. Schöpfungsträume und Körperbilder 1500-2000* (ed. by Richard van Dülmen), (Wien, Köln, Weimar, 1998), pp. 389-408: 393.

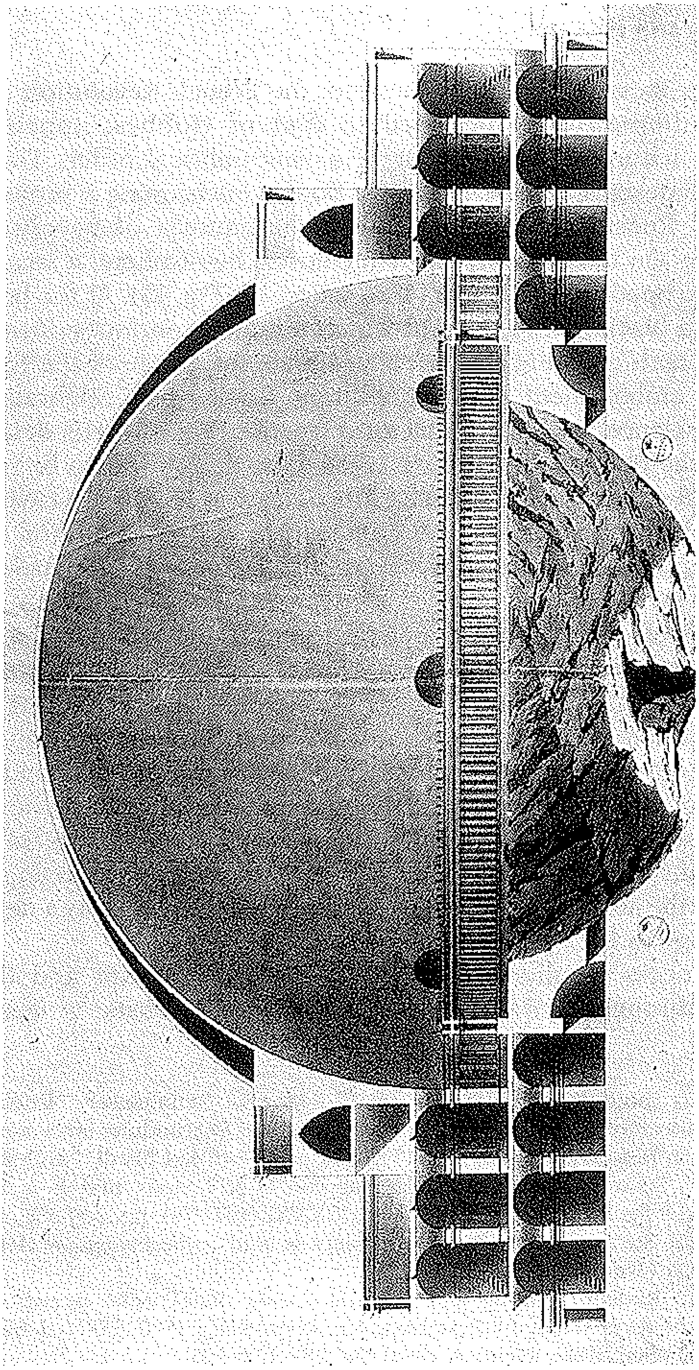


Fig. 13. Etienne-Louis Boulée, *Temple of Reason*, Drawing, ca. 1793, Florence, Uffizi.

Fig. 14. Etienne-Louis Boulée, *Goddess of Nature*, Drawing, ca. 1793, Florence, Uffizi.

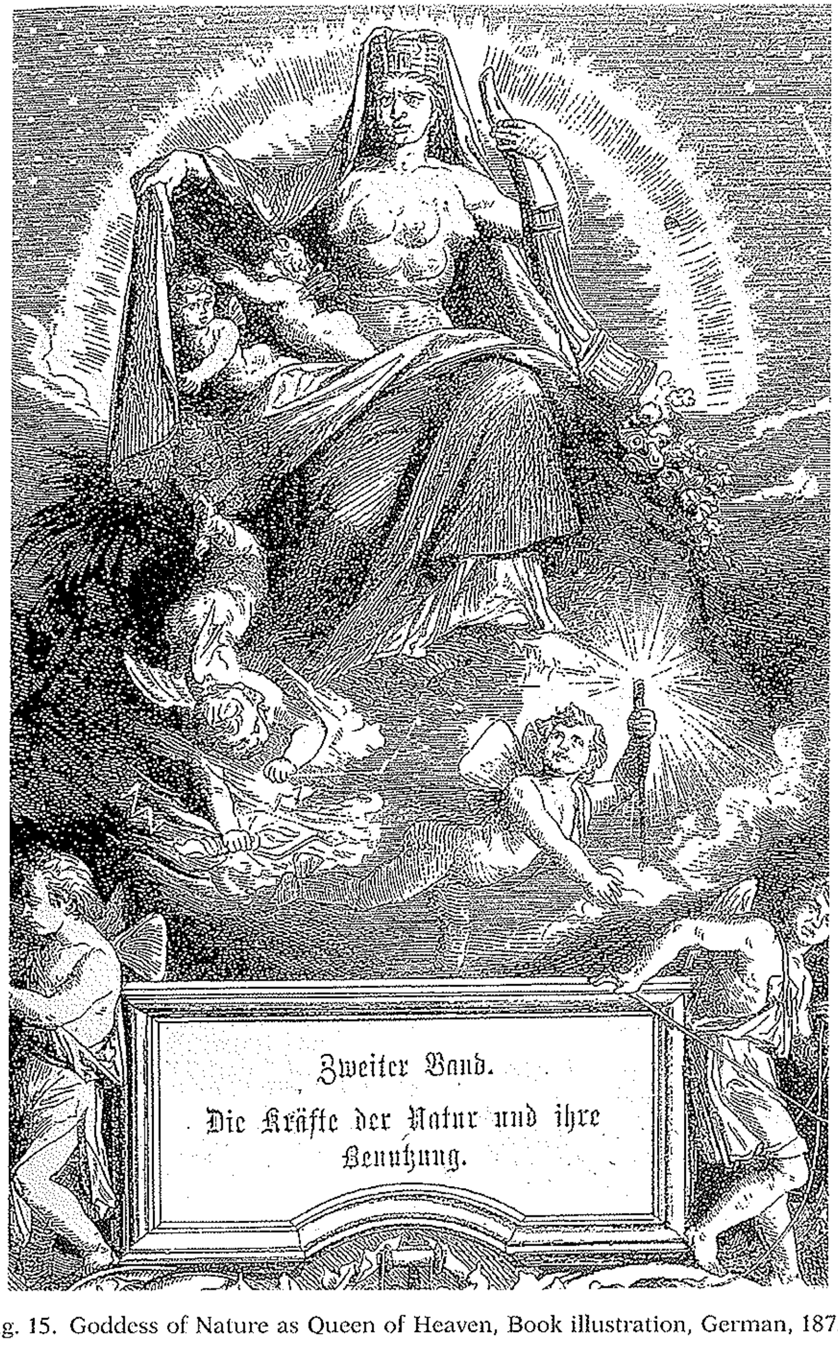


Fig. 15. Goddess of Nature as Queen of Heaven, Book illustration, German, 1872.

cubism and constructivism, became creators of artificial visual worlds subject to autonomous systems of rules. Yet with increasing distance comes a return to an older concept of a personified nature.

VII. Distancings

In recent decades, two decisive caesuras have taken place. The first occurred with the photographing of the entire earth from space during the Apollo mission to the moon. For the first time, human beings could view their entire world from a distance (Fig. 16). As various studies have shown, probably no other argument has done more to awaken ecological consciousness than these photographs, reproduced millions of times over.

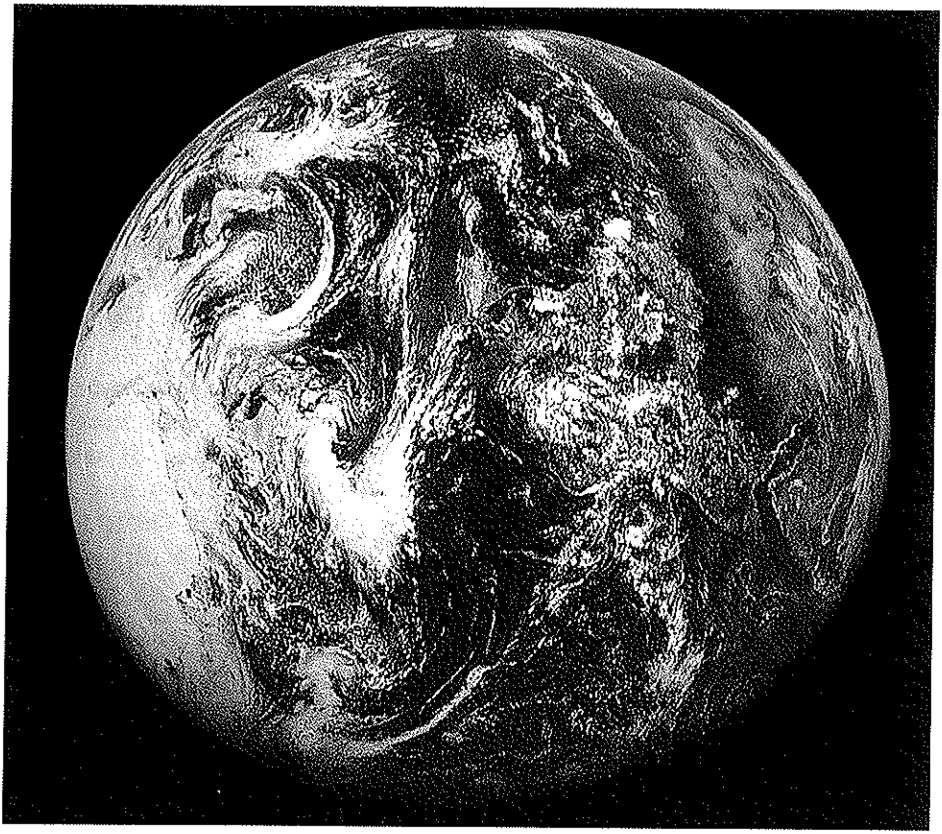


Fig. 16. View of the earth from space.

As these images showed, the earth really was round; it was also extremely beautiful, comparatively tiny, and its thin atmosphere seemed deeply vulnerable. In its loneliness and isolation, it suggested the need for protection.[34]

The second break has been effected by the combination of artificial intelligence with the new media, seeming to efface the boundary between humanity and nature. Donna Haraway's "Reinvention of Nature" may be taken as symptomatic of a hope fixed on Cyborgs, hybrids of human and machine that neutralize the dichotomy between man and nature within the human being itself – for the benefit of both.[35] Many propagandists see the internet as a forerunner of such biomechanical entities on a large scale. It has not yet been comprehended in a single image, but a view from space could probably visualize the network connections of the internet through the nocturnal illumination of nodal points (Fig. 17).[36] In the economic, social-psychological, and political spheres, the internet is seen as a quasi-sublime power, and there are many scientists and politicians who have characterized it as the breeding ground of a worldwide, direct democracy. Yet while it boasts unlimited freedom and anarchy, it also reproduces the lethal side of the state of nature, against which Hobbes wanted to erect the Leviathan: we need only recall the ever-growing number of viruses, the flood of sadistic pornography, or the uncontrolled activities of political sects. Many other arguments could be made to demonstrate that the free traffic of the internet evinces those qualities ascribed by Hobbes to the state of nature: "solitary, poor, nasty, brutish, and short".[37]

The double character of the internet becomes even clearer in its role as a place for the imitation and re-creation of nature. Some may have heard of the project to make the internet an archive of nature, reproducing the declining variety of natural species and thus compensating the stages of destruction of our biosphere. On the other hand, it also documents the aspiration to create a hybrid world of

[34] Wofgang Sachs, "Der blaue Planet. Zur Zweideutigkeit einer Ikone", in *Scheidewege. Jahresschrift für skeptisches Denken*, 1993/94, vol. I, pp. 168-189. Most influental was James Lovelock, *The Ages of Gaia. A Biography of our Living Earth* (New York, 1988).

[35] Donna Haraway, *Die Neuerfindung der Natur. Primaten, Cyborgs und Frauen*, (Frankfurt/New York, 1995).

[36] Michel Serres, *La Légende des Ans* (Paris, 1993), p. 60f.

[37] Horst Bredekamp, "Der Leviathan und das Internet," in *Interact! Schlüsselwerke Interaktiver Kunst* (exhibition catalogue, Duisburg, 1997), pp. 41-47.

Fig. 17. View of the earth at night.

artificial beings. In recent years, as 35,000 plant and animal species have become extinct, more than 40,000 new creatures have been "born" in the so-called "Technosphere" of Jane Prophet.[38] As a purely visual world, it makes up a very suggestive part of the "iconic turn" of our times.

In this context, numerous artists are experimenting with the interplay of destruction and new creation. Among them, the Austrian artist Christa Sommerer is one of the must successful. In collaboration with Laurent Mignonneau, she has created elaborate computer "animations" in which life is reduced to the ability to appear to act and to be seen. Sommerer's *Life-Species* of 1997, a further development in the internet of the work *A-Volve* of 1995, can be seen as an attempt to imitate an active state of nature. *A-Volve* made it possible to create and influence artificial fish in a pool of water; *Life-Species* permits the same, but now on the internet: it "enables visitors to integrate themselves into a 3-dimensional complex virtual world of artificial life organisms that react to the visitors' body movement, motion and gestures. The artificial life creatures also communicate with each other and so create an artificial universe, where real and artificial life are closely interrelated through interaction and exchange".[39] The artist becomes a *natura naturans*; surrounded by her creatures, she produces a new nature in which life is beautiful and diverse, but is also a model of Darwinistic evolution (Fig. 18). The destruction of our biosphere is both criticized and compensated in a playful recreation of ever new classes of species in an artificial communication-animal, a rebirth of the Hobbesian state of nature.

* * *

Without maintaining, like Bruno Latour, that "we never were modern,"[40] I hope nonetheless to have shown that the present-day debate is prefigured not so much in the Renaissance, but in medieval personifications of nature in art. The optimism of the Renaissance evoked in the opening lecture of the symposium[41] served to mute nature's

[38] http://clever.net/quinion/sibh/j2a-tech.htm

[39] http://www.mic.atr.co.jp/Christa/Works/Concepts/ LifeConcept.html. Cf.: Christa Sommerer and Laurent Mignonneau, "Art as a Living System," in *Art @ Science* (ed. by Christa Sommerer & Laurent Mignonneau), (Vienna and New York, 1998), pp. 148-161.

[40] Bruno Latour, *Nous n'avons jamais été modernes* (Paris, 1991).

[41] Jürgen Mittelstraß, "Historical and Epistemological Aspects of the Concept of Nature", in this volume.

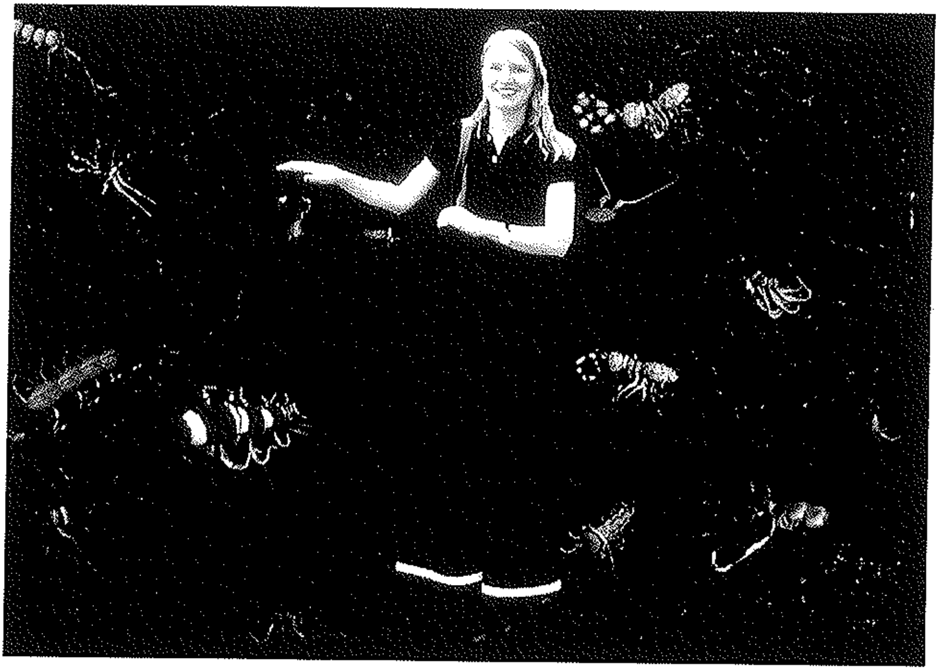


Fig. 18. Christa Sommerer as Nature, ca. 1996.

complaints;[42] this process, however, has been halted by the ecological movement of recent decades. If I may close with a bit of irony: the best thing about the destruction of nature at the end of the 20th century is that it has reconstructed the modernity of Middle Ages.

Translation: Melissa Torson Hause.

[42] Modersohn (note 5), p. 190.

ART AND THE GLOBAL MOBILIZATION AT THE TURN OF THE MILLENNIUM[1]

(Comment on Prof. Bredekamp's Paper)

FRANK FEHRENBACH

We have heard that the image of 'Mother Nature' responds to an older image: that of nature as a distanced power, who withholds her goods from humanity, yet who at the same time demonstrates, through her own example, ways to overcome deficiency. Nature is conceived technomorphically, as a craftswoman who is not always perfect in her products.

The philosophical and religious traditions behind this image are clear:

There is Plato's conception, for example, of the Demiurge who imperfectly imitates the world of Ideas, and the neo-platonic vision of a perfect world of Ideas that become contaminated in their materialization. There is the Judeo-Christian belief in a 'natura lapsa,' a perfect divine creation that was damaged in man's Fall. And there is the idea (not yet articulated in Alain de Lille's *Anticlaudian*, and, it seems to me, specifically early modern) that nature is perfected by man, that culture, as a technology, creates a second nature which gradually replaces the original. This involves a harmonistic motif, one we find depicted, for example, in the central ceiling fresco in Francesco I de Medici's studiolo in the Palazzo Vecchio in Florence (Fig. 1). In Vincenzo Borghini's sketch of the program, the thought is made clear: unfinished nature voluntarily offers her products (in this case, an unpolished gem) to Prometheus, who, as an embodiment of human technology, in turn guarantees the

[1] I wish to express my gratitude to Michael Cole, Princeton/ Chapel Hill, for his translation of the German text.

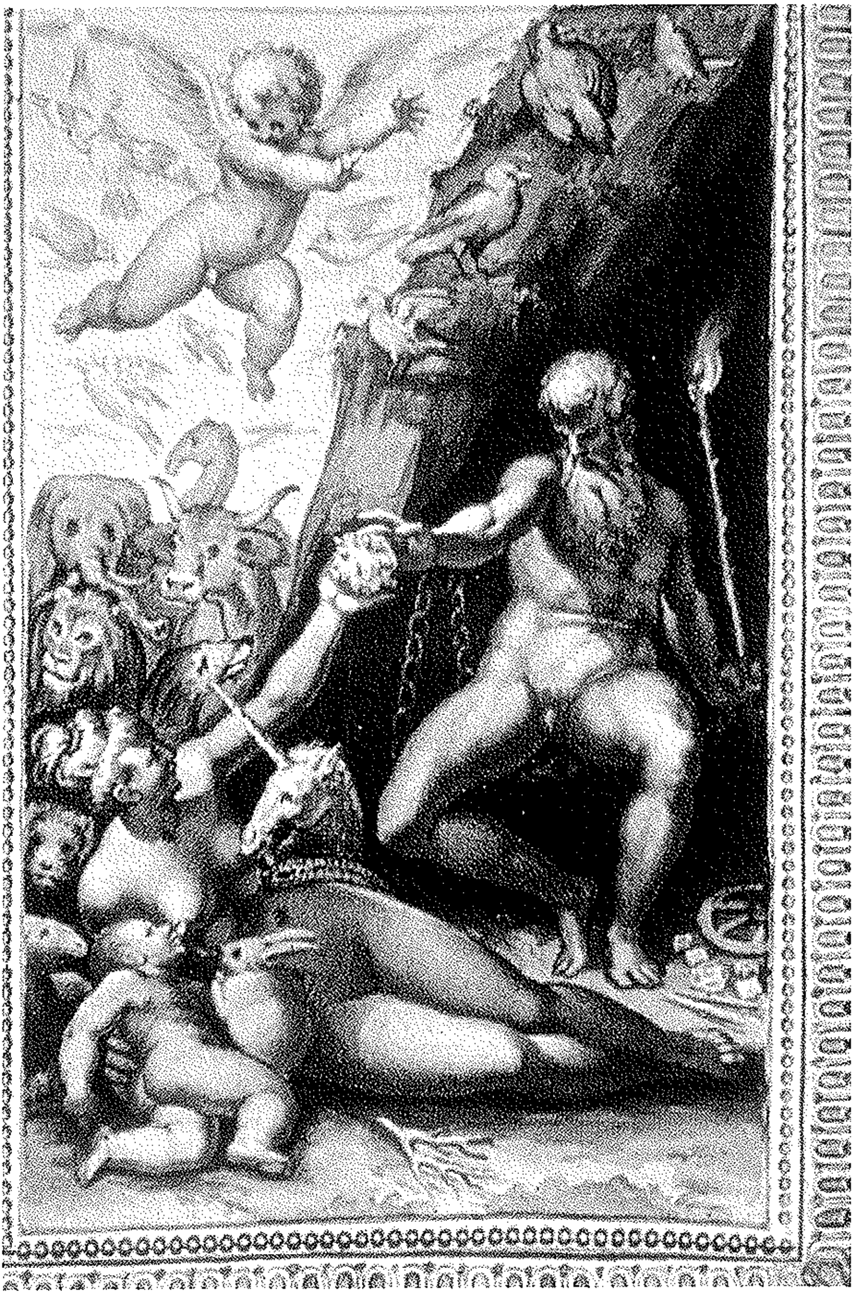


Fig. 1. Francesco Morandini (Il Poppi), *Prometheus receives a gem from Natura*, Florence, Palazzo Vecchio, Studiolo of Francesco I., after 1571.

perfection of the raw material. Borghini emphasizes that, in order to achieve a perfected culture-nature, Nature and man must mutually rely on one another.[2]

Such utopian images have a consistent aim which is reached partially through the assimilation and partially through the overpowering of nature: it is the aim of achieving the perfection of the arts (as in Giorgio Vasari),[3] complete knowledge (as in Francis Bacon's Atlantis)[4] or, as we have learned, the total state (as in Hobbes). It is a utopia in which every shortcoming is overcome, in which every hope for permanence is reflected. It is a utopia that stands as the anti-type of agrarian society, a society that, as Rolf Peter Sieferle has recently shown,[5] must constantly exert itself to eliminate new injuries to its labile balance of energy.

Such parameters are no longer valid since it has been possible for humanity globally to transform a permanently negative balance of energy into prosperity and population growth. In the second half of the twentieth century, the earth's surface is more and more characterized by what Sieferle calls the 'total landscape' without nature in the traditional sense. Ours is an epoch of acceleration and transformation. My question about Bredekamp's argument would thus be the following: is the 'agrarian,' technomorphic vision of a completable, surmountable nature – and man – still meaningful for art at the turn of the millennium? In elaborating this question, I would like to begin with Leonardo da Vinci.

No allegorical representations by Leonardo of nature as a whole are known to us, but we do have a few analogous texts. In them, we find the motifs Bredekamp has mentioned: a plaintive nature, damaged by the desires of humanity, but also a vengeful, death-dealing nature of dearth[6]. Turning to the few surviving paintings with landscape backgrounds, we see that the earth's surface is represented, uniquely, as a product of transition: rivers wind their ways or dry up, mountains waver and fall, the

[2] See S. Schaefer, *The Studiolo of Francesco I de' Medici in the Palazzo Medici* (Ph.D.Diss. Bryn Mawr College) Bryn Mawr/ PA 1976; Ph. Morel, *'Le Studiolo de Francesco I de' Medici'*, in AAVV., *Symboles de la Renaissance* II (Paris, 1982), pp. 187-197. Cf. related sketches of, for example, Giovanni Battista della Porta (*Magia Naturale*) and Giambattista Gelli (*I capricci del bottaio*).

[3] Cf. H. Belting, *Das Ende der Kunstgeschichte?* (Munich, 1983).

[4] Cf. W. Krohn, *Francis Bacon* (Munich, 1987).

[5] R.P. Sieferle, *Rückblick auf die Natur* (Munich, 1997).

[6] See for this duality (and its parallel in the rhetorical tradition) the author's *Licht und Wasser. Zur Dynamik naturphilosophischer Leitbilder im Werk Leonardo da Vincis* (Tübingen, 1997), pp. 229ss.

ground, empty of human life, reveals itself to be the result of erosion, a snapshot in which we seek rest and equilibrium in vain (Figs. 2-4). One could think of Aristotle's *Meteorology*, in which the constant exchange between land and water is emphasized – the epochal pendular movement that was to become of such great significance for the Roman philosophy of nature.[7] Leonardo, however, goes beyond this vision. In his writings, he formulates geological hypotheses that imply the death of terrestrial life: in the future, the world will either be fully covered with water, or without any at all.[8] One must question how playfully these prognoses are intended. What is, however, certain is that Leonardo was one of the first to think from mechanistic premises to something like global contingency – the idea of an unknown geological future that takes no heed of humanity. The emphasis is on history and contingency. Leonardo's background landscapes are in transition, they are subjected to alterations and destructions of the largest scale. These landscapes are early examples of the global transformations that *humanity* has now undertaken. Following Blumenberg, the thesis would be that the shocking historicity of a mechanized nature justifies humanity's own global manipulations.[9]

Global transformation, whose witnesses and protagonists we are, does not just rectify an earlier state of deficit, consuming the fossil energies of the earth's crust and releasing its components into the earth's atmosphere. The present global transformation does not just respond to a jealousy over a stepmother Nature. And even less is the aim of this transformation still that of nature's completion. Activity, as Jakob Burckhardt noticed, has now its aim within itself. The technological transformation consists in the mobilization of every material and social structure. Where once there was being, now there will be motion. Leonardo anticipated this, for example, with the phantasmagoria of a gigantic cannon that could shoot the earth out of its position at the center of the cosmos, and which could thereby set the earth in motion[10] – a technologically produced Copernican change, a fantasy of omnipotence in the service of global mobilization. Simultaneously, we find a

[7] Aristotle, *Meteorology*, I, 351a19 – 353a27, cf. *Physics* IV, 222a; see Seneca, *Natural Questions*, III, 30. 2-4.

[8] For these geological alternatives see especially *Codex Leicester*; furthermore *Manuscript F* in the Institut de France, Paris.

[9] See H. Blumenberg, 'Selbsterhaltung und Beharrung. Zur Konstitution der neuzeitlichen Rationalität', in H.Ebeling (ed.), *Theorie-Diskussion. Subjektivität und Selbsterhaltung. Beiträge zur Diagnose der Moderne* (Frankfurt/ M., 1976), pp. 144-207.

[10] *Codex Madrid I*, first folio recto (n.p.).

Fig. 2 – Leonardo da Vinci, *Portrait of a Lady ('Mona Lisa')*, Paris, Louvre. Detail (1504 – 16).

Fig. 3. Leonardo da Vinci, *Madonna with Child and St. Anne*, Paris, Louvre (c. 1510).

Fig. 4. Detail from Leonardo da Vinci, *Madonna with Child and St. Anne*, Paris, Louvre (c. 1510).

dynamization of ethics and of anthropology, as in Pico della Mirandola: He derives the dignity of humanity from its indeterminateness and potential for development, from its capacity for self-transformation.[11] Something similar can be said of Machiavelli's State. Emptied of content, the imperative transformation becomes 'theology of labor'.[12]

Nature, accordingly, is still of interest only as long as she provides material for transformation. Since the middle of the nineteenth century, the question of her *telos* has been of little interest to the arts, and of still less to the sciences. The role of the stepmother has changed: She faded, and now she must allow us to plunder her pantries for a few centuries. Thereafter, we must come up with something new, if we do not want to give up, for example, the capacity for limitless reproduction we have taken over from her.

How does modern and post-modern art behave before this panorama? As it always does: both affirmatively and critically. The great transformation and acceleration were partially anticipated by the arts. They quickly abandoned the slow, concrete view of agrarian society, and they staged dynamics of speed, shock and standstill. In their most advanced forms, those of film and video, the visual arts participate in the acceleration, indeed explosion, of time in the industrial age. But in this, art also lets us experience what takes place around us. No question, art has discovered time.[13] Perhaps one can ask whether time has even become the final residue of nature, the manipulable, but also, ultimately, unavailable Other, the persistent enigma of both science and philosophy, motherly-stepmotherly, fortune and hazard within one's own lifetime. But as for what might follow the total transformation, the exhaustion of natural and psychic resources – for this, I am afraid, even the arts don't yet have pictures.

[11] Pico della Mirandola, *De hominis dignitate*, ed. by A. Buck (Hamburg, 1990), p. 6.

[12] See the classical study of M.D. Chenu, *Théologie du travail* (Paris, 1955).

[13] For a recent bibliography: *Das Phänomen Zeit in Kunst und Wissenschaft*, ed. by H. Paflik (Weinheim, 1987).

LANGUAGE AS NATURE AND LANGUAGE AS ART

STEPHEN C. LEVINSON

1. Background

The perennial pendulum

Observations and theories about the nature of language constitute one of the oldest forms of intellectual inquiry. The preoccupation is not hard to understand: language and human nature seem inextricably intertwined, and the gulf between our own species and other animals – whether it is conceived of as the possession of high intelligence, consciousness or culture – seems intimately connected to the possession of language. The lack of continuity with other species, together with our own cultural diversity, has invited us over the millennia to think of ourselves as *outside nature*, as quintessentially products of culture. But there has always been a perennial view of another kind: that we are cultural and linguistic beasts by virtue of *human nature*. On the first view what is emphasized is the variety of languages, on the second what is emphasized is the deep, hidden commonalities between languages. Eight hundred years ago, scholarship already lurched between the poles of linguistic relativism and universal grammar.[1] Indeed, over two and half millennia of the Western intellectual tradition views have oscillated between viewing language as part of human nature, or alternatively,

[1] "Among scholastic theoreticians of language the renowned Paris savant of the twelfth century, Pierre Hélie, declared that there are as many kinds of grammar as their are languages; whereas in the thirteenth century, *grammatica universalis* was considered indispensable to give grammar a scientific status. Roger Bacon taught: *'Grammatica una et eadem est secundum substantiam in omnibus linguis, licet accidentaliter varietur'*" (Jakobson, 1961:264).

seeing language as essentially part of human culture. Although the twentieth century has seen a veritable explosion of knowledge and theory in the language sciences, this particular ideological issue continues to dog us. We still have not found a satisfactory way to bridge the tired old Nature:Nurture issues.[2] As the authors of a recent book on the subject put it: "The answer is not Nature *or* Nurture, but Nature *and* Nurture. But to say that is to trade one platitude for another; what is necessary is to understand the nature of that interaction" (Elman *et al.*, 1996:357). The current swing of the pendulum has the language sciences out on a Nature pole, with language often treated as an 'instinct' (Pinker, 1994, Gopnik, 1997; but see Tomasello, 1995). But what I want to suggest in this paper is that to transcend the oscillations of the pendulum we need to find a new framework that will focus our inquiry on the peculiar kind of interaction in language between biology and culture.

2.0 Strategies for naturalizing language

The last half of this century has been much preoccupied with *naturalizing language*. By this I mean, trying to find a place in nature for what a long tradition has often assumed is indisputably a part of culture. Like most practicing linguists, I am generally sympathetic to the strategy. We are awed by the complexity of language, and the ease with which children learn it. We are also impressed by the neurophysiological adaptations that make language possible. But the particular 'naturalizing' strategy generally adopted in the language sciences has taken a peculiar turn with which I want to quarrel.

'Simple Nativism' vs. 'Coevolutionism': or why there is more than one language

The particular strategy for naturalizing language now dominant amongst linguists and psychologists holds that language is a mere projection of universal internal mental structures. I will dub the view 'Simple Nativism'. On this view, natural selection – or even perhaps an evolutionary accident – has delivered to our species two fundamental

[2] The history of the opposition in our own cultural tradition is explored in e.g. Collingwood, 1945, and the papers by Mittelstrass and Bredekamp, this volume. The corresponding contrasts in other cultural traditions can be strikingly different; see, e.g., Descola and Pálsson, 1996; Ellen and Fukui, 1996.

kinds of mental endowment which are directly reflected in language. The one is architectural and is constituted by universals of syntax, which are constraints on possible rule systems. The view that this system ('Universal Grammar') is innate is of course associated with Chomsky. The other relevant endowment, on this view, is a structure of mental content: a rich set of innate concepts, given by some uniform central 'language of thought', together with specialized mental faculties that input to it, as in the influential views of Fodor (1975, 1983) – or alternatively, as given solely by a prestructuring of specific domains of human problem-solving, as in the views of the 'evolutionary psychologists' (see Barkow *et al.*, 1992).

'Simple Nativism' might seem inevitably to presuppose an evolutionary perspective. But Chomsky for one decisively rejects the idea that our innate linguistic abilities have evolved as adaptive features.[3] He thinks he has discerned deep, underlying, quirky constraints which limit the class of possible human grammars and which are in many respects anti-adaptive – e.g. they make the parsing of sentences difficult. Dennett (1995:487) puts his finger on the issue:

> The very considerations that in other parts of the biosphere count *for* an explanation in terms of natural selection of an adaptation – manifest utility, obvious value, undeniable reasonableness of design – count *against* the *need* for any such explanation in the case of human behavior. If a trick is that good it will be routinely rediscovered by every culture.

So we have a kind of reversal of the general line of argumentation: in the human field, adaptive strategies need no genetic underpinning, only non-adaptive ones do! Hence Chomsky's interest in the quirky details of syntax and the belief that it is these non-adaptive patterns which establish the innate nature of language in his very special sense of 'Universal Grammar'. In fact, there is no real incompatibility between the common-sense view that language in a broad sense has evolved as a highly adaptive communication system and Chomsky's view that the quirky details of syntax are accidental – the latter may well be side-effects of the evolution of language as a communication system. For this reason, Simple Nativism seems quite compatible with an evolutionary perspective (Pinker and Bloom, 1990).

[3] Chomsky (1982:321) suggests that Universal Grammar may in some way be a side effect of laws of growth or form applied to the massive human cortex. Elsewhere he admits to general skepticism about the theory of natural selection: "In my view (in this respect I may be a little more heretical), natural selection in itself does not provide anywhere near enough structure to account for what happens in evolution" (cited in Campbell, 1983:97).

However, this entire strategy for naturalizing language seems to me to be wrong, at least in emphasis. For it entails ignoring or minimizing the very substantial differences between languages and cultures.[4] Culture itself is an evolved system that allows rapid adaptation to varying conditions and which has made it possible for us to invade almost every ecological niche on the planet. The right strategy for naturalizing language, I will argue, is therefore not to ignore those linguistic and cultural differences, but to embrace them. We are built to handle the diversity: language is a bio-cultural hybrid. The way to naturalize this duality of traditions, genetic and cultural, is through the theory of coevolution. Coevolution can be studied in symbiotic relations between species. But the idea of the mutual adaptation of two gene lines can be extended (perhaps somewhat metaphorically) to the idea of the mutual adaptation of a gene line and a line of cultural transmission.[5] The concept of genetic/cultural coevolution is now familiar through the work of Dawkins, 1976; Cavalli-Sforza and Feldman, 1981; Boyd and Richerson, 1985; Lumsden and Wilson, 1981; Durham, 1991; Laland *et al.*, 1995, and others. Theories here vary across a spectrum from sociobiological reductionism to mild interactionism – in what follows I shall presume a model of the mild interactionist type (as in Durham, 1991) in which

[4] There is much talk in linguistics of 'language universals', so that outsiders to the field may well be forgiven for thinking that there is a large body of properties that all languages are known to share. This is not the case. On the one hand, Chomsky and followers have posited highly abstract properties, constantly varied under changes of theory, which are difficult to test and hence never demonstrated for more than a handful of languages. On the other hand, Greenberg (1961) and followers have searched for more superficial, empirical generalizations over a few hundred languages; these generalizations turn out almost invariably to be statistical tendencies in conditional form (e.g., if a language has verb-last word order, the chances are high it has relative clauses in front of the nouns they modify). It may come as a surprise to the general reader to know that we have good information on only perhaps 7% of the 7-8000 odd languages of the world (the higher estimate is probably correct, but even that we do not know).

[5] There are many problems with the idea that the culture track is similar to the genetic track – it clearly lacks Mendelian segregates and recombination, and it supplements vertical transmission with horizontal transmission more like viral infections than genealogical descent (see Sperber, 1996). One eminent biologist has even stated that the idea of a parallel between biological and cultural evolution has done much more harm than good (Gould, 1991:63, cited in Dennett, 1995:342). But as Dennett (1995:345) remarks, the truth about whether cultural replicators are really like biological ones will turn out to lie somewhere in the fertile ground between the possible extremes. The study of language, a human ability midway between biology and culture, is the best possible place to try and get a little further.

culture has a life of its own, but nevertheless is supported by and interacts with our biology. There is evidence for adaptation of the human gene pool to such cultural practices as dairy farming, swidden agriculture (increased malarial ecologies being compensated for by malarial resistance), female infanticide, and so forth. But the very best and most obvious exemplar is language, which for inexplicable reasons has so far played little role in coevolutionary models (but cf. Deacon, 1997). We cannot run like a horse because we have a vocal tract in the way; we are the only mammal that cannot eat and breathe at the same time, because our larynx is lowered in order to maximize the length of the vocal tract; we have hearing specialized to the frequencies of human speech; we have brain areas and neural pathways dedicated to speech processing (see Lieberman, 1984). And all this hardware is there because the cultural traditions of languages are there; and the cultural traditions are there, because the hardware enables them.

Without this theory of twin-track evolution, it would be hard indeed to understand *why there is not just one language*. Pinker and Bloom (1990:716), Simple Nativists by inclination, consider this conundrum as it pertains to word meaning. They admit to no firm answers, but add that it is just more practical for "the genome to store the vocabulary in the environment". But for the 'environment to store the information', it has to be a self-reproducing system of its own. That is the whole point of the coevolutionary perspective: culture creates and maintains just the environment that will exploit the possibilities in the genome, which in turn enable the culture. Because the genome has, as it were, yielded over the business of fast adaptation to another self-replicating line, we inevitably end up with one species with many languages.

Much more needs to be said about both coevolutionary theory in general, and its application to language in particular, but that would be another paper and indeed another author. Suffice it to say that, as Dobzhansky (1962:18) said 40 years ago, there is a feedback relation between culture and biology and that we have some worked-out ideas about how to account for the apparent Lamarkian effects of culture on genome – through such mechanisms as sexual selection, the Baldwin effect and (most controversially) group selection. Contrary to some Simple Nativists (e.g., Tooby and Cosmides, 1992) there is nothing mystical in these sorts of processes, whereby, for example, cultural adaptations like warm clothing and harpoon technology make possible the colonization of the Arctic circle, whereupon natural selection in turn engenders physiological adaptations to cold (such as stock body form, or vasodilatation in the limbs). Moreover these processes give us some glimpse of the origin of language in the tension between cultural and genetic tracks, where ever more complex behavioral demands put a premium on cognitive capacities, whose development in turn made possible higher orders of cultural form in an accelerating spiral of cognitive and cultural complexity.

Simple Nativists, if they are aware of this line of argument at all, are unaccountably hostile to it: they claim that all the regularities have long been fixed in the human mind, and that ideas about interactions at the biology/culture interface are as vague as the cultural relativism which is their main target.[6] They take as their bottom line the fact that languages just seem too complex for children to learn – neither the smartest apes nor the smartest machines can do it. If language is essentially coded in the genes, then it seems that the apparent diversity must be mere surface camouflage on invariant substrate. But this argument carries little weight with coevolutionists: the complexity can be divided between innate learning biases on the one hand and patterns stored in the cultural environment on the other – patterns that have precisely evolved to fit the learning biases. For a language to be viable as a cultural tradition, it has to be designed to latch on to innate learning biases.

Unfortunately, it is doubtful that the development of a sophisticated coevolutionary theory of language is likely to carry much weight with Simple Nativists. What may have more effect is to collect examples of the kinds of phenomenon which seem more tractable to a coevolutionary view than to a Simple Nativist one, and that is the strategy I shall follow here.

A telling example: infants are built to 'tune in' to specific languages

Let me provide an immediate example of the way in which we seem *built* to handle linguistic diversity. Infants, long before they learn

[6] Simple nativism holds that "the rich computational architecture of the human mind" is "where sufficiently powerful ordering processes – ones capable of explaining the phenomena – are primarily to be found"; and the approach criticizes the coevolutionary perspective as sharing, along with the 'social science model', a vague or even mystical ontology: "attempting to locate in these population-level processes the primary generator of significant organization has caused these processes to be fundamentally misunderstood" (Tooby and Cosmides, 1992:47). Biologists on the whole will find this unconvincing: the function of culture is its ability for swift change: "it should follow that the fittest genotypes are those that least restrain tradigenetic [cultural] rule flexibility" (Markl, 1982:19).

language, are highly sensitive to the speech sounds around them. There seem to be a number of initial innate biases. Acoustic continua are categorically perceived, so that e.g. a continuous series of sounds between /i/ and /e/ and /Σ/ is partitioned into just three kinds of sound. There thus seems to be a kind of innate category grid. But something dramatic happens to this initial state within the first six months of an infant's exposure to the sounds of a particular language: the acoustic space becomes systematically and ineradicably distorted – sounds that are acoustically equidistant will now become assigned to same or different categories along language-specific lines (Kuhl and Meltzoff, 1996; 1997).

The end result is, as we all know, the set of spectacular biases in our auditory perception which make adults unable even to *hear* the difference between sounds that are fundamentally distinct in some other language. Thus the initial, innate categorical perception system ends up systematically skewed. Exposure to a specific language *rebuilds* our perceptual acuities, and it does so at such an early age that it seems inescapable that the system is built for variation, i.e., built for "tuning in" to the local system, whatever it turns out to be. But the character of that cultural tradition in turn is bound to be organized around a selection from the initial innate category grid – because cultural transmission and learning will always be biased by prototype sounds.

We are in the unusual position, thanks to the work of Kuhl, that we know that monkeys also subject acoustic continua to the same sort of categorical perception. But they do not have the ability to warp the perceptual space in accord with the dominant speech sounds – indeed there is very little evidence of any learning from the acoustic character of others monkeys' calls (Kuhl, 1991; Kuhl and Meltzoff, 1997; Hauser, 1997:324).

Now a Simple Nativist perspective might well predict the initial perceptual biases here, but it would be hard put to explain the specifically human characteristic – namely the restructuring of acoustic space to suit the local language in the first months after birth. Here a co-evolution perspective makes a lot more sense: since cultural traditions change at a much faster rate than the genome, the system is built to handle diversity. In fact we know a great deal about the rapidity of sound changes in language (e.g., in New York, /E/ went through /e/ to /i/ in words like *bad* in just 65 years; Labov, 1994:74-5), and we also know that sharing accents is a crucial marker of group membership, which deeply effects the life chances of individuals.

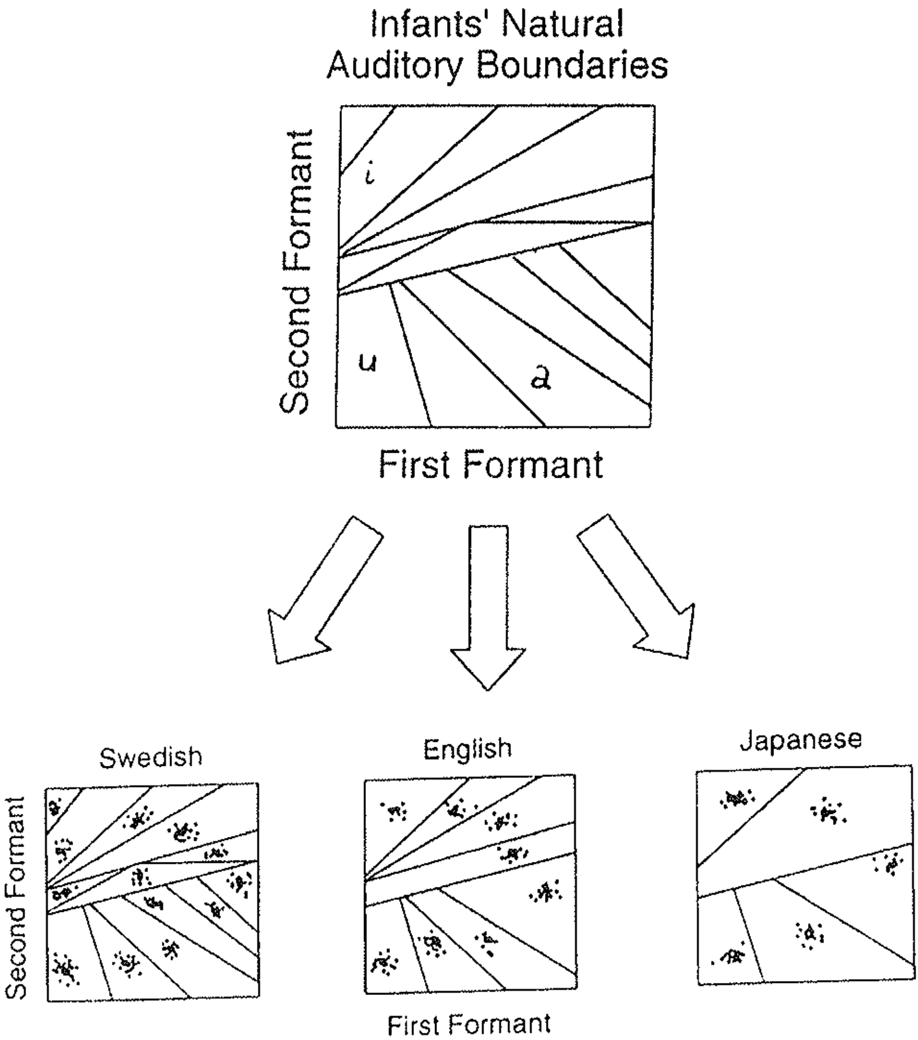


Fig. 1.

3.0 The content of linguistic categories

As mentioned earlier, Simple Nativism is a double-barreled doctrine about the prestructured nature of both the form (or grammar) and the content (or semantics) of natural languages. Both aspects of the doctrine are open to serious question, but for reasons of space I shall here confine myself to a critique of the content side. The idea, recall, is that the *content* of language, the conceptual categories underlying linguistic expressions, are universal by virtue of innate endowment. Languages merely code a pre-existing universal 'language of thought' (Fodor *et al.*, 1975).[7] As Pinker (1994:82) has succinctly put it:

> Knowing a language then is knowing how to translate mentalese into strings of words and vice versa. People without a language would still have mentalese, and babies and many nonhuman animals presumably have simpler dialects.

Three domains are often cited to substantiate such semantic universals: the domains of kinship, color and spatial categories.[8] The spatial ones are the most interesting, because it seems clear that spatial reasoning seems to lie behind many other kinds of thinking – we seem to be highly visual spatial creatures, whose natural aptitudes in spatial reasoning lend themselves to adoption in other domains. But let me turn first to color and kinship.

3.1 Color categories in language

Until 1967 it was generally thought that the way in which languages segment the color space was essentially arbitrary, or culturally relative. Then Berlin and Kay (1969) collecting data from twenty languages, showed that there were fundamental shared patterns under the diversity. In a revised version of the theory (by Kay and McDaniel, 1978), the following are the main universal claims:

1. All languages have Basic Color Terms, that is, a set of terms which jointly exhaust the color space. (Words like *blonde* restricted to hair, or *scarlet* which is kind of red, or *avocado* which is primarily a name of an object, are not Basic Color terms.)
2. There are 6 primary foci, or landmark colors, black and white and the four Hering opponent colors (red vs., green, blue vs. yellow), which form the 'best exemplars' of the six first color words.

[7] Within linguistics there has been considerable debate about two versions of this doctrine. Fodor's version is that every word meaning corresponds to an antecedently existing native concept, no matter whether we are considering the meaning of *tree* or *logarithm*. Others imagine that there is a role for constructivism: complex cultural concepts can be built out of simpler native concepts – see Levinson, 1997b for discussion.

[8] See, e.g., Leech, 1981: Ch 12, Miller and Johnson-Laird, 1976.

3. There is a cultural evolution of languages, such that at *Stage 1* languages divide the color space into cold/dark and warm/light areas (with three of the perceptual foci each), then at *Stage 2*, the warm/light area (covering red, yellow, white) splits into white vs. red/yellow categories, and so on successively until each of these composite categories breaks down into its elementary primaries, the Hering opponent hues.

Figure 2 shows the expected division of the color space for a Stage 2 language with three basic color terms, with a 'warm' vs. a 'white' vs. a 'cold' term dividing up the color space among them (it also shows the universal foci around which color terms are organized).[9]

The theory is a frequently-cited, textbook example of semantic universals, which seems indeed to fit the Simple Nativist account: our innate perceptual and categorial system projects 'color' as a semantic domain, and systematically constrains its subdivision. From this, the lesson has been taken that in time the rest of the lexicon will be found in a similar way to be projected from perceptual and cognitive universals.[10]

But recent findings have opened up the entire issue again, challenging especially the first and third claims, that all languages have Basic Color Words in the favored sense, with the composite semantics indicated. For example, in the language Yélî Dnye (spoken on Rossel Island in Papua New Guinea), the existence of Basic Color Words as originally envisaged must be in doubt (Levinson, 2000). To describe colors, reduplicated descriptive terms are used (e.g. "cockatoo – cockatoo" to denote white). Three of these – those describing black, white and red – are fairly conventional metaphors (although not without competing alternatives), but the rest grade into fresh simile and metaphor. On the face of it, this may look like an incipient Stage 2 three-

[9] Color in human psychophysics varies on three dimensions (usually denoted hue, saturation and brightness). The figure shows an approximation to the Munsell color chart (exact reproduction of colors is not possible in such a print), which is a Mercator-style projection, as it were, of the three-dimensional color solid. There are many intriguing discrepancies between the physics and the psychophysics, most notable here the 'color circle', whereby the shortest perceptible wavelengths are closest to the longest. On why human color vision is psychophysically tridimensional, see Shepard, 1992, who claims that it is an adaptation to the need for color constancy under the varying illuminations on our planet.

[10] Despite warnings from Berlin, Kay and Merrifield, 1991:24 against "sweeping conclusions". It is clear that color may be unusual, in that it is not often that the peripheral nervous system may be involved in the structuring of semantic fields.

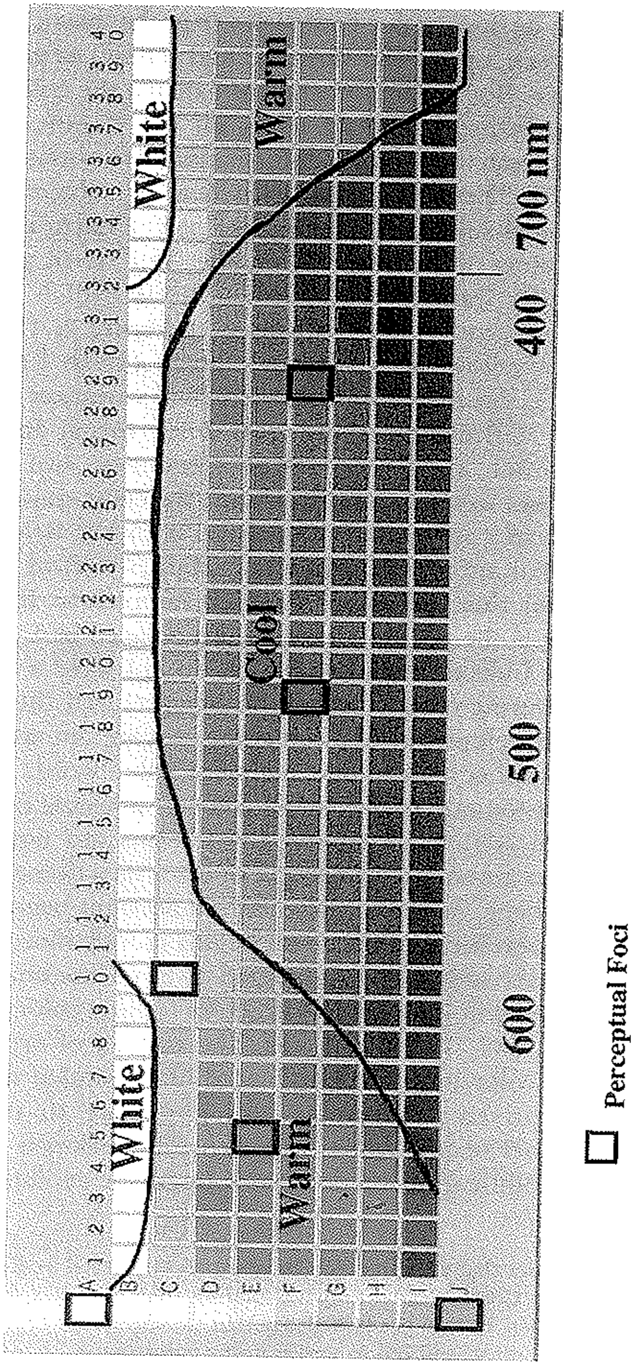


Fig. 2 – The Predicted Type of Stage 2 (three-term) Color Term Systems.

term system, but the terms are not composite (e.g. the 'black' term does not cover blue and green, or the 'red' term red and yellow) as predicted by generalization 3 above. Nor do the three terms exhaust the color space as predicted by generalization 1; indeed using all the resources at their command (including fresh metaphors), informants leave about half of the color space unnamed. There is also a great deal of subject variation. Figure 3 shows a typical subject response: the "parrot" term covers pure reds only, the "cockatoo" term pure whites, the "nut" term pure black. These are the relatively three well-established terms, which the theory wrongly predicts should universally pattern as in Figure 2. This subject also uses similes for yellow ('dried leaves'), green ('fresh leaves'), and purple ('fruit species'), but there is much individual variation here.

By the original definitions, these Yélî Dnye terms thus fail to constitute BCTs (which should be simplex lexemes, not primarily referring to objects, that together jointly exhaust the color space), and the expressions fail to form a fully conventionalized semantic field.

One of the original authors (see Kay and Maffi, 1999) of the theory has recently reviewed this and other counterexamples to the original theory, and now adopts the position (originally advanced by Lyons, 1995; 1999), that there are indeed languages which do not have a systematic semantic domain covering color. Instead, he suggests that there are two major routes to the development of a full color lexicon, one as originally hypothesized, and another that allows incipient color words to emerge *before* there is any systematic treatment of color as a lexical domain.[11]

The consequence is that systematic color terms are not *linguistic* universals: there is no automatic projection of color as a domain into the lexicon of every language. As the Simple Nativist account begins to looks less attractive, so a coevolutionary account begins to look more plausible. On a coevolutionary account, color perception gives us 'landmark colors'. These landmark colors will then act as attractors for any color terms that emerge: as Deacon (1997:119-20) remarks "the pattern of errors in use and transmission of color terms will be biased like a loaded die, so that over time the linguistic references will converge to match the neurophysiological foci of perceptual experience". It takes a process of transmission with modification – a process of linguistic evolution – to fix

[11] Kay & Maffi consider that the three Yélî Dnye expressions used to describe black, white and red are Basic Color Words, notwithstanding their complex form and derivation from object names. But they acknowledge that the expressions fail to have the expected composite semantics, and fail to partition the color space.

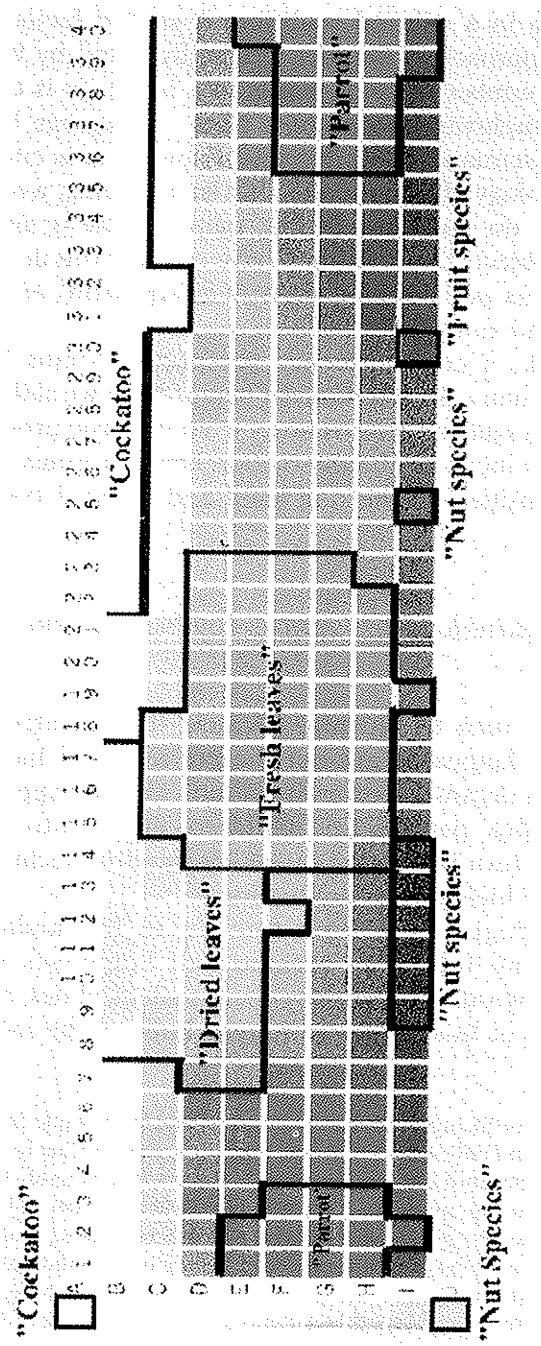


Fig. 3 – Distribution of Color Terms in Yélî Dnye (Rossel Island).

a perceptual bias in a cultural tradition. A second factor that favors a coevolutionary approach is the fact, originally noted by Berlin and Kay (1969), that the number of color words in a language is correlated with technological complexity in a society. Now, a language like Yélî Dnye, which has no systematic color domain, is found in a culture in which there is no technology of color at all – that is, no dyeing, weaving, painting tradition. If you do not have dye or paint – that is applicable color separated from objects that naturally have colors – you do not need color words – you may as well describe red fruit as 'ripe fruit', or green leaves as 'young leaves', and so forth.

In sum, then, a coevolutionary perspective seems better able to predict the facts than a Simple Nativist perspective: we shift the burden of explanation for language patterns away from intrinsic properties of mind alone and instead focus on the interaction between innate perceptual (or cognitive) propensities on the one hand and cultural traditions on the other.[12]

3.2 Kinship terminologies: supra-individual systems of bio-social classification

Let me now turn to kinship, because it illustrates a simple but important point: languages are not the projection of individual minds. Kin term systems organize a diversity of individual perspectives – those of males and females, parents and children, etc. – into one integrated system, which in turn is adapted to the surrounding social system, where it serves to guide biological reproduction.

Kin terminologies have been thought to be candidate semantic universals for the following reasons: all languages seem to have systematic set of words which codify socio-biological ties, and in the great majority of cases at least these seem to be built on the same 'elementary

[12] Co-evolutionary theorists have in fact seized on the example from the beginning. Lumsden and Wilson (1981:43ff) point out that (in a way similar to my example from auditory space) four-month old infants already show a (presumably innate) color categorization for the Hering opponent hues. See also Durham, 1991:213-23, who recounts the experiment by Rosch (1973), who showed that peoples whose language has few color terms can more easily be taught terms conforming to the landmark colors. But it is Deacon (1997) who most explicitly makes the point being made here, which is strongly reinforced by the newly established fact that color is not strictly a universal semantic domain.

kin types', namely M (mother), F (father), B (brother), Z (sister), S (son) and D (daughter), H (husband), W(wife). Now immediate qualifications are in order here. First, given adoption and other social practices, it is not biological ties that are classified by such systems, so much as relationships treated *in the idiom of biological ties*. Secondly, the 'elementary kin-types' are the members of the nuclear family, and many societies don't have nuclear families, downgrade paternity, have transitory marital relationships and so on, so the primary status of notions like 'father' may be in doubt.[13] But my purpose is not to question the basic assumptions here, but to point out how kin-term systems require a coevolutionary perspective.

Take the Dravidian kin-term system, variants of which are used by all the Dravidian societies of South India and beyond, and whose proto-Dravidian ancestor can be reconstructed dating back 5000 years or more (Trautman, 1981).[14] The Dravidian terminology fits into the world of South Indian castes. The system is exhaustive: anyone in one's caste is a presumptive kinsman, and one must marry inside one's caste, and thus marry a kinsman.

Like many other kinship systems, the Dravidian system makes distinctions between males and females, older and younger siblings, and 2 or more generations up and down from ego, as indicated in Figure 4 (from Levinson, 1977). But the essence of the Dravidian kinship terminology is a cultural distinction between 'parallel' and 'cross' kin, which assigns siblings of generations above ego to different categories. Thus my MZ (mother's sister) and FB (father's brother) are, for me, in the parallel category; but my MB and FZ are in the cross-category.[15] For the generations above ego, the rules for assigning kin to parallel vs. cross categories are essentially: (a) opposite sex-siblings are of opposite category, same sex siblings are of same category, (b) marriage joins persons of the same category, (c) sons are of the same category as their fathers, daughters are of opposite category, except that (d) children in ego's generation are of the same category as their parents, and finally (c)

[13] In matrilineal systems of kinship, the official ideology may even deny the role of the male in reproduction (Fathauer, 1962). For a classic case of such a system where there is no nuclear family and no exclusive sexual rights in marriage see Gough, 1962.

[14] This system exists in myriad variants: many of the countless sub-castes of South India have distinctive variants of their own; see e.g. Beck, 1972.

[15] I shall use the following customary abbreviations for the nuclear family kin-types: M (mother), F (father), B (brother), Z (sister), H (husband), W (wife), Son (son), D (daughter), so that e.g. MBD is read as 'mother's brother's daughter'.

Core structure used in over 25 Dravidian cultures, can be reconstructed for proto-Dravidian, c. 3000 BC or older.

The system is
- *exhaustive:* all members of the same caste are kinsmen
- associated with an obligatory *marriage rule*

Example: Tamil (KavuNTar caste, Kongu Na Tu)

Generation		CROSS		PARALLEL	
		male	female	male	female
+2		*appici*	*ammayi*	*appaaru*	*appattaa*
+1		*maamaa*	*attai*	*appaa*	*ammaa*
	older	*maittunan*	*nankayaa*	*aNNan*	*akkaa*
0					ego
	younger	*maittunan*	*koRuntiyaar*	*tampi*	*tankacci*
-1		*marumakan*	*marumakaL*	*makan*	*makaL*
-2		*peeran*	*peetti*	*peeran*	*peetti*

Fig. 4 – Dravidian Kin-Term Systems.

ego's parents are always parallel. The application of these rules is illustrated in Figure 5.

Now, crucially the term for MB is also the term for FZH, and the very same term is typically used for a wife's father. These equations indicate a presumption of a man's marriage to the daughter of his MB or his FZ; and most Dravidian societies have a rule of cross-cousin marriage, enjoining marriage with either FZD or MBD or both (and as a matter of fact an average of about 20% of marriages are with first cousins of this type in Dravidian societies – Trautman, 1981:216-28).

Now a moment's reflection will show that the rules for cross/parallel assignment just given for ascending generations would, if applied to ego's generation and below, engender incest: marriage joins people of the same

Rules for Cross/Parallel in senior generations:

- Opposite-sex siblings of my parents are 'cross'
- Same-sex siblings of my parents are 'parellel'
- Sons are the same category as their parents, daughters are opposite category, except in ego's generation
- Marriage joins people of same category in higher generations

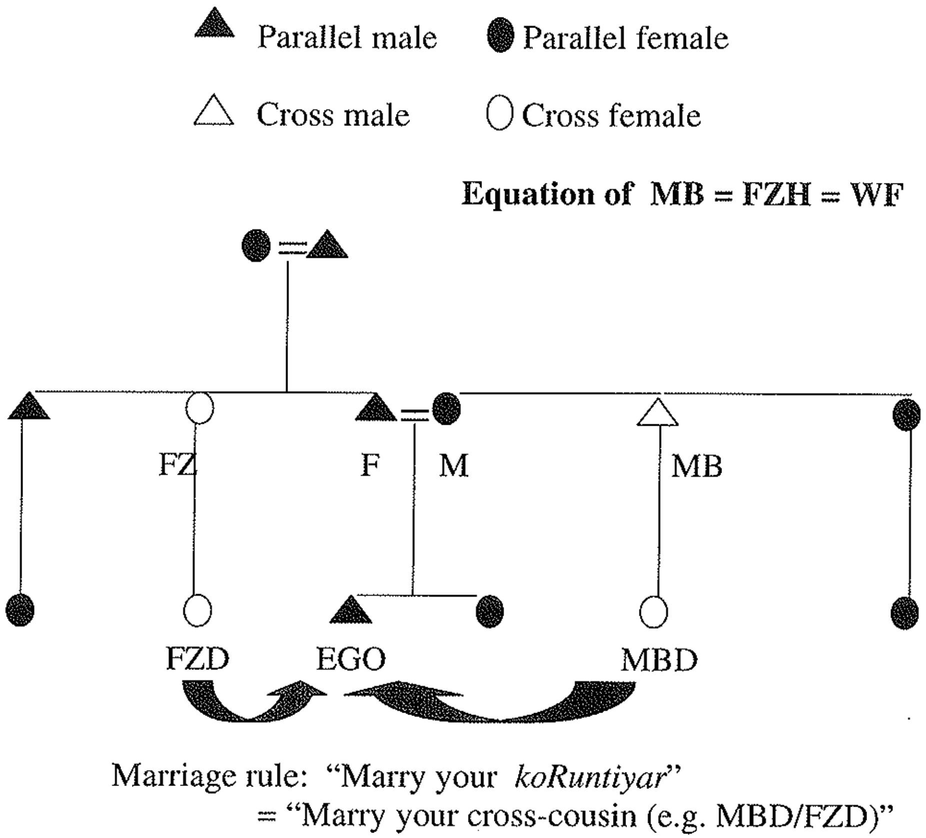


Fig. 5 – The Cross-Parallel Distinction in Dravidian Kinterms.

category, and since (for ego's generation) children are the same category as their parents, a male might be enjoined by the rules to marry his sister! Thus the rules for cross/parallel assignment must change: in ego's generation and below one must marry a person of *opposite category*, and brothers and sisters must be of the *same* category, thus ensuring outbreeding – as illustrated in Figure 6:

Rules for Cross/Parallel assignment in ego's generation and below

- ego's generation and below: marriage joins persons of *opposite* category (otherwise incest!)
- brothers and sisters are of *same* category

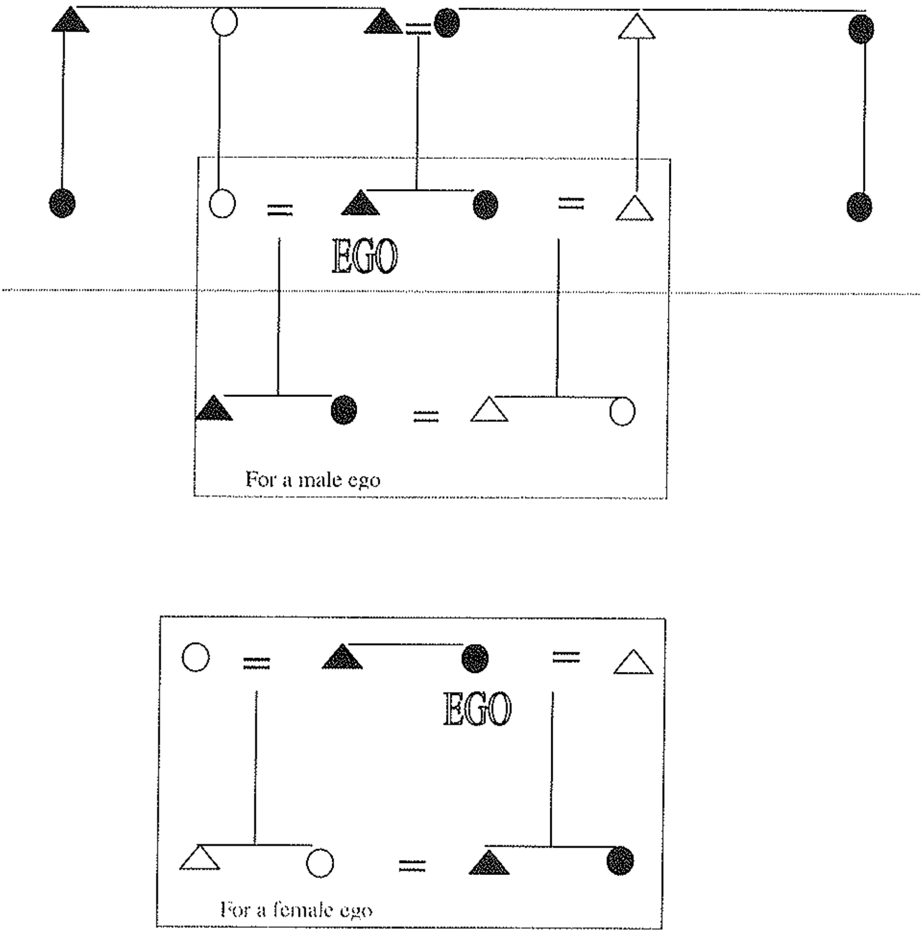


Fig. 6 – Dravidian Kinterms: Cross/Parallel Assignment in Junior Generations and Different Perspectives on the System.

The kin diagram also makes clear another fundamental point: the system organizes many different points of view into a coherent whole. For example, my sister and I share the same terminology for the generations above. But for the generations below, we have different points of view:

my children are Parallel for me (or for my brother), but Cross for my sister.

The point of this example is the following. Here is a set of terms which have a culture-specific dimension – the Cross/Parallel distinction – which is adapted to the societal conditions, including a cross-cousin marriage rule and an assumption that every caste-member is a kinsman. It has a supra-individual logic of design, yet it organizes individual viewpoints into a coherent whole. No individual designed this the system; and because it organizes a totality of distinct individual perspectives, it cannot be a projection of any individual's 'innate ideas'. Rather, it is the product of cultural evolution, which has evolved over thousands of years to fit the society it is used in (and in fact many variants of the Dravidian system exist, each finely attuned to the social structure of different castes). But at the same time it organizes biological reproduction: it embodies a marriage rule on the one hand, and on the other, it militates against incestuous unions through its classification of nuclear family members as always in the unmarriageable category. So once again, we have a bio-social system, here one which is tuned to both local cultural conditions and general outbreeding conditions. How can we get design without a designer? Darwin showed us the only way: transmission with slow modification, but the kind of theory we need is a theory of the co-evolution of culture and biology.

3.3. Spatial categories in language and cognition

Presumptions of universality

There are good reasons to think that if there are such things as innate ideas, then spatial concepts should be prime candidates. Spatial thinking is an adaptive necessity for any higher animal species, and is thus likely to constitute an ancient, modular or domain-specific process shared across many mammalian species. Indeed there is good evidence for phylogenetic continuity across the primates in the neural architecture for spatial cognition. So this is the very last area in which we would expect to find significant cultural variation. Indeed, many philosophers, linguists and psychologists have confidently spelt out universals of spatial language and cognition – for example, they have posited the following properties of naive human spatial *coordinate systems*:

– naive human spatial cognition is primarily egocentric in character

(Piaget and Inhelder 1956, Clark 1973, Lyons 1977, Miller and Johnson-Laird 1976, etc.)
- it is anthropomorphic: coordinates are established through the planes of our body (left/right; front/back; up/down) (Kant, 1768; Cassirer, 1923; Poincaré, 1946; Clark, 1973; Miller and Johnson-Laird, 1976, etc.)
- it makes no use of 'absolute' or geocentrically fixed angles (Talmy, 1983; Miller and Johnson-Laird, 1976).

The presumption has been that these properties are fixed biases in human cognition, and will thus project directly into universals of semantics. Indeed, it has been presumed that simply by looking at the spatial system in any language, one obtains a good picture of our universal language of thought (cf. "Space and force pervade language .... these concepts and relations appear to be the vocabulary and syntax of mentalese, the language of thought" Pinker 1997:355).

Recent work by myself and colleagues has shown that these confident predictions are false (Levinson, 1996, Pederson *et al.*, 1998). Once one turns away from the familiar, written languages the diversity of spatial systems in languages becomes rapidly manifest. There are many languages in the world where the primary system of spatial coordinates is not egocentric (or *relative* as I shall say) but is rather based on fixed, arbitrary external coordinates, a bit like our north/south/east/west system of cardinal directions (systems I will call *absolute*). A vignette of such an absolute system will help to make vivid how such a system works.

Guugu Yimithirr

Guugu Yimithirr (GY) is an Aboriginal language spoken at Hopevale, in Northern Queensland, by the descendants of a hunting-gathering group (see Haviland, 1979). Central to linguistic competence in this language is the ability to use the cardinal direction system and the underlying orientation it requires. There are four named cardinal directions, thought of as edges of the horizon, with the northern quadrant skewed about fifteen degrees from our north, as illustrated in Figure 7.

The four root terms can be further inflected to yield about 50 terms indicating motion towards a direction vs. motion from it, location at it, or vectors in a direction with focussed start and end points, etc. (see Haviland, 1993, Levinson, 1997a). The language has no locutions glossing 'to the left of', 'to the right of', 'in front of', 'behind', etc., comparable in use to the English terms. Thus instead of saying "the boy is left of/behind

Guugu Yimithirr
- Aboriginal language spoken in Cape York, Queensland
- No words for 'left of', 'in front of', 'behind' etc.
- Instead, a cardinal direction system, skewed from our system
- Complex morphology, with case and perspective indicated, c. 50 terms

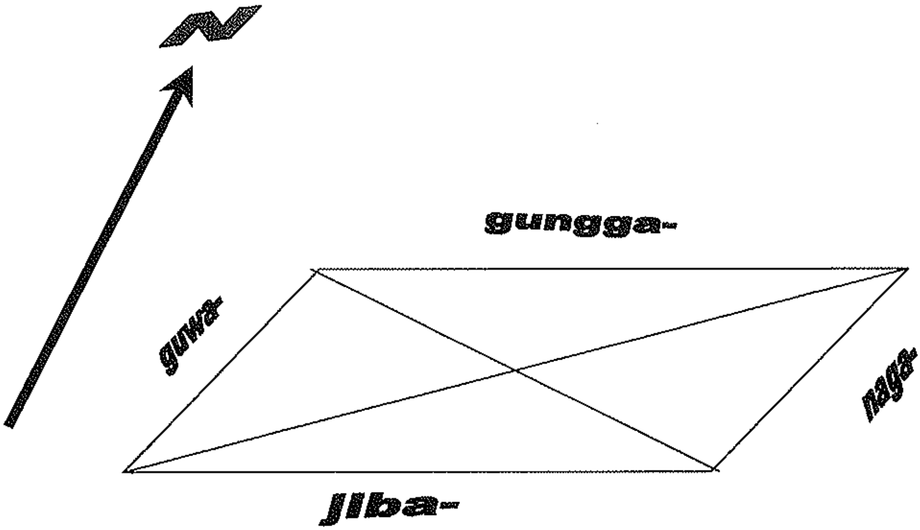


Fig. 7 – 'Absolute' Fixes-Bearing Systems in an Australian Language.

the tree" or "Take the first turning to the left", one is always forced into locutions of the kind 'The boy is to the north/east etc. of the tree', or 'take the first turning to the north' etc. (Levinson, 1997a). The system is applied also in small-scale space, as in 'pass me the northern cup' or 'there's an ant on your eastern leg', and even in virtual space, to describe, e.g., events on a television, or in a dream (in fact I am happy to be able to report that to enter heaven you must head north).

It is customary to describe all motions with directional terms ('John went west' rather than just 'John's gone'), often supplemented with gesture. Gesture gives analog accuracy to crude digital lexical specification of direction, and thus plays an important part in communication.

Such a system obviously requires that all speakers of the language are correctly oriented at all times and (less obviously) know or can calculate the absolute bearings of any place from any other (because if they are to describe a journey they will need to describe the direction). We have directly spot-tested subjects' abilities to point to any location from novel locations deep in the bush. The results show extraordinary dead-reckoning skills, more accurate than those achieved by homing pigeons, making it clear that what some species do by slow-evolved dedicated hardware, humans can do by culturally-developed software (Levinson, 1997a; in prep). Figure 8 compares the performance between 15 pigeons released about 70 km from home base and their bearings on the horizon, and 11 Guugu Yimithirr speakers similarly displaced to an unfamiliar location in forest surroundings, estimating a location by pointing.[16]

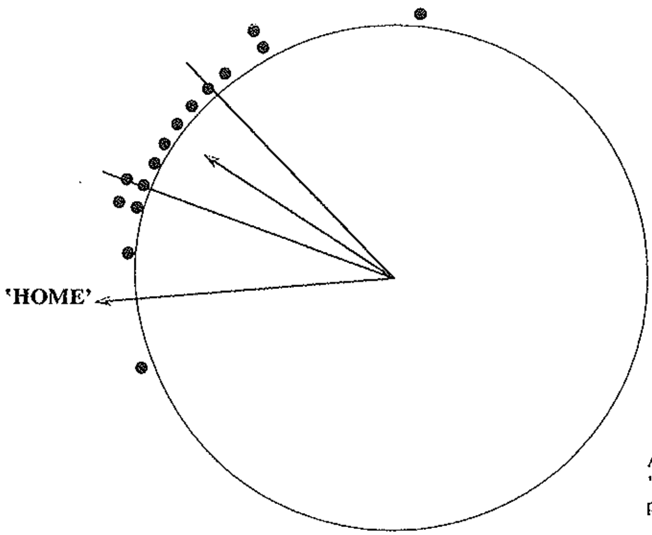
The findings are interesting: they show that speakers of this language are running a constant background calculation of their location with respect to other locations, maintaining their location on an accurate, oriented mental map. This is the necessary overhead of using a system otherwise so elegant in its utility and simplicity. By contrast, Dutch or English speakers under comparable conditions approximate to random, or at best weakly systematic, estimates of direction. It is clear then that Guugu Yimithirr speakers are at least doing some *additional* computation to say Dutch speakers, namely, running a mental compass and positioning system.

But do they *really* think about small-scale spatial relationships fundamentally differently from you and me? We need a simple method of probing for their non-linguistic "coding" or internal representations, their 'Language of Thought' as it were. Here is a simple method. We can get subjects to memorize a spatial array and then get them to select from a set of alternatives the one they saw previously, as illustrated in Figure 9.

The subject facing one direction, say south, is trained to memorize the top card in Figure 9. Then he is rotated 180 degrees, so that he is facing the other way (north) and his task is to choose the same card that he saw before. If, like us, he rotates his coordinate system with himself, he will chose the bottom card to the right of the diagram (he has, say, thought about the red square as to his left). If he employs co-ordinates located in the environment, these coordinates will not rotate with him, and he will chose the card at the bottom left.

What we find is that in any task based on this kind of rotation, the Guugu Yimithirr speaker will select the solution that relies on 'absolute' external coordinates and the Dutch speaker will select the solution based

[16] However, the Guugu Yimithirr estimates are to a location *other* than home-base and one in fact rarely visited, a considerably harder task.

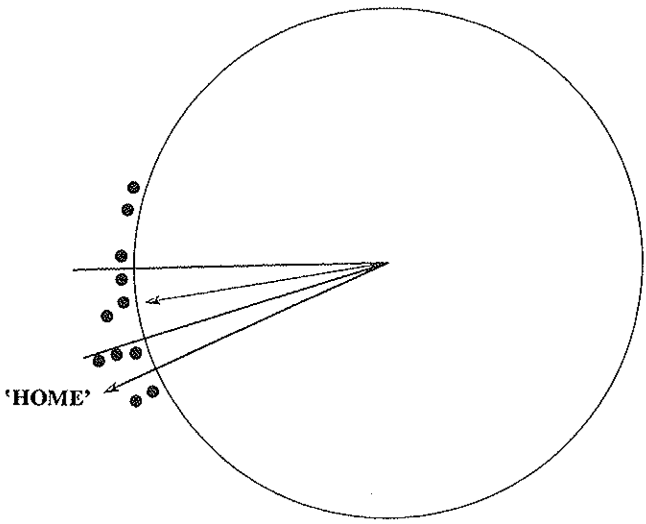


Homing Pigeons

Home direction: 265
Mean angle: 303
Mean vector length: 0.900
Mean angular deviation: 25.6
Homeward component: 0.713

After E. Batschelet (1981)
'Circular Statistics in Biology'
p. 11f.

Homing pigeons: Directions at vanishing point



Guugu Yimithirr speakers (Queensland)

Laura

Home direction: 245
Mean angle: 260
Mean vector length: 0.970
Mean angular deviation: 14.0
Homeward component: 0.935

Guugu Yimithirr speakers estimating the location of Laura at about 80 km.

Fig. 8 – Dead Reckoning in Two Species.

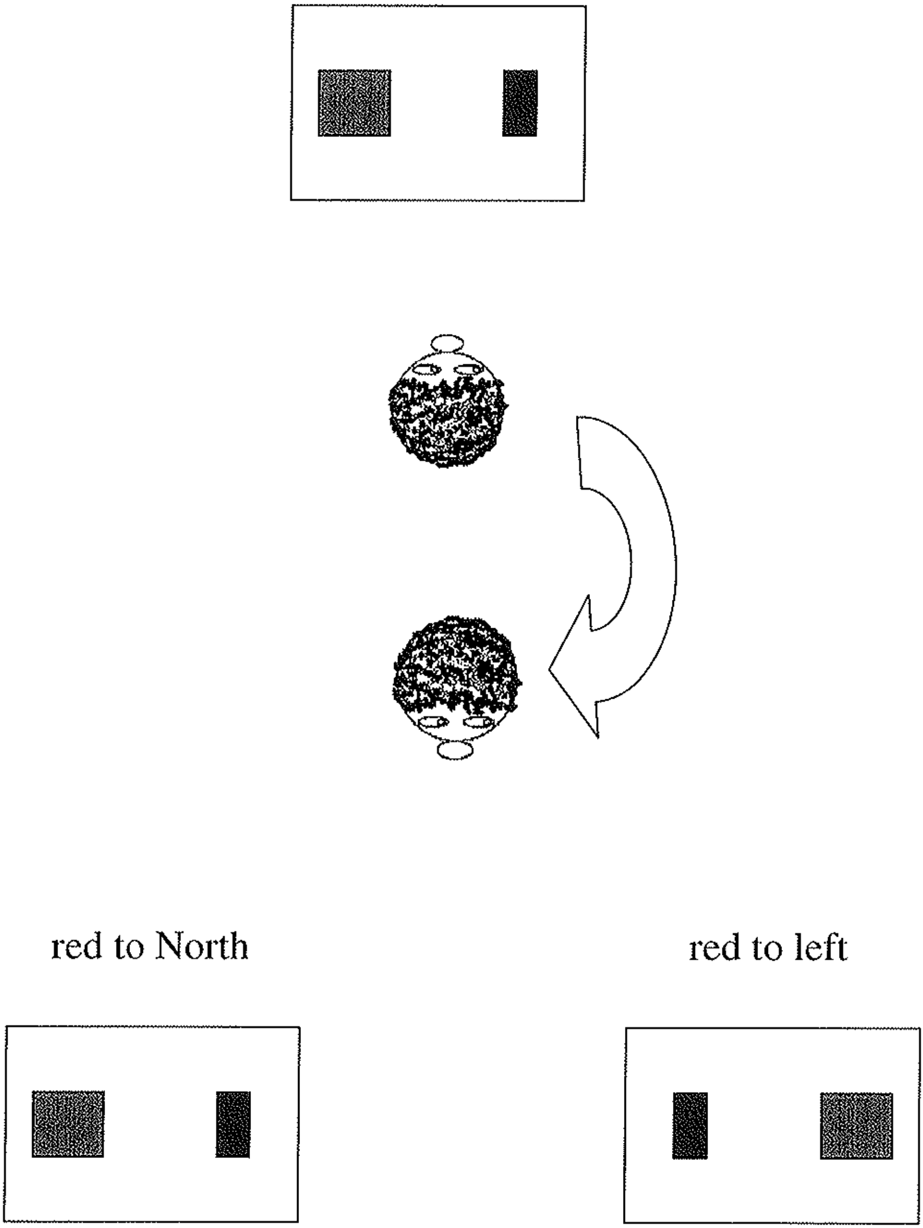


Fig. 9 – Experimental Techniques for Testing between 'Absolute' and 'Relative' Coding in Memory and Reasoning.

on egocentric 'relative' coordinates. In fact, we get a systematic picture over a range of experiments that explore non-linguistic memory of various kinds and reasoning over spatial relations.

We have gone on to elaborate these methods and with a number of collaborators have tested the replicability of these results in a good sample of languages and cultures. The finding is that wherever a subject speaks a language with a relative (left/right/front/back) system and no absolute system of co-ordinates, there is a corresponding use of relative coordinates in non-linguistic tasks, and vice-versa, where a language only uses absolute co-ordinates, non-linguistic coding is in absolute terms (Levinson, 1996; Pederson *et al.*, 1998). We have also gone on to do detailed work on child language, to explore when children master these absolute coordinate systems. Contrary to the claims of Piaget that abstract 'Euclidean' concepts would be universally late acquired, such systems are mastered by children as young as four years old (Brown and Levinson, in press). This is important, because it shows that, just as in the case of the infant's recalibration of acoustic space, the child is so cognitively equipped that it can adapt relatively rapidly – as its cognitive processes mature – to the locally predominant semantical concepts.

In summary, what these studies show is the following. First, languages can vary fundamentally even in the core of this domain, the coordinate systems underlying spatial description. Secondly, such linguistic differences imply cognitive differences. The reason is simple enough: *since you may want to describe arbitrary spatial experiences in the future, you must remember them in terms which will support that later linguistic description.* If you remember a spatial array in terms of left and right, you cannot later describe it in terms of north and south, and vice-versa. Language and cognitive style have to be congruent.

Clearly, these facts are not in line with the expectations of Simple Nativism, whereby when we learn a language all we do is map inner Language of Thought concepts onto outer language words. But nor do they necessarily imply the opposite extreme, in which the inner codings are an 'introjection' of an *arbitrarily variable* cultural tradition. For the linguistic traditions seem to build on one of three kinds of coordinate system, egocentric, object-centered and environmentally fixed, which in turn can be seen to play a role in our neurophysiology of spatial orientation (Levinson, 1996). Such an interplay between the architecture of our bodies and the elaborations of cultural traditions is parallel to the much simpler picture in the color domain (or acoustic space). There, too, we had innate color foci (or acoustic foci), given to us by our psychophysics, which bias the cultural transmission so that they form the focus of color terms (or language-specific acoustic categories). So here in the spatial domain we see the interplay of native propensities and cultural factors, perhaps suggesting a general model. The suggestion would be that rather than thinking primarily in terms of 'innate ideas' – what Elman *et al.*, 1996 call 'representational nativism' – we should think in terms of architectural biases in perception, and specific neurophysiological systems for, e.g., keeping us aware of our position in space.[17] These pre-existing systems bias the transmission of language as a cultural tradition, giving us the regularities and near universals to be found in semantic and conceptual systems.[18] There is no innate notion of 'north', but there is a pre-existing system for orienting ourselves in a larger environment, on which a notion of 'north' can be built. Thus the burden of explanation for the regularities and learnability of languages can be spread across the two tracks of self-replicating information, closely bound as they are in the coevolutionary perspective.

Conclusions

I have suggested that the currently favored strategy for naturalizing language, Simple Nativism, is misguided in emphasis. The strategy locates all the central generalizations in an invariant mental endowment fixed by natural selection far back in the history of the species. In short, "language is just a biological system" (Chomsky, quoted in Campbell, 1983:97). What is wrong with such a view is that it not only minimizes the essential facts of variation, but that it views the variation as 'noise'.[19]

[17] The doctrine of "innate ideas" has of course a distinguished history from Plato through Descartes, Leibniz and Kant to modern thinkers like Chomsky (Stich, 1975). But from the point of view of current neuroscience, it is hard to see how innate *representations* (as opposed to architectural biases of various kinds) could actually be instantiated (see Elman *et al.*, 1996: Ch. 5). Singer (this volume) points out how architectural biases create expectancies in the visual system, which then interact with experience to give the Gestalt constancies of interpretation.

[18] Similarly, coevolutionary perspectives suggest that the kind of strong (but not absolute) tendencies found in language typology of the Greenbergian school (see, e.g., Greenberg, 1961; Croft, 1993) might be related to cognitive biases of various kinds. See Hawkins (1994) for suggestions.

[19] As mentioned in an earlier footnote, the degree of variation in the existing 8000 or so languages is currently unknown, since well under 10% have been properly studied. Of these 8000 languages, about half are spoken by less than 10,000 speakers, and of these, half again by groups of less than 1000 (Harmon, 1995). Thus much of the variation lies in ancient traditions maintained by very small human groups. Just as we are

Instead, a strategy that views human nature as built to *expect* cultural patterning, as evolved hand in hand with culture, seems a better direction to look for a theory that will supersede the old Nature:Nurture dichotomy. Coevolutionary or dual-track inheritance models are much better adjusted to the essential nature of language, a sustained and complex interaction between biology and culture. In turn, language, which has on the whole played a minor role in these models, may prove to be crucial to their proper development.

In sum I have argued that:

- human nature, our mental constitution, is equipped for variation, in language as elsewhere (as illustrated by infants reactions to phonetic experience),
- he variation is embodied in cultural and linguistic traditions (cf. kinship, color, space),
- traditions are supra-individual (cf. kinship), organizing a shared linguistic and cognitive coding essential to communication (cf. space),
- traditions exploit neurophysiological biases and processes, neglecting some of them, while amplifying others and building elaborate conceptual structures on top of them.

I took as my first example of the nativist provision for culture the human infant's system for 'tuning in' to the locally significant speech sounds. Let me take as my final example the amazing phenomenon of sign language. Children raised to deaf parents switch the modality of the entire language system from the auditory-vocal channel to the gestural-visual one. (The modality independence of language is already evident from reading and writing of course, but that is presumably a secondary

losing much of the biodiversity of the world in a massive extinction event similar to the loss of the dinosaurs (see papers by Raven and Markl, this volume), so we are losing most of the human diversity (some estimates suggest loss of 90% of the languages of the world by the end of next century). The two great extinctions, biological and cultural, are linked of course, since they are due to the loss of the ecological niches that support small, specialized populations. Just like biological adaptations, these languages and cultures are ancient adaptations, the loss of which not only reduces human experience and knowledge (including knowledge about the natural world), but also our awareness of the many different, viable ways of arranging human affairs. Such loss will enormously impoverish the scientific study of human language and culture, which still lacks its Darwin, has already lost its Galapagos, and will soon lose its continents of variation, as it were.

and parasitic phenomenon.) Sign-languages are now known to share many structural properties with spoken languages and like spoken-languages are processed largely in the left-hemisphere despite the visuo-spatial nature of the system (which might bias it to right-hemisphere processing). Some researchers conclude that we must be built *in advance* for just one of two modalities (Hauser, 1997:245). But children born deaf *and* blind shift the system to touch, although we currently know very little about such language systems. In any case, sign languages again illustrate the need for a coevolutionary perspective: sign language traditions have emerged only in the context of recessive hereditary deafness, and transgenerational maintenance of sign languages in turn depends on this genetic trait's maintaining a community of signers (Aoki and Feldman, 1991).

There will be skeptics who doubt the need or efficacy of any strategy for naturalizing language: would it make a difference to how the language sciences actually proceed? The answer is affirmative: coevolutionary models redirect attention, for example, to the flexibilities and inflexibilities of learning mechanisms (issues finessed by the Simple Nativists, but essential as we saw to infants' initial relationships to linguistic sounds).[20] But the main reasons to situate language in the natural landscape are two. First, there is the perennial hope that we may supersede the ideological trivialities of the current level of Nature: Nurture controversies. Secondly, and more importantly, one simply wishes to understand where language fits in with the rest of natural history. It is the big picture that suffers most under the current rule of Simple Nativism or its radical alternative, extreme cultural relativism.

REFERENCES

Aoki, K. and Feldman, M.W. 1991. 'Recessive hereditary deafness, assortative mating, and persistence of a sign language', *Theoretical Population Biology* 39:358-372

Barkow, J. Cosmides, L. and Tooby, J. (eds.) 1992. *The adapted mind*, Oxford: Oxford University Press

Batschelet, E. 1981. *Circular statistics in biology*, New York: Academic Press

Beck, B. 1972. *Peasant society in Konku: A study of right and left subcastes in South India*, Vancouver: University of British Columbia Press

[20] See, e.g., Tomasello *et al.*, 1993, Elman *et al.*, 1996.

Berlin, B. and Kay, P. 1969. *Basic color terms*, Berkeley: University of California Press

Boyd, R. and Richerson, J. 1985. *Culture and the evolutionary process*, Chicago: Chicago University Press

Brown, P. and Levinson, S. (in press). 'Frames of spatial reference and their acquisition in Tenejapan Tzeltal' in G. Saxe, E. Turiel, and L. Nucci. (eds.), *The growing mind*, Erlbaum

Campbell, J. 1983. *Grammatical man*, London: Allen Lane

Cassirer, E. 1923. *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*, Berlin: Cassirer

Cavalli-Sforza, L. and Feldman, M. 1981. *Cultural transmission and evolution: a quantitative approach*, Princeton University Press

Chomsky, N. 1982. 'Discussion of Putnam's comments', in M. Piatelli-Palmarini (ed.), *Language and learning: the debate between Jean Piaget and Noam Chomsky* (pp. 310-324), Harvard University Press

Clark, H. H. 1973. Space, time, semantics, and the child, in T.E. Moore (ed.), *Cognitive development and the acquisition of language* (pp. 28-64), New York: Academic Press

Collingwood, R. G. 1945. *The idea of nature*, Oxford: Clarendon Press

Croft, W. 1993. *Typology and universals*, Cambridge: Cambridge University Press

Dawkins, R. 1976. *The selfish gene*, Oxford: Oxford University Press

Deacon. T. 1997. *The symbolic species*, New York: Norton

Dennett, D. 1995. *Darwin's Dangerous Idea*, London: Penguin

Descola, P. and Pálsson, G. (eds.) 1996. *Nature and society: anthropological perspectives*, London: Routledge

Dobzhansky, T. 1962. *Mankind evolving: the evolution of the human species*, New Haven, CT

Durham, W. 1991. *Coevolution*, Stanford University Press

Ellen, R. and Fukui, K. (eds.) 1996. *Redefining nature*, Oxford: Berg

Elman, J., Bates, E., Karmiloff-Smith, A., Parisi, D. and Plunkett, K. 1996. *Rethinking Innateness*, Cambridge, MA: MIT Press

Fathauer, G. 1962. 'Trobriand', in Schneider and Gough 1962:234-69

Fodor, J. 1975. *The language of thought*, Cambridge: Harvard University Press

Fodor, J. 1983. *The modularity of mind*, Cambridge, MA: MIT Press

Fodor, J., Fodor, J. and Garrett, M. 1975, 'The unreality of semantic representations', *Linguistic Inquiry* 4:515-531

Gopnik, M. (ed.) 1997. *The inheritance and innateness of grammars*, New York: Oxford University Press

Gough, K. 1962. 'Nayar: Central Kerala', in Schneider and Gough 1962:298-404

Gould, S. 1991. *Bully for Brontosaurus*, New York: Norton

Greenberg, J. 1961. 'Some universals of grammar with particular reference to the order of meaningful elements', in J. Greenberg (ed.), *Universals of language* (pp. 73-113), Cambridge, MA: MIT Press

Harmon, D. 1995. 'The status of the world's languages as reported in the Ethnologue', Southwest Journal of Linguistics 14:1-33

Hauser, M. 1997. *The evolution of communication*, Cambridge, MA: MIT Press

Haviland, J.B. 1979. 'Guugu Yimidhirr', in R.M.W. Dixon and B. Blake (eds.), *Handbook of Australian languages*, I (pp. 27-182), Canberra: Australian National University Press

Haviland, J. 1993. 'Anchoring, iconicity and orientation in Guugu Yimithirr pointing gestures', *Journal of Linguistic Anthropology* 3(1):3-45

Hawkins, J. 1994. *A performance theory of order and constituency*, Cambridge: Cambridge University Press

Jakobson, R. 1961. 'Implications of language universals for linguistics', in J.H. Greenberg (ed.), *Universals of language* (pp. 263-278). Cambridge, MA: MIT Press

Kant, E. 1768. Von dem ersten Grunde des Unterschiedes der Gegenden im Raume. Translated as: 'On the first ground of the distinction of regions in space', in J. van Cleve and R.E. Frederick (eds.) (1991). *The philosophy of right and left: Incongruent counterparts and the nature of space* (pp. 27-34), Dordrecht: Kluwer

Kay, P. and McDaniel, C. 1978. 'The linguistic significance of the meanings of basic color terms', *Language* 54(3):610-46

Kay, P. and Maffi, L. 1999. 'Color appearance and the emergence and evolution of basic color lexicons', *American Anthropologist* 101(4), 743-760

Kay, P., Berlin, B. and Merrifield, W. 1991. 'Biocultural implications of systems of color naming', *Journal of Linguistic Anthropology* 1(1):12-25

Kuhl, P. 1991. 'Human adults and human infants show a "perceptual magnet effect" for the prototypes of speech categories, monkeys do not', *Perception and Psychophysics* 50:93-107

Kuhl, P. 1994. 'Learning and representation in speech and language', *Current opinion in neurobiology* 4:812-22

Kuhl, P. and Meltzoff, A. 1996. 'Infant vocalization in response to speech: vocal imitation and developmental change', *Journal of the Acoustical Society of America* 100(4), Part 1:2425-38

Kuhl, P. and Meltzoff, A. 1997. 'Evolution, nativism and learning in the development of language and speech', in A. Gopnik (ed.), *The inheritance and innateness of grammars* (pp. 7-44). Cambridge, MA: MIT Press

Labov, W. 1994. *Principles of linguistic change: internal factors*, Oxford: Blackwell

Laland, K., Kumm, J. and Feldman, M. 1995. 'Gene-culture coevolutionary theory', *Current Anthropology* 36(1):131-46

Leech, G. 1981. *Semantics*. (2nd edition), Harmondsworth: Penguin

Levinson, S.C. 1977. *Social deixis in a Tamil village*, PhD Thesis, University of California, Berkeley

Levinson, S.C. 1996. 'Frames of reference and Molyneux's question', in Bloom. P. *et al.* (eds.), *Language and Space* (pp. 109-169), Cambridge, MA: MIT Press

Levinson, S.C. 1997a. 'Language and cognition: the cognitive consequences of spatial description in Guugu Yimithirr', *Journal of Linguistic Anthropology* 7(1): 98-131

Levinson, S.C. 1997b. 'From outer to inner space: linguistic categories and non-linguistic thinking', in J. Nuyts and E. Pederson (eds.), *Language and conceptualization* (pp. 13-45). Cambridge University Press

Levinson, S.C. (in press). 'Yélî dnye and the theory of basic color terms', *Journal of Linguistic Anthropology*, 2000

Levinson, S.C. (in prep.) Matrilineal clans and kin terms on Rossel Island

Lieberman, P. 1984. *The biology and evolution of language*, Cambridge, MA: Harvard University Press

Lumsden, C. and Wilson, E. O. 1981. *Genes, Mind and culture: the coevolutionary process*, Cambridge, MA: Harvard University Press

Lyons, J. 1977. *Semantics*, Vols 1 and 2, Cambridge: Cambridge University Press

Lyons, J. 1999. 'The vocabulary of colour with particular reference to ancient Greek and classical Latin', in A. Borg (ed.), *The language of color in the Mediterranean: An anthology on linguistic and ethnographic aspects of color terms* (pp. 38-75). Stockholm: Almqvist & Wiksell International

Lyons, J. 1995. 'Colour in language', in T. Lamb and J. Bourriau (eds.), *Colour: Art* and *Science* (pp. 194-224). Cambridge: CUP

Markl, H. 1982. 'The power of reduction and the limits of compressibility', *Behavioral and Brain Sciences* 5:18-19

Miller, G. and Johnson-Laird, P.N. 1976. *Language and Perception*, Cambridge, MA: Harvard University Press

Pederson, E., Danziger, E., Wilkins, D., Levinson, S., Kita, S. and Senft, G. 1998. 'Semantic typology and spatial conceptualization', *Language* 74:557-589

Piaget, J. and Inhelder, B. 1956. *The child's conception of space*, London: Routledge and Kegan Paul

Pinker, S. 1994. *The language instinct: How the mind creates language*, New York: Morrow

Pinker, S. 1997. *How the mind works*, New York: Norton

Pinker, S. and Bloom, P. 1990. 'Natural language and natural selection', *Behavioral and Brain Sciences* 13:707-784

Poincaré, H. 1946. *The foundations of science*, [translated G.B. Halsted]. Lancaster, PA: Science Press

Rosch, E. 1973. Natural categories. *Cognitive Psychology* 4:328-50

Schneider, D. and Gough, K. (eds.) 1962. *Matrilineal kinship*, Berkeley: University of California Press

Shepard, R. 1992. The perceptual organization of colors. In J. Barkow, L. Cosmides and J.Tooby (eds.), *The adapted mind* (pp. 495-532). Oxford: Oxford University Press

Sperber, D. 1996. *Explaining culture*, Oxford: Blackwell

Stich, S. (ed.) 1975. *Innate Ideas*, Berkeley: University of California Press

Talmy, L. 1983. 'How language structures space', in H. Pick and L. Acredolo (eds.), *Spatial orientation: Theory, research and application* (pp. 225-282). New York: Plenum Press

Tomasello, M. 1995. 'Language is not an instinct', *Cognitive development* 10:131-56

Tomasello, M., Kruger, A.C. and Ratner, H.H. 1993. 'Cultural learning', *Behavioral and Brain Sciences* 16:495-552

Tooby and Cosmides 1992. 'The psychological foundations of culture', in J.H. Barkow, L. Cosmides and J. Tooby (eds.), *The adapted mind* (pp. 19-136). Oxford: Oxford University Press

Trautman, T. 1981. *Dravidian kinship*, Cambridge Studies in Social Anthropology. Cambridge: Cambridge University Press

CHANGING CONCEPTS OF THE NATURE-NURTURE DEBATE[1]

WOLFGANG KLEIN

... and they began to speak with other tongues,
as the Spirit gave them utterance.

Acts 2:5

1. Introduction

A friendly nature has provided us with the remarkable capacity to couple our thoughts, wishes and intentions with sound waves and to transmit these to other human beings, who, with varying accuracy, are able to reconstruct these thoughts, wishes and intentions. We are able to speak, and we are able to understand. The view that we owe this talent to nature is not self-evident. For many centuries, people used to think that it was the Spirit that gave them language. We, however, share in the belief that this gift is part of our genetic endowment, the result of complex adaptive processes over millions of years. It is specific to our species – a claim that has occasionally been disputed, but never by a member of some other species. It is this capacity which allows human beings an orientation in their environment different from that of a monad in a world ruled by the laws of pre-established harmony, different from that of a bee in a world governed by the rigid interaction of principles of the bee hive. It is the verbal transmission of all kinds of theoretical and practical knowledge from one generation to the next, of rapidly changing situation-bound information from one individual to the other that set the stage for the particular kind of behaviour which human beings call human. It is language which makes possible all higher forms of cognition as well as

[1] I wish to thank Steve Levinson for discussion and help.

that particular kind of interaction between members of a species which is characteristic of man and woman. It is language which renders the human being human.

But no one is born with a language in his or her head. When thrown into this world, the child is literally an "infans" – someone who does not speak. But every new-born is able to learn Guughu Yimidhirr or Rossel, Tzeltal or Tamil, or any other language spoken in the social environment in which he or she happens to grow up. Thus, the individual's capacity to speak and to understand, the *linguistic competence*, has two different but equally indispensable sources. These are the innate, genetically transmitted language capacity and the socially transmitted knowledge of what is particular to, for example, Italian as compared to any other language. The child's innate language capacity has to be applied to a particular input – the structured and meaningful sound waves produced by parents, siblings and other people in the social environment. Language has a biological side, and it has a social side. There is no doubt that each of these components is equally necessary for the *infans* to become a *zoon logon echon*. Opinions vary, however, with respect to their precise nature and their relative weight.

The dispute is old, and it has been couched in various terms. Are words *physei* or *thesei*, is our behaviour, including verbal behaviour, determined by *race* or by *milieu*, is the adult's linguistic competence a biological or a cultural phenomenon? In Steve Levinson's words: "..., over two and half millennia of the Western intellectual tradition, views have oscillated between viewing language as a part of human nature, or alternatively, seeing language as essentially part of human culture. Although the twentieth century has seen a veritable explosion of human knowledge and theory in the language sciences, this particular ideological issue continues to dog us. We still have not found a satisfactory way to bridge the tired old Nature: Nurture issue." (Levinson, in this volume, p.x). He then notes that at the end of the millennium, the "swing of the pendulum has the language sciences out on the Nature pole." I am not sure that this observation is correct for the entire community of linguists. In their majority, linguists have no particularly outspoken view on this issue at all. They just do their research, and the outcome of this research is usually more or less compatible with either perspective on the Nature: Nurture debate. This, incidentally, may be one of various reasons why this debate does not seem to come to an end: there are many theoretical arguments, even more speculations, but no crucial empirical evidence. I agree with Levinson, however, in that there is an highly influential school of thought in linguistics which pushed the pendulum in this direction – Generative Grammar. Since its initiation by Noam Chomsky in the 1950s, the "generative enterprise" has undergone many substantial changes. But one of its most stable ingredients is the notion of an innate "language acquisition device" and, closely connected to this notion, of "Universal Grammar". Whereas generative grammarians focus on the form side of language and tend to avoid questions of semantics, there are a number of scholars who advocated the view that on the meaning side, too, there is a universal "language of thought" (a term first introduced by Jerry Fodor) or "mentalese" (Steve Pinker's term, originally introduced by David Lewis as a joke) – a set of concepts which comes as part of our genetic endowment and underlies the semantics of all natural languages. It is these two notions which have given rise to what Levinson calls "Simple Nativism": "It holds that both in form (syntax) and content (semantics) language is essentially innate." Syntax is governed by an innate "Universal Grammar", and the ideas encoded are just elements of the "Language of Thought." (Levinson, in this volume).

Levinson challenges "Simple Nativism" on this second field – the way in which meanings are encoded across languages. Semantical differences between languages are by far too substantial to justify a universal and innate "Language of Thought". He does not scrutinize this notion itself – in fact, it is not easy to understand what such a "Language of Thought" could look like. Instead, he examines three examples, the expression of space, the expression of colour, and the expression of kinship relations, that clearly involve universal components of the *condition humaine*. Physically, we all live in the same kind of space. Physiologically, we have the same kind of visual system. Biologically, we have the same kind of relatives. Hence, these three areas are good candidates for universal concepts and conceptualisation. Still, there is massive cultural variation, reflected in linguistic form and content. Levinson's case is convincing, and I can't but express my agreement.

This is the worst that can happen to the discussant of a paper. So, all I can do is to wonder how someone with a different view would try to escape the conclusion. In principle, it can be challenged on empirical or on conceptual grounds. I do not think that an attack on the empirical side would lead very far. Even if further research showed that the analyses presented by Levinson are false or incomplete – there is still overwhelming evidence that different languages encode space, colour and kinship in very different ways. I do believe, however, that there are problems on the conceptual side. They are not specific to Levinso's claim but characteristic of the entire Nature: Nurture debate over the millennia, and they are due to the fact that the underlying concepts are so ill-defined. When we ask whether language is primarily part of human nature, or primarily part of human culture – then it should be clear what "language" is and what "nature" and "culture" are. I do not believe that they are sufficiently clear.

2. What is "culture", what is "nature", what is "language" – what is the issue?

The *Encyclopedia Britannica* defines Culture as:

> the integrated pattern of human knowledge, belief and behaviour. Culture thus defined consists of language, ideas, beliefs, customs, taboos, codes, institutions, tools, techniques, works of art, rituals, ceremonies, and other related components.

This definition does not strike us by its conciseness or clarity; in fact, no definition of culture I have ever read does this. But it is surely useful in that it lists a number of things which, in one way or the other, everybody associates with culture. But it is also clear that each element of this list is brought about by the particular mental and physical capacities of the human species, and hence is a result of our biological nature. *Human culture is a product of human nature*. This view is not self-evident. If we assume, as most of mankind has always done and still does, that human knowledge is a gift of God, or of the gods, then there is another source of culture – in the sense defined above – than our biological nature. If we do not assume this, however, then the opposition between "culture" and "nature" is somehow misplaced. Where else should all of this knowledge, belief and behaviour come from if not from our little grey cells and perhaps other parts of our body? All that is left is an opposition between "cultural" and "non-cultural" aspects of our biological nature, where the former include such things as ceremonies and works of art and algebra, whereas the latter includes things such as the fact that we have a collar-bone and blood and no wings. It is Nature, and only Nature, which has created our biological nature, and it is this biological nature which has created human culture.

But what is Nature? The *Encyclopedia Britannica* does not venture a definition of this notion. Is it everything that surrounds us? But what surrounds us are trees and stones and clouds, or, rather, entities that we identify as such. What surrounds us is oxygen and helium and silicon and carbon, or what certain analytic procedures thought out by the human mind have revealed as such. It is protons and neutrons and electrons, or what other analytic procedures thought out by our mind have made us to believe. Or is Nature not just these entities but rather the interrelationship between them, as the ingenuity of Hooke and Huygens, Lavoisier and Heisenberg has uncovered it? What we consider to be Nature is a product of the human mind. This does not mean, of course, that the trees and stones and clouds, the elements of which they consist as well as the relations which obtain between them exist within the human mind. But our notion of Nature is a product of our mind. It is a very vague concept and of hardly any interest to those who investigate it. Physics is the study of *physis*, but what physicists really study is the attraction between bodies or the refraction of the light. Speaking of Nature is just a *façon de parler* to talk about the unknown with which we have to deal.

It is not accidental that the notions of Culture and of Nature are so hard to define. They are not definable; they are clouds. This does not mean that they are useless. They serve as initial labels for sets of phenomena which await concrete analysis. As such, they are convenient to begin with, also appropriate for after-dinner conversation, but most confusing when taken too seriously. Does this mean that the entire old debate between the "culture side" and the "nature side" of language is meaningless? I think it lost a great deal of its meaning at the very moment that we – that is the minority of enlightened scholars who no longer believe in spiritual beings – gave up the notion that there might be entities *beyond* nature to whom we could owe part of what we are and what we know. But I also think that it still makes scientific sense to the extent to which we are able to couch it in terms of the concrete processes which bring language about.

But what then is "language"? Even a first glance in a comprehensive dictionary rapidly shows that this word is used in many divergent ways. Language, too, is another one of those convenient labels which allow global reference to an interrelated set of phenomena that seem worth investigating. If this investigation is to become concrete, we must look at specific linguistic phenomena, not at language. Ever since Ferdinand de Saussure at the beginning of this century, linguists distinguish at least three types of linguistic facts. There are, first, those which characterise the *ability* to learn and to use particular languages – the *faculté de langage* or simply *langage*, as Saussure said. It is this capacity with which any normal human being is born. This fact is beyond doubt, just as the fact that it must somehow be part of our nervous system. But there are also a number of open questions that are accessible to empirical investigation, such as, to mention but a few:

– is it fully there from birth, or does it need some time to develop?

– does it deteriorate with age, and in what way?

– is it specific to our species, or is also found in other animals, for example, higher primates? And if so, why don't they use it normally?

– is it "domain-specific", i.e., is it just a special instantiation of human memory and cognition in general, or is it a separate "module" in our brain?

These questions are not easy to answer, but they are sufficiently clear to be scientifically investigated.

There is no cultural component in this mere capacity. It is just part of our genetic endowment. But the capacity as such does not suffice: what the child, and the adult under appropriate circumstances, has to do is to learn a particular language such as Spanish, Bengali or Kpelle – a *langue*, as Saussure said. A langue is a system of expressions with specific properties. Linguists disagree to some extent on what these properties are and how such a system should be analysed. But they agree on two points. First, a linguistic expression is a particular combination of a *form* – usually a sequence of sounds – and a *meaning*. Second, there are elementary expressions ("words") and complex expressions formed by certain morphological and syntactical operations ("phrases, sentences, texts"). In a nutshell, every language has a lexicon – this is the inventory of elementary expressions, and it has a grammar – these are the rules according to which words can be modified and put together. Again, there is a number of obvious question which concern properties of these systems, such as:

– what does the English expression which is written *nature* mean?

– what does the expression *the* – the most-frequent word of the most-spoken language of the world – mean?

– how does the meaning of the complex expression *the only book* result from the meaning of its parts?

– why is possible to say *the only book* but not *an only book* or *three only books*?

– what is the function of case marking?

It is these questions to which the linguist's daily efforts are mostly devoted. Some of them have found good answers – temporary answers, as usual in research, but still good answers, and others are completely opaque. Worldwide, there are several thousands of such systems, and they differ considerably. This variation does not preclude, however, that there are commonalities, as well. There may even be properties which are found in any such pairing of sounds and meanings – linguistic universals, and for these universals, it might make sense to assume that they are part of our genetic endowment.

The third set of linguistic facts is related to what Saussure called *parole* – the actual communication between human beings in a given situation, such as chatting, cursing and praying, telling a joke, giving route directions, describing the *Mona Lisa*, arguing about nature and culture, singing in the rain. As a rule, linguistic communication involves more than one participant, but there are also atypical cases, such as writing a diary that is intended for no one else. Typical questions about this type of linguistic phenomena are:

– which other components of the human mind, beyond the particular sound-meaning coupling used, play a role in communication – such as memory, reasoning and intentions?

– how does the form of communication interact with the social structure of the community in which it is used?

– how does communication via sound-meaning coupling interact with other forms of human communication, such as facial expression, gestures and the like?

– how does human communication differ from communication among dogs, dolphins or lobsters?

Again, these are difficult questions; but they are accessible to empirical investigation, and much has been found out about them. But it is also clear that this type of linguistic phenomena is by far the most difficult to study, for the simple reason that it involves so many interacting factors. It has physical components, such as the acoustics of the room or the properties of the paper on which something is written; it has biological components, such as the voice properties of the participants, it has social components, such as the personal relations between speakers, it has cognitive components, such as the spatial knowledge necessary to give route directions.

Clearly, any debate on the balance between "nature" and "culture" in "language" is pointless so long as we talk about "language" without any further differentiation. It is obvious that the *faculté de langage* is part of our genetic endowment. It is also obvious that *parole* involves all sorts of factors, and their weight in concrete cases varies considerably. In what follows, we will only deal with *la langue* – that is, with the knowledge which the mature speaker has about the particular sound-meaning coupling in "his language" and the ways in which elementary expressions can be turned into more complex ones. There is massive variation across linguistic systems, hence this knowledge as a whole cannot be part of the genetic endowment: it is cultural. But this does not prevent parts of it from being universal, and hence possibly innate: these parts are "nature". But when the issue is stated this way, we run into precisely the conceptual problems discussed above. Instead, we should look at the concrete processes which bring about the speaker's knowledge of his or her system.

3. Genetical and experiential transmission of linguistic knowledge

Within the limits of human perfection, the Queen of England is a perfect speaker of English. She was not born with this knowledge, but with the capacity to acquire it, and now she knows the particular sound-meaning coupling of elementary expressions as well as the rules according to which these can be combined so as to form larger meaningful expressions. The Queen of England also knows many other things, such as how to use this knowledge in order to achieve certain aims; but these aspects do not interest us here: we are only interested in her "linguistic knowledge" in the sense just explained. This knowledge is somewhere stored in her royal brain. How did it get there?

Nature has provided her, as anybody else, with two ways to pass on information – by means of the genetic code, and by means of whatever is perceived by the sensory organs and further processed by the brain. I shall call the former, genetic transmission, and the latter, experiential transmission. Genetic transmission is a relatively stable process, robust, and with very limited – but potentially important – possibilities of variation. We know of no way in which acquired information could be genetically transmitted. Experiential transmission is less robust, but much more flexible. In particular, it allows for transport of information which an individual has gained by experience to some other individual, and thus for increasing of the amount of knowledge available to everybody. All of this is not new, but it should be kept in mind in what follows.

The use of a language in a particular social situation is the most important way to transmit information from the mind of one individual to the mind of others. But this concerns the experiential transmission of some information of whatever sort *by means of language*. But how is the individual's linguistic knowledge itself transmitted – genetically or experientially? I can state my view on this as follows:

> Genetic as well as experiential transmission of information plays a role in the creation of linguistic knowledge in the individual; but whatever is specific to linguistic knowledge comes from other individuals by experiential transmission.

This is a hypothesis, at variance with what many linguists believe (see the brief discussion in section 1). Given the present state of knowledge on the origins of language in the individual, it can neither be proven nor refuted at this point. But there are some elementary armchair considerations that might shed light on it. What belongs to a perfect speaker's linguistic knowledge? Usually, linguists divide it into four components (there are more refined distinctions, and there is perhaps some overlap – but this does not affect the argument): knowledge of lexical items, knowledge of phonology, of morphology and of syntax. Let us briefly consider these in turn.

LEXICAL KNOWLEDGE includes, for example, that the sound sequence /buk/ is paired with the meaning "book". This knowledge cannot be genetically transmitted, since it varies from language to language: more or less the same meaning is paired with /bu:x/ in German, with /kniga/ in Russian, with /liber/ in Latin, and so on. In fact, there is probably no sound sequence which is coupled with the same meaning in all languages of the world (perhaps with the exception of /koka kola/). Lexical knowledge in its entirety must be experientially transmitted – and knowledge of words is by far the most important component in linguistic knowledge. If you were to know all elementary sound-meaning pairs of Chinese, but not a single grammatical rule, you were a much better speaker of Chinese than someone who knows the entire grammar of Chinese but not a single word.

PHONOLOGICAL KNOWLEDGE is probably less varied, since there is considerable overlap in the phonological systems of individual languages. But for genetical transmission of phonology, overlap and similarities are not enough: it is only possible when the relevant properties are found in *all* languages of the world. But clearly, English has sounds which, for example, German or French do not have. As any other English child, the Queen of England had to learn experientially that there is a sound spelled "th" – in fact, two such sounds –, whereas French or German kids do not learn this so long as they only learn French or German. Hence, the phonological subsystem can not be genetically transmitted, either.

What could be innate, however, are more abstract properties of sounds. There is some reason to assume that the number of phonetic features used in the sound systems of languages is limited to a small class, as defined by the potential of the human auditory and articulatory systems. These systems, in turn, are genetically determined; but they are not part of linguistic knowledge itself. This raises an interesting possibility. It may well be that experiential and genetical transmission of linguistic properties, here the properties of sound systems, operate on different levels of "granularity". What is genetically given are elementary properties such as "lips are closed" or "vocal cords vibrate", and what has to learned from other speakers via experiential transmission are specific clusters of these properties. But it is these clusters which define a speaker's knowledge of his or her language.

MORPHOLOGICAL KNOWLEDGE is extremely varied again. In German, the plural of *Lamm* is *Lãmmer*, the plural of *Haus* is *Hãuser*, the plural of *Tor* is *Tore* or *Toren*, the plural of *Stuhl* is *Stëhle*, the plural of *Fernseher* is *Fernseher*, the plural of *Radio* is *Radios*. No other language has such a morphological system (in fact, some languages, such as Chinese, have no inflectional morphology at all). Hence, this knowledge cannot be genetically transmitted. German kids must learn it by analysing utterances which they hear in their social environment, in a word: morphological knowledge is experientially transmitted.

This leaves us with SYNTACTICAL KNOWLEDGE, that is, knowledge of the rules of how expressions can be put together to form more complex expressions. This is the realm of linguistic knowledge in which the Generative School – that influential school in linguistics which has pushed the pendulum very much towards the nature side (cf. section 1) – has mainly been looking for universal and innate principles. The agenda is not closed here; but two things are clear. First, those syntactic properties which are normally dealt with in descriptive grammars must be learned by social interaction and input analysis. These are properties such that in English, the definite article precedes its noun, in languages such as Rumanian, it follows it, and in still other languages such as Latin, there is no definite article at all. In English, the direct object normally follows the lexical verb (*John bought a book*), in French, this depends on whether the direct object is a pronoun or a lexical noun (*Jean achetait un livre, Jean l'achetait*), and in German, there are numerous possibilities (*Hans kaufte ein Buch, Hans hat ein Buch gekauft, Ein Buch hat Hans gekauft, Gekauft hat Hans ein Buch*). This knowledge cannot be genetically transmitted. Second, it is not to be excluded that there are universal constraints on syntactic rules; but so far, any attempts to identify these have not been very successful. Still, the possibility exists and should be kept in mind. But is clear that the bulk of a speaker's syntactical knowledge must be experientially transmitted: it does not come from the genes, it comes from interaction with the social environment.

Summing up, it appears that almost everything the Queen of England knows about English does not come from the genes of her noble ancestry: she had to learn it by using her eyes and ears and tongue and cheeks as well as selected parts of her nervous system. Does this mean that genetic transmission plays no role at all? Surely not: our genes provide us with the capacity to acquire linguistic knowledge – but they do not give us this knowledge.

4. Conclusion

As was said in the first section, I essentially share Levinson's views – there is enormous cultural variation across languages, and this fact reduces the possibility of a Universal Grammar and a universal "language of thought" – whatever this may mean – beyond comparatively trivial constraints, such as that all languages allow their speakers to express spatial relations, or that words are linearly ordered. There may be more interesting universal constraints, but their existence remains to be shown. Other than Levinson, however, I do not think these facts should be seen as a step towards repositioning the pendulum of the Nature:Nurture debate. At the turn of the millennium, we should put an end to this perennial debate and turn to concrete issues.

REFERENCES

Levinson, Stephen C. 2000, 'Language as Nature and Language as Art', this volume

PART IV

THE CHANGING CONCEPTS OF NATURE: GENERAL ASPECTS

L'IDÉE DE NATURE EN MORALE ET EN THÉOLOGIE

JEAN-MICHEL MALDAMÉ

INTRODUCTION

Un des textes fondateurs de la culture universelle nous rapporte qu'au commencement, Adam, archétype de l'humain, fut confronté à la multitude des êtres créés par Dieu. Le texte biblique dit qu'il les nomma (gn 2,20)! Pour beauoup, nommer est un simple acte de désignation – comme placer une étiquette sur des objets. Rester à ce seul point de vue serait trop simpliste. Nommer est bien davantage. Nommer, en effet, c'est faire deux choses essentielles à la vie de l'esprit. D'abord, distinguer et délimiter, ce que les philosophes appellent définir ou différencier. Ensuite, arracher un être à ce qu'il a d'individuel pour voir en lui le représentant d'une classe ou d'une catégorie. Or ce sont là des actes fondamentaux dont il faut reconnaître qu'ils sont réalisés par la science qui vise l'usage rigoureux du concept.

Dans cette attitude fondamentale, le langage commun utilise le terme de nature. Dans son acception courante et dans le monde scientifique, le terme de nature désigne l'ensemble de ce qui est donné à l'expérience humaine. L'emploi de ce terme unique pour nommer une diversité repose sur la conviction que la totalité n'est ni un chaos ni un magma informe, mais une unité dont la diversité même est emplie d'intelligibilité. Cet emploi donne au terme de nature un sens très général, mais il prend des sens différents lorsqu'il est employé par un physicien, un biologiste, un psychologue, un historien, un philosophe ou un théologien.

Cette multiplicité n'est pas pure confusion, car dans l'usage du mot nature se produit le phénomène suivant. Un sens est privilégiée et par rapport à lui, les autres sont ordonnés. Ce processus éclaire le danger encouru par la nomination adamique: absolutiser son point de vue – symboliquement désigné dans le mythe d'origine comme la main-mise sur l'arbre de la connaissance du bien et du mal (gn 2,17). La tentation consiste à considérer que la nature découverte par la science est la nature en elle-même. Pour éviter une telle erreur, fruit de la précipitation, je pense qu'il est nécessaire de revenir au sens premier du terme de nature; ceci permettra de bien comprendre la situation de la pensée actuelle et de nouer un dialogue serein entre les disciplines, permettant un usage clair des notions de nature et corrélativement de culture et de civilisation.

1. *La notion de nature*

La notion générale de nature se rapporte à ce qui est donné à l'observation, de la plus primitive à la plus élaborée et de la plus immédiate à la plus sophistiquée. Pour bien comprendre le sens de ce terme aujourd'hui, il convient de revenir au commencement de l'essor de la pensée rationnelle; celle-ci repose sur une rupture toujours actuelle, la mise à distance du sacré.

1. La notion de sacré caractérise une vision du monde où agissent des forces ou des être conçus à la manière de l'action humaine et donc capables de volonté et d'intention. Les grands livres d'Homère nous rapportent la manière dont les dieux mènent les hommes à s'entre-déchirer. Plus généralement, le sacré voit dans tout phénomène observé une intervention d'être divins. Il y a des génies, bénéfiques ou maléfiques, dont l'action est liée à un lieu ou un élément du monde, mais aussi des grands dieux à l'action plus large, voire universelle. Pour se concilier les forces à l'œuvre dans le monde, l'homme est invité à se référer à des rituels où la magie joue un rôle important.

La naissance de la pensée rationnelle a tenu à distance de tels êtres. Socrate a été accusé d'impiété; son attitude illustrait une attitude commune aux philosophes qui donnaient une explication désacralisée. Dans cette perspective, s'est mise en place une idée de nature dont le sens a été fixé par Aristote; il constitue aujourd'hui un présupposé de la méthode scientifique. Il a été présent lors de la naissance de la science classique qui a récusé l'ésotérisme et l'hermétisme de la Renaissance[1]. Il existe encore aujourd'hui dans les sciences cognitives où on utilise le terme de «naturalisation» pour dire l'attention au fonctionnement du cerveau et aux mécanismes cognitifs pour comprendre l'esprit humain.

[1] Cf. Robert Lenoble, *Histoire de l'idée de nature*, Paris, Albin Michel, 1969.

2. Aristote qualifie de naturel ce qui provient d'un être qui tient en lui-même le principe de sa transformation. Avoir en soi le principe de son mouvement, telle est la caractéristique de la nature. Dire avec le philosophe «Avoir en soi», c'est tenir à distance les explications par référence au sacré ou au divin. Aristote en effet hérite de ceux que l'on appelait les «physiologues» chez qui on trouve la première description et d'explication des phénomènes sans faire appel à la magie ou aux discours mythiques.

Pour Aristote, la science se propose d'étudier les transformations dans le cadre d'un discours cohérent et logique. Plus précisément, le terme grec *phusis* caractérise la génération et la croissance d'un être. La nature dit Aristote, est «le principe du mouvement des êtres naturels», et il précise: «principe immanent en quelque sorte»[2]. Aristote souligne que cette définition exclut toute action extérieure. Est appelé naturel, ce qui n'a son origine ou son état que par lui-même et sans l'intervention d'un agent extérieur. Le naturel s'oppose à l'artificiel, c'est-à-dire produit par les artisans.

Cette définition demeure aujourd'hui encore dans les sciences et dans l'usage commun qui en dépend. La notion de nature signifie ce qui est donné dans l'autonomie de son être.

L'autonomie de l'être est manifeste dans son développement et sa croissance ou sa puissance de génération. Pour cette raison, le terme latin choisi pour traduire le terme grec de *phusis* a été celui de *natura*, transcrit comme tel dans les langues européennes. *Natura* vient de la forme passive du verbe qui signifie naître, *nascor*; *natus sum* signifie: «je suis né», mais plus largement, «je prends mon origine, je proviens». La forme première a donné dans les langues latines un ensemble de termes dont la proximité n'est pas toujours apparente: naïf, naissance, naître, natif, nation, naturalisation, natal, naturel, naturisme, naturalisme,... Cet ensemble de termes se réfère à la richesse de la naissance[3].

Or dans une naissance, il y a deux aspects. Le premier, qui est obvie, est que la naissance est le commencement de la vie. Le second est plus abstrait: la naissance manifeste une identité, car l'être qui continuera de

[2] Aristote, *Métaphysique*, livre delta, 4, trad. Tricot, 1984, t. I, p. 254-258.

[3] Cf. André Pelicier, *Natura. Etude sémantique et historique du mot latin*, Publications de la Faculté des lettres de Montpellier, PUF, 1966.

vivre sera le même. La notion de nature glisse donc de la désignation d'un moment de la vie inscrit dans le temps à ce qui caractérise le vivant comme tel dans son identité qui transcende le temps.

Si l'on relève la diversité des emplois du terme de nature selon les disciplines et, plus encore, les interprétations selon les philosophies, on peut dire que tous les emplois manifestent la tension qu'il y a entre les deux aspects du sens originel: la naissance comme moment du temps ou événement, et la définition d'une identité qui est intemporelle.

Natura – naissance:
- 1. Naissance comme premier istant
  - a. Une chose donnée
  - b. La totalité donnée
- 2. Naissance comme manifestation (dans la durée)
  - a. Une identité permanente
  - b. Un dynamisme

Les interprétations philosophiques liées à la science s'interrogent de manière plus radicale sur la naissance. Est-elle un simple résultat qu'une définition caractérise ou bien l'expression d'un dynamisme inscrit à l'intime de l'être? Parler de naissance, en effet, n'est-ce pas reconnaître une puissance génératrice des éléments eux-mêmes, leur aptitude à produire leur être? Parler d'identité n'est-ce pas chercher des règles et des lois qui fondent une permanence? La notion de nature se doit alors de tenir les deux exigences: celle de l'identité et celle du dynamisme qui assure la permanence et la fécondité.

3. Cette notion de nature s'est fort bien accordée avec le monothéisme biblique. En effet, le refus par la Bible d'une représentation de Dieu et son combat contre l'idolâtrie, qui est d'une certaine façon une divinisation des éléments de la nature, fondent une conception d'un Dieu séparé, le Dieu trois fois saint de la vision d'Isaïe reprise dans la liturgie chrétienne.

La théologie chrétienne a repris le terme de nature pour désigner l'existence qui se tient face à Dieu, en soulignant que la création fonde une autonomie. Le verbe qui est employé dans le récit biblique de la création au chapitre premier de la Genèse est le verbe «séparer». Dieu est distinct de son œuvre. La notion de nature a pu se développer dans ce sens. La nature est ce qui est donné selon un type bien précis et bien délimité.

Le terme de nature désigne l'ensemble des êtres; ils forment un ensemble donné à l'étude du scientifique et du philosophe; il désigne aussi ce qui caractérise chaque être et répond à la question de son identité, le terme de nature a pu recevoir un sens dynamique lié à la notion de création. La nature atteste, voire exprime, une intention qui la traverse et qui la fait aller de l'avant vers son achèvement.

A ce point de notre réflexion, nous reconnaissons que le terme de nature a un sens général et qu'il a aussi une multiplicité de sens particuliers puisqu'il change en s'appliquant aux sciences de la matière, aux sciences de la vie, aux sciences de l'homme et même à la théologie. Cette situation particulière demande à être clarifiée en répondant à la question: quel est le sens premier du terme de nature? En effet, lorsqu'un terme occupe un champ sémantique d'une telle ampleur, s'il ne se dissout pas c'est qu'un sens est privilégié. Aussi pour être rigoureux, celui qui emploie le terme de nature doit reconnaître que son propre usage est enraciné dans un domaine et une méthode particuliers; ceci l'amène à reconnaître que lorsqu'il l'utilise hors de son domaine de compétence, il emploie le terme dans un sens qui est plus large que le sien propre. Cette démarche est éclairée par l'histoire des sciences, où l'on voit comment le sens du terme nature change avec la manière dont la science s'unifie autour de tel ou tel paradigme[4].

2. *La notion de nature dans les sciences aujourd'hui*

Le sens très général du terme de nature se modifie avec son enracinement dans les sciences. Il importe de reconnaître comment aujourd'hui s'entrecroise dans notre langage deux sens différents qui relèvent de la science classique et des nouveautés de ce temps.

1. La science classique était liée à un souci de mathématisation qui utilisait des formalismes qui liaient les phénomènes entre eux de manière nécessaire. Le déterminisme dominait les travaux scientifiques. Il portait en lui une philosophie de la nature qui était attentive à la fixité des règles, à la constance de leurs effets et donc à la permanence de leur identité. Le terme de nature a donc été amené à recouvrir le sens ancien d'essence dans l'héritage de la pensée platonicienne de la Renaissance[5]. La nature d'un être désigne ce qu'il est ou plus exactement ce qu'Aristote appelait le

[4] Cf. Werner Heisenberg, *Physique et philosophie*, trad. fr. Paris, Albin Michel, 1971. Alexandre Koyré, *Etudes d'histoire de la pensée philosophiques*, Paris, Gallimard, 1971.

[5] Cf. Maurice de Gandillac, *La Philosophie de la Renaissance*, dans *Histoire de la philosophie*, Paris, Gallimard, 1973.

To ti ên einai, les médiévaux le *quod quid erat esse*, ce qui demeure identique dans tous les changements d'état et qu'exprime la conjugaison du verbe être à plusieurs temps[6].

A l'âge classique, la notion de nature est liée à une vision du monde qui est à la fois celle des spiritualistes et des matérialistes prolongeant la coupure marquée par Descartes entre l'âme et le corps. La question de la liberté est alors devenue décisive pour caractériser l'homme transcendant le monde de la matière, comme le montre la philosophie morale de Kant.

2. Une telle conceptualisation a été peu à peu modifiée par l'essor des sciences au cours de ce siècle. En physique fondamentale le formalisme de la mécanique quantique a modifié la lecture déterministe de l'intime de la matière. L'essor de la biologie est lié à une modélisation qui est plus souple et plus compréhensive de la complexité et de l'unité des systèmes. En thermodynamique, l'étude des systèmes a montré la complexité des phénomènes liés à l'action d'un grand nombre de particules, action formalisée dans un système non intégrable. En sciences humaines également, les statistiques sont plus fines et permettent de faire droit à la singularité des comportements.

Les concepts nouveaux liés à la mécanique statistique, comme ceux d'attracteur étrange, de fractal et de chaos déterministe, ont introduit dans le champ de la pensée scientifique une plus grande souplesse. Aussi la science d'aujourd'hui est-elle dans une situation nouvelle par rapport à la science de l'âge classique. Elle n'est plus dominée par l'image d'une nature déterminée à produire des effets prévisibles, mais elle est marquée par une conception de l'être plus attentive à la temporalité.

Tout être est le fruit d'une histoire ou d'une évolution. Il est ce qu'il est, non pas en vertu d'un enchaînement infaillible de causes et d'effets, mais de manière contingente. Il aurait pu ne pas être, ou être autre qu'il n'est. Il garde en lui-même cette marque de cette non-nécessité, ce qui est dit par le terme de contingence.

3. Un tel déplacement a un effet sur le sens général du terme de nature. Dans ce nouveau contexte de pensée, le terme de nature désigne toujours deux choses: d'une part, l'ensemble des êtres qui sont donnés à l'observation à un moment du temps, et, d'autre part, le principe intime de leur être. Les deux emplois du terme sont aujourd'hui marqués par le contexte général de la pensée scientifique; la nature est le fruit actuel de

[6] Cf. Emile Bréhier, *La Philosophie au Moyen-Âge*, Paris, Albin Michel, 1971.

l'histoire cosmique et biologique. Elle est une réserve de possibles pour l'avenir. Pour l'ensemble des êtres et pour chacun, le terme de nature désigne un état toujours précaire et modifiable de manière que l'on ne saurait prévoir rigoureusement.

Le terme de nature se rapporte à ce qui est le résultat d'une incessante transformation par des lois rigoureuses laissant place à de la nouveauté. Lorsque le terme nature est employé pour dire la totalité de ce qui est donné, il désigne une histoire qu'il est impossible d'écrire à l'avance. La nature est une possibilité toujours nouvelle d'agencements et de rencontres. Si cette possibilité n'est pas infinie, elle est toujours réelle.

Nature
- 1. Ensemble des êtres comme fruit de l'histoire passée ou évolution
- 2. Le principe de leur être comme réserve de possible pour l'avenir

Cette conception renouvelée de la nature concerne la compréhension que l'homme a de lui-même. Il ne s'agit pas seulement pour Adam qui représente tout homme de nommer les êtres qui l'entourent, mais de se nommer lui-même, à la fois dans sa relation aux autres êtres, mais surtout à son semblable et à sa propre personne. Il importe alors d'introduire un terme nouveau, celui de culture.

3. *Nature et culture*

Le terme général de nature désigne un donné qui porte en lui une ouverture qui est une capacité de production de nouveauté. Le sens du terme s'applique aussi à l'homme dont la nature doit être reconnue comme un champ de possible. La réalisation concrète de ses possibilités a pour nom culture ou civilisation[7].

1. Le terme de culture provient de l'expérience agricole. La culture est l'art de faire produire au sol et au terroir nourriture, vêtement, habitat et moyens de communication. La culture fait face à la nature dans une altérité qui est double. Elle est à la fois un prolongement de la nature et une explicitation des potentialités et richesses de ce que l'on appelle, dans le monde de l'économie, des ressources naturelles. Mais elle est aussi une

[7] Cf. Serge Moscovici, *Essai sur l'histoire humaine de l'idée de nature*, Paris, Flammarion, 1968.

lutte pour la transformer et lui faire porter un fruit que d'elle-même elle ne saurait porter. L'âge industriel a porté ceci à son comble.

Le terme de civilisation provient de l'expérience politique. La civilisation est l'œuvre de la société humaine qui non seulement exploite les ressources naturelles, mais est attentive à la transformation de l'homme par l'éducation, la formation et la gestion des ressources qui ne se réduisent pas aux éléments sensibles de la réalité.

Culture et civilisation définissent une hominisation du donné. Pour dire la situation ainsi créée, le terme ancien d'artificiel ou d'artefact a été repris pour s'opposer à la nature. Est naturel ce qui n'est pas humanisé. On parle de ressources naturelles par opposition à ressources humaines; on parle de sciences naturelles par opposition aux sciences humaines.

Mais une telle opposition ne doit pas inviter à ignorer que l'essor de la culture et le progrès de la civilisation ont pour effet de modifier les frontières; ce qui semblait irréductible et inaccessible cesse de l'être – ce qui fait que l'environnement humain est de moins en moins naturel, de plus en plus façonné par l'homme. Le paysage rural, le milieu urbain et les grands milieux qui font la biosphère sont maintenant humanisés, pour le meilleur et pour le pire[8]. D'où l'importance des questions écologiques et les débats en bioéthique.

2. Les rapports entre culture et nature ont été pensé sous la domination du paradigme de la science classique comme antagonistes. La nature serait ce qui est immergé dans le sensible; matière ou énergie, formes ou forces seraient le domaine de la nature, tandis que la culture et la civilisation s'occuperaient de l'activité de l'esprit, intelligence et raison qui sont d'un autre ordre. Dans cette perspective, la nature a été pensée comme ce à quoi il fallait s'opposer ou ce qu'il fallait maîtriser. La nature est perçue comme violente, aveugle et même hostile; elle doit être apprivoisée et domestiquée, ou encore ritualisée et symbolisée par le langage et le travail. L'image adamique recevait dans ce contexte un sens nouveau. Il était d'autant plus fort que le contexte de pensée était marquée par le mythe de la chute. La nature aurait été bonne et parfaitement soumise à l'homme, avant les accidents de l'histoire; l'homme devait non seulement maîtriser, mais se racheter par le travail et la domination des éléments. Sous le para-

[8] Cf. Christine Larrère, *Les Philosophies de l'environnement*, Paris, PUF, 1997.

digme de la mécanique rationnelle, se retrouvaient à la fois les positivistes, utopistes de la technique, les humanistes et les spirituels.

C'est contre cette conception des rapports de l'homme et de la nature que la philosophie de l'existence s'est rebellée. Elle a constaté que la culture était une construction de soi. L'homme, pour les philosophies existentialistes, ne se définit pas comme une nature intemporelle, mais comme un projet, une réalisation de soi. La nature est alors champ du possible ouvert, sans référence à l'universel qui fondait la morale classique exprimée par Kant dans la célèbre maxime.

Une telle opposition a mené à des impasses. Celles de la crise écologique! Celles aussi de la politique, car, à vouloir construire l'homme hors de toute référence universelle, on a bâti des systèmes concentrationnaires et totalitaires, dans l'oubli de la personne. Celles enfin de la morale, dans la mesure où les interventions techniques sur le corps de l'homme montrent leurs limites, dans l'oubli de la grandeur de l'homme, grandeur inscrite dans son corps.

Au fondement de ces dérives, il apparaît qu'il y a eu une erreur. A savoir l'ignorance que l'homme est à la fois matériel et spirituel, charnel et pensant, sensuel et intellectuel. Aussi il n'échappe pas aux lois de la nature en général; il est lui-même un objet de la nature.

Culture et civilisation s'inscrivent dans le champ du possible dont les bornes sont fixées par les règles qui régissent le monde sensible – physicochimique ou biologique. Les œuvres les plus spirituelles s'inscrivent dans une logique qui est celle de la nature.

Les changements dans la science devraient permettre de sortir de cet oubli et de rendre à l'homme sa place dans la nature et ne de pas faire de la culture ce qui est contre la nature, mais au contraire ce qui est le propre de la nature humaine. La nature humaine est son aptitude à la culture comme œuvre de l'esprit.

3. Les explications disponibles grâce à la théorie de l'évolution et l'étude de l'émergence de l'homme moderne permettent de mieux comprendre le rapport entre nature et culture. Un élément important est ce que l'on appelle la néoténie ou juvénilisation. En comparaison avec les autres espèces animales voisines, il apparaît morphologiquement que le petit d'homme naît immature. Il est désadapté vis-à-vis de son environnement. Il serait donc inapte à la survie s'il n'avait en lui la capacité d'apprendre. Faute de régulation interne, le petit d'homme doit apprendre. Il le fait par son lien avec la communauté humaine qui le porte et qu'à son tour il prendra en charge. L'homme est humain par l'éducation dans un

temps qui passe largement ce qui advient dans les autres espèces animales où l'empreinte et le mimétisme jouent un rôle. Aussi rien d'humain ne se fait sans être le fruit d'une éducation et donc d'une culture. Le biologique n'est vécu par l'homme que dans une culture et selon des règles qui sont le fruit de l'apprentissage[9].

Les actes les plus élémentaires et les plus biologiques comme manger, se déplacer, se reposer, se reproduire,... sont le fruit d'une culture. C'est d'ailleurs pourquoi les problèmes matériels (physiques, physiologiques, économiques,...) de l'homme sont toujours surdéterminés psychologiquement: le rapport à la nourriture, le rapport à son identité sexuelle, à l'autre homme différent et semblable, ne sont pas régis par le déterminisme biologique, ils sont vécus dans le réseau symbolique de la culture et dans une civilisation.

Nature humaine réalisée	1. Culture (travaux agricoles et arts) 2. Civilisation (vie politique et communication)

Il apparaît donc que l'opposition positiviste et idéaliste entre nature et culture ne tient pas. Ainsi opposer «le naturel» et «l'artificiel» par manière d'exclusion est trop simpliste, car le rêve romantique d'une nature pure est une illusion, au même titre que la volonté de voir en la nature l'autre de l'homme. Rien n'est donné à l'homme qui ne soit déjà humanisé. On peut donc dire que la nature de l'homme est d'être culture. Sont fausses les alternatives qui opposent le biologique et le moral, le biologique et le social, la nature et la culture ou la civilisation. Toute perception est déjà culture, car il y a humanité, avant tout œuvre humaine[10].

Cet élément est confirmé par ce que l'on sait de l'aptitude du cerveau à enregistrer ce qui lui importe pour que la vie humaine soit heureuse. Ceci est également confirmé par ce que l'on sait de la génétique où il importe de distinguer entre ontogénèse et épigénèse.

[9] Cf. François Tinland, *La Différence anthropologique*. Essai sur les rapports entre la nature et la culture, Paris, Aubier-Montaigne, 1977.

[10] Cf. Maurice Merleau-Ponty, *Phénoménologie de la perception*, «Bibliothèque des idées», Paris, Gallimard, 1945: «Tout est fabriqué et tout est naturel chez l'homme, comme on voudra dire, en ce qu'il n'est pas un mot, qui ne doive quelque chose à l'être seulement biologique – et qui en même temps se dérobe à la simplicité de la vie animale, ne détourne de leur sens les conduites vitales, par une sorte d'échappement et par un génie de l'équivoque qui pourrait servir à définir l'homme», édit. Tel-Gallimard, p. 221.

Cette conception du rapport entre nature et culture explique pourquoi l'humanité est une et diverse. Elle est diverse, parce que rien n'est donné une fois pour toutes à l'identique pour tout le monde. Il n'est pas de langage unique pour les hommes. Il n'est pas de vie sexuelle uniforme dans les âges culturels. Mais l'humanité est une, dans son exigence de passer d'une capacité encore ouverte à une détermination précise. Ce qui caractérise l'humanité est non seulement sa capacité de s'humaniser, mais le désir d'être pleinement humain.

4. *L'esprit et la nature*

Le fait de privilégier la culture pose une question nouvelle. En effet parler de culture suppose que l'on prenne acte de la grande diversité des cultures et civilisations humaines. On risquerait succomber à la tentation adamique en absolutisant la sienne et en ordonnant les autres à soi. La question est alors: S'il n'est d'humanité que dans la culture, et s'il n'est pas de réalisation exclusive, est-ce que cela n'entraîne pas un certain relativisme?

1. Cette question relève de la morale fondamentale. Elle importe aussi à la politique et à la gestion des ressources en matière d'éducation, d'information et d'art. C'est pour éviter le piège du relativisme que la notion de nature s'avère indispensable. En effet, le terme de nature désigne l'exigence de croissance de l'être humain vers sa parfaite réalisation. Aussi en matière humaine, dans les registres de l'action sociale, politique ou éthique, la référence à la nature participe des deux éléments qui lui donnent sens.

En premier lieu, la nature dit l'identité; parler de nature humaine, c'est dire à l'homme son identité et lui rappeler son origine et sa fin. L'usage de la notion de nature humaine vient alors répondre à deux exigences qui fondent la morale: elle fixe un idéal et invite à aller de l'avant.

L'usage du terme de nature rappelle au sujet moral que tout autre être humain lui est égal en dignité et qu'il est comme lui sujet de droits et de devoirs. La notion de nature fonde l'exigence du respect sur l'unité de l'espèce humaine; elle précise que cette unité n'est pas seulement biologique; elle est morale, juridique, spirituelle. En disant l'identité humaine, la notion de nature exprime également un autre fondement de la morale: l'exigence d'un devenir de soi. Dire «nature humaine» donne à tout homme et aux diverses cultures un idéal ou encore un projet, un horizon, un objectif qui mobilise les forces et permet une actualisation du possible.

En second lieu, la nature est une réserve de possible pour aller vers l'avant. Elle est désir: désir de savoir, désir d'aimer et d'être aimé, désir d'être compris, désir de se prolonger par delà la mort dans sa descendance, désir de réaliser pleinement son être. La notion de nature invite alors à reconnaître que le présent est le fruit de ce qui l'a précédé et que l'avenir est toujours ouvert. Le présent est contingent; il est le fruit d'un passé qui aurait pu donner un autre fruit; mais il est source d'un avenir qui peut prendre divers visages. L'exigence de liberté n'est plus posée comme ce qui fait face à un monde déterministe, mais comme la réalisation particulière d'un potentiel toujours ouvert. La reconnaissance de la contingence n'est pas un consentement à l'arbitraire.

Nature humaine	1. Identité de l'homme (origine et fin) – idéal moral
	2. Désir – responsabilité et souci de l'avenir

2. Sur ce point, la théologien a des choses à dire qui lui sont propres. Il considère en effet un autre rapport que celui de la nature et de la culture ou de la civilisation. Il prend en compte la relation entre Dieu et l'homme. En théologie chrétienne, ce rapport est pensé sur deux registres. Le premier est lié à la notion de création; le second est lié à la notion de salut. Le premier est une donnée de fait universel, analogue à la conception de l'enfant: elle le précède et le constitue dans l'autonomie. Le second est lié à l'histoire humaine: elle est exprimée en terme de vocation et de rencontre personnelle.

La manière de marquer la différence varie selon les théologies. Certaines théologies sont attentives à valoriser l'une ou l'autre de ces relations. Certains utilisent le terme de religion en englobant dans ce terme toutes les attitudes religieuses, parlant alors de religion naturelle pour dire que tout homme créé à l'image de Dieu peut et même doit savoir qu'il tient son être de Dieu. D'autres, au contraire, privilégient l'autre aspect; ils utilisent au terme de grâce un sens majeur, en le réservant à l'homme qui est en lien d'amour et de foi avec Dieu, en tenant à distance une nature qui est source d'opacité, voire d'inimitié avec Dieu.

La solution qui de mon point de vue respecte ce que nous apprennent les sciences est que l'identité humaine se manifeste dans la culture qui réalise le vœu de sa nature et donc que les ordres de la nature et de la grâce ne sauraient être antagonistes. La nature s'accomplit dans la grâce et la grâce couronne la nature, selon l'expression de saint Thomas d'Aquin devenue un adage de la théologie catholique: «La grâce ne détruit pas la nature, mais la mène à sa perfection» (*Somme de théologie*, Ia, q 1, a 8, 2m).

3. Du point de vue théologique, les renouveaux actuels de la notion de nature, invitent à un discernement sur la notion même de nature. L'usage du terme de nature repose sur la conviction qu'il y a une correspondance entre la nature et l'esprit humain, à preuve l'essor de la science et la rigueur de la pensée morale ou philosophique. Cette correspondance a été reliée depuis toujours à la théologie.

Celle-ci voit dans la nature comme l'expression d'une volonté divine. L'homme étant à l'image de Dieu et capable d'activité de pensée est ainsi capable de lire dans la nature la marque de l'esprit divin. Tel est un des fondements du sentiment religieux. Nous avons relevé au commencement qu'il était tenu à distance par l'esprit rationnel pour ce qui relève de l'interprétation en termes de magie ou d'intervention arbitraire.

Mais dans le cadre de la raison, l'interprétation de la nature comme expression de la volonté divine, s'entend de deux manières différentes. La première est l'interprétation que, pour faire vite, je qualifierai de romantique[11].

La nature est l'expression même de la volonté de Dieu. Connaître la nature revient à connaître Dieu. Bien des scientifiques reprennent à leur compte l'usage que faisait Spinoza de *natura naturans* et *natura naturata*. La *natura naturata* étant ce qui est donné à observer, la *natura naturans* le dynamisme qui préside et qui, pour Spinoza, est divin par nature.

Le monothéisme strict récuse cette manière de voir les choses. Si la nature exprime l'action de Dieu, ce n'est que par manière de trace ou de marque. Dieu étant séparé de son œuvre et irréductible à elle. Cette conviction donne un sens précis au terme de création, qui n'est ni une émanation, ni une aliénation de l'être divin, mais une œuvre libre qui fonde l'autonomie des créatures. L'essor de la science me semble confirmer cette interprétation dans la pleine reconnaissance de l'autonomie des créatures par rapport à Dieu. La nature est un don qui porte la marque du créateur.

CONCLUSION

La notion de nature est utilisée dans les sciences. Elle ne cesse de varier même au sein même d'une même discipline particulière. Pour le physicien ou le chimiste, la notion de nature n'est plus la même depuis que

[11] Cf. Georges Gusdorf, *Le Romantisme*, t. II, deuxième section, «Le savoir romantique de la nature», Paris, Payot, 1993.

des concepts nouveaux ont été introduits. De même pour les sciences de la vie et les sciences humaines au statut différent. Il en va de même dans le débat philosophique et théologique. Il importait donc de relever ce fait: l'idée de nature est soumise à variation.

Refuser de voir ce fait mènerait à absolutiser un point de vue et donc renoncer à l'universalité qui est impliquée dans la notion de nature et tout particulièrement lorsqu'elle est employée pour dire l'humanité de l'homme et les exigences morales qui en découlent.

Dans une telle situation, il convient aussi de reconnaître que cette variation invite à un renoncement: la réalité n'est pas conforme à l'idée que nous en avons. Il faut reconnaître que la nature ne saurait être objectivement saisie dans la transparence du concept et de son idée. Cette constatation invite à deux attitudes pratiques. La première est de privilégier le dialogue interdisciplinaire. La seconde est que l'esprit humain ne saurait être lui-même sans s'interroger sur les modes de sa connaissance.

Ainsi pourra se surmonter la tentation adamique dont je parlais au commencement et qui consiste à prendre la place du créateur. La nature est le fruit d'une interprétation. Il convient d'assumer la responsabilité de son interprétation. La lumière de la grâce pouvant ouvrir sur un accomplissement qui ne contrarie en rien les données de la science, bien au contraire.

BRIDGING THE GAP BETWEEN NATURE AND TRANSCENDENCE

MARIANO ARTIGAS

At the turn of the millennium the dialogue between science and theology is developing rapidly. However, it is in no way an easy affair. If we admit that there is a methodological gap between empirical science and theology, we could even wonder whether such a dialogue could exist at all. Moreover, naturalism time and again uses empirical science to present metaphysics and religion as meaningless or useless.

I intend to show that our present scientific worldview opens out a perspective which is coherent with the existence of purpose and religious values. We find ourselves now at a vantage point that enables us to explore these issues on solid grounds. It can be argued that, for the first time in history, we have a scientific worldview that is, at the same time, complete and rigorous, and is closely related to ideas of self-organization, rationality, and information. Also, the development of epistemology permits us to combine the logical, historical, and sociological perspectives, reaching a balanced view on the nature of empirical science. Finally, the development of science-based technology has made us more aware of the ethical implications of scientific progress. I am going to use this threefold vantage point as the framework of my argument, the purpose of which is to build a bridge connecting science and theology. Due to the space available, I must confine myself to a brief sketch; a full explanation can be found in a forthcoming book (Artigas, 1999).

My reflection is divided into four parts. The first is devoted to considering which method should be used to study the philosophical and theological implications of science. These implications are analyzed in the three following parts, which deal respectively with the ontological implications and the corresponding image of God (second part), the epistemological implications and the corresponding image of man (third part), and the ethical implications (fourth part).

1. *Science Transcends Itself*

Empirical science should not be used as the basis of reductionist or naturalist approaches, because it includes not only factual knowledge, but also its necessary conditions, which can be taken as presuppositions whose analysis constitutes a philosophical and theological task.

There are three kinds of such presuppositions. The first is an ontological presupposition; it concerns the intelligibility or rationality of nature, and is closely related to natural order. The second is an epistemological presupposition; it concerns the human ability to know natural order, and includes the different forms of scientific argument. The third is an ethical presupposition; it refers to the values implied by the scientific activity itself, and includes the search for truth, rigor, objectivity, intellectual modesty, service to other people, cooperation, and other related values.

In addition, there is feedback from scientific progress to these presuppositions, because the progress of science retro-justifies, enriches and refines them. Actually, as these presuppositions are necessary conditions for the existence of science, scientific progress is a sufficient condition for their existence, and enables us to determine their scope. Seen in the light of that feedback, the analysis of each one of those presuppositions can provide a clue to the philosophical meaning of scientific progress and, therefore, to its theological relevance.

2. *Self-Organization and Divine Action*

The ontological presuppositions of science refer to the existence of nature and natural order, because empirical science studies natural patterns.

For the first time in history, we have a scientific worldview which provides a unified picture, because it includes all natural levels (micro – and macro-physical, as well as biological) and their mutual relations.

This worldview is centered around a dynamic process of self-organization. Our world is the result of the deployment of a dynamism that produces different natural levels with new emergent characteristics, and therefore with new kinds of dynamisms, in such a way that nature is creative in a real sense.

The development of physics and chemistry has provided the basis for a new biology which uses some basic concepts which apply also on the physico-chemical level, especially the concept of "information". Information is materialized rationality. It includes plans that are stored in spatio-temporal structures and guide the successive deployment of natural dynamism and the corresponding formation of increasingly complex patterns.

Natural order is contingent, as it is the result of singular circumstances. However, nature is full of organization, directionality, synergy (cooperativeness), and very sophisticated activities.

All this is most coherent with the "continuous" activity of God, the Creator who has conceived the natural dynamism and uses it to produce, according to the natural laws, a world of successive levels of emerging innovations. Our world does not exhaust the possibilities of the creation. God usually acts respecting and protecting the natural capacities of his creatures, and He has given them great and marvelous potentialities which are never exhausted, so that new results can always be produced or expected. However, in the production of new systems and processes we can only develop potentialities which are already contained in the created natural world.

In this context it is worth considering a kind of definition of nature provided seven centuries ago by Thomas Aquinas which runs this way: "Nature is nothing but the plan of some art, namely a divine one, put into things themselves, by which those things move towards a concrete end: as if the man who builds up a ship could give to the pieces of wood that they could move by themselves to produce the form of the ship" (Aquinas, 1965). This idea has now more empirical support than in Aquinas' time and fits very well with the present worldview. Now we can say that God acts this way and can provide many striking examples. Therefore, scientific progress retro-justifies, enriches and refines the ontological presupposition of science, turning order into self-organization, and shows the central part that natural and divine creativity play here.

3. *Scientific Creativity and Human Singularity*

Likewise, there is feedback from scientific progress to the epistemological presupposition of science, which is connected with the human ability to know nature's order.

Indeed, nature does not speak, and natural science is possible because we are able to build specific languages which allow us to pose questions to nature and to interpret the answers provided by our mute partner. This shows that, although we are a part of nature, nevertheless we transcend it.

Creativity plays a central role in the progress of science. In contrast with earlier ideas, contemporary epistemology points out that creativity is an essential ingredient of the scientific enterprise: we need it every time that we formulate a new hypothesis, or propose a new experiment, or perform an experiment and interpret it, or establish new stipulations. Scientific creativity has to be adapted to the constraints imposed by coherence and experience, but it is indubitably a central feature of science.

Scientific creativity is one of the most astonishing capacities we possess. Empirical science steadily progresses in spite of the fact that, on purely logical grounds, we could never be sure of having obtained true knowledge. We are able to build on foundations that, even though they are not completely firm, are good enough to support impressive skyscrapers.

Scientific creativity is a proof of our singularity. It shows that we possess dimensions which transcend the natural ambit and can be labeled as spiritual. The very existence and progress of the natural sciences is one of the best arguments that show our spiritual character. But, at the same time, the success of scientific method shows that our spiritual dimensions related to creativity and argument are intertwined with our material dimensions, so that we are a single person constituted by both aspects.

All this is coherent with the view that man is a co-creator who participates in God's plans, and has the capacity of carrying the natural and the human ambits to more and more evolved states.

Also on this level we can appreciate that scientific progress retro-justifies, enriches and refines the epistemological presuppositions of science. Thanks to this progress, we know better our own capacities and we are able to develop them in a line of increasing creativity which corresponds to God's plans. Obviously, the scientific enterprise acquires a completely new and fascinating meaning when we see it as a task that God has entrusted to us, so that we may increasingly participate in his knowledge and mastery over the natural world. Then, cultivating science becomes a human task which has a deep divine meaning, and it should be carried out with a deep gratefulness and respect towards the plans of the Creator.

4. *Science and Values*

The meaning and relevance of science reach their highest peak when we consider its ethical presuppositions. Empirical science is, above all, a human enterprise directed towards a twofold goal: a knowledge of nature that can be submitted to empirical control and, therefore, can provide a dominion over nature. Therefore, the meaning of science is also twofold: the pursuit of truth and the service to humankind. In this case, it is obvious that scientific progress retro-justifies, enriches and refines these goals, and provides better means for their implementation.

Besides, scientific work requires an entire set of values, such as love for truth, rigor, objectivity, intellectual modesty, cooperation, interest in solving practical problems (medical, economic, and so on), so that scientific progress contributes to the spread of those values.

The progress of science and of science-based technology always creates new problems of a humanist character. Therefore, their progress is a source of new challenges which require basic moral values as well as social responsibility and ethical creativity.

The new worldview presents a creative universe which has made possible the existence of creative intelligent beings who are, at the same time, carriers of insignificance and of grandeur. This worldview is entirely consistent with the emphasis on God's respect towards creation. The resulting model of God and divine action underlines God's involvement with creation and God's respect for human freedom.

God can also be viewed as an artist. The universe and, in a personal way, intelligent beings such as ourselves, participate in his creativity. This is most consistent with the self-organization of nature and with human freedom. Our world does not exhaust God's creativity and perfection. Any representation of God will always be partial and imperfect. Nevertheless, we can know and experience those features of divine wisdom and love that we need to find the meaning of our lives.

Following an ancient image provided by Seneca (Seneca, 1961) and used fifteen centuries later by Luis de Granada (Granada, 1989), God can be referred to as "the mind of the universe" not in a pantheistic sense, but to express the idea that our universe exhibits rationality, information and creativity; that it makes possible the existence of human beings who are strictly rational and creative; and that all this requires a divine foundation and a participation in God's creativity.

If we compare this theistic perspective with other positions, we realize that it stands the criteria which we apply in the natural sciences.

Its explanatory power is very high, while atheism and agnosticism leave everything unexplained. It has also a very good predictive power because it provides a rational basis for human responsible and creative activity, while atheists and agnostics, if they are coherent with their position, have no basis at all for a moral way of living: they can be honest in spite of the fact that they are atheists or agnostics. It has the support of independent proofs and can be integrated in a chain of mutual support with other generally accepted views: mainly with those of science, as they have been developed jointly with an analysis of the present scientific worldview, but also with the central core of most religious views and with the basic human aspirations. Here we can find a common ground which could be accepted by most religious people and could foster religious views.

REFERENCES

Aquinas, T., 1965, *In octo libros Physicorum Aristotelis Expositio* (Turin-Rome: Marietti), p. 131

Artigas, M., 1999, *The Mind of the Universe* (Templeton Foundation Press: Philadelphia and London)

Granada, L. de., 1989, *Introducción del Símbolo de la fe* (Madrid: Cátedra), pp. 129-130

Seneca, L. A., 1961, *Quaestiones naturales* (Paris: Les Belles Lettres), pp. 10-11

CONCLUSION

THE FUTURE OF NATURE

HUBERT S. MARKL

1. *Humankind and Nature – Humankind in Nature*

It seems surprising that the Pontifical Academy – an assembly of most distinguished scholars – would find the numbers-game of the turn of the millennium worth calling for an assessment of our changing concepts of nature. Does anyone really believe that the turn from 1999 to 2000 is some crucial instant in time, as our chiliastic forefathers felt when the year 1000 was coming up? For the evolution of knowledge, also of knowledge about nature, just as for the evolution of nature itself, there is certainly nothing special about such a transition date. But the same is evidently not true for the evolution of our perception of time and of our place in its flow.

Thus, beyond the mere magic of numbers, we are from the outset taught a lesson by the very title of this symposium, namely that the rules governing our thinking about reality are something quite different from those governing the processes in reality itself – as far as we can perceive them. We should remain aware of these double standards of epistemology when we reflect upon our concepts of nature, or, as I will do, upon our concepts of the future of nature. In fact, we are often inclined to segment and denominate even continuous change in nature into discontinuously perceived phenomena. We talk about our perceptions and propositional representations of nature, as if we were speaking of nature itself. However, our thoughts are never derived only from an external world acting on our minds, but always just as much from our minds acting on and acting in this external world, and even more confusingly, acting as part of this world, and, of course, from thoughts acting on thoughts. Some philosophers even consider the whole external world as a mere construction of our minds, a figment of our personal or collective imagination, as it were. That is where pure theorizing may end if unfettered by the sobering discipline of empirical experience, i.e., by testing thoughts in reality (whatever this may be). It is only empiricism which can salvage us from the unlimited arbitrariness of individual or collective solipsist world-views – at its best, empiricism which is critically confirmed and corroborated by many independent observers, which we then call scientific empiry as opposed to anecdotal experience..

The evolutionary perspective – again combining theory and empirical tests –, which can be the only view of nature by a present-day natural scientist, closes a very peculiar circle between nature and our concepts of nature – which thus turn out to be nature's concepts of itself. It is this circular interaction between what nature is and what nature – through the human mind – thinks of itself, which will be at the center of my following remarks on the future of nature.

Of course, I am only too painfully aware that any discussion of the future of nature can only be even more speculative than whatever else we may have to say about nature. Some say that we can actually know almost nothing about the future of nature, because of the properties of complex, non-linear, dynamic systems, of which nature is, of course, the paragon example – the "mother of complex systems," as the arab saying would go. But, as often, we may never know how much or how little we know, unless we try to find out.

But what shall the notion "Nature" mean in such a sentence when spoken by a natural scientist? I cannot go on without putting my cards about this on the table of the Pontifical Academy, thus maybe only disclosing my, a scientist's, prejudices. For an evolutionary biologist who does not shy away from the consequences of our evolutionary insights, nature can only mean: the universe, everything in it which is accessible to the inquisitive methods of science. This would evidently even comprise many universes – if they were more than theoretical cosmologists' pipe-dreams.

It is this deep conviction – whether spelled out or not – that there is only *one and the same* nature – including the human species as far as it can be studied by science – that can be investigated by all scientists – of all ages, past and future, of all places, of all races, of whatever gender – which is the foundation of our conviction, which is just as deep, that there can be only *one and the same* coherent body of knowledge about this nature, without any remaining contradictions at the end of our pursuit of this knowledge. In other words: we believe that there can be only one scientific truth with regard to this nature at least for us human beings.

This may sound like an almost Catholic view of nature. At least in that respect there is common ground with what the Pope has taught in his most recent encyclical on "Fides et Ratio," even though he founds his conviction in the firm belief in one Creator revealed in His Creation – which we call nature – as well as through his scriptural revelations.

At least as far as the unity of the universe is concerned, most scientists work on the assumption that there is only one explanation for all of nature. Of course, there are different perspectives, different ways of access to this one world, different subjective experiences – e.g., the artistic, the moral, the religious ones – but there can be only one and the same scientific truth about Nature that is at least what scientists hope and work for. Following Jürgen Mittelstrass' list of world-views, one may feel tempted to add another one, a monist, a Spinoza's world – if there were not too many spiritual and religious connotations connected with it, about which a scientific monist world view has nothing to say.

If we thus trust in such unity of and continuity within nature – which is, of course, more a belief or conviction, or a postulate of practical reason, than an absolutely proven fact –, it must also follow that in reflecting and researching on the most singularly challenging offspring of nature, namely the human species, whatever is learned in reliable knowledge about ourselves – whether with the methods of the natural sciences or with those of the social sciences or with those of the humanistic study of human culture – can only be different aspects of *one and the same* truth about ourselves, about what we are, where we came from and where we may be going.

In such wide perspective, the consilience of knowledge, on which Edward O. Wilson so articulately insists, is only a logical consequence of the unity of nature, of the unity of humankind and of the unity of possible knowledge of both of them. Although – as far as I see it, and here I beg to differ from Wilson – this unification may not be achieved by extending concepts and insights of evolutionary biology to encompass all that can ever be found and studied in our species – just because it is without doubt a biologically evolved species – but by trying to integrate what the independent biological, social, cultural, psychological or philosophical pursuits of knowledge about ourselves have been revealing and will reveal to be true. Thus, I can only see the call for consilience as a call for uniting forces in order to overcome the divisive and misleading dichotomies which have for so long haunted our understanding of nature and of ourselves in it, as when we oppose the Animal Kingdom versus Humankind in evolution, Nature versus Nurture in the development of behaviour, Nature versus Culture in history, natural propensities versus moral rules in ethics and so on. Only by overcoming such split-brained views of the human place in the universe, not as an inexplicably natural/supranatural twin being, but as *one* being, natural down to its boots and up to its mind, will we be able not only to get a unified, a truly consilient perspective on all of nature including ourselves, but also be able to look at the future of nature in a coherent fashion. This may make it necessary to look in a new way not so much at us but at nature.

It is the most important precondition of a rational, and, as such, at least to some degree predictive view on nature's future that we see ourselves not as some kind of fallen angel, alien intruder or as some aberrant or deranged scourge of nature, but as its constituent and heir. And, as such, again not only as just one constitutive part among many others, as any arbitrarily chosen biological species, but as a unique, a quite extraordinary kind of natural species, through which nature entered into an entirely new stage of its many billion years' evolution, which not only participates in its future evolution as any other species does, but which more and more commands and determines this future, for better or worse. In having evolved the human species, nature, as it were, has begun to take control of its own future, has become able to give it purposeful direction, has in a way become responsible for its own future development. But, mind you: all this holds only if we truly perceive the human species not as opposed to nature but as its most recent integral part, its own culminating invention. If the word invention sounds too intentional for some of you, I must insist that from such a comprehensive evolutionary perspective, human technological and economic inventiveness is nothing but nature's way of intentionally acting upon itself and forming its own future – maybe leading to progressive success or to disastrous failure, but in both cases also bearing at least partial responsibility for such an outcome.

If that seems like a strange way to argue about nature, I can only remind you that the evolutionary, the truly Darwinian perspective of putting humankind not against nature but fully inside nature has the disturbing consequences of feedback circularity, as disturbing to our traditional ways of looking upon nature as to those of looking upon ourselves, consequences which have up to now hardly been thought through to their ends. I will try to take at least a few tentative steps in this direction. It will not be steps leading backward to a reductionist *regressus ad infinitum* but rather steps forward to a naturalist *progressus ad infinitum*.

Let me now, from such a philosophical vantage point, try to look at the future of nature (comprising our own species!) in five quick steps, only briefly sketching out some conceivable lines, but never forgetting that the horizons for different, unforeseen developments are wide open, that evolutionary creativity, unpredictable enough as such, has been multiplied thousandfold by having evolved the creative mind of the human species, thus literally not only entering into a new stage of creative freedom but really having created such freedom of future development of man *and* of nature, or to be more precise: of man (and of course: of women) *in* nature. I will look at these questions from an evolutionary, an ecological, a cultural, an anthropological and finally from a moral perspective, going in rapid succession all the way from planetary to human nature. While doing this, I will, of course, restrict myself to only the short-term future, because the long-term is dark. In fact, astronomers tell us, that on the long run our planet will be engulfed by the expanding red giant sun and evaporate together with all of mankind, proving John Maynard Keynes right, who remarked that on the long run we will be all dead – except maybe those of our descendants who by then have escaped into outer space.

2. *The Evolutionary Perspective*

Let us first throw a quick glance on the consequences of ongoing biological evolution for the future of nature. Being relentlessly driven along at the rapid pace of human cultural change, we are always in danger of suffering from a slow-motion illusion when looking into our biological environment, which humans have for so long regarded as completely stable, as so aptly expressed by Carolus Linnaeus slightly more than 200 years ago: *Species sunt tot, quot creavit ab initio infinitum ens.* Well, we know better now in three respects. We know first that billions of species of microbes, animals and plants have evolved over perhaps more than 3 billion years, and that probably more than 99% of them have become extinct by whatever natural causes. We know second that, due to expansion of the human species over several thousand years both in numbers and in per capita consumption of natural resources, we are in the middle (not as some see it: only at the beginning) of one of the major extinction events in the evolution of life on earth. With human occupation and exploitation of, overall, between 10 and 90% of the space of natural ecosystems and of a rising fraction of net biomass production all over the planet, there can be no doubt that we take part in and in fact cause one of the largest changeovers of biodiversity in a shorter period on the geological time-scale than life has ever experienced or suffered. This will, unfortunately, be true even if we do everything to protect and maintain what is left of the biomes of our biosphere, which we should do by all means, but in fact do only in lip-service in large parts of the world. Thus, even though we may be able to let a number of beautiful species, dear to our hearts, survive in some kind of semi-domesticated, nature-park-like fashion, they will only be sad remnants of the splendour of life in their former natural environments, and will – for genetically inexorable reasons – on the long run never be the same again, but rather look-a-like genetically impoverished derivatives of former natural species. It might well be that some of them may only survive in the form of frozen germplasm in gene banks – or maybe even only in genome sequences in the internet –, to be revived if necessary to demonstrate what generations ago had been Siberian tigers, African rhinos, great pandas or river dolphins. But what will definitely have gone forever are the natural biocoenoces and ecosystems to which they belonged and which cannot survive without their symbiotic member species combinations.

However, we know thirdly that, at the same time as the biosphere is completely restructured under the bolide impact of the human species, an entirely new table is set for the evolution of new species or for the expansion of existing ones which can make use of the never-before experienced superabundant opportunities of 6, 8 or even 10 billion human individuals and by the multibillion tons of biomass of our slave species of domesticated agricultural plants and animals. Probably never before has such a wealth of food supplies been provided so rapidly for an unlimited number of parasites and pests (as we, from our egoistic viewpoint, regard them), room for an entirely new surge of bioevolutionary creative developments, certainly not to our pleasure, but clearly bearing witness to the creative powers of natural selection. And we know very well: the harder we fight these parasites and commensals the more they will thrive and resist our means of destruction, unless these are effective enough completely to wipe out a parasite species – but even then they only clear a niche for the next inventive occupant to take possession of it.

Thus, to sum up this quick overview of clearly foreseeable evolutionary aspects of the future of nature (including ourselves): biological evolution does not stand still; exactly because the impact of our super-dominating species is so cruelly effective against a large part of the existing biodiversity, it is at the same time by itself a most effectively accelerating agent of new evolutionary development. Only by someone who would value biological nature only according to species counts – 100 species of birds or butterflies gone but 100 species of nematodes, fungus or mites replacing them – this process of decline and rise could be looked at with equanimity. For whoever cherishes biological nature in its richness of beauty and creative complexity it is a process of heard-rending destruction and emotional loss. But since nobody knows how to return humankind from its present overblown and even still increasing state to one which could peacefully live alongside of the existing richness of living nature, and since even as massive a moral force as the Catholic church is less than helpful in curbing the continuing growth of the human population, we will have to face the reality of an evolutionary sea-change caused by our imperialist, colonialist species which will impose on future human generations on end the need to fight and to come to grips with an onslaugth of evolutionary forces trying to thrive on what we regard as our resources, and above all trying to thrive on that most easily accessible resource of biomass on earth: on members of the human species.

3. *The Ecological Perspective*

This brings us directly to the second, the ecological perspective of the future of nature. Human ecological relationships have evolved over millions – if looking upon the hominid family – or at least over several hundred thousands of years – if looking only at *Homo sapiens* – under conditions which, for 99,9% of the human population, no longer exist. Since the invention of agriculture and animal husbandry about 10,000 years ago, the human species has actively, purposefully, persistently, successfully and irreversibly remodeled its relationship to the biotic and abiotic environment, bringing about the evolutionary changes which I have just briefly described. In the most advanced agricultural civilizations, artificially managed agro-ecosystems dominate over two thirds and even up to more than 90% of the inhabitable land. These areas are more and more under the guidance of scientific knowledge and, utilizing the most sophisticated modern technologies, artificially kept in a state of very high productivity of consumable biomass, characteristic of very early stages of natural ecological successions. In other words, billions of humans can only survive by continuously and artificially managing a sizeable fraction of the biosphere in a way that provides our species with needed resources, but which, by its very nature, can never become stabilized in a state of ecological equilibrium because we cannot allow it to arrive there, if we want to keep it most productive for us.

If you now include the human exploitation of forest, river, lake or marine ecosystems and add to that the pressing need to keep at least a marginal fraction of natural ecosystems unexploited in their pristine state by actively sheltering and guarding them against – further – exploitative human intrusion, it must become evident for everyone considering these bare facts of the present state of the biosphere that not only those vast areas of land exploited by us directly for agricultural production, but actually almost the whole biosphere as an essential ecological resource for human survival is already and will increasingly need to be purposefully and responsibly managed by our own species. Not because we could flatter ourselves in preposterous hybris that we are able to manage the whole planet better than nature, left alone, could do it by itself, but because – with all our limited insights and capabilities – we cannot escape the responsibility of taking care of and, where possible, cleaning up the mess which free-running human population growth and relentlessly progressing human cultural evolution has made of the biosphere. It is thus not a *delusion de grandeur* which forces us to accept the role of managing our way of behaving (or rather misbehaving) in the biosphere, but the sad necessity of someone who has carelessly set fire to his house and who should at least do everything to extinguish it, even if he may be well aware that he himself might never be able to rebuild the house as it had been before. "To manage the biosphere" thus, of course, is not an entitlement to carry on recklessly doing what comes to mind and exploiting whatever may seem exploitable, but rather first to get as clear an understanding as possible of the conditions of a surviving, sustainable biosphere and of what should be done and what may not be done in order to reach that goal, and second to organize and control our own behavior – morally, legally, technologically, economically – in such a fashion that we really do have a chance to attain that goal.

To sum up my second point about the future of nature from an ecological perspective: the human species, whether we like it or not, has become the super-dominating species of the global biosphere and therefore has to manage the biosphere by controlling not so much the natural environment but by controlling above all humankind itself – its reproductive and propagative behavior, its habits of exploitation, consumption and waste disposal. Thus, from an ecological viewpoint, nature has overwhelmed itself through the evolution of our species: history in that sense is only another word for ongoing evolution. As a product of nature as well as of culture, the human species is in such a perspective an artefact of its own making, its own creation, in one word: selfmade Man. But nature has – through the evolution of our species for the first time in billions of years – found a way to also reflect on its state and to take measures for controlling its own future development. Thus, if humans try and learn to manage the biosphere, it is not human hybris acting against nature, it is nature's way of continuing its evolutionary path to progressive organic complexity and flexibility. Having become conscious of itself through the human mind, nature has found the means to continue its evolution beyond the reaches of biological-genetical evolution alone. Science and technology thus can be regarded as the tools by means of which nature can proceed along the way taken when giving birth to the human species and its conscious mind. While biological evolution in its so-to-speak Darwinian state is characterized by the unintentional trial-and-success adaptation of gene pools by natural selection, the rise of the human species has given nature the possibility to become self-aware of its situation and of the causes and consequences acting within itself, and thus enabled it to proceed further in a goal-directed, purposeful way through the cultural evolution of human kind. This is not in opposition to nature or against the natural laws of creation. Quite contrary, it fulfills the very potentials of creativity embedded in an evolving nature.

4. *The Cultural Perspective*

We have thus moved along right into the middle of the cultural perspective of the future of nature. To look at human culture only from the viewpoint of setting the goal of keeping the biosphere sustainable, which is just another word for keeping it as a suitable place for humankind to survive, of course means grossly to underestimate what human culture or rather human cultures in their hundredfold diversifications can mean for the future of nature. In the first place, we should never forget that the notion of culture is derived from the Latin verb *colere*, that is, from cultivating the land for growing plants for consumption by humans and their domesticated animal slaves, servants and companions. This means that culture at its very basis is not a human activity directed against nature but one of making natural productivity usable by humans. Nature in its uncultivated state is not at all a very hospitable place for human survival. While we may be most afraid of large predators hunting humans for prey, the real natural enemies are, of course, minute parasites causing infectious diseases and, above all, poisons of all kinds with which plants and animals try to defend themselves against herbivors and predators, including us humans. The real work of cultivation meant, therefore, not so much to intensify harvesting but to continue purposefully what biological evolution without intention had done for billions of years: select according to suitability, thus producing adaptations to the new, the anthropogenic environment. At its very basis, cultural evolution thus meant nothing else but the continuation of natural evolution, but *for our own purposes*. Therefore, it is entirely appropriate to regard the artificial, man-made agricultural ecosystems from the early beginnings in Mesopotamia, the Nile, Indus or Hwangho valleys or in the highlands of Meso – and South America or New Guinea to the present day as nature in cultural disguise, and to see the agricultural future on the face of our earth as part of the future of nature in the geological age of the Anthropozoicum.

And just as learning from trial and success, selection by consequences under limiting constraints, gaining experience, insights and wisdom under the pressing needs of subsistence led our ancestors to improve cultivars and cultivation processes, any future progress of the agrobiological sciences in developing higher-quality, higher-yield, more pest-resistent, environmentally less vulnerable strains of agricultural plants will continue to produce a new kind of nature out of the stocks of existing natural resources. While our ancestors, looking for the means to influence the productive yield of genetic resources, could only select what had been provided by mutational chance or accident, recombinational genetic technologies now enable us not only to emulate the selection part of biological evolution, but also to increase the variation potential from which to select. It seems difficult to regard this step as any more "unnatural" than the traditional ways of cultural selection that have been the very fundament of evolution of human culture, and thus also of human nature.

Therefore, agricultural biotechnology and genetic technology are only a consistent continuation of human evolution in its interaction with living nature, which makes it neither harmless and natural, nor contranatural and dangerous in itself. In each and every case of its application to responsibly warranted purposes, it has to prove its worth prior to wide-scale application. To see in this a violation of natural creation is the expression of a rather limited understanding of what creation is actually about. The other way round would make rather more sense: the creative powers of modern biotechnology could well be regarded as the consistent continuation of that very kind of natural, evolutionary creativity which let the human species come into existence in the first place and thus could open up the opportunities for human intellectual creativity as an extension of evolutionary genetic creativity. There seems, therefore, to be more "natural" justification in the application of scientifically guided biotechnology than in the unbiologically dualistic view of the living world as divided between biological nature on the one side and non-biological human culture, science and technology on the other side.

To avoid being misunderstood, I want to spell out quite clearly that what I have said here about the cultural perspective of the evolution of nature is not an expression of "the scientistic mentality ... leading many to think that if something is technically possible, it is therefore morally admissible" as it has been castigated in "Fides et Ratio" (88), and that it should also not be seen as an expression of the "illusion, that thanks to scientific and technical progress, man and woman may live as a demiurge, single-handedly and completely taking charge of their destiny" (*ibid.* 91). Far from that. We will have to struggle with all of our insightfulness and inventiveness even to be able to keep our population numbering in the billions alive and to keep at the same time the biosphere surviving against the odds of a world which will continue to provide us with unforeseen challenges rather than with the entitlement to a self-made garden of Eden. But it is one thing to accept that *any* application of *any* technology needs responsible, moral weighing of costs and benefits and is not in itself justified just because it can be regarded as quite natural, and it is quite another thing to refute the misguided argumentation that scientific-technological progress must evidently be unnatural or even counternatural because it can only be achieved through human culture and not through natural-biological processes excluding human intellectual creativity. In fact, human intellectual inventiveness and mental freedom from purely genetic programming of behavior does not make our peculiar cultural creativity an unnatural usurpation of forbidden powers, always to be put under the suspicion of immorality. It is this very creative freedom which makes us "the moral animal", that is, the only species that is in constant need of moral guidance in order to make good, responsible use of this freedom. Therefore, I see no disagreement between the view of the human species and its culture, as revealed here, and the clear admonition directed to scientists in "Fides and ratio", "to continue their efforts without ever abandoning the sapiental horizon within which scientific and technological achievements are wedded to the philosophical and ethical values which are the distinctive and indelible mark of the human person" (ibid 106).

5. *The Anthropological Perspective*

This brings us straight to the fourth perspective of the future of nature, the anthropological view from the standpoint of the individual human being. Since every human individual is – just as the whole species – an outcome of natural evolution, whatever we do to our biological constitution will influence the future of nature by changing our own nature. Most of us will, of course, when pondering this situation, immediately think of the newly developed possibilities of interfering with human reproductive processes and especially of genetic manipulation of the human germ line. However, even though I will return to these aspects shortly, it seems to me that we should again step back for a moment and consider whether it is really true that human rights and human dignity have only become an issue and been endangered by the recent development of reproductive and genetic technology, whereas up to now human individuals have only lived under perfectly natural *and* moral conditions over thousands of years of human cultural development, in due respect of their personal dignity.

I think that to pose the question in such a way, us to answer it in the negative. One could hardly imagine anything that more cruelly deprives human individuals of their inalienable human rights to life in personal freedom and in bodily integrity, than what highly respectable, so-called "high cultures" under the close moral guidance of just as respected, so-called "high religions" have imposed on at least some, often even large fractions – often female – and even majorities of their populations: slavery, witch-hunting, religiously motivated cruel mutilation, torture, capital punishment of innocent victims; there isn't anything in even the most complete book of sadist practices which has not been applied diligently and even under the pretense of religious duty and devotion to millions of sufferers – and often the pratice still continues even today. Thus, human cultures of the past have never shied away from inflicting gravest damage to human nature without regard to its dignity, as little as they have shied away from inflicting such damage on other species. They have also never hesitated – again with little respect for human freedom and dignity – to subject growing-up girls and boys to the most severe pressures of indoctrination in order to make them conform to a society's habits and norms, even such which, from a standpoint of enlightened human dignity, can only be judged as abominable deprivations of the most basic human rights.

It would, therefore, seem appropriate – when dealing with imagined or real new dangers for human dignity as a result of the new possibilities of reproductive and genetic technologies – not to be infatuated with the impression that these undisputable dangers – just because they are new and hitherto unknown – are in any way more serious and despicable than the long-existing and readily-used arsenals of depriving human individuals of their freedom and dignity. This is evidently not so for thousands and thousands of healthy boys and girls who owe their lives to artificial conception and embryo transfer more often than not more dearly loved boys and girls than many born unexpectedly and unwanted under the most natural circumstances. And I can also not see that the future of human nature as one respecting individual rights and dignity is unacceptably compromised if some of the most severely genetically malformed and permanently disabled individuals are not exposed to a cruel, short life and early death if we try to avoid such a development, which to call natural – although logically correct – would mean making what occurs by the forces of nature the ultimate moral imperative, a form of naturalistic fallacy of jumping from "is" to "ought" which moral philosophy has long taught us to avoid. And even if the example of the possible cloning of human individuals comes to mind – which most of us would want to see precluded by force of law for good moral and social reasons – it should be remembered well that – in case of success – the worst that could come out of it would be a completely new human being with all its human rights and with the undiminished entitlement to respect for its dignity.

It seems necessary to emphasize strongly here that such argumentation neither aims at any kind of eugenic amelioration of the human gene pool nor can it in any way – neither logically nor morally – support such mistaken eugenic goals. It is also not convincing that the increasing costs of healthcare budgets would force us to earnestly consider such eugenic cleansing of the human gene pool, for the following reasons, among others:

- The increase of costs for healthcare is caused far more by rising medical expenses during the last years of aging patients than during the first years of genetically severely handicapped individuals;

- most genetically seriously handicapped human beings die in their first months or years of life – well before reaching reproductive age, even with best medical treatment, and thus cannot contribute to the genetic load of human population;
- of those, who do survive to reproduce, one person's handicap more often than not is another person's special gift;
- an overall degradation of the human gene pool has never been proven and seems highly improbable, since its genetic composition is mostly dominated by the more than 90% of human population receiving little medical attendance that could favor the survival of genetically severely handicapped newborns, especially in the third world;
- in the remaining 10% of the human population who can afford to receive such special medical attendance, costs of healthcare seem not so much driven by genetic deterioration but rather by rising numbers of medical practitioners.

It seems therefore not only immoral and illogical to turn to eugenic gene pool management of the human population, but also quite improbable that there is any real danger that the human species could first go broke and than maybe even extinct because of exaggerated healthcare efforts for genetically severely handicapped newborn individuals.

Therefore, it seems to me that, while we have good reason to look with sober judgement and full moral responsibility on all these new or sometimes not-so-new perils of scientific and technological progress, not being carried away too easily by the "sweet temptation of feasibility", there is also every reason to consider open-mindedly what advances in human biology might have to offer us in order to avoid or cure suffering and to help human beings to live fulfilled and undeprived lives. Not everything that comes into the reach of feasibility needs to be done, and there is certainly much that should not be pursued at all out of respect for human freedom and dignity. But it seems to me that this aspect of the future of nature, namely the future of our human nature, is so much more determined by the powerful processes of cultural evolution, especially by the almost unfettered "cloning" of misleading ideas, superstitions, prejudices, anxieties, chauvinist beliefs and unethical desires by means of indoctrination, public seduction, suggestive advertisement and immoral (and sometimes even purportedly moral) coercion, that we should do well not to worry so much about the most novel but rather about the most perilous and quite often quite ancient dangers to human nature in the future of nature.

6. *The Moral Perspective*

That takes me to my fifth and final consideration with regard to the future of nature. I have, I hope, been able to make it clear enough why I believe that the future of nature at least from now on, but actually for quite some time already, cannot be treated as if it were independent of the future of what is traditionally regarded as being beyond nature: human life and culture, the world of human thought and imagination, in one word: the mental world in which every one of us lives just as self-evidently as in the natural surrounding world. In fact, none of us would for even one moment deny that it is this mental world of the human mind that is the very core of our human nature. Compared to it, everything else which can be called upon to make us distinctive from our animal relatives – be it an upright stride or hairless skin, feeding or mating habits or whatever else – seems insignificant, with only the exception of human language, but then it is, of course, our capacity of creatively using language which, more than anything else, is the tool with which we can become aware of the mental worlds of others and with which we can give others access to our private theatre of imaginative plays, creative narratives, and original thoughts and feelings.

Since we owe this capacity for conscious thoughts and emotions and their expression – in hitherto still inexplicable ways – to our supersized brains which are – in ways much better explained – the outcome of the process of the natural evolution of our species, one cannot focus on the future of nature without ending up focussing on what this mental world, which some feel compelled to call supranatural even though it has grown from the natural, and its further development may mean for the future of nature.

It may be said that nature, as I have already stated, through the evolution of the human species, the human brain and the human mind has found a way to reflect upon itself, on its past and present conditions, and even – to some limited degree – on possible future developments. If nature thus has become conscious through human consciousness and free to act through human freedom, it has brought itself to the point where the future no longer only occurs to nature according to the laws and boundary conditions existent in our universe, but to the point where the future becomes a potential to be realized, a goal to be achieved and worked for, not "makeable" in the sense of being completely under the control of performance, but very much so in the sense of imposing on conscious actors responsibility for their conscious actions. That means to say that "to make a future" is very different from just letting it occur by behavior, namely it obliges us to act according to reason and to be responsible for what is made. Of all creatures in nature it is only our human species through which nature can act in such ways. Therefore, because we have evolved the capacity to not only behave but to act on purpose and thus to "make a future", we cannot escape the responsibility to do so.

It is this fact of our nature which makes us dependent on moral guidance, that is, on guidance as to how to pass judgement on what is good or bad and how we should lead our lives. To ask about both the meaning *of* and the meaning *in* our lives is just another way of asking for moral guidance in order to know what is good and what is worth striving for, working and suffering for. Nature has not completely set us free without giving us a well-equipped package of desires, emotions, hopes and fears, longings and needs in order to keep us going and searching. But with all these inborn emotional driving forces we are like a self-starting locomotive machine fully equipped with engine and fuel but much in need of a clear vision of where to go and of a map telling us how to get there. Clearly, there are some who feel that to keep this engine running and to experience the good feelings that go along with it may be all there is to make life worth living and that this therefore already answers the question with respect to the meaning of such life. But most of us want – at least at times – to reach beyond that, to define a goal to reach for and to manage to do so during the course of our lives.

This is clearly a point at which a biologist should stop trying to pontificate, even if he is allowed to speak to the highly esteemed audience of a Pontifical Academy. But this may be exactly the point at which *ratio et fides* may be able to meet and join company. Therefore, I will close my reflections on the future of nature by suggesting that it might not be the worst kind of companionship, if religion left it to the sciences to do the work of understanding the world including ourselves and maybe even the "ghost in the machine," and if the sciences left it to religions – or, for non-believers: to philosophy – to try their best in providing that vision and guidance with which the sciences, by themselves, cannot supply us.

Finito di stampare
nel mese di novembre 2000
dalla
Scuola Tipografica S. Pio X
Via degli Etruschi, 7
00185 Roma