The Emergence of Complexity

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Bibliografische Information Der Deutschen Bibliothek
Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen
Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über
http://dnb.ddb.de abrufbar

ISBN 3-89958-069-9

www.upress.uni-kassel.de

Umschlaggestaltung: Bettina Brand Grafikdesign, München
Druck und Verarbeitung: Unidruckerei der Universität Kassel
Printed in Germany

Preface

The main topic of this book is the emergence of complexity - how complexity suddenly appears and emerges in complex systems: from ancient cultures to modern states, from the earliest primitive eukaryotic organisms to conscious human beings, and from natural ecosystems to cultural organizations.

Because life is the major source of complexity on Earth, and the development of life is described by the theory of evolution, every convincing theory about the origin of complexity must be compatible to Darwin's theory of evolution. Evolution by natural selection is without a doubt one of the most fundamental and important scientific principles. It can only be extended. Not yet well explained are for example sudden revolutions, sometimes the process of evolution is interspersed with short revolutions. This book tries to examine the origin of these sudden (r)evolutions.

Evolution is not constrained to biology. It is the basic principle behind the emergence of nearly all complex systems, including science itself. Whereas the elementary actors and fundamental agents are different in each system, the emerging properties and phenomena are often similar. Thus in an interdisciplinary text like this it is inevitable and indispensable to cover a wide range of subjects, from psychology to sociology, physics to geology, and molecular biology to paleontology. Evolution knows no disciplinary boundaries.

Many complex systems have despite their names quite simple microscopic components. The complexity arises from local interactions. One of the core questions is how to use simple local rules to generate higher levels of organization from elementary actors. But this is only the beginning. We must also answer the question whether these higher levels are stable or unstable, temporary or permanent. And we should examine, if the simulations which enable our understanding of complex systems are at the same time an obstacle to understanding, because the complexity of closed systems is inherently limited. Typical simulated artificial systems - for example Cellular Automata - are closed and usually isolated from the environment. The complexity of these systems is often temporary and limited. Typical real complex systems are open and embedded in or connected with other systems. The unlimited complexity which arises in natural complex systems is not temporary.

To describe and capture the essential principles of complex systems, a unified language and notation is necessary. In this text emphasis is placed on an agent based view of complex systems. Many books on complexity and emergence are vague and unclear, because they do not give a clear and precise definition or description of the main concepts in terms of agents. In my opinion, the only way to achieve a unified theory of complex adaptive systems is to use the counterpart from computer science: Multi-Agent Systems.

The core ideas are illustrated with simple figures and graphics. Pictures can not *replace* mathematical proofs or computational simulations. But they enable an easy understanding of the text. Although Julio M. Ottino has emphasized in his Nature commentary "Is a picture worth 1,000 words ?" (Vol. 421, (2003) 474-476) that exciting new illustration technologies should be used with care, he admits that visual imagination is a central element of scientific imagination and that images are often part of the thought process. Seeing is in fact inextricably linked to understanding and discovering, and like Lynkeus the sentry in Goethe's "Faust II", scientists are born to discover new things: "Zum Sehen geboren, Zum Schauen bestellt, Dem Turme geschworen, Gefällt mir die Welt."

Since I am a physicist and a programmer, I use the familiar languages of physics and computer science, and I do not try to explain the fundamental terms here. A familiarity with the basic notations and terms of both subjects will be helpful in understanding the analogies and conclusions of the text, for example in physics the basic principles of Quantum Mechanics (Tunneling Processes, Heisenberg's Uncertainty relation, . . .), the fundamental conservation laws, the terms mass and energy, the difference between conductors and semiconductors, etc. and especially in computer science the terms agent, object and class, the basic principles of Object-Oriented Programming (OOP) and the elementary operations of the Unified Modeling Language (UML).

Formatting of the text was sometimes tougher than writing it, for example the "emergence" of figures on new pages which often teared larges holes in the carefully formatted text. LaTeX is great as long as you do not try to make anything special. But if you try to change something predefined as margins, positions of particular figures and font sizes, it can be frustrating.

Acknowledgements

This text would not have been possible without the inspiration and support from many people and institutions. First of all I would like to thank the university libraries and their staff members in Göttingen and Kassel, the marvelous SUB (Staats- und Universitäts Bibliothek) in Göttingen and the great UB/LMB (Universitäts Bibliothek / Landesbibliothek und Murhardsche Bibliothek) in Kassel. I have been lucky to have unlimited access to two of the best university libraries in Germany.

The great scientists who have worked on the problems of complexity which I admire are Herbert A. Simon, Philip W. Anderson, Murray Gell-Mann, W. Brian Arthur, Stuart A. Kauffman, Stephen Wolfram, John H. Holland, Peter Schuster, John Maynard Smith, Harold Morowitz, Steven Strogatz and Chris Langton, mainly researchers of or affiliated to the Santa Fe Institute (SFI). I learned a lot from their revolutionary and pathbreaking publications in this exciting, interdisciplinary field. In the following text I have tried to gather as many interesting pieces as possible from these great researchers in the sciences of complexity to assemble them to a coherent picture to find the answer of one question, how complexity emerges in complex adaptive systems.

My colleagues Dr. Bernhard Schlichtherle and Björn Albowitz have read large portions of an early manuscript version and offered many suggestions for improvement. Håkan Kjellerstrand, a swedish software developer, read the manuscript carefully and provided many useful comments. Interesting discussions with Dipl.-Inf. Alexander Weimer from the University of Paderborn improved the work and were of considerable importance.

I am also very grateful to the professional staff of Kassel University Press for the excellent support and cooperation, and I am especially thankful to Beate Bergner for her encouragement and patience, and to Susanne Schneider for technical support.

Finally, of course I would like to thank my parents and Manuela Frye for their support during the writing of this text.

Calden,
April 2004 — Jochen Fromm

Contents

Chapter 1

Introduction

1.1 Open Questions

At the beginning, the whole universe was not larger than a small dot, the dot of this 'i' or the dot at the end of this sentence. How did this dot-world become as complex as we know it today ? Why did the big bang not form a simple gas of particles, or condense into one big crystal ? How can the universe start with a big explosion and end up with life, history, and culture ?

What is the Origin of Complexity ?

The universe is much more than just a turbulent mess of particles tumbling around each other. As Paul Davies notices in the introduction of 'From Complexity to Life' [63], the physical universe is obviously awesomely complex. He describes that complexity is found on all scales:

The world is awesomely complex

> "On an everyday scale of size we see clouds and rocks, snowflakes and whirlpools, trees and people and marvel at the intricacies of their structure and behavior. Shrinking the scale of size we encounter the living cell, with its elaborate customized molecules, many containing thousands of atoms arranged with precise specificity. Extending our compass to the cosmos, we find complexity on all scales, from the delicate filigree patterns on the surface of Jupiter to the organized majesty of spiral galaxies."

Although a galaxy is very impressive, it is more the size than the complexity which arises amazement. A galaxy has a diameter of many thousand light years, whereas a typical hurricane is a few hundred miles wide. Yet their complicated spiral structure looks very similar, and even the “eye” in a hurricane corresponds to the black hole in the core of a galaxy. This has been emphasized by Eric J. Chaisson in his book “Cosmic Evolution” [22]: “Interestingly enough, the pancake shape, the spiral-arm structure, the distribution of energy, the differential rotation pattern, and many other morphological characteristics of hurricanes bear an uncanny resemblance to those of spiral galaxies [..] even the “eye” in a hurricane conjures up the purported “hole” (black or otherwise) in the cores of most galaxies.” But a hurricane is only one complex phenomena among millions of complicated structures and processes found on Earth. Richard Dawkins remarked in “The Extended Phenotype” [29], that each body is like a galaxy of cell nuclei:

> “...if we actually could wear spectacles that made bodies transparent and displayed only DNA, the distribution of DNA that we could see in the world would be overwhelmingly non-random. If cell nuclei glowed like stars and all else was invisible, multicellular bodies would show up as close-packed galaxies with cavernous space between them. A million billion glowing pinpricks move in unison with each other and out of step with all the members of other such galaxies.”

Jupiter’s turbulent atmosphere with vast cloud layers and band structures is very complex, but the turbulent patterns are not substantially more complex than the chaotic mixing patterns in an ordinary cup of coffee. The dry, dusty and dull surface of Mars with layered rocks, dry river valleys and sand dunes is not more complex than the Namibian desert of South Africa.

Life is the source of Complexity

All galaxies and stars are only the background or theater for the really complex processes of life on inhabitable planets like our Earth. The lifeforms on Earth form together an extremely complex world. According to the Encyclopædia Britannica, “more than $2,000,000$ existing species of plants and animals have been named and described, many more remain to be discovered.” From microscopic bacteria to 100 metres tall mammoth trees, the living beings cover all niches of the ecosystem, from the hot springs of Yellowstone National Park to the ice masses of the arctic regions and from the deep-sea regions of the oceans to the highest mountains. Human beings consist of $10^{14} = 100,000,000,000,000$ cells, and each living cell is “a marvel of detailed and complex architecture” (Encyclopædia Britannica). In fact life is the major source of complexity on Earth. Without life, our planet would look as dead as the moon or as friendly as the Mars.

Many complex natural forms and structures as landscapes, rivers basins and mountains can be found on "dead" planets, too. They can be described by fractals, which have been examined in detail by Mandelbrot, Falconer and many others [98, 47]. Fractal structures are created by physical and geological evolution, and fractals appear in living systems as well. They are a standard "tool" of evolution to produce complex structures.

Fractal Structures

The development of living beings and life-forms is described by Darwin's theory of evolution. Evolution can produce complex forms, for example fractal structures. But the theory of evolution alone does not predict things are getting more and more complex. Yet the world is full of complex adaptive systems, which consist of a large number of mutually interacting and interwoven parts. Examples are neural and social networks, nervous and immune systems, economies and ecologies. Modern biological life-forms are so complex that it is hard to imagine how they could have assembled spontaneously from the chemicals available on the primitive Earth.

Life is subject to Evolution

Maybe this is one reason why many American citizens are still not convinced of Darwin's theory of evolution. Although the USA is the country with the highest technology level, the most famous universities and the best scientists, about two-thirds of the US public believe that alternatives to Darwin's theory of evolution should be taught in public schools. Constance Holden reports that "15% to 20% of high school biology teachers teach creationism" [71]. Critics argue that purely random processes could never have produced humans. Charles Robert Darwin himself discussed the difficulties of evolution in "The Origin of Species" [28][1]. He was aware of the large gaps in the fossil records and the absence of transitional forms. The other source of difficulties are according to Darwin organs and organisms of extreme perfection and complication.

Difficulties of Evolution

Organs, organisms and species of extreme complication apparently exist, but they did not appear over night. They are the result of million years of evolution. Yet we know since Darwin there have been huge extinctions and large abrupt jumps in the history of evolution. One of the puzzles that remain to be solved in science is to reveal the processes behind the large gaps and abrupt jumps in the fossil record. Are they responsible for extreme complicated organs and organisms ? Is evolution punctuational and abrupt or

[1] The complete content of his famous book "The Origin of Species" is freely available in the internet, for example at http://www.bartleby.com/11/ or http://www.bbc.co.uk/education/darwin/origin/index.htm

gradual and continuous ? As we will see in this book, it can be both, and the large gaps correspond to a sudden revolutionary emergence of complexity. Normally evolution is steady, gradual and continuous. From time to time evolution gets stuck when a large fitness barrier is reached, and evolution stagnates. It waits until massive catastrophes break these barriers or single agents are able to cross them through a tunneling process. Revolutions in evolution are possible because there are natural obstacles for evolution which cause stagnation, deadlock and jam. Fitness barriers set the boundaries of normal evolution.

Evolution gets stuck

If this is correct, then the emergence of extreme perfection and complexity in evolution can be reduced to a series of smaller emergence events: the emergence of something very large or complex can be reduced to the emergence of many smaller, unspectacular items. If evolution is interrupted by a series of short and fast (r)evolutions associated with the emergence of new features and properties, then emergence becomes itself a self-similar concept. The emergence and appearance of the modern man was not possible without many other smaller and less spectacular appearances of mammals with hairs and fur, vertebrates with backbones and chordates with nerve cords millions of years ago. One large step is composed of many smaller steps, which are in turn accumulations of even smaller steps.

Evolution, Revolution, Emergence

For biological evolution, many of these steps and transitions have been already described precisely 1995 in the pathbreaking book of John Maynard Smith and Eörs Szathmáry [144]. They list the major transitions during biological evolution (see chapter six), and they argue that the major transitions in the way in which genetic information is transmitted between generations are the main reason why complexity has increased in the course of evolution.

The Major Transitions

But evolution knows no disciplinary boundaries, and it is not constrained to biology. It is the basic principle behind the emergence of nearly all complex systems. In order to understand the evolution of complexity completely, an interdisciplinary examination of evolutionary Multi-Agent Systems is necessary and essential. If the thesis of John Maynard Smith and Eörs Szathmáry is correct, it should be applicable to other systems, too. In this small book we want to examine especially memetic and cultural evolution.

The emergence of complexity can be observed in computer experiments, agent-based simulations and of course in the history of complex systems, subject to the social sciences psychology, sociology, history, archaeology and anthropology, and to the Earth sciences palaeontology and geology. The opposite of research focused on grown complexity and complex systems is reductionism, which means to take a system apart and to look at the most elementary particles or agents and their interactions. It is represented by traditional high energy particle physics, in which researchers shatter matter into the smallest pieces, look for the most fundamental particles and try to describe their interactions in precise mathematical terms.

Reductionism compared to Emergentism

The traditional philosophy of reductionism is "let us first find the most fundamental parts and laws". The complementary philosophy of emergentism is "let us first find out how complexity arises in complex systems, how macroscopic phenomena arise from microscopic interactions." Both directions are important, reductionism and emergentism. The discovery of atoms, elements and other fundamental particles and the corresponding theories made natural science possible in the first place. But if we don't know what kind of macroscopic phenomena can arise from these microscopic elements, particles and laws, then this knowledge is disjointed and noncoherent.

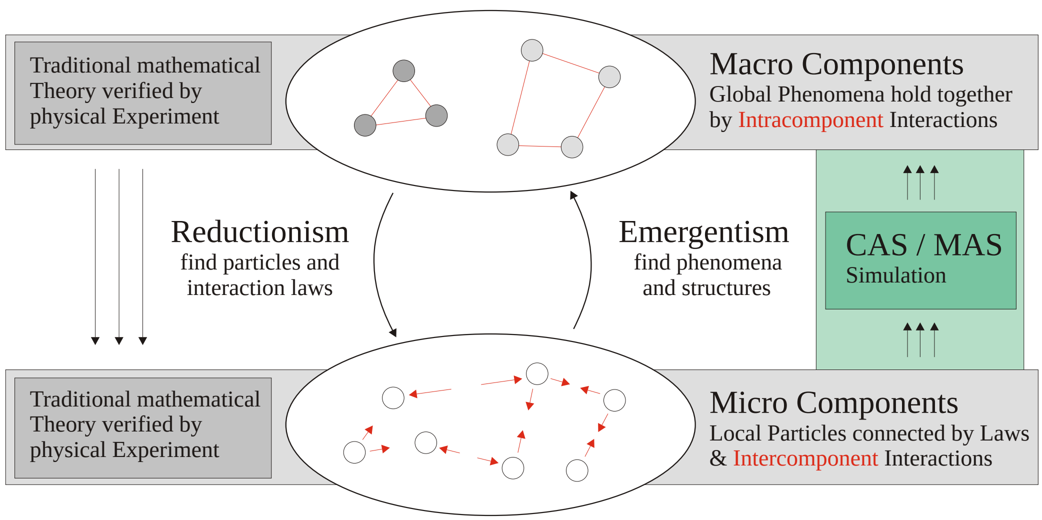

Fig. 1 Reductionism and Emergence

Emergentism

Emergentism is the observation of global emergent phenomena, principles and structures in simulations or experiments. Usually these are feedback-phenomena which arise from local agent interactions, and which influence them in turn. A crowd emerges from a theater or lava emerges from a volcano, but they both don't shape or influence the interactions inside the theater or the volcano. The name emergence in complex systems is used if there is a feedback from the phenomena to the agent again.

As Immanuel Kant (1724-1804) says in his Critique of Pure Reason, concepts without percepts are empty, and percepts without concepts are blind. So on the one hand concepts without percepts, categories without impressions or theories without experiments are empty, abstract and unprovable (for example String Theory in physics), and on the other hand percepts without concepts, impressions without categories or experiments without theories are blind, indiscriminate and misleading (for example alchemy or chemistry before the dicovery of elements). Theory, model, categories & thought on the one hand, and practice, experiment, impressions & observations on the other hand form a unit.

Theory and Experiment are a Unit

Reductionism and emergentism form a unit, too. Traditional mathematical theories verified by physical experiments are usually related to reductionism (the top-down view to lower levels). They describe the particles, laws and interactions based on particular symmetries and invariance principles on a given level or scale. New computational theories and agent-based simulations are more related to emergentism (the bottom-up view to higher levels). Agent based simulations and theories describe phenomena between certain predefined traditional levels, they are the connection and missing link between the phenomena and processes on different scales. Reductionism provides the scaffold and defines the main stages and levels, emergentism is the framework which describes the life on these different layers and provides the stairways and the elevators. Reductionism and emergentism are complementary and supplementary to one another, emergentism needs a grounding and a base, reductionism needs connection and coherence: emergentism without reductionism is vague and unclear, reductionism without emergentism is unconnected and noncoherent.

Reductionism and new Emergentism are a Unit

Many former particle physicists like Murray Gell-Mann and George A. Cowan, the co-founders of the Santa Fe Institute, and Stephen Wolfram, the creator of Mathematica, have recognized early that particle physics is not the path to the ultimate truth and insight. Knowledge of the most fundamental elementary particles and their physical laws is not sufficient to understand all things [77]. New global macroscopic phenomena, laws and principles can emerge from many mutual local interactions on a microscopic scale.

Even in theoretical physics - in which scientists look for the smallest and most fundamental particles, strings and laws - scientists agree that finding the most fundamental particles and their rules is not enough, as Philip Anderson said [2, 151] : "The ability to reduce everything to simple fundamental laws does not imply the ability to start from these laws and reconstruct the universe. In fact, the more the elementary particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science, much less society".

Reductionism in traditional Neuroscience

Neuroscience for example is very good in telling you how individual, single neurons and synapses work. And although there have been decades of research, no neuroscientist can describe or explain the whole picture, the overall pattern of activity. The essential link from the bottom level of neuroscience to the top level of psychology has s.th. to do with neural assemblies, this is known since Donald Olding Hebb (1904-1985) coined the notion "cell assembly" in 1949 [66]. Yet the problem of understanding the total action of the nervous system and the behavior in terms of neural assemblies is not solved.

Emergentism in current Neuroscience

The leading neuroscientist Terrence Sejnowski is confident that over the next decade there will be some answers. A news release issued by the Salk Institute[2] to announce a publication in the Sept. 26 issue of Science (2003) with University of Cambridge professor Simon Laughlin [90] says

> "This is an important era in our understanding of the brain, we are moving toward uncovering some of the fundamental principles related to how neurons in the brain communicate. There is a tremendous amount of information distributed throughout the far-flung regions of the brain [...] In the past, we were only able to look at brain function by looking at single neurons or local networks of neurons. We were only able to see the trees, so to speak. With breakthroughs in recording techniques including brain imaging, which gives us a global picture of brain activity, and advances in computational neurobiology, we can now take a more global perspective. We're looking at the entire forest, and we're asking the question: How has the forest evolved?"

In other scientific fields and areas, researchers are asking similar questions. The important common questions about complex adaptive systems (CAS) are the questions about the emergence of complexity, the role of self-organization, the origin of cooperation and specialization and the relation between different CAS (inclusions, embeddings and hierarchical structures). The five fundamental questions we want to examine and answer in this book are the questions of

[2] see http://www.sciencedaily.com/releases/2003/10/031002053904.htm

The five fundamental Questions

- **Emergence**
  How can global structures and phenomena suddenly emerge from simple local interactions ?
- **Self-organization**
  How can systems without organizer organize themselves to higher and higher levels of complexity ?
- **Cooperation**
  Why do selfish agents cooperate with each other to form large groups, teams and clusters of agents (composite or aggregate entities) ?
- **Specialization**
  How can agents produce an aggregate entity that is more flexible and adaptive than its components ?
- **Inclusion and Embedding**
  How are different CAS related to each other ?

The first question is concerned with the emergence of complexity in the internal and external world, how global features, structures and phenomena suddenly emerge from simple local interactions in the mind, in the society and other complex systems. Even theoretical physicsts now think this question is important. As Laughlin and Pines say [89], "The central task of theoretical physics in our time is no longer to write down the ultimate equations but rather to catalog and understand emergent behavior in its many guises, including potentially life itself. We call this physics of the next century the study of complex adaptive matter." Can we find the key to the emergence of complexity ?

The second question is related to organization without organizer. How can systems organize themselves to higher and higher levels of complexity in a process of self-organization ? Although there is no central organizer, self-organizing systems are able to reach higher levels of complexity.

Many emergent composite phenomena involve the aggregation and accumulation of different agents. Agents are by definition autonomous and selfish, and they act on their own behalf [80]. So the next interesting question is why and how different selfish agents cooperate with each other to form groups and teams.

Another interesting question related to specialization of agents is, as John H. Holland says in his Book 'Emergence' [73], "How can the interactions of agents produce an aggregate entity that is more flexible and adaptive than its component agents ?”

And finally Murray Gell-Mann argues in his article about complex adaptive systems (CAS) that especially the connections between different CAS are interesting [56]: “some of the most interesting questions about CAS have to do with their relations to one another. We know that such systems have a tendency to spawn others. [...] One of the most important branches of the emerging science of CAS concerns the inclusion of one such system in another.” Can a new CAS emerge or appear in an old CAS ? How is such a new CAS embedded and included in an already existing and established system ? We will take a closer look at all these interesting questions in the following text.

In this **first chapter** we look at the definitions of Complex Adaptive Systems (CAS), emergence and self-organization, consider temporary forms of emergence and examine the emergence of complexity within a species or lineage (anagenesis) by repeated recombination or continuous merging and splitting of elementary units. We will look at the right tools for examining complex systems: Multi-Agent Systems (MAS) and Cellular Automata (CA). Although physicists neither study complex systems nor have the right tools to study them, physical notions like energy and entropy can be useful to understand complexity. Chapter Overview

In **chapter 2** we deal with small jumps in complexity, caused by ordinary lineage splitting (cladogenesis), bifurcations of phylogenies and the emergence of new species or agent classes. We show that they are equivalent to a transfer of complexity from an internal to an external dimension, or to the transition from ‘to have’ to ‘to be’. Transitions across the natural agent boundary for more complex agents arise through the basic forms of object interactions: aggregation (composition) and inheritance (specialization) which are again merging and splitting operations between agents. They can be used to cross the agent boundary. Chapter 2

In **chapter 3** we look at some major examples of inheritance and memetic phylogenies (trees of evolution) for different complex adaptive systems subject to memetic or cultural evolution. These cultural evolution trees look of course very similar to the more familiar trees in natural biological evolution. A huge biological phylogenetic tree can be found in the ‘Tree of Life’ special issue of Science[3], June 2003 [44]. Chapter 3

[3]Have a look at the Tree of Life at http://www.sciencemag.org/feature/data/tol/

The next chapter concentrates on aggregation, the complementary operation to inheritance. **Chapter 4** examines the origins of cooperation in selfish agents. The question of aggregation and cooperation is always important, especially if we know the complementary inheritance trees already, as for example in evolutionary biology. Cooperation, aggregation and group formation are essential factors for the emergence of more and more complex agents and life-forms, and a basic condition for the embedding of new complex adaptive systems.

Chapter 4

Chapter 5 deals with large jumps in complexity through the emergence of species of a new class with substantial changes or CAS of a completely new type, including the question how different CAS are related to each other and how a new CAS can be embedded in an old one. The two main reasons for a large, abrupt jump in complexity are tunneling processes due to internal pressure (high competition, population pressure,...) and catastrophes due to external influence (asteroid impact, climatic change,...). They can cause large transitions across the common boundary of genetic CAS and memetic CAS, the shared phenotype. We analyse in detail the role of the extended phenotype, the Baldwin-Effect and the extinction-emergence relation between the extinction of old systems and species on the one hand, and the emergence of totally new systems or species on the other hand.

Chapter 5

Finally in **chapter 6** we consider the different levels of evolution and their boundaries. The frontiers of knowledge are expanded through mental and scientific revolutions, which are examined in the first sections. The highlight of the chapter are of course the lists of the major integrative steps of evolution, the thresholds of evolution which mark the revolutions and the emergence of new CAS. We consider possible future steps and examine the very first step, which corresponds to the most fundamental physical theory.

Chapter 6

1.2 Complex Adaptive Systems

Complex systems consist of a large number of mutually interacting and interwoven parts. Examples are neural and social networks, nervous and immune systems, ancient and modern cultures, languages and writing systems, economies and ecosystems, ... The general approach to study a Complex Adaptive System (CAS) [136] is a computer simulation, in which repeated iteration of simple local rules in a population of interacting agents leads to complex global phenomena. In the following we use a definition of a CAS based on John H. Holland (see Appendix A for details) and the notion of an agent :

Definition of CAS

A CAS is a complex, self-similar collectivity of interacting adaptive agents.

This definition of a Complex Adaptive System (CAS) is closely related to the definition of a Multi-Agent System (MAS), and it defines a CAS simply as a form of complex MAS with adaptive agents. A Multi-Agent System is defined as [154] *a system composed of multiple, interacting agents.* CAS and MAS do not only sound similar, they describe the same systems. Whereas the name CAS is associated with the high-level phenomena and structures of a complex system, the name MAS is associated with the low-level components and elements of it. A complex adaptive system is just a system which can be simulated, described and explained by a dynamic Multi-Agent System. Simulations of Multi-Agent Systems can be described in turn as complex adaptive systems. In CAS, MAS and agent based models is the basic question according to Robert Axelrod [6] the same: "how to use simple local rules to generate higher levels of organization from elementary actors".

Definition of MAS

Social scientists have recognized that MAS are a natural tool for studying complex social systems and societies [36]. Agent based models are the state of the art in social sciences. They have become a major topic within the field of sociology [96], politics [6] and economics. Since Minsky's famous book 'The Society of Mind' [100], we know that we can apply them also to understand the mind and the behavior of neural networks.

Scientists who study general complex systems should recognize that MAS are essential, too - not only for simulations and experiments, but also for definitions and theory. Multi-Agent Systems (MAS) are the only way to achieve a unified theory of Complex Adaptive Systems (CAS). The study of complex systems needs to find such a unified theory, as the first international

Theory of CAS must be based on MAS

conference on complex systems of the NECSI (http://www.necsi.net/) has shown: the name of the proceedings which reflects the subject areas was "Unifying Themes in Complex Systems" [13]. Without a unified theory, the study of complex systems crumbles into the different subject areas : psychology, sociology, molecular biology, computer science, ...

A unified Theory of CAS

It is hard to find a unifying theory of complex systems without a common language, which must be based on the basic building blocks: agents. As soon as you loose the connection to agents and Multi-Agent Systems, you get more journalism than science and the text becomes vague and unclear. For instance, Yaneer Bar-Yam's interesting textbook "Dynamics of Complex Systems" [12] is not bad, but he does not use the notion or concept of an agent. The name agent is not even mentioned in the book.

You can not talk about chemistry without knowing or mentioning atoms and elements, or you are getting the alchemy of the middle ages. And you can not talk about physics without knowing or mentioning atoms and fundamental particles, or you are falling back into the metaphysics of the middle ages. Likewise you can not talk about CAS without knowing or mentioning agents and their interactions.

Perplexity instead of Complexity

This has been noted and criticized by John Horgan in his June 1995 Scientific American editorial entitled "From complexity to perplexity". In his glib dismissal of all work on complex systems, he doubts that science can ever achieve a unified theory of complex systems, and he points out the lack of a "unified theory" of complexity.

CAS are self-similar Systems

Yet not only different CAS are similar, a CAS itself is self-similar according to our definition. The agents of the CAS can be considered as small CAS, the CAS in turn as a whole can be represented by an agent. Paul Nurse has observed a remarkble self-similarity between organisms and single cells [110]: "Many of the properties that characterize living organisms are also exhibited by individual cells. These include communication, homeostasis, spatial and temporal organization, reproduction, and adaptation to external stimuli. Biological explanations of these complex phenomena are often based on the logical and informational processes that underpin the mechanisms involved." And he concludes that "new approaches are needed to determine the logical and informational processes that underpin cellular behaviour."

Cells communicate with each other as large organisms do. They adapt themselves to the environment and keep the internal conditions constant in a changing environment : Homeostasis is reached by negative feedback control, in organisms and cells. Although the individual cell and the cell-group are quite different, certain properties and features seem to be invariable or invariant. Cells specialize themselves in different ways like larger organisms, and they reproduce themselves like their larger counterparts. These invariant properties are the basic properties of CAS:

Essential properties of CAS

- C - Communication and Complexity by Specialization & Cooperation
- A - Adaptation (Homeostasis), Feedback, Growth, Reproduction
- S - System with spatial and temporal Organization

CAS can be found everywhere. In fact the entire real world is complex. Tamás Vicsek argues in [150]: "Because almost every real system is inherently complicated, to say that a system is complex is almost an empty statement - couldn't an Institute for Complex Systems just as well be called an Institute for Almost Everything ?" He points to a fundamental flaw or problem of CAS. The theory of CAS has the power to be the theory of everything or nothing. It explains nothing if the scientists can not find a "unified theory". It explains everything because the entire real world is complex.

Institutes for almost Everything

There are three major CAS research institutes for almost everything which try to solve this problem: the famous SFI (http://www.santafe.edu/), the NECSI (http://www.necsi.net/) and the much smaller ISCS (http://www.complexsystems.org/). The Santa Fe Institute (SFI) has done pioneering work in this field. The history of the SFI is described by Waldrop in his book 'Complexity' [151]. In his book you can also find also a beautiful definition of complex adaptive systems, which is quoted in the appendix.

CAS Research Institutes

All of them, the SFI, the NECSI and the ISCS are not very old, although complex systems are known for a long time and complexity is not quite a new phenomena. Scientists in Biology, Medicine, Economics, History, Psychology and Sociology have always studied complex systems. Warren Weaver, one of the first who discussed the meaning of complexity, noticed 1948 [153],

History of research related to complexity

> "The significant problems of living [or complex] organisms are seldom those in which one can rigidly maintain constant all but two variables. Living things are more likely to present situations in which a half-dozen, or even several dozen quantities are all varying simultaneously, and in subtly interconnected ways."

And he goes further and predicts

> "It is tempting to forecast that the great advances that science can and must achieve in the next fifty years will be largely contributed to by voluntary mixed teams [..], their activities made effective by the use of large, flexible, and highspeed computing machines."

Computer simulations are essential

Weaver was right. Genetics and Molecular Biology would not be possible without computers. And since the development of faster and better computers, increasingly complex computer languages and sophisticated operating systems, complex systems became accessible through agent based simulations in a new way [50]. This is the reason why the research institutes for complexity and complex systems are very young. With powerful computers, small interdisciplinary research institutes were suddenly able to attack the mysteries of huge complex systems.

1.3 Physics and Complex Systems

Although especially physicists like Murray Gell-Mann, George A. Cowan and Stephen Wolfram developed the theory of Complex Adaptive Systems (CAS) and Cellular Automata (CA), physics is not an optimal theory to describe these systems. Physicists like to emphasize the importance of emergence and complex systems, exactly because they are the opposite of fundamental particle physics and reductionism.

Physicists lack Tools and Topics

If there would be a school laboratory with the task of studying CAS, or if CAS would be object of study in such a school laboratory, then physicists would be like pupils or students who have neither the right tools or microscopes, nor a free place where they can sit down, because every interesting place is already occupied (by biologists, archaeologists, anthropologists, linguists, psychologists, sociologists and others). The right tools for the study of CAS are Multi-Agent Systems [160, 154, 141, 104] and Cellular Automata [159, 75] used in and known from Computer Science. But physicists use traditionally Mathematics as the main tool, for example Differential Equations and Differential Geometry.

Books of physicists about complexity

The difficulties become visible in Schuster's book about CAS [136] and Badii and Politi's book about complexity [7]. The former contains a primer on deterministic chaos, and a large chapter about neural networks, but not a single word about a connection between these areas. In fact there is no magic theory of chaos in neural networks or fluid dynamics. Even if there is no easy connection, this is definitely worth mentioning. Neural networks and fluid systems produce extremely complicated behavior, which has largely resisted general analytical approaches. Schuster recommends evolutionary games as a solution, which do not belong to traditional physics. But although theory is a kind of game, a primitive evolutionary game alone is not a theory. Simple Rock-Paper-Scissor games in the sense of game theory are not the magic key to the understanding of complex systems. The "Two Hats" game in the final chapter certainly does not explain consciousness.

In the summary of the latter in chapter 10, Badii and Politi write that answering of the question "What is complexity ?" is quite hard - although the book is named complexity. In fact the whole book seems to look constantly for an answer to the fundamental question what complexity might mean, and tries to find the right tools to examine complex systems: it covers the theories of formal languages and automata, probability and information theory, thermodynamics and statistical mechanics. But it can find neither the right tool nor a convincing answer to the question what complexity is.

Physicists concentrate on Graphs & Networks

So physicists with their inherited inclination for mathematical modelling and equations often concentrate their work on power laws and network structures [16]. See Newman's review article "The structure and function of complex networks" [105] for a good introduction. Complex networks are the backbones of complex systems. Any complex system, which consists of many mutually interacting components, has an "underlying" network. This canonical or natural network describes the components (=nodes) and their interactions (=edges). Complex systems which have been created through evolution often can be described by scale-free, self-similar or small-world networks and graphs.

Networks & Complex Systems

Maslow, Sneppen and Alon write in [16] : "The very first question one may ask about such a [complex] system is which other components a given component interacts with ? This information systemwide can be visualized as a graph, whose nodes correspond to individual components of the complex system in question and edges to their mutual interactions. Such a network can be thought of as a backbone of the complex system. Of course, system's dynamics depends not only on the topology of an underlying network but also on the exact form of interaction of components with each other, which can be very different in various complex systems. However, the underlying network may contain clues about [...] the evolutionary history of the complex system in question."

Complex networks are interesting, but are not the main focus in this text. We will not pursue this topic further. Instead we take a closer look at the evolution of a complex system. And first of all we consider the right tools to study such a system.

1.4 Multi-Agent based Simulations

MAS and CA

The right kind of tools to model and simulate complex systems are Multi-Agent Systems (MAS) and Cellular Automata (CA). Cellular Automata [159, 75] are a special kind of Multi-Agent System [160, 154] with very primitive agents similar to finite state machines (FSM), arranged on a rigid grid, and interacting with one another by very simple rules. MAS and CA are used today to explain complicated and complex adaptive systems, for example in

- economics
- biology (evolution and coevolution)
- history and conflict analysis
- politics and political science
- sociology and social science

Game Theory

All of these subjects are fields where Game Theory has been applied in the past more or less successfully. Today agent based simulations are supplementing and replacing Game Theory as a tool for understanding how groups of people and intelligent individuals interact with each other. A game in the sense of Game Theory is a simulation where agents, called players, seek to maximize their payoff by choosing between a limited number of strategies, for example the Prisoners' dilemma or the 'Hawk vs. Dove' Game.

The 'increase payoff' behavior is a simple mathematical formulation of the general behavior of an autonomous agent, which acts according to its definition in Kauffmann's words 'on its own behalf' [80]. The payoff in more complicated agent models is measured through emotions, in evolutionary models in terms of offspring.

C-Theories

After Game Theory came Cybernetics, Catastrophe and Chaos Theory. Steven Strogatz says in his Book 'Sync' [148] in the epilogue "Every decade or so, a grandiose theory comes along, bearing similar aspirations and often brandishing an ominous-sounding C-name. In the 1960 it was cybernetics. In the '70s it was catastrophe theory. Then came chaos theory in the '80s and complexity theory in the '90s." and goes on to explain that the science of complex systems misses a well defined calculus

> "Chaos theory revealed that simple nonlinear systems could behave in extremely complicated ways, and showed us how to understand them with pictures instead of questions. Complexity theory taught us that many simple units interacting according to simple rules could generate unexpected order. But where complexity theory has largely failed is in explaining where the order comes from, in a deep mathematical sense, and in tying the theory to real phenomena in a convincing way [...] I think we may be missing the conceptual equivalent of calculus, a way of seeing the consequences of the myriad interactions that define a complex system."

New digital Language of Nature

I think we have such a calculus already, it only looks very different. It is named computer science, and its core technique is not the differential and integral calculus, but simply Object Oriented Programming (OOP) which is described in the graphical notation of Unified Modeling Language (UML, see http://www.omg.org/uml/). The analog mathematical language of continuous functions and operators to describe nature has turned into the digital language of discrete elements and operations to describe complex systems.

Galilei said mathematics is the language of nature, that the book of nature is written in mathematics. Modern philosophers and scientists as Stephen Wolfram and Edward Fredkin say that the language of nature is digital, and that nature is a huge digital book in form of a Cellular Automata. But it is always dangerous to say that nature is written in a certain, fixed language. Nature and science are both subject to evolution.

Organized & Disorganized Complexity

The transition from the language of mathematics to the language of computer science corresponds to the transition from disorganized to organized complexity. According to Warren Weaver [153], disorganized complexity can be found in a system with many loosy coupled, disorganized and equal elements, which possesses certain average properties as temperature or pressure. Such a system can be described by 19th century techniques: mathematics, differential equations, statistical techniques or methods of thermodynamics and statistical mechanics.

Organized complexity can be found in a system with many strongly coupled, organized and different elements, which possesses certain emergent properties and phenomena as currency values, behavior patterns or phenotype forms of living beings. Such a system can not be described well by the 19th century techniques. 20th century techniques of computer science are more appropriate. Mathematical calculations are replaced by computational simulations.

	Pure Theory	Theory	Instrument, Technique	Practice	Pure Experiment
19th century techniques	Number Theory	Mathematics (analog & continuous)	Analysis (differential & integral calculus)	Natural Sciences (physics)	Observe physical systems & Nature
transition		Game Theory, Cybernetics, Catastrophe & Chaos Theory	techniques & tools of nonlinear dynamics	disorganized → organized complexity	
20th century techniques	Turing Machines, Automata	Computer Science (digital & discrete)	OOP & MAS	Social Sciences (sciences of complexity)	Observe complex systems & Culture

Tab. 1 Transition from Mathematics to Computer Science

The replacement of game theory by the much more powerful general agent based simulations corresponds to the replacement of mathematics by computer science as the optimal tool to examine complex adaptive systems. Among the first who studied complex adaptive systems with agent based simulations are the members and founders of the Santa Fe Institute since 1986, long before Multi-Agent Systems and Object-Oriented Programming (OOP) became popular.

What is Emergence ?

In the case of Cellular Automata the agents are well understood. But even if the elements of agent based models, the agents, are well understood - which is not always granted - it is not clear, how the interaction of agents produces complex patterns and groups of agents and how complexity can suddenly emerge in multi agent systems.

The most complex form of emergence is the relationship between genotype and phenotype in biological evolution and artificial life [88]: the phenotype consists of the structures and dynamics that emerge through development and interaction with the environment in the course of time. Here the system and the agent itself are very complex. This is possible, because the agent delegates the task of creating itself to the environment (more about this later in chapter four). Agent based simulations are usually less complicated. CA are a complex system with simple agents, MAS are simple systems with complex agents. Of course Multi-Agent Systems can have a complex structure, too, but if agents **and** their interactions are very complex, the system can become easily intracktable.

Emergence in CA and MAS

	System, Phenomena	Agents, Objects, Components	Basic local Rules	Emergent Phenomena
Cellular Automata (CA)	complex patterns & structures	simple agents, finite state machines (FSM) or automata	Transition Table	Propagating structures e.g. Gliders
Multi-Agent System (MAS)	simple structures (today)	complex agents, complexity depends on internal structure	Communication language, Agent intentions	Power, Culture, etc.
Living Systems, Biology	complex	complex	Genotype	Phenotype

Tab. 2 Complexity in CA and MAS

1.5 Emergence

The word *Emergence* has the Latin origin *emergere*, from *e(x)* + *mergere* to plunge. It contains the word 'merge', but has a contrary meaning: it is the opposite of immersion, fusion, combination and merging of two separate things. The Oxford Dictionary says that *to emerge* is to become apparent, come to light; (of something unexpected) to turn up, present itself, to appear as a result, to emanate.

Emergence Definition

Philip W. Anderson highlighted the idea of emergence already 1972 in his article "More is Different" [2], which states that a change of scale very often causes a qualitative change in the behavior of the system. For example, when one examines a single molecule of H_2O, there is nothing that suggests liquidity :

Examples of Emergence

* one water molecule is not fluid,
* one gold atom is not metallic,
* one neuron is not conscious,

* one amino acid is not alive,

* one sound is not eloquent.

But a collection of millions of water molecules at room temperature is clearly liquid, a collective interplay of millions of neurons produce consciousness, and a common interaction of millions of gold atoms cause metallic properties. Liquidity, superfluidity, crystallinity, ferromagnetism, metallic conduction are emergent properties [42]. As Anderson says "More is Different".

Can we understand Emergence ?

Can we understand the process by which emergent properties appear and by which entire new class of entities come into being ? Why does complexity increase over time ? What mechanisms are at work ? Jean-Marie Lehn said [93]: "As the wind of time blows into the sails of space, the unfolding of the universe nurtures the evolution of matter under the pressure of information. From divided to condensed and on to organized, living, and thinking matter, the path is toward an increase in complexity through self-organization. The species and properties defining a given level of complexity result from and may be explained on the basis of the species belonging to the level below and of their multibody interaction [..]. At each level of increasing complexity novel features emerge that do not exist at lower levels, which are deducible from but not reducible to those of lower levels".

This is a nice description, but a bit vague and unclear. The next sections try to shed more light on this interesting topic. We will argue, that there are different forms of emergence: temporary emergence due to fluctuations and clash of opposite forces, and other types of emergence leading to a permanent increase in complexity. We will further examine the connection to dissipation, extinction, cladogenesis and transfer mechanisms.

Only with the right language

To get away from unclear formulations and vague descriptions, the right computational tools, a unique language and a coherent notation are necessary. J.M. Ottino argues in his Nature article "Engineering complex systems" [115] "Advances [in the study of complex systems] will require the right kinds of tools coupled with the right kind of intuition." The right tools are Multi-Agent Systems (MAS), the natural tools to simulate and examine complex systems. This has been mentioned several times now, but it is important to emphasize it, because some researchers still work with old-fashioned models and notions (Nash equilibrium, zero-sum game, etc.) of mathematical Game-Theory.

Jean-Marie Lehn mentioned Self-Organization as the main reason for the emergence of complexity. Most complex systems can organize themselves even without a central organizer or central organizing authority, they show signs of Self-Organization. It is "as if all the ingredients in your kitchen somehow got together and baked themselves into a cake" as Bill Bryson has noticed [17]. But of course this won't happen. It only looks like this.

1.6 Self-Organization

J.M. Ottino argues that "the hallmarks of complex systems are adaptation, self-organization and emergence - no one designed the web or the metabolic processes within a cell." [115]. Technological, artificial and cultural systems become organized by human influence, but many natural systems become structured by their own internal processes [161]. They organize themselves. Self-Organization is the tendency of large dynamical systems to organize themselves into a (critical) state of higher organization. Patterns at the global level of a system emerge solely from numerous interactions among the lower-level components of a system [43].

Definition of Self-Organization

For agent-based systems with a hierarchy of intelligent autonomous agents the question of self-organization seems to be clear: the alpha agent at the top of the hierarchy determines the organization. The strongest ape in the group, the general in the army, the CEO in the company, the president in the country, the pope in the church, the professor in the university. But the term self-organization is used to describe patterns in rainfall [111, 119], rippled dunes [43], sand-piles and earthquakes [10] as well. In this case self-organization means to establish a distributed organization without a common organizer who influences the order: organization without organizer.

Rainfall, Dunes, Sand-Piles

In many self-organized building or formation processes there is a local activation process (autocatalysis), which is accompanied by a longe-range antagonistic (inhibitory) effect that results from the depletion of the building material. This is the mechanism for the formation of sand dune stripes, and a multitude of other porous and striped patterns [43].

Yet it is misleading to assume that Self-Organization is an isolated process completely without external influence. A self-organized system needs a constant and continuous input of energy from the outside. It is able to dissipate energy and organization from the environment to create and built-up an artificial or abstract organizer in form of emergent critical states, attractors or whirls.

Such an emergent property can be a simple pyramid structure in form of a sandpile with a critical slope in Per Bak's famous model of self-organized criticality [10]. The self-organized criticality arises from the clash of opposite forces: on the one hand accumulation and concentration due to static friction between the grains of sand, and on the other hand dispersion and expansion due to gravitational forces which exceed the threshold of friction.

SOC Self-Organized Criticality

"Self-Organized Criticality" (SOC) has been introduced by Per Bak, Chao Tang and Kurt Wiesenfeld in 1987 [8, 9]. It describes scale-invariant fluctuations at a critical point in natural systems without organizer. The probability for large avalanches or earthquakes is below this critical point very small, above this point very high. At the critical point itself (for example the slope of a sand-pile), there is no typical scale for the avalanches or fluctuations: they can have any size.

There are many similarities between Per Bak's famous sandpile model and the process of insight. As friction between tectonic plates is the cause of earthquakes and friction is the cause of avalanches in sanpile models, incongruities and fractures in meaning are the cause of insights and laughter. Insights and laughter are mental earth-quakes.

Laughter in humans, earthquakes in the crust of the earth, avalanches in granular piles, lightnings or rainfalls in the atmosphere [119], are examples for self-organized criticality. All these different systems show the common properties of avalanches and scale-free distributions of events :

System	Crust of Earth, Tectonic plates	Granular pile (Sand,Ice)	Atmosphere, Clouds	Mind, Thoughts
Energy source	Convection, Moving plates	Addition of Grains	Sun-Energy, Evaporation	Think about a contradiction
Energy storage	Tension	Gravitational Potential	Vapour, Voltage	Attention to contradiction
Site of fracture and tension	Fracture in the crust of the Earth	Unsteadiness of profile or surface	border of cloud, fracture in charge	Fracture in meaning, Incongruity
Threshold determined by	Friction	Friction	Saturation, Capacity and insulating layer	Habituation, Censors
Release of energy	Earthquake	Avalanche	Rain Event, Lightning	Laughter, Insight

Tab. 3 Self-Organized Criticality (SOC) in different systems

1.7 Merging and Splitting of Agents

Complexity emerges from the clash of opposite forces, and is characterized by consonance in dissonance, regularity in irregularity, cooperation in separation, integration in differentiation, order in chaos, simplicity in intricacy and unity in diversity. The marvelous fractal structures of strange attractors in chaos theory show for example a high degree of order in chaos.

Repeated 'Stretching and Folding' is the key to the emergence of complex structures in nonlinear dynamics and the reason for the high complexity of strange attractors [135, 147]. A strange attractor typically arises [147] when the flow is contracting in some direction and stretching in another. This continuous 'Stretching and Folding' cause trajectories to diverge endlessly, while they remain confined to the bounded region of the attractor in phase space at the same time. The figure illustrates this basic mechanism in a simple Rössler attractor.

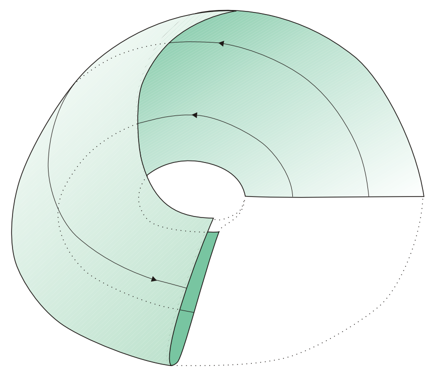

Fig. 2 Stretching and Folding

This form of complexity is closely related to the notion of beauty in art, strange attractors are known for their beautiful and delightful structures. Complexity arises from the sunshine in the rain as rainbows, from the sense in nonsense in form of insights, from the collision of reason and emotion in social relations, leading to a combination of opposite feelings, as we know well since Shakespeare's epic work. Complicated situations arise from hesitation in action (Hamlet), from love in hate and despair in love (Romeo and Juliet), from pleasure in displeasure, etc.

Chaos, fluctuations and complexity generally emerge through a repeated application and combination of two complementary forces or operations. A stretching, splitting, isolating and separating force on the one hand, and a complementary folding, merging, combining and unifying force on the other hand. A continuous sequence of merging and splitting operations applied to agents, species and items results in complex structures and systems, from strange attractors to galaxies, and from natural to cultural and artificial systems.

Subject, Field, Science	Complex Object	Merging, Integration	Splitting, Differentiation
Natural Science - Folding and Stretching			
Physics (Chaos Theory)	Strange Attractor	Folding	Stretching
Physics (Cosmology)	Galaxies, Clusters	Gravitation	Expansion
Physics (Astronomy)	Elements, Stars, Supernovae	Fusion, Gravitation	Dispersion, Radiation pressure
Meteorology (Weather)	Thunderstorms, Hurricanes	Contraction in Low pressure Areas	Expansion in High pressure Areas
Geology (Plate tectonics)	Complex Surface or Crust	Folding & Collision of plates → Mountains	Stretching & Splitting of plates → Oceans
Merging and Splitting of Code and Data			
Biology (Life)	Living system	Creation, Concentration	Destruction, Dissipation
Biology (Evolution)	Species	Cooperation, Symbiosis	Separation, Cladogenesis
Biology (Evolution)	Genetic Code	Recombination	Variation, Mutation
Informatics (Cryptology)	Code	Congruence Class Creation	Exponentiation
Computer Science (Programming)	Program, Application	Merging Code & Data	Splitting Code & Data
Social Science - Cooperation and Division of Labor			
Sociology (Division of Labor)	Society	Cooperation	Specialization
Politics (‘Dissemination’ Model)	Culture	Local Convergence	Global Divergence & Polarization
Psychology (Flow activities)	Personality, Agent	Restlessness, Continuation, Integration	Restriction, Concentration, Differentiation
Merging and Splitting of Knowledge, Voices and Story Threads . . .			
Science	New Publication	Merging of Publications	Splitting of Pulications
Music	New Composition	Merging of Voices, Motives & Themes	Splitting of Voices, Motives & Themes
Poetry	New Poem	Merging of Verse lines & Styles	Splitting of Verse lines & Styles
Literature, Film	New Book or Movie	Merging of Events & Story Threads	Splitting of Events & Story Threads

Tab. 4 Merging and Splitting

In Axelrod's "Dissemination" Model [6], in sociological theories about the "Division of Labor" [59], in psychological "Flow" theories [25] the basic mechanism involves always the clash of two opposite forces.

Tectonic Plates

Birth of Oceans

Without the merging of splitting of tectonic plates, the surface of the Earth would be simple, flat and everywhere covered with water. The merging and folding of plates creates huge mountains, the stretching and splitting of plates creates deep oceans. For example the Atlantic Ocean was created in the last 180 Million years through the splitting and separation of the North & South American plate on the one hand and the Eurasian & African plate on the other hand. If two tectonic plates drift apart, an ocean is created.

Emergence of new Mountains

If two tectonic plates collide, mountains emerge (Rocky Mountains, Alps, Himalaya, ...). The Himalaya Mountains including Mt. Everest were created in the last 50 Million years through the collision of the Indian and Eurasian plate. More complex structures arise through the repeated merging and splitting of

* Genetic Code (Biology, Evolution)
* Exons and Introns (Molecular Biology)
* Code and Data (Programming Languages)
* Firms, Companies (Economy)
* Countries and Cultures (Politics, see Axelrod's "Tribute" Model)

Power and Freedom

In the last case, splitting of countries increases individual freedom and liberty and decreases the power of the group, whereas merging or occupating of countries increases obligations and restrictions for the individual, but the power of the group as well. The right balance between freedom and obligation, between the needs of the individual and the needs of the group is necessary for a success of the group or community.

Natural Operations

Merging and splitting are natural operations for increasing complexity in complex systems, which consist of a large number of mutually interacting and interwoven parts. Every operation which increases complexity in systems with many parts, nodes and components must involve more than one part, node or component. Different parts can be merged, linked and melted together, or a single component can be splitted, divided and separated into several distinct parts. Examples are listed in the following Table.

Field	System	Agents
Business	Companies	Workers, Employees
Economics	Economy	Firms, Companies
Politics	Country	States, Parties
Neuroscience	Neural Assemblies	Neurons
Psychology	Mind	Neural Assemblies
Astrobiology	Stars	Elements
Astronomy	Galaxies	Stars
Physiology	Organs, Tissue	Cells
Biology	Organisms	Organs, Tissue
Ecology	Ecosystem	Species, Organisms

Tab. 5 Systems and Agents

Balance between Merging & Splitting

The concrete operations behind merging and splitting of agents can be based on activation and inhibition, stretching and folding, or expansion and contraction. To increase complexity, you need the right balance between merging and splitting of components, or in the case of networks, a coarse equilibrium between connecting and separating of nodes.

* Merging components alone leads to huge, solid components without structure, connecting nodes alone leads to a dense, incomprehensible network

* Splitting components alone leads to a chaotic explosion or proliferation of parts, separating nodes alone leads to many small, isolated pieces

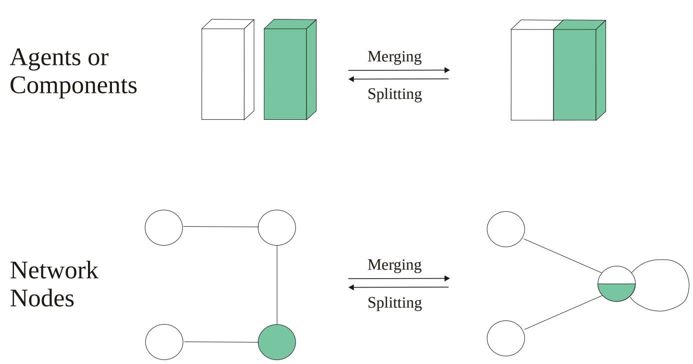

Fig. 3 Merging and splitting of agents

The balance in the universe as a whole between merging and splitting on the one hand, and between order and chaos on the other hand seems to be just right. Too much randomness and chaos, and the universe would form a gas of particles, an unstructured anarchy. Too much order, and the universe would condense into one big uniform crystal with regular structure. Too much merging and gravitation, and the universe would clump together to a giant black hole. Too much splitting and expansion, and the universe would split into billions of isolated elements.

Finding this balance is important and indispensable in many complex systems and activities. Too much specialization in sociology leads to isolation and lack of communication. Too much cooperation results in uniformity and superfluous communication. To keep this delicate balance is often not easy. If it has to be done by hand in a creative activity, it is often considered as an art. Outstanding persons who create great works of science, poetry or music are rare and often admired. They usually have the unique ability of interweaving and interlocking differnt

Science, Music, Poetry

* Threads of Knowledge, Ideas, Publications (in science, e.g. Charles Robert Darwin, Isaac Newton, Albert Einstein)
* Muscial Voices, Motives and Themes (in classical music, e.g. Johann Sebastian Bach, Antonio Vivaldi, Wolfgang Amadeus Mozart)
* Verse lines, Styles, Story Threads (in classical literatue, e.g. James Joyce, William Shakespeare, Johann Wolfgang von Goethe)

in a new, interesting and fascinating way. J.S. Bach, for example, used in his fugues and contrapuntal works merging and splitting of different voices to create complex, dense, polyphonic music. Concertos which were invented by Corelli, Torelli and Vivaldi, developed by Vivaldi, Albinoni and Bach, and shaped in its modern form by Mozart and Beethoven, are based on the solo-tutti contrast, on the merging and splitting of solo parts and orchestra parts. And usually the structures of sonatas and concertos are characterized by a fast-slow-fast alternation of stimulating, fast and inspiring parts on the one hand, and relaxing, slow and lyrical parts on the other hand.

Merging & Splitting of Voices

Classical sonatas and concertos emphasize themes and musical motives. During the development of a sonata for example, the themes of the introduction or exposition are altered, extended and modulated. They are merged and splitted over and over, until the theme from the beginning is recapitulated in its original form at the end.

Merging & Splitting of Themes

A poet tries to merge and split verse lines in a new and interesting way. Different verse lines are splitted and connected by appropriate rhyme forms.

Merging & Splitting in Poetry

J.W. Goethe created for example the following intricated rhyme structure (FAUST II. 1. Akt.[4]) in form of a rainbow in a verse which describes the complexity of a rainbow:

```
"So bleibe denn die Sonne mir im Rücken.          A           (-ücken)
Der Wassersturz, das Felsenriff durchbrausend,    |   B       (-ausend)
Ihn schau ich an mit wachsendem Entzücken,        A   |
Von Sturz zu Sturzen wälzt er jetzt in tausend,       B
Dann abertausend Strömen sich ergiessend,             |   C   (-iessend)
Hoch in die Lüfte Schaum an Schäume sausend,          B   |
Allein wie herrlich, diesem Sturm erspriessend,           C
Wölbt sich des bunten Bogens Wechseldauer,            D   |
Bald rein gezeichnet, bald in Luft zerfliessend,      |   C
Umher verbreitend duftig kühle Schauer.               D
Der spiegelt ab das menschliche Bestreben.        E   |       (-eben)
Ihm sinne nach, und du begreifst genauer:         |   D
Am farbigen Abglanz haben wir das Leben."         E
```

Merging & Splitting in Science

Just as a poet tries to merge and split verse lines in a new and interesting way, a scientist does the same with publications. A scientist usually takes several publications, which he names in the bibliography, and merges them to a new publication. He splits each publication into relevant and irrelevant parts until he has isolated the essential threads of knowledge, and recombines the different fragments, filaments and threads to a new work. By interweaving and interlocking the different threads of knowledge, the scientist creates a new thread of insight and information.

The emerging pattern in poetry carries a content or a message, but it is also enjoyable for the reader. The emerging pattern in a scientific publication is enjoyable, but it should also expand our knowledge of culture and nature. The goal is to "observe or understand something that no one has ever observed or understood before"[112].

What is Science ?

Science is the active and creative engagement of our minds in an attempt to understand nature: "The object of research is to extend human knowledge of the physical, biological, or social world beyond what is already known"[112]. Gregory Derry gives the following description of science in his book "What science is and how it works" [32]:

> [Science is] "starting with ideas and concepts you know, observing the world, trying different things, creating a coherent context,

[4]available online at several places, for example http://www.bartleby.com/19/1/ or http://www.ibiblio.org/gutenberg/etext00/7fau210.txt

> seeing patterns, formulating hypotheses and predictions, finding the limits where your understanding fails, making new discoveries when the unexpected happens, and formulating a new and broader context within which to understand what you see."

Yet every publication is temporary and uncertain. A report from the 'National Academy of Sciences' says "scientific results are inherently provisional [...] all scientific results must be treated as susceptible to error" [112]. A scientific proof or publication is like a program, you can never be sure if it is free of errors and mistakes, and mostly it contains a lot of them. It only becomes a part of common knowledge, if it is true and contains no mistakes, if it is accepted, cited and remembered by the scientifc community. Science is "shared knowledge based on a common understanding" [112], and it is based on a culture of doubt. Richard P. Feynman said "Religion is a culture of faith; science is a culture of doubt". He has defined science as the belief in the ignorance of scientists and experts: "Science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers in the preceeding generation... As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts" [49].

Scientific results are temporary and provisional

Science is a culture of Doubt

René Descartes (1596 - 1650) said "Dubium sapientiae initium" (Doubt is the origin of wisdom). This doubt and uncertainty are fundamental. Feynman says further [48] "if we did not have a doubt [...] there would be nothing worth checking, because we would know what is true". As a scientist you should doubt even yourself and your own theories constantly. Without doubts of yourself you would not get any new ideas because you would not consider many new publications at all. Doubt, honesty, objectivity and fairness are scientific values, belief, arrogance, prejudice and certainty are not. Belief is in the majority of cases harmful for science, even the belief in abilities or superiority. As a scientist you should

Scientific values

* never believe *the others* are much better than you or make no mistakes (that would lead you easily on the wrong track or in blind alleys)
$\Rightarrow$ science is constant *doubt* instead of belief & certainty

* never believe *you* are much better than the others or make no mistakes (that would keep you from testing and examine other works)
$\Rightarrow$ science is constant *examination* instead of arrogance & prejudice

In the words of Feynman [48] "I believe that to solve any problem that has never been solved before, you have to leave the door to the unknown ajar. You have to permit the possibility that you do not have it exactly right". Scientists have to test a huge number of temporary theories and combinations to find new theories, esp. those who are different than already existing ones. Of course the number of successful approaches and useful theories is much smaller than the number of less successful approaches and useless theoretical constructs.

Evolution permits less successful objects

Likewise evolution checks many less successful species before it finds one successful. This constant test is done by merging and splitting of genetic code. Merging and splitting or continuous recombination are powerful generators of diversity. Together with a form of natural selection, such powerful generators of complexity are necessary for the evolution of complex life-forms, since the number of possible ways of putting genetic 'words' or codons together in a gene or chromosome is huge, about $20^{1,000,000,000}$ in a human chromosome[5]. This is an inconceivable, tremendous large number, much larger than the number of elementary particles in the entire physical universe. A human chromosome corresponds to a monumental 1 GB large program, and every human as 46 chromosomes in each cell.

Combinatorial Explosion

To find the right combination by a fast and simple algorithm is impossible or extremely improbable. Evolution had to test an enormous and awesome number of combinations to assemble large sequences of nucleotides in a meaningful and convenient way. According to the Encyclopædia Britannica, our set of genes and chromosomes work only because "natural selection, over a 4,000,000,000-year history of life, has destroyed enormous numbers of (temporary) combinations that did **not** work". The huge tree of all living beings from the present back to the origin of life is only a scrawny and meager scrag compared to the immense and incredible large number of short-lived temporary organisms of the past with no descendants and less successful offspring.

Temporary Life-Forms

[5] For a nice illustration of the basic genetic terms, see the graphics gallery "From Gene to Function" at http://www.accessexcellence.org/AB/GG/. The 4 nucleotide bases Adenine (A), Thymine (T), Cytosine (C) and Guanine (G) form $4^3 = 64$ possible three letter words or codons CCG, UGA, CAA, AUG, GAU, ... which in turn specify the 20 standard amino acids Phenylalanine, Leucine, Serine, Alanine, Glutamine, ... A human chromosome has about $3*10^9$ letters in form of A-T or G-C base pairs. Therefore a chromosome is a sequence of $10^9 = 1,000,000,000$ three letter 'words' and contains roughly 1 GB = 1,073,741,824 bytes of data. A chromosome corresponds to a monumental 1 GB large program !

1.8 Temporary emergence

Merging and splitting of agents or components is certainly one of the basic mechanisms which increase complexity in agent based models and complex adaptive systems (CAS). This increase is often accompanied by instability and therefore temporary, transitory and transient. Systems with strong fluctuations support the emergence and appearance of complex structures, but also the liquidation and disappearance of structures. Temporary emergence is connected to a fluctuation of complexity.

Temporary emergence through complexity fluctuations

To increase complexity permanently, emergent phenomena are not enough, the system itself or its components must be changed and the temporary phenomena must become a permanent one, for example through a transfer, growth or capture process, or through the appearance of new stable agent or system forms. If this does not happen, a temporary increase in complexity vanishes again.

Emergence in artificial life and Cellular Automata is according to Russell K. Standish [146] defined by macro phenomena : "An emergent phenomenon is simply one that is described by atomic concepts available in the macrolanguage, but cannot be so described in the microlanguage". The macrolanguage usually is based on observed global structures, principles and laws. In *The Game of Life*, this macro phenomena can for example be a glider, see [88]:

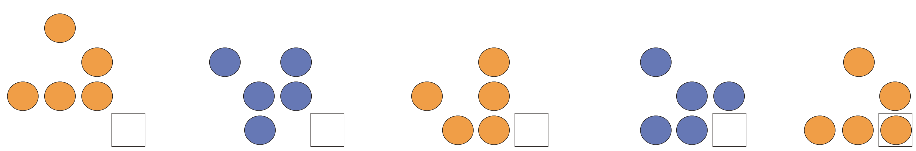

Fig. 4 Emergence of a macro phenomena (a Glider from *The Game of Life*)

But the complexity of Cellular Automata (CA) [159, 75] is limited. Objects like gliders are at the upper limit, and they are usually discovered manually or by capturing software. Moreover, automata in which complex patterns appear are not stable, typically complex patterns appear *and* disappear rapidly.

Emergence of patterns in CA

A cell in a CA is a finite automata or finite state machine (FSM), and much simpler than a full autonomous agent. The behavior of a cell is governed by the state transition table of the CA, and is determined completely by the states of the neighbors. Stephen Wolfram is convinced that Cellular Automata are even a 'a new kind of science' [159]. They are not really a fundamental new tool but still an important way of modelling complex systems.

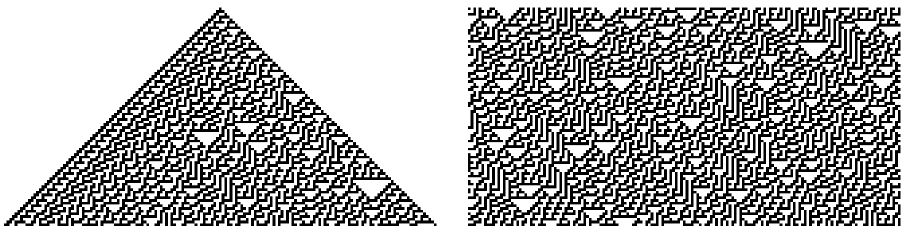

Fig. 5 Cellular Automata - Rule 30 (with different initial conditions), see http://mathworld.wolfram.com/Rule30.html

Generally speaking, complex adaptive systems consist of intelligent autonomous agents. An intelligent autonomous agent is more complex than an finite automata.

Emergence of coherent light beams in a Laser

Another example for emergence is the laser. The German physicist Hermann Haken has often emphasized, that the coherent light beam of a Laser (which means Light Amplification by Stimulated Emission of Radiation) is an emergent phenomena.

But without a continuous input of energy which produces a population inversion, the emergent phenomena of coherent light is unstable. It is not possible to produce of coherent laser beam of high order without constant energy supply.

Laser contain a medium which can be pumped to a higher energy state. In the medium there must be a downward transition from the upper energy level triggerable by stimulated emission. To produce a laser beam, a critical point named population inversion must be achieved: the majority of the medium must be pumped to an upper energy level.

A few photons emitted by 'spontaneous emission' can trigger an avalanche of stimulated emissions, which amplify the light of a few photons to a high-intensity beam. In a laser you have local, microscopic atoms which emit photons with global, macroscopic influence (coherent laserlight), and the feedback of global, macroscopic light which causes again stimulated emission in local atoms.

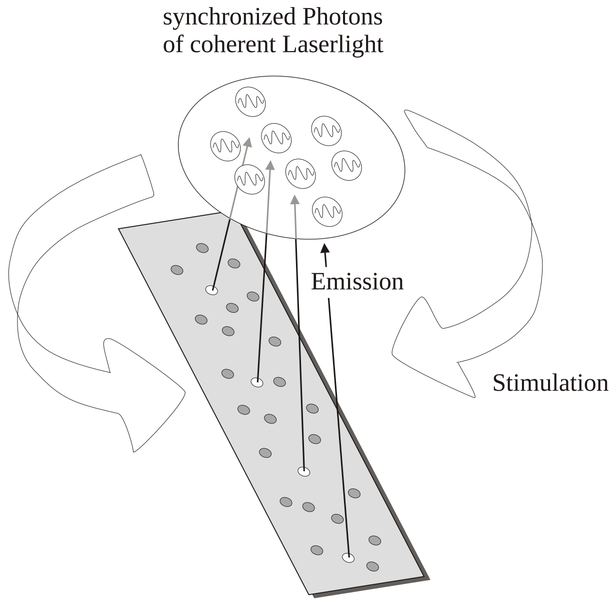

Fig. 6 Emergence of coherent light by stimulated emission

Like many other 'dissipative structures', the coherent light of a laser requires the constant inflow of energy. A steady consumption, destruction and dissipation of energy enables the production, creation and concentration of coherent light beams.

Dissipation is Loss of Energy

A loss of energy through dissipation (for example as heat) contracts the flow in phase space. In nonlinear dynamics and chaos theory, a map or flow is called dissipative, if it contracts volumes in phase space [147]. Dissipation is important for the emergence of strange attractors, because it is responsible for the contraction and attraction of orbits (folding is possible through nonlinear dynamics, linear dynamics can only stretch phase space). In contrast to dissipative maps and flows, conservative maps and flows preserve volumes in phase space. Conservative systems do not have chaotic attractors and they do not lose energy.

For a strange or chaotic attractor you also need sensitive dependence on initial conditions caused by stretching and expansion of volume in phase space. A strange attractor arises if volumes of phase space are contracted in one dimension (dissipation) and stretched or expanded in another dimension (sensitive dependence on initial conditions). A complex strange attractor needs both: expansion and contraction, stretching and folding, convergence and divergence, dissipation and augmentation.

1.9 Emergence and Dissipation

Emergence/ Dissipation Duality

Dissipation is related to dispersion and means originally the transfer or loss of energy to heat energy. A system is dissipative if it loses energy to waste-heat through friction, viscosity or some other process that dissipates energy. Dissipation increases heat, entropy and disorder. The complementary process of emergence in form of macroscopic accumulated structures decreases entropy and disorder. In a thermodynamic sense, the emergence of order and complex structures is just one side of the emergence / dissipation duality. There is a natural duality between dissipation and emergence as two complementary sides of a transfer.

Augmentation, accumulation and concentration as the opposite of dissipation is not a concentration of phase space (in nonlinear dynamics, dissipation is equal to a concentration of *orbits* due to energy loss). It is a concentration of agents, order and energy. Dissipation on the contrary means a loss of order, a dispersion of agents and a disappearance of organized complexity.

Dissipation	Emergence
Loss of organized Complexity	Yield of organized Complexity
Loss/Waste of Energy	Gain/Yield of Energy
Dispersion	Augmentation/Accumulation
Disappearance/Destruction	Appearance/Creation
Decrease Order and Organization	Increase Order and Organization
Increase Entropy	Decrease Entropy

Tab. 6 Dissipation and Emergence

Entropy and Disorder

Usually we expect that systems, left to themselves, get less organized. In isolated systems that exchange neither energy nor matter with their surroundings, the entropy continues to grow according to the second law of thermodynamics until it reaches its maximum value at what is called thermodynamic equilibrium. The opposite is self-organization: a system which tends to become more organized if it is left to itself. Thermodynamics tells us this can not happen in isolated systems.

Prigogine's dissipative structures

Evolution depends on open systems. In open systems the entropy can decrease by transformation of energy. This is what Ilya Prigogine called dissipation. Prigogine [124] and Katchalsky [78] were the first who tried to describe the formation of complex structures in nonequilibrium systems. But the so-called dissipative structures introduced by Prigogine [125, 124, 126], remain controversial. Philip W. Anderson and Daniel L. Stein assert [3] that there is no developed theory of dissipative structures as claimed by Haken, Prigogine and collaborators and that perhaps there are no stable dissipative structures at all.

But in fact there are systems existing and established only on the basis of a continuous dissipation of matter-energy. If we consider the so-called 'dissipative structures' as structures built by transfer of complexity and entropy, they become less mysterious. Living systems use a kind of controlled dissipation/emergence. If a structure emerges in this way, more complex structures can be built on top of it in the same way, and a large pyramid of life is created. This pyramid looks like the pyramid in Fig. 7, which resembles 'Life's Complexity Pyramid' from Zoltán N. Oltvai and Albert-László Barabási [113].

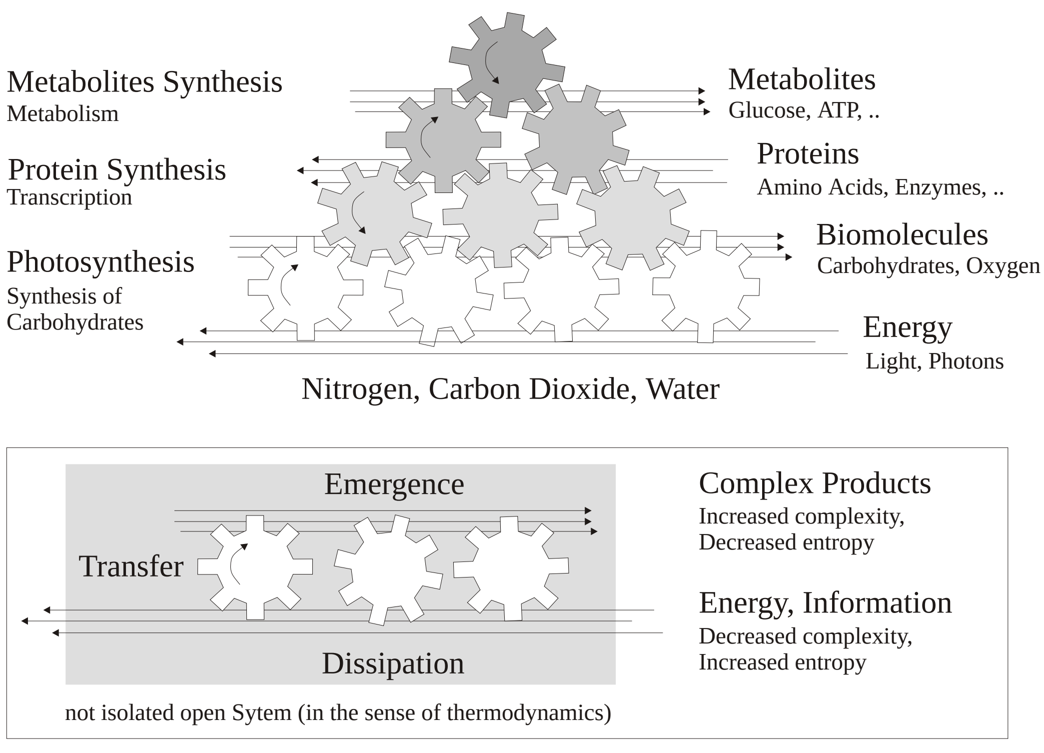

Fig. 7 Dissipation and Emergence

Anabolism/ Catabolism Duality in Metabolism

Metabolism consists of two parts, catabolism - exogen/exergonic splitting of metabolites and molecules which release energy - and anabolism - endogen/endergonic merging of molecules which uptake energy. Generally catabolism is a kind of dissipation which releases energy, anabolism is a kind of emergence which uptakes energy.

The energy that is gained from dissipation and destruction of incoming energy is used as fuel for the cell metabolism to build and create new complex structures like metabolites and proteins. Life seems to be a continuous struggle against decay, and the structures of living systems are maintained only due to a constant pump-in of matter-energy.

What is Life ?

The architecture and appearance of an individual is determined by his genes. But growth does not stop suddenly if it is grown-up. The adult just has reached an short-term equilibrium between growth and decay. Erwin Schrödinger says 1944 in his book 'What is Life': "Living matter evades the decay to equilibrium." He continues that living matter avoids the rapid decay into the inert state of 'equilibrium' by extracting order from the environment.

A living system constantly exchanges material with the environment, as Schrödinger notices, the German word for metabolism is Stoffwechsel (=exchange of material). This exchange allows the system to free itself from the entropy it inevitably produces and enables it to extract order from the environment. A living system is characterized by constant pump-in and pump-out of energy and continuous flow-in and flow-out of matter. A *steady state in dynamic flow* equilibrium between dissipation, decay, break-down, increasing entropy and dissappearance of order on the one side and emergence, creation, built-up, decreasing entropy and appearance of order on the other side. When this balance is disturbed, and cells are undergoing cell division in an uncontrolled way (either too few or too many) the result is decay, death and cancer.

Propaganda: Construction of Image & Destruction of Enemy's Reputation

In Metabolism, the anabolism (built-up) is possible through a permanent catabolism (break-down). Likewise, political propaganda is the construction of the own image or reputation through the permanent destruction of the enemy's image and reputation. That's what politicians can do best: to destroy the reputation of the political enemy, to blame and to accuse each other of being greedy, lazy, corrupt, dishonest, unreliable, incompetent, incapable and unable to do the job.

	Import, Material,Food	Living Mechanism	Purpose, Product	Export, Waste
Algae, Plants	Water,Energy, Carbon Dioxide	Photosynthesis	Carbohydrates for Growth	Oxygen, Water
Cells	Amino Acids	Protein Synthesis	Proteins	Spliced RNA
Cells	Proteins, Oxygen	Metabolism	Metabolites, Amino Acids	Metabolic waste Carbon Dioxide
Organs and Organisms	Oxygen, Food	Breathing, Digestion	Proteins, Growth	Carbon Dioxide Excrements
Household	Shopping	Daily Life	Maintenance of Life	Rubbish, Waste
Firm	Raw Material, Credits	Production, Payment	Products, Profit, Growth	Waste
State	Import	Economy	Growth, Maintenance	Export
Sect, Political Party	Members, Money, News	Propaganda	Power, Profit, Growth	Destroyed Reputations
Army, War Machine	Members, Money, Targets	Propaganda, War	Power, Profit, Growth	Destroyed Targets

Tab. 7 Living Mechanisms

Politicians during Election Campaign

The Vanishing Voter project at Harvard University[6] has found out that voters are tired of politicians busy pointing at each other. During an election campaign politicians are usually attacked by opposition parties, so that "politicians are more concerned with fighting each other than with solving the nation's problems". Modern politicians are essentially actors, and modern campaigns "seem more like theater or entertainment than something to be taken seriously". 43% claim that "Republicans and Democrats are so alike that it does not make much difference who wins" and nearly 90% say that "most political candidates will say almost anything in order to get themselves elected". Politicians also like to promise things. Khrushchev said "Politicians promise to build a bridge even when there's no river". Promising is comparable to borrowing a good image and reputation from the future. You have to pay the price for the better image in the future if the voter remember your promise.

[6] see http://www.vanishingvoter.org/

Chapter 2

Growth and Transfer of Complexity

2.1 Jumps in Complexity

Evolution is the key to complexity. As Peter Schuster says in his article "How does complexity arise in evolution ?" [137], "It is commonplace to state that complexity has increased in the evolution of the biosphere". Why does complexity increase and grow during evolution ? And why does it sometimes appear very rapidly and suddenly in the course of evolution ? Schuster continues to notice "Information and complexity do not seem to have gradually increased during the history of life on Earth. Palaeontologists have discovered rather large and abrupt jumps in structural and functional complexity in the fossil record".

Growth of Complexity

In order to answer these fundamental questions, it is useful to look at the different means by which complexity increases in a CAS in the course of evolution. First of all, complexity does not increase everywhere. Human beings with self-consciousness belong apparently to the most complex life-forms in the known universe. Human consciousness is unique among living beings, and as far as we know life on our planet is unique in our universe. The more complex the emergent phenomenon is, the more local it seems to be.

Extension & Localization

This can be easily verified by the definition and application range of the different sciences. The more complex the emergent phenomenon, the more abstract are the theories of the corresponding science. The laws of physics describe concrete particles with precise mathematical equations, whereas sociology is full of vague and unclear abstractions. As Randall Collins says [23], "Sociological prose at its worst is considered virtually impenetrable". The laws of physics (esp. gravity) can be applied to the whole universe and our solar system, the laws of biology to the ecosystem on the surface of the Earth, the laws of sociology to cultures, which developed in countries with good climatic conditions, the laws of psychology to individuals of these cultures, which live in the populated regions of these countries.

Expansion & Confinement

Thus a continuous expansion of complexity with the emergence of more and more complex composite objects is only possible through an increased localization and confinement to a limited space. The price for the extension and expansion of complexity is the limitation and localization of the corresponding spatial extension.

The three Means for Growth

If we direct our attention to these confined spaces, it still remains to be clarified by what kind of means complexity increases in a CAS in the course of evolution. W. Brian Arthur has identified three means by which complexity tends to grow as systems evolve in his article "On the Evolution of Complexity" [4]. The three mechanisms are :

1. Increase in coevolutionary diversity (new species or niches)
   Agents appear in a CAS which seem *to be* an instance of a new external agent class, type or species. The CAS seems *to have* new agent types and capabilities.

2. Increase in structural sophistication (new capabilities)
   The agent seems *to have* new internal capabilities, functions, subsystems or structures, which seem *to be* instances of new classes, types or species.

3. Increase by "capturing software"

The first two means are closely related [4] : "In the first [mechanism], ecosystems - collections of many individuals - become more complex, more diverse, in the course of evolution; in the second, individuals within ecosystems become more complex, structurally deeper, in the course of evolution". They concern the emergence of new agent forms/capabilities (small jumps), whereas the last mechanism deals with the emergence of a new CAS (large jumps).

If you exchange the notions system and agent in the enumeration above, the first two mechanisms become equivalent. Representing a whole CAS by a single agent turns mechanism 1 into 2: An agent with increased internal diversity has new capabilities, functions or subsystems. The view of a single agent as a whole CAS turns mechanism 2 into 1: A CAS which becomes structurally deeper contains agents of a new class, type or species.

Agent ↔ CAS

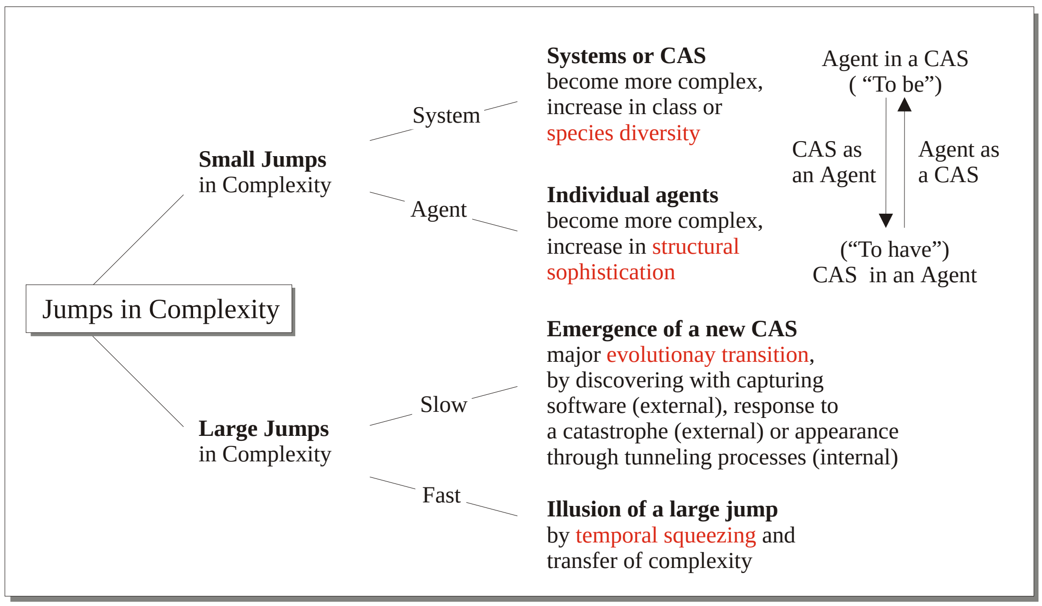

Fig. 8 "Emergence" as a jump in Complexity

Small jumps in complexity are caused by (1) new agent forms/species in a system and (2) new agent abilities/capabilities in an individual agent. New agent abilities appear usually before completely new agent forms appear. As we will see in this chapter, new agent forms appear usually through a transition from (2) to (1), from the agent to the system.

Small Jumps

Because the first two mechanisms are closely related and a CAS has a self-similar structure, complexity can be transfered from the second form to the first (from the agent to the CAS) or vice versa. Such a transfer of complexity is always possible, if the agents of a CAS or MAS and the CAS itself have a similar and compatible structure. For example, if the agents have a flexible, internal structure (the behavior or capabilities of an agent) and a compatible, stable, external structure or dimension (the class or type of an agent in the class structure of the system). In this case complexity sometimes seem to

Transfer of Complexity

appear suddenly during a transfer process. The usual direction of a transfer is from the agent to the system, because the internal structure of the agent is often more flexible than the external class-structure of the whole CAS.

All these means increase complexity in agents or CAS in small steps, whereas the third mean is connected to a large jump in complexity and is equivalent to the emergence of a new complex adaptive system (CAS). The reason for large jumps can be the recognition of structures from an external observer, if new units of selection are discovered and selected on a higher level of organization, a response to the challenge of an external catastrophe, or a tunneling process to higher levels of complexity caused by internal processes (pressure, competition, etc..).

Large Jumps

Once the building blocks are available or the new CAS is created, combinatorial explosion can lead to exponential increase in complexity. Large jumps are sometimes named "evolutionary transitions". The emergence of a new CAS at a higher level of complexity, an "evolutionary transition", takes place if the emergent macro phenomena (Phenotype) of one level become the building micro blocks (Genotype) of the next level. We shall come back to this point later in chapter five, and start with the discussion of mechanism (1), how systems become more complex.

2.2 Stability and Innovation

Copy and Change Mechanism

The easiest way to create complexity and simple evolution is reuse by 'copy and change'. If a programmer writes a new program, he takes the source code of an old one or an example project, copies it, and starts to make some changes. The same can be said about authors and writers who write a new article or book, composers who create music,.... The basic processes are replication and change. Replication means to duplicate, copy and reproduce something. Change means to modify the form or function by variation, adaption, adaptation, customization or mutation.

The properties and the methods of an object or a class in object-oriented programming can be for instance be changed by adaptation and extension, by adding new functions or variables. The knowledge and the methods of an autonomous agent can be changed by learning and imitation.

Flexibility but low Stability

As we have seen in the first chapter, a natural description for complex adaptive systems are Multi-Agent Systems. A constant process of replication and adaptation leads to a flexible, but unstable system.

Let us start with a single adaptive agent, who is able to reproduce itself or is replicated by some external mechanism. Repeated application of replication/duplication and adaptation/change mechanisms results in systems with higher complexity. Thus the diversity of a system increases gradually with each adapted agent. The price for this flexibility is stability. The system is very flexible but not stable, and the ability to store information is low. A useful new modification can always be cancelled instantly by a new adaptation or adaption. The complexity you can reach with these two basic operations is limited, because evolved features can be erased completely by new adaptions.

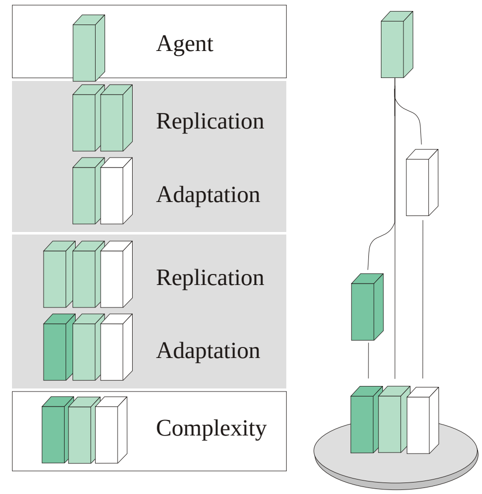

Fig. 9 Replication and Adaptation

A system is able to reach higher levels of complexity, if it contains a stable, fixed or permanent part. A Cellular Automata (CA) has no such solid or stable part. No cell can keep information longer than one time step. That's why the complexity of emerging phenomena in CA is limited and temporary (this is also partially due to the fact that the system is usually closed). On the other hand, if the whole system is stable and rigid like a solid body, it is unable to adapt itself.

Thus a complex adaptive system must have a flexible and a stable component, for example long-term and short-term memory, genetic and behavioral traits, classes and instances, types and implementations, roles and capabilities, niches and species. Without flexibility, it would be rigid and fixed, without stability, it would not be complex. Adaptation without learning is just changing.

Flexible and Stable Subsystem

CAS often unite two different, separated systems, a flexible and a stable one. Two isolated system are not very useful. Two separated systems which are connected by a transformation or transfer process combine flexibility with stability. The flexible systems is able to adapt itself to new situations and changing environments. The transfer process which bridges the gap or the

Reconcile Stability & Innovation

boundary between the stable and flexible components is used to carry the information from the flexible to the stable system. The stable system in turn must be able to grow in order to store the new information (by the way, growth is an essential property of all complex adaptive systems, of societies, firms, life-forms, . . .). Together the processes of adaptation, transformation and growth reconcile stability and innovation.

The flexible part can be erased and liquidated without loosing any important information, whereas destructions in the stable system result in heavy information loss. The gap, boundary or interface between the flexible and the stable system protects the information stored in the stable system, and keeps the flexible system open for innovation.

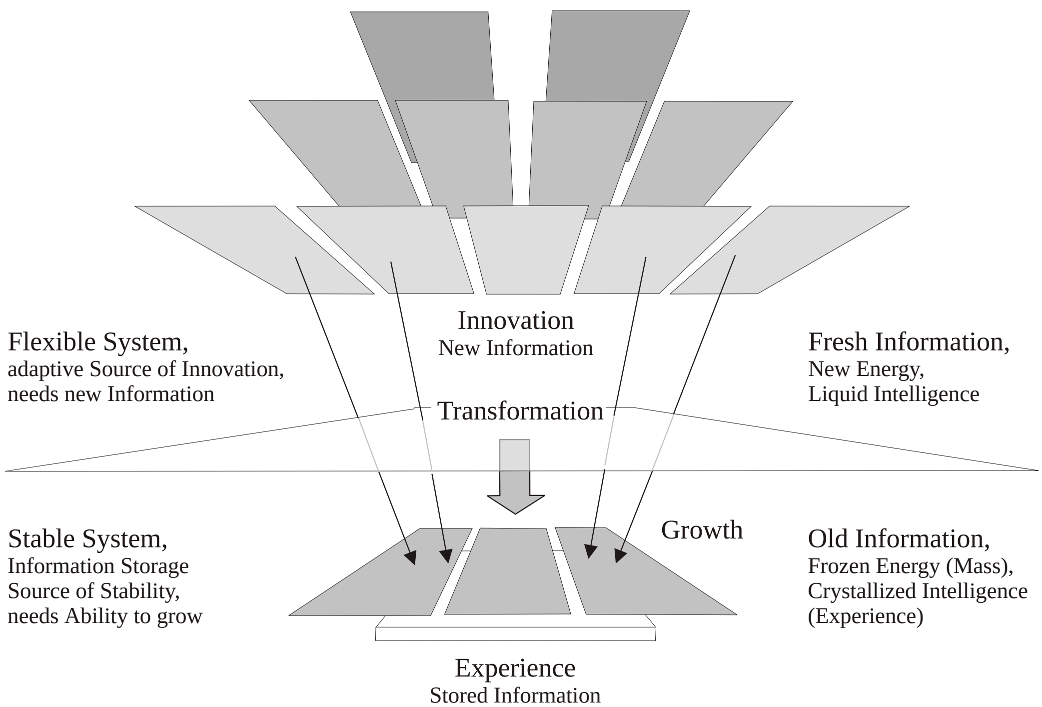

Fig. 10 Growth and Transformation

Of course the stable system needs a protection against decay and obliviousness. It must have the properties of *solidity, immutability and durability*, and therefore needs memory and remembrance, along with the ability to grow.

The flexible, adaptive system needs a protection against immutability and durability. It must have the properties of *liquidity, fluidity and flexibility*, and therefore needs decay and obliviousness. Maybe this is also a reason why we sleep - to forget things and to clear the mind, to restore the capacity to cope with the constant inflow of new information. Although the true reason for sleep was unclear and unknown for a long time (see [70] for a good introduction to the science of sleep), it certainly plays a role in brain development, since babies sleep much more than adults[1]. There is growing evidence of memory consolidation through sleep [33]. If sleep serves to consolidate memories, we sleep in fact to remember better. But remembrance and obliviousness are two sides of a coin. To think more clearly, it is also necessary to remove, delete and forget unnecessary information.

Why do we sleep ?

The brain needs to liquidate unimportant old memory traces to store new informations. It is not possible to reach higher levels of intelligence and complexity without a constant supply and inflow of new information, organization or energy, which are stored first in a temporary form, until they are processed further. The temporary memory, buffer, storage or system must be erased from time to time to make room for new information.

Intelligence can appear in different forms[2]. Raymond B. Cattell and John L. Horn discovered the difference between ‘fluid intelligence’ and ‘crystallized intelligence’. Fluid or liquid intelligence is related to normal, external visible intelligence. Intelligence has the latin origin intellegere and intellectus, the past participle of intellegere = “to understand, to perceive”. Intellegere in turn comes from two Latin words: inter “between”, and legere “to choose”. Intelligence, therefore, is the capacity to think or choose, to select, and to discriminate. It is the capacity to acquire and apply knowledge, the ability to cope with new problems and the general mental capability to reason, solve problems, think abstractly, learn and understand new material, and profit from past experience.

Fluid and crystallized Intelligence

Definition of Intelligence

Crystallized intelligence is related to stored, internal visible intelligence. In psychology it is the amount of experience and information you obtain and the skills you develop over time. Stored knowledge and experience are frozen forms of intelligence, just as writing is a frozen form of language.

[1] convincing evolutionary reasons for the origin of sleep are discussed later in the context of evolution and extinction in chapter five

[2] like energy, intelligence can appear in different forms. Since Albert Einstein discovered his famous $E = mc^2$ equation we know that mass is equivalent to energy. Mass is a kind of frozen or crystallized energy, energy which has happened or is waiting to happen.

2.3 Science and Language

Science as a CAS

Simple examples of CAS are language and science itself. First there is the case of science itself. Publications are the memory of science. Articles in Journals are the flexible short-term memory of science (temporary atoms of insight), books are the stable long-term memory (assembled expert knowledge, experience and collected insights). A publication is temporary. The transfer mechanism is citation and quotation. If a publication is accepted and often cited, it becomes part of the common knowledge and is repeated or recorded in books of the next generation.

Language as a CAS

Second there is the normal everyday language. The stable system of an everyday language consists of the collectivity of word and rules, the syntax and semantics, and all the different figures of speech. The flexible system of a language are the new word-combinations and metaphors.

System	Content	Age	Metaphors, Semantics	regular/irregular verbs, Syntax
flexible	current words and rules	young, new	vivid, fresh	regular
stable	fossils of ancient rules, figures of speech	old, ancient	dead, frozen	irregular

Tab. 8 Language

Different kinds of Metaphors

Metaphors are used to describe the new, the nearly-indescribable. When a metaphor is so common that people usually take it for granted, it is called a dead metaphor. A dead metaphor is a commonly used metaphor which has become a part of ordinary language, and is treated as any other word. Speakers are normally unaware that they are even using a metaphor. When the metaphorical aspect has worn off, and the metaphor is dead, the word becomes a polyseme - the different meanings co-exist side by side, the context determining the appropriate translation.

Current language is littered with dead metaphors, it is a tissue of dead metaphors. Like the climatic traces of the past is conserved in the antartic layers of ice, the linguistic structures of the past are conserved in the tissues of language. Cultural metaphors such as the 'mouth of a river', 'neck of a bottle', 'paying attention' and the 'leg of a chair', are dead metaphors which have become lexicalized (or frozen) into the language as literally true. The word 'Understanding' itself is a dead metaphor, having its origins in the idea that "standing under" something was akin to having a good grasp of it or knowing it thoroughly. Originally, metaphor ($\mu\epsilon\tau\alpha\varphi o\rho\alpha$) was a Greek word meaning "transfer". As George Lakoff has pointed out [87], a metaphor is a mapping from one conceptual domain to another, and not only a poetic figure, but the fundamental way we comprehend abstract things. It is [87] "principally a way of conceiving of one thing in terms of another, and its primary function is understanding".

regular & irregular Verbs

But metaphors are not the only dead fossils in language. Steven Pinker, psychology professor at Harvard University, has tried to understand the evolutionary origin of regular and irregular verbs in his book "Words and Rules"[122]. Regular verbs like walk and smell form the past tense by adding -ed. Irregular verbs follow no rule : the past of spring is sprang, but the past of cling is not clang but clung, and the past of bring is neither brang nor brung but brought.

Bascially his theory says that irregular verbs, which seem to follow no rule or pattern, are fossils of ancient rules, like the Pyramids of Giza and Macchu Picchu which are fossils of the ancient Egyptian and Inca culture. Historical survivors of what were once systematic rules. Rules so old that we can't remember they existed. The indo-european language, the ancestor of Hindi, Persian, Russian, Greek, Latin and English, had rules that replaced vowels, for example the past of senk (sink) was sonk.

The irregular verbs belong to the oldest verbs of a language, the regular verbs of the past are the irregular verbs of today. Through rules we reshuffle and combine words and syllables to bigger words. These products of rules can survive the original rules, because the human mind can compensate the missing rule through context, lexical and semantic clues. The human mind uses two systems: the sensoric and motoric, semantics and syntax, lexicon and grammar, words and rules. Irregular verbs use more the sensoric part, regular more the motoric part.

During the evolution of language, once vivid and new metaphors became dead metaphors and part of language, and the meaning of words changed (semantics). But the rules (syntax) also evolved, once vivid regular rules became dead irregular rules, and as a result we have irregular verbs such as "go, went, gone".

Every time a metaphor 'dies' and is transfered to the stable system, the number of different meanings is increased. Similarly, every time a rule 'dies' and is transfered to the stable system, the number of different irregular rules is increased.

2.4 Unified Modeling Language

Transfer Mechanisms

In the case of long-term memory and language, the transfer mechanism to the stable system is connected to learning, habituation and repetition. Another possible mechanism for the transfer and transformation of information from the flexible to the stable system of a CAS can be the 'merging' and 'splitting', 'melting' and 'isolating' or the 'separation' and 'aggregation' of agents (see [64] for a recent book about agent 'melting and splitting' in computer science, although the terms here are used in a slighty different context). These fundamental operations can be used to transfer complexity from the agent to the CAS or vice versa.

Reuse Mechanisms

In order to describe this in detail, a short explanation of the notations or operations in object oriented programming is useful. In the following we use the basic types of reuse mechanisms in object-oriented programming to define and describe different types of complexity and their evolution. According to the classic 'Gang of Four' Book (the book about "Design Patterns" from Gamma, Helm, Johnson and Vlissides [55]) , and the elements of the Unified Modeling Language (UML, see `http://www.omg.org/uml/`), the basic types of reuse mechanisms for objects in object-oriented programming are

- Association
  reuse by a general relationship between instances of the two classes. There is an association between two classes if an instance of one class must know about the other in order to perform its work.

- Inheritance
  reuse by subclassing, lets you define the implementation of one class in terms of another's

- Aggregation (or Composition)
  reuse by assembling or composing objects to get more complex functionality

- Delegation
  reuse by connecting methods : a object that receives a request delegates operations to another object

Association is the most general form, inheritance and aggregation are an essential part of every object-oriented language, and delegation is the most complicated mechanism related to event-handling. Inheritance and aggregation are complementary and supplementary to one another. Inheritance separates objects, aggregation merges objects. All four elementary operations are depicted in a diagram as a link connecting two objects or classes.

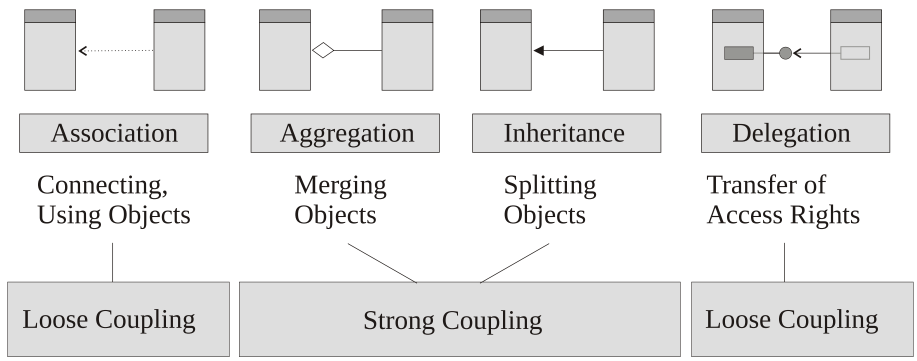

Fig. 11 UML Operations

Inheritance: 'to be'

Aggregation, inheritance and delegation influence each other. The degree of aggregation and composition on the one hand, and inheritance and specialization on the other hand determines the amount of necessary delegation. Through inheritance objects become objects of a certain class, and agents become agents of a certain type. The more such an object 'is' of a particular class or type, the more it needs to delegate special tasks to other objects, and the more special tasks are delegated to it. Strong inheritance and specialization require delegation and division of labor.

Aggregation, Delegation: 'to have'

Through aggregation objects or agents can delegate tasks to internal objects. They 'have' access to private objects and internal sub-agents. Aggregation increases the internal standard capabilities, delegation increases the external or auxiliary possibilities. Aggregation and delegation are the glue which keeps agents and objects together, and they are closely related. Aggregation in agents leads to internal delegation, delegation between agents leads to external aggregation. Through delegation objects or agents can gain access rights to methods of other public objects and external agents (delegation usually works with method pointers) and they 'have' the right to access methods of other objects.

With inheritance and aggregation/delegation you can reach the same purpose. For instance using inheritance, a rectangular window-class 'is' a (rectangular) subclass of a general window, whereas windows using delegation 'have' access to a class that knows how to draw a rectangular window.

Since inheritance is associated with ‘to be’ and aggregation with ‘to have’, a change from aggregation to inheritance or vice versa is like a transition between ‘to have’ to ‘to be’. We will examine this kind of transition in detail in the next sections.

‘to have’ and ‘to be’

Strong specialization through repeated inheritance increases the necessity for delegation in the system. It relocates the boundary for internal/external delegation. After a specialization, tasks which have been delegated before to own, aggregated, internal sub-agents must be delegated to external agents. The ability of the agent to delegate general tasks to its own, internal sub-agents is reduced, and the agent is restricted to a certain role or type. A restriction of agent rights and tasks through inheritance and specialization is often accompanied by an extension of access rights to other agents in form of delegation. Specialization is like a change from internal to external delegation.

Balance between Rights

Through specialization of single agents, the MAS or CAS is becoming more complex. A specialization from a normal position to a specialist is like a transition of complexity from an agent to a CAS. The role or task boundary between agent and CAS is shifted, the agent is restricted to certain tasks, areas or fields, whereas the overall system is expanded to include new agent forms, and the diversity in form of the number of types and classes in the CAS increases. Through specialization the agent loses power and rights, but its capabilities in a particular field increase. Becoming a specialist, expert or master in a particular field is like a transition from ‘to have’ to ‘to be’.

Specialist, Expert, Master

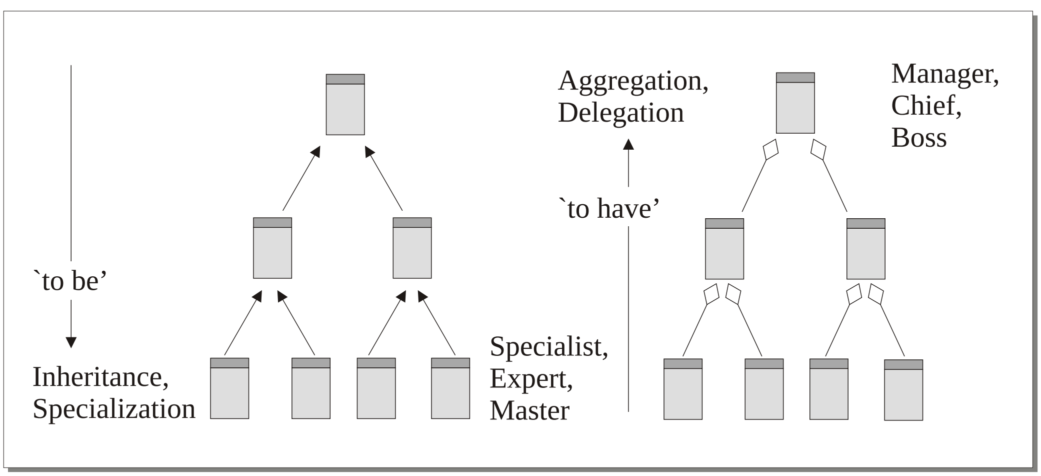

Fig. 12 Inheritance and Delegation

Through aggregation and internal delegation, an agent is becoming more complex, if it is able to gain the complexity of a whole CAS. A promotion from a normal position to a manager, chief or ruler is like a transition of complexity from a CAS to an agent. A whole system is merged to form a unit and restricted to do what the manager says, who delegates the tasks to the corresponding agents. The inclusion of new special agents through aggregation reduces the need for external delegation and increases internal delegation. Aggregation is like a change from external to internal delegation.

Manager, Chief, Boss

The new manager-agent gains the power, rights and complex capabilities which the agents of the system lose, but the special capabilities of the manager itself in a particular field decrease. Becoming a manager, chief, boss in a particular field is like a transition from 'to be' to 'to have'. The managers at the top 'have' the possibilities to delegate tasks to every agent in the system.

	Agent → CAS	CAS → Agent
Agent Transition	to have → to be to become a specialist	to be → to have to become a manager
Spatial Order, Agent Types and Classes	Separation, Specialization, Splitting	Accumulation, Aggregation Merging
External	expansion of CAS to include and create new agent forms	restriction of CAS to do actions of agent
Temporal Order, Capabilities	Specialization, Segregation of power and capabilities	Generalization, Aggregation of power and capabilities
Internal	restriction of agent rights to use all capabilities	expansion of agent rights to gain more capabilities

Tab. 9 Transfer of Complexity

The two basic operations, aggregation (composition) and inheritance (specialization) are the crucial factor for the growth of complexity. Inheritance is related to Arthur's 1st mechanism mentioned at the beginning, the increase of structural sophistication of the system outside of the agent. Aggregation is related to Arthur's 2nd mechanism, the increase of structural sophistication inside of the agent.

Inheritance, Aggregation

They are complementary merging and splitting operations for objects and agents, operations which change the agent boundary. Any operation with changes a boundary can cause a transfer or emergence of something. Therefore aggregation and inheritance can be used to transfer complexity between different dimensions and subsystems.

2.5 Aggregation and Inheritance

Internal Dimension, Aggregation

In order to resume the discussion about the transfer of complexity between different subsystems or components, assume that the flexible system is the agent itself, who has some inner dimension as in the figure below, and the stable system is the role- or class-structure of the system. The internal or inner dimension of a single agent characterizes for example the different methods and strategies the agent can apply, and becomes visible through its action and behavior in the course of time. You can call it the 'temporal' or 'time'-dimension.

Increase of structural sophistication inside of the agent (Arthur's second mechanism) is reached by adding new capabilities, methods and sub agents. Internal complexity is increased by aggregation or composition, the melting and merging of sub agents through learning and adaptation. Aggregation takes place within a class, object or agent.

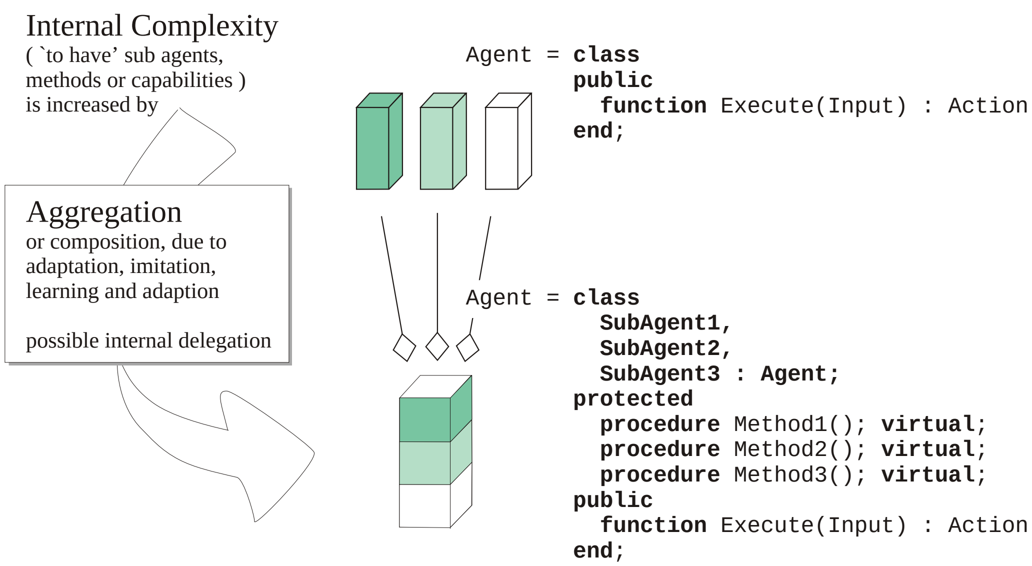

Fig. 13 Internal Complexity

Merging or aggregating of agents means generally a number of (sub-) agents is aggregated or conglomerated into a single agent. The selected agents are accumulated, assembled, condensed, combined, united or just come together to become a part of a larger group. They work together and can communicate directly with each other. The number and type of the different aggregated agents determines the internal structure or inner complexity of the agent.

The external or outer dimension, the role- or class-structure of the stable agent system, is visible in the 'spatial' or 'space'-dimension. The type, species or class to which an agent belongs determines its position on the external reference system.

External Dimension, Inheritance

Increase of structural sophistication outside of the agent (coevolutionary diversity, Arthur's first mechanism) is reached by adding new species, niches or agent forms. External complexity is increased by inheritance and specialization, by means of class and species formation, and through splitting and separating of agents. Inheritance takes place outside of an agent, it changes the class of an agent, which is constrained to a certain class or role. John H. Holland calls this process 'Constrained Generating Procedures' (*Cgp*) [73]. The agents are clearly separated from each other and each agent is constrained to a certain class or role.

Constrained Generating Procedures

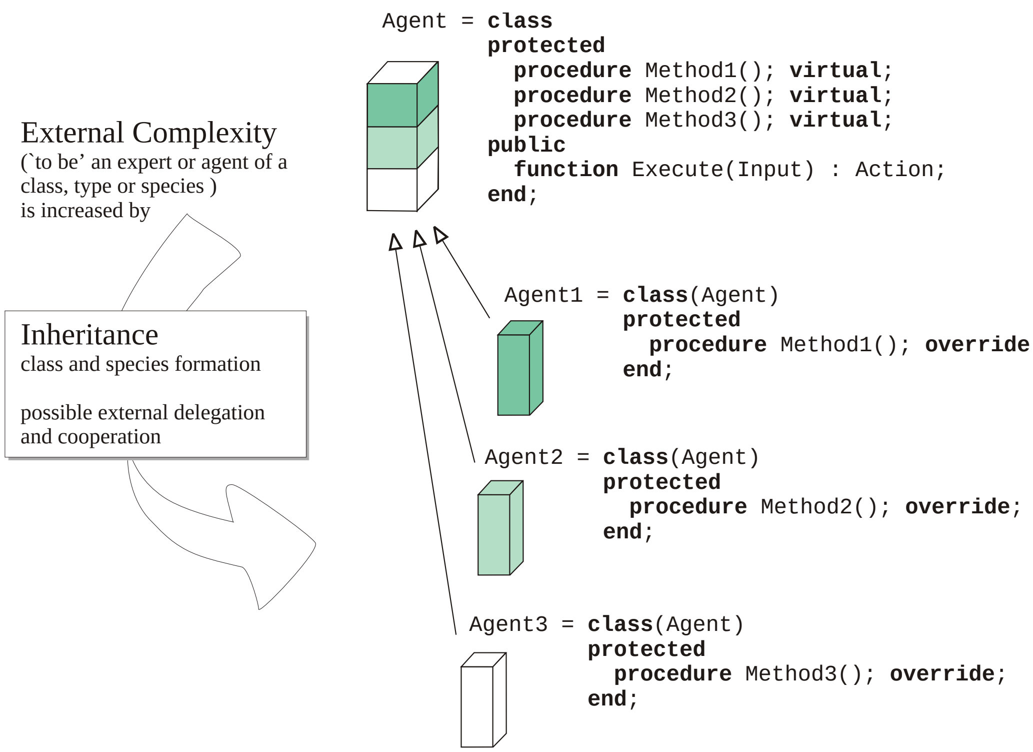

Fig. 14 External Complexity

External Class & Internal Structures

The external and the internal dimension in a MAS, and accordingly the flexible and the stable system can have many different names, for example you can distinguish between interagent and intraagent complexity, interspecies and intraspecies complexity, private and public regions, external and internal regions, or between phenotypic and genotypic systems. John Tyler Bonner [15] calls these two systems somatic and genomic. Somatic complexity is internal, within an individual multicellular organism or agent, and genomic complexity external, between individual organisms or agents in a community. We use the language of object-oriented programming, where the internal complexity in classes is related to the capabilities, structure and functions of an agent or object, and the external complexity is defined by the class structure and agent forms of the system.

The Agent Boundary

The boundary or border between the two systems is always the agent itself. The agent boundary is a natural boundary for all MAS. It is the shared or common interface (or contact surface) of the inner and the outer dimension. The inner 'agent' dimension is defined as everything inside the agent, the complete phenotype structure. The outer 'system' dimension is defined as the properties and features visible from the outside, which are determined by the genotype structure or the agent class.

A sudden change in the boundary of both systems causes a transfer of complexity between them. As we will see in the next section, the means mentioned to increase the complexity in the two different systems (aggregation and inheritance) are in fact means to transfer complexity from one system to another. They act on the agent boundary. Aggregation of agents is a gluing or merging operation, inheritance is a splitting or cutting operation.

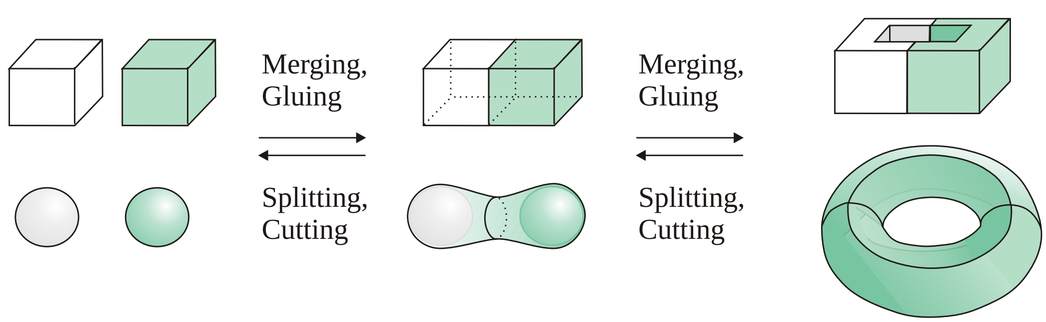

Fig. 15 Topological Operations

Merging and splitting operations of agents involve inherently a topological change of the agent boundary, and a change associated with a boundary is always closely connected to the emergence and appearance of objects. Merging or gluing increases the volume and the number of objects in the inside or the internal world of the agent, splitting and cutting increases the number of objects and elements in the external world outside of the agent.

The boundary is the set of elements which the outside and the inside have in common. In topology, the boundary ∂S of a set S of a topological space is the set's closure minus its interior. You can stretch, bend and deform a shape as much as you want to without changing its topology. Bending, twisting, and stretching are allowed, but cutting and gluing are not. The "surgery" operations merging (gluing) and splitting (cutting) change the topology of an object, and separate the different topological equivalence classes.

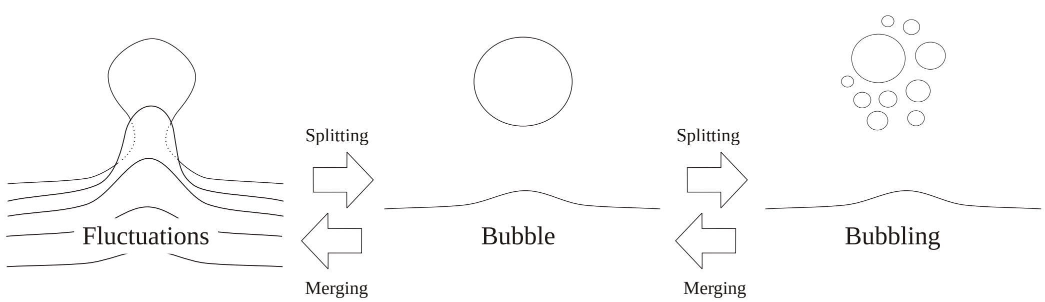

Fig. 16 Boundaries and Bubbling

Therefore it is not surprising that merging (aggregation, composition of agents) and splitting (inheritance, specialization of agents) operations are responsible for the emergence of complexity. They inherently change the boundary of an agent, and the emergence of a new agent requires the change of its definition, bounday or interface with the agent system. In fact, the emergence of a new kind of system is always possible at a clear boundary of a system.

Merging & Splitting

The transfer of complexity between the two different systems, the flexible and the stable system, the inner 'agent' dimension and the 'outer' system dimension, can be reached through merging and splitting, gluing and cutting, aggregation and inheritance, generalization and specialization. This kind of transfer usually involves merging in one dimension, which reduces complexity, and splitting in the other, which increased complexity again.

2.6 Emergence and Transfer

Aggregation and composition transfer complexity from the outer to the inner dimension. Previously different and separated objects, which have been splitted somehow before in the outer dimension, are merged inside the agent or object. Aggregation is a splitting in the outer dimension followed by a merging in the inner dimension. The complexity in the object increases, whereas the complexity outside the object decreases.

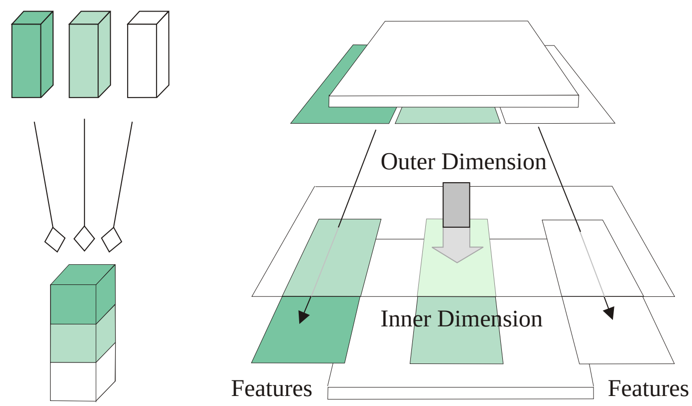

Fig. 17 Transfer from outer to inner dimension

The effect of repeated aggregation is high accumulation and self similarity. Aggregation, accumulation and composition lead to big agent-groups, which are contained in larger agents. These agents in turn can be combined to form even bigger agents etc., until a fractal or self-similar structure emerges.

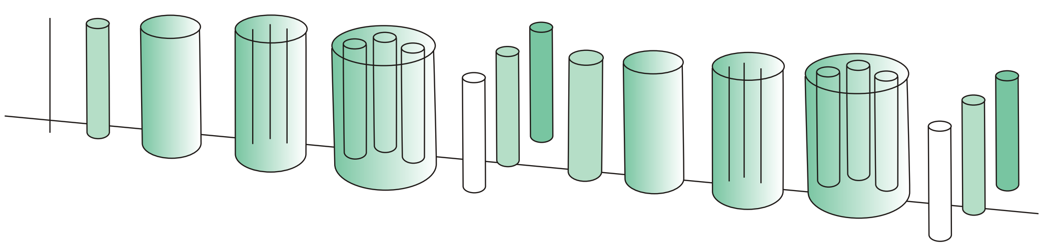

Fig. 18 Self-similar structure

At the beginning of this chapter we have argued that small jumps in complexity are caused by (1) new agent forms/species and (2) new agent abilities/capabilities. Aggregation leads to the second mechanism, agents become more complex through new abilities in the inner dimension. Of course aggregation creates more complex structures if the aggregated agents are different from each other. Therefore we need the complementary operation, specialization or inheritance. Inheritance leads to the first mechanism, CAS become more complex through new agent forms in the outer dimension.

If a single object or class (which has been extended or merged before in the inner dimension) becomes to large, it can be splitted into two or more different classes, and each class inherits certain methods or capabilities. This is the basic principle of inheritance in object-oriented programming, but can be observed in some Design Patterns, too, for example the 'State' and 'Strategy' Design Patterns [55], which describe the condensation of states and strategies into isolated objects.

Inheritance and specialization transfer complexity from the inner to the outer dimension. A complex agent is splitted into several simpler ones and new agent forms, types and classes appear.

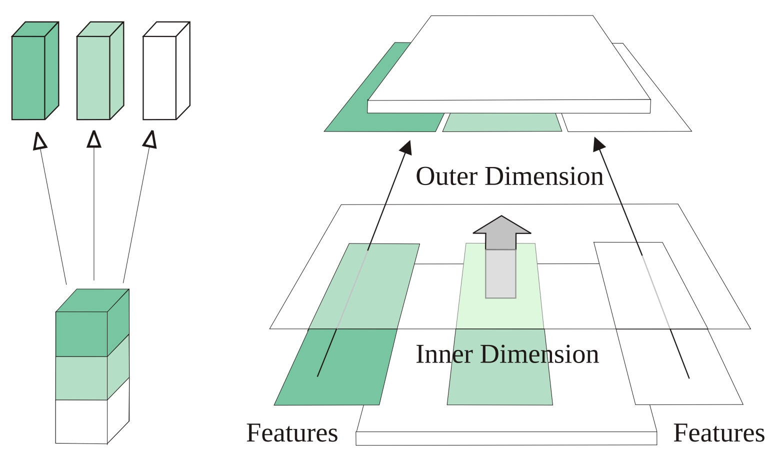

Fig. 19 Transfer from inner to outer dimension

If you consider only one dimension, complexity seems to appear or disappear suddenly. If you look at both dimensions, it vanishes in one and appears in the other. Complexity is transfered through inheritance from the inner dimension of the agent to the outer dimension of the CAS, because the new agents or objects are simpler (have reduced internal complexity) but more diverse (have increased external complexity). Emergence as Transfer

The transition from the inner to the outer dimension is the transition from 'to have' to 'to be' [54]. Before the transition, the agents *have* a lot of possibilities and capabilities. After the transition, the agents *are* agents of a certain class who play a certain role and *are* constrained to the actions of that role. Suddenly new agent roles, classes or types appear, which increase the complexity. The price for this emergence of complexity in the outer dimension is the reduction of complexity in the inner dimension. Complexity emerges in the outer dimension only because it is transfered from one dimension to another, the overall complexity is conserved.

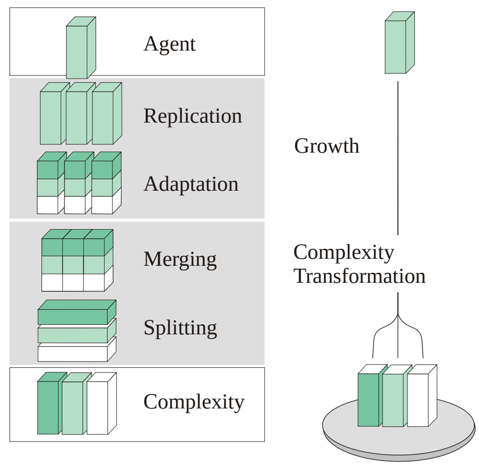

Fig. 20 Emergence of Complexity

We become what we are through a sequences of major transitions: we become a pupil, a student and an employee when we go to school, learn at the university or work for a company. In the school as a pupil you have all subjects and possibilities. In the university as a student, you study only one subject and have limited possibilities. As a university professor or an employee for a company, you work in a certain special area of a particular subject.

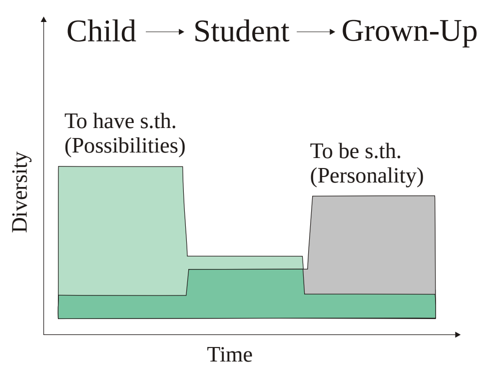

Fig. 21 Process of Becoming

Graduations are the rituals that mark the points of transition from 'to have' to 'to be' and the abrupt changes which accompany them. The different phases of life are separated by ritual ceremonies and graduation rituals. The effect of repeated graduation and inheritance is of course high specialization. Agents become experts of a smaller and smaller areas until they know everything about nearly nothing. Inheritance is an irreversible one-way process.

Once an object or agent has specialized itself through inheritance, it is usually not used for other purposes. For an agent, a series of transitions through inheritance and specialization leads to an accumulation of complexity in a particular field or area. The longer you work in the same area, the more you become an expert, but the smaller are the possibilities you have.

Repeated transfer from internal to external complexity through inheritance and continuous specialization results in phylogenetic trees, similar to the phylogenies (trees of evolution) known from biological evolution. The leafs of the hierarchical tree are highly specialized agents for a particular subject or purpose.

Hierarchical Phylogenetic Trees

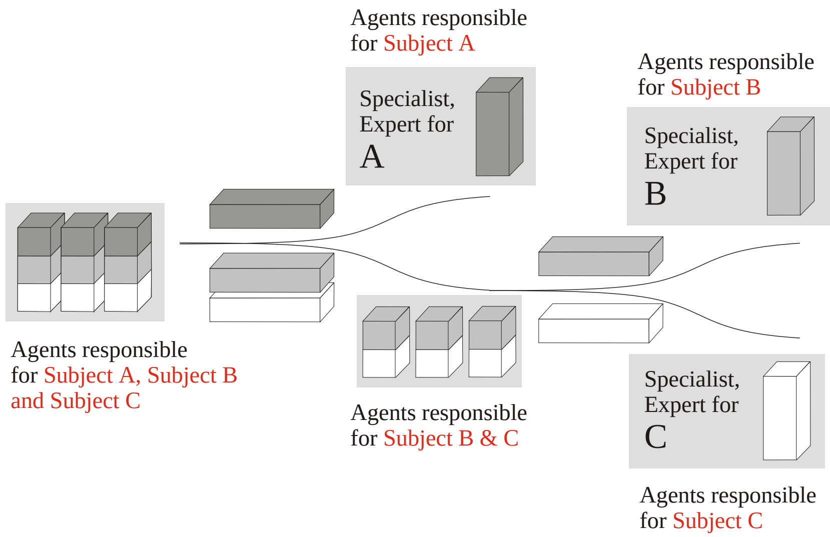

Fig. 22 Repeated Specialization & Inheritance

In modern programming languages, the integrated development environments offer huge hierarchical object-oriented class libraries, for example the MFC (Microsoft Foundation Class Library, Visual C++), the VCL (Visual Component Library, Delphi) and the FCL (Framework Class Library, .NET). What an object oriented programmer does is basically an aggregation of these elements: he picks and selects certain objects of these class library trees, accumulates and aggregates them to a program, and connects the elements by delegation and event handling.

Hierarchical Class Libraries

Merging and splitting through aggregation (composition) and inheritance (specialization) are complementary processes. Modern programming environments take over the inheritance part and offer already a full tree of inherited classes, you just have to do the aggregation part. The full tree of a hierarchical class library has a very high (external) complexity, whereas a typical template for a primitive agent or application has a very low (internal) complexity. Through a continuous process of merging and aggregation, complexity is transfered from the outer to the inner dimension and the application growths. Splitting and specialization of large classes result in turn in a transfer from the inner to the outer dimension.

Likewise biologists know and possess the full phylogentic tree of species. Therefore one of the main questions in ecology and evolutionary biology is the question of aggregation and cooperation: why do selfish agents cooperate with each other ?

Aggregation and inheritance (or class formation) are complementary and supplementary to each other. Aggregation increases internal diversity, inheritance external diversity. New agent abilities (2) are gained through aggregation, adaptation, learning and increased internal diversity. Based on these extended methods and abilities, new agent forms and species (1) appear through inheritance which increase the external diversity of the system. New agent forms in turn enable the aggregation of new agent groups.

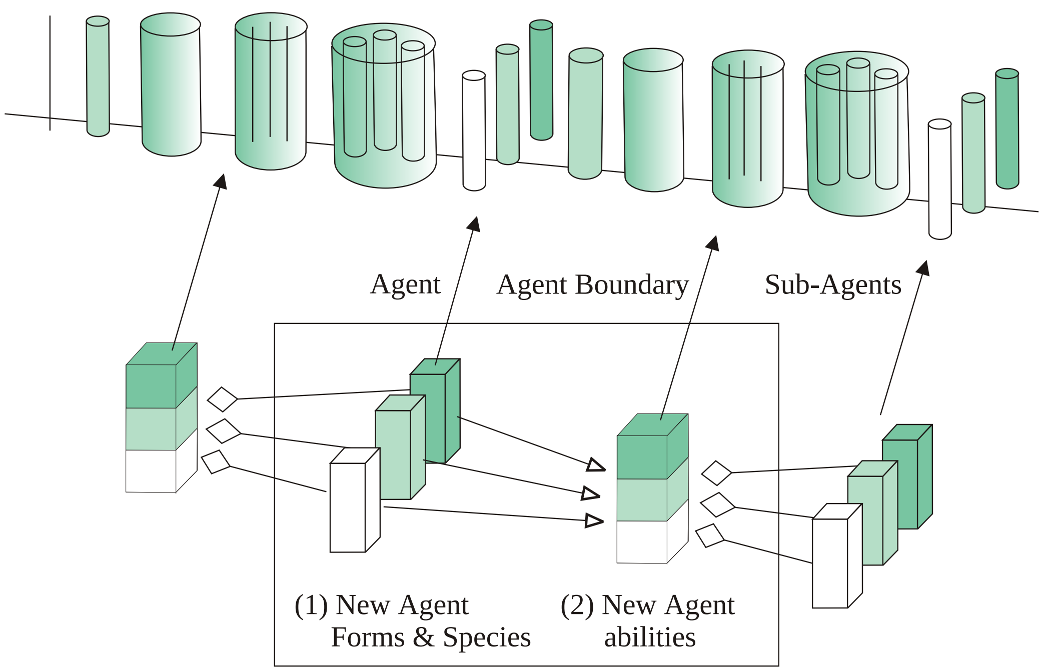

Fig. 23 Chain of Merging and Splitting

Cooperation *and* speparation, aggregation *and* inheritance, merging *and* splitting are needed to increase complexity. If you combine both mechanisms, you get a long continuous chain or a tree of complexity transfers. In every transition step accross an agent boundary complexity is transfered between different regions, through aggregation or merging in one dimension and separating or splitting in another. At the bottom level there is usually a process of merging and splitting, too, for example in form of variation and recombination.

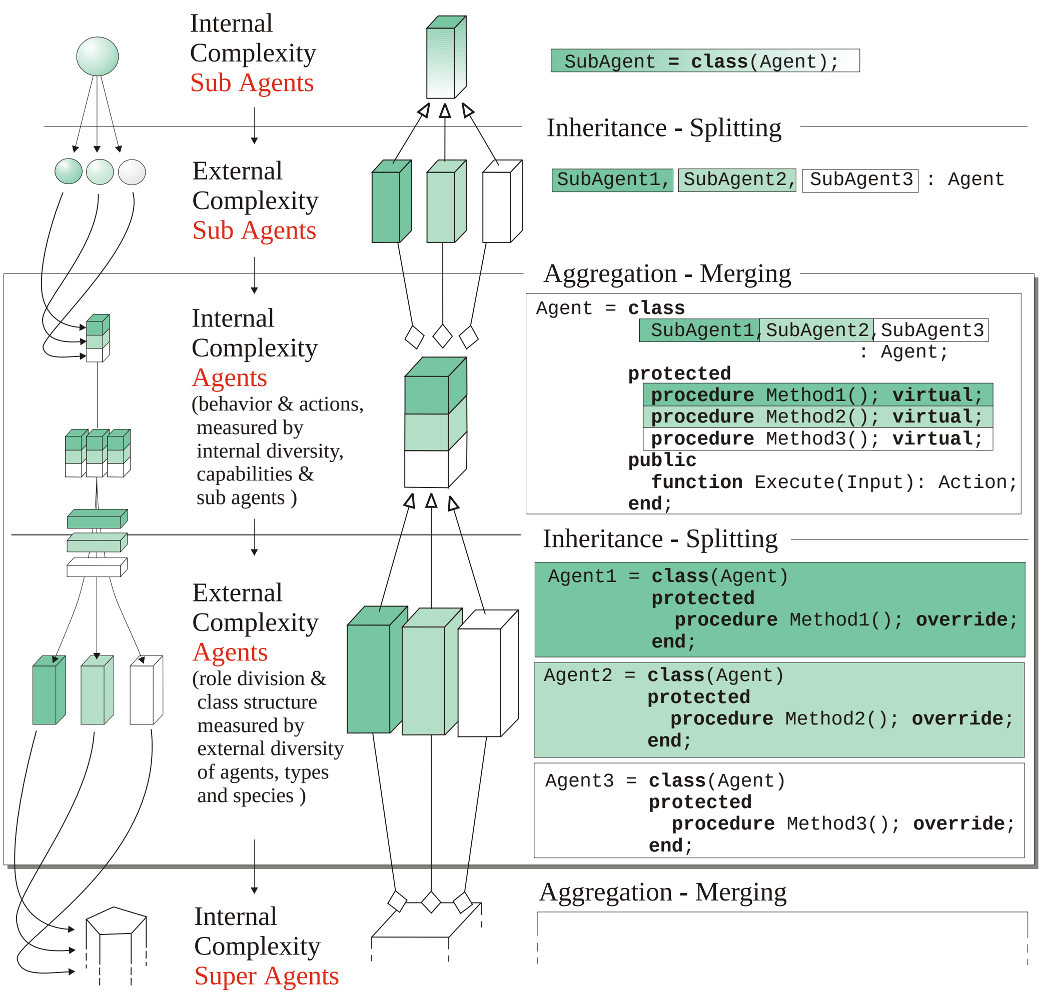

Fig. 24 Continuous Transfer of Complexity

Although feedback loops in this linear chain or hierarchical tree are possible, normally the chain is not closed and the resulting graph contains no cycles or feedback loops. Yet a feedback loop from an upper level to a lower level can be found in natural examples of group formation and election. In the language of design patterns it is described by the Composite Design Pattern [55]. It is a very common pattern in Object-Oriented Programming (OOP). A composite object with several aggregated components is again an object of the component class, the whole is of the same class as the parts. Examples for it can be found in the next chapter in the section about "States".

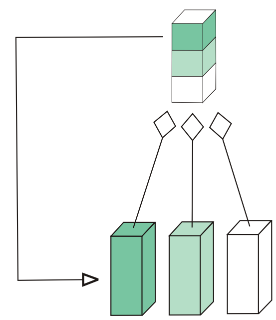

Fig. 25 Composite Design Pattern

External Delegation requires Cooperation

Inheritance needs aggregation: the transfer of complexity from an inner to an outer dimension makes only sense if the specialized objects are aggregated, assembled and connected, if the agents work together, if they can delegate tasks to each other. If the different agents can not be connected or loose contact, the external diversity is worthless, because the agents can not delegate tasks to other agents in this case. External delegation requires cooperation. Agents are autonomous and selfish by default. Therefore group-formation, aggregation and cooperation is a necessary condition for the emergence of complexity in agent-based systems. How and why agents form a group, the different kinds of reciprocity and the origin of cooperation is discussed later in chapter four.

Internal Delegation requires Specialization

Aggregation needs inheritance: the transfer of complexity from an outer to an inner dimension makes only sense if the aggregated agents are specialized. If totally equal agents are merged, the power of the group is raised, but the overall inner complexity is not substantially increased. There is a lack of possible internal delegation among identical agents. Internal delegation requires specialization. Examples of specialization among agents are discussed later in chapter three.

Through a transfer process due to aggregation and inheritance or merging and splitting, no complexity is created or destroyed, the complexity in the overall system is constant. Similar to the 2nd law of thermodynamics, which says that the order of closed and isolated systems does not increase, there seems to be a conservation law for complexity, which says that the complexity of closed and isolated systems does not increase.

2.7 Complexity and Energy

The conservation of complexity can be compared to the conservation of energy. Physicists define the word energy as the amount of work a physical system is able to do. Energy, according to the definition of physicists, can neither be created nor consumed or destroyed. For example, if the kinetic energy increases, then its potential energy decreases by the same amout.

The conservation of energy is one of the basic physical principles. Just like energy can be transfered from one form to another, complexity can be transfered from one dimension to another - quite interesting, because complexity is closely related to entropy, and entropy in thermodynamics with energy, and all three quantities are abstract terms.

	Ability to	Fight against	Based on	Related to
Thermodynamic & Physical Quantities				
Energy (free Energy)	* do Work * change things	Force	temporal integration of Power	Power, Work
Entropy	* change * adapt * forget	Order, Regularity	heat added / temperature at which it is added	Disorder, Randomness, Chaos
Psychological & Mental Quantities				
Creativity	* be original & imaginative * generate novel idea	Simpleness, Monotony	Diversity & Novelty of ideas	Diversity, Novelty
Intelligence	* acquire and apply knowledge * think and understand	Ignorance, Nescience, Stupidity	Complexity of cognitive Schemata	Complexity

Tab. 10 Complexity and Energy

Like energy, which can appear in different forms, complexity can appear in different forms: internal/external, somatic/genomic, genotypic/phenotypic, etc .... In later chapters we will see more similarities and analogies between complexity and energy. Complexity can be transfered *and* borrowed like energy. Borrowing of energy/complexity is for example necessary for tunneling processes. More about this later in chapter five.

2.8 Cladogenesis as Transfer

The transfer from internal to external complexity is related to the emergence of new species in biology: intraspecies complexity within a species is a form of internal complexity, interspecies complexity between different species is a form of external complexity.

Definition of Species

Species are according to Encyclopædia Britannica independent evolutionary units which share a common gene pool. Such units are groups of populations reproductively isolated from one another, represented by a lineage in the phylogeny (a tree showing the evolution of a system).

Emergence of new Species

The emergence of a new species, which is marked by a bifurcation or lineage splitting in the phylogeny, is explained in the theory of evolution by a two-stage theory. The first step to an emergence is caused by an (accidental) interruption in the gene flow between two populations, for example through geographic separation and isolation. The two genetic isolated groups then become more and more different as a product of natural selection.

Intraspecies Complexity

Every living organism is unique. You will not find two animals, plants or humans who are exactly identical in nature. Evolutions produces no clones. Even animals of the same species can be distinguished if you observe carefully enough. In a biologcial evolutionary system, the diversity of the shared gene pool is a measure for the "internal" complexity. The diversity of the different species is a measure for the "external" complexity. A transfer of complexity takes place if a species or lineage is split into two.

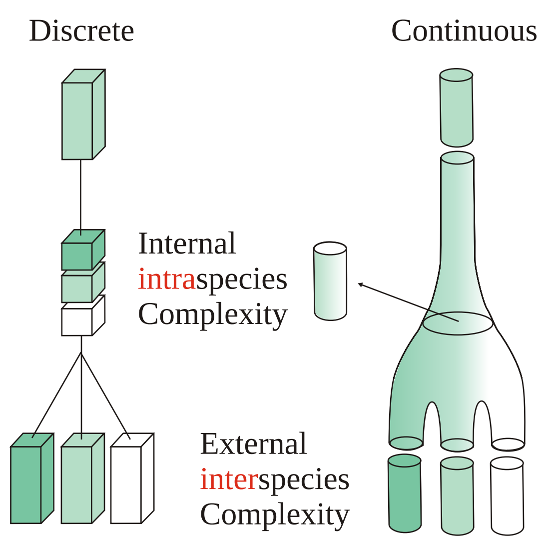

Fig. 26 Discrete and Continuous Transfer of Complexity

Transfer of complexity from continuous intraspecies complexity to discrete interspecies complexity is named cladogenesis in biology. Evolution within a species or lineage is named anagenesis, evolution of new species when lineage splits into two or more separate lines is named cladogenesis. Cladogenetic evolution increases diversity of species, anagenetic evolution increases diversity in a species.

Definition of cladogenesis & anagenesis

The effects of anagenesis are often not fully recognized, because their are unspectacular and more familiar. On the one hand we take for granted that everyone is a unique and individual person, but on the other hand we are surprised if farmers and zoo attendants can distinguish between every individual animal of a group. We usually do not recognize the diversity within a species except our own one (especially if they are new or strange), because the differences between individuals in a species are smaller than the differences between individuals of different species. Only if suddenly a species or lineage splits into two, the internal diversity becomes visible through new lineages, species or agent classes.

Own species vs. other Species

Individuality & Similarity

Just as animals of little known species are thought to be identical, languages as Englisch, Spanisch, Italic, French, Russian and German are considered as single languages. But there are several variations and dialects of each language. German dialects are for example Niedersächsisch, Friesisch (which is similar to Englisch), Fränkisch, Hessisch, Sächsisch, Pfälzisch, Bayerisch, Alemannisch and Schwäbisch. We know the dialects of our own native language, but we are usually not aware of the countless dialects of other languages (for example Russian or Chinese). We see the intraspecies complexity of our own language, but only the interspecies complexity of other languages.

Dialects & Languages

If the phylogenetic tree of evolution is compared to a river, then we see the branch or creek of the river we live in as a full stream, but the other branches only as thin line. Richard Dawkins has coined in "River out of Eden" [31] the metaphor of a genetic river. The source is the first DNA replicator, and the river is a stream of genes stretching back from all of us to this original ancestor:

Genetic River

> "The river of my title is a river of DNA, and it flows through time, not space. It is a river of information, not a river of bones and tissues; a river of abstract instructions for building bodies, not a river of solid bodies themselves."

Genes in different branches (different species) do not mix, whereas genes confined between the same river banks mix and combine in individuals of a given species. Like the water molecules of a river streamline share common temporary clusters, the genes of a spieces share a common temporary body.

> "...the genes that survive in the river will be the ones that are good at surviving in the average environment of the species, and perhaps the most important aspect of this average environment is the other genes of the species; the other genes with which a gene is likely to have to share a body..."

His river network or basin corresponds to the phylogenetic tree of species, the tree of life. The emergence of new species corresponds to the emergence of new creeks or branches during a branching or bifurcation of the river. The 'tree-width' or width of a branch is a measure for the diversity within a species. Thus intraspecies complexity within a species is the width of the stream (or more precisely the width of the particular branch), interspecies complexity between different species is the number of river different streams, branches or creeks.

Starting with Eukarya, organisms consisting of one or more eukaryotic cells, the tree of life splits into Bikonts (green plants) and Opisthokonta (fungi, animals), which in turn split again in Chordates, Vertebrates, etc. In the 'Tree of Life' special issue of Science, June 2003 [44], was a wonderful picture of this vast tree of life. Have a look at the tree of life here http://www.sciencemag.org/feature/data/tol/. Some nodes are clickable ! The complementary green tree of life, a phylogeny of plants which was also discussed in the special issue [116], can be found at http://ucjeps.berkeley.edu/TreeofLife/.

TOL
Tree of Life

For the memetic evolution of culture and memes we can construct similar evolution trees and phylogenies, but they are less familiar. Some of them can be found in the next chapter as examples.

During a bifurcation or branching of a river or circuit, no current is lost. Kirchoff's second Law says the sum of the currents entering a node must equal the sum of the currents exiting a node. Similarly, we have seen that during ordinary lineage splitting (cladogenesis) or bifurcations of phylogenies no complexity is lost. The increased complexity through the emergence of new species or agent classes in lineage splitting does not appear out of nothing. A lineage can only branch and split into two new lineages, because it has an extension, a 'tree width', which is a measure for the diversity and complexity of the lineage. The sum of tree widths before and after the bifurcation stays

Kirchoff's
second Law

constant. During the emergence of new species no complexity is created, it is only transfered or transformed from an intraspecies, harder visible form, to an interspecies, easier visible form of complexity. The sudden emergence of new complexity through the emergence of new species is an illusion.

2.9 Vertices and Interactions

Lineage splitting or bifurcations of phylogenies correspond to vertices in Quantum Field Theory. A Vertex is a singular interaction point at which particles branch and rejoin. In ordinary Quantum Field Theory interactions among elementary particles occur at definite points in spacetime. When a single elementary particle breaks in two or two particles join into one, it occurs at a definite moment in spacetime, marked by a vertex.

Quantum Field Theory

In string theory [158], the propagating point particle is replaced by a propagating string, and a diagram has no singular interaction points or point vertices. When a string breaks into two strings, there is no definite moment of interaction. You can not say when and where it occurs precisely.

String Theory

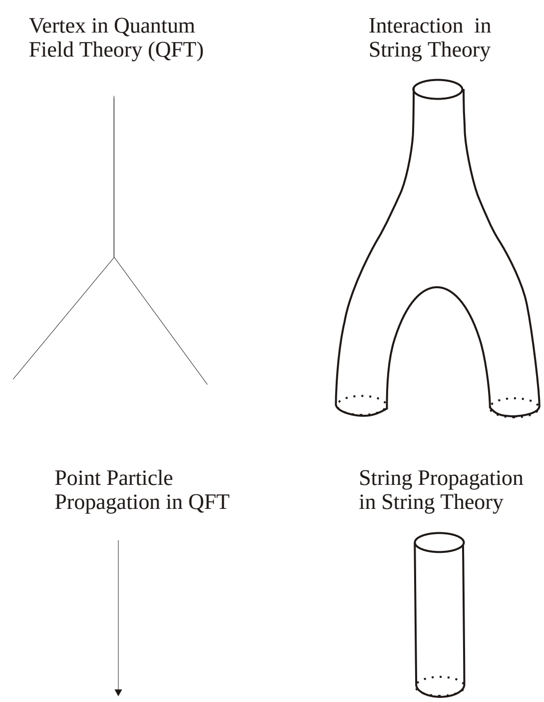

Fig. 27 Vertices and Interactions

Edward Witten from the Institute of Advanced Study in Princeton gives a good illustration of string theory in his public lecture "Duality, Spacetime and Quantum Mechanics"[3]. The success of string theory is partly based on the fact that it does not allow the sudden emergence of particles. It has no singular interaction points or point vertices which allow the sudden appearance and disappearance of particles. Point particles and vertices cause many of the known problems (singularities and infinities) of ordinary Quantum Field Theory. They were partly solved by complicated renormalization techniques. But Quantum Field Theory still has a problem, it can not explain why point particles can interact with one another through point vertices. How can a point-particle split into two particles if it has no extension ? String theory fills this gap of explanation: interactions occur through a process of merging and splitting of particle "tubes".

Thus like branching points in evolutionary trees which describe the emergence of new species, vertices in Quantum Field Theory and String Theory which describe the emergence of new particles are related to a transfer of complexity, too.

Conclusion

Let us recapitulate the arguments of this chapter: In order to increase complexity permanently and to reconcile stability and flexibility, you need two systems, a stable and a flexible one, which are separated by a boundary, gap or interface. One of this natural boundaries is the agent itself. Sudden emergence of complexity is possible at this boundary, if complexity is transfered from the agent to the system (inheritance, specialization) or vice versa from the system to the agent (aggregation, composition).

The former type of emergence, the emergence of new species, is found in lineage splitting (cladogenesis) or bifurcation of phylogenies, if intraspecies complexity within a species is transfered to interspecies complexity between species. It s a transfer of complexity from the agent or species to the system through inheritance and specialization This is related to Arthur's first mechanism (1) the increase of structural sophistication of the system or coevolutionary diversity outside of the agent. Repeated inheritance and specialization leads to large evolutionary trees and phylogenies. Some unusual memetic examples can be found in the next chapter three.

The latter transition from the system to the agent through aggregation and composition is found in ordinary anagenesis, if individual agents of cer-

[3] see http://online.itp.ucsb.edu/online/plecture/witten/

tain species are getting more complex through learning and adaptation, or agents are getting more complex as a group through group-formation, aggregation and cooperation. This is related to Arthur's first mechanism (2) the increase of structural sophistication inside of the agent. Some examples can be found in the chapter four.

New digital Calculus

This chapter was a bit technical. In order to describe the emergence of complexity in Multi-Agent Systems in detail, it is necessary to use the right language and notation. The natural language to describe agents is the language of object-oriented programming (OOP). The two basic operations for objects and agents are aggregation and inheritance. Together they form the conceptual equivalent of the differential calculus in traditional mathematical analysis. Integration and differentiation are the basic tools to describe the properties of functions in terms of other functions, aggregation (merging, composition) and inheritance (splitting, specialization) are the basic tools to describe the properties of agents in terms of other agents.

Chapter 3

Examples

Morowitz [101] provides in his book 28 examples of emergence, from the neurons, cells, animals, mammals and humans to language, technology and philosophy. We consider in the following section especially the most interesting ones, the emergence of culture and life in nature. Culture in this context is defined by all the knowledge, values, institutions, behavior patterns and beliefs shared by a society. Together all these patterns create the unique ‘character’ and ‘personality’ of a society. Ancient cultures for example shared certain primitive beliefs, built large temples and monuments, communicated in now unknown languages, and used complicated hieroglyphic writing systems to record them.

Examples of Emergence

Life, language and consciousness are complex things and appeared through evolutionary transitions. Many of the major evolutionary transitions mark the emergence of new CAS. We come back to this complicated process later. But as we know from sociology, many of them are also connected to the division of labor between agents.

Complexity, which is transfered from a single agent to the system or group - from the character of the agent to the character of the group - is closely related to division of labor in sociology. The individual agent gives up freedom and flexibility and is constrained on certain tasks. The total group of agents gains in structure what each agent loses. The following examples show this division of labor in memetic phylogenies for different complex adaptive systems. Just as you can draw phylogenies (trees which show the evolution of living organisms) for genetic evolution and natural organisms (see http://www.sciencemag.org/feature/data/tol/), you can draw phylogenies for memetic evolution and cultural objects.

Memetic Phylogenies

3.1 Life

Definition of Life

There is no generally accepted definition of life. Of course there are many different physiological, biochemical, genetic or thermodynamic definitions. The genetic definition according to Encyclopædia Britannica is very simple and places emphasis on the importance of replication: a system capable of evolution by natural selection.

DNA, RNA, Proteins

Evolution relies on hereditary information carried by genes which are composed of nucleic acids or DNA. In cells, there is a division of labor between nucleic acids that store (DNA) and transmit (RNA) information, and proteins composed of amino acids that catalyse chemical reactions and form the structure of the body [144, 145]. DNA is necessary for producing Proteins. Proteins are necessary for replicating DNA. Who was first, DNA or RNA? The question is wrong, both simply co-evolved together from a common ancestor, ancient RNA enzymes.

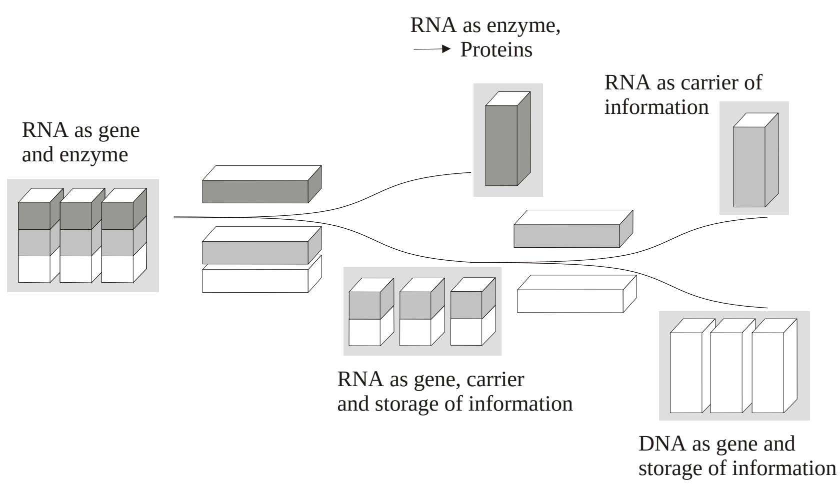

Fig. 28 Origin of Life

RNA as gene & enzyme, Ribozyme

Today, it seems plausible [145], "that there was at first no such division of labor and that RNA molecules performed both functions". RNA enzymes, ribozymes, can act like proteins. Ribozymes can acquire amino acids as 'cofactors', just like the messenger RNA is attached to certain amino acids during the construction of proteins in the translation process. These RNA enzymes of nucleic acids and amino acid cofactors split into protein enymes (made of amino acids) and messenger RNA (made of nucleic acids).

3.2 States

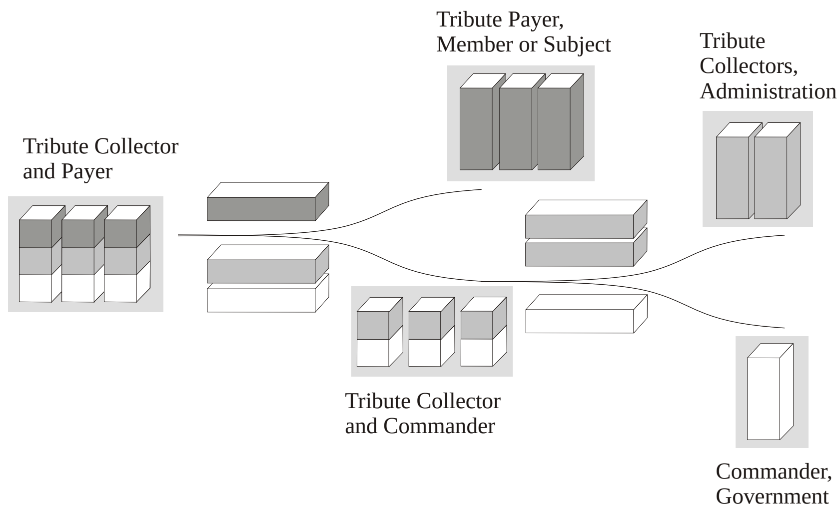

Fig. 29 Origin of States/Empires

Another example is the origin of states, empires and kingdoms. All of them are often based on taxes and tribute. The process of state formation and creation under the influence of taxes has been examined by Robert Axelrod in his tribute model [6]. With his tribute model (for "Building Political Actors") he captures the essential properties of power and explains the origin of states and empires. Power is the ability to act and to influence events. The power of an agent is his present means to obtain a certain goal. It depends on the number of agents which provide support and assistance due to a strong commitment or good relation. Thomas Hobbes has described this 1651 in his LEVIATHAN :

Taxes & Tribute

What is Power ?

> "The POWER of a Man, (to take it Universally,) is his present means, to obtain some future apparent Good. The Greatest of humane Powers, is that which is compounded of the Powers of most men, united by consent, in one person, Naturall, or civill, that has the use of all their Powers depending on his will; such as is the Power of a Common-wealth: or depending on the wills of each particular; such as is the Power of a Faction, or of divers factions leagued. Therefore to have servants, is Power; To have Friends, is Power: for they are strengths united".

An agent in possession of control or influence over others has naturally more power than a single isolated agent who is not supported by others. In terms of agents, power becomes a concrete, measurable parameter.

> *Power is like freedom, peace, rights, solidarity, commitment, progress, resolution, information and culture an abstract concept, process or principle, which can be observed as a concrete, real phenomena or emergent property in Multi-Agent Systems.*

Tribute Model

In Axelrod's tribute model, power is considered as such an emergent property. Each actor is able to choose between pay and fight, and actors who are involved in paying or collecting tribute increase commitment and loyalty to each other. Actors with high commitment act together and form an alliance or state. Paying tribute or taxes has indeed been an important part of all early civilizations [149] : "The principal economic feature common to all the early civilizations was the institutionalized appropriation of surpluses from the lower classes by the ruling group."

In the tribute model, an actor can be tribute payer and collector, so any actor can rise to a powerful ruler. Certainly there can not be more collectors than payers, so it is likely that a few powerful tribute collectors emerge, who exploit many tribute payers. The tribute collectors in turn may split in collectors and rulers.

If a person pays taxes to a state, or a state tribute to an empire, the result is the same, because a state can be represented by a person. Another elementary attribute of states besides taxes is military service. The agent transfers the access rights to Fight() and Pay() methods to the composite class.

Objects are Agents without Sovereignty

One of the essential properties of agents is autonomy and sovereignty. Contrary to simple objects in object oriented programming (OOP), they can decide and determine if they execute an action or not. An OOP object or class always executes a method if it is called by another class or object. If an agent becomes a member of a state or group, it is partially "reduced" to an object again. It loses sovereignty.

Thomas Hobbes writes in his LEVIATHAN about the origin of states : "by Art is created that great LEVIATHAN called a COMMON-WEALTH, or STATE, (in latine CIVITAS) which is but an Artificiall Man; though of greater stature and strength than the Naturall, for whose protection and defence it was intended; and in which, the Soveraignty is an Artificiall Soul".

Translated in the modern language of politics and Multi-Agent Systems: Politics is the art of forming a common group out of individual agents with different interests, of creating an abstract and artificial agent, which contains, represents and protects a group of agents. The sovereign agents are partially reduced to objects, and the so gained sovereignty is used to create a new agent with represents and acts for the group. In the language of object-oriented programming this process is described by a COMPOSITE design-pattern [55]:

Politics and OOP

```
// Part
Component = class(Agent)
  int Wealth

  Pay()   // Taxes
  Fight() // Military Service
  Execute(Input)
```

```
// Whole
Composite = class(Component)
  int CommonWealth
  List Members
  Pay() -> For all Members c do c.Pay()
  Fight() -> For all Members c do c.Fight()
  Execute(Input)
```

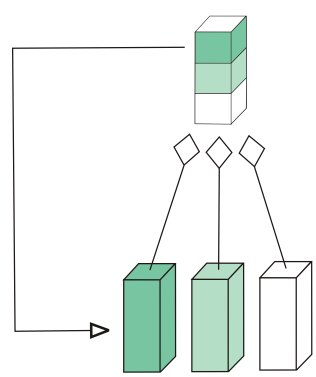

Fig. 30 COMPOSITE Design Pattern

The paradoxical and peculiar thing of the COMPOSITE design pattern is the feedback loop from the accumulated aggregation of components to the component. The composite class contains a collection or a list of many members and sub-agents, which are objects of a certain component class. Yet it is a subclass of this component class itself. The pattern treats individual objects and compositions of objects uniformly (the aggregation has similar methods and properties), it is an expansion combined with a restriction, an extension associated with a confinement.

3.3 Temples and Monuments

Palaces, Temples, Tombs

As mentioned above, all early civilizations collected and raised taxes. The taxes allowed the ruling class to plan and execute large scale building projects. The basic kinds of monumental architecture in early civilizations are [149]: Palaces, Temples and Tombs. All of them are houses, houses for Rulers, Gods and the Dead, respectively.

Rulers, Gods, Dead

The first gods were often based on the remembrance of dead kings and rulers [76]. Usually the **dead ruler** was considered as a **god**, and there was no clear distinction between the three notions. Similarly, there was no clear difference between early temples, tombs and palaces. Egyptian pyramids are a mixture of tomb, palace and temple, a combination of mortuary, royal and religious complex.

A Maya pyramid [134] symbolized a mountain with a temple on top. Usually Maya pyramids have one or more stairways to reach the temple at the top. Sometimes they contained a tomb for a king, for example the Temple of Inscriptions in Palenque with the tomb of Pakal. Originally they were simply stepped terraces built to support a building (a house, a temple or a palace) on top. As we can observe in Palenque, where the royal palace looks very similar to the surrounding temple pyramids, there was not always a clear distinction between palace, temple or tomb.

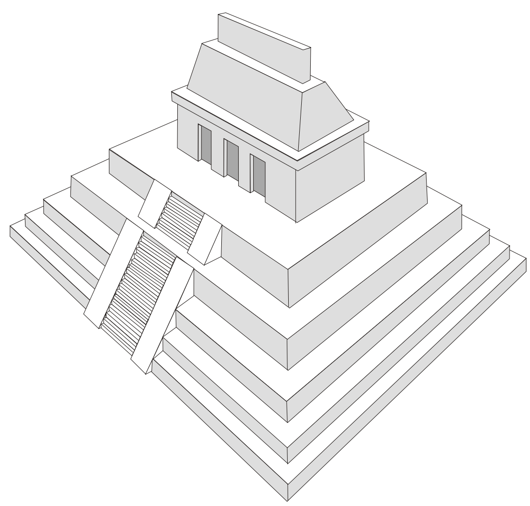

Fig. 31 Maya temple-pyramid

Maya & Egyptian Pyramids

In ancient Egypt the sun and the stars were of central importance. An Egyptian pyramid [94] symbolized a sun or a shining star, the top was the artificial star itself and the edges were the rays of the star. It was always a tomb for a single king. There was never a temple on top of an eyptian pyramid, always in front of it, and no pyramid had stairways, there were in fact symbolic stairways for the king to ascend to the stars. Compared to a typical Maya pyramid the alignment of elements differ, but the elements are the same and the low differentiation between tomb, palace and temple is very similar.

The Egyptian ruler, the pharao, became originally after his death as a dead ruler a god. Since a dead ruler needs a tomb, a ruler a palace, a god a temple, and the deceased pharao was all this together in one person, the monumental pyramids were a tomb, a palace and a temple at once. The early pyramid complex of the Old Kingdom was religious temple, mortuary tomb and eternal royal palace for the pharao at the same time.

Pyramid Complex

It was the eternal house of the pharao, a palace of stone with chambers for sleeping, eating and receiving guests. The sleeping chamber was the mortuary tomb, the chamber for receiving guests the hall of the mortuary temple. The pharao was seen as the son of sun god Re/Ra, therefore he needed an appropriate eternal house. As the house of a sun god, the pyramid represents a star or sun. Just as light rays connect the sun and the earth, the pyramid should be a connection between heaven and earth, working in the opposite direction.

The purpose of the pyramid was to transform the king to a shining star and enable him to enter the realm of the stars. In the book "Temples of Ancient Egypt" [140], Dieter Arnold writes on page 47 : ". . . it becomes clear that the pyramid was not just a tomb, but that it had evolved into the site of a mystery that allowed the dead king to unite with the Ba of the sun god."

Purpose of the Pyramid

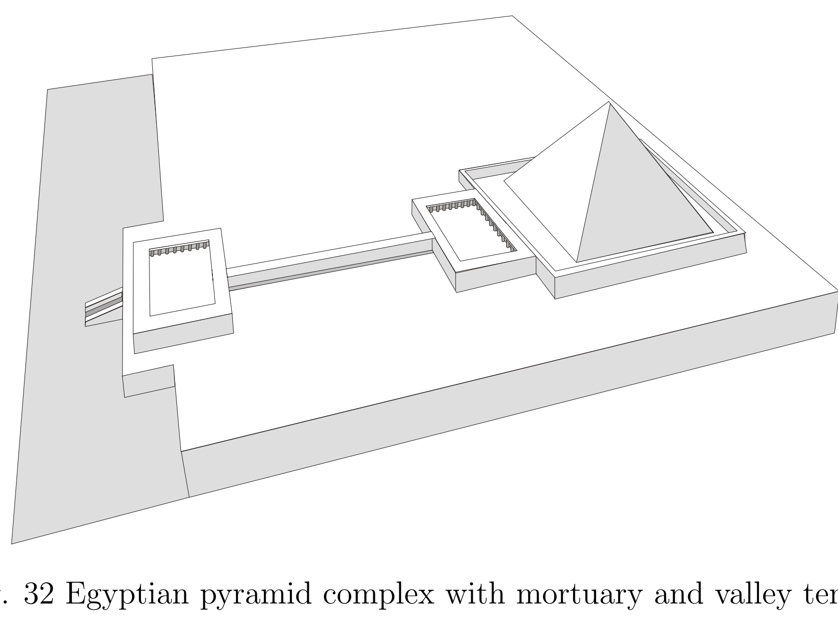

Fig. 32 Egyptian pyramid complex with mortuary and valley temple

In ancient Egypt, people thought that the soul consisted of three parts: the Ba, the Ka and the Akh. The Ba, represented usually by a human-headed bird, was the spirit of a person, that left the body at death. It was believed, that the Ba could re-enter the body or similar things, e.g. statues or images that resembled the body. The unification of Ba and Image was described with "to embrace" and it was the process, that allowed the gods to "live" in their statues, just as the Ba (Soul) lives in the human body. The core of an Egyptian temple -the sanctuary of the god or the innermost chamber- was a shrine with a small statue or figure. This statue was not an image of the body of the god, it *was* the body of the god, the place where he was able to materialize himself. The pyramid *was* the body or image of a sun. This fact enabled the Ba of the sun god Re to live in it. So the Ba of the deceased pharaoh was able to unite with the the Ba of the sun god, or was able to become like it - so that the pharaoh became completely a son of Re. Utterance 486 of the pyramid texts says : "Re will take Pepi by the hand, to where a god may be."

Evolution of ancient Monuments

The architecture in mortuary complexes evolved in ancient Egypt later from huge pyramids in the *Old Kingdom* to palaces and large temples in the *Middle Kingdom* and finally to sophisticated tombs in the valley of the kings during *the New Kingdom*.

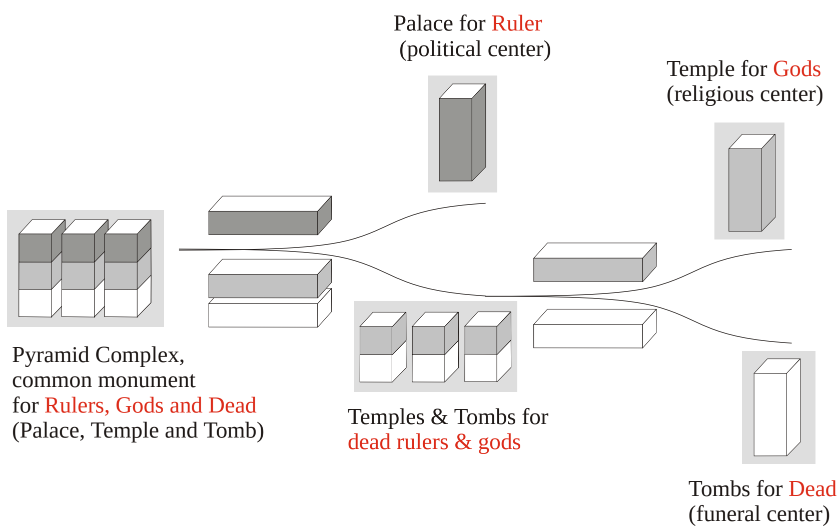

Fig. 33 Origin of Temples

In the Middle Kingdom the pyramid complex evolved into a palace for the living ruler and a temple complex for the deceased king. The temple complex in turn evolved during the New Kingdom into a temple for the gods, and the dead rulers were buried in plain, but skillful decorated tombs. The architectural evolution from pyramids to palaces, temples and tombs corresponds to the separation of the political/royal complex (palace), the religious/sacred complex (temple) and the mortuary/funeral complex (tomb).

3.4 Language and Writing Systems

The origin of language is still a matter of discussion. In a special multidisciplinary issue of science about the evolution of language from February 2004 [27], Constance Holden and Elizabeth Pennisi examine the origin of speech [72] and language [117].

Yet there are already convincing theories about the origin of language. The theories of Durkheim, one of the founders of sociology, were based on "Division of labour" [59]. It is also a basic concept in anthropology to explain the origin of language. Apes use legs and arms for locomotion. Human bipedalism freed the hands from locomotion, which became free for tool-using and communication. But the process of division of labor does not stop here: Early hominids used gestures and sounds for communication [58, 34], until language freed the hands from communication.

Evolution of ancient Language

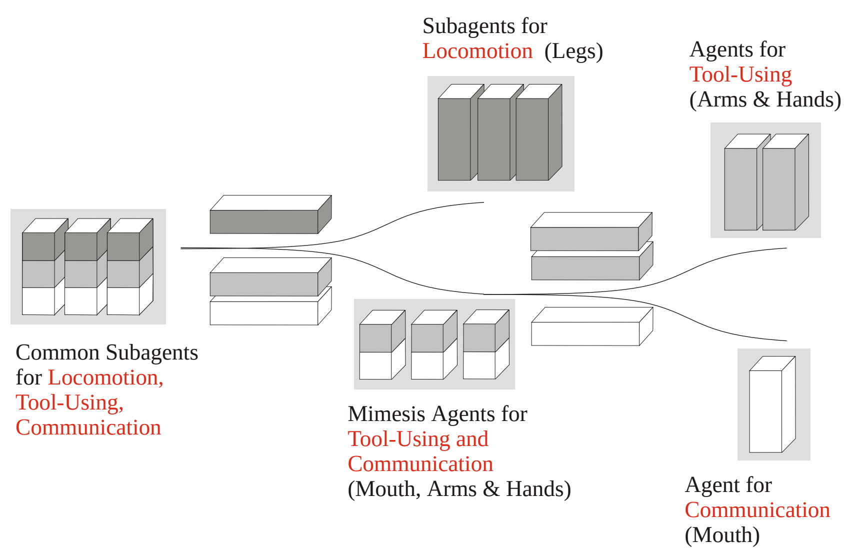

Fig. 34 Origin of Language

Mimetic Skills

The gestural theory [24] says that language evolved not from animal cries but from manual and facial gestures. In fact it evolved out of a mixture of both. According to Merlin Donald [34] and Michael C. Corballis [24], the mimetic skills (describing events in nature by imitation, mimic and gestures) are the missing link between emotion controlled sounds in animals and fully developed and articulated language in humans. Mimetic processes/skills together with primitive sounds have the same functions as language : representation and communication.

You can not learn language for yourself, only from others. Language is like a net that is connecting people and enables sharing and exchanging of knowledge and information. Merlin Donald argues, that this net orignally was formed by mimetic skills/processes in addition to primitive sounds.

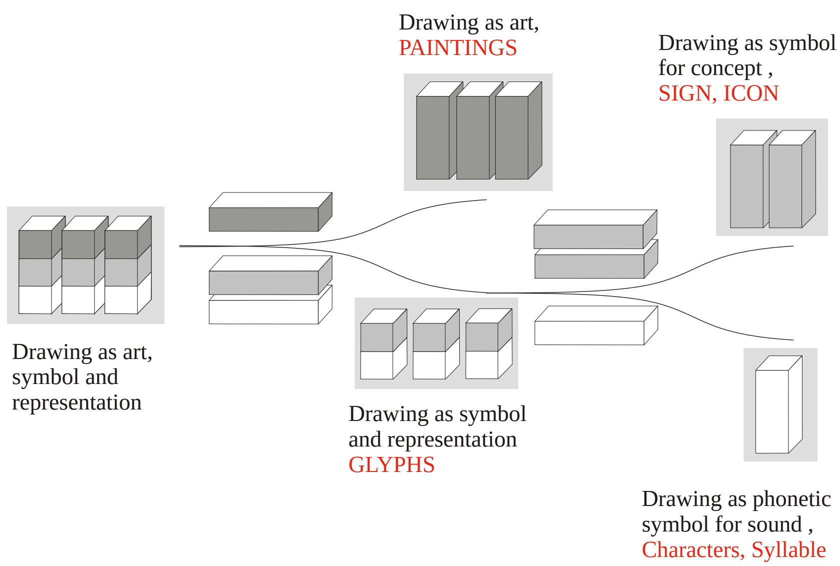

Fig. 35 Origin of Writing Systems

Evolution of ancient writing Systems

Written language is a form of frozen language. Geoffrey Sampson defines writing as ‘to communicate relatively specific ideas by means of permanent, visible marks’ [133]. Writing systems have a relatively short history, most of which is open to inspection. One distinction between the origin of writing systems and the origin of language and speech is that [133] “in the case of the former we can delve far enough back into the past to come close to the beginnings of the phenomenon”. Whereas human vocal-auditory language is about 50,000 years old, the oldest writing systems are only 5,000 years old:

the Sumerian cuneiform system, the Egyptian hieroglyphs and the Chinese symbols were created around 3,000 BC.

3,000 BC writing was at the edge of knowledge and advanced technology. It was used according to Sampson [133] to solve pressing material or organizational problems. Like computer technology today, it was invented to solve administrative and computational problems : how to calculate taxes, exchange rates and other things.

Pictures, graphics and drawings are a natural and easy way to communicate ideas before an abstract repesentation of a spoken language exists. The earliest writing systems were based on graphics and images (for a good overview, see the book of Andrew Robinson, 'The Story of Writing' [130]). The graphics, graphs and cave-drawings evolved into pictographical signs and more or less abstract symbols.

Although all early writing systems began as pictorial representation, you can observe the development most clearly at the Egyptian hieroglyphs, which contain a mixture of several different systems : from Logographic systems (a graph/sign for a word, idea or concept) to the Syllabic systems (a symbol for a syllable) and finally to our Alphabetic systems (a character for a phoneme/sound).

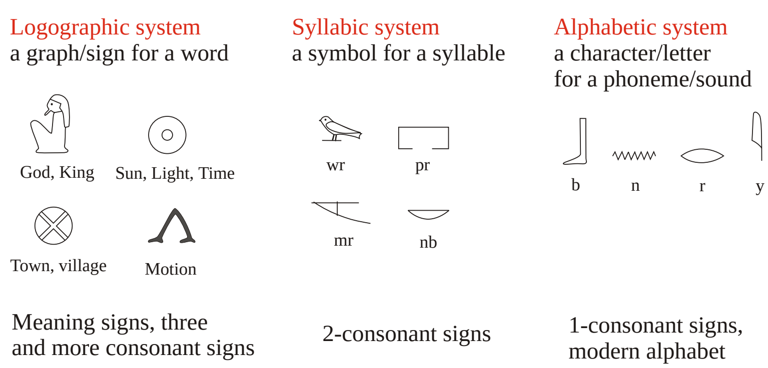

Fig. 36 Egyptian Hieroglyphs mirror the Evolution of Writing Systems

All writing is based on speaking, but once a writing system has become established, it develops a tradition and a momentum of its own [18]. This is similar to the emergence of other CAS. Once a new CAS has emerged, it develops a life of its own, if it is the cell metabolism, the economy, a political system or something completely different. A writing system can be used for different languages and can evolve separately.

3.5 Literature

There are many different writing styles and genres, fiction based on imagination and non-fiction based on facts, poetry (literature in metrical form) and prose (ordinary writing). Some of the most ancient forms of literature can be found in ancient Egyptian tombs.

The early Egyptian tombs contained a primitive form of personal autobiography [95], a list of hieroglyphs for food offerings, remembrance and identification. The list for offerings was replaced later by a prayer for offerings, and the list of titles by a short autobiography.

The Egyptian autobiography contains the account of achievements in a man's career or profession (novel), a self-description as a person of moral worth (autobiography), and an appeal to visitors of the tomb or monument for offerings (prayer). Early Egyptian tomb inscriptions are novel or tale, autobiography and prayer at the same time.

In fact autobiographies of persons, tribes and clans seem to be the true origin of legends and novels. Most authors write about themselves, even Goethe does this in Faust, and Shakespeare in Hamlet.

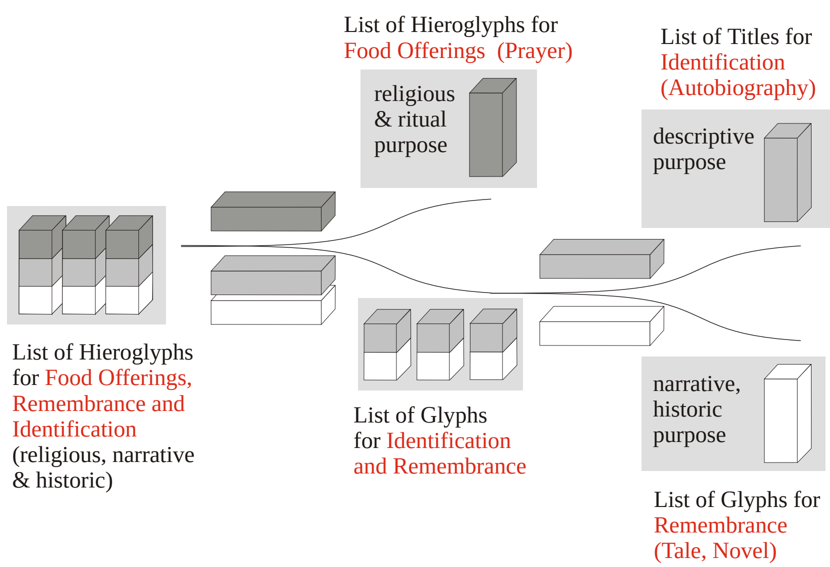

Fig. 37 Origin of Literature

3.6 Show Business

William Shakespeare (1564-1616) was an actor, writer and part-owner of an acting company. The actor Shakespeare and the playwright Shakespeare are one and the same person.

Likewise Wolfgang Amadeus Mozart (1756-1791) was a performer, composer and conductor. The performer Mozart and the composer Mozart are one and the same person, too (other composers who were great peformers at the same time are J.S. Bach for the organ, Antonio Vivaldi for the violin, Ludwig van Beethoven, Franz Schubert, Robert Schumann for the piano).

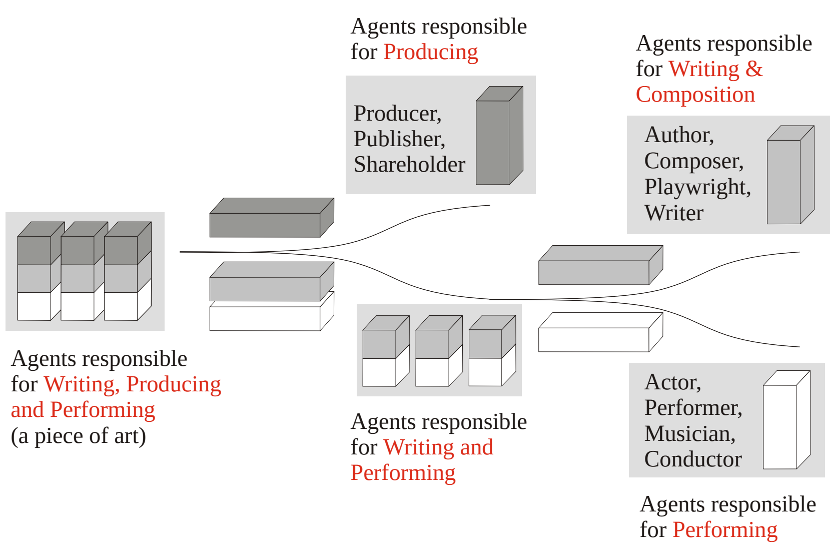

Fig. 38 Origin of Show Business

There are many different forms of languages. In music, musicians use notes to describe sounds, in physics, physicists use the language of mathematics to describe natural phenomena. Psychologists and sociologists use natural language to describe psychological and social phenomena. Computer scientists use programming languages to describe programs and applications. Programming and computer languages are a compromise between the objects a computer can understand and the things a human can follow.

3.7 Computer Languages and Compilers

In the early days of computer science, operating systems, languages and compilers had not been invented. Who was first, the operating system or the application ? The compiler or the language ? The Browser or HTML ? To create, load, execute and unload a program you need an operating system. To create an operating system, you need to execute/run programs, because the operating system (OS) is a large program itself.

The resolution is evolution. Operating systems and applications co-evolved together. Some programs evolved to permanently loaded operating systems, some programs evolved to temporarily loaded applications for these systems. Others evolved into hardware or device drivers, loaded if required. They separate the application tier from the details of the hardware tier, and make the applications hardware independent[1].

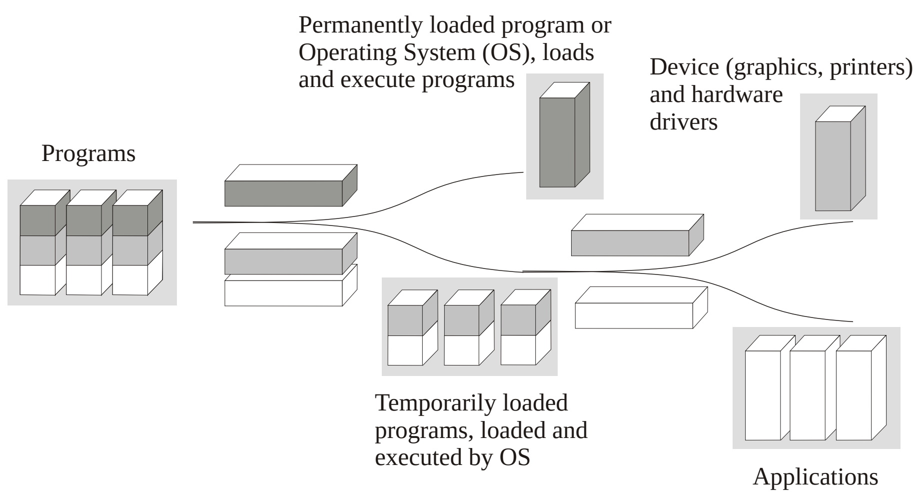

Fig. 39 Origin of Operating Systems

Hardware drivers for hard disks, graphics and sound cards are written in machine code or assembler, and today they are delivered together with the Hardware from the manufacturer, and installed in the Windows system. Unix was originally written in Assembler. DOS and the first forms of Windows are written mainly in C but with large, time-critical parts in Assembler, too.

[1] Many DOS programs were delivered with dozens of different printer drives. Users were always in trouble to select the right printer driver, and sometimes the right driver could not be found at all.

Operating systems and hardware drivers, the condition for complex high-level applications, were produced in the last dozen years with the help of Assembly languages, the first simple forms of programming languages. Like Oxygen, the basis of life, was produced 2 billion years ago by photosynthetic activity of cyanobacteria, the first simple forms of life.

The biological analogy goes deeper: Like the first living beings, unicellular organisms and bacteria (prokaryotes), who can be found everywhere, small units of Assembler code can be found everywhere even in modern high-level languages like C and Pascal. Just as we have biological viruses, we have unfortunately also computer viruses. As the genetic code is the basis of all life, machine code is the basis of all computers.

Like higher life-forms developed on the basis of lower life-forms, high-level languages developed on the basis of low-level languages. The question 'who was first, the compiler or the language, the browser or HTML', must be answered with 'no one, both co-evolved together'. You can say : of course the browser or compiler was first. Once a compiler/browser was available, you could wrote programs/web pages. But before people can write a browser or compiler, they must know the language. So the language must be first, too.

The answer is again evolution. Web-Browser and HTML coevolved together. They arose from the need to display any document on any system. This need was especially strong at CERN, where the web was born, and where different scientists from all over the world work on different projects and computers. The ancestors of Browsers are programs which display their own proprietary file format, and the ancestors of HTML are the common structures and rules in hundreds of different file and text formats.

	File Formats	Assembler
proprietary format, software or hardware dependent	.wpd Corel WordPerfect .doc MS Word .rtf MS WordPad (Rich Text Format) .pdf Adobe Acrobat (Portable Document Format)	Z80 Zilog 6502 MOS Tec/Rockwell .. 80x86 Intel (AMD) 680x0 Motorola
independent	→ .htm HTML Hyper Text Markup Language	→ Pascal,Basic,C High Level Languages

Tab. 11 Different Formats and Languages

The evolution of Browsers and the universal HTML (Hyper Text Markup Language) is comparable to the evolution of alphabetic writing systems. Alphabetic writing systems can encode any language. In symbolic or logographic systems (like Chinese) you have to invent a new sign for every new word. In order to cope with a similar form-function dependence, you had to invent a new assembler language for every new processor, and a new file format for every word processing program.

Compilers and languages coevolved together, too. Compilers emerged from the need to execute the same program on different machines with different processors. The ancestors of compilers are special assemblers together with their programs which run only on certain systems or processors. The ancestors of higher languages are common data structures, methods and control structures used in these programs.

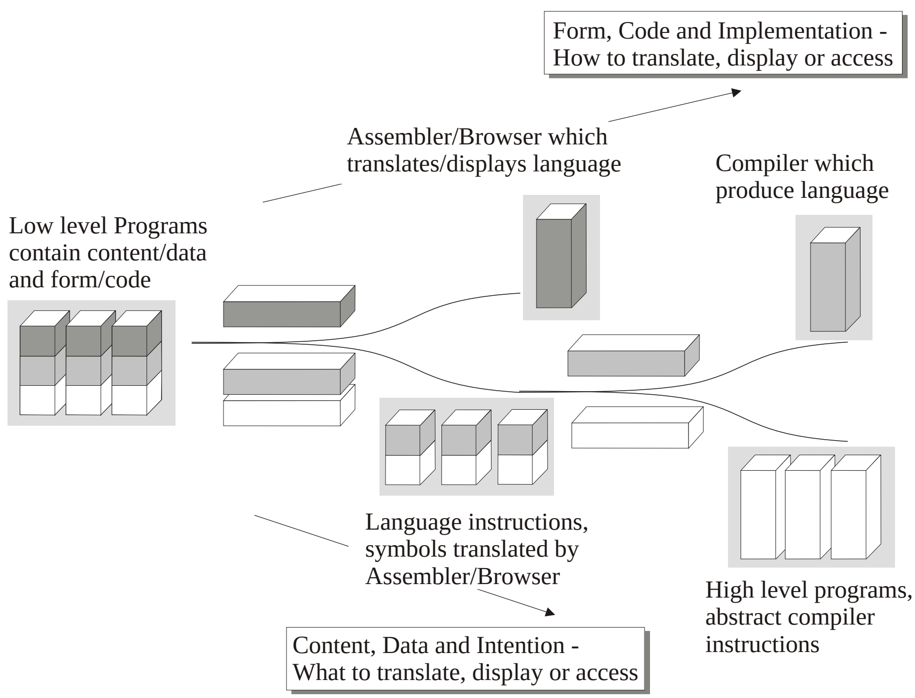

Fig. 40 Origin of Compilers

The evolution of Browsers and compilers is connected to the separation of form, code, implementation from content, data, intention, respectively. Originally, programs contained and combined form, code & format (how to do s.th.) and function, data & content (what to do information).

Assembler, compiler and browser concentrate themselves on the "how to" question. They know how to translate into machine code, assembler code or how to display content and data, but they don't know what to translate or display. Documents or files know the content or data but not the detailed code sequences. HTML files contain the content or information of web sites, but don't know how to display it, source code files contain the data of programs in symbolic form, but don't contain the detailed machine code sequence.

This separation of form and content, of 'How to do' and 'What to do' splits one niche into two new niches, which can be occupied by specialized agents. A new tool creates a new niche for those who manufacture and produce it, and one for those who apply it. The basic tools of computer science are tools to translate and process programming languages.

Instruction	Code	Data
	Implementation Assembler, Compiler Interpreter Active (processes data)	Intention Sourcecode Document Interpreted instructions Passive (is processed)
Action Delegation	How to do	What to do
	Application, Practice Agent, Worker, User Actor	Theory Manager, Producer Composer, Writer
Information	Form, Design	Content, Function
	Client Browser Multiple Instances Flexible	Server Web-Server Single Instance Stable

Tab. 12 Separation from Code and Data, Form and Function

Languages are at the core of computer science. There are dozens of programming languages today, although computer science is a young field. As Bjarne Stroustrup said, comparison of similar languages like C and Pascal is rarely meaningful : "Language comparisons are rarely meaningful and even less often fair. A good comparison of major programming languages requires more effort than most people are willing to spend, experience in a wide range of application areas, a rigid maintenance of a detached and impartial point of view, and a sense of fairness."

But it makes sense to compare different kinds and classes of programming languages (procedural, object-oriented,..) to study the evolution of them. To quote Bjarne Stroustrup again : "It is my firm belief that all successful languages are grown and not merely designed from first principles." All programming languages are tools for instructing machines. Like living beings, they have evolved from simple languages like Assembler, the 'bacteria' which existed since the beginning of computers, to modern object-oriented languages of high complexity. In the last twenty and more years, programming languages have grown more and more complex.

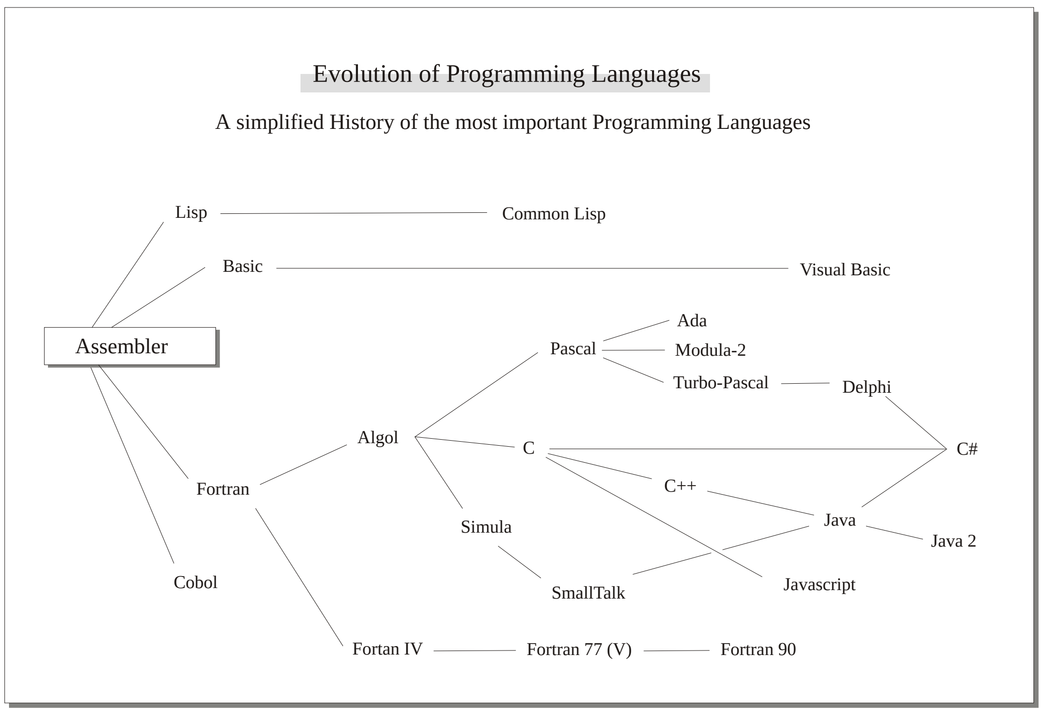

Fig. 41 Evolution of Programming Languages

This picture shows the evolution of the most important programming languages (based on http://www.levenez.com/lang/ and http://www.digibarn.com/collections/posters/tongues/). Each language has its special niche in the ecology of computation. The environment of a language in the ecology of computation is determined by the kind of users which use it, and by the type of the target operating system. Different languages were adapted during the time to different 'niches'. Cobol was adapted to the business niche, Fortran to the scientific niche, Basic to the beginner niche. C and

Pascal were adapted to the niche of windows programming and evolved into C++ and Delphi, respectively.

A target platform offers a niche for a programming language, because the choice of a programming language for a project depends on the operating system of the target platform. Assembler programming is used for raw and fast programming of an operating system itself or for games, hardware drivers and time-critical applications without use of an operating system. Structural/procedural programming is used for DOS or console applications. Object oriented programming is used for Windows and Linux.

As in nature, 'natural selection' causes some languages to die out while others appear, flourish and grow. Some languages like Ada, Algol, Cobol, Fortran and Prolog are now nearly extinct, whereas others like C, which are closely connected to successful systems like Windows, had many successors (C++ and C#). But most basic languages which have found a niche are still alive, as Assembler, Basic[2], Pascal and C.

Programming languages have co-evolved together with programming environments (Assembler, Compiler, Visual Studios) and operating systems. Complex object-oriented languages are used today with large integrated development environments or visual studios. The languages with powerful, good and low-priced programming environments of course had an evolutionary advantage: TURBO-PASCAL from Borland became so popular because it was good, fast and low-priced. C# is becoming popular, because it is supported by the overwhelming market-power from Microsoft, which includes a powerful development environment with Visual Studio .NET and a fast run-time engine, the .NET Framework from Mircosoft.

New forms of languages emerged to fill new niches and to describe the interactions between the software objects created with these programming languages, for example SQL (Structured Query Language) to describe database access, UML (Unified Modeling Language) to describe interactions between objects, ACLs (Agent Communication Languages) to describe interaction between agents, SOAP (Simple Object Access Protocol) and BPEL (Business Process Execution Language) to describe interactions between Web Services. Just as the fittest species survive the natural selection process, the best and 'fittest' languages are bought and used by the users.

[2]Basic is only alive due to a frozen historical accident : Bill Gates developed at Harvard a version of the programming language for one of the first microcomputers, see http://www.microsoft.com/billgates/bio.asp

But even the best current programming language or most sophisticated agent architecture today is unable to produce self-consciousness or self-conscious agents. Consciousness is a complex phenomena which has kept scientists busy for centuries. Of course it is not difficult to give a coarse and rough description of the emergence of consciousness, which we will try in the next section.

3.8 Conciousness

> "Man is only a reed, the most feeble thing in nature, but he is a thinking reed. The entire universe need not arm itself to crush him. A vapor, a drop of water suffices to kill him. But, if the universe were to crush him, man would still be more noble than that which killed him, because he knows that he dies and the advantage which the universe has over him, the universe knows nothing of this."
>
> Blaise Pascal, Pensees ("Thoughts"), 1660

What is Consciousness ?

What is this consciousness that makes us so superior, a thing or a process or some mystic issue ? There are many Metaphors to describe consciousness [92]: Consciousness as a flame, spotlight, a footlight before which scenes are enacted, a flowing river, a stream of thoughts, a powerless rider, ... Lev Vygotsky writes in "Thought and Language": "Thought is born through words ... Consciousness is reflected in a word as the sun in a drop of water. A word relates to consciousness as a living cell relates to a whole organism, as an atom relates to the universe. A word is a microcosm of human consciousness".

Consciousness is a process

As Minsky noted in his fascinating script [99] "The Emotion Machine", the term consciousness is a 'suitcase-word' with many meanings. The most common sense out of this suitcase is the awareness of the surrounding world, of the self, and of one's thoughts and feelings. We speak of consciousness as if it is a thing and are going to "to lose/regain consciousness", but in fact it is more a dynamic process, as Kolb and Whishaw state in [84] : "despite the difficulty of saying exactly what consciousness is, scientists generally agree that it is a process, not a thing". It emerges only if the nervous system is complex enough, so it is a property of a high-level nervous system, not of a single neuron or a small group of neurons, as Searle noticed [139] :

> "Of course you can't say of any molecule, this one's wet, or this one's liquid; but the whole system is liquid. In exactly the same

> way you can't say of any neuron, this one's conscious; but the whole system is conscious."

One requirement for consciousness is that our world model is large and detailed enough to recognize ourself in it. Normally the language provides the building blocks for the world model. It enables us to identify the self with the representation of the self in it, and thus makes the self accessible to attention. *Consciousness brings ourself into the center of our own attention.* Of course the capacity and capabilities of the cognitive system therefore must be large enough to build up a detailed world model. In [81] Kihlstrom says :

> "In order for ongoing experience, thought, and action to become conscious, a link must be made between its mental representation and some mental representation of the self as agent or experiencer."

Consciousness is the thought of the 'Self' as part of the environment. At the same time it is linked to every other thought, because the idea of the 'Self' includes every part of the body. To recognize oneself as part of the environment means to recognize you are an insignificant part of the environment, and at the same time this part is the most important part for you. This oscillation between everything and nothing, between total insignificance and highest importance, between joy of existence and fear of death makes consciousness so interesting and complex.

Perplexity, Confusion, Complexity

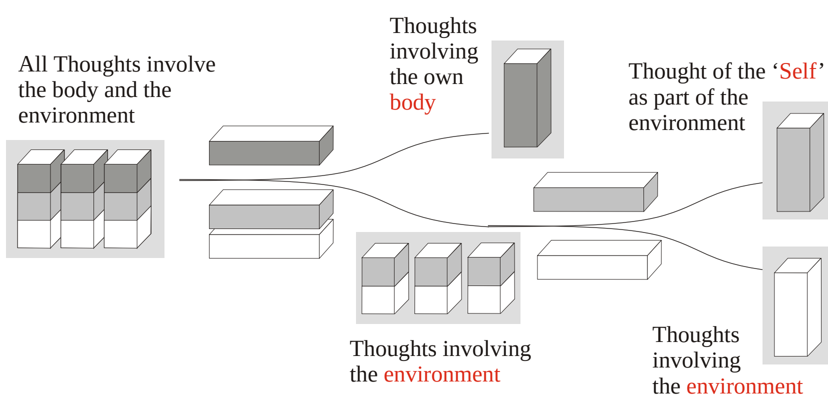

Fig. 42 Origin of Consiousness

Mind-Body Problem

In the next two decades, we will able to solve all the ancient philosophical mysteries relating to the mind: the mind-body problem [82], the ancient problem of consciousness [83]. But the price for this is high: it probably requires us to modify the usual and conventional concept of a self, a soul and a unique identity, which is deeply rooted in out christian western culture. This can and will be frightening. Blaise Pascal had a vague feeling that this is about to happen. It accompanies his apt description of the confusion and perplexity caused by self-consciousness:

> "When I consider the short duration of my life, swallowed up in the eternity before and after, the little space which I fill and even can see, engulfed in the infinite immensity of spaces of which I am ignorant and which know me not, I am frightened and am astonished at being here rather than there; for there is no reason why here rather than there, why now rather than then. Who has put me here? By whose order and direction have this place and time been allotted to me? The eternal silence of these infinite spaces frightens me."

Next big Paradigm Shift ?

Copernicus showed us the earth is not the center of the solar system, Darwin showed us that humans are not at the center of all life-forms, Einstein showed us that our current reference frame (or coordinate system) is not the outstanding center of all reference frames , and the new fundamental paradigm shift will show us that we (the soul or the self) are not at the center of ourselves. Since Copernicus we know that the earth is not a fixed and motionless object, since Darwin we know that humans like all other species are subject to evolution, since Einstein we know that even space-time is curved and not fixed or absolute, and since the findings of Sejnowski [127] and the other major neuroscientists we should know that development and change is the essence of living beings. Not only the days are changing, if they appear and disappear one after another. We are changing constantly, our consciousness appears if we wake-up and disappears if we sleep [69]. The impression of being something stable, constant and unchangeable is an illusion.

Chapter 4

Groups, Rituals and Cooperation

4.1 Groups and Cooperation

We have seen several examples how lineage splitting, bifurcations of phylogenies, and the emergence of new agent classes and actor roles through specialization and division of labor can increase diversity and complexity. But without an opposite attractive or unifying force, diversity alone is useless. Specialized agents need other agents to delegate tasks they can not handle alone. In biology and ecology, different species depend on each other and often form symbiotic relationships, for pollination , transport and shelter or nutritional, defensive and cleansing purposes.

Cooperation, Symbiosis

But cooperation alone is not sufficient for complexity, either. Two equivalent species or agent classes will not gain much if they form a symbiotic relationship without specialization. They will of course be more powerful, but not substantially more complex. If we have a unifying force, we need diversity and division of labor [157]: ‘Intelligent individuals do not automatically combine to form intelligent groups’, only if ‘each autonomous agent adopts a more limited role in a group-level cognitive structure’.

Cooperation, Specialization

Complexity arises from the combination of both, from unity in diversity, from stability in instability, from regularity in irregularity, from cooperation in combination with separation and specialization.

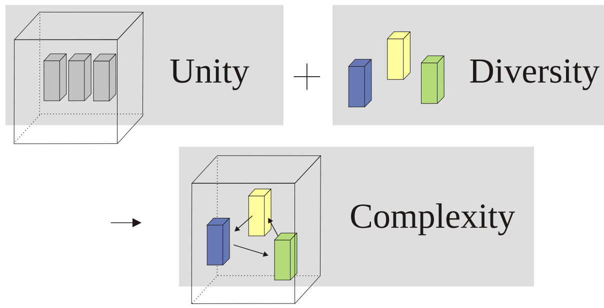

Fig. 43 Unity in Diversity

Social Rituals

In modern societies, social rituals and ‘Flow activities’ are the unifying forces which reinforce mutual cooperation. Ritualized assemblies, meetings, ceremonies and festivals are essential to establish a feeling of fellowship and solidarity in every culture, society and group, from the dances of an African tribe and ancient Egyptian festivals to modern rock concerts and sport championships.

Rituals & Indirect Reciprocity

Characteristic properties of rituals are mass assemblies, common stereotyped behavior and synchronized actions. A social ritual can arise from any synchronized procedure regularly followed by a group of persons. Because these rituals usually are enjoyable, they connect the interests of the group with the interests of the individual and reinforce selfless behavior towards the group. Selfless behavior which arises from social rituals is often based on indirect reciprocity. Altruism based on indirect reciprocity is one of the theories at the interface between biology and sociology which try to explain cooperation.

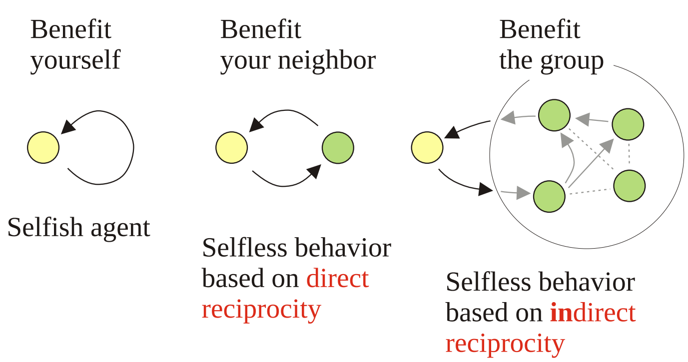

Fig. 44 Direct and Indirect Reciprocity

In the theory of evolution, there are different approaches to explain cooperation and to resolve the contradiction between the 'selfish genes' [30] and selfless, altruistic behavior. From the biological point of view there are four reasons for the existence of cooperation:

Altruistic Behavior

* Direct reciprocity (Agent ↔ Agent)
* Indirect reciprocity (Agent ↔ Group)
* Kin selection (Gene ↔ Gene)
* Group selection (Gene ↔ Meme)

Evolutionary theories of cooperation are based on kin selection, group selection [157] and reciprocal altruism with direct [5] or indirect [109] reciprocity. *Kin selection* means a gene increases its reproductive success, if it helps in promoting reproductive success of close relatives of its bearer.

Direct Reciprocity

The theory of *direct reciprocity* is simple: benefitting your neighbour means benefitting yourself. Altruistic actors use their neighbors to help themselves. Direct reciprocity and reciprocal altruism works, if and only if all actors cooperate [5]. Wilson and Sober say about strongly altruistic groups: [157] 'Life in the [strongly altruistic] community presupposes that each will work for the benefit of others as much as for himself, that no-one will be egoistic. Should one person claim that he has an inherent right to gain for himself at the expense of others, the entire fabric collapses." Altruism and direct reciprocity are very vulnerable to abuse, because they are a permanent source of temptation for defection to use the help of others without helping in return. The difference between what is best form an individual's point of view (to defect) and from that of a collective (to cooperate) is shown in the well-known game of the prisoner's dilemma [5, 108]. Fixed spatial structures and repeated interactions promote cooperation [107]. Then helping your neighbor pays off, because your neightbor will help you as well.

Indirect Reciprocity

Using *indirect reciprocity*, an agent can increase his image score and reputation if he cooperates [109]. This image score increases in turn the probability, that other agents will cooperate with him in the future. Indirect reciprocity can be viewed as direct reciprocity between an agent and a group. An agent who raises his image score raises his 'group-score' in the group. In indirect reciprocity, benefitting a member of a group means benefitting the group.

The principles of direct and indirect reciprocity can be reduced and unified to one principle if we introduce a general abstract agent, which can be a simple agent or a composite agent representing a group of agents. Then indirect reciprocity can be reduced to direct reciprocity between abstract agents (or between an agent and a group of agents).

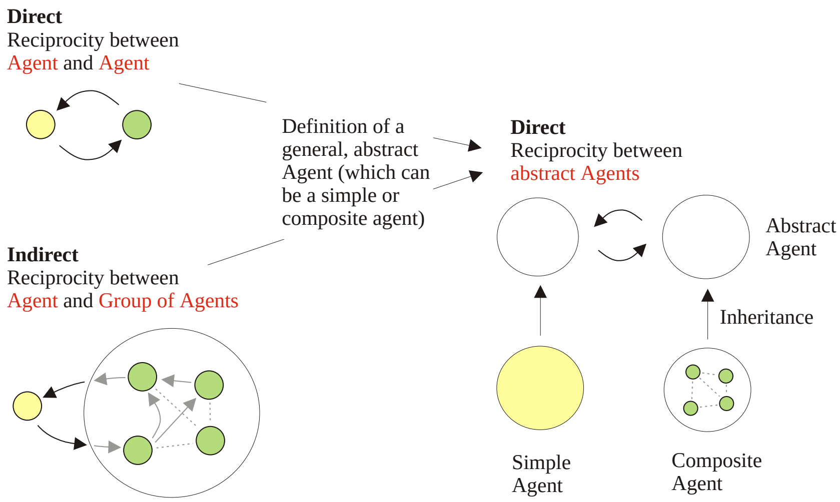

Fig. 45 Unification of Indirect and Direct Reciprocity

A community based on direct or indirect reciprocity only works if all members, agents and actors cooperate. If this is guaranteed by certain rules and memes, then the group which owns and applies these rules and memes may have an evolutionary advantage over other groups, and the memes for cooperation survive better than other memes. This is the case in the theory of 'group selection'.

4.2 Group formation and selection

Natural selection can be applied to the group level, because groups like individuals can be the vehicles of selection [157]. If organisms are the phenotype of genes, then groups are the phenotype of memes. In the competition between different groups, groups with cooperating members will have a higher fitness and hence more chances to survice. Moral rules correspond to genetic rules in this case.

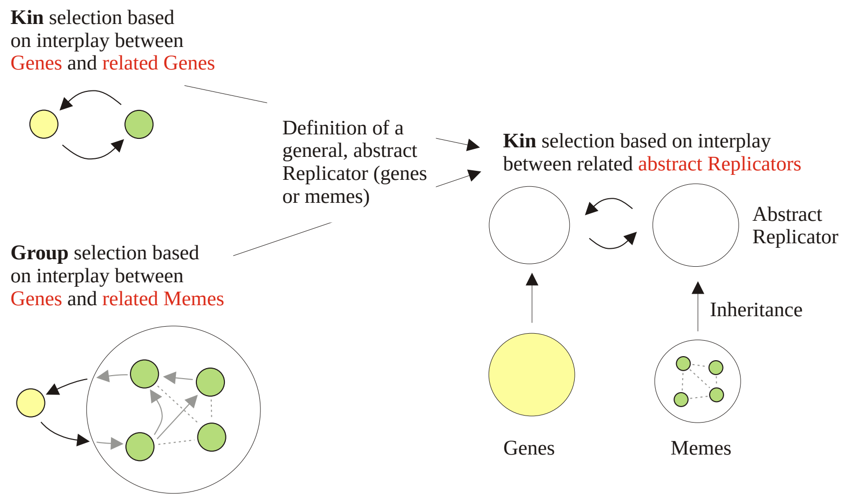

Fig. 46 Unification of Kin and Group Selection

Like the principles of direct and indirect reciprocity, which can be reduced to one principle by introducing an abstract agent, kin and group selection can be reduced to the same process if we introduce a general abstract replicator, which can be a gene or a meme. Then group selection can be reduced to kin selection between abstract replicators. These abstract replicators can be genes, memes or other forms of replicators.

According to the 'selfish gene' metaphor of Richard Dawkins [30], we are "nothing more than throwaway survival machines for our genes". In group selection, the moral rules are 'selfish memes' manipulating their environment, which are using groups as machines for survival. Groups are survival machines for memes, the genotype of the next higher level. Group selection is an interplay between different levels of complex adaptive systems, between gene and meme. Memes increase the fitness of certain genes, and these genes in turn increase the fitness of the corresponding memes.

Group Selection

An advantage of group formation is the exclusion of parasites. As Peter Schuster explains in [137], the formation of a new hypercycle, group or unit is endangered by parasites. The evolution of a membrane, wall or boundary which separates the group-members from the environment protects the members of the group by exploitation through parasites. At the same time the new closed group is a new unit of selection.

Groups & Parasites

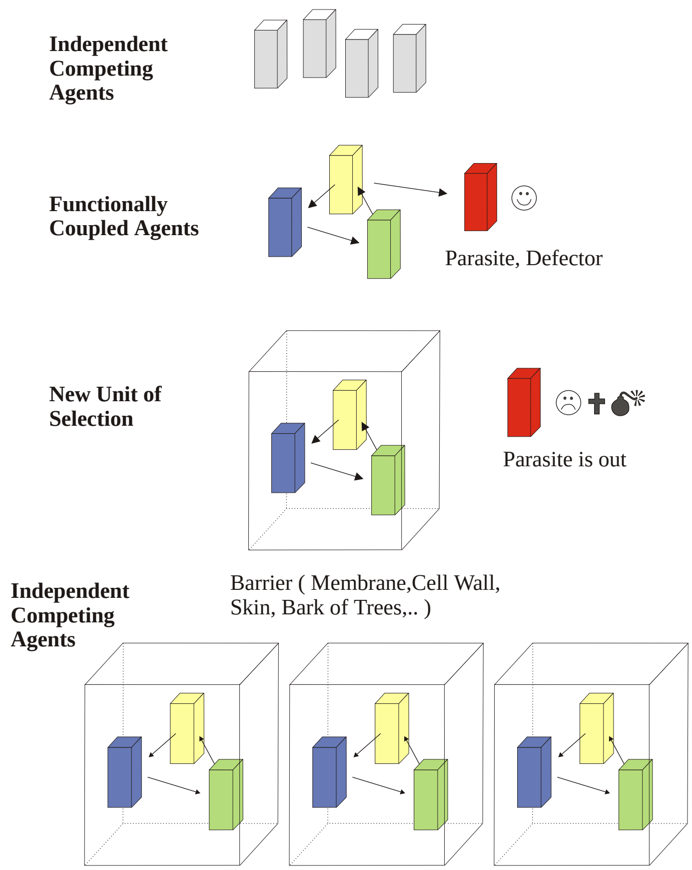

Fig. 47 Exclusion of Parasites, according to Peter Schuster in [137]

But Schuster argues in the same article that integration takes place when resources are abundant and cheap. This is wrong. Especially the times of scarcity, catastrophes and austerity are catalysts for great jumps in complexity. In these times the evolutionary pressure melts agents together or forces them to develop and use new tools, which in turn increases specialization, dependence and cooperation.

As Wilson and Sober notice [157], "Group-level vehicles should be most commonly observed in situations that place a premium on group-level functional organization, such as extreme physical environments, extreme persecution, or extreme intergroup competition."

4.3 The social meaning of rituals

Biological theories and especially group selection explain why groups of altruistic, selfless actors emerge and survive. Sociological theories explain what special kind of altruistic groups survive. From the sociological point of view cooperation and altruism can be explained by social theories about social groups and rituals.

Biology, Sociology

	Political Ideology	Army	Club, Association	Religion
Idea	Democracy, Socialism,..	Force, Team-Spirit	Team-Spirit	God,Allah,..
Group	Nation/Party	Military (elite) group	(Sport) Club	Church,Sect
Group-Member	Republican, Socialist,..	Soldiers	Players, Members	Believer
Sacred Symbol	Flag, Party-Symbol	Star,Cross, Flag,..	Coat of arms, Emblem	Cross,Star, Half-Moon,..
Assembly, Gathering	Party Congress, Convention	Parade, Roll-call	Game,Meeting	Mass,Prayer
Hymn	National anthem	Marching-songs	Songs	Songs
Clothes	Uniform	Uniform	Tricot	Robes

Tab. 13 Social Groups

Randall Collins shows in his book 'Sociological Insight' [23], that people divide the world in two categories, the sacred/holy and the normal/profane, because the divine represents the group or society itself. The duality of the sacred and the profane corresponds to an alternation of two modes of social organization : the mode in which each agents pursues his own task, and the mode in which all agents assemble to pursue the tasks of the group.

What is holy ?

Religious terms mirror group-related interactions : Sin is to be selfish, because selfish behaviors disrupt group-level organization. Unselfish behaviors contribute to group-level organization and are revered. Heaven symbolizes the secure sense of belonging to the group, Hell exclusion from it. A blessing is wishing that someone will benefit from the group. A curse is wishing, that someone will not benefit from the group anymore or will be excluded from the group.

Groups & Religions

The basic elements of social groups are symbols and rituals : Symbols are the common things, which represent/symbolize the group, are whorshipped and must be approached seriously and respectfully. Rituals are the common actions, which melt the group together.

Besides social rituals every social group has certain rules to hold the group together. The moral rules of religions are especially strong and concern basic actions. Members who break the rules are punished or excluded.

Social Rituals

But rules alone are not sufficient. Because a selfish agent tries to pursue his own interests, each agent has to be told regularly what these rules are and why he should follow them. This is done by social rituals. Collins [23] identifies three main components of these rituals: the group must be assembled, the actions must be ritualized and sychronized, and there must be an emblem or symbolic object that focuses the group's idea of itself.

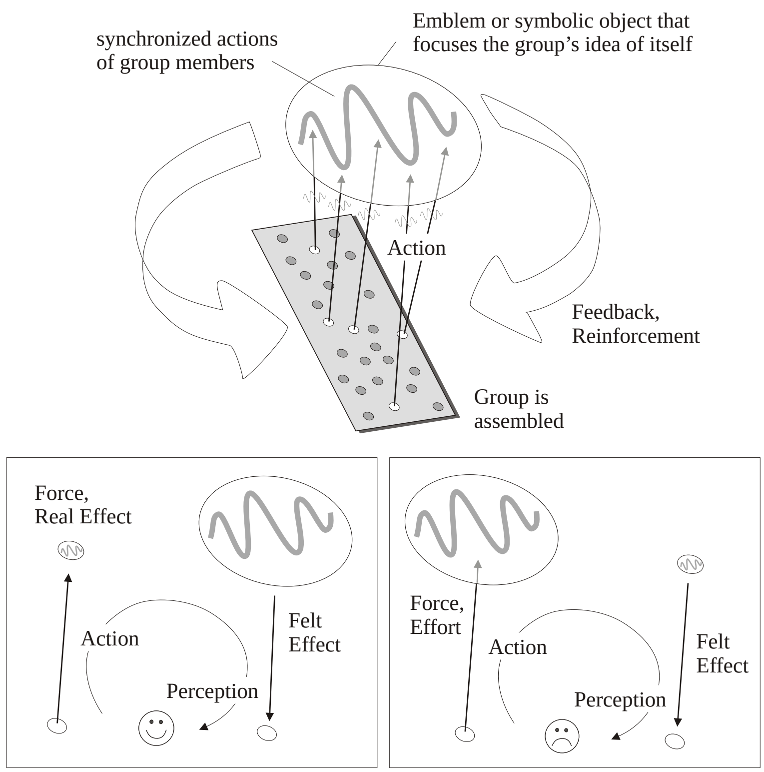

Fig. 48 Social ritual according to Collins [23]

Steven Strogatz says in his Book 'Sync' [148] "For reasons I wish I understood, the spectacle of sync strikes a chord in us, somewhere deep in our souls. Its a wonderful and terrifying thing."

Why is synchronity so wonderful and amazing ? If you are not involved personally in it, it is just a beautiful unity in diversity. If you are involved in it, you can explain it at least partially. It has something to do with real and felt effects, with feedback illusions and effort-effect balance.

Effects of Synchronity

In animals and humans, the basal ganglia controls the force of movements. The pathways and circuit structure is complex and complicated, but the coarse picture roughly is: if the body is weak and the perceived feedback is smaller than expected, force must be increased (tiresome frustration), if the body is strong and the perceived feedback is bigger than expected, force can be decreased (enjoyable relief). Synchronous group phenomena can lead to a feedback illusion, which causes joy and pleasure. Joy and pleasure in turn reinforce the willingness and tendency of the individual agent to go again to such a meeting or assembly. Humans like to go to all kind of sport, religious or musical festivals, feasts, processions, meetings or assemblies.

Pleasure, Feedback

The glue that binds groups together results from ritualized assemblies and the strong emotions they arise. It is the shared experience of a common feeling or illusion. This is one of the reason why people vote. The influence of a single voter is nearly zero. Yet most people vote, because it is a duty, and because it feels good - the shared experience of the feeling one could change the country. For a single voter this is an illusion, a single voter has no influence. Voting is a ritualized group-formation process, which usually takes place during a short time - the election day. The short time is necessary to keep the illusion alive.

Social Glue

Synchrony is important in ritualized actions that melt agents together to a group, for example in singing or religious rituals. Agents live in a constant perception-action cycle. In synchronous group action and social rituals the action of the individual becomes indistinguishable from the actions of the others. A merging and melting of perception-action cycles takes place. Thus a single agent has the impression or illusion that it can move a whole group of agents with a little finger. The recognition of sudden, unexpected power results in joy and pleasure.

Feedback Illusion

Social rituals reinforce indirect reciprocity, because they connect the interests of the individual agent with the interests of the group. The agents gain social or emotional energy from the social rituals in assemblies, feel better and stronger because they are part of a group which is much stronger than they are as individuals, and are thus motivated to obey the rules of the group. As Collins [23] says, “by plugging into the group situation, individuals can make themselves stronger and more purposeful.”

4.4 Basic social Rituals - Wars and Games

Wars & Games are part of history

Wars and games have always been a part of human history. Peaceful prehistoric societies were very rare. Only the participants and the form of the weapons have changed. Prehistoric wars between tribes involved spears, arrows and swords, historic wars between kingdoms and states were characterized by the use of the full range of advanced weapons from guns, missiles to bombs and political weapons. Modern wars between firms and companies are fought with economic weapons, modern sport games between clubs and nations are based on economic possibilities, too.

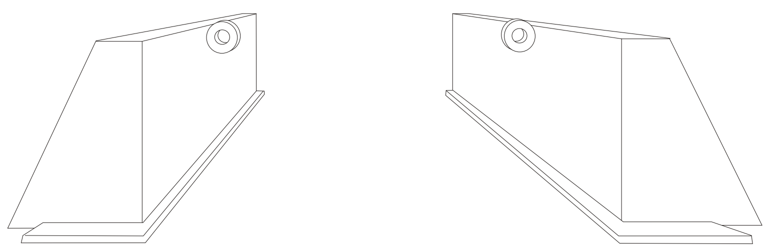

Fig. 49 Typical Ballgame-court of ancient Maya

Social Rituals

Wars and games are basic social rituals. A war is like a game based on a set of rules, and usually the participants obey them. Sometimes of course the participants and parties are cheating. For example in a civilized war in our global mass media world today, a civilian is not allowed to fight, and a soldier is not allowed to kill a civilian. A civilian who fights is cheating.

Ancient Maya

Games among the ancient Maya were a serious business. There is evidence that the losers were killed and sacrificed during certain eras. A ball-game was a special, small war. And a real war between ancient cities was a kind of ritual game. One of the purposes was to make many captives, which were sacrificed like the losers in the ballgame. There was no clear distinction between a priest (for the sacrifice) and a judge (for the game), and there was no clear distinction between a war and a game.

Mode	Exploration, Growth in knowledge	Exploitation Growth in power/wealth
Free, unconstrained	PLAY	FIGHT
Constrained ritual	GAME	WAR

Tab. 14 Wars and Games are basic rituals

Today sport games and wars are very different activities. Yet like virtual video games, real sport games are nothing but virtual, simulated wars between two parties. The common root of a social ritual becomes visible in many similar properties. A war and a game are opened and declared, and they are closed and officially finished again. Each participant is represented by a group, a team or an army. There are certain rules, and some tools or weapons are allowed, others are strictly forbidden, and all parties try to win. To be successful you need the right strategies and tools, and the essential thing is training. The teams and members must practise and exercise the right movements and actions over and over again. After the game or the war, the winners or the successful team members are honored and praised in their community.

Sport Games are virtual Wars

	Game, Bluff	War
is usually..	virtual, funny, harmless	real, serious, dangerous
needs ..	competition, seriousness	harmlessness
offers	insights, mental resources	wealth, material resources

Tab. 15 Wars and Games compared

A pure game is harmless and sometimes useless, but offers new insight and access to mental resources without the negative aspects of war and fight. A pure war is a great risk for both sides, because it is of course dangerous and lethal, but it has in most cases a good reason or purpose and a concrete result in form of new access rights to material resources. Without clear rules a war and a game will end in chaos and confusion. A 'total' war which is really taken seriously will end in a catastrophe, the lack of any doubts and scruples leads to massive death of whole groups and genocide. A 'total' game where nothing is really taken seriously will perhaps be very funny, but it will loose tension and eventually become boring.

Pure Game

Total War

To be acceptable and enjoyable, a game needs supplementary war-character, seriousness and competition, and a war needs supplementary game-character and harmlessness. People want wars with (video-) game-character, and games with war character. Wars and games are complementary to one another, they form a dichotomy.

War-Game Dichotomy

Science contains a fundamental game/war dichotomy, too. Theoretical science is a game with models and theories, a search for the fundamental particles and rules, whereas experimental science is a war with reality, a constant fight to beat natural obstacles and bugs with the newest measuring instruments. Real science is of course a combination of both, theories, which can be verified experimentally (games are verified by and applied to concrete places and theaters of war), and experiments, which verify theoretical results and predictions (wars verify predictions of games).

Theory is a game

The preparation for theory and experiment corresponds to a game and a war. Excercising and practising theory means to play with different theories. To find the right theory for a hard problem is a game. You have to test and check all kind of different theories and select the best. If you constantly play around with new theories, chances are good that you will discover the one you need. Theory is a game which needs creativity, and creativity in turn needs play. The driving force behind new discoveries is of course the pleasure of finding things out. Children play games because it is fun, and scientists play with theories for the same reason. In the words of Richard P. Feynman [48]: "This [the things that have been found out] is the yield. This is the gold. This is the excitement, the pay you get for all the disciplined thinking and hard work. The work is not done for the sake of an application. It is done for the excitement of what is found out".

Experiment is war

Experiments are done for the sake of verification, but have often useful applications. Excercising and practising experiments means to fight with measurement tools, errors and problems. To find the right data which consolidates and validates the theory, you need to eliminate carefully every potential error and bug. This is a daily fight for experimental scientists, with requires thorough investigation, a lot of patience and strong perseverance. The byproduct are useful applications of the developed technology. Experiment is a war which needs precision, accuracy and patience, and precision in turn needs fight against bugs and errors.

	Theory (Game)	Experiment (War)
weapons, tools	pencil and paper, computer calculations	measuring instruments, computer simulations
Positive aspects, best case	true insights and exciting discoveries, fun	useful applications and verifications, joy
Negative aspects, worst case	has often no real or useful application or practical uses	offers often no true discoveries and insights

Tab. 16 Theory and Experiment as Game and War, respectively

An example for experimental scientists are programmers or software developers who are working in applied computer science. They setup and define an experiment if they write a program, they run the experiment if they run the program, and they constantly try to fight and eliminate the bugs they find during the run of the program.

Rutherford said "All science is either physics or stamp collecting". Physics at his time was mainly hard applied mathematics and application of complicated mathematical theories. Rutherford himself was not very good in mathematics. Whereas physics represents in this case theory and mathematics, stamp collecting represents experimental science, it means to classify phenomena, to collect and gather data and information, and to present and store it in an ordered manner.

Experimental Scientists: Gatherers of Data

Observers and experimental scientists gather new experimental data to consolidate and refine existing theories. Observers as gatherers of data are the ancestors of experimental scientists. On the contrary, **thinkers and theoretical scientists** hunt new theories to find one that explains the available data. Thinkers as hunters for insight are the ancestors of theoretical scientists. So theoretical thinkers and experimental observers correspond to ancient hunter and gatherers. Just as hunter and gatherers have evolved into organized cattle-breeders and farmers, thinkers and observers have evolved into full scale theoretical and experimental scientists. Both need to be tenacious and open-minded to be successful and ingenious scientists.

Theoretical Scientists: Hunters of Theories

4.5 Rituals, Play and Development

Ingenious scientists need creativity and imagination. Mihaly Csikszentmihalyi writes [26] "creative individuals alternate between imagination and fantasy at one end, and a rooted sense of reality at the other" and acknowledges that "there is no question that a playfully light attitude is typical of creative individuals".

Creativity and Play

The right combination of playfulness on the one hand and seriousness on the other hand is important to explore new ideas. A strong motivation, intense enthusiasm and ability of focused concentration is useful to make new discoveries and inventions. Charles Darwin wrote in a Letter to Galton "I have always maintained that, excepting fools, men did not differ much in intellect, only in zeal and hard work; and I still think this is an eminently important difference".

Playfulness and Seriousness

A genius or great scientist needs to "play seriously" with new theories and technologies to make discoveries and inventions. Playing is also the job of a child. Arthur Schopenhauer (1788-1860) said every genius is a child, and every child is a genius to a certain extent. In a certain sense, a genius stays a child and tries to avoid rituals. During the development, daily rituals are getting more and more important. They are the grid and scaffold of our personality. Already Aristotle knew: We are what we repeatly do. And what we are determines what we do.

Genius and Child

Fig. 50 Process of Becoming (Someone or Something)

Organisms specialize themselves by mainly reactive and goal-directed, but also accidental and random selection of certain behaviors and actions, which in turn modulate and influence other behaviors. Cells specialize themselves by activation of certain genes and producing certain proteins which in turn may regulate other genes. According to Kauffman, a cell type corresponds to an attractor in the gene regulatory network. Through a long sequence of steps, transitions and cell-divisions, a stem cell in the embryo which has every possibility becomes a special cell of a grown-up which is a cell of a particular type.

The free play of the infant turns into the (ritual) games of children, the fights in school become wars in business and the real world. An infant has every possibility, and is nearly nothing. A grown-up is something, and has only a few possibilities to become anything else. During a sequence of transitions from 'to have' to 'to be' [54], and a number of transitions from internal to external dimensions of complexity, we loose more and more possibilities and chances, but gain more and more personality and reputation. Henri Bergson (1859-1941) said our life is a continuous process of becoming. The older we get, the more our actions grow stiff into the same personal ritual forms.

Although ritual work is tiresome and boring for an individual, as already noticed true social rituals in a community are very enjoyable, especially if they are connected to 'Flow'-Activities. 'Flow' activities are described in the case of psychology by Mihaly Csikszentmihalyi in his excellent book "Flow" [25]. The 'Flow' state of Mihaly Csikszentmihalyi is a very enjoyable experience, a state of absorption and total involvement in an activity, a state of focused concentration on a certain goal. People in a 'Flow' state feel strong and in effortless control, unselfconscious, and at the peak of their abilities.

'Flow' Activities

'Flow' Activities

1. require the learning of new skills
2. set up goals
3. provide clear feedback

'Flow' Activities for a Person

In a typical 'Flow' Activity, skills match the challenges and the opportunities for action, and following a 'Flow' experience with deep concentration and a sense of control and satisfaction, "the organization of the self is more complex than it had been before" [25]. The 'Flow' experience can also occur in a society, and just as a person can enjoy a *flow activity* and can become more complex as a result of experiencing flow, a society can enjoy a *flow activity* and can become more complex.

4.6 Rituals and 'Flow'-Activities

> "Wo es um Leben und Tod geht, zählen die kleinen Bedenken nicht mehr. Wo nur das eine Ziel, der Sieg, angestrebt wird, erscheint das Leben so einfach und überschaubar wie nie zuvor. [..] Jeder einzelne wird ergriffen von dem Wunsch dabei zusein."
>
> Werner Heisenberg in "Der Teil und das Ganze", 1969

Rituals are often connected and linked to 'Flow'-Activities [25]. A 'Flow' activity for a society is a national, monumental project in which nearly all members of the society are directly or indirectly involved, for example building a pyramid, the Apollo Space Program, a war and a national sport game. It needs a huge but achievable goal: to build a pyramid, to bring a man to the Moon, to win a war or a game. All these activities can be exciting and inspiring.

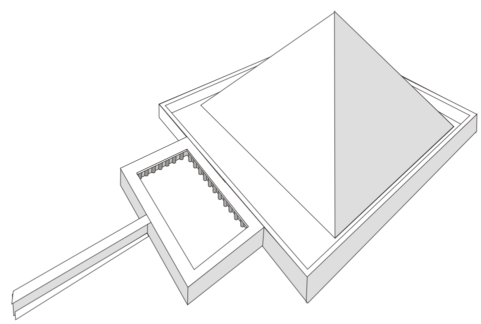

Fig. 51 Egyptian Pyramid

Enjoyable Activity ?

We have no evidence that the pyramids of the Maya or the Egyptians were built by slaves. So building a pyramid must have been an exciting and enjoyable experience. How is it possible that stacking up million tons of stone is enjoyable ?

It was certainly mysterious

Many of the workers must have believed in the pyramid and its magic function. All the things we know today from history, psychology, mathematics, chemistry, physics, biology, .. were not known at 2500 BC, the world must have been a big mystery. The number $\pi = 3.141592\ldots$ is still a mystery to some people today, but it was certainly at the edge of knowledge at that time. The pyramid was a mysterious place, where the pharao became a shining light and ascended to the stars, a site of a mystery that allowed the dead king to unite with the Ba ('the spirit') of the sun god.

The building site of a pyramid was very large, so there was plenty of room for a lot of overseers and supervisors. From a farmer to an overseer - this is not bad. So at least some of the overseers must have enjoyed their work, because it was the pyramid that made them important.

Yet it is still a mystery for many of us today, why all this people, and there must have been a few, worked indefatigable at the construction of a huge monumental stone heap. Why did the people in the middle ages build large cathedrals ? Because they were good christians, they believed in god and they wanted to obtain eternal life. But there is a deeper reason that connects cathedrals and pyramids. Stacking up million tons of stone was enjoyable because building a pyramid was a ‘Flow’ activity for the ancient society.

Cathedrals & Pyramids

The term ‘Flow’ can also be applied to a king that embodies and represents a society, and to the society itself. Processes which can be found in agents who respresent and embody whole complex adaptive systems, can sometimes be found in these systems, too. If the mind of a person can be described as a society of agents [100], then we should be able to explain and describe the phenomena in such a society of agents with psychological processes. Like building a cathedral or bringing a man to the moon, building a pyramid was a monumental national project, a ‘Flow’ activity for the ancient societies and for the king who embodied it, because it satisfies all necessary criteria.

‘Flow’ Activities for a Society

It is first of all hard to find a clearer goal than an unfinished, huge pyramid, and second the height of the pyramid provides clear feedback about the situation and the work done, and third it requires of course the learning of new skills to build a pyramid.

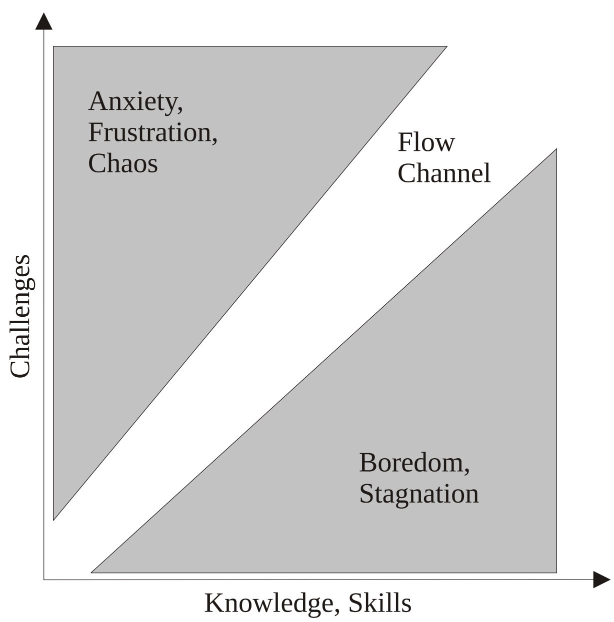

Fig. 52 Psychological Flow Channel

Skills & Challenges

During a 'Flow' activity or process, the agent, person or society moves along a 'Flow' channel [25]. The skills and abilities are adequate to cope with the constantly changing challenges at hand, so that the complexity of the agent, person or society increases continuously.

Increasing Complexity

In Csikszentmihalyi's book, the last paragraph of chapter 2 reads : "Following a flow experience, the organization of the self (or a society) is more complex than it had been before. It is by becoming increasingly complex that the self might be said to grow. Complexity is the result of two broad psychological processes : differentiation and integration". The same process of differentiation, specialization and gain of self-confidence & sovereignty on the one hand combined with integration, cooperation and loss of autonomy & self-determination on the other hand can make a society more complex.

	Self	Society
absolute absorption in an activity	No thinking about the "Self" or possible problems of the "Self", no other activities.	no conflicts and no thinking or discussing about the society
loss of autonomy & self-determination, concentration on a certain goal	all agents of the mind or all their activities are directed to a certain goal	everyone works towards a certain, fixed goal, full cooperation and integration
learning new abilities, differentiation, specialization	Each new situation offers a new task and challenge that requires abilities and skills. In a 'Flow' activity, one's skills are adequate to cope with the constantly changing challenges at hand, and the skills are continuously increasing.	Each member of the community and specializes on a certain task, thus becomes an expert in his field. New members or agents are created continuously (by evolution, growth, and 'immigration') to cope with the increasing challenges.
feeling strong and in control, increased self-confidence, and sovereignty	if the challenges never exceed the skills, the "Self" is able to cope and grow with every new situation. The continuously increasing number of solved tasks, the lack of thinking about the own problems, and the increasing abilities result in larger self-confidence	The community feels powerful, strong and self-confident because it is able to cope with difficult situations or monumental tasks. It has an expert for every kind of work, and can divide large tasks by delegating them to many different members.

Tab. 17 Analogies between the Self (Psychology) and the Society (Sociology)

Differentiation in a society means specialization and division of labor: everyone has a special task, some workers became bakers and butchers, some became experts in cuttings stones, other in transporting or shipping them. Integration on the other hand means cooperation, concentration and restriction: All workers are working together towards one single goal, represented by the pyramid. Every member of the community feels great, because he is part of the great and powerful "pyramid" community, the Egyptians.

Differentiation, Integration

It was the construction of large monuments like pyramids and temples that held the people together and that gave meaning to the life of the ordinary worker. In this sense, the pyramids built Egypt, as Mark Lehner said in a National Geographic article about the Old Kingdom. It was a cyclic process: ancient Egypt built pyramids, and the pyramids built in turn ancient Egypt. Any other form, a tower (the Sumerian temple towers or Ziggurats helped to build ancient Mesopotamia) or a wall (the Chinese wall helped to build China) would have done it as well. What matters is absolute absorption in an activity, and focused concentration on a certain goal for a long time.

'Flow' Activities create Societies

'Flow' Activities for societies - building a big wall, a huge tower, a monumental pyramid or a giant rocket - can increase the complexity of a society dramatically. But the really large jumps sometimes named "evolutionary transitions" take place only through the emergence of a completely new CAS at a higher level of complexity. One of these jumps was the jump from genes to memes and the beginning of memetic evolution.

4.7 Genes and Memes - Memetic Evolution

Groups are often the base for the emergence of new CAS in existing CAS, especially for memetic CAS, because groups are related to the phenotype of memes. The name memes was coined by Richard Dawkins, in chapter 11 of his famous book "The Selfish Gene" [30]. Whereas genes are genetic replicators propagating by reproduction, memes are cultural (or 'memetic') replicators propagating by imitation. They represent ideas, traits, customs, rules or laws as Dawkins explains [30]: "Examples of memes are tunes, ideas, catch-phrases, clothes fashions, ways of making pots or of building arches. Just as genes propagate themselves in the gene pool by leaping from body to body via sperms or eggs, so memes propagate themselves in the meme pool by leaping from brain to brain via a process which, in the broad sense, can be called imitation."

Definition of Memes

Memetic Evolution

The three basic examples for memetic evolution are language, culture and personality, which belong to anthropology/linguistics, archaeology/sociology and psychology, respectively.

Genetic Evolution	Memetic Evolution of Language	Memetic Evolution of Culture	Memetic Evolution of Personality
Genes (Genotype)	Memes : words and rules of individual persons	Memes : Language, Myths, Religion, Habits, Traditions	Memes : Language, Memories, Beliefs, Attitudes, Traits
Individual Person/Animal (Phenotype)	Language shared by a group	Culture shared by a group	Personality shared by the 'society of mind'
Survival of the Fittest, best (best adapted to the environment, Natural Selection)	Fittest Language survives (easy to learn and apply, fast, good and comprehensive communication)	Fittest Culture survives (best adapted to other cultures, members satisfied)	'Best' Personality survives (Emotions determine what is good or bad)
Timescale 1,000-1,000,000 years	100-1000 years	100-1,000 years	10-100 years, during a lifetime

Tab. 18 Genetic and Memetic Evolution

Memetic evolution apparently is not possible without genetic evolution. How do genetic and memetic evolution influence each other ? Dawkins says in "The Selfish Gene" [30] "Memes and genes may often reinforce each other". We have argued earlier, that this gene meme interaction takes place in group selection.

Mental Organs

Is our mind a kind of mental 'organism' with mental 'organs' as Pinker suggested in "How the mind works" [121] ? Do we have mental organs evolved by natural selection ? Yes and No. The interesting thing at Pinker's "How the mind works" book is that it is wrong and right at the right time. His right sentences contain errors, and his wrong sentences contain truths. A thought provoking book.

"Our physical organs owe their complex design to the information in the human genome," Pinker argues, "and so, I believe, do our mental organs". This is wrong. Mental organs owe their complex design to memetic evolution, to recombination of memes. Word are the building blocks of language, and language is one of the building blocks of thought. But we have to learn words and language painfully, they are not specified by our genes. Children have to acquire certain mental organs or memes. And they do this by *innate delegation*.

Living organisms replicate and reproduce themselves. During replication, not the organism itself is copied, but the genetic material containing the information needed to construct a new organism. The construction plan is copied, not the construction. Controlled by the emotions, the interaction with the environment (food collection) results in growth, until a new organism is constructed.

Body Construction Plan

Likewise, the neural structure and material of the infant brain contain the information needed to construct a new mind. Controlled by the emotions, the interaction with the environment (information collection) results in learning, until a new mind is constructed. Emotions control the behavior and the delegation of tasks to the environment.

Mind Construction Plan

Usually, both processes occur at the same time, the mind and the body coevolve together. Development takes time. And both are 'social' processes. Cells interact with their environment, which determines the type of a new cell. The behavior of an infant is highly social, too [41]. It depends on interaction with its caretakers. Language for example can not be learned alone, only from others.

And both processes are not based on complete 'descriptions' or blueprints. They must be completed by placing the agent in an appropriate environment. They are based on "how to grow" instructions.

Elman et. al argue [41], that it is not clear what is meant by nature or nurture. They ask what is meant by 'innate'. Usually, 'nature' is understood as all influences from genotype, whereas 'nurture' means all things learned by experience. But they say correctly that there is no one-to-one linear mapping between genotype and phenotype. The genotype-phenotype relationship is highly nonlinear : "genetic constraints interact with internal and external environmental influences, and they jointly give rise to the phenotype".

Nature and Nurture

Quartz and Sejnowski add in their 'constructivist manifesto' [127], that cognitive and neural processes fundamentally interact during development. They say that the development and growth of neural systems is controlled to a large amount by the interaction with the environment. A visual field which has never received an input can not develop the right neural connections.

Interaction controls Development

Without the right stimuli and influences from the environment, the best genetic plan is useless. You can not understand the neural or genetic blueprint or construction plan without considering the interaction with the environment. Intelligence and complexity emerge through interaction with the environment.

This is the way how nature builds complex living systems: by constructing blueprints through evolution and natural selection, which *delegate the task of constructing a complex system to the environment itself.* As Quartz and Sejnowski say [127, 128], the representational properties of the cortex are constructed by the nature of the problem domain confronting it. This is the most flexible representational structure one can imagine.

Innate Delegation of Self-Construction

The question "How does the brain wire itself ?" is easy. It does not wire itself completely. To a large amount it is determined by the environment. Genes specify what kind of adaptive agents will grow up in a suitable context and environment, and how the helpless infant agent can delegate tasks to it. The environment specifies how this agent and its internal structures are constructed.

If the brain is the hardware, the mind is the software - as Minsky says [100], the mind is what the brain does - and both are based on different evolutionary processes. The array of "mental organs" evolved separately, and must be impressed on each child in every generation again. As Pinker says, natural selection must be viewed as "the only evolutionary force that acts like an engineer, 'designing' organs that accomplish improbable but adaptive outcomes". This is right, but there is more than one kind of natural selection. Selection happens on the level of the individual *and* on the level of the group.

Basically any kind of complex adaptive system is shaped by evolution and natural selection, and there are as many natural selection processes as there are complex adaptive systems. Each complex adaptive system has its own special selection process, and its own genes, memes or other elementary unit of recombination.

A new level of complexity is reached, whenever a new complex adaptive system "emerges" in an old complex adaptive system. The complex adaptive systems of "Language" and in general of "Culture" emerged more than 50,000 and 5,000 years ago in the complex adaptive system of the ancient human ancestors, when the gene was supplemented by the meme.

Chapter 5

Emergence of new Systems

5.1 Emergence of a new CAS

A new Complex Adaptive System (CAS) can emerge in an existing CAS, if it is "embedded" in the old CAS. The figure below, which has a self-similar or fractal structure, shows how this is possible in principle. Three agents communicate which each other about the relations in a small complex system, a cycle of three elements. The representation of the small complex system is itself a CAS, which is embedded in the old CAS.

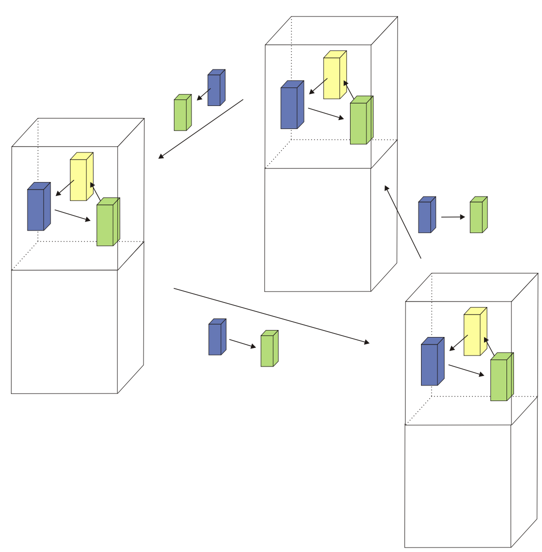

Fig. 53 Emergence of a new Complex Adaptive System

Memetic CAS

In this chapter we examine how a new CAS can emerge in an old CAS. Usually completely new CAS are memetic CAS which are based on memes instead of genes. A memetic CAS is very similar to a genetic CAS. It has a genotype, a phenotype and is subject to evolution and natural selection. But the genotype of a new memetic CAS is not genetic. Memes are like genes replicators, but they are not based on nucleic acids or DNA.

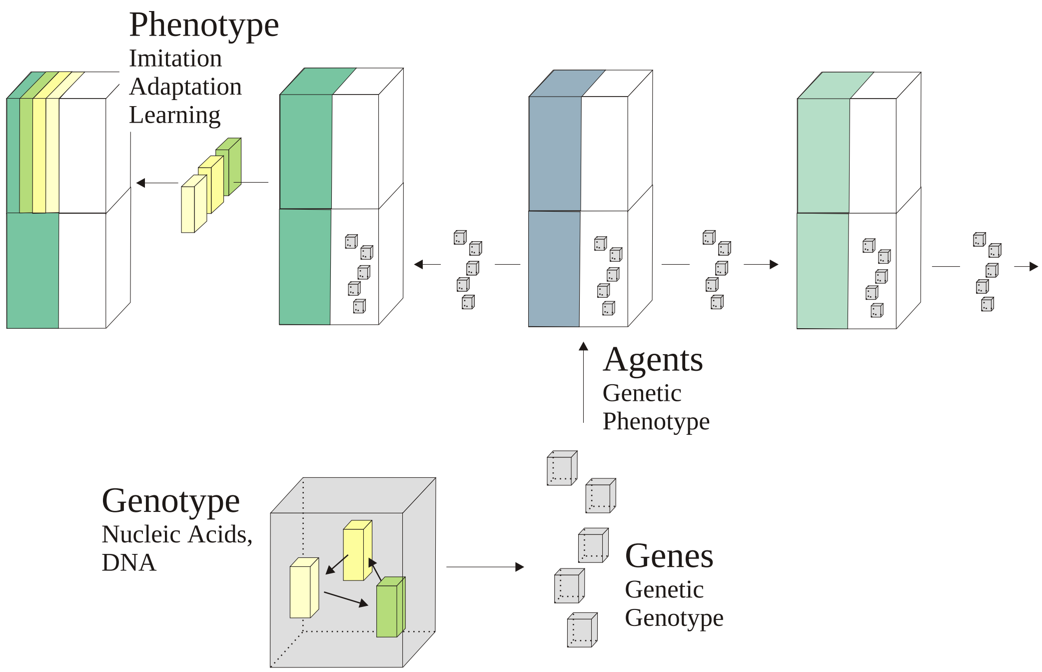

Fig. 54 Genotype and Phenotype in Genetic Evolution

Genes propagate by reproduction

Genes are implemented in the genetic code, which is written in nucleic acids. This code is translated into amino acids and proteins, and through the interaction with the environment the corresponding phenotype is created. Memes are abstract rules, recipes, ideas or informations. They can be implemented in any information processing system, for example in the phenotype of an genetic CAS. The memetic genotype is related to or part of the phenotype of the old CAS.

Memes are abstract

Whereas genes are carried around by their survival machines, memes 'hover' over their survival machines. Memes are not physical entities, they are abstract self-replicating patterns of information [30], mental entities which exist in the physical world only as an instance, an approximation or a process. They are ideas and informations for instance defined by a definition which uses classes, categories and generalizations, mathematical objects (perfect lines or mathematical points) or limiting values as Dirac's delta function $\delta(x)$ in physics.

Genes are concrete and specific blueprints, memes are abstract and general instructions. You can recognize and propagate a coarse idea, a general rule or a vague information without fully knowing it. The receiver might implement the meme in a different way. Memes are abstract, like an abstract class interface, which is implemented in a certain programming language, an abstract rule, which is applied to a certain case, or an abstract suitcase word, which has slightly varying meanings in different contexts and which can only be understood by analogies and metaphors.

Memes propagate by imatation

Memes propagate from agent to agent and from group to group by imitation, adaptation and learning. While genes are genetic replicators propagating by reproduction, memes are cultural (or 'memetic') replicators propagating by imitation. This propagation is interrupted if agents are isolated from one another. The phenotype of a memetic CAS is based on group-formation and aggregation on the phenotype level of the old CAS.

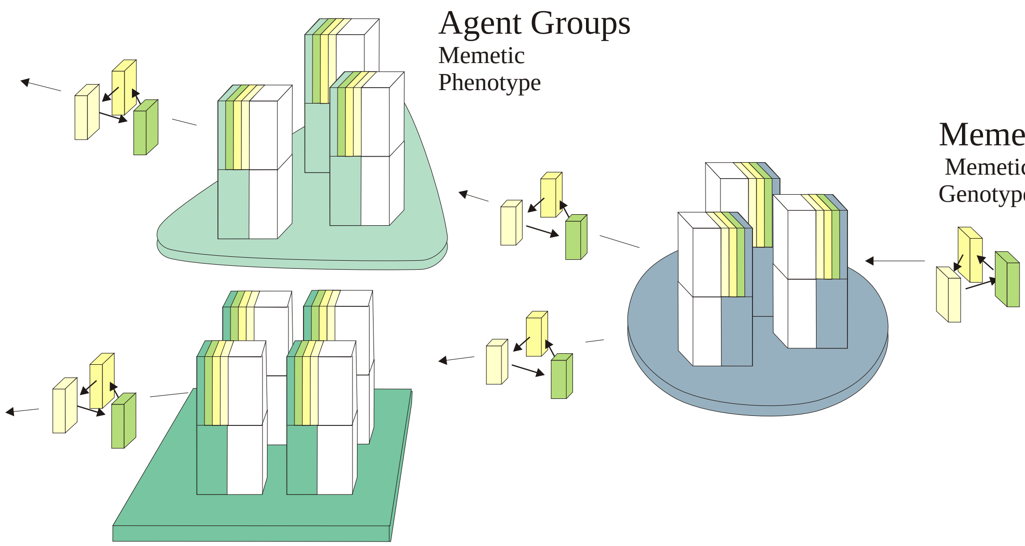

Fig. 55 Genotype and Phenotype in Memetic Evolution

Because the old CAS is always needed as a foundation or base for the new CAS, and the new CAS changes the fitness landscape substantially, the old CAS can not easily change once a hierarchy of CAS is built on top of it. As W. Brian Arthur says [4], "a genetic sequence can change easily, but the genetic code can not; new organisms can appear, but the cell and metabolic chemistry remain relatively fixed; new financial derivatives are constantly seen, but the securities-and-exchange rules stay relatively constant".

New CAS exert pressure

Likewise new software programs appear, but the binary code does not change, new hardware and computer appear, but the architecture (serial processor, address-bus, memory partitioned in bytes, IDE hard disk...) stays the same, new intelligent species appear, but the neural code - the neuron as a basic building block - is relatively constant. *As if the CAS at the base feels unable to move under the pressure and weight of the CAS built on top of it.*

Extended Phenotype

A new embedded CAS is independent of the old CAS, because it can be embedded in other CAS or described by formal rules or principles. As in the case of languages and writing systems, the new CAS develops a life of its own once it has become established. The languages and tools we use, the houses we build and the cars we drive belong to what Dawkins calls the "Extended Phenotype" [29]. The true phenotype is larger than the body, it is made of all the effects the genes have on the world. These effects are the tools by which the genes lever themselves into the next generation, and they may reach outside the body wall [29].

Independence in inter-dependence

Yet everything in the normal phenotype - the body - is under direct control of the genes, whereas the genes have only weak influence and no direct control on the extended phenotype. The extended phenotype outside the body is independent of the genes confined in a body. At the same time - as long as there is no other system or carrier available - it depends on the old CAS as a foundation or base. A kind of *independence in interdependence*.

The phenotype of a low-level system becomes part of the genotype of other, high-level systems. As Peter Schuster said [137], the process of evolution which shapes complex adaptive systems did not change, "the objects and not the dynamics of evolution become more sophisticated in the course of the history of life".

Origin of Memetic CAS

To examine the origin of memetic CAS in genetic CAS, it is useful to look at language as the most basic memetic CAS. We resume the discussion about the origin of language in chapter three. Increasing division of labor between mouth, arms and legs for communication, tool-using and locomotion, respectively, enabled the origin of language.

This division of labor increases the diversity and complexity of the phenotype and enables the interaction between genetic and memetic evolution.

Gene-meme interaction, which is comparable to group-selection which was discussed earlier, is essential for the emergence of new CAS.

Usually the interaction between genetic and memetic evolution is weak - they act on different timescales, and the genotype of one CAS can be related to the phenotype of another. In genetic evolution the individual person or animal is the phenotype, for memetic evolution part of the genotype.

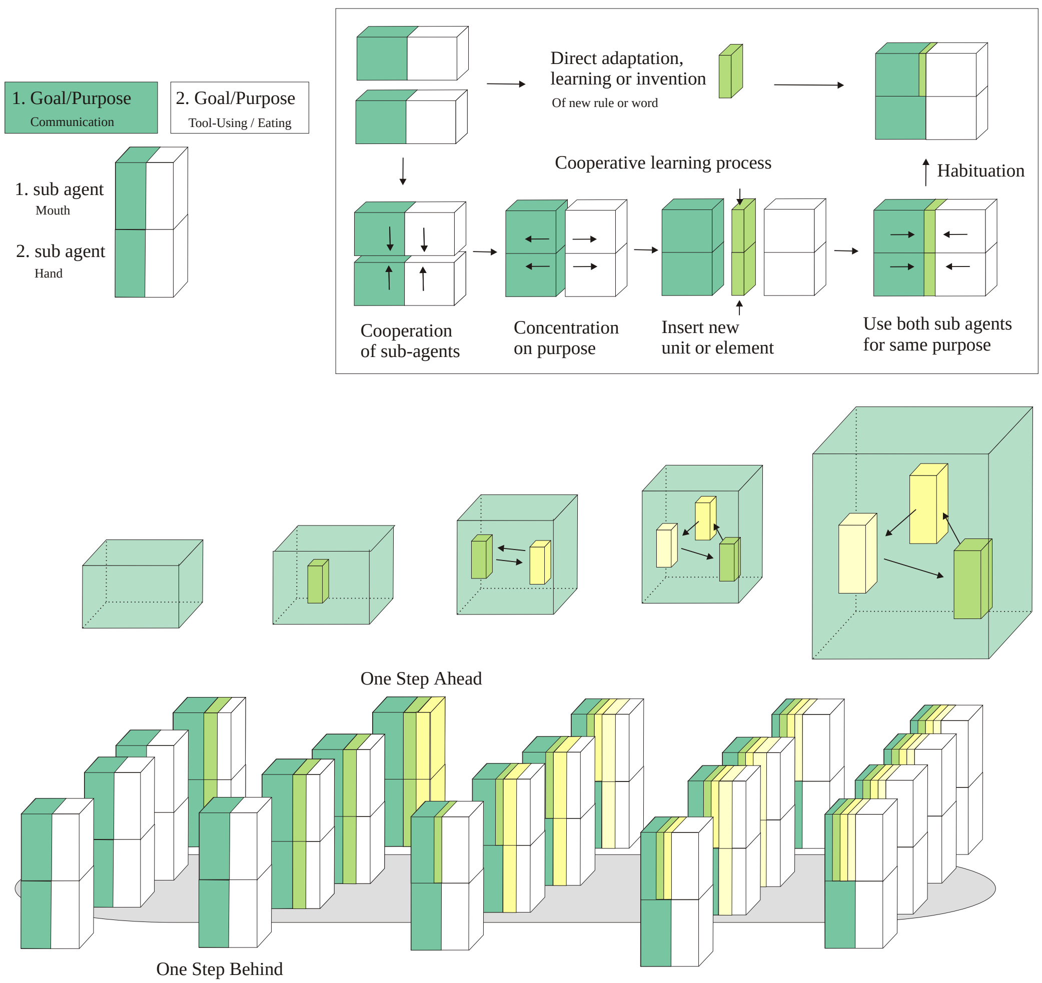

Fig. 56 Emergence of a new CAS in an old CAS

But the influence and interaction is much stronger if a new memetic CAS emerges. Memetic evolution started with the evolution of language. Like apes and normal animals, the early Hominids lacked the capacity for learning and using language, and language was constrained to sounds controlled by emotions [65]. Modern Humans have the capacity for learning and using language, and today there are many different languages. Somewhere in between during the early stages of evolution, language was not fully developed, and Humans had no full 'language capacity'. This is the point were both systems have influenced each other.

Origin of Memetic Evolution

The human ancestors described events in nature by 'mimetic skills' [34]: imitation, primitive sounds, mimic and gestures. With the help of 'mimetic skills' early hominids were able to establish a primitive language. We still use gestures, pointing or painting to explain complicated things.

Helpful Mimetic Skills

In this way they changed the environment for genetic evolution: the primitive 'virtual' language and the communication process became part of the environment. Individuals with bigger brains, human-like larynx and better language capabilities showed better fitness in the new environment. The genetic evolution of bigger brains in turn increased and shaped the environment for memetic evolution. This is related to 'The Baldwin Effect' [11, 68, 1], which says that genetic evolution can be influenced by acquired behaviors, and that learned *behavior* at the level of the individual can affect evolution at the genetically level.

The Baldwin Effect

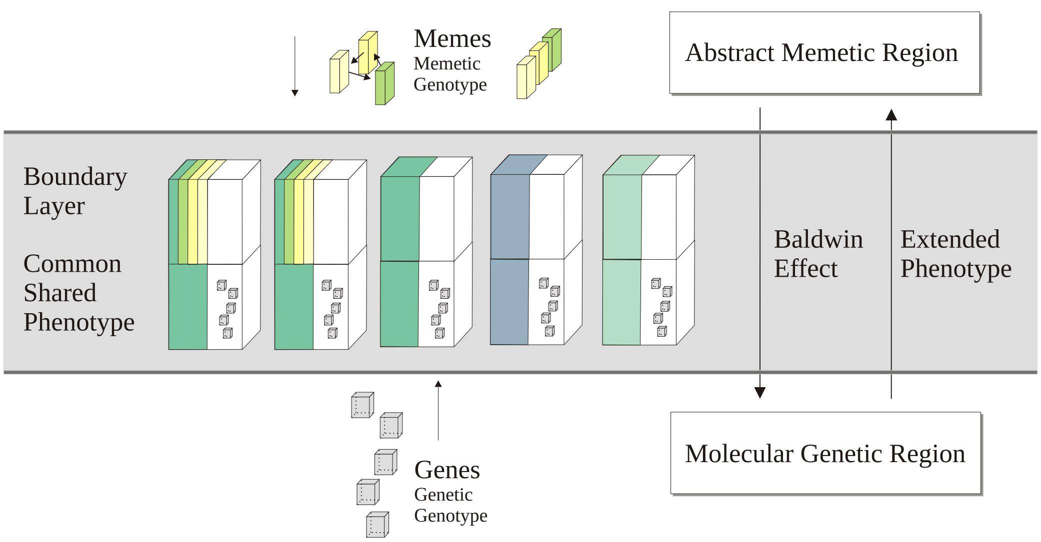

Fig. 57 Phenotype as Boundary Layer

The Baldwin Effect is related to a transfer of complexity from memetic to genetic CAS. An extended phenotype is formed and influenced by a new memetic CAS, and the phenotypic plasticity replaces missing physical abilities (for example the ability to speech). The new auxiliary phenotypic complexity is only borrowed. The Baldwin Effect is a payback of borrowed phenotypic complexity which is not grounded in the genetic CAS.

memetic → genetic

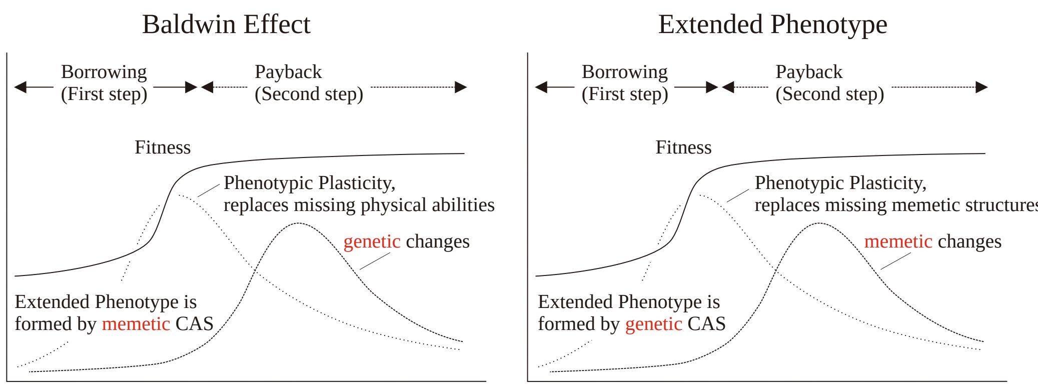

Fig. 58 Baldwin Effect & Extended Phenotype

During the emergence of new memetic CAS, a transfer across the common phenotype boundary of genetic and memetic CAS takes place, and this transfer across the common phenotype boundary works in both directions through a borrowing-payback process.

An extended phenotype can also be formed by a genetic CAS, and the phenotypic plasticity in this case replaces missing 'mental' abilities or memetic structures (for example lacking words). Mimetic skills as gestures can replace missing physical abilities *or* missing mental structures as ideas, words and concepts. For example, sometimes you use gestures or paintings to explain something because you lack the right word or description, but nevertheless you still have the ability to speak. The general "Extended Phenotype" Effect is a payback of borrowed phenotypic complexity which is not grounded in a memetic CAS (for example extended phenotypic effects [29] like special kinds of "tool using" which are based on phenotypic structures, rules and laws that go beyond already existing memetic CAS). Basically any kind of temporary tool or language, auxiliary device or description, intermediary system or law, can be used as an auxiliary tool until a full device, description, language or system is available through a new memetic CAS.

genetic → memetic

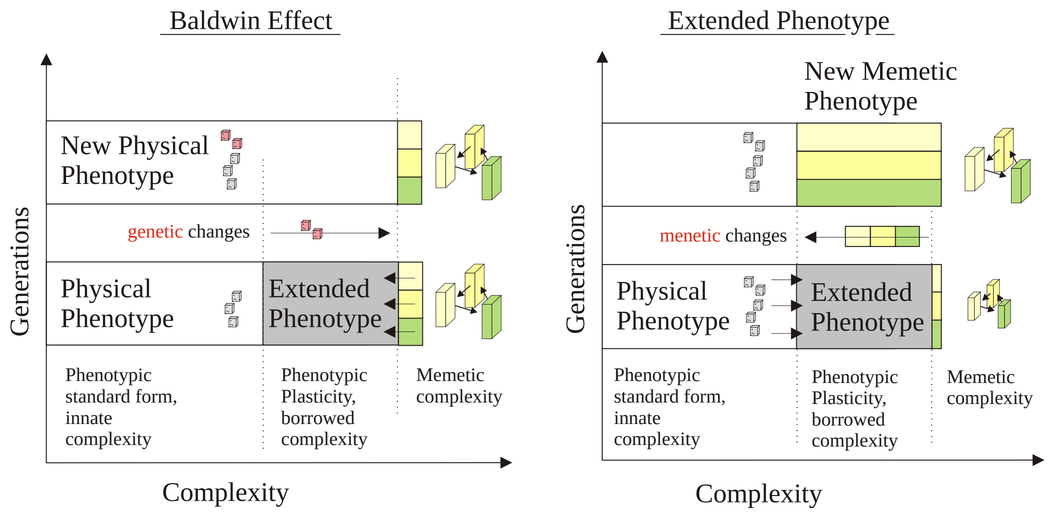

Fig. 59 Boundary Shift

Concerning the first auxiliary and intermediary languages in the present case, the emerging memetic capabilities and the advantages of the first primitive and fragmentary languages shared in a group were a catalytic tool to accelerate the genetic development of bigger brains. The genetic evolution accelerated in turn with bigger brains the development of better memetic systems and capabilities. In the beginning, genetic and memetic evolution probably catalyzed each other. Once the bodies and brains reached the full capacity for learning a language, this influence weakened again, and the two systems became more and more separated.

Effects of Group Selection

The whole process is complicated, long-winded and slow. It is based on extended phenotypic effects, cooperation within a group, borrowing of abilities and skills, and involves the Baldwin-Effect, Gene-Meme Interaction and effects of Group-Selection. Developing memetic capabilities is costly and expensive for the agents. To become a base for a new CAS, the agents must accept a temporary decrease of fitness, and they must invest in bigger and better intelligence (larger brains) with unclear payoff.

Tunneling Process

The process can be compared to a tunneling process in Quantum Mechanics. A transition to a new CAS which is normally forbidden by a potential or fitness barrier becomes possible through tunneling. The borrowing of complexity through the help of ‘mimetic skills’ is similar to the borrowing of energy.

5.2 Tunneling and thresholds of evolution

With the beginning of memetic evolution and the emergence of new memetic CAS, apparently a major threshold of evolution has been reached and crossed. Thresholds of evolution mark the emergence of new CAS. They can be regarded as potential barriers between different level of organization and complexity.

Through cooperation agents can delegate tasks to other agents, or agents can borrow the capabilities of other agents. The same applies to sub-agents of agents. If agents of a complex adaptive system borrow capabilities from all available sub-systems to concentrate on just one thing (for example language and communication), they can "tunnel" through the potential barrier to the CAS on the next higher level.

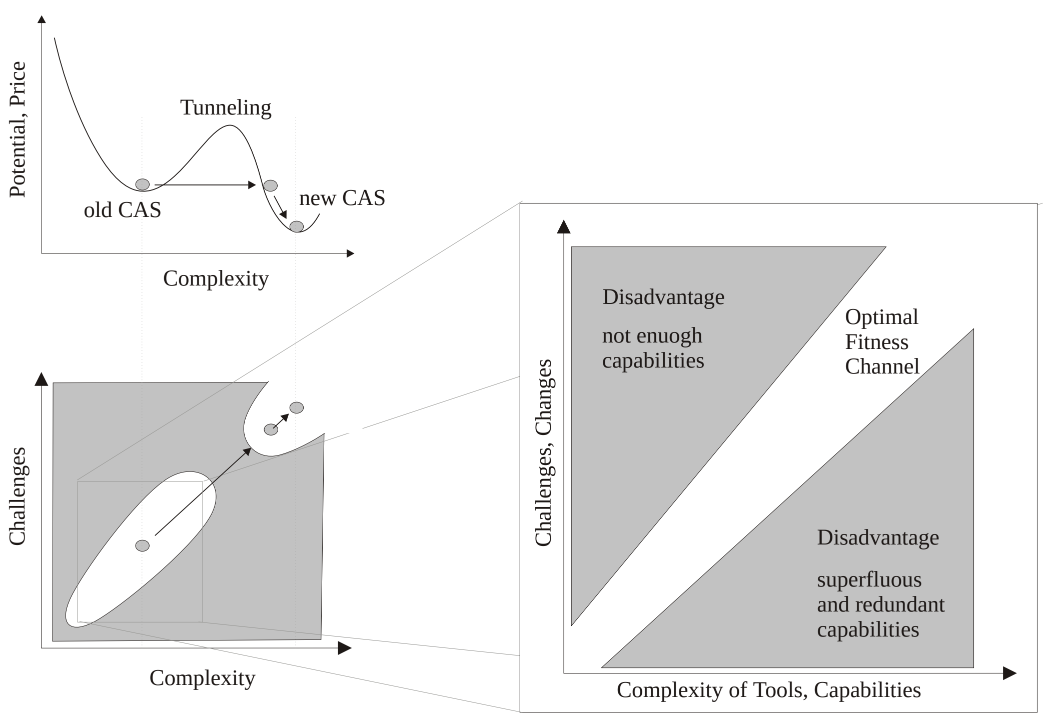

Fig. 60 Tunneling to new CAS

This is of course a simplified description. The real process may involve several tunneling processes through more than one potential barrier, since evolution takes place normally in rugged landscapes [118]. Stuart Kauffman has developed the NK-model to simulate a multi-peaked “badlands” landscape. According to this model, adaptive evolution is an uphill or downhill walk on a rugged fitness landscape. But adaptive evolution can be more complex. It can contain tunneling processes through peaks in the fitness landscape. Each of these tunneling processes requires the borrowing of capabilities from all available sub-systems.

Tunneling through a potential barrier is a phenomena forbidden in classical mechanics. Quantum mechanics allows particles to borrow energy, if they pay them back in the time which is determined by the Energy-Time uncertainty relation $\Delta E \Delta t \geq \hbar/2$. If a particle borrows enough energy, it can pass the potential barrier and pay the energy back.

For a CAS the tunneling is a slow process along the fitness/flow channel, and it happens through borrowing and exploiting all available capabilities by each individual agent, by modifying their behavior. The payback is what we know as ‘The Baldwin Effect’, when the modified behavior is replaced through genetic and other modifications.

The flow channel can be found in other systems, too, in psychology or sociology. It is bounded by a potential barrier which marks the limits of combinatorial possibilities to increase the complexity of the system with combination of available sub-systems.

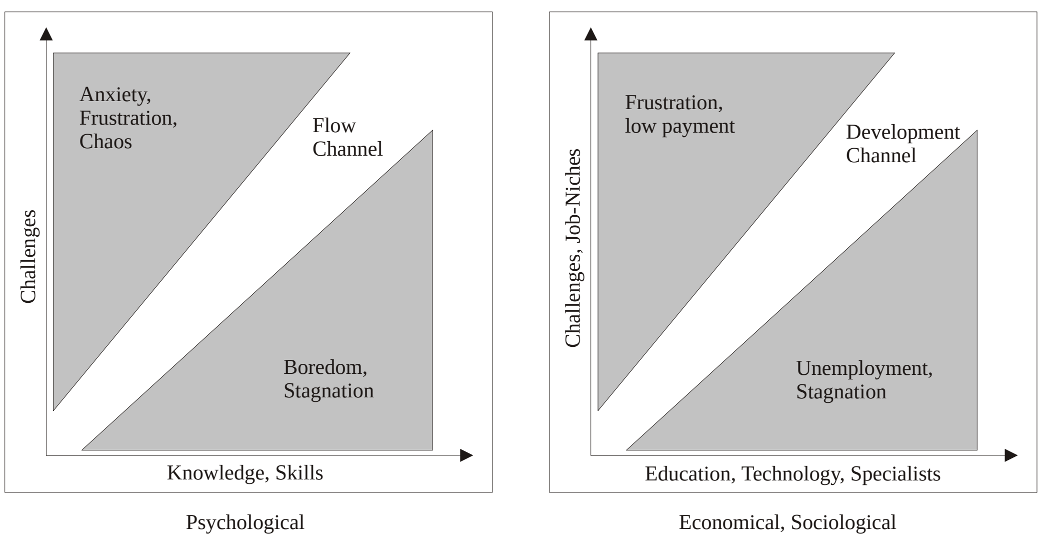

Fig. 61 Psychological, sociological and economical ‘Flow’ channels

5.3 Catastrophes as catalysts

The potential barrier can be heavily decreased by an external catastrophe like an asteroid impact, an ice age or a scorching drought. Humans seek to prevent catastrophes, technological and natural ones. Floods, droughts, volcanic eruptions and lightnings are frightening and dangerous, impacts of asteroids and meteorites are even more deadly and could easily kill millions or billions of people. Yet lightnings and impacts have played an important role for the development of life on Earth.

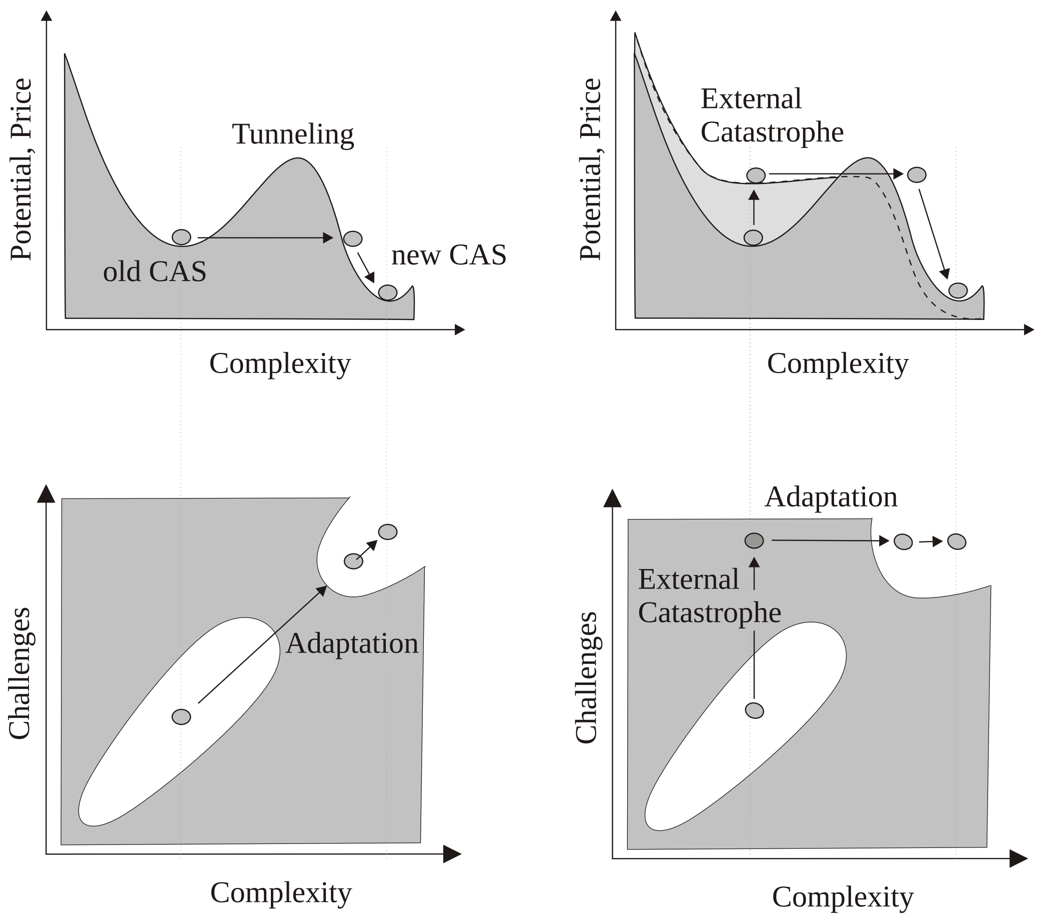

Fig. 62 Catastrophes as catalysts

Sean B. Carroll opens his nature article about the evolution of complexity and diversity [21] with the words “it is widely accepted that the evolution of any particular organism or form is a product of the interplay of a great number of historical contingencies". Catastrophes are an important class of these historical events.

Catastrophes increase Challenges

Catastrophes can cause a sudden change in the environment (extinction of species, climatic or environmental changes, ...). An agent or a CAS in an abruptly changing environment is confronted with increased danger, difficulties, trouble and challenges. It moves upwards on the vertical axis in Figure 62. It is a relative movement, you can also say the environment is changing "under the agent". The agent leaves the region of optimal fitness and experiences a high pressure to increase the fitness again[1]. If the agent does not use all possibilities including every kind of extended phenotypic effect it will perish or vanish.

Necessary Adaptations

The necessary adaptations cause changes in the architecture of the agent or the CAS, the complexity increases, and the agent moves on the horizontal axis in Figure 62 sidewards. A catastrophe can be a challenge for a complex adaptive system to grow in complexity. If this challenge is too low, adaption or adaptation are not necessary, if it is too high, the agent is unable to adapt itself to the new situation and is destroyed. If it is just right, the challenge can be a catalyst to reach new levels of complexity.

Positive Effects of Catastrophes

Asteroid and comet impacts can annihilate whole ecosystems, but scientists agree that they were also necessary factors for the evolution of life [114, 155, 97, 106]. According to the "Small Comets" theory from Louis A. Frank [51] small comets may provided the young Earth with water. Lightning bolts produced nitrogen oxides (NOx) and ozone [129]. Ice Ages catalyzed the development of language, better tools and the emergence of intelligence [19, 20], droughts and floods supported the appearance and disappearance of cultures [60]. Generally speaking, catastrophes which cause mass extinctions and annihilate large parts of complex systems also catalyze the emergence of new complex adaptive systems. Abrupt changes in the fitness landscape caused by catastrophes are nature's recipe for escaping the danger of getting stuck in local fitness maxima.

[1]This can happen a scientist, too. There are a lot of small and big catastrophes which happen to a scientist : the sudden recognition that you are much more stupid then you have ever thought, that you have not found any useful solution or have been going up a blind alley for the last 5 years, that a bright genius has discovered a much better approach you do not understand before he was 22 or that someone has published similar results a few month before you. Those who are adaptive enough survive, those who are not adaptive enough perish.

5.4 Emergence and Extinction

Extinctions as the consequences of catastrophes are the other side of emergence. The extinction of dinosaurs for example is associated with the emergence of mammals. The extinction of mammoths and saber toothed tigers is associated with the emergence of new hunting techniques (hunting groups with sharp-pointed weapons) and the modern man or the Homo sapiens sapiens.

Reasons for Extinctions

Most extinctions have been caused by fluctuations in sea-level and climate change due to meteorite impacts, volcanic activity, glaciation or Ice Ages. Mass extinctions seem to occur roughly every 20-50 million years, probably the average period of large meteorite impacts. This climate and temperature fluctuations in the history of the earth were strong enough to transform large part of the earth into hot deserts or frozen ice.

Two major Trends

Animals have only two major goals: survival & reproduction. They must keep the balance between exploration & exploitation and between attack & protection survival techniques. Although all catastrophes generally favor small, flexible and intelligent animals, which are able to cope with the new inhospitable situations, we can distinguish or identify two general trends. Periods of extreme cold climate are an advantage for animals with good exploration and attack abilities. Periods of extreme hot and dry climate are an advantage for animals with good exploitation and protection abilities.

- Cold times, glaciation or Ice Ages seem to support good exploration, explorative abilities, intelligence, agility, movability, predators and cooperative hunting techniques. They are an advantage for warm-blooded mammals, and all intelligent predators and animals who are able to play, learn and cope with difficulties. In icy times, animals flock together and become active.

- Dry, hot times and "desert ages" (Triassic times) support good exploitation and preservation of resources, economical use of energy and hard shells. They are an advantage for cold-blooded reptiles and all stoned or 'dumb' animals with fast reflexes who usually don't move too much, and are able to save water for future use. In hot times, animals go their own way and become passive.

There were many different large mass extinctions in the history of life on Earth [14]. Scientists generally agree that there are six major extinc-

P-Tr Extinction

tion events[2]. The worst extinction of all was the Permian-Triassic (P-Tr) mass extinction millions of years before the time of the dinosaurs. It wiped out nearly 95% of all life-forms on Earth. The Cretaceous-Tertiary (K-T) extinction killed only 65% of all life.

But every extinction has also a positive effect. Bill Bryson noticed [17] "Crises in the Earth's history are invariably associated with dramatic leaps afterwards." The extinction of the mammal-like creatures (thorapsids) at the end of the permian era 250 Million years ago cleared the way for the early reptilian dinosaurs, and the extinction of the dinosaurs 65 Million years ago cleared the way for mammals.

Snowball Earth

One of the earliest time period of mass extinction was the Precambrian ice era, the greatest, most extensive Ice Age, when the Earth was frozen to a giant snowball [152]. It did nearly freeze over completely, only a ring of bright water around a deep-frozen Earth provided the refuge that life needed to persist [46]. Yet life was not wiped out entirely. The end of the Proterozoic era marks a major evolutionary change, as the first multicelled animals (metazoans) start to appear in the fossil record. Single celled organisms became multicellular life. Animals as diverse as worms, arthropods, and our own chordate ancestors all appear within a few million years. This cambrian explosion was the "Big Bang" of animal life. It is the birth of shells, scales, spines and teeth, as well as external and internal skeletal structures.

There was certainly multi-cellular life before the Cambrian. But only a deep-frozen snowball Earth was able to catalyze the development of complicated multi-cellular life. As long as the environment is friendly, there is no need to cooperate or move around. In icy times, animals flock together and become active. In hot times, animals go their own way and become passive.

Reason for P-Tr Extinction

During the Permian-Triassic (P-Tr) mass extinction the global temperature of the Earth was raised about 10° C, which triggered the emergence of cold-blooded reptiles. This infernal extinction had many causes. The geologists Paul Wignall and Gerald Dickens have gathered evidence[3] that the extinction went on for 80,000 years, and identified the killer(s). The P-Tr extinction was first caused by massive volcanic eruptions ('basalt eruptions') in an area now known as the Siberian Traps. The Earth's crust splitted apart and released curtains of lava across an entire continent, maybe caused by a meteorite impact. The carbon dioxide emitted from the lava raised

[2] see http://www.bbc.co.uk/education/darwin/exfiles/index.htm

[3] see http://www.bbc.co.uk/science/horizon/2002/dayearthdied.shtml

the temperature of the Earth about 5° C. The rise of temperature melted methane, a frozen gas at the seabed. The released Methane in turn raised the temperature of the Earth even more, about 5° C to a total of 10° C. This temperature rise was enough to tansform large part of the land into deserts, killing 95% of all species. But it cleared the way for the early cold-blooded reptiles. The advantage of reptiles is not to do too much. They have fast reflexes, but usually do not move much, so they are good in saving energy and water for future use.

Warm-blooded mammals have developed the technique of quiet or NREM sleep to save energy. According to Stephen LaBerge [86], this is the reason why mammals sleep. NREM sleep is related to energy saving in warm-blooded animals, REM sleep is related to infant brain development during the gestation or pregnancy in viviparous animals.

Why do we sleep at all ?

The first mammals evolved in the shadow of dinosaurs, in the late triassic/early jurassic period 180-200 million years ago. These early warm-blooded mammals were small and furry and looked like modern mice. Despite these many mammal-like characteristics, it is thought they still laid eggs. NREM or quiet sleep evolved at this time 200-180 million years ago in the late Triassic or early Jurassic period, when warm-blooded mammals first evolved from their cold-blooded reptilian ancestors [86]. It has the function of an energy saving mechanism for warm-blooded mammals. Cold-blooded reptiles are dependent on external energy sources, warm-blooded mammals are independent on external energy sources. But to keep a fixed internal temperature consumes a lot of energy, especially predators like modern lions sleep very much to save energy.

NREM sleep

The reason for NREM sleep

REM or dream sleep evolved 130 million years ago during the cretaceous period, when early viviparous mammals gave up laying eggs and first began to give birth to living infants [86]. Dreaming has the function of stimulation and preparation. A baby before it is born is paralyzed and isolated from its environment, the same condition as during REM sleep. Yet the brain must be active to develop itself. This paradox is resolved by dreaming. It seems to be a mechanism to ensure brain development during the time before birth (gestation or pregnancy). REM sleep and dreaming help in preparing the child for the unlimited stimulations it will soon have to face. It is necessary for development and facilitates wake-up.

REM sleep

The reason for dreams

Passive energy saving NREM sleep is the price for being active, warm-blooded and independent from external (sun-) energy. Active energy expensive REM sleep is the price for being passive, protected and isolated from the external environment during development before birth.

K-T Extinction

Although the evolution of mammals started early, the massive emergence of mammals began only after the K-T extinction. The cause of the K-T mass extinction is well known. Remains of the huge asteroid impact which caused the extinctions of the dinosaurs 65 Million years ago are still visible today[4]. The impact was so strong and tremendous, that nearly 65-70% off all species, including all dinosaurs died out in relatively short time - the Cretaceous-Tertiary (K-T) extinction [123, 52]. But the dramatic change in the fitness landscape and the end of the Dinosaurs was the chance and the possibility for the mammals to conquer the Earth.

Extinction Event	Extinction (of many)	Emergence of
End of Proterozoic Era, Precambrian glaciation, 'Snowball earth'	Single celled organisms	Multi-cellular (metazoan) life first shells, spines & teeth skeletal structures
Late Cambrian (hot climate)	soft-bodied organisms	hard-shell bodies
Late Ordovician (glaciation and ice age)	immovable organisms, immobile filtre feeders	emergence of nerve cords, fish, sharks & predators
Late Devonian	marine species, jawless fish	amphibians and land plants
Late Permian - Triassic P-Tr, (very hot climate)	tribolites and thorapsids (mammal-like creatures)	cold-blooded reptiles
Late Triassic	reptiles and amphibians	upright walking dinosaurs (bipedalism)
End cretaceous K-T, (cold and inhospitable climate)	dinosaurs	warm-blooded mammals with fur or hair
Last Ice Age	mammoths and saber toothed tigers	Modern man, Homo sapiens sapiens.

Tab. 19 Mass extinctions

Emergence of complex Mammals

The deadly asteroid wiped out the dinosaurs, and left an empty space that mammals could fill. It cleared the way for warm-blooded mammals. The advantage of the mammals was small size, higher flexibility and enhanced intelligence, and they were protected by fur and hair against the cold climate. Only the mammals were adaptive, smart and intelligent enough to survive the cruel conditions after the impact.

[4] see `http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=11268`

H.G. Wells said in the "The Time Machine" (Chapter X): "Intellectual versatility is the compensation for change, danger, and trouble [..] There is no intelligence where there is no change and no need of change." Since intelligence is a measure for the complexity of cognitive schemata, you can also say: There is no complexity where there is no change and no need of change. Large abrupt changes in a complex **adaptive** system require and reflect huge sudden changes in the environment.

no Change, no complex Systems

5.5 Life at the Edge of Chaos

Catastrophes appear in systems at the 'edge of chaos', a region between order and chaos with a delicated balance between two opposite forces. A disturbance of this balance causes fluctuations and catastrophes. Periods of stability are interrupted and interspersed with times of instability, stress and challenge.

Catastrophes at the Edge of Chaos

Life on Earth appeared in several aspects near the 'edge of chaos', regions with large fluctuations. It evolved on the surface of the Earth, between the hot chaotic magma near the core of the Earth and the icy, motionless higher atmosphere, and between the huge pressure at the bottom of the deepest ocean and the thin air at the top of the highest mountain. Bill Bryson noticed about the pressure at the ocean floor [17]: "Even at the average ocean depth of 4 km the pressure is equivalent to being squashed beneath a stack of fourteen loaded cement trucks."

The orbit of the Earth is at the border between chaos (the infernal temperatures near the sun) and order (the extreme coldness of space). Our solar system is located in the outer, friendly regions of the galaxy with a low density of radiation, black holes and comets, between the lethal conditions near the core, and the void of empty space.

Orbits at the Edge

In all these systems, we have hugh pressure, infernal temperature and chaotic turbulences near the core, in contrast to very low pressure and icy temperatures in the outer regions. If the balance between these extremes is disturbed, all kinds of catastrophes arise: asteroid impacts, lightnings, volcanic eruptions, earthquakes, ice ages, droughts and floods.

	edge of chaos	between chaos and order	fluctuation, catastrophe	advantage, positive effect
solar system (life)	outer, friendly regions of galaxy	between black holes, radiation, comets at the lethal core & the void of empty space	comet or asteroid impact	water and organic material from small comets
planetary system (life)	orbit near the sun	between infernal temp. of the sun and extreme coldness of space	asteroid impacts	impacts increase the fitness of intelligent species
planet (life)	surface of Earth, crust of planet	between hot, high pressure core and cold, low pressure atmosphere	lightnings, volcanos, earthquakes	production of nitrogen oxides and ozone, fertile ash
planet (culture)	regions with moderate temperature	between hot desert and icy poles	ice age, drought	pressure to cooperate and develop new tools
planet (culture)	coasts, rivers	between sea or water and dry land	floods	fertile mud, opportunity to cooperate

Tab. 20 Life at the edge of chaos

As we have seen, most of them have a dramatic effect and can result in large mass extinctions, but they have also a positive effect and can catalyze the emergence of complexity. Volcanic eruptions and floods produce fertile earth and mud, comets can import water and organic material and ice ages or droughts increase the pressure to cooperate and develop sophisticated tools and higher forms of intelligence. Every catastrophe is a challenge and an opportunity for an adaptive system to develop intelligent strategies in order to cope with the difficult new situation.

Positive Effect of Earthquakes

Even earthquakes have a positive effect. They are a sign of plate tectonics, which renews and rumples the surface of the earth. Bryson argues, that the Earth would be a less complex ocean planet without plate tectonics [17]: "if the Earth were perfectly smooth, it would be covered everywhere with water to a depth of 4 km. There might be life in the lonesome ocean, but there certainly wouldn't be football".

Catastrophes & ancient Cultures

In memetic and cultural evolution, catastrophes trigger the emergence of new systems and species, too. The first spark that ignites the raise and the fall of a civilization is often a climatic catastrophe. The emergence and the collapse of several early civilazations has been triggered by climatic catastrophes, there is a lot of evidence [38, 40, 39, 60] that the collapse of the

Maya Civilization was caused by large century-scale droughts and declines in rainfall.

It was also a major drought in North Africa 5000 years ago (around 3000 BC), which probably ignited the spark that initiated civilization in the Nile Valley[5]. The Old Kingdom in ancient Egypt - one of the first true cultures of the world - collapsed again under a scorching drought [45] around 2200 BC. In contrast to the Maya civilization, the civilization in Egypt recovered after the climatic catastrophe. And with each recovery (the old, middle and new kingdom) they made an important cultural step forward. The droughts in Egypt were heavy, but not as deadly as the century-scale droughts the Maya had to endure. A disastrous climatic event can lead to a cultural jump, if it forces the people to cooperate and unite - like the temperatures in the ice age and the droughts in Egypt. But if they are too strong, the whole culture vanishes or is wiped out. As said above, the challenge by the event should not exceed the short-term possibilities of adaptation.

Ancient Egypt

Droughts

Ancient Egypt, the country along the Nile, was like a catalyst for the development of the first higher civilizaton. The Nile river threatened the country each year with a huge flood, and it was the home of dangerous animals like crocodiles and hippos, but also a plenty source of food in form of fresh fish. It was a natural highway which connected and united the different parts of the country. The fertile mud of the inundation facilitated agriculture. The long idle time during the flood and the inundation period

Floods

[5] Rock paintings in the Sahara, which were discovered 1934, show that nothern Africa was once a habitable and populated savanna. Civilization along the Nile began to develop at the time, when the climate in North Africa changed from rainy to arid 5000 years ago. Foreigners from the land west of the Nile migrated to the only dependable source of water, and mixed with the native agrarian people. The nomadic people, used to move at night, brought their knowledge about trading, astronomy and cattle-breeding to egypt. The native agrarian people had developed advanced techniques for farming, irrigation and measuring of fields and water heights. The arriving desert people settled down, and the hunters became cattle breeders, the gatheres farmers. Driven from drought-stricken North Africa by the merciless sun, they surely contributed to early forms of sun-worshipping in the Old Kingdom. In the March-April 2001 issue of ARCHAEOLOGY magazine, Farouk El-Baz from Boston University contends that it was the merger of these two peoples - Nile farmers and desert nomads - that served as a catalyst of the early ancient Egyptian civilization. According to El-Baz, it was the cross-fertilization of the agrarian river dwellers and the nomadic people of the desert that made the construction of the great Egyptian monuments possible. The increasing population required better social organization to manage the distribution of surpluses. So the need to feed huge numbers of immigrants may have triggered the civilization in egypt.

supported common projects like building pyramids. These common projects in turn built the society.

At the Edge of Chaos

The water supply of the Nile was constant and high enough to enable a good life. It was fluctuating and changing enough to challenge the people from time to time. All in all it was just right, like the position of our planet in the solar system or the position of our solar system in the galaxy : If our solar system would be closer to the core of the galaxy, the amount of comets and radiation would be too high. If it would be too far away at the edge, the rate of comets would be too low. If our planet would be less/more distant to the sun, it would be too hot or too cold.

5.6 Hypercycles and Attractors

The essential component which enables the tunneling process is often an autocatalytic cycle, hypercycle or attractor. Or a group of agents in 'Sync' [148] with synchronous actions. Synchronous and cooperative actions can lead like hypercycles to the formation of stable groups. Cooperation and stability are essential for the emergence of complexity, because they are needed to balance the instability at critical points or phase transitions between order and chaos, where complex structures appear and disappear rapidly.

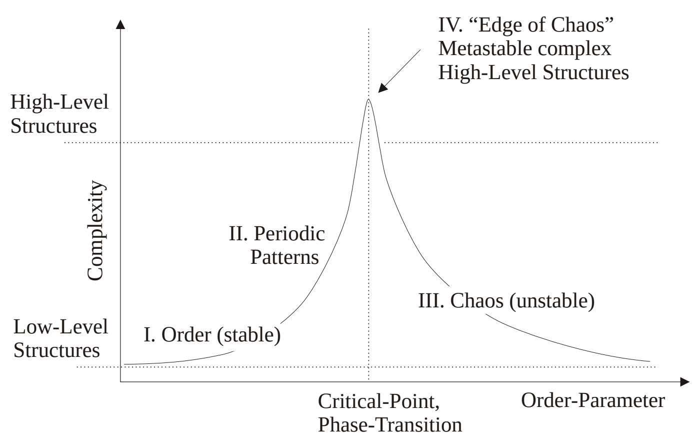

Fig. 63 Edge of Chaos

Spontaneous order is usually short-lived and rapidly replaced by spontaneous disorder. Complex structures are often unstable, especially if they appear at 'the edge of chaos'. Hypercycles or attractors are stable structures. Combination of both results in increased complexity of the system :

Stability in Instability → Unity in Diversity → Complexity

The stable structures are not only necessary to balance the instability at a critical point, they are also the fundamental units and building blocks of the stable part from the CAS on the next higher level. As said before, a CAS needs a stable and a flexible system in order to reach high levels of complexity. Cycles, hypercycles or attractors are the basic building blocks of the new CAS. Hypercycles of replicating molecules, the citric acid cycle, attractors in gene regulatory networks, perception-action cycles in agents and attractors in neural assemblies are the basic blocks of high-level CAS.

Since the elements of a hypercycle are not all available during and directly after a tunneling process, it is completed through temporary support by intermediary agents. Some components of the hypercycle are replaced by 'auxiliary' agents - this corresponds to the borrowing of energy in Quantum Mechanics - until all necessary agents are available. Auxiliary Agents

Hypercycles have been proposed by Schuster and Eigen [35] to explain the origin of life and replicating molecules in prebiotic evolution, similar to the attractors in gene regulatory networks suggested by Stuart Kauffmann [79]. The origin of cell metabolism was recently investigated by Morowitz et al. [37, 138]. The central element of metabolism is the citric acid cycle. A nice overview of the citric acid cycle can be found at the "Cell Processes" section of the interesting BioTech graphics gallery at `http://www.accessexcellence.org/AB/GG/`. The early intermediary citric acid cycle probably looked different from the standard cycle today, perhaps a combined reduction of carbon dioxide CO_2 and synthesis of carbon compounds in form of citrate [138]. Morowitz et al. suggest in their article [37] elements (for instance acetic acid and ATP) which have been replaced in the original, intermediary citric acid cycle. Hypercycles Citric Acid Cycle

Before Object Oriented Programming (OOP) and the perception-action cycle of agents in Multi-Agent Systems (MAS) evolved, different windows, objects and agents communicated with messages. Messages (at least in 'Windows' systems) are an early form of event handling in procedural programming, they require a central control system which handles and manages the message queues. In OOP there is no central control system, the processing of messages is done normally by event handling and delegation. But at the time many 'Windows' operating systems were written (Unix, Linux and Microsoft Windows are written originally mostly in Assembler and C and not in C++), all elements of object oriented languages were not completely available, and Perception Action Cycle Messages, Events & Delegation messages were used as a temporary solution. Similarly, before the elements and structures of everyday language were completely available, the question-answer cycle was closed by mimetic skills (gestures, paintings, etc). Every child uses gestures and pictures or pointing and painting to describe things more clearly. And before neurons and the perception-action cycle of cognitive systems evolved, different cells communicated with simple auxiliary molecular messages, until electrical event handling emerged and chemical signaling was replaced by electrical propagation of action potentials.

Question Answer Cycle

As discussed in chapter four, another important feedback cycle can be found in social rituals of group formation. Temporary support in this case is offered by catastrophes, which melt people together, and naturally unifying landscape features as rivers, coasts and mountains. Instead of cultural rules, rituals and laws which keep the group together, auxiliary and temporary agents in form of natural events and constraints melt the group together during the time of transition.

old CAS	building blocks	temporary support, intermediary agents	autocatalytic cycle, critical phenomena	new CAS
prebiotic primitive soup	molecules which catalyze each other	whirls, turbulences, hydrothermal vents	hypercycle of molecules	replicating molecules
RNA	replicating RNA molecules	ribozymes	hypercycle of proteins/enzymes	proteins as enzymes
proteins	carbohydrates, proteins, enzymes	pyrophospates replaces ATP,..	citric acid cycle	metabolism
cell	genes, cells		attractor in gene regulatory network	multicellular organisms
cells	cells, receptors	intracellular molecular communication	perception-action cycle, Action Potential	neurons, neural system
procedural programming	parameters, procedures	message handling	Perception-Action Cycle, Events	Objects, Agents
one-word utterances	words and rules	mimetic skills replace words	sentences,question-answer chains	language
competing tribes, nomads	language, rules, laws	unifying landscape features as coasts, rivers, mountains	social rituals of group formation, assemblies	culture, laws
competing & changing traits	language, habits, thoughts	'loud thinking', Description of self by others	self, self-consciousness	personality

Tab. 21 Thresholds of evolution mark emergence of new CAS

5.7 Emergence and Discovery

The essential component which enables the transition process can be an external observer, too. For example in science as a CAS, new scientific theories are discovered by outstanding and often lucky researchers. The discovery of revolutionary theories is often accompanied by a paradigm shift (more details about the effects of paradigm shifts are mentioned in the next chapter).

Emergence without Observer

Without an external observer, a new CAS emerges in an old CAS as described in the last sections: First fractions of a new CAS appear, often at "the edge of chaos", the phase transition point between order and chaos. Some agents of the old CAS are so lucky or so smart to "recognize" this because the new CAS or the extended phenotype increases their fitness substantially (in the case of an autocatalytic cycle, hypercycle or attractor, this "recognition" is of course unconscious, automatic and blind - if you can speak of recognition at all).

If this happens, a new CAS can emerge through a complex process of group selection, Gene-Meme Interaction, Baldwin Effect and borrowing of complexity. The structures of the new, virtual CAS are 'simulated' or 'emulated' with additional acquired behavior or auxiliary tools of the agents on the phenotype level, for example mimetic skills and gestures, until the elements and building blocks of the new CAS are completely available. This simulation of a new, virtual CAS through borrowed or auxiliary complexity is equivalent to a tunneling process.

The emerging new CAS changes the fitness landscape of the environment for the old CAS, because the "pioneer" agents have an evolutionary advantage (for example language) compared to normal agents. Then the Baldwin Effect [11] can lead to the emergence of a new CAS, if it embodies and anchors the additional behavior on the genetic level of the old CAS. Once the genetic conditions and requirements are fulfilled, a new CAS can emerge and start to develop itself.

With Observer

But a new CAS can also be recognized and created by an external observer, who observes fractions of a new CAS at "the edge of chaos". The external observer does not need to borrow complexity or use tunneling processes, because he is outside the system and is not impeded by any potential barrier. He is able to discover, capture and analyze the basic elements of a new CAS, and can create a new system from the ground up. This is what W. Brian Arthur has named increase of complexity by "capturing software" [4] : a kind of "capturing" process by a single external observer. Usually the

Capturing Process

observer is also the one who has created or simulated the artificial system. Interesting structures in *The Game of Life* for example are often discovered or captured by a special kind of search software. A list of search programs can be found on the website of David Eppstein at the UCI (University of California, Irvine) at `http://www.ics.uci.edu/~eppstein/ca/search.html`

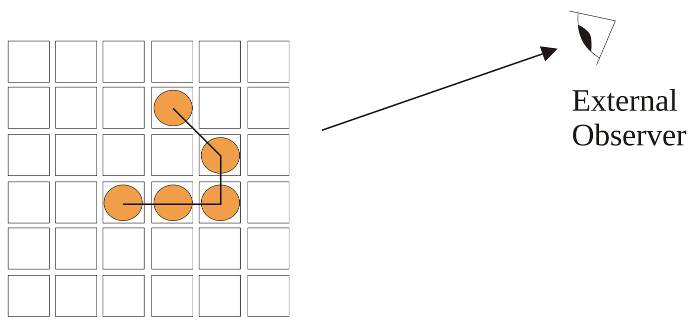

Fig. 64 Increase of complexity by "capturing" processes

Universal Computation

Like Turing Machines, some Cellular Automata (CA) are capable of universal computation. It is possible to simulate a very simple and primitive kind of "universal" computer with special structures like spaceships, oscillators and gliders. But such a simulated computer would be awfully slow, and it has to be discovered and constructed manually. No universal "Deep Thought" computer will ever be simulated with a CA which is able to give the ultimate answer to "Life, the Universe, and Everything". People who claim that CA are capable of universal computation often miss the point. The point is an universal computer does not emerge automatically. You have to search and discover suitable structures like gliders and spaceships, and construct a suitable system yourself. With such a universal computer you can in principle simulate anything, the only drawback is that it may take a very large amount of work, time and memory to do it ...

Yet discovery of components and structures is an essential element for the invention of new tools and weapons and for construction of artificial systems. For example "Design Patterns" in Object Oriented Programming were used and discovered before they have been proposed. Discovery and invention are closely connected. For example Louis Pasteur discovered 1862 the principle of sterilization which is known as "pasteurization" and Alexander Fleming discovered 1928 Penicillin and Antibiotics.

5.8 Jumps in Complexity

Besides surprising discoveries and manual capturing processes, so far we have examined three main reasons for large sudden jumps in complexity:

- catastrophes
- tunneling processeses
- the illusion of sudden emergence

The first two points cause a substantial increase in complexity through the emergence of new agent or CAS forms. The last point only arises the illusion of emergence through a transfer of complexity from an internal dimension to an external dimension. This transfer occurs for example at the bifurcation or branching points of phylogenies, and is in biological systems a transfer from an intraspecies complexity within a species to an interspecies complexity between different species.

Illusion of sudden Emergence

There are other reasons for the illusion of a sudden emergence. We are inclined to pay more attention to the spectacular, large and dangerous fossils and life-forms. But all important new species (reptiles, dinosaurs, mammals) were small and unspectacular at the beginning. They often lived for a long time in the shadow of much larger and older species.

Species start small

Likewise all important ancient cultures were small and unspectacular at the beginning, for example the Romans or the ancient Egyptians. The predecessors of ancient cultures were small groups and tribes. The leaders and priests of the ancient cultures as well as their monumental projects were often really stupid, compared to our knowledge today. Their intelligence was not as impressive as the size of their monuments. The early pyramids were huge as dinosaurs, but they were not very complex. Just like a pyramid has a very simple structure, the early ancient society had a plain and simple structure with simple-minded leaders. Many mysteries of ancient cultures are in the eye of the beholder.

Cultures start small

Another reason for the illusion of emergence in biological evolution is also in the eye of the beholder. Historic events looking spontaneous are often slow processes. Fossils which prove the emergence of complexity in biological life-forms are squeezed beneath tons of rock and stone. Millions of years are compressed to a few meters. What looks like a spontaneous emergence in the fossil remains is therefore sometimes only the image of a slow process.

Temporal Squeezing

Temporal squeezing and transfer of complexity can create the illusion of large, sudden jumps in complexity.

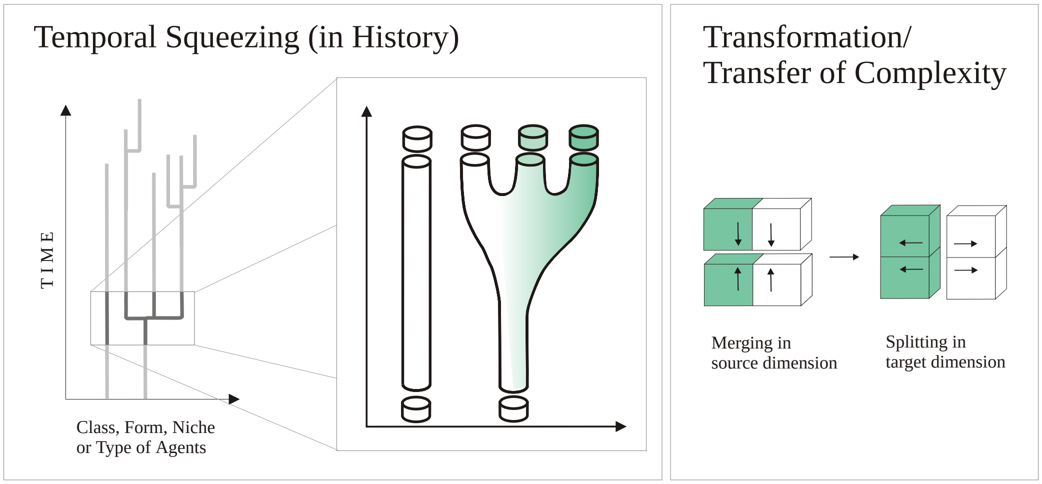

Fig. 65 Illusion of abrupt, sudden Jumps in Complexity

If thousands of years are compressed to a few cm, slow and steady increases in complexity look like fast abrupt jumps. It is unlikely that the evolutionary thresholds which separate the major integrative levels of evolution were crossed very fast. These evolutionary thresholds that mark the major integrative levels of evolution are the points where the greatest jumps in complexity happened: through the emergence of new CAS and substantially new agent forms.

Large Jumps require large Changes

Real large jumps which are not an illusion have always massive causes. The evolution and devlopment of a complex *adaptive* system reflects and mirrors the complexity of the environment. A large change in complexity is often the answer on a large challenge or a catastrophic change in the environment. Without a complex environment, there will be no complex agents. A complex environment is a surrounding with unpredictable fluctuations, challenges and changes. Humans are complex because they live and grow up in a complex environment. As Herbert Simon says in 'The Sciences of the Artificial' [143]

> "A man, viewed as a behaving system, is quite simple. The apparent complexity of his behavior over time is largely a reflection of the complexity of the environment in which he finds himself"

Humans face continuously incongruities during their development. In fact every situation with unresolved incongruities is a small catastrophe and a huge cognitive challenge. We will examine the relation between incongruities, insights and mental revolutions in detail in the next chapter.

The challenge for a complex system in general can be an external catastrophe in form of a climatic change or a meteorite impact, or an internal catastrophe in form of high population pressure or strong competition which support tunneling processes. Both catastrophes can cause jumps between substantially different complexity levels. Thus the two main reasons for large, abrupt jumps can be combined to one major reason: large rapid changes in the environment in form of catastrophes, 'internal' catastrophes for single agents or 'external' catastrophes for whole systems. *Internal* catastrophes are local, dramatic personal events for single agents or individuals which can trigger tunneling processes. *External* catastrophes are global, catastrophic general events which can cause large scale mass-extinctions and sudden emergence of species. Of course all catastrophes, whether internal or external, can trigger a tunneling process or a large jump to higher levels of complexity.

Catastrophes are large Changes

. . . and trigger jumps or tunneling processes

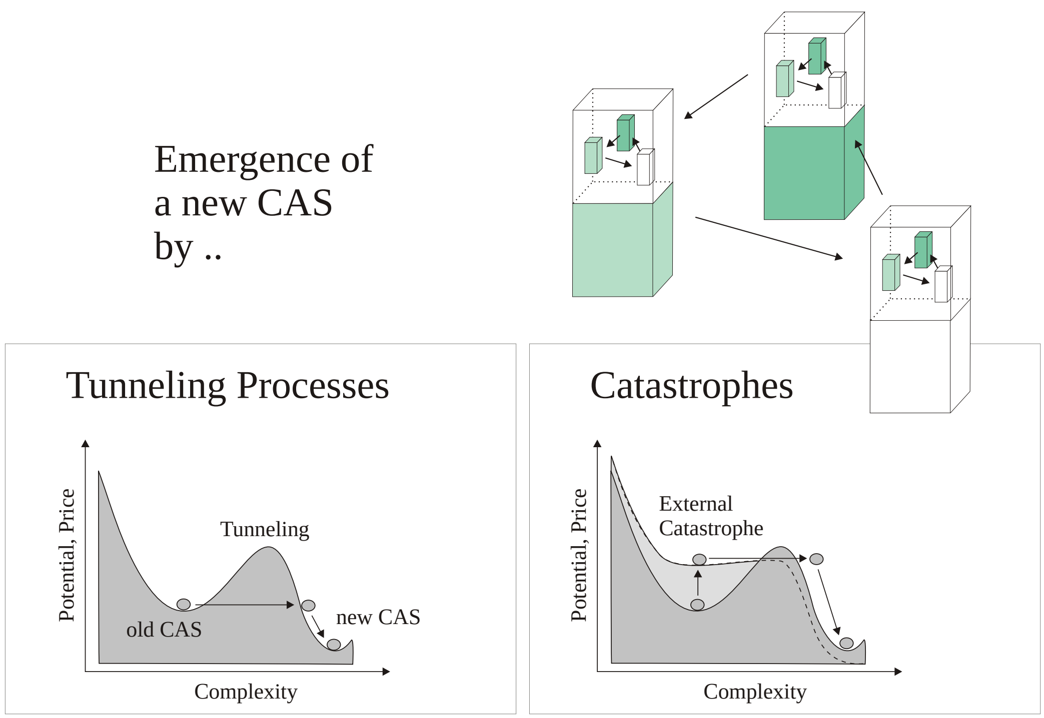

Fig. 66 Large Jumps in Complexity through Emergence of new CAS

External & internal Catastrophes

External catastrophes with general, widely extended changes and global consequences affect a whole CAS. *Internal* catastrophes with dramatic personal changes and severe individual consequences affect single agents: a personal tragedy or disaster, a great loss or misfortune, an inevitable accident, etc. . An external catastrophe in a CAS causes naturally many internal catastrophes in each agent of the system.

Catastrophes cause a lot of stress and pressure in autonomous agents. Without stress, pressure and challenges there is no need for a sudden emergence of complexity or intelligence. New complex abilities or sophisticated capabilities require difficult environments. The emergence of complexity in a CAS is a response to pure stress, strong pressure and huge challenges.

Chapter 6

Levels and Boundaries

6.1 Insights and Invariance

Before we come to the major integrative levels of evolution, to the different complexity bands and their boundaries, we examine revolutions and catastrophes in a completely different system, in the human mind. We are continuously extending the boundaries and frontiers of knowledge, everyone personally in his or her small private world and in science as a whole. Science is "shared knowledge based on a common understanding" [112]. It is the current knowledge of the scientific community and the continuous quest for its extension and expansion. Every major discrepancy, lack of explanation or contradiction in a new scientific experiment can be a catastrophe and the end of an established theory. Every new situation for a human or an agent is a cognitive puzzle or problem, which can turn into a catastrophe if it can not be solved by thinking and reasoning.

Catastrophes for the Mind

Knowledge & Science

There are two kinds of thinking, rational and logic reasoning on the one hand, and intuitive, unpredictable thinking on the other hand. Intuitive thinking is used in ordinary thinking and everyday life, strict logic resaoning is used in mathematics. In mathematics, every new *theorem* or proposition is made out of statements and definitions. The truth is a problem or puzzle, which has to be solved through a *logic proof*.

Reasoning and Intuition

In Multiagent Systems, cognitive psychology or situations of everyday life, every new *situation* is made out of perceptions and schemes, and is a cognitive problem or puzzle, which has to be solved through the process of *intuitive insight* or understanding.

	Rational reasoning, deliberate proof	Intuitive thinking, unconscious insight
Field	Mathematics	Everyday Life, Psychology
Agent	Mathematician	Agent
Object	Theorem, Proposition	Situation
Parts	Statements, Definitions	Perceptions, Schemes
Process-Speed	Slow, logic proof	Sudden, intuitive insight
Process-Kind	provable, understandable	not easy understandable

Tab. 22 Reasoning and Intuition

Why can we discover new things and laws in nature at all ? How do we gain new insights ? What happens during an insight ?

Invariance, Redundancy

Herbert A. Simon says [142], "It is a familiar proposition that the task of science is to make use of the world's redundancy to describe that world simply." To compress a picture or to describe something, we try to find a simple description with low or minimal redundancy, which led to the definition of Kolmogorov complexity.

Why can we discover laws in nature at all ? The answer for physics, as Eugene Wigner explains in "Symmetries and Reflections" [156] convincingly, lies in (local) invariance principles (of space-time). Gauge invariance, Galilean invariance, local translational, rotational and time-translational invariance enable the formulation of laws of motion at all.

Pattern Recognition Devices

Minds are pattern (re)cognition devices. Invariance is an extreme case of a global pattern. During pattern recognition, many patterns are assigned to same class. Invariance of space-time means every point in space-time belongs to the same class and behaves in the same way. Discovery of a new law, which is based on a certain invariance principle, is like a global pattern recognition. Usually one invariance principle is disregarded and considered as a special case of a more general invariance principle.

Invariance, Recognition

Invariance is the base of recognition. We can only recognize things, if they stay roughly the same, if they are invariant in time. Experiments must be repeatable and reproducible to verify a theory. To recognize means to be able to identify again s.th. that one has seen, heard, etc before. Plato argued that all learning is remembering and recollection.

We can only perceive items as objects of a certain class, if they are invariant in space, if they share a common property, if the invariance of a certain system property allows the formulation of categories, concepts and classes. The formulation of categories in traditional biology is possible, because members of a species share common properties, a certain feature of them is invariant under exchange of individuals of a certain species. The creation of the periodic table was possible because some elements have similar behavior and properties.

In order to be able to create a theory or a process description in the first place, we must keep something constant and fixed, a frame of reference or a coordinate system. We can not deal with systems in which everything is changing constantly. If we setup an equation of motion, we assume the coordinate system is fixed or constant. To deal with other people, we assume that we are always dealing with the same person, that they are fixed or constant, and have a certain kind of unchanging personality. How should we deal with other people if they are changing constantly ? And that's what they do.

This is the paradox of perception: Invariance is a necessary condition to enable perception at all on the one hand, but is an obstacle to the refinement of knowledge on the other hand. If we recognize during an insight that something which was thought to be invariant is changing or variable, we extend our frontier of knowledge. In science these kind of expansions are known as scientific revolutions, in the mind they are similar to mental revolutions.

Paradox of Perception

6.2 Scientific and Mental Revolutions

Neither scientific progress, nor thinking itself, is a continuous, smooth and steady process of adding new ideas. Unsteady, sudden progress in science occurs during scientific revolutions and "paradigm shifts", when new ideas, theories and paradigms emerge.

Paradigm Shifts

A new, revolutionary discovery needs a temporary lack of explanation, a contradiction or a small deviation that can no be explained. Without a challenging discrepancy or a tiny mismatch between observed facts and predicted results, there is no need for a new discovery. Discrepancies are a trigger to discovery. Gregory Derry gives the following examples [32]: a small unexpected difference in a density measurement of oxygen and nitrogen provided a clue for the existence of argon, and a minor unexplainable discrepancy between the calculated and the observed orbit of Uranus led to the discovery of a new planet, Neptune.

..need a lack of explanation

The big scientific revolutions are of course not the discoveries of new elements or planets. They are the discoveries of new fundamental worldviews, theories and paradigms: the discovery of a mathematical theory of electricity and magnetism by James Clerk Maxwell (the Maxwell Equations), the discovery of a mathematical theory of gravitation and motion by Isaac Newton (the famous laws of Newton) or the discovery of a mathematical theory of space-time by Albert Einstein (special and general relativity).

Newton, Maxwell, Einstein

Many new theories were rejected by famous journals like Nature and Science because they contained speculations too remote from reality to be of interest to the reader. David Ruelle's association of strange attractors with turbulence was so revolutionary, that the now classic paper with the Dutch mathematician Floris Takens "On the Nature of Turbulence" [132] which introduces the concept of "strange attractors" was rejected by the editor of an appropriate scientific journal (see [131]). Of course the editor had it's own ideas about turbulence. Ruelle says "The editor did not like our ideas, and referred us to his own papers so that we could learn what turbulence really was." Their paper was rejected by the editor because it overturned the prevailing theory, a theory in which the editor of that journal was an acknowledged expert. Finally he published it himself in a journal where he was an editor himself.

Large revolutions cause rejection

Feigenbaum had similar problems to publish his results. And the mathematical theory of Beta-decay was formulated by Enrico Fermi in 1934 in a paper which was rejected by the journal Nature. The editors rejected Fermi's paper on the grounds that it was too speculative. Postulating an invisible particle which magically carries away energy without a trace was too heavy for them.

This is typical for scientific revolutions. First the new theory is totally rejected, then after the revolution suddenly no other theory seems possible. Scientific revolutions have been examined in general by Thomas Kuhn in his famous und influential book called "The Structure of Scientific Revolutions" [85]. He has coined the name paradigm shift to describe them.

Paradigm Shifts

Like the discovery of a new element or planet, the discovery of a new paradigm is not possible without an unsolvable puzzle, loose ends, unexplainable observations or empirical facts that don't fit in the current paradigm. Before an evolution becomes a (r)evolution for a short time, there must be a crisis, a non-equilibrium between observed and predicted facts. A short time before a paradigm shift, nothing seem to make sense anymore, or at the other extreme, people say that science has come to an end, and that some questions are forever unknowable. Just before the revolutionary discovery

..need a a crisis

of Quantum Mechanics and the appearance of Einstein's relativity theories, Max Planck was urged 1875 not to choose physics because the breakthroughs had all been made there. John Horgan, who has written a glib dismissal of all work on complex systems in his June 1995 Scientific American editorial entitled "From complexity to perplexity", has claimed recently in his book "The End of Science" [74], that science has come to an end again. He is wrong. It is always only the current paradigm which has come to an end or is 'running out of steam'. Before a major paradigm shift, science and progress seem to come to an end.

Before a Paradigm Shift

Normal situation/science, Process of evolution	Puzzle solving within a (well-defined) paradigm Gradual consolidation & refinement of an existing paradigm Discovery of new details (increase degree of precision) **Equilibrium** between observed and predicted facts
Process of revolution, transition to new paradigm, worldview or meaning	solving the puzzle of finding a new paradigm, co-existence of old and new paradigms Discovery of new theories (increase degree of levels), non-equilibrium between observed and predicted facts **Chaos and Confusion**
Scientific or mental revolution completed	Puzzle of finging a new paradigm solved, Replacement of an existing paradigm, Number of paradigm levels increased, **Equilibrium** between observed and predicted facts restored

A short time after a paradigm shift, suddenly everything seems to make sense again, and the new paradigm seems to explain everything. In fact it does not. There are always enough questions that we cannot yet answer, and so there are always some major discoveries and great paradigm shifts waiting for us.

After a Paradigm Shift

Normal science is an evolutionary process inside a certain system or paradigm, the gradual refinement of an existing paradigm and the slow discovery of more and more details. Spectacular science is a (r)evolutionary process outside the current system or paradigm, if someone solves the puzzle of finding a new system, theory or paradigm, and a paradigm shift takes place.

Very similar shifts have been identified by John Morreall on a completely different level. He has examined laughter and humor, and in his aim to reconcile the three different humor theories (incongruity theory, superiority theory, relief theory), he invented the term of a psychological shift [102].

The question why we laugh is old and goes back to the great thinkers and philosophers. The three major humor theories are the *Incongruity Theory* formulated by Kant and Schopenhauer, the *Superiority Theory* from Aristotle, Plato and Hobbes, and the *Relief Theory* associated with Freud.

1. Incongruity-Resolution (Fracture in Meaning)
   A scene or a joke becomes funny when we expect one outcome and another happens. Humor occurs when things that do not normally go well together appear, when it seems that things are normal while at the same time something seems wrong, and we can find an sudden explanation for it.

2. Superiority/Disparagement (Fracture between Self and Bad Feeling)
   We laugh at a clown because we feel "superior". The recognition of a sudden superiority ("Sudden Glory") is pleasing, and the relief about a removal of a threat causes laughter and joy.

3. Relief/Release (Fracture in Goal-Directed Action)
   According to Freud, censors in the mind cause unconscious barriers, if they inhibit forbidden thoughts and actions. This inhibition can cause the accumulation of pent-up "energy". If the censor is removed, fooled or by-passed, the relief about the liberation from these inhibitions by internal censors results in an pleasurable outburst of energy - laughter.

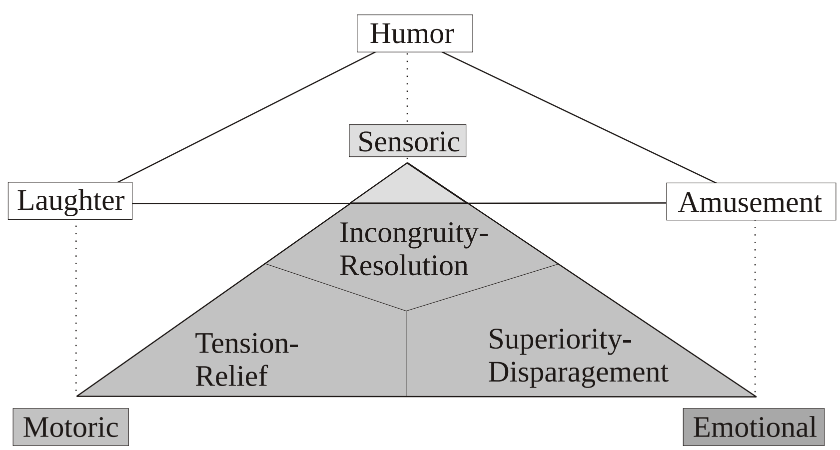

Fig. 67 Humor Prism

All three theories descibe a fracture and a shift along this fracture, a fracture in meaning if you do not see what you expect to see (Superiority Theory), a fracture in goal-directed action if you can not do the things you would like to do (Relief Theory) and a fracture between the 'Self' and bad properties or feelings if you suddenly recognize you do not have the unpleasant property you could have (Superiority Theory).

Psychological Shifts

This psychological shift is similar to the paradigm shift of Thomas Kuhn. Both cause an avalance or flood of activity after a period of very low activity due to incongruities, contradictions and discrepancies. In scientific revolutions, a new paradigm emerges, in mental or cognitive revolutions a new worldview or insight appears.

Science progresses as a result of the clash between theory and experiment, between speculation and measurement. In the same way normal insights arise as a result of the clash between expectation and perception, between belief and reality.

Censors cause Rejection

Like the editors of famous journals, who rejected theories which are too strange, censors in our mind unconsciously reject new ideas, too. Marvin Minsky describes the idea of censors and suppressors in chapter 27 of his classic book "The Society of Mind". Already Sigmund Freud used the term "Censor" to describe unconscious mental processes. During the process of understanding, often an additional hint (for example at the punchline in jokes) is used to by-pass the censors, and suddenly the incongruities between belief and reality, between expectation and perception vanish. "It (the situation) can't be true" turns suddenly into "Of course, it (the new theory) can't be wrong".

	Scientific Revolution (Thomas Kuhn)	Mental Revolution (John Morreall)
Field	Science	Cognition
Insight	New Paradigm	New Worldview
Shift	Paradigm Shift	Psychological Shift
Physical Expression	Avalanche of Publications	Laughter, Avalanche of neural activity
Memory	Publications, Books	Short-Term Memory, Long-Term Memory
Crisis leading to Anomaly	Contradiction in results/experiments	Incongruity in events/situations

Tab. 23 Scientific and Mental Revolutions

6.3 Emergence and Boundaries

Knowledge is largely a byproduct

Knowledge revolutions do not appear suddenly without effort and as we have seen without preceding lack of explanation. And of course new knowledge appears at the boundary or frontier of already existing knowledge. The driving force behind the emergence of substantially new ideas is curiosity and the joy connected to new discoveries and insights (or the displeasure over discrepancies and incongruities). Knowledge is largely a byproduct of our quest for pleasure and our pursuit of happiness.

Complexity is largely a byproduct

Likewise, complexity does not appear through a mysterious act of creation out of nothing. The driving forces behind the emergence of complex living systems are evolution, natural selection and the struggle of self-reproducing replicators, whether genes or memes. The main reason is the overwhelming emotional pleasure inherently connected to survival and reproductive success (or the huge displeasure due to lack of food or abilities to mate with s.o.). Thus complexity in living systems is largely a byproduct of the natural search for pleasure through survival and reproduction.

. . . of supper- and pairing-times

Animals as throw-away agents of their selfish genes have an enormous strong drive for survival and reproduction. Whenever in the natural world there is happening something interesting, it is either supper-time and pairing time[1]. Animals without the ability to eat and mate successfully vanish sooner or later and make room for new species.

Although complexity seems to appear from nowhere sometimes, it increases constantly on Earth during insights (the mind grows), supper-times (the body grows) and pairing-times (the species grows). But we notice it only if a certain threshold is reached, if it is transfered to a visible dimension. As said before, we don't recognize the full effects of anagenesis, we see the intraspecies complexity of our own species, culture and language, but only the interspecies complexity of other species, cultures and languages. Familiarity influences recognition: in our own species everyone seems to be different, in other foreign or strange species everyone seems to be equal. But it is not self-evident that every individual is different, and it is a prejudice to say every individual of other species is equal.

We have seen in the earlier chapters that the emergence of complexity is usually connected to a transfer of complexity, a transfer between differ-

[1]see for example the Blue Planet BBC TV series http://www.bbc.co.uk/nature/blueplanet/

ent systems (internal and external, genotypic and phenotypic, genetic and memetic, short-term and long-term, flexible and stable, ...). Different systems must be separated by something: a border, an interface or a surface. The border can be fluent, blurred and smooth, or sharp, clear and abrupt. If it is clear, sharp and lucid, any transition of something across it is obviously like an emergence of something. As the word "emergence" suggests, *the emergence of complexity is always possible at a clear boundary or border of a system.*

Emergence at clear Boundaries

In MAS and CAS there is a natural boundary, the agent itself. On the one hand anything which happens in an object or agent is not visible from the outside due to encapsulation, on the other hand public properties, features and classes are well known. The boundary between the private internal structure and the public external structure is the class of the agent itself.

In chapter one we have considered temporary emergence in systems with very simple agents (for example CA) through basic merging and splitting operations. Merging and splitting of agents affect inherently and naturally the agent boundary.

In chapter two we have considered transitions across the natural agent boundary for more complex agents through the basic forms of object interactions: aggregation (composition) and inheritance (specialization) which are again merging and splitting operations between agents. They can be used to cross the agent boundary. Merging, aggregation and composition transfer complexity from the outer to the inner dimension. Splitting, specialization and inheritance transfer complexity from the inner to the outer dimension.

Agent Boundaries

In chapter three we have looked at some examples for specialization and phylogenetic trees, and in chapter four at some examples for aggregation, cooperation and group formation.

In chapter five we have considered large transitions across system boundaries which are triggered by catastrophes or tunneling processes. Fitness barriers set the boundaries of evolution. Revolutions in evolution are possible because evolution gets stuck from time to time when a large fitness barrier is reached. Evolution waits until massive catastrophes break these barriers or single agents are able to cross them through a tunneling process. The largest transitions can be found between two completely different and much more complicated systems, genetic CAS and memetic CAS. The common boundary in this case is the shared phenotype.

System Boundaries

In all these cases the emergence of new agent or system forms is associated with a transfer across a boundary. For the emergence of new species the species boundary (a transfer from intraspecies complexity within a species to interspecies complexity between species), for the emergence of new agents the agent boundary (a transfer from intraagent or internal complexity within an agent to interagent or external complexity between agents).

System	External System	Boundary	Internal System
Ecosystem	Ecosystem	species class or type	species
MAS, CAS	MAS	agent class or type	agent
Evolution	Memetic CAS	shared phenotype	Genetic CAS
Matter	gaseous (liquid)	shared surface	liquid (solid)
Memory	stable long-term	obliviousness boundary	flexible short-term

Tab. 24 Emergence and Boundaries

During the emergence of new memetic CAS a transfer across the common phenotype boundary of genetic and memetic CAS takes place. The transfer in both directions works through a borrowing-payback process: a transfer from memetic to genetic CAS is a payback of borrowed phenotypic complexity which is not grounded in the genetic CAS (the Baldwin Effect).

A transfer from genetic to memetic CAS is a payback of borrowed extended phenotypic complexity which is not grounded in the memetic CAS (extended phenotypic effects like special kinds of "tool using" which provide phenotypic structures, rules and laws that go beyond already existing memetic CAS).

Stokes Theorem

Changes in the complexity of a system are equal to the stream of complexity through the boundary, as long as there are no sources or sinks inside the system. This is very similar to Stokes Theorem. One of the core laws of physics and differential geometry, Stokes Theorem[2], says the stream through a boundary ∂M of a manifold M is equal to the field change in the enclosed volume

$$\int_M d\omega = \int_{\partial M} \omega$$

[2] see http://mathworld.wolfram.com/StokesTheorem.html

For a vector field $\vec{F}$ in $\mathbb{R}^3$, this is known as the divergence theorem. The divergence theorem relates volume integrals to surface integrals. It says in the absence of sources and sinks (which create and destroy 'matter'), the field density within a region of space can change only by having it flow into or away from the region through its boundary. The volume integral of the divergence is equal to the net flow across the volume's boundary.

Divergence Theorem

$$\int_V (\nabla \cdot \vec{F})\, dV = \int_{\partial V} \vec{F} \cdot d\vec{a}$$

As already mentioned, fitness barriers set the boundaries of evolution. Levels of substantially different phenotype complexity are separated by huge fitness barriers or walls. These walls are mirrored by the gaps in the fossil record and the borders between the different prehistoric eras and periods. Prehistoric eras can be distinguished at all because they have different fossil flora and fauna. The appearance of new vegetation forms and animal species is the reason the different eras and periods have different names. New species typically appear at boundaries between geologic deposits (strata), although fossil forms often persist virtually unchanged through millions of years in one or more sedimentary strata.

Boundaries between Levels

6.4 Band Level Structure

The fossil record is discontinuous. One reason for this is that the fitness of species is discontinuous. At least the fitness of an organism is not proportional to its complexity, even if evolution has produced and selected more and more complex organisms. Higher complexity can considerably reduce the fitness, due to an increased cost for acquirement and maintenance of sophisticated abilities. Fitness barriers between species and agents of substantially different complexity set the boundaries of evolution, and they divide the available niches into a band level structure.

Fitness Barriers

Evolution explores every direction, but some directions are temporarily blocked by barriers. An animal can invest either in internal complexity (intelligence) or in external complexity (specialization or growth), but not in both, because hybrid strategies have reduced fitness and viability. In the following, the former possibility is named the vertical direction, and the latter possibility is named the horizontal direction.

Horizontal Dimension

The horizontal dimension is defined by the external organism size. It is the straightforward direction of normal evolution which increases diversity of species and causes changes in organism size. Species are becoming stronger, bigger and more specialized. Specialization and growth are useful for a short time, and they can block evolution in the vertical direction. The internal complexity or intelligence is not changed fundamentally as long as there are stronger, bigger and more specialized competitors.

Vertical Dimension

Thus fitness barriers separating band levels are found in the vertical dimension. The vertical dimension is defined by the internal complexity and intelligence of organisms. It involves substantial changes in structure, form and function of agents. The more flexible and intelligent an organism, the higher its position on the vertical axis. Too much flexibility and intelligence is very expensive in the short run, because stronger, bigger and more specialized competitors are an insurmountable fitness barrier. But in the long run it pays off, and too much growth is not recommendable in the long term: metabolic rate increases, dependency on special environmental conditions increases, flexibility decreases, population density decreases, etc.

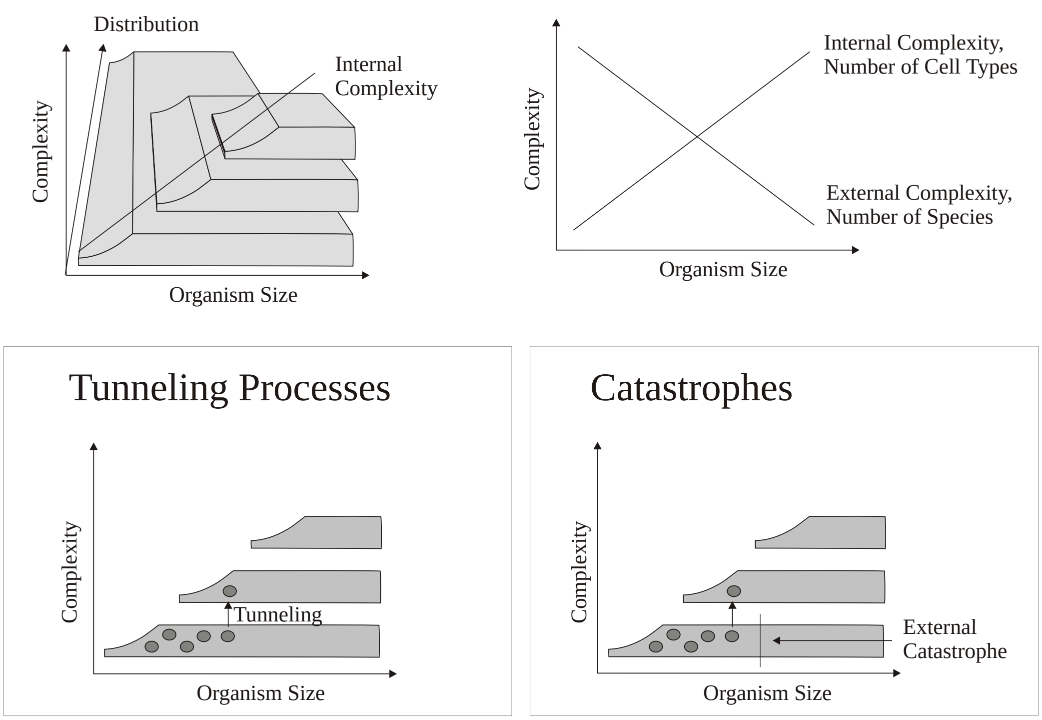

Fig. 68 Internal and External Complexity, Band Level Structure

If agents or species manage to break the fitness barrier and reach a higher level of complexity, they constrain in turn naturally the organism size in lower levels. Thus organisms with very large size have always a high internal complexity, there is no amoeba or bacterium as large as a whale. According to John Tyler Bonner [15], the size of an organism or agent is related to its internal complexity (cell differentiation or somatic diversity) and external complexity (species or genomic diversity). He argues that external complexity or species diversity seems to decrease with the size of the organism: "The larger the size group of organisms, the fewer the number of species in that group" [15]. In contrast to the decreasing number of species, the internal complexity is increasing with organism size, since there is an increase in the internal division of labor and the number of cell types with increasing size. Therefore the total amount of complexity remains similar for different size groups [15]: "As one goes from small to large organisms, the external diversity goes down, and the internal diversity goes up".

Large Organisms have small Populations

but high internal Complexity

We do not observe a totally steady and continuous increase in internal complexity during evolution. One reason is probably related to the discontinuous internal complexity, since the number of cell types is related according to Kauffmann [79] to discrete attractors in gene regulatory networks. Another reason are the natural fitness barriers between species and agents of substantially different complexity.

Attractors in regulatory networks

In any case there are band-level structures similar to semi-conductors which represent the overall amount of niches for species of a certain level of complexity. Between these complexity bands are regions with very low fitness for agents, just as energy bands are separated by regions with very low conductance for charge carriers or electrons in semiconductors.

Complexity Bands

In semiconductors[3] we have an energy gap or a forbidden zone between different energy bands, in evolution we have a complexity gap between substantially different species or agent forms (reptiles, dinosaurs, mammals, ..). Electrons (Agents) can not remain within this range of energy (complexity), because the conductance (fitness) is too low.

Normally the gap in semiconductors is bridged by thermal energy and fluctuations. These thermal fluctuations correspond in biological evolution to chaotic search or random variation due to continuous genetic recombination. At the point of absolute zero the upper conduction band is empty.

Band Gap

Similar to the tunneling processes between different band level in semi-

[3] see Britney's Guide to Semiconductors at `http://britneyspears.ac/lasers.htm`

conductors, a tunneling process can take place to higher forms of internal complexity, especially if external influences like catastrophes act as catalyst. The effect of catastrophes is similar to the population inversion in semiconductor lasers and the working of a Photodiode (the opposite of a Light emitting diode LED): electrons are excited by an external source from the valence to the conduction band.

	Evolutionary Systems	Semiconductors
Agents	Agents, Animals	Charge carriers, Electrons
Environment	Environment	Crystal structure of Semiconductor
Property	Complexity of Phenotype	Energy
Normal Zone	Survival with fitness possible	Electrical conduction possible
Forbidden Zone, Band Gap	Low Fitness	Low Conductance

Tab. 25 Semiconductors and Evolutionary Systems

Avalanche in new Bands

After a tunneling process following a catastrophe, the organism size often increases dramatically, for example after the K-T Extinction mammals started with a small size and increased dramatically. This avalanche or chain reaction is possible because a new "complexity band" has been reached and because the average organism size has been reduced abruptly in the preceding catastrophe.

Abrupt Jumps are necessary

Adaptive Systems mirror Environment

Thus the answer to the question how it was possible that there were many large abrupt jumps in the history of evolution is: large abrupt jumps were needed to populate new complexity bands. Large abrupt jumps in the complexity of an *adaptive* system are triggered by catastrophic and dramatic changes in the environment, because the evolution of a complex *adaptive* system mirrors the complexity of its environment. The process of evolution is interspersed with short revolutions, because periods of environmental stability are interrupted and interspersed with times of instability, stress and challenge. These revolutions with sudden large changes are possible because normal evolution gets stuck before fitness barriers and walls which are too large.

Evolution is sometimes temporarily restrained, and the larger the restraint, the larger and faster the succeeding revolution. Restraints cause revolutions, without the censors of the catholic church no Darwinian or Copernican Revolution would have been possible. It was in fact the church which made Darwin and Copernicus famous scientists and immortal heroes - a little bit ironic, because this is exactly the opposite of the original catholic intention. In general, the restraints can be internal, intrinsic or "self-made": bigger organisms of the ecosystem "crust" can prevent the emergence of more complex smaller organisms. Evolution waits until massive catastrophes smash these fitness barriers to pieces or single agents are able to cross them through a tunneling process.

Restraints cause Revolutions

Catastrophes, mass extinctions and tunneling processes are followed by the emergence of new organisms of much higher complexity. And this is probably the only possible way to reach substantial higher forms of complexity, which are obviously separated by large fitness gaps from the lower forms. If there would be an easier way, evolution probably would have found it.

The only way ?

Transitional species between different "complexity bands" have a very low fitness. This marginal fitness obviously inhibits a high population density during a minor or major transition, and reduces the probability of finding transitional species.

Darwin has noted the absence or rarity of transitional varieties [28]. He acknowledged that there is an absence of transitional forms in the fossil record, which is characterized by large gaps: "why, if species have descended from other species by fine gradations, do we not everywhere see innumerable transitional forms ?" [28].

One reason is that the major and bigger transitions happen when the population density is low and the typical organism size is small, for example during a tunneling process or after a catastrophe which catalyzes the emergence of a new level of complexity. Population bottlenecks due to climatic changes or other unfavorable conditions affect large animals more than smaller ones, because populations of large animals are smaller, and because large animals consume much more resources (for instance the basal metabolic rate for birds and mammals is proportional to body mass M^b, where b is a constant and roughly $2/3 \ldots 3/4$).

Transitions at low population density

Intermediate forms have typically small size and low fitness. The number of agents which successfully tunnel through higher forms of complexity will obviously be low. Darwin noted in the conclusion of 'The Origin of Species' [28] that the intermediate varieties exist in lesser numbers than other species:

"We have reason to believe that only a few species are undergoing change at any one period".

Because the fitness and the population density (esp. of the crucial part) is low at the point of the major transitions, the probability of discovering fossil transitional forms is very small. We have only a few complete fossils - a dozen or maybe a hundred pieces - of the big dinosaurs, but they have lived millions of years.

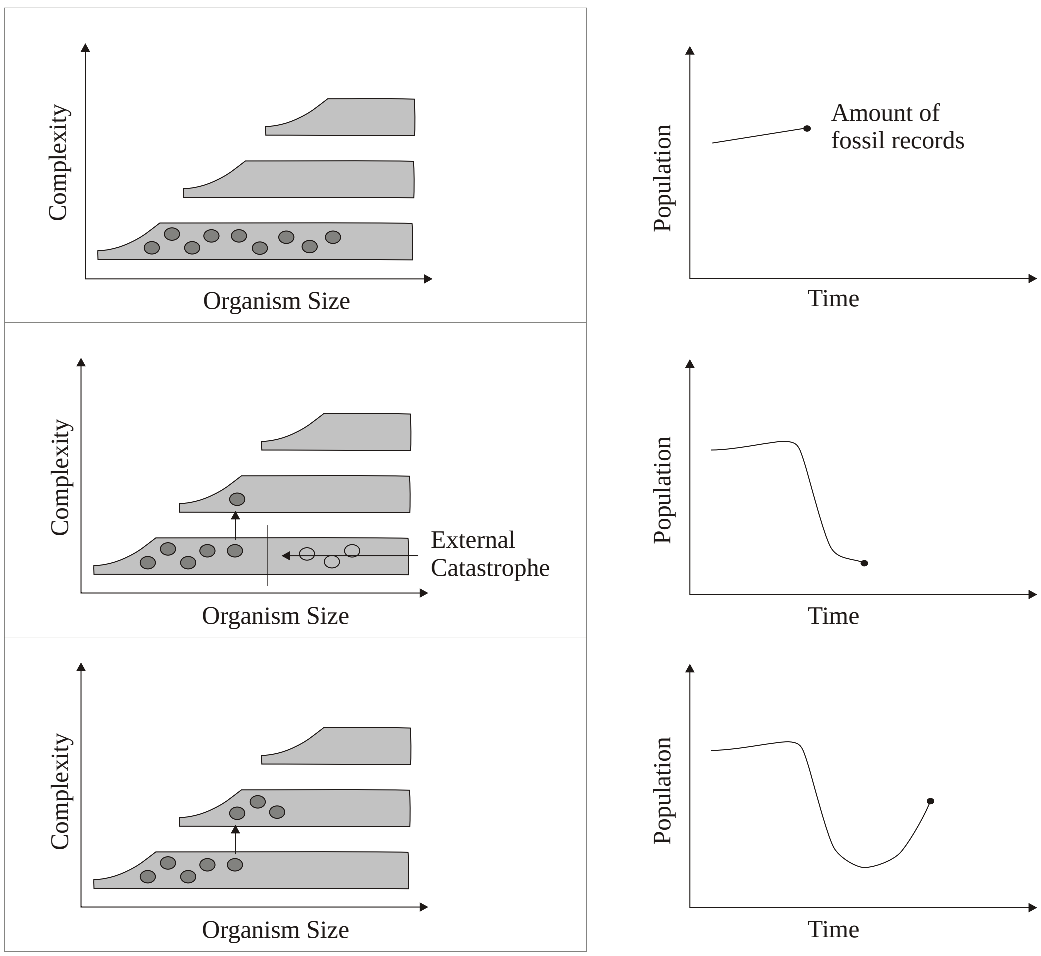

Fig. 69 Population at Transition Process

From all the millions and millions of dinosaurs, only a small fraction remains as fossil witnesses of ancient times. The fossil 'sampling rate' is very low. Because the population density is low at transitions, and the time scale of the transition roughly corresponds to the sampling window for fossils (maybe 1,000-10,000 years), transitional forms fall easily through the fossil sampling grid. Moreover species of a new, higher complexity class are inconspicuous and unspectacular at the beginning, because they start like the early mammals with a small size.

Large populations and large species do not mark the beginning of major transitions, at best they announce the end or dawn of an era. But they are useful to identify the transitions, to define the different "equivalence classes", "complexity bands" and major integrative levels of evolution.

6.5 Major integrative Levels of Evolution

The emergence of new CAS in CAS leads apparently to a self-similar structure. And a CAS has a self-similar structure itself : the agents of the CAS can be considered as small CAS, the CAS as a whole can be represented by an agent. Complex systems have a self-similar, scale-free and hierarchical structure. This has been emphasized already 1962 by Herbert A. Simon in his article 'The Architecture of Complexity' [142], which has been reprinted as Chapter 7 in his book 'The Sciences of the Artificial' [143]. It is one of the first articles about complexity. The central theme in this article is that "complexity frequently takes the form of hierarchy and that hierarchic systems have some common properties independent of their specific content".

As Heylighen says [67], "they consist of subsystems, which themselves consist of subsystems, and so on, until the simplest components we know, elementary particles". As said in the beginning, perhaps even elementary particles are not so elementary at all. However, at the present time the particles of the Standard Model are the most fundamental units. They appeared first during the evolution of the universe[4]. Evolution added more and more hierarchy levels, from particles to atoms, molecules, cells, organs, organisms, groups of organisms and societies.

John Maynard Smith and Eörs Szathmáry even argue that the major transitions in the way in which genetic information is transmitted between

[4] See the Contemporary Physics Education Project (CPEP) website at `http://cpepweb.org`, especially the impressive and comprehensive CPEP chart of fundamental particles and interactions at `http://particleadventure.org/particleadventure/frameless/chart_print.html` and the cosmology chart at `http://universeadventure.org/`

generations are the main reason why complexity has increased in the course of evolution [144].

In this section we want to consider different lists of the major transitions. Harold J. Morowitz [101] has distilled a list of 28 steps, “The Twenty-Eight Steps”. He begins with the emergence of ‘something’ from nothing, which is named ‘The Primordium’.

Morowitz’s “Twenty-Eight Steps”

1. The Primordium
2. Large-scale cosmological structures
3. Stars and nucleosynthesis
4. Elements and the periodic table
5. Solar systems
6. Planetary structure
7. Geospheres
8. Metabolism
9. Cells - prokaryotes (cells without nucleus)
10. Cells - eukaryotes (cells with organelles)
11. Multicellularity
12. Neurons and ‘animalness’
13. Deuterostomes (Chordates with nerve cord)
14. Cephalization (centralization of neural organs in the head)
15. Fish, Animals with backbones (Vertebrates)
16. Amphibians
17. Reptiles
18. Mammals

19. Arboreal mammals (living in trees)
20. Primates
21. Apes
22. Hominids
23. Tool makers
24. Language
25. Agriculture
26. Technology & Urbanization
27. Philosophy
28. The spirit

A drawback of Morowitz's enumeration arrayed in a temporal sequence is the overlapping of steps. Elements were for example formed in stars and super novae, so the evolution of elements in Step 4 and solar systems in Step 5 certainly overlaps very much. The same problem arises between Step 22 Hominization and Step 23 Toolmaking. The overlapping points mark the emergence of completely new systems. Between Step 22 and 23 is the transition from genetic to memetic CAS, the major change or extension from biological to cultural evolution. Between Step 7 and 8 is the transition from physical to biological evolution, and between 4 and 5 the transition from cosmological and stellar evolution at the very beginning to physical and chemical evolution.

And in my opinion the last point does not really fit in this list. The appearance of team spirit or the emergence of consciousness should perhaps be placed somewhere between 22 and 24. If we leave out the last point, we can observe a simple fact: the higher the complexity (the higher the number of the step), the lower seems to be the quantity or abundance of the item. There are an incredible number of elements, roughly about 10^{70} atoms in the Universe. Each star has about 10^{50} atoms, and there are about 10^{20} stars in the universe. The exact number of inhabitable planets is unknown, but certainly much lower, perhaps roughly one in a galaxy. There are about 10^{10} galaxies with at least one inhabitable planet, but only a few which lasted long

Expansion, Confinement

enough to develop forms of complex life. The same argument applies for life on Earth itself (No. of Cells > No. of Bacteria > No. of Animals > No. of Primates > No. of early Hominids) until humans appeared and changed the landscape. Again it becomes apparent that large organisms have small populations, the larger the size group of organisms, the fewer the number of species in that group" [15]. As noticed at the beginning of chapter 2, the more complex the emergent phenomenon is, the more local it seems to be. A continuous expansion of complexity and the emergence of complex composite objects is only possible through an increased localization and confinement to a limited space.

Whereas Morowitz lists 28 steps which has been passed by evolution on our planet, the Encyclopædia Britannica argues that "the evolutionary account of life is a continuous history marked by stages at which fundamentally new forms have appeared" and lists only 5 major steps in the entry to 'Emergence'. The first summarizes Morowitz steps 8-9, the second is in coincidence with step 10 and the third does not appear in the list of Morowitz. The fourth combines again step 12-14, and the last point merges step 15-22.

The 5 Major Transitions due to Encyclopædia Britannica

1. the origin of life (8-9)
2. the origin of nucleus-bearing protozoa (10)
3. the origin of sexually reproducing forms; with an individual destiny lacking in cells that reproduce by fission
4. the rise of sentient animals, with nervous systems and protobrains (12-14)
5. the appearance of cogitative animals, namely humans (15-22)

The list looks like a condensed version of Morowitz's "28 Step List". The advantage of a short list is that there are fewer problems with overlapping steps. The disadvantage is that a condensed five step list is certainly too coarse to contain every major step.

However, the diversity of such lists seems to be as high as the diversity of life itself. Harold J. Morowitz finds 28 steps, the Encyclopædia Britannica 5 steps and Richard Dawkins notices only 10 major thresholds in his book "River out of Eden" [31]. Dawkins' thresholds focus on group formation (teams of genes, cells, neurons) and information processing or communication (nervous system, language, radio).

	Threshold	Description
1	Replicator Threshold	Origin of Life Self-reproducing replicators
2	Phenotype Threshold	Replicators survive not by virtue of their own properties but by virtue of causal effects on something else, which we call the phenotype
3	Replicator Team Threshold	Each gene contributes to the environment, which all genes then exploit in order to survive. The genes work in teams.
4	Many Cell Threshold	Phenotypes can arise whose shapes and functions are appreciated only on a scale hugely greater than the scale of the single cell.
5	Nervous System Threshold	High speed information processing. Action can be taken on a timescale much faster than the one that genes can achieve directly
6	Consciousness Threshold	Origin of Mind
7	Language Threshold	Group information processing. The “brains” work in teams. Common understanding of shared knowledge.
8	Cooperative Technology Threshold	Common use of shared tools.
9	Radio Threshold	Long Distance Communication - it now becomes possible for external observers to notice [us]
10	Space Travel Threshold	

Tab. 27 Major Transitions of Richard Dawkins

The first five points are OK, the rest does not turn out well. The cooperative technology or tool threshold should preceed the threshold for language, or should at least overlap with it. Stone tools in the stone age were a kind of primitve cooperative technology. The language threshold should definitely preceed the consciousness threshold. Self-consciousness is impossible to achieve without a form of language. Tools and Language belong to what Dawkins calls “Extended Phenotype” [29], but they do develop a life of their own.

Moreover he has certainly claimed the transition of the ‘Space Travel Threshold’ too early. We can not really travel through space. All we can do is hop around in the atmosphere of our planet and its near environment. As the pioneer and voyager probes and the Mars rovers (Pathfinder, Opportunity and Spirit) have shown, machines can travel much easier through space, because they don't need life-support systems, and they do not need to come back. If someone will cross the space travel threshold, it will be machines, not humans.

John Maynard Smith and Eörs Szathmáry published 1995 their book on "The Major Transitions in Evolution" [144], and a simplified version "The Origins of Life" in 1999 [145]. They emphasize that the major transitions are the ones which alter the way in which information is transmitted between generations, and in their list of the major transitions [144], they focus on biological levels: Replicators, Genetic Code (RNA-DNA), Protocells, Eukaryotes, Sex (Haploid-Diploid Cycle), Cell differentiation, Multicellularity, Gene regulation, Animal societies and Language.

Emergence of	Entity		Whole / Composite
Replicators	Replicating molecules	→	Populations of molecules in compartments
Chromosomes	Independent replicators	→	Chromosomes
Genetic Code	RNA as gene and enzyme	→	DNA + protein
Eukaryotes	Prokaryotes	→	Eukaryotes
Meiotic Sex	Asexual clones	→	Sexual Populations
Cell differentiation, Multi cellularity	Protists	→	Animals, plants, fungi
Animal societies	Solitary individuals	→	Colonies
Language	Primate societies	→	Human societies

Tab. 28 Major Transitions of John Maynard Smith and Eörs Szathmáry

Somewhere between the 28-step list of Morowitz and the 10-step list of Dawkins is the following list with 12 steps, ordered by scientific fields, and based on the books of Richard L. Coren "The Evolutionary Trajectory" [91] and Max Pettersson "Complexity and Evolution" [120]. Note that each level or threshold in these lists is always a step towards more complex organization [67] and towards less population sizes. The more complex a organism, the less frequent it is, and the smaller the population.

This chronological list also names extinctions, the other side of emergence. As mentioned before, the extinction of dinosaurs for example is associated with the emergence of mammals. The extinction of Ice Age animals as the mammoth and saber toothed tigers is associated with the emergence of modern man during the last Ice Age, also scientists are not sure (it is known as the 'Pleistocene overkill hypothesis').

Level/Range	Event/Entities	Time/Age
0 Physical	Big Bang First Fundamental Particles First Atoms, Molecules Galaxies and Solar Systems	$-10^{10} =$ -10,000,000,000
1 Chemical	Formation and Solidification of Planets (Earth), First Life, Cells without Nucleus (Procaryotes), Oxygen increases	$-10^{9} =$ -1,000,000,000
2 Biological	Cells with nucleus (Eucaryotes), Multicellular Organisms, Plants Colonize Land, First Vertebrate, Dinosaurs	$-10^{8} =$ -100,000,000
3	Extinction of Dinosaurs Mammals	$-10^{8} =$ -100,000,000
4	Primates,Hominid Families	$-10^{7} =$ -10,000,000
5 Anthropological	Homo.sapiens	$-10^{6} =$ -1,000,000
6	Extinction of Ice Age animals Homo.sapiens.sapiens, Tribes	$-10^{5} =$ -100,000
7 Social	Civilization:Language Settlements/Households	$-10^{4} =$ -10,000
8 Religious	Civilization:Writing Religions/Societies/Cultures First Nations, Sciences	$-10^{3} =$ -1,000
9 Political	Communication:Printing Firms/National Companies First Computers	$-10^{2} =$ -100
10 Economic	Communication:Computing International Companies First Networks of Computers	$-10^{1} =$ -10
11 Digital	Now Internet	$10^{0} =$ 1
12 Artificial	Artificial Intelligence (AI)	$10^{1} =$ 10

Tab. 29 Chronological list of major integrative Levels

Further not included steps in this list maybe Human Robots, Extinction of Humans, Machines which colonize space, ... It is of course difficult to predict future steps. Similar to weather forecasting, prediction becomes less effective and harder the more you try to extend it into the future. It is pointless and nearly impossible to predict all future steps.

Logarithmic Scale

The time scale of the major evolutionary transitions seems to be logarithmic (or exponential). Evolutionary processes take place on a logarithmic timescale. Why is a logarithmic timescale most appropriate to describe the major levels of evolution ? This is indeed an interesting question, because this means that the more complex structures become, the faster they appear. Or in other words, the relatively simple structures at the beginning are much harder to accomplish for evolution than the more complex structures billions of years later.

We are Stardust

Billion & Million Year Timescales

As always a part of the problem is in the eye of the beholder. Our familiarity with the Earth, our human view point disturbs our impartial and unbiased scientific view. The complexity on Earth is the absolute exception in the universe. What we take for granted is not self-evident and normal. The diversity of elements from carbon to iron is a result of astrobiological and stellar evolution. We are made of stardust: all elements in the Universe that are heavier than hydrogen and helium are created either in the centres of stars through nuclear fusion during their lifetimes or in the supernova explosions that mark the demise of larger stars. The material of the planets once was made in stars. Stellar evolution happens only on a billion year timescale. Likewise the genetic code in every life-form and the Oxgene atmosphere is not self-evident and normal. Evolution needed a very long time to construct them, on a million year timescale that is unfamiliar to us.

Exponential Process

Power Laws

A logarithmic time scale means that some exponential process is at work, which causes avalanches, cascades, chain reactions, and other types of exponential growth, where the rate of change is proportional to the population size. A linear relation on a logarithmic scale becomes an exponential relation on a linear scale. Or, as Per Bak explains in "How Nature works" [10], a straight line in a logarithmic plot characterizes a "power law", that is to say some quantity N can be expressed as some power of another quantitiy: $N(s) = s^{-c}$, or $\log N(s) = -c * \log(s)$. The slope c is the critical exponent.

Exponential Growth

Power laws can be observed in many things, for example the metabolic rate can be described by a power law, or the exponential growth of a population in an empty habitat. The human population has grown explosively in the last 4000 years. Because memetic evolution is certainly proportional to the population size, the speed of memetic evolution has grown exponentially in the last 4000 years, too, which brought us books and writing systems, automobiles and planes, telephone, television and computers.

Power laws are important in phase transitions or at 'the edge of chaos', where fluctuations occur on all sizes, in the distribution of earthquakes, city sizes, traffic jams, in the frequency or probability of words in language,.. Basically they say, that big events (earthquakes/avalanches/cities/..) are rare, and small ones are frequent.

Often a certain threshold must be reached, before an exponential growth takes place in a system. Below the threshold is nearly no change, and above the threshold suddenly exponential growth: the critical mass in nuclear chain reactions, the first autocatalytic sets of molecules with catalyze each other, the first question answer chain or perception-action cycle, the first multicellular organisms, or the state of criticality in Per Bak's sand pile model.

Critical Threshold

But not every threshold is an evolutionary step or transition to higher complexity. Sand pile avalanches or earthquakes do not increase complexity, although their distribution can be described by power laws. The reason is that the agents or components in these systems do not act on their own behalf.

S. Kauffmann defines in "Investigations" [80] an autonomous agent as something which acts on its own behalf. A new level emerges, if a self-sustained and stable group of agents cooperates and acts on its own behalf, to satisfy the interests of the whole group. Actually, to cooperate means to support the stability and the interests of the group. Many religions, ideologies, cultures try to connect, to link and to reconcile the interests of the individual with the interests of the group. The self-similar structure of a group or complex adaptive system is usually similar to the structure of each agent.

Agents act on their own behalf

Complex systems have a nested or hierarchical structure [67]: they consist of subsystems (parts/components/agents), which themselves consist of subsystems and so on. Power laws are a natural description of fractal, self-similar and hierarchical structures. They describe the relation of certain values as length, size, volume or number of parts to a particular scale or measure. The exponent is related to the fractal dimension.

Power Laws and Fractal Systems

A system is complex, when it can be represented efficiently by different models at different scales. An evolutionary transition takes places, if a higher level of complexity emerges, and the first subsystems or components of this new, higher level appear. The more complex a system becomes and the more evolutionary transitions have happened, the more opportunities and niches are created for new complex adaptive systems.

Avalanche of "niches"

Usually, one subsystem triggers another, and together they form a web of systems. The oppurtunity for a new subsystem, its "niche", often depends on other "niches" or subsystems. For example the emergence of language opened many other niches and triggered the emergence of consciousness, writing-systems, literature, high level-cultures, etc. The emergence of solar systems opened a niche for planetary systems and the essential niche for life on inhabitable planets. The discovery of the DNA triggered the whole science of molecular genetics, and the discovery of the differential calculus by Newton and Leibniz opened a niche for physics and brought physics to life. In principle there are as many niches as systems and agents, because every system or agent occupies a particular niche. Possible systems, niches and oppurtunities are:

Subject	niche	occupied by	opportunity
Astronomy, Cosmology	astronomical orbit	planets, solar systems	to circle around the sun or the center of a galaxy
Biology, Ecology	biological or ecological niche	organisms, species	to survive in ecosystems (or food-web)
Science	scientific niche	scientists/ researchers	to do research in science (web of ideas and theories)
Economy	economic niche	firms/ companies	to survive/make money in economies (web of firms)
Business	job	job holder	to work for or represent a firm (web of employees)
Political Economy	political	parties	to survive/make policies in politics (web of parties)
Political Business	political job	politicians/ political actors	to work for or represent a party (web of political actors)

Tab. 30 Niches and Occupations

Avalanche of evol. Systems

If a new "niche" on a new level is created and filled, than others emerge, which in turn cause others to appear, and so on, until an avalanche or cascade of niches fills in a chain reaction all possible kinds of niches. CAS have the tendency to spawn new CAS. Stellar & cosmological evolution made physical & chemical evolution of elements, planets and geospheres possible. Physical evolution in turn enabled biological evolution, and biological evolution triggered memetic evolution. This exponential growth which leads to hierarchical and self-similar systems can be best described on a logarithmic time scale.

6.6 Randomness and Uniqueness

Is Evolution random ?

Simon Conway Morris proposes [103] that evolution inevitably converges to to higher life forms as humans. Stephen Jay Gould says [61, 62] that the evolution of life on Earth developed by luck : Re-run the tape of life and the outcome must be entirely different, no humans and maybe not even intelligence.

Individuals and Instances are unique, Levels are not

Who is right ? Both. The agents, entities and individuals of a CAS are certainly unique and random, but the different types of CAS are not arbitrary. The major evolutionary steps are not random. Most are connected to processes of group formation. There are not arbitrary many possibilities how you can create a useful system and a group out of simple elements on a higher level of complexity. And once a higher level has been reached, evolution seldom goes back. A CAS which is used as a foundation for a hierarchy of higher-level CAS can not change easily under the pressure and weight of the CAS built on top of it. So each major transition that was connected to the emergence of a new CAS was like a ratchet.

How much of evolution is truly random ? Dr. Stephen Jay Gould, the Harvard paleontologist, aks the question in his book "Wonderful Life" [61] what would happen, if the tape of the history of life were rewound and replayed. He argues that "any replay of the tape would lead evolution down a pathway radically different from the road actually taken". In fact every *instance* of a CAS is random and unique. Every human is unique, you will not find two countries, cultures, languages or religions which are identical, two persons who have the same knowledge or personality, or two immune system which are equal.

Parallel Evolution

But the different *classes and types* of CAS are not random. Evolution often occurs parallel on separated continents or between completely different species: the evolution of marsupial mammals in Australia mirrors the evolution of placental mammals on other continents (the Tasmanian wolf corresponds to the normal wolf, the Wombat to the groundhog, the marsupial anteater to the true anteater, . . .), because the different animals have adapted themselves to similar niches. The shark as a fish and the dolphin as a mammal have similar form and morphology, because they have adapted themselves to the same aquatic environment.

This is the same reason why different languages and cultures share so many common properties. Evolution is an irreversible process. If you would play evolution back and replay it again, the result would certainly look different. But the overall result would be similar: although the details of the system differ, more intelligent and complex species would evolve over time. There are certain universal classes of CAS. Despite their diversity, all members of a certain class of CAS share universal properties. All languages for example have the purpose of communication, they have a syntax and combine words to form sentences. And although they were isolated from each other, most of the ancient cultures started with construction of monumental buildings (pyramids, walls, temple towers, . . .) , the development of religion, agriculture and writing systems, and the raising of taxes and tribute.

6.7 The first level

The first system

We will certainly not be able to imagine all future integrative levels of evolution or all evolutionary thresholds that mark the major integrative levels to come, because we are a part of it, and the future is unpredictable. But what was the very first system, with the most fundamental elements ? The first level is certainly described by the most fundamental theory. The most basic theory is physics, and the most fundamental theory it has to offer currently is string theory.

The most fundamental theory

But string theory is far too complicated to be the final truth. It has a heavy dimension problem, because it assumes 10 or 11 dimensions to be true. We also have 6 theories (Type I, Type II A, Type II B, ..) which are connected by duality and are limiting cases of one mysterious, magic M-theory (M stands for Magic, Mystery, or Matrix). Strings seem to be only one kind among other objects like “D-Branes”. The whole theory is based on dualities and symmetries : the “Super” in Superstring theory comes from Supersymmetry, the conjectured symmetry between Fermions and Bosons.

Is string theory the last word . . .

This is too complicated and involves too much symmetry to be fundamental. Symmetries are fine to describe phenomena and principles in complex systems, without caring about the details. But this looks like a beautiful, complicated theory that describes emergent phenomena. There is no experimental evidence that the 10 or 11 dimensions of String theory really exist. In chaos theory, strange attractors emerge through a basic process of merging and splitting. If you want to describe the topological form of a strange attractor in 3 dimensions, for example the Lorentz attractor, you can stretch and fold a 2 dimensional sheet in a 3 dimensional space. The attractor itself has a fractal dimension of about 2.06.

Perhaps - a bit speculative but at least a plausible explanation - the extra dimensions of String Theory have something to do with reality as a 4-dimensional Poincaré section of a 11-dimensional world. Even if the additional dimensions do not really exist, they could be used as an explanation to explain otherwise incomprehensible phenomena and complex processes. Evolution can produce complex fractal structures, which have fractal dimensions.

Seiberg and Witten have found some interesting relations between Supersymmetry, Quantum Field Theory (QFT) and Superstring Theory. But if the best QFT is only an approximation, and string theory is related to QFT and gauge theories, maybe String Theory is just an approximation, too. String theory is like Quantum Field Theory probably an approximation, a beautiful mathematical description of symmetries, dualities and principles. A great mathematical formulation of "emergent" phenomena. Perhaps the best you can do with pure mathematics.

. . . or just a complex approximation

The final theory perhaps will look different, probably a theory which is very hard or even impossible to describe mathematically. You can not even describe the behavior of a simple Cellular Automata mathematical correctly. Or daily phenomena like turbulence in fluids, chaos in large neural networks or complexity in social or cultural systems.

Looking for a final theory

6.8 The final theory

Is the universe discrete or continuous, digital or analog, constant or evolutionary ? If there is one thing we know for sure it is the last point: the universe evolves. At the beginning it was not larger than the dot at the end of this sentence. Now we have millions of galaxies, solar systems and planets, and at least one planet of outstanding complexity with 2,000,000 life-forms: our Earth.

Discrete, digital or evolutionary

If there is a mysterious deterministic theory beyond and beneath Quantum Theory and General Relativity, it maybe is digital or discrete, but first of all it should be compatible to the theory of evolution. Digital theories are currently modern, because computers as our main tools at the time are digital and discrete. Just as the analog language of mathematics has been replaced by the digital language of computer simulations in many areas of science, the digital language of computers will certainly be replaced someday by a more advanced language to describe nature. Nobody knows how this

Evolution is the fundamental theory

language will look like, but if it is not based on evolution it certainly can not be fundamental. If one thing has not changed since the big bang, it is evolution itself. The languages of science change, evolution stays the same.

Are Particles Products of Evolution ?

A part of the problem in the search for the most fundamental theory is the theoretical search for elementary forces and fundamental laws on the hand, and the separated, independent experimental search for elementary particles and fundamental elements on the other hand. It is possible that there are no isolated particles or interaction forces at the most fundamental level except the products and principles of evolution. Particles and laws seem to co-evolve and emerge together. In a deterministic theory beyond quantum mechanics, particles (the carrier of mass) and forces (the carrier of interaction) probably emerge from space-time and affect it at the same time.

Quasi & virtual particles

Mass is an emergent property

Perhaps all elementary particles are just emergent quasi particles, and the three principal pillars of modern physics, Quantum Mechanics (QM), Special and General Relativity, describe emergent phenomena. Mass for example seems to be an emergent property. The "standard model" does not explain the mass of the particles. Experimental physicsts use to say it is the obscure Higgs particle which have not been found, theoretical physicsts debate if mass is a tension or vibration of a string (String theory), an excitation in a background of little fibers or a disturbance in spin foam models (Loop Quantum Gravity). We use the same name "mass" for the mass of solid matter and for the mass of an elementary particle, although they are different things (compound vs. elementary) on different scales. Scale invariance or self-similarity is typical for emergent properties, according to Laughlin and Pines [89], "many emergent physical phenomena regulated by higher organizing principles have the property of insensitivity to microscopics"[5]. Quantum

[5] spin, charge, energy and mass are all fundamental conserved quantitites. Since all matter constituents (fermions) have half-integer Spin 1/2,3/2,.. but force carriers (bosons) have integer Spin 0,1,2,.. it is obvious that spin is related to mass. Current theories like Quantum Field Theory (spin-statistics theorem) and Superstring Theory (supersymmetry) have no satisfying or simple explanation. Maybe matter constituents emerge through a kind of periodic rotation or twisting of microscopic space-time structures, like a satellite is stabilized by a constant (symmetry-breaking) rotation around its axis. Nearly all stable systems in the universe use or show some kind of rotation. Stars rotate around the center of a galaxy, planets revolve around the center of a solar system, moons circle around planetary systems, electrons whirl around the center of atoms. On a microscopic scale beyond our current reach, somewhere near the Planck scale, massive particles seem to arise by a kind of rotation or periodic movement, like the famous Blinker in Conway's Game of Life. If mass is an emergent property, then charge is probably one, too. Charge

Mechanics is built on many strange principles (Wave-Particle Duality, Uncertainty Relation, Quantization, Probabilism, Pauli Principle, Spin). Both relativity principles can be formulated as statements of symmetry and become important at large masses and high velocities. There could be a simple plausible explanation for many of the strange principles of QM as emerging principles in a deterministic theory beneath QM[6]. But as Stephen Wolfram points out [159] "it has never been entirely clear which of them are in a sense true defining features of quantum phenomena, and which are somehow just details". Moreover, such a deterministic theory is like String Theory currently unprovable, because the scale of such a theory is far beyond our current experimental reach.

Deterministic Theory beneath QM . . .

But besides the already mentioned doubts that Quantum Mechanics (QM) is the final truth, there are other strong hints that such a theory exists. Dr. Shoucheng Zhang, Professor of Applied Physics at Stanford University, argue in his article "To see a world in a grain of sand" [162], that many Condensed matter phenomena like superconductivity, superfluidity and the quantum Hall effect are best described by quantum field theories of quasi-particles and collective excitations, the same quantum field theories that are used to describe elementary particles. George Johnson formulated it in this way [77]: "Elementary particles like photons and gravitons, the carriers of electromagnetism and gravity, might not be so elementary after all - they might emerge as ripples in the vacuum of space, bubbling up from the quagmire similar to the phonons, excitons and polarons in solid-state physics."

. . . should be evolutionary

The basic problem is if we assume the universe consists of something - say particles with certain mass or strings with certain vibrations - we naturally come sooner or later to the question what causes the properties of the fundamental particles or strings. Is there a mechanism which gives the particle their mass - the obscure Higgs particle - or which causes the vibrations of strings ? As Ray Kurzweil says in his review of Wolfram's NKS Book [159] "It should be further noted that if someone actually does succeed in establishing such a digital theory of physics, [based on a kind of Cellular

is related to matter and anti-matter. Particle and antiparticle have identical mass and spin but opposite charge. So charge maybe emerge by a matter/anti-matter (temporal ?) symmetry breaking operation. See http://CPEPweb.org

[6] The principles could be explained by a deterministic theory beneath Quantum Mechanics: Wave-Particle Duality, Uncertainty Relation → quasi particles, waves are involved; Quantization → underlying system elements are discrete; Probabilism → chaos as in Cellular Automata; Pauli Principle, Spin → ?

Automata or similar concepts] we would then be tempted to examine what sorts of deeper mechanisms are actually implementing the computations and links of the Cellular Automata".[7]

If the universe is a giant Cellular Automata, as Stephen Wolfram, Edward Fredkin[8], and the late Konrad Zuse have proposed, who has made the rules for it ? Who was first, the particles, strings and elements with their properties spin, mass and charge or the corresponding rules, forces and laws ? Whenever such a chicken-egg question appears in the context of other complex systems, it turns out that both have co-evolved together. For example, the question who was first, the DNA which is necessary for producing proteins, or the proteins, which are necessary for replicating DNA, has been discussed in a previous section. Both simply co-evolved together.

Particles and Laws evolved together

Thus one possible solution is: as particles with certain properties (spin, mass, charge) emerged, the corresponding laws emerged, too. This would explain why in Quantum Field Theory properties like mass, spin and charge are related to coupling constants, which determine the kind of possible interactions. Electric charge means the particle can couple to and interact with a photon, strong color charge means a quark can interact with a gluon, etc. Laws and rules should be determined by the particles and states, and the particles and states should be determined by the rules. Similar to the curvation of space-time in general relativity: mass curves space-time, and space-time curvation determines the movement of mass.

Should anything be fixed ?

We think in terms of the familiar, for instance everything should be made of something, like stones, bricks, atoms or elementary particles, but the fundamental truth may not be familiar. If everything has appeared gradually in the course of cosmic evolution[9], why should anything be fixed or fundamental ? Are perhaps all elementary particles we know just emergent quasi or virtual particles ? Is there a mysterious deterministic and evolutionary theory beyond and beneath Quantum Theory and General Relativity ? Such questions are, for the moment, of course speculative in the extreme.

Virtual Whirl

But if this is true, then it would mean that no particle would really exist in the macroscopic sense of a solid body. Everything would just be a virtual, turbulent whirl or a dynamic disturbance. Like a solvable knot in

[7] http://www.kurzweilai.net/meme/frame.html?main=/articles/art0464.html

[8] see http://www.digitalphysics.org

[9] see the cosmic evolution web site at http://www.tufts.edu/as/wright_center/cosmic_evolution/ and the CPEP chart "The history and fate of the universe" at http://universeadventure.org/chart.html

a string which looks like an extended massive structure, but which vanishes if we pull at the ends of the string. Or a whirl in a turbulent flow, which ceases to exist if the flow stops. Then the problem is the search for the most fundamental *particle* itself and there is nothing at the most fundamental level, only particles which emerge as a kind of whirl or attractor. In chaos theory for example it is possible that two fixed points, a source and a sink annihilate each other in a bifurcation - similar to the annihilation of a particle after a collision with the corresponding antiparticle. But since such a theory is currently out of experimental reach and therefore unprovable, this is only a tempting speculation.

Nothing at the bottom

The world is so complex that philosophers alone can hardly understand it. In the words of Kierkegaard: Philosophers think they have constructed a palace of ideas, but in fact they live in a barn next to the vast splendid palace of existence. Great thinkers and scientists are aware of the fact that their knowledge is small and incomplete compared to the enormous complexity of phenomena and processes of the natural world. Even the most sophisticated theory is only a cheap colorless picture of a rich colorful world. Goethe writes in Faust I: "Grau, treuer Freund, ist alle Theorie, Und grün des Lebens goldner Baum".

Splendid Palace of Existence

Nature is much more complex than every existing theory and goes beyond our imagination. Richard P. Feynman wrote "The imagination of nature is far, far greater than the imagination of man. No one [..] could ever have imagined such a marvel as nature is" [48]. As Isaac Newton said, scientists are like children playing at the seashore, what we know is not more than a peeble while the great ocean of truth lies undiscovered before us.

Nature & Imagination

Chapter 7

Conclusion

Evolution is not a smooth, continuous process. It is marked by abrupt, unsteady changes and jumps in complexity. We have seen the emergence of complexity at these points is often only possible because it is balanced by an opposite or complementary process.

A continuous expansion of complexity and the emergence of complex composite objects is only possible through an increased localization and confinement to a limited space, often 'at the edge of chaos'. The price for the extension and expansion of complexity is the limitation and localization of the corresponding spatial extension.

Expansion, Confinement

If something emerges very suddenly or fast, it has often been blocked before by an obstacle or barrier. Dogmatic stagnation, immovable congestions or immobile jam before fitness barriers are often followed by sudden revolutions. Fitness barriers set the boundaries of evolution. Fast revolutions in evolution are possible because evolution gets stuck from time to time when a large fitness barrier is reached. Evolution waits until major events (e.g. massive catastrophes) break these barriers or single agents are able to cross them through a tunneling process.

Revolution, Stagnation

The price for the emergence of new species is always the preliminary reduction of diversity in the shared gene pool of the involved species. Increased external or outer complexity (related to agent class structures and species diversity) has the price of decreased internal or inner complexity (related to agent behavior structures and diversity in species).

Expansion, Reduction

Life is only able to maintain and increase order because it constantly consumes and destroys order in form of energy and information from the environment. If something emerges and appears, usually something else vanishes

Emergence, Dissipation

or disappears. Extinction is often followed by emergence. Emergence in the form of emergent phenomena through creation, concentration and accumulation is possible because something else is subject to destruction, dissipation or dispersion. In a thermodynamic sense, emergence is just one side of the emergence/dissipation duality. In an evolutionary sense, emergence is the the opposite of extinction. Emergence in the form of appearance of completely new species with extended complexity is possible because there are massive extinctions in which many older species disappear.

Emergence, Extinction

Thus what we fear most and try to avoid - catastrophes, death and extinctions - and what we admire most and try to understand - complexity, life and emergence - is closely related to each other. One is not possible without the other, no complexity without catastrophes, no life without death, no emergence without extinctions.

The evolution of complexity occurs at enormous cost. Birth, creation, concentration and accumulation is possible because something else is subject to death, destruction, dissipation or dispersion, and the emergence of completely new species is usually accompanied by the mass extinction of older species. Complexity and its emergence are inextricably linked to catastrophes and extinctions. The Encyclopædia Britannica notices in the entry about life: “man exists today, complex and reasonably well adpated, only because of billions of deaths of organisms slightly less adapted and somewhat less complex.”

Even systems which seem to produce complexity for free must pay a price. Permanent recombination or constant merging and splitting of agents or components are the basic mechanisms which increase complexity in agent based models, Multi-Agent Systems (MAS) and complex adaptive systems (CAS). This mechanism produces complex structures only for a short time, the more complex, the shorter the duration, similar to the energy of virtual particles according to Heisenberg’s Uncertainty relation. It is a kind of virtual, borrowed and temporary complexity. The price for such a sudden increase of complexity is a fast pay-back in form of a decrease in complexity. Temporary increases in complexity due to fluctuations are accompanied by instability. As easy as complex structures emerge during the process of merging and splitting, they vanish again after a short time.

Merging & Splitting

Yet small or temporary increases in complexity are possible. The constant merging, splitting and recombination of agents can be viewed as a clash of opposite forces. This clash of contrary and opposite forces (activation and inhibition, stretching and folding, merging and splitting,...) is character-

Temporary Emergence

ized by consonance in dissonance, regularity in irregularity, order in chaos, simplicity in intricacy and unity in diversity. But to increase complexity permanently, the system itself or its components must be changed. New agent or system forms must appear.

Increasing Complexity

W. Brian Arthur has identified three means by which complexity is permanently increased in the evolution of complex systems [4]: increase in "species/niches" diversity, in structural sophistication and increase by "capturing software". Based on these three basic mechanisms, we have examined the emergence of complex structures, systems and properties, and analyzed the reasons for sudden jumps in complexity.

Aggregation Inheritance

Increase in structural sophistication is related to aggregation and composition, increase in species diversity is related to inheritance and specialization. Aggregation and inheritance are the two basic merging and splitting operations for agents, the counterpart to integration and differentiation in mathematical analysis and differential calculus. They also transfer complexity, aggregation from the outer to the inner dimension, inheritance from the inner to the outer dimension.

Facts & Illusions

Through temporal squeezing and transfer mechanisms, the illusion of sudden emergence can arise, although there was no sudden jump in complexity at all. Temporal squeezing and transfer of complexity can create the illusion of abrupt, sudden jumps in complexity. This form of illusion arises often in bifurcations of phylogenies or ordinary lineage splitting (cladogenesis). We have shown that this lineage splitting, which characterizes the emergence of new species or agent classes, is equivalent to a transfer of complexity from an internal to an external dimension. If agents are merged in one dimension and splitted in another, sudden emergence of complexity is possible through transfer and transformation of complexity. In this case complexity is usually transfered from an invisible or less visible, flexible system to a more visible, stable system (the transition from 'To Have' to 'To Be').

Tunneling Processes, Catastrophes

Adaptive Evolution is not only an uphill or downhill walk on rugged fitness landscapes as Stuart Kauffman said in [118]. It can be interrupted by abrupt jumps on or changes of the fitness landscapes caused by external catastrophes. And it can contain tunneling processes through peaks in the fitness landscape.

The transition or tunneling to new agent or CAS forms causes the greatest jumps in complexity, the evolutionary thresholds that mark the major integrative levels of evolution. The essential component which enables the tunneling process is often an autocatalytic cycle, hypercycle, attractor or a group of agents in 'Sync' with synchronous actions, because stable structures are needed to balance the instability at critical points or phase transitions, where complex structures appear and disappear rapidly. The Baldwin Effect is viewed in a new way as a 'Payback' after a tunneling process and the emergence of a new complex adaptive system, when it embodies and anchors new, additional 'phenotype' behavior on the genetic level of the old complex adaptive system.

Catastrophes which annihilate large parts of complex systems also catalyze the emergence of new complex adaptive systems. Extinction and emergence are closely connected with each other: the extinction of old species often clears the way for the emergence of new species with new sophisticated abilities and more flexible or complex behavior. There is no complexity where there is no change and no need of change. Abrupt changes in the fitness landscape caused by catastrophes are nature's recipe for escaping the danger of getting stuck in local fitness maxima.

Emergence of complexity and life on Earth was and is possible only because the emergence of complexity is balanced by a dissipation or disappearance of order and energy. Life, the prototype of a complex system, is a *steady state in dynamic flow* equilibrium between dissipation, decay, breakdown, increasing entropy and dissappearance of order on the one side and emergence, creation, built-up, decreasing entropy and appearance of order on the other side. The whole life on earth is nothing but a turbulent whirl in the constant flow of sun energy. Like consciousness ceases to exists if the neural information flow stops, metabolism dies if the energy flow through the body stops, a political party vanishes if it can not gain new members, and a state begins to crumble if UN sanctions stop all imports, all forms of life on earth would soon come to an end if the sun would stop shining.

Summing up, we can give the following, preliminary and coarse set of answers to the questions of the introduction about the hallmarks of complex systems:

- **Emergence**
  Emergence out of nothing is an illusion. As René Descartes (1596 - 1650) said, "Ex nihilo nihil fit" (Nothing comes out of nothing). Global structures and phenomena can suddenly emerge from simple local interactions, because other structures or species are subject to extinction, dissipation or destruction. They can appear very fast, because they sometimes have been blocked before by obstacles or fitness barriers.

But their fast emergence can of course also be an illusion. Temporal squeezing and transfer of complexity, for example at bifurcations in phylogenies (lineage splitting or cladogenesis) can create the illusion of abrupt, sudden jumps in complexity. The greatest jumps in complexity are caused by the transition or tunneling to new agent or CAS forms, often accompanied or catalyzed by tunneling processes or catastrophes.

- **Self-organization**
  Systems without organizer organize themselves to higher and higher levels of complexity, because they are open and not isolated, which allows them to extract information, energy and complexity from their environment. A self-organized system needs a constant and continuous input of energy from the outside. It is able to dissipate energy and organization from the environment to create and built-up an artificial or abstract organizer in form of emergent critical states, attractors or whirls.

- **Cooperation**
  Selfish agents cooperate with each other to form larger groups, teams and clusters of agents, because they use and exploit others to help themselves. Agents usually still act on their own behalf if they are supporting others. The four major biological reasons for cooperation, direct reciprocity (agent-agent), indirect reciprocity (agent-group), kin selection (gene-gene) and group selection (gene-meme) can be unified to just one reason: *reciprocity*. Reciprocity between abstract virtual agents, which can be a simple or a composite agents, and reciprocity between abstract virtual replicators, which can be genes or memes.

- **Specialization**
  Agents are able to produce an aggregate or composite entity that is more flexible and adaptive than its components, because specialization and division of labor increases flexibility and adaptability.

- **Inclusion and Embedding**
  According to the definition CAS are self-similar systems. An Agent can be seen as a CAS, and a CAS can be represented by an Agent. Moreover, a new CAS can emerge in an existing CAS, if it is "embedded" in the old CAS, if the genotype of the new CAS is related to or part of the phenotype of the old CAS.

The answer to the question how it was possible that there were large abrupt jumps in the history of evolution is simple: many rapid jumps are an illusion and in the eye of the beholder: complexity at bifurcation of phylogenies for example does not appear suddenly, it is only transfered. Complexity also seems to appear suddenly at transitions, because transitional forms have a small organism size, a low fitness and a low population density, and thus fail to be recorded by the low fossil 'sampling rate'. Grandfather species that started a new line or lineage were often too tiny to be preserved.

The real large abrupt jumps in the complexity of an *adaptive* system are triggered by catastrophic and dramatic changes in the environment, because the evolution of a complex *adaptive* system mirrors the complexity of its environment. Large jumps in evolution require large changes in the environment, and in fact they have always massive causes. The process of evolution is interspersed with short revolutions, because periods of environmental stability are interrupted and interspersed with times of instability, stress and challenge.

If they are not to large, catastrophes, mass extinctions and tunneling processes are followed by the emergence of new organisms of much higher complexity. And this is probably the only possible way to reach substantial higher forms of complexity, which are separated by large fitness gaps from the lower and simpler forms. If there would be an easier way, evolution probably would have found it.

Appendix A

Holland's Definition of a CAS

The notion of a Complex Adaptive System (CAS) in the text is based on John H. Holland's definition. Holland defines a CAS as a collectivity of interacting adaptive agents. An agent by definition gathers information about its surrounding and applies certain methods (including schemata) to select an appropriate action.

Murray Gell-Mann prefers a definition [56] which includes schemata and information processing and which is not built on the notion "agent". Holland's version is more general, because it covers systems with agents who do not use schemata to process information.

His definition of Complex Adaptive Systems, can be found for example in Waldrops book 'Complexity' [151], (page 145) : "Holland started by pointing out that the economy is an example par excellence of what the Santa Fe Institute had come to call 'complex adaptive systems'. In the natural world such systems included brains, immune systems, ecologies, cells, developing embryos, and ant colonies. In the human world they included cultural and social systems such as political parties or scientific communities. Once you learned how to recognize them, said Holland, they all seemed to share crucial properties.

First, he said, each of these systems is a network of many "agents" acting in parallel. In a brain the agents are nerve cells, in an ecology the agents are species, in a cell the agents are organells such as the nucleus and the mitochondria, in an embryo the agents are cells, and so on. In an economy, the agents might be individuals or households. Or if you were looking at business cycles, the agents might be firms. And if you were looking at international trade, the agents might even be whole nations. But regardless of how you define them, each agent finds itself in an environment produced by its interactions with the other agents in the system. It is constantly acting and reacting to what the other agents are doing. And because of that, essentially nothing in its environment is fixed.

Furthermore, said Holland, the control of a complex adaptive system tends to be highly dispersed. There is no master neuron in the brain, for example, nor is there any master cell within a developing embryo. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. This is true even in an economy. Ask any president trying to cope with a stubborn recession: no matter what Washington does to fiddle with interest rates and tax policy and the money supply, the overall behavior of the economy is still the result of myriad economic decisions made every day by millions of individual people.

Second, said Holland, a complex adaptive system has many levels of organization, with agents at any one level serving as the building blocks for agents at a higher level. A group of proteins, lipids, and nucleid acids will form a cell, a group of cells will form a tissue, a collection of tissues will form an organ, an association of organs will form a whole organism, and a group of organisms will form an ecosystem. In the brain, one group of neurons will form the speech centers, another the motor cortex, and still another the visual cortex. And in precisely the same way, a group of individual workers will compose a department, a group of departments will compose a division, and so on through companies, economic sectors, national economies, and finally the world economy.

Furthermore, said Holland - and this was something he considered very important - complex adaptive systems are constantly revising and rearranging their building blocks as they gain experience. Succeeding generations of organisms will modify and rearrange their tissues through the process of evolution. The brain will continually strengthen or weaken myriad connections between its neurons as an individual learns from his or her encounters with the world. A firm will promote individuals who do well and (more rarely) will reshuffle its organizational chart for greater efficiency. Countries will make new trading agreements or realign themselves into whole new alliances.

At some deep level, fundamental level, said Holland, all these processes of learning, evolution, and adaptation are the same. And one of the fundamental mechanisms of adaptation in any given system is this revision and *recombination* of the building blocks".

Appendix B

Definition of Complexity

It is hard to find a clear, concise and precise definition of complexity. The rough and coarse meaning is equivalent to complication: "made of many intricately related parts" and "not easy to understand". To give a precise and exact definition is inherently difficult, because something is complex if it can not be described in a simple way.

As a physicist, Murray Gell-Mann argues in his article "What is Complexity" [57] that you need a measure to describe what is meant by complexiy: the length of the most concise system description, or the length of a concise description of the system's regularities. But to define such a measure is a problem of its own.

Some authors avoid the problem to give a precise definition of complexity. Herbert A. Simon defines complexity in his article 'The Architecture of Complexity' [142] as a property of complex systems. He says "I shall not undertake a formal definition of complex systems. Roughly, by a complex system I mean one made up of a large number of parts that interact in a non-simple way." Yaneer Bar-Yam starts in his textbook "Dynamics of Complex Systems" [12] with a similar simple definition: "A dictionary definition of the word "complex" is: "consisting of interconnected or interwoven parts".

R. Badii and A. Politi try the same in their book about complexity [7]. But they give a different dictionary definition. They say in the Preface the usual dictionary definition of complexity is: "a complex object is an arrangement of parts, so intricate as to be hard to understand or deal with." (Webster, 1986).

Of course all these simple definitions are better than definitions like "Complexity is the opposite of simplicity" or "I-know-it-when-I-see-it". But because there are different definitions, the questions arises what the basic or most fundamental definitions of complexity are. What is the essence of complexity ?

Whereas a thesaurus says complexity is a thing like intricacy, complication, entanglement, elaboration, difficulty, diversity, variety, multiplicity and variation, dictionaries distinguish generally two kinds of complexity

* a property of an external process related to a complicated nature
  Degree to which a system's design or structure is difficult to understand; the condition of being difficult to understand, or being made up of many interrelated things

* an internal property of a complicated thing or item
  the quality or state of being complex, complicated and compounded; something that is complex, involving a lot of different but interrelated parts:

Warren Weaver was one of the first who started 1948 a discussion about complexity in his article "Science and Complexity" [153]. He distinguishes between disorganized and organized complexity.

Disorganized complexity can be found according to Weaver in a system with many loosy coupled, disorganized and equal elements, which possesses certain average properties as temperature or pressure. Such a system can be described by 'nineteenth-century techniques' : statistical techniques or methods of thermodynamics and statistical mechanics.

Organized complexity can be found in a system with many strongly coupled, organized and different elements, which possesses certain emergent properties and phenomena as currency values, behavior patterns or phenotype forms of living beings. Such a system can not be described well by the 'nineteenth-century techniques'.

Weaver says [153] "A wide range of problems in the biological, medical, psychological, economic, and political sciences are just too complicated to yield to the old nineteenth-century techniques which were so dramatically successful on two-, three-, or four-variable problems of simplicity. "

These are the problem fields that were examined in Weaver's time after the second world war through the tools of Game Theory, and which are today topic of research for Multi-Agent Systems. Today we would say complexity is a property of complex, complicated and interestingly organized systems which a rich structure. The components of a complex system and the interactions between them can be described by a complex network, which has often scale-free properties or a power-law degree distribution [105].

Complex systems are difficult to describe and explain, because they have a complex structure and organization. The first way to define complexity is to focus on the process of description and explanation itself. Complexity in this case is related to the amount of difficulty in understanding, describing and explaining systems. The second way to define it is to focus on the target of the description. In this case complexity is a property of a complex system and is closely connected to the levels of structures and organization of it.

1. **Complexity as a Process**: Description and Explanation
   How difficult is a system to describe and to explain ?

   (a) Complexity is the characteristic property of complicated systems we don't understand immediately. It is the amount of difficulties we face while trying to understand it In this sense, complexity resides largely in the eye of the beholder - someone who is familiar with s.th. often sees less complexity than someone who is less familiar with it

   (b) (Kolmogorov or Algorithmic complexity) The complexity of a system is the length of the message or the amount of information required to model and describe it. In the case of a data-file or picture, the complexity is just the length of the losslessly compressed data.

   (c) (Complexity is abstract and context-dependent) Complexity is an abstract notion, which has meaning only in relation to some context : physical complexity, geometric complexity, algorithmic complexity,..

   (d) (Predictability, Order, Stability) Complexity is

      * order in disorder,
      * stability in flexibility,
      * predictability in randomness,
      * structure in variation

      Pure order does not represent complexity, because the order is predictable. The system lacks change or flexibility. Pure randomness does not represent complexity either, because the disorder is predictable. The system lacks structure and stability.

(e) (Complexity theory) Complexity theory is the theory of complex, self-organized systems, which consist of many closely connected and interwoven parts and which are difficult to understand and explain. The basic concept of complexity theory is that systems show patterns of organization without organizer (autonomous- or self-organization). Simple local interactions of many mutually interacting parts can lead to emergence of complex global structures.

2. **Complexity as a Property**: Organization and Structure
How structured, intricate, hierarchical and sophisticated is a system ? How many layers of order exist ?

(a) (Hierarchical complexity) Complexity is determined by the number of levels on which structures can be found, and by the complexity of these structures. A system has the property of high complexity or is very complex, if it can be represented efficiently by different models at different scales.

If it can be represented by the same models at different scales, or if it has scale independent properties, it is a self-similar, scale-free or fractal system. The interactions of components can often be described by a scale-free or small-world network.

(b) (Complexity scale) A complexity scale is a method to classify complex systems in different levels and stages : how many mutually interacting parts has the system, and how simple are these connections and interactions and the parts itself

(c) (Self-organized criticality) Complexity originates from the tendency of large dynamical systems to organize themselves into a critical state, with avanlanches or "punctuations" of all sizes. In the critical state, events which would otherwise be uncoupled became correlated. (Per Bak in PNAS Vol 92, July 1995, 6689-6696)

(d) (Evolution, Uniqueness) Complexity is the property of a complex system or its evolution. A complex system is created by evolutionary processes. There are multiple pathways by which a system can evolve. Many complex systems are similar, but each instance of a system is unique.

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