The N∃W and the DIFFERENT

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FOREWORD (2006)

I am publishing the ten year **old** *The New and the Different* on the Web with minimal editing. I completely realize the awkwardness of its shape, style, and language. But I believe it still has something NEW in it. I tried to express it in the simplest language possible.

My INTRODUCTION to *The New and the Different* tells the story of the manuscript. It was my first attempt to formulate a chemist's view of the world, stimulated by Ulf Grenander's Pattern Theory.

Since 1995, when the manuscript was finished, a lot of things have happened. Ulf Grenander and I completed *History as Points and Lines*, I was privileged to watch Ulf's work on *Patterns of Thought*, the ashes of 9-11 fell on the fresh page of history, the Iraq slaughter splashed a bloody Rorschach test on it, and the flat world turned out to be dreadfully bumpy for big wheels. Linguistics seemed to me a comforting distraction.

I see this manuscript as a bulky packet with a few seeds for a NEW perception of **evolving complex systems** (ECS- or X-systems) in which we are destined to live like fish in muddy water. Do we really need any new vision of the world? See Chapter 32: COMPLEXITY AND EVOLUTION. Will the seeds germinate?

Speaking about seeds, the science of Everything is probably as old as agriculture. The art of growing plants starts with soil and develops slowly. Ancient Sumerian dream books were the first publications on abstract bonding. The Greeks discovered atomism—the greatest idea of physics, according to Richard Feynman. Benedict Spinoza suspected that the order of ideas is the same as the order of things. Georg Cantor noticed that there was not so much difference between both. Ulf Grenander gave atomism a mathematical form and he surveyed and mapped the entire huge expanse of Everything. The soil is ready. More literature is reviewed in my other e-publications.

My most important personal discovery since 1995 has been the realization of the contrast between the physical theory and a theory of complex systems. Since the number of interconnected and well paid brilliant minds in the world is very high, it can be postulated that a lack of progress in some direction for more than 50 years is a proof that the direction is an impasse. I believe that in order to achieve a still lacking understanding of evolving complex systems we have to abandon the paradigm of scientific theory that has been serving us flawlessly if applied to **well defined systems**. Unaccustomed to the concept of **novelty**, it stumbles on the threshold of **evolving complexity**. This is exactly why the atomistic understanding of Everything remains a rare intellectual oasis populated with a minimal number of people: the visitor has to discard the equipment with which he or she makes a living.

The central for Pattern Theory idea of atomism goes back to the less mercantile times when philosophers regarded creativity of intellect and search for truth as the real meaning of life.

My current work is inspired by Hannah Arendt's inimitable *The Human Condition*.

Ideas do not die.

Yuri Tarnopolsky

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INTRODUCTION

I was born in the former Soviet Union.

I became a dedicated chemist in my teens after I had seen a demonstration of chemical experiments at a local college.

I was hypnotized by chemical names, strange formulas, and miraculous change of color right before my eyes. Soon I was more or less familiar with the high school chemistry, much ahead of the curriculum. Yet I was open to many other things, not necessarily bordering with chemistry. After high school I even considered psychiatry as my future career. I took up chemistry, however, and joined the Soviet academe as a professor of chemistry in Krasnoyarsk, a large city in Siberia.

My bookshelves were stuffed with books on chemistry and psychiatry, but there was much more—physics, biology, mathematics, logic, Aristotle, Lucretius, Descartes, and utopian literature. A rich collection of folk tales from all around the world was a source of new magic after the miracles of chemistry had become routine.

In 1977, after my fifteen voluntary Siberian years, I came back to my native city of Kharkov in the warm Ukraine. In the summer of 1979, I applied for emigration visas. By that time, however, the Soviets, in a tug of the Cold War, had suddenly stopped emigration and, like many thousands of other applicants, I was refused the visas.

Having demonstrated my disloyalty to the Communist government by my intent to change allegiance, I was completely cut out from the society, with no chance of any professional employment. Neither did I belong to the distant world of freedom. In my "refusenik" status I was able to appreciate the profound realism of Bosch, Breughel, Goya, Dali, and other artists of surreal worlds. Like in the famous picture of Maurits C. Escher, I could climb or descend the social stairs with an equal result: they led nowhere.

The deep intellectual isolation of the refusal stirred up the memories of the books I read all my life. I was so far removed from the world that I could see it all at once, like we see the moon, although only its one side.

Among major conceptual revolutions, the introduction of set theory by Georg Cantor in 1880 was one of a kind. While previously mathematicians had operated with numbers and points, set theory gave them the tool to deal with any objects. Since a set can be not only a collection of numbers but also a collection of things, people, or ideas—and even a mix of all three—science acquired the language to talk about **everything**. With a hindsight, the abstract message of set theory was a promise of a universal approach to the world as a whole and a movement toward a universal knowledge, like in the times of Aristotle.

About the same time thermodynamics came up with an idea of a great generality, introducing the way to measure chaos by entropy. Chaos was one of the most ancient pre-scientific concepts of humanity and it appeared quite natural to apply the idea of entropy (Rudolf Clausius, Ludwig Boltzmann) to many areas beyond traditional physics. Thermodynamics—a very inappropriate term—turned out to be as universal as mathematics, and not just a part of theory of heat engines. For a while it had balked at the phenomenon of life, but in this century it smoothly covered the controversial area of non-equilibrium phenomena with the new idea of **order from chaos** (Ilya Prigogine).

Thermodynamics is applicable to very large collections of more or less similar objects, such as molecules exchanging energy. Scientific publications, scientists, and large assemblies of people are large collections exchanging information. Economics deals with many thousands of entities exchanging value and information. All those areas can be treated as thermodynamic systems although human nature is defiantly individualistic.

When in 1859 Charles Darwin discovered some intimate properties of large collections of organisms, he expressed them in anthropomorphic terms of **struggle** for existence, **competition**, and **selection**. That was a new class of phenomena of universal importance, far beyond plants and animals. About one hundred years later it became clear that organisms were involved in exchange of genetic material. In due time the concept of **information**, rooted in the much older concept of entropy, embraced humans, organisms, and machines, as well as yet unheard and unseen aliens from distant galaxies. The spread of universal messages of science over previously isolated fields of knowledge has been typical for the entire twentieth century.

By the second half of this century it looked like science—so successful and omnipotent with polymers, genes, semi-conductors, and computers—should be able to answer any question about individuals and societies. Complex phenomena, however, have been neither fully understandable nor fully manageable.

Moreover, a new dark cloud appeared on the intellectual horizon. Complex phenomena—whether they were called dynamic systems, adaptive systems, or ordered chaos—seemed to be unpredictable in principle. Although we are moving toward an integral vision of the world, we feel ourselves more and more like the ancient Greeks who knew that gods always had the last word. Chance is the Zeus of the new Pantheon.

As a chemist watching the conceptual drama of modern science, recorded in scores of popular books, I felt myself far away from the stage. While mathematics with sets and probabilities, physics with thermodynamics, and biology with selection had universal messages were reaching far beyond their immediate fields, the chemists stayed focused on stirring their bubbling pots. Bright undergraduates dozed at lectures on chemistry and kept complaining that chemistry had no theory. Although organic chemistry developed its own theory of a distinctive beauty, chemistry remained almost entirely descriptive and the theory was more hindsight than foreseeing. Yet I believed that chemistry, too, might have a universal message which started taking shape in my mind.

Practically all comments to the folk tales in my collection contained references to a book by a Russian ethnographer Vladimir Propp, (Propp, 1971), who had systematized Russian folk tales as "molecules" consisting of the same "atoms" of plot arranged in different ways, and even wrote their formulas. His book was published in the 30's, when Claude Lévi-Strauss, the founder of what became known as structuralism, was studying another kind of "molecules," the structures of kinship in tribes of Brazil. Remarkably, this time a promise of a generalized and unifying vision of the world was coming from a source in humanities. What later happened to structuralism, however, is a different story, but the opportunity to build a bridge between sciences and humanities was missed. Humanities could be a rough terrain for study as well as for career .

I believed that chemistry carried a universal message about changes in systems that could be described in terms of elements and bonds between them. Chemistry was a particular branch of a much more general science about breaking and establishing bonds. It was not just about molecules: a small minority of hothead human "molecules" drive societies toward change, a nation can be hot or cold, both a child playing with Lego and a poet looking for a word to combine with others are in the company of a chemist synthesizing a drug.

Chemistry has always been the most voluminous science. The yearly crop of chemical knowledge is densely packed into dozens of thousands pages of *Chemical Abstracts*, where original articles can be compressed in a few lines of a short digest. Some chemical compounds include millions of atoms arranged in a strict order. It is hard to find another science as well adapted to dealing with complexity as chemistry.

In 1979 I learned by accident about a mathematician who tried to list everything in the world. I easily found in a book store the first volume of *Pattern Theory* by Ulf Grenander (Grenander, 1976) translated into Russian.

As soon as I had opened the book, I saw that it was exactly what I was looking for and what I called "meta-chemistry," i.e., something more general than chemistry, which included chemistry as an application, together with many other applications. I can never forget the physical sensation of great intellectual power that gushed into my face from the pages of that book.

Although the mathematics in the book was well above my level, Ulf Grenander's basic idea was clear. He described the world in terms of structures built of abstract "atoms" possessing bonds of certain kind. Body movements, society, pattern of a fabric, chemical compounds, scientific hypothesis—everything could be described in the atomistic way that had always been considered indigenous for chemistry. Grenander called his atoms of Everything "**generators**," which tells something to those who are familiar with group theory, but for the rest of us could be a good metaphor of generating complexity from simplicity. Atomism is a millennia old idea. In the next striking step, much appealing to a chemist, Ulf Grenander outlined the foundation of a universal "physical chemistry" able to approach not only fixed structures but also "reactions" they could undergo. He attributed to generators selective affinities to each other and the ability to form bonds of various strengths. That was pure chemistry.

By that time, due to innumerable discussions with my refusenik friend Eugene Chudnovsky, now professor of physics at the State University of New York, I got very much interested in the problem of origin of life. I learned from him about nonequilibrium thermodynamics, works of Manfred Eigen on molecular evolution, and the physical picture of the world in general. Origin of life represented for me a more general question about how everything evolved from nothing. I hoped to find a clue in pattern theory.

Oddly, the refusal brought me both freedom from small everyday problems and a peace of mind that I never had before. Only two problems occupied my mind—mere survival and chances of future freedom—while petty problems attacked an average Soviet citizen like the birds in the Alfred Hitchcock's movie, of a smaller size, but more numerous.

I was unable to wait patiently until a turnaround in Soviet politics would open the door slammed into the face of thousands potential emigrants. The watchful eye of the Soviet secret police soon noticed my anger. In 1983, after four years in the refusal, I was arrested and put on trial for defaming the Soviet system. I wound up in a Siberian labor camp.

My trial, in which I took no part, revived my old interest in abstract problems. I was accused of making a statement in an open postcard sent abroad that I had been illegally detained in Russia, harassed, and the escalation of harassment could lead to my imprisonment. That was qualified as defaming the Soviet system because obviously nobody could be arrested in Russia without any crime. Therefore, I was in fact arrested and punished for having predicted that I would be arrested and punished. There was little I could do but trust the hidden abilities of my body and the defenders of human rights abroad.

It was a typical logical paradox, a strange loop, as Douglas R. Hofstadter called it in his fascinating *Gödel, Escher, Bach* (Hofstadter, 1989).

As soon as I had been able to buy a notebook in the labor camp, I started writing. I did not have more than half an hour a day for writing, and not every day. Even if I had more time, I would not be able to extract more energy from prison food. But I had over one thousand days—enough to build my own little Rome.

In the camp I had no scientific literature at all. In my third year there, I learned from a friend that the third volume of Ulf Grenander's book had been translated into

Russian. Sending books to prisoners was forbidden. Nevertheless, probably, because it was 1985, and Mikhail Gorbachev had come to power, the book reached me in the camp.

At the end of my term, I took out the metal coil from my spiral-bound notebook and sent the pages as letters. When I came home in 1986, I assembled the notebook with the coil and empty covers that I had brought with me from the camp.

In 1987 my family and I came to the USA. I managed to resume my professional career as a scientist. In my free time I was writing a book about my recent past where I told mostly about my search for the clue to the Russian mystery, as well as the mystery of complexity, against the backdrop of the camp life. My *Memoirs of 1984* were published in 1993 by the University Press of America.

The time came to retrieve my old spiral notebook. After many years it still seemed to contain some sound ideas. In a library I ran into proceedings of a symposium on complexity held in Montpellier, France, in 1984, the peak of my Orwellian adventures, see Complexity (1985). I resumed reading literature on complexity, the new emerging field of knowledge, of which the chemists—the born navigators through complexity—kept staying away.

I had lived in Rhode Island since 1988, but only in 1994 I finally met Ulf Grenander, professor of mathematics at Brown University, Providence, RI. His new book on pattern theory had just been published.

After this introduction,

"The time has come," the walrus said,
"To talk of many things:
Of shoes—and ships—and sealing-wax—

Of cabbages—and kings—
And why the sea is boiling hot—
And whether pigs have wings."

*

1. THE EVERYTHING

We are going to talk about the Everything.

Regarding terminology, I have to say right from the start that I cannot define my most important terms, least of all Everything. Instead, I will use something like the sign language of an explorer setting foot on a new land where people speak an unknown language. I would point to myself and say my name. I would walk and say "walk." I would draw a picture of the mind on the sand and say "mind."

To define an object is to name a larger class of objects to which it belongs.

Cats and dogs are pet animals. The dog is the pet animal that barks and the cat is the one that meows. The man, as Aristotle said, is a biped animal without feathers. Good or bad, those are definitions under the logical umbrella of animal. There is nothing larger than Everything, however, and no umbrella can cover it. All I can do is to list its major components as I find suitable for my particular goal.

First, Everything is something that existed before life and is still relatively independent of it. Stars, planets, some geological formations, minerals, bodies of water, and atmosphere are examples of what we can abiotic things, or just things, for short.

Second comes life in the form of organisms.

Life gives birth to the third kingdom of Everything—mind with its dreams, thoughts, ideas, art, and knowledge.

The fourth kingdom of Everything includes man-made objects: buildings, machines, clothes, toys, bureaucracy, law, etc. This is about all, but I am tempted to extend the list.

I would put computer files into the fifth domain. I believe that although computers are man-made things, the content of their files belongs to an independent kingdom akin to life. A file lives a life of its own, with birth, development, productive work, reproduction, and death, sometimes in an accident. I would qualify the origin of the Web as the very first genesis of a life-like system observed by a single generation. We have now even computer anthropologists, like Sherry Turkle.

The sixth domain, money, came with things as mind came with life. I am in no way an expert in the subject, but for those watching the modern financial markets, whether with awe or greed, the metaphor of life may seem appropriate. It seems to me that money lives a life if its own, represented in a multitude of species exchanging values and interacting with other domains and each other in a complicated way. Money has made a long way from the primeval "bacterial" form of coins, and, to its glory and peril, from the safety of the laws of conservation that the humble matter enjoys.

I would reserve the seventh domain for everything I have left out, as well as for the future species, gadgets, humanoids, aliens, etc.

If somebody disagrees with me, I will not insist. Anybody can offer a personal classification of Everything. Anyway, by Everything I mean really everything: atoms, molecules, organisms, things, thoughts, poems, and what not. When I mean it as a whole, and not as a substitute for a list, I capitalize the word: Everything.

There is so much of everything in Everything that right on the first pages I am already having difficulties with terminology. We need different words for non-man-made things and man-made-things, lives of bacteria, computer file, and corporation, etc.

Whatever Everything is, it is obviously very big. A large encyclopedia is a short review of Everything, and the Library of Congress is a more detailed, although somewhat loose, description. The World Wide Web looks like Swiss cheese with more empty or irrelevant space than the substance, but at least Aristotle and Plato are cocooned there.

The size of this book is going to be about 300 pages, and I have to trim Everything to bare bones in order to present it to the reader. Let us X-ray Everything, look at its skeleton, and leave its soft living tissues, full of juice and vigor, to various particular sciences.

Why do we need Everything as a whole, anyway? What an eccentric object of study!

I am deeply intrigued by the origin and evolution of Everything. Unlike an astrophysicist, who starts Everything with the Big Bang, I believe that Everything is being created every moment, even as we speak. I am interested not in the Big Bang but in the quiet sweet chiming of the Little Bell announcing from time to time that something **New** has just come into being and its voice is heard against the constant background rustle of hordes of **Different** things crawling into the world like locust.

Something new always appears and always in the same way: there was nothing like that, and—look!—here it is. Sometimes it is *very new*, like life, man, aircraft, TV, computers. Sometimes it is *less new*, like a new breed of dogs, another industrial corporation, cable TV, laptop computer, a different coffee-maker, cereal, car model, etc. Sometimes, it is only a new label on a generic toothpaste.

Sometimes, the New comes with a thunder. Take, for example, biological evolution: there was no life, and—boom!—here come algae, plants, fish, insects, amphibians, mammals, and—vawoom!—here is man.

Isn't it a thrilling mystery that this book had not existed before it was written? What a childish question? One might say. But if we pull at this one, a string of other questions, more and more serious, will come out.

Amazingly, the concept of this book had been out of question for some time before it took shape in author's head. Incredibly, it is safe to say that neither the author nor even the reader existed one hundred years ago. Moreover, the way people lived those days was rather different from the conditions of our present civilization. Why did it change and why to its present state?

By backtracking history we might make more discoveries. It is just astounding that there were times when there were no books at all, and no science, and not even life on earth. There was no Earth, and no Sun, and, probably, not even the nature as we know it. Gradually all that came into being, the Everything appeared, and more things will appear in the future.

What we see around and inside us, all objects that we know about, from atoms to stars, from stones to ideas, from a paper clip to a super-computer, from viruses to humankind—all that is Everything. Our knowledge about Everything grows, expands, wriggles, pushes, trembles, merges, divides, grows again, expands again—becomes more and more complex, difficult, specialized, detailed, numerous, but the more complex it looks, the more we suspect that there is a profound unity, and the more anxious we are to decipher the universal code of Everything.

In our mental journey from the snug bud of the primeval Everything to its present grandeur, everything on our way is new, everything appears at a certain moment. Yet a sage warns us: "There is nothing new under the sun." If TV was new but the cable TV was not as new as the first TV had been, than probably TV itself was not as new as we believe it was. In fact, it was a love child of movie and radio, and radio itself was a successor of the ancient watch towers that passed the news about an approaching enemy by using the smoke of a fire as signal. This method of transmitting information is still in use in the Vatican where the election of a new Pope is signaled by the color of the smoke from the chimney.

What is really new and what is just a different kind of the old stuff? Can we measure such things as novelty, and complexity, like we measure out water and flour for making bread or ingredients for a cocktail?

Moreover, if mindless life and human mind were just an offspring of inanimate matter, we can ask ourselves to what exactly degree matter had been inanimate before life emerged, or even to what degree man is actually animate. A new series of childish questions could spring from there. Can there be something even more animate than humans or at least more intelligent? What is next after man?

Where everything comes from? What is everything built of? Will all that ever disappear? Those are fundamental questions of science, philosophy, and religion. Although possible answers are, luckily, of no immediate importance for our everyday lives, we might want to know the answers just out of childish curiosity, and—who knows—there might be even some use of it.

I have to state in the very beginning that I am not pretending to know the answers. All I want is to present a particular vision of Everything, the shadow of its skeleton in just one of many possible projections. The picture of Everything that I see with my eyes closed is more in line with Picasso than with Rubens.

More than two centuries ago the French mathematician and philosopher René Descartes imposed an implacable apartheid on mind and matter, the two major races of our experience. Even in our today's perception, inanimate matter, life, and especially mind are separate plateaus split by deep canyons. If we are planning to stalk the evolution of Everything, we know in advance that we will have to somehow pass over the precipices between the three. Although the division is not as popular as it used to be and there is a good deal of reconciliation and search for common ground, there is still no reliable bridge to cross the abyss. Mind and Matter—the two M-words—mark the most mysterious mind-muddling mismatch. I am especially interested in seeing mind and matter under one tree, hand in hand, like Adam and Eve.

From the whole cornucopia of species of matter and mind I would like to bring molecules and thoughts to the foreground. Usually, when we discuss one, we do not touch the other and do not see them side by side, like we never see both sides of the moon at the same time. If I were a painter, however, I would paint them both in view, Picasso-style.

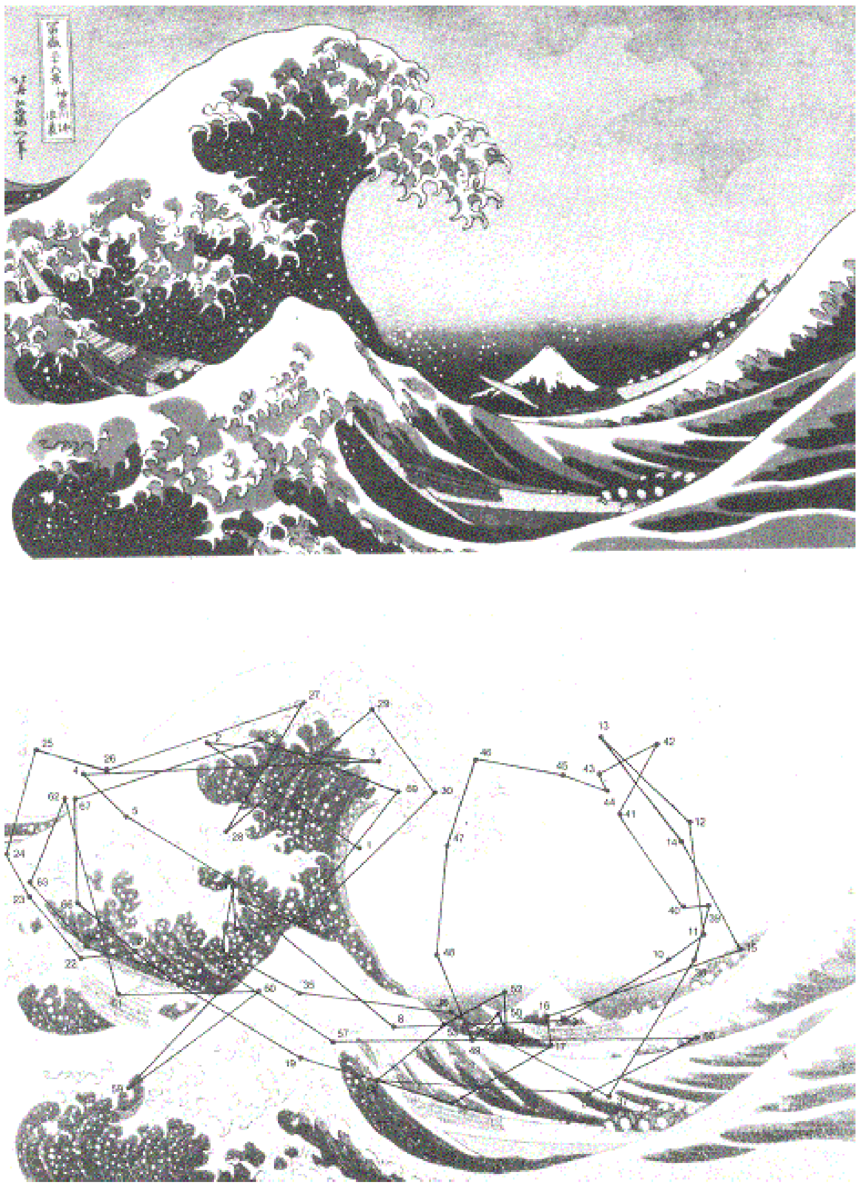

Figure 1.1. ***The Wave*****, by Katsushika Hokusai (1760-1850), Japan. The bottom diagram shows the pattern of eye movements and fixations made by an observer viewing the picture. From Goldstein (1984).**

Suppose, somebody else has drawn that picture and I look at it for the first time. My eyes will move over it, stopping at some spots, skipping others, and jumping back to some. An example is displayed in **Figure 1.1** (Goldstein, 1984). The bottom diagram shows the pattern of eye movements and fixations made by an observer viewing *The Wave*, by Katsushiki Hokusai (1760-1850, Japan).

We can see in *The Wave* some major components of Everything: wind, clouds, water, wave, people, boats, beauty, fear, and hope displayed in two dimensions.

In the next several chapters, trying to sketch up a primitivist portrait of Everything, I will have to put a multi-dimensional picture existing in my mind into a linear sequence of words. Let us note that *The Wave* by Hokusai can be linearized in at least two dramatically different ways, for example, with a scanner converting it into a computer file, or by two lines from a totally unrelated to Japan poem by Arthur Hugh Clough (1819-1861, England):

> On stormy nights when wild northwesterns rave,
> How proud a thing to fight with wind and wave!
>
> (Clough, 1951)

This book is a linearization of the picture of Everything as I see it in my imagination. I would like to present it as a natural sequence of movements of the mental eye jumping from one point to another, with repetitions, returns, and omissions. I just do not know any other natural way to do that: unlike a TV image, Everything cannot be scanned line after line.

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2. THE CHILD

For many reasons the child is my starting point, reference notch, and the center of Everything.

There is nothing we know better than our own life. Childhood is its beginning, best of all preserved in memory, not laced with any science, philosophy, or prejudice. Childhood is my soul that, like in a tale by Oscar Wilde, leaves my body and talks to me as an equal.

Unlike the adult lives, childhood is open to observation and we can watch it again and again in our own family or somebody else's. A child is the best embodiment of evolution. The parents have the privilege and pleasure to watch it for years.

The newborn children know just the essentials of survival but they start learning immediately. Children are allowed to ask any question, and the more the better. Gradually they grow and emerge as human beings with large and complex knowledge, each of them developing a web of ties with other brains, books, and computers.

While it could be hard enough to understand how something appears from something else, the origin from nothing is the most intriguing aspect of any evolution. The child is unique in the sense that it starts with zero knowledge: this is certainly something the adult does not possess. Some childish questions remain unanswered even after maturity comes and so they are for some scientists. With age, the more answers people know, the less questions they ask. A scientist with a taste for mysteries is a perennial child, and for him or her the questions of childhood just switch to a larger object—the Everything.

It is the childish absence of knowledge—the innocence (a word out of fashion)—that might help us understand how knowledge appears. Not only logic but also impressions, images, and fantasies are child's legitimate means of understanding. Nothing restricts its freedom of mental flight.

Like many children I was troubled with the problems how it could be that I had not existed, how I was born, and, especially, how it could possibly be that I would not exist. Childhood ends when a person realizes that the universe does not revolve around him or her. How everything appears is a transformation of the question with which I had been concerned for quite a time until the problems of my own origin, existence, and end ceased to bother me.

I am going to borrow from childhood the art of making complex simple and simple complex.

Let us start with simplification. Human face is a complex object with a lot of detail, but a child manages to simplify it by drawing circles and ovals for head, eyes, nose, and mouth. The primitive portrait fits billions of human faces.

By a slight modification we can specify gender or race, which still would cover billions. If we take a photo, however, it will match only a single individual and, probably a few his accidental look-alikes. Can we draw a simplified portrait of Everything so that everybody would recognize it but without showing the detailed and enlarged sections of its image, say, its lips or ears?

The other basic function that the child can perform well without knowledge is turning simple into complex. The child builds sand castles from indistinguishable grains of sand. The child playing with Lego takes small blocks and right before our eyes complex structures develop from simple elements.

Both functions have parallels in the experience of our civilization. Science develops a general theory that fits a multitude of particular cases—this is simplification. New products of ever increasing complexity are engineered and built by technology—this is complexification.

The earth that carries the child also ages and emerges as a carrier of ever more complex biosphere and growing and cumbersome civilization, and we can suspect that there is some similarity between the evolutions of both. We can suspect that all particular evolutions, be it a computer or a butterfly, look alike if we portray them in a childish style of lines, circles, and ovals.

The image of a child playing with toys such as Lego and Meccano will accompany us throughout this book. We start our voyage at this point and we will move toward both Nothing and Everything, not in any strict order but the way our eyes moves over a picture.

While the child builds a small Lego universe, we shall try to build a toy universe of our own, hoping to learn something about the design of a larger one.

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3. THE NEW METAPHYSICS

In the times of the childhood of human thought, philosophy comprised all general knowledge, and the ancient philosophers felt free to treat all problems and answer all childish questions.

With time, philosophy of nature split into particular sciences—physics, chemistry, biology, etc. The explosion of human knowledge followed the explosion of the universe after Big Bang. Due to the intimidating size of what now can be called Everything, none of the natural sciences can even think about the old problem of how Everything comes into being and no particular science deals with Everything. Physics can explain why a bird flies, but the origin of the bird is not a physical problem. Biology can explain why the birds flock together, but cannot tell why they do not fall to the ground. Chemistry can explain how molecules aggregate and cluster into the bird's body but not how the bird sees the world.

Modern science is so successful because it scrutinizes particular objects or collections of objects and rejects Everything. It conquers nature by dividing it. The balance of building fences and building a community—two of basic human instincts—seems to be shifted toward separatism and specialization still clearly prevailing in science. True, the particular problems of particular sciences are mostly of no importance for a neighbor just across the hallway. But it is also true that discoveries in the border areas between two or more sciences could be exceptionally rewarding. The drive toward balance and harmony, however, is yet another basic human instinct.

For quite a while we have been watching a development of a new area of thinking that struggles with an apparently impossible task to generalize the accumulated knowledge about the world. Driven by the instinct of explanation—probably, a sublimation of the insatiable instinct of possession—we ask ourselves new questions which turn out to be an echo of the first probing voices at the dawn of knowledge and even earlier. Not only the names of Aristotle and Plato are respectfully pronounced again, but even God becomes a physical concept, and the word *metaphysics* is not outright offensive.

It is not that sciences really merge and coalesce—there is no such process in sight. What we are witnessing is not a development of a new interdisciplinary area either. A new synthetic approach to most fundamental problems of the nature is gradually emerging as an independent body of reasoning.

There is still no proper name for the new Science of Everything. We could call it omnistics, or holistics, or pantology, or science of complexity, or science of Everything—

whatever. It is not clear whether it will give us anything in excess of what lessons of kindergarten, religious faith, history, science, and common sense can give. It could be just a transient para-scientific fad or an ultra-sophisticated computer game. Whatever it is, it has no visible intention to dominate the scientific democracy: it is just another science that builds the fence of its own, and it is very difficult to say if any edible crop will grow in its garden to the benefit of mostly skeptical or indifferent neighbors.

Anyway, there are clear signs that we are entering the times when the neglected synthesis will be called back. The title of a relatively recent book by John D. Barrow *Theories of Everything* (Barrow, 1991) is a modern paraphrase of the Latin title of the book by Lucretius *De Rerum Natura*, two thousand years older, which means "On the Nature of Things" (Lucretius, 1947). The first most extensive book on Everything begins with atoms, ends with intimate human relationships, and is written in a powerful poetic language.

For some time, scientists have been feeling a new urge to take a satellite's look at the planet of human knowledge, fly over the traditional borders, and make some generalizations in the spirit of childish questions. It turned out that it is much more difficult to do now than it was in times of Aristotle and Lucretius. We probably know too much and our mind has been flattened by the gravity of the existing knowledge that has been shaping us since birth. Still, there is a hope that someday we will be able to treat cabbages and kings equally from the point of view of a highly abstract and universal science.

The new emerging approach can be compared with the view of planet Earth from a space ship. An astronaut cannot see state borders between the countries: the globe is a whole. From the point of view of classical mechanics, there is no difference between the earth and the ship because the space ship is just another, much smaller, celestial body.

Looking into the window, the astronaut might see his own face dimly reflected in the glass and overlaying the view of Earth. In a sense, his head is as large as the globe and it is a universe in itself. The lifeless mineral Earth carries life, the mindless living cells of human body carry mind. There should be a point of view—from a large distance—that could capture the whole picture.

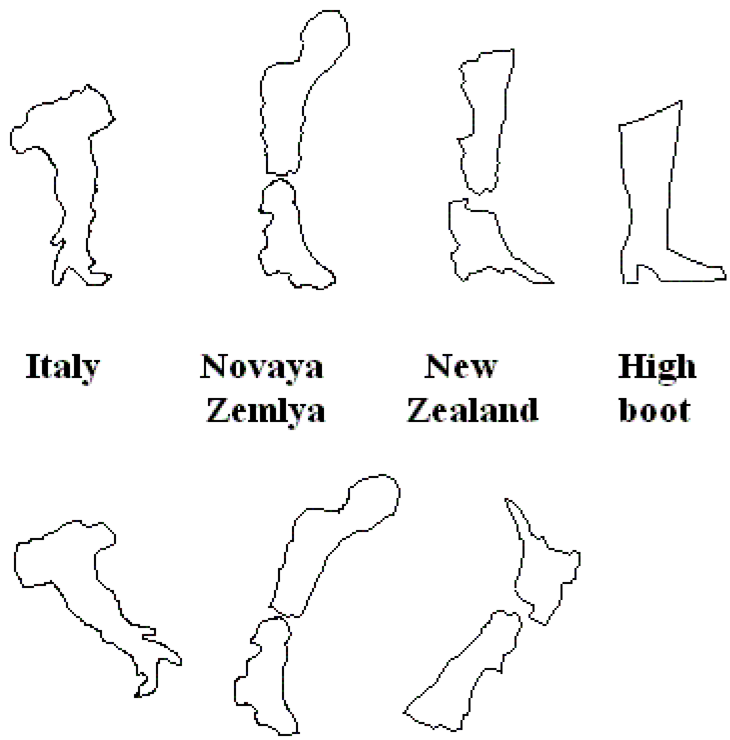

Figure 3.1. Contours of Italy, New Zealand, Novaya Zemlya, and a high boot. The bottom pictures show the contours as they look on the map.

There is a science of everything, one might say, and it is mathematics which is not intimidated with the abyss between matter and mind.

The great mathematician Henry Poincaré wrote: "Mathematics is a way to name many things with one name" (Poincare, 1946).

From the point of view of mathematics, there is no difference between two shoes, two countries, two apples, and two ideas—they all are just two. Moreover, a combination of an apple and a country is the same as a combination of an idea and a shoe—just two objects. Moreover, an apple and an idea are both just single objects, as single as an atom or a paper clip.

Of course, mathematics does this trick because it strips objects of all their sensual flesh, but it can always stop half-way. There could be a point of view from which there is no difference between mind and matter, but in a less abstract and negative way. For example, there is a point of view from which there is no difference between Italy, New Zealand, the Russian island of Novaya Zemlya, and a high boot because they all are *boot-shaped* and not because they all are just *geometrical forms*, see **Figure 3.1**. It would be good to find a branch of mathematics that could provide a single name for molecule, animal skeleton, and village community.

The mathematics we need exists, it is called Pattern Theory, and its basic ideas underline this book. Pattern theory is somewhat younger than the new metaphysics and their ways have not yet crossed.

The new metaphysics is being explored mostly by physicists and, to a lesser extent, by biologists. Both sciences developed some universal principles that can be applied well outside their own borders and are general enough to fit Everything. Strangely enough, chemists have been mute in this process of exploration of intellectual space, although chemistry is the largest separate body of scientific knowledge.

This book is a chemist's view of Everything.

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4. THEORIES OF EVERYTHING

Before taking stand as a chemist, I would like to give a very casual and selective overview of some recent and not so recent books which outline the area of new metaphysics dealing with Everything.

While this old-new area of human thought is still fresh, the best way to learn about it is to read the original works. They contain minimum mathematical formulas, are addressed to wide educated audience, and adorned with elements of humor, poetry, art, and entertainment. They bear a strong imprint of the personality of the author, usually, an outstanding scientist. It is a new kind of literature, where science is spiced with philosophy, memoirs, wit, and fiction. It is not exactly what is meant by popular science that explains the developments in primary science—there is no other primary science for the science of Everything. I would compare this new genre with travelers' stories about their real or imaginary journeys through exotic countries—*Gulliver's Travels* by Jonathan Swift, or Marco Polo's account.

It was the physicist Erwin Schrödinger who gave a powerful impetus to the modern study of life, as well as a sample of the new brand of literature, in his *What is Life from the Point of View of a Physicist* (Schrödinger, 1992), first published in 1944.

Schrödinger was a founder of modern metaphysics in the sense that he had attempted a unified approach to matter, life, and mind. He introduced a somewhat oxymoronic idea of quasi-periodic crystal (sounds like disordered order) as an image of specific properties of life. He explained the ability of life to maintain its complex order by feeding on "negative entropy", i.e. on the order of nutrients, which were decomposed to much less ordered products of metabolism, while their order was retained by the living system.

Schrödinger's view of mind is not as clear as his vision of life. He imagined mind as an independent realm from which ideas come and where they go after the death of the material substrate. He was most of all interested in consciousness and he was the first to focus on the unique importance of novelty for the phenomenon of mind. He displayed a gossamer of ideas so delicately novel and fragile that they could hardly survive interpretation. Here are some examples:

"The fact is only this, that new situations and the new responses they prompt are kept in the light of consciousness; old and well practiced ones are no longer so."

"In brief: consciousness is a phenomenon in the zone of evolution. This world lights up to itself only inasmuch as it develops, procreates new forms."

In now almost forgotten works by Norbert Wiener—my most captivating reading in the late 50's, when his *Cybernetics* (Wiener, 1961) was allowed to be published in communist Russia—a vital parallel was established between the minds of humans and computers and their relation to machines and animals. It was an idea as revolutionary as Darwinism, and potentially as controversial. The promise to build computers which would match and exceed all human abilities has not been delivered, however, but, as a solace, the danger of computers has not yet manifested itself as clearly as that of cholesterol.

An exemplary reference of a more systematic literature is *Mind from Matter?* by Max Delbrück (1986), a scientist with homes in physics, biology, and sociology.

The posthumously edited course of lectures by Max Delbrück comprises topics from evolution of cosmos and origin of life to evolution of language. He considers the development of science as a continuation of the evolution of mind. Currently, mind, which appeared as just another adaptation to environment, takes up the problem of understanding itself.

The major problem posed by the author is whether a theory of universe could explain the transition from the world without life and mind to the world as we know it.

Delbrück starts with evolution of the Cosmos and runs through evolution of life, species, man, brain, vision, perception, and cognition. Then he discusses such achievements of cognition as ideas of causality, time, space, numbers, and infinity. Here a bumpy road starts where mind cannot rely on common sense anymore: logical paradoxes, problems of decidability, relativity, and quantum mechanics.

Delbrück's book is a concise course of modern philosophy of nature, as well as a bird's view of science as a whole. It sets up a pattern for almost all other books on the subject. They are, first of all, brief histories of Everything we see around us, compiled from the sources provided by particular sciences. Some authors just throw Everything in the reader's face and walk away, while others invite the reader for a refreshing journey along selected routes.

Delbrück's history of Everything is, actually, a manifesto about a double existence of the world—once as matter, then as its mapping in mind.

As Delbrück concludes, we do not know the answer to the title question "Mind from Matter?" but the development of modern science is certainly heading toward using less discrimination in dealing with both. There is more matter in mind and, vice versa, more mind in matter than Rene Descartes thought. This general idea of the unity of the world is a guideline of modern metaphysics.

In rich, ingenious, and ultimately original *Gödel, Escher, Bach: An Eternal Golden Braid* by Douglas R. Hofstadter (1989), where mathematics and sciences of the mind are intertwined with art, the most famous seam of human mind—Gödel's theorem—is put on the foreground.

Another book in line with Max Delbrück is *The Emperor's New Mind* by Roger Penrose (1989).

Penrose follows the same way from matter to mind as Max Delbrück. He tries to unravel the tantalizing mystery of thinking and consciousness. He believes that the way human mind works is fundamentally different from the way computer does. He presumes a random (non-algorithmic, non-rigid) component in human thinking. He believes that there is a yet unknown physics which governs the borderline between strict determinism and unpredictability. He discusses the importance of *natural selection* of algorithms in mental processes. In his sequel *Shadows of the Mind: A Search for Missing Science of Consciousness* (Penrose, 1994), he ties the mysterious component to quantum effects in certain cellular structures.

There is some similarity in Penrose's position and the expectations before the dawn of molecular biology. When Roger Penrose looks for unknown phenomena in our brain, it appears as a déjà-vu of the situation when, before the discovery of the DNA double helix, some new and unknown physical effects were thought to be responsible for the mystery of life. After molecular biology had revealed basic mechanisms of life, no place for mystery was left and no new principles of nature were discovered: life was just a very complicated chemistry.

Ilya Prigogine is one of the founders of thermodynamics of life. He showed in a series of books, among them *Order out of Chaos* (Prigogine and Stengers, 1984) and *Exploring Complexity* (Nicolis and Prigogine, 1989), how, following Schrödinger's idea, order can be maintained in a system, which, like a whale, filters out order (food) from the flow of energy (sea water with plankton) and spits out chaos (pure water and excretions). Such systems exist on the through-flow of energy, like a water mill is brought into motion by the water in a creek. The mill extracts work from the energy of the flow. Life extracts order from food or sunlight. Similarly, an ordered system maintains its order because it is supplied by energy in an ordered form, for example, in the form of light, and dissipates it in a more disordered form of heat.

Prigogine's object of study was **dynamical system**—a large collection of mostly similar objects that interact with each other. It means that the behavior of a single object (element of the system) depends on the behavior of those objects with which it interacts. In such systems close initial conditions lead to diverging final conditions. Prigogine pointed out that this was the way our human history evolved. Complex phenomena can be predictably unpredictable.

As Prigogine and many others showed, the behavior of dynamical systems is chaotic only to a certain extent. At some critical conditions the system starts behaving in a more or less coherent way, and there are some possibilities to predict either its global parameters or some other characteristics.

The science of complexity started by Prigogine continues to evolve, grow, and diverge, with more emphasis on direct computer simulation instead of calculations. This area became known as the science of chaos, with many popular books written about it, one of them *Chaos: Making a New Science* by James Gleick (1987).

One of the latest books on the problem of order and chaos are *The Origins of Order* by Stuart A. Kauffman (1993). This rich book requires a certain background from the reader, but there are popular books on the subject (Kaufmann, 1995, Lewin, 1992; Pagels,1988; Waldrop, 1992).

Science of complexity today is a mathematical study and computer simulation of systems that consist of many different interacting sub-systems. Such systems are more structured than classical dynamical systems. Society, ecosystems, economics, developing fetus, brain, etc. are examples.

The local behavior of a component of the system is relatively simple, although not necessarily predictable. It is the large number of components that makes the global behavior hardly predictable. The solution used in science of complexity is to duplicate the real system with its model in a computer and to experiment with it.

It turns out that, when the behavior of components and external parameters are varied, such complex systems behave between a complete chaos and a completely predictable order. More significant and practically important situations, however, fall between those two extremes. The behavior of complex systems reminds **phase transitions**, for example, when frozen water melts, boils, and turns into steam. The system goes stepwise through states of different regularity.

The River That Flows Uphill. A Journey from the Big Bang to the Big Brain, by William H. Calvin (1986) complements the pre-existed literature in many ways. This fresh and sparkling book, as well as Calvin's other book, *The Cerebral Symphony* (Calvin, 1989), does not contain any pessimistic warning or pointing to a paradox. Full of faith in our ability to understand anything, it is a real feast of ideas about time, genesis, and mortality, in all their aspects.

Calvin is focused on the problem of mind, which lies exactly within his neurophysiological expertise, but reaches as far as geology and history. The key to the mystery of mind, in his opinion, is random variations and selection which are common to all processes of life, intelligence , and society. Everything emerges accidentally, in many copies undergoing selection and multiplication. The starting point of evolution is, therefore, chaos, chance, and large numbers. Same principles extend over mind, although we do not yet know the detailed mechanisms of "the random road to reason". This direction of thought considers the process of copy-making as fundamental for the design of the world as the free fall of a released rock.

The idea that all stages of evolution starting with life were, actually, one process—the process of replication and selection—was expressed by Richard Dawkins in *The Selfish*

Gene (Dawkins, 1989). He views all processes of life in a larger sense as replication and selection of blocks of information which he called memes—paraphrased genes. A basis for meta-biology was thus created. From this point of view, which I share, life is a much wider phenomenon that biological life, and it is not necessarily tied to polynucleotides and proteins.

Manfred Eigen developed a captivating picture of pre-life evolution of molecules (Eigen, 1979) in his *The Hypercycle. A Principle of Natural Self-Organization*. His theory is very general and not limited by chemistry. Eigen showed how self-reproducing molecules—not organisms—can struggle for existence, survive, die, and evolve. His "molecules" can be any objects that follow certain rules of behavior, and their internal structure is not essential. Eigen's most popular book *Laws of the Game* (Eigen and Winkler, 1993), remarkably profound and written in an exceptional style, is a typical journey through Everything, including art. The book presents mathematical equations not in their analytical form—it does not contain a single formula—but in various games performed with beads and available to anybody.

Lawrence B. Slobodkin contributed a very much enjoyable book to the new science: *Simplicity and Complexity in Games of Intellect* (Slobodkin, 1992). It could be best of all described in his own words: "It is an account of an intellectual sailboat voyage or walking tour. Those modes of travel are not the quickest ways to reach a destination, but if the voyage itself is the destination, if the travelers are healthy and the weather fair, there are no better ways to enjoy the parts of the world that are invisible from an airplane or motocar." With many fresh views and illustrations of the problem, he emphasizes game as a universal pattern of intellectual activity.

John L. Casti in *Complexification. Explaining a Paradoxical World Through the Science of Surprise* invites into a dizzying panopticum of facts, ideas, and references from the islands of the Everything Archipelago as different as Greenland and Madagascar (Casti, 1994).

John H. Holland in *Hidden Order. How Adaptation Builds Complexity* displays not only an array of extraordinary ideas about the development of complexity as result of simple rules but the very spirit of modern metaphysics as science of Everything (Holland, 1995).

The Theories of Everything. The Quest for Ultimate Explanation by John Barrow (1992) is, probably, the most critical review of the search for a universal foundation of knowledge.

With profound and sober realism author explores the borderlines of the known, where new yet unknown and missing pieces of knowledge could be found to fill up the jigsaw puzzle. One such missing piece, according to the author, is the basic principles of the development of complexity. Yet another such exploration suggests that there are properties of Nature which cannot be described in the traditional physical way.

John D. Barrow uses the criterium of algorithmic compressibility as the fundamental criterium of theoretical tractability. He points to the difference between *computable* properties, which can be calculated according to the laws of Nature, and *listable* properties, which can be just taken as they are. The description of such listable objects cannot be compressed. The only way is the full description. For example, the motion of a thrown stone is an infinite sequence of positions at certain moments of time. It can be compressed into a simple physical formula. Moreover, the same formula would describe a motion of any thrown object. Of course, the formula would miss some details of the motion which are not essential if we need just a good but not perfect approximation.

On the contrary, the information in a driver's license is strictly individual and a stack of driver's licenses cannot be compressed into any kind of a formula without the loss of the most essential content. For statistics, however, the name and address do not matter at all, and a formula of age distribution among drivers would substitute for a stack of drivers licenses.

Let us take a note of the difference between computable and listable objects. As I believe, pattern theory developed by Ulf Grenander is a way to compress listable objects and make them computable (Grenander, 1976, 1978, 1981, 1993, 1995).

Quoting John D. Barrow, "Of course, we must be circumspect in our use of such a loaded term as "Everything." Does it really mean Everything: the works of Shakespeare, the Taj Mahal, the Mona Lisa? No, it doesn't." To pattern theory it does.

A complete review of omniscientific literature, starting with antiquity, would take a heavy volume and immediately become obsolete. The new publications keep flowing in, with *Consilience: The Unity of Knowledge* (Wilson, 1998) being a notable recent example. My selection of references is based on my subjective feeling of pleasure they gave me, my evaluation of the degree of originality, and my need to borrow some ideas for my own purpose. There are many other excellent books, but I cannot review them all. The mentioned books contain extensive bibliography covering the entire area and they could lead the reader to hundreds of other sources.

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5. A UNIVERSE IN A BOX

My approach reflects my chemical background and chemical thinking, but not in the sense everybody understands chemistry. I am not interested here in describing chemical processes, if only for mere illustration.

Matter—at least on Earth—consists of chemical compounds, life is a series of chemical transformations, and the activity of our brain is nothing but a fireworks of chemical discharges. Like mathematics is not just about numbers, chemistry is not just about chemicals. Rather I want to say that from a certain point of view, chemistry is a specific application of a more general scientific concept that can be applied also to life, mind, human societies, and many other things.

Among other sister "chemistries" one is right on hand in the form of such toys as Lego, Meccano, Erector, building bricks, and other similar games in which complex constructs can be built from a set of parts. I will call them all Lego for short because this term has already become as generic as aspirin. Lego, which is about parts and their connections, is my alternative chemistry.

As a child I used to spend hours with my first Meccano set. I made a couple of simple things according to the manual but quickly lost any interest in pre-designed structures and could not force myself to follow the manual. It made no sense to me to build something that had been built before. Still, what I built was always inspired by the world around. I made a loom weaving real fabric and a lathe turning a wax ingot, although I had seen them only on picture or in a movie.

Naturally, I could not build something I had not known what it was. It is impossible to know an unknown. My own model of an airplane remained an airplane and not a car, although I could combine both into a flying car. By selecting and combining parts at random I could make an infinite number of constructs without any reference to reality, but they all would be of equal value as something non-existent as opposed to the variety of existing things. Some of them could be recognized as distant relatives of existing things, like the Christian cross being an unexpected relative of airplane, and some would look like chimeras.

Apparently, everybody knows what Lego is and everybody goes through it on his own or watching his or her children. Unlike many other games it is played not by two rivals but solitarily and there is no loser. God does not need Devil to play the Lego of Everything.

While serious people leave Lego in their childhood, a chemist has the privilege of playing a kind of Lego for his or her entire life. Many chemists have Lego sets in their labs.

They build molecular models from a set of standard parts connected in a specific way, see **Figure 5.1**. They can also play to self-oblivion with an electronic Lego on a computer display or do what chemical geniuses of the past did—work with paper and pen. Most recently, chemists found a way to manipulate real molecules one by one.

Figure 5.1. Molecular models of shape (A) and bonding (B).
Source: www.indigo.com

All construction toys include a set of pieces—building blocks—that can be joined by pegs and holes, bolts and nuts, press-buttons, snap-joints, sticks, etc.

Theoretically we can imagine a construction game consisting of sticky balls of different size which can join each other in various combinations, like fish eggs. Furthermore, we can have a Lego made of pieces of soft modeling clay of totally arbitrary and changeable shape, connected in infinite number of ways. We can build anything from pieces of modeling clay by pressing them together—and this is how sculptors work. Art is, probably, the most unrestricted and uninhibited construction game.

Unlike pieces of modeling clay, atoms resist deformation and can be connected only in a limited number of ways. There are a surprisingly large number of strict limitations imposed by nature on their connectivity and shape and this is what makes them so similar to common building bricks made of stiff plastic.

The game of Lego is a good model to illustrate some of the basic structural concepts. Let us take a closer look at the hardware of children's play. If the connections are of the peg-and-hole type, any two rigid pieces have a limited number of possible connections. If the connections use bolts and nuts, as in Meccano, the parts can be combined at different angles.

Although there are many permitted ways of connection and the number of combinations is immense, still more connections are prohibited and even larger number of imaginable combinations is in fact impossible. There is quite a lot of pre-existing order in Lego.

The Lego game is a sequence of two repeating steps, following in a certain order, like a string of 1 and 0 or A and B.

Step A. The child takes two pieces in both hands and joins them.

Step B. Using both hands, it takes apart connected pieces.

Suppose, the child becomes invisible, or quasi-invisible, like in the Japanese Bunraku theater where actors in black robes pretend being invisible when they manipulate large dolls, or, as in Kabuki theater, unroll a blue floor cover symbolizing the sea water.

Then we would see that, by way of trial and error, a certain set of parts is *self*-assembling, for example, into a castle. It all starts with a single initial piece or two joined pieces and becomes a more and more complex object. Suddenly, as if hit by a mysterious catastrophe, it falls apart and gradually a car appears. We can see the process in every detail, can videotape it, but if we did not know that there was a player, we would classify the process of assembly either as a miracle of creation or as self-assembly according to unknown laws of nature.

Looking at the child playing Lego, we can ask series of childish questions:

1. Who assembled the creator of the structures? (And who assembled the assembler of the creator?)
2. How did the first manual appear? (And how did civilization start?)
3. What is imagination? (Why are there pictures in ancient caves?)
4. What is assembly? (How was the first ax invented if there was nothing like it before?)
5. What is a castle? (A descendant of the cave?)
6. Can a computer play Lego on its own? (Is there anything in the world that acts on its own?)
7. It all looks complicated. What is complexity?

This is the curse of being curious: we have retrieved a whole bunch of grave problems, some of them smelling of the mold and dust of centuries.

It looks like Lego is related to some most fundamental problems of science (fortunately of no practical importance).

When a Lego house breaks apart under invisible hands, it is something that can be associated with inanimate matter. We can see degradation, erosion, and wear all around us. It is only the process of assembly in Lego that looks like miracle. There is a certain inequality—or asymmetry—between the two aspects of evolution: creative and destructive ones.

Something always happens in the world inside and outside us. If Everything is a Lego, there should be a child out there.

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6. CHAOS AND ORDER

Chaos and **order** are among the first words the student of Everything has to learn.

As it is always the case with most important things, we cannot define chaos and order without falling into a vicious logical circle: chaos is absence of order and order is absence of chaos. We will try to understand what chaos is by playing with it, turning around, taking apart, talking about it, and trying it on tooth.

Let us start with the vague statement that chaos means **unlimited** possibilities and order is **limitations** and restrictions.

We have a chaotic system when every state of the system is possible, moreover, equally probable. Order is when something is impossible or less probable. Order is a hindrance. Most of the Ten Commandments are prohibitions. The law always punishes in the name of order.

We can express order in a positive way by saying that certain states are more probable, but because the total of all probabilities is always constant (normalized, as the mathematicians say), other states are automatically suppressed.

To express order in a positive way, we need a detailed knowledge about the behavior of the system. The knowledge about what is impossible sets imagination free to look for the possible. The preference of either way is subjective: my preference of negative commandments ("thou shalt not...") makes me feel free. When I am told what to do, I feel instinctive resistance.

Anyway, for many complex systems with many degrees of freedom it is easier to say what is impossible than to list everything possible. This is the major asymmetry of Everything.

We will try to understand Everything by playing with Lego, a system with enormous freedom. Of course, we cannot list its states. We can start with a few simple combinations, but it is obvious that even a limited number of parts can be joined in a great multitude of ways, which is exactly the beauty (and the mathematical terror) of it.

The states in a game like tic-tac-toe are much easier to list because they are well defined: there are only three blocks, EMPTY, 0 and X, and they can be in strictly defined positions on nine fields.

Suppose any of the three parts can appear on any field with equal chances. In this case we could say that the system is completely chaotic. The real game, however, exhibits a significant order: the number of zeros and Xs cannot differ more than in one, the total number of zeros and Xs can only grow, and there are many impossible situations when skilled players compete.

The game of chess is incomparably more complex. Nevertheless, we can neither make two moves in a row, nor move a knight like we move a bishop, nor do many other things. One could say that the right of the pawn to be promoted to any piece on the last rank is by no means a restriction, but think about how many other figures are denied that privilege.

The order in the form of rules means that some states (or sequences of states) are less probable than others, whether it is expressed in negative or positive form. We can move from the strict order to chaos by relaxing order, lifting the prohibitions, and omitting restrictions. Let us try to do that with the game of chess.

In our pursuit of freedom, let us make all pieces equal, not specify their moves, and not make any difference between black and white fields. One can put any piece on any field and take off any piece. One field can house as many pieces as you wish. The quartet of two royal couples can have a friendly chat in one corner field, for example.

Of course, the game loses any sense. Freedom is wonderful, but not in the form of a real mess. But it can be even messier: let us allow any partner to make more than one move in a row.

There is still a lot of order in such a system. The number of fields is limited, and so is the number and types of the pieces. We can lift those limitations too and have as many pieces as the board can hold—more chaos!—but there is another road to more chaos: how many moves can be done in a second?

We just cannot imagine how far the chaos can go. We come to a picture which has no analogy in the real world, where the infinitely chaotic chaos never exists. We can really appreciate the divine order of this world where even clouds and waves can take only a prescribed variety of shapes. Does pure chaos really exist?

If we recall the Lego made of modeling clay, we can expand even that ultimate freedom. Imagine that clay can disappear, pop up out of nowhere, swell, and collapse at any place and any time. Is anything more chaotic than that? Of course! Let us allow the transformation of clay into any other chemical substance and mixture. This is what a game without rules means, but somebody can probably expand even that chaos.

Reason is useless in systems with complete chaos and complete order. Only a blend of both is the substrate for human mind.

Note that all fantastic properties of the super-chaotic system are derived from our knowledge about what is possible in nature. We know, for example, that matter can have different chemical composition or that solid bodies retain their shape. We cannot imagine, however, what we cannot imagine because we do not know anything about it. We come to the ultimate super-chaos when we cannot quote a single prohibition.

The above speculations on chaos are nothing but a mental play, a Lego of imagination. There is no such thing as pure perfect chaos in nature. We can talk about chaos seriously only if we start with defining a system, which is already a severe restriction. World is always ordered chaos, but the degree of order can vary over time. This is what evolution is about. From one point of view—I share it—evolution is the build-up of complexity. From another—wide spread—it is the build-up of order. From yet another, however, order in a system can never increase on its own. Are order and complexity synonymous? This is a question we shall keep in mind.

It looks like we cannot define chaos without order and *vice versa.*

Instead of using two words—chaos and order—we can talk about *entropy*. We need this concept mostly to communicate with various sciences because everybody has been talking about entropy for over a century. Although the mathematical expression for entropy looks always the same for any system, not everybody knows mathematics. A poet, for example, is not supposed to know it at all.

In this book I will use mostly a kind of childish mathematics. We will not need any numbers but just **ZERO**, **ONE**, and **MANY**. From the point of view of mathematics, one is **ONE** but two is **MANY**. For common sense, however, two is definitely not **MANY**, we need a real **MANY**, and whether it is one hundred or two million does not matter. We will need also such concepts as **SAME, DIFFERENT, MORE, LESS, AND, OR, NO**, and very few others of the same kind. We should not be encumbered by the weight of the apparatus to fly over everything.

To explain what entropy is in a particular case, we first need to describe a system. It means that we either list all its states or give the rule of listing. There are different ways to do that and various illustrations can be found in scores of books, but they are well beyond the **ONE/MANY** math.

Here I am going to suggest a very loose interpretation that might be useful in understanding what the entropy of anything is, not just that of a particular system.

A system is a list of its states. This is not a definition, of course, but just the circular way to introduce the concepts of both system and state. We can say that a system runs through its states, and being in a certain state is the way the system exists.

If all states are equally probable to appear next moment, the system is completely chaotic. As soon as some states are less probable than others, the system exhibits some order, even more so if some are prohibited.

We distinguish between the following two categories of states: those which are practically possible and those which are on the list of theoretically possible ones but are practically less possible or even impossible. It means that all states of the system are in a sense possible, only some are forbidden, i.e., practically impossible. It makes no sense to forbid something impossible. If the states of a system fall into the categories of permitted and forbidden ones, albeit with some probabilities, the entropy of the system goes down while the degree of order goes up. The measure of the maximal possible chaos for any system is the number of its states when all of them have equal probability. The chaos of a tossed coin is minimal: just heads or tails. The chaos of a dice with six facets is more than that, but do not ask me about numbers. The **MANY** of the dice is **MORE** than the **MANY** of the coin. That's it.

Entropy is, roughly, a degree of chaos, usually described precisely, and not in a sloppy way on fingers. But my undermath of chaos and order knows only two numbers: **ONE** and **MANY**. I believe that will do. Here is what entropy without numbers means.

Suppose, we are watching a system and something about it changes. It can change either from **ONE** to **MANY**, or from **MANY** to **ONE**. If it changes from **ONE** to another **ONE**, it can be split into two previous modes, one after the other. This sounds like abracadabra, but let us consider two apparently very similar tasks (**Figure 6.1**)

1. Draw a line starting from the point.

2. Draw a line ending at the point.

While performing the first task, we can draw any line of any shape and length from the point. The number of all possible lines is infinite, but we do not need to think about it: any line would do. From **ONE** state we jump to **MANY** equally possible and equally permitted states. This is easy, and if we put the pencil on the starting point beforehand, we can draw such a line with closed eyes.

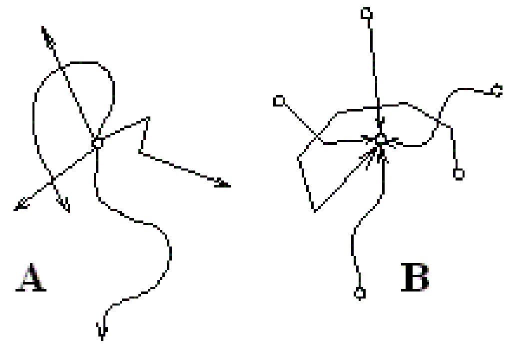

Figure 6.1. ONE to MANY (A) and MANY to ONE (B) operations.

Performing the second task, I have the same variety of choices: I can draw any line of any shape and length from any point, as long as I wish, but I have to see what I am doing. Sooner or later I will have to bring the line to the final point, as if *an invisible hand* forced me do it. From **MANY** equally possible states I have to jump to **ONE**.

There are as many lines going from one point to anywhere as from anywhere to one point. Still, in our world, there is a great and dramatic inequality between the two tasks. This asymmetry is a fundamental property of our real world because there is always a higher price for one of the two.

Here is yet another example. With a short movement, with closed eyes, in an instant, we can scatter a box of candies over the table, but we will have to spend more energy and time for putting them back into the box. We have to move each candy separately from **MANY** locations to almost **ONE** (**FEW**, in other words), while initially we had to kick each piece from almost **ONE** point to *any* of **MANY** points.

The laws of Everything—its most general physics—treat the two directions as greatly unequal.

We have to spend energy in both dispersing and picking up the candies, but this energy will be in two different forms. In one case it is a "chaotic" energy that does not care about locations and directions. It increases the chaos of the system and produces a multitude of random movements that become known only *afterwards*. In the other case, the energy produces a multitude of organized movements between two points known or designated *beforehand*.

The above examples illustrate what chaos and order are from a very general point of view.

Chaos is the maximum possibilities and no restrictions, but within the framework of the system. Thus, molecular chaos ideally means that any one among zillions of molecules in a bottle can move in any direction completely free until it collides with another molecule. The short moment of collision is the only possible event with the participation of two molecules. There is no bond of any kind between any of them.

Complete chaos is practically impossible in nature. Even gas in a bottle is restricted by the walls. Complete order is equally impossible: nothing lasts forever.

Social chaos is a complete anarchy when anybody can do whatever one can imagine. Probably, there has never been such a situation in the history of mankind because even animals have inherited or learned restrictions on their behavior. Social order, however, may change to fermenting and turmoil with the consistency of changing weather.

In accordance with our intuition, freedom is choice: if we have a situation when from **ONE** possible state we can switch to **MANY**, we move from order to chaos, for example, when the child gives his Lego castle a good kick.

If from **MANY** possible states we can switch to **ONE** (or **LESS** as **MANY**), we move from chaos to order. Example: the child looks at **MANY** scattered parts, but takes **ONE** and snaps it on the half-built house. The decision may take quite a while.

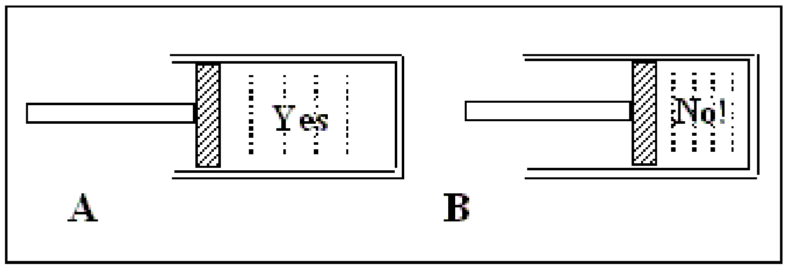

Figure 6.2. Gas in a cylinder with a piston: relaxed (A) and restricted (B) states.

Order starts with a ***DON'T***. One may ask, however, how we can control entropy? If we just say "Don't!" to the system, it will not obey.

Let us take a traditional example: a filled with gas cylinder and a piston, see **Figure 6.2**. When we move the plunger from position **A** to position **B**, all space outside the plunger becomes forbidden for the gas inside the cylinder: no molecules of gas could be found there. The more we compress the gas the more states are forbidden. We cannot make them all forbidden—that would be the ultimate order—because there is the minimal non-zero volume of a compressed gas. The entropy of the gas, therefore, decreases when we compress it. As soon as we take our hand off, the gas pushes the plunger back.

We have to perform **work** and spend **energy** in order to **forbid** the gas to occupy some theoretically available states. This is true about any system: ordering a system can be achieved only by performing **work** and spending **energy**. On the contrary, to increase entropy, we don't need to do anything, just leave the system on its own: the gas will expand, the clean room will turn into a mess, the car will fall apart, the marriage will collapse, the nation will lie in shambles. And if somebody reminds me about the Adam Smith's invisible hand in an apparently chaotic economy, I will in turn remind about the constant energy-consuming hard work on production and about the hard reliable infrastructure without which there is no economy at all.

We have just mentioned **energy**, another fundamental concept of Everything. This is one of its practical definitions: energy in the form of **work** is what we need to make order out of chaos, and energy in the form of **heat** is what we need to make chaos out of order. Well, we can make work from heat, too, but at a price.

This is what abstract energy is about. We may need energy to make **MANY** out of **ONE**, for example, when we crack a nut, and we may need it to make **ONE** out of **MANY**, when we pick up candies. We will come back to this distinction when we discuss bonds.

There is no long-term order without a supply of energy. Mind and body both need food as the source of energy. Our brain sometimes consumes twenty percent of all energy produced in our body.

Even if we have not many alternatives but just two and must make an important life decision, it is a hard work to decide, and it can take a lot of sweat.

Of course, if we pump energy into a system, it should come out somehow because of the law of conservation of energy. In fact, the incoming energy is as qualitatively different from the coming out (dissipated) one as a new car from a used one with 200,000 miles behind, although both can bring me to my job.

There is a lot of anarchy in nature, whether inanimate or animate, and order can be achieved only at a price. There is a price tag for the enforcement of any restriction, and if the evolution on earth has achieved a great order, somebody had to foot the bill. No wonder, that the greatest philanthropist—the Sun—was a respected member of the ancient Pantheon of many nations, and is still being given due honors by both respectable TV weathermen in good suits and naked ladies on the beaches.

If the American Congress looks like a mess and a muddle and we are wondering what we are paying for with our taxes, we should remember that to bring it in order would, probably, cost much more. Order is expensive. To accomplish a certain goal in a system with just **ONE** or **FEW** outcomes is much easier than to do that when there are **MANY** possible outcomes, provided equal chances.

To summarize, entropy is a measure of the ratio between order and chaos in a system. So is temperature. The higher the temperature, the more chaos is in the system. The higher the entropy the more chaos is in the system. What is the difference, then?

Temperature and entropy are closely related. While entropy rules the world politics, temperature associates with such prose as the kitchen, hot iron, bath tube, and car engine. The much talked about Queen Entropy steals all royal glamour, and temperature is just her chamber maid.

Temperature is not commonly considered such a universal concept. It seems to be something strictly physical, but in fact, it is universal, too.

Temperature is an intensity of chaos, while entropy is its relative amount. Temperature is like the price of apples, while entropy is like their weight. The cost of buying apples is weight times price.

ENERGY = ENTROPY × TEMPERATURE

COST = AMOUNT × PRICE

The expenses of producing order depend not only on the amount of order but also on the price of order. The higher the temperature, the more expensive the order is.

The temperature of Everything is not measured with a thermometer, but the same principle can be used. The household thermometer "shows" the temperature which is, actually, the impact of hits of molecules of the ambient air or water on the molecules of the thermometer.

As Schrödinger noted, "The pendulum clock is virtually at zero temperature." Nobody touches it and nobody hits it with a hammer.

A hot issue in the press is the hotter the more times it is mentioned per day.

The political temperature of a region can be measured by the frequency of conflicts there.

In a hot growing public company there is a lot of happenings, changes, innovations, and it is high in the news and on the stock market.

Temperature, therefore, is as high as the number—the **MANY**—of events in a system. The more events, the more difficult it is to predict them, the more uncertainty is there, and the harder it is to bring it under control. The streets of Los Angeles, Bosnia, Somalia—those are some recent examples of the developments of the 90's, so hot that they were at times impossible to control.

The problem is that it is not easy to measure thermodynamic parameters outside physical systems. It is always possible, however, to notice a small change, and if most changes go in one direction, it is easy to say that the system warms up or, on the contrary, cools down.

Temperature is a relative value. We can easily compare two football games and determine which is hotter, but looking at a single object we cannot decide anything. A scale can be built, therefore, by comparing several systems. Absolute zero is when nothing happens at all. Any new temperature can be placed somewhere between two known steps of the scale.

One may immediately forget my **ANY-MANY-MORE** mantras but I hope to have made an intuitive impression that temperature, energy, and entropy are universal concepts applicable not only to refrigerator, stove, or bath tube but also to computers, societies, and Everything. From this point of view, statistics is nothing but an elaborate gauge of social thermodynamics and the front page of a newspaper is the upper part of a global thermometer.

7. LEGO BIG AND SMALL

The Lego game displays an essential property of evolution: work against entropy.

The deconstruction of everything does not need a creator: an earthquake, a good jolt, or just time will do the job. A politician who promises destruction is more likely to deliver on his promise than the one who builds.

The disintegration of the structure can go on its own, but the process of building cannot. Sooner or later, the piston will come off, the cylinder will be dented, and everything will end up in rust.

Each Lego block in the process of building is chosen out of **MANY** blocks and is brought to **ONE** out of **MANY** possible points of contact with the growing structure. When the block is taken away from its **ONE** and only position, we do not care much where to put it: **MANY** places would do.

Like evolution, Lego generates the complex out of the simple. At the same time it lacks the continuity of evolution. The models of car, house, and airplane are not connected to each other, they are not stages in an evolution of a certain object, and they can be built in any sequence or not built at all.

Lego seems fragmentary: it deals with separate objects but not with Everything. Still, isn't the big world is just a very big Lego? Let us look for some relatives of Lego, and if we find a Super-Lego, there must be its Super-Child.

Example 1. Project Apollo

Project Apollo (July. 1969) was a high tech space Lego game with several pieces connected and disconnected in a certain sequence.

There were two different dockings during the mission. At a certain step of a mission to the Moon, space ship **A** undergoes a series of rearrangements (**Figure 7.1, Part I**) and separates into the complex of lunar and orbital modules **G**, and the remnants of rocket **C** and **F**. The separation of orbital module **D** from rocket **A**, re-orienting it 180^{o}, and docking with lunar module **B** remaining in the rocket before the landing occur at close range. At the end of the mission (**Figure 7.1, Part II**), lunar cabin **L** takes off, leaving platform **K** on the Moon and docks with orbital module **D**, this time approaching from a long distance. All that intricate game reminds me a series of chemical transformations which I tried to portray with a series of equations.

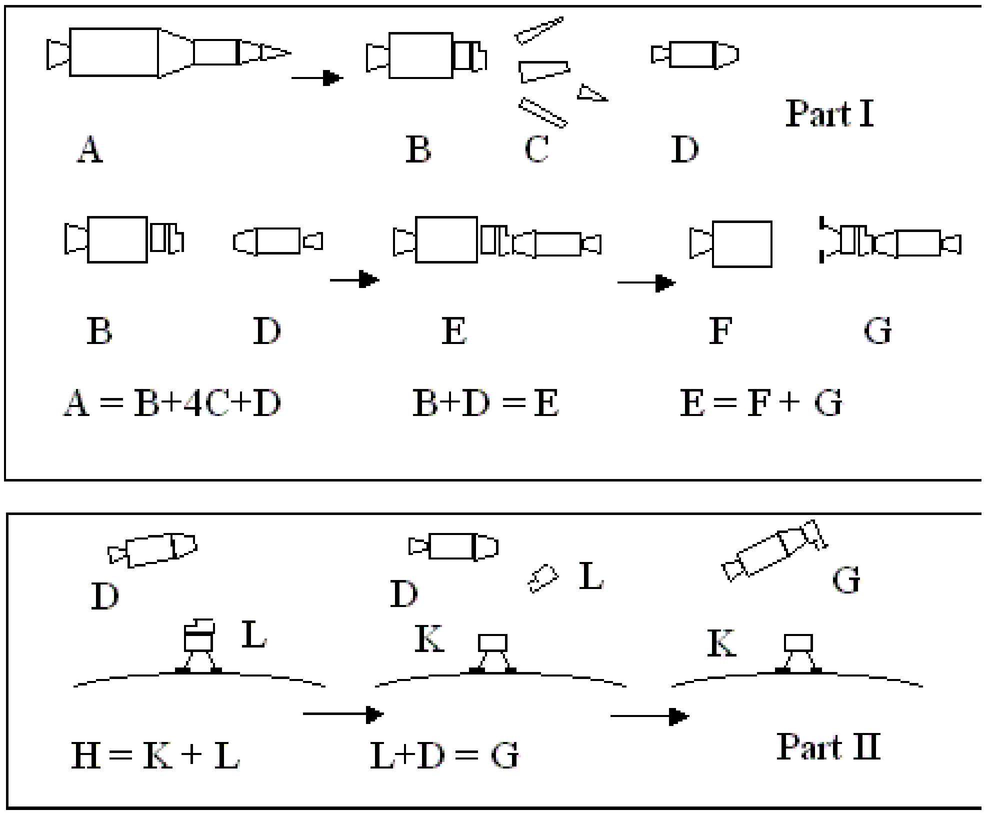

Figure 7.1. Space mission Apollo 11

When the lunar module with platform **K** lands on the Moon, a bond forms between the Moon and the module. They are held together by the force of lunar gravity and energy should be spent in order to break up that bond. This is how we commonly understand bonding in chemistry and physics: we have to spend energy in order to break the bond.

As the lunar mission is completed, the bond between the lunar module **L** and platform **K** standing on the Moon unlocks and the bond between the two modules is re-established. Both dockings require energy in the form of work. Energy alone, however, would not bring into contact the two modules separated by a great distance in empty space because it is exactly the case of **MANY** to **ONE**. There are many directions of their independent movement. As the physicists would say, they have **MANY** degrees of freedom: they can displace and rotate. Only a very narrow bundle of trajectories end with a contact. Moreover, out of that limited bundle only the contact of two parts of the docking device moving in a specific direction ends with a firm grip, which is the purpose of the entire operation. On the contrary, when the four parts of cover **C** are dropped off, it does not matter where they are going.

In practice, it looks like somebody takes the modules into invisible hands and connects them—somebody who knows the positions of both modules and can manipulate them, not without errors, though. The entire Apollo operation can be displayed in the style of the Bunraku theater.

The operation can be directed either from a control center on Earth or by two astronauts in separate modules, with their minds linked by a radio channel, so that the Super-Child would have a split personality.

Note that it is much easier to disconnect the two modules than to assemble them in space. As soon as they are separated, they can go in any direction. Much more fuel should be spent for docking than for separation.

The world of bonds shows a complexity of its own. We are used to the idea that the bond is something hard to break, for example, the chemical bond. Here we see a different type of bond that consumes energy for its own formation and maintenance. The **magnet** and a piece of iron attract each other. The bond between an **electromagnet** and a piece of iron belongs to a different type: energy is needed to keep the bond and as soon as the electrical current shuts off, the piece of iron falls off.

It turns out that the space venture, one of the finest accomplishments of our civilization, bears some resemblance to a popular children's game with the same mechanical nature of the bond. This time, however, pieces of the giant and exorbitantly expensive adult Lego are joined by highly educated and mature human beings manually: by pushing buttons. (Aren't all our technological games just a way to stay immature as long as possible?)

Of course, any assembly of any mechanism from solid parts has the same nature. I took space technology as illustration because we do not see there either hands pushing the parts toward each other or any clutches, pliers, tweezers, etc. The modules look completely independent, like molecules before they form a chemical bond.

Example 2. Enzyme

Our next Lego look-alike comes from the plateau of life. It resides inside either a living cell or a test tube where certain conditions are maintained and various molecules are rushing around in the frenzy of chaotic movement, on a stage tightly packed with furniture and props which themselves may, all of a sudden, change their positions.

Enzyme is a collective name for a multitude of large molecules performing very specific functions. An enzyme makes weak and labile bonds with another molecule called substrate. With a certain degree of imagination, it looks like the enzyme takes the substrate into two invisible hands, breaks it into two pieces, and releases them into its own surroundings. We do not need any chemical formulas to portray this fundamental biochemical function, see **Figure 7.2**.

Conversely, the enzyme takes the same two pieces and combines them into the wholesome molecule. The enzyme does its job with uncanny precision, works only on certain classes of substrates and ignores anything else. Enzymes perform also other more delicate functions not accompanied by radically changing the whole structure.

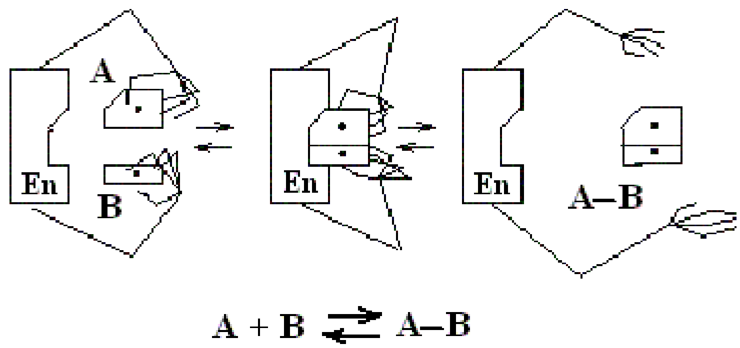

Figure 7.2. Enzyme at work.

All we need to know about molecules at this point is that they are constructs built of Lego pieces of some kind, namely, atoms.

From the mental distance of abstraction, the activity of an enzyme is very much similar to the space bonding and separation. There must have been a creative Super-Child behind all that, the one who invented this molecular machine. We cannot find, however, neither a script, nor quasi-invisible actors in black cloaks who move the molecules around. No mind is involved in the enzymatic catalysis, either.

If we had a series of similar phenomena with mind taking part only in some of them, would that help us understand the deep nature of mind?

Almost no knowledge and very limited skills are required from the child playing Lego. Enormous amount of knowledge and skills is required from astronauts. Nothing of the kind is required from the enzyme, not even life, because an isolated enzyme works in a test tube and even in a basement wash machine.

Although there are no actors, no hands, and no manual, there is a price to pay for the perfection of the natural automatism: the enzyme usually does both assembling and taking apart indiscriminately, depending on what is available as the substrate. It works in the mindless machine-like way: if the fragments are nearby, it would connect them, if the bonded molecule comes up, it would slice it.

When the child assembles the Lego parts it increases the complexity of the structure. If the child would like to play an enzyme, it would snap on and split just two parts without any attention to what is attached to them, for example, any couple of a red and a green parts. It will result not in a build-up of complexity but in a certain equilibrium between fragments of different size. If there are more fragments than constructs, the assembly will prevail because the enzyme will collide with the abundant fragments more often than with constructs. If the assembled blocks prevail, the enzyme will do the splitting on them. In equilibrium both processes have the same rate.

If the enzyme worked at an assembly line, where only the parts would be transported to it, while the assembled parts would be immediately carried away, it could build without destruction. We can also reverse such a line, so that it would work in the opposite direction, because all movements are reversible. This is what happens in the cell, which is a complex manufacturing plant with shipping and receiving. In the test tube, when the enzyme is brought into contact with multitude of parts, it will start connecting them until the assembled parts accumulate and than there will be an equilibrium between building and destruction.

If we begin to get used to far reaching leaps across the Everything, we may notice that the enzymatic reversibility has a parallel in the activity of the mind. If we are able to capture the larger picture, mind looks like the builder of ever increasing body of knowledge, like enzymes that have diligently built the entire abundance of life species. If we look through a microscope at elementary acts of mind, we can see only bonds either broken or closed, as I hope to illustrate along the line, and we will not notice the ongoing growth of knowledge. Most of the production of the individual mind immediately goes to waste, which prevents clutter. The sane mind is the forgetting mind.

All enzymes are catalysts. There are catalysts, however, which are not complex enzymes but very simple chemical compounds, for example, metals, silica, alumina, or even common clay. Still, they perform the same general function as the enzyme does and in a similar way. We will talk more about catalysis later (Chapter 40). A vast area of chemistry is dedicated to chemistry of catalysis. It is widely believed that catalysis was responsible for the origin of life on Earth. Any catalyst, however, is inherently crazy: it is able to destroy what it builds.

Example 3. The Chemist.

Let us take another example of this kind, closer to the realm of mind.

A highly skilled and intelligent chemist writes a chemical formula, then a couple more, and then he joins them together into an equation. Then he approaches his bench, takes liquid **A**, solid **B**, mixes them, and obtains the desired third compound **C** which is neither of the above starting materials. The structures of all three "real" compounds are represented on the paper. At the same time the real transformation takes place with mindless molecules. The chemist acts as a big child who combines pieces of molecular

Lego, following his imagination, working as a giant living enzyme. In a different experiment, the chemist might just follow a procedure described in a journal paper, using much less imagination, like the child who builds a model along the manual. This example involves not only mind, however, but also various man-made things such as chemicals and glassware. The next chapter will discuss a purely mental activity, with no inanimate matter involved, and, as most people believe, without any practical significance at all.

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8. CLOUDS AND ELEPHANTS

My last example of the Lego class game is poetry. I choose it because nothing seems to be farther from science, engineering, business, and even Lego than poetry. It is a long shot in the playfield of Everything. Again, let us look from a distance.

A poet picks up words swarming in his or her head and connects them in a three-dimensional object: a poem. The first dimension is the line. The words follow each other, connected by sometimes twisted rules of grammar. The second dimension is vertical: stanzas or just lines form a sequence of statements or images which follow the poet's imagination. They build up the subject matter, if any.

Usually, in good poetry, there is a third dimension—the hidden, invisible statement which we derive or decode from the written text.

Here is an example from Emily Dickinson (1959).

I took my power in my hand
And went against the world;
'Twas not so much as David had,
But I was twice as bold.

I aimed my pebble, but myself
Was all the one that fell.
Was it Goliath was too large,
Or only I too small?

In short, it is about the bitterness of failure. Most of what is said in the above poem can be stated in plain language:

I decided to do something that was
apparently very challenging.
I failed. Was it because
my task was too difficult or because
I had not enough strength?

Note that the plain language interpretation will be different with different readers. The best poetry is the one which people understand differently and argue about it.

The subject matter of the poem is something that most of us probably experienced at some time, and it is no such big deal in itself. What is the difference between the prosaic statement and a poem? Why do poets compose poetry?

Poetic language is something that we do not use in common life, even if we are poets. We do not hear it at work, in the street, in the speeches of politicians, and do not read in legal and business documents, unless poetry is deliberately included. We hear poetry in lyrics and in commercials.

Poetry is everything but everyday language, whether formal or casual. It is a separate form of speech, not for the purpose of communication. It is saturated with links to what is not explicitly said in the text itself, but left out. To use the vocabulary of the Web, it is written in hypertext.

The function of the common language used for description and communication is to accurately represent (or misrepresent) certain facts, questions, or directives. Poetry is a play, a game for one, like Lego, which creates a world of its own, having a limited similarity to the real world where the common language is used, but rooted in it, bonded to different areas of reality, author's personal unique experience, and even the reader's experience, not known to the author, of course.

Poetry raises more questions than it answers.

"I took my power in my hand..." Had the author been dominated by somebody before that? Was her power in somebody else's hand?

"And went against the world..." Not really against the whole world? What was that the author wanted to challenge? David was bold enough to fight Goliath. It is an obvious hyperbole to be twice as bold.

"The pebble" does not mean really a small stone. It is a metaphor, used only because the image of David had been already introduced and the poem displays against the Biblical episode. The pebble, not a big stone is something a woman can throw. Or the pebble means a small, timid act of defiance?

The author fell, although not literally, of course, but what happened to the stone? Did it ever fell on the ground? The author says that only she did, nobody and nothing else. The final question does not make sense: if one object is too big in comparison with another, then the other one is too small.

Why did not the author simply tell what happened? What was the challenge and how she failed, and if she did, so what?

The world of poetry and art in general has many more degrees of freedom than the real world. It is the world without Criminal Law. In the real world elephants stay in no direct contact with clouds, other than through intricate meteorological influence. In poetry they can meet in the same line (Emily Dickinson):

On this long storm the rainbow rose,
On this late morn the sun;
The clouds, like listless elephants,
Horizons straddled down.

Art is defenseless against mockery but has the power of time on its side. It is easy but useless to criticize a poet for inconsistency, contradictions, violations of the laws of nature and logic, standards of language, obscurity, extravagance, and bias. We can criticize a poet for banality, smooth blandness, photographic vision, being like everybody else, and having any quality a good secretary possesses. I have seen published poetry in the style of my own "I decided to do something that was…" which is a dime a dozen.

There is a fourth dimension in poetry that connects separate poems written at different time and at different circumstances into the whole life work of a particular poet.

For example, there is a link between the first poem about a failure (non-success) and the following two about success (non-failure):

This is an early poem by Emily Dickinson:

Success is counted sweetest
By those who ne'er succeed.
To comprehend a nectar
Requires sorest need.

This is a later one:

A face devoid of love and grace,
A bareful, hard, successful face,
A face with which a stone
Would feel as thoroughly at ease
As were they old acquaintances,—
First time together thrown.

We can compose a book from poems about success and failure written by poets of different nations at different times.

William Butler Yeats put the subject matter of his short poem in its title *To a Friend whose Work Has Come to Nothing* (Yeats, 1956):

Now all the truth is out,
Be secret and take defeat
From any brazen throat,
For how can you compete,

Being honor bred, with one
Who, were it proves he lies
Were neither shamed in his own
Nor in his neighbors' eyes?

The Russian poet Boris Pasternak, better known in America as the author of *Doctor Zhivago*, put a related idea in just two casually inserted lines:

But you must not yourself
tell failure from victory.

The fifth dimension of poetry is its links with human culture in general. Here is an excerpt from Adrienne Rich, a modern poet (Rich, 1983). This is a true example of poetic hypertext.

Two handsome women, gripped in argument,
each proud, acute, subtle, I hear scream
across cut glass and majolica
like Furies cornered from their pray:
The argument *ad feminam*, all the old knives
that have rusted in my back, I drive in yours,
ma semblable, ma soeur!

Furies are goddesses of vengeance in Greek mythology. *Ad feminam* , *to woman* in Latin, is a paraphrase of logical term *ad hominem*, *to man* which means to appeal not to reason but to emotions and prejudices. *Ma semblable, ma soeur* means "my likeness, my sister" in French and is a transformation (paraphrase) of "Hypocrite lecteur!—mon semblable—mon frère!" which is the end of the poem *To the Reader* by the great French poet Charles Baudelaire and means "Hypocritical reader, my likeness, my brother." What a maze of bonds and allusions spreading through time and space and compressed in a few lines! But even if you do not know all that, you still can understand what the quotation is about. Like human brain, poetry can lose big chunks without losing its wits. Sometimes, however, poets just show off.

Poetry is not an easy work (**Figure 8.1**). It takes energy, time, failure, and despair. Even a productive poet writes a limited volume of poetry during his life. Emily Dickinson wrote 1,775 poems, but many of them were only short fragments. Others were real line-manufacturing facilities.

Writing poetry is like walking a tight rope. As with any creativity, the chaotic world of the poetical Lego is ordered by harsh constraints that the poet creates for himself, partly following traditions, partly defying them. In addition, the energy of the poet is spent on trying—like in science—to stay away from what anybody else can say, not to repeat what any other poet said before, and keep a delicate balance between reality and arbitrary combinatorics. In rhymed poetry the energy and time are spent also on the masochistic search for the combination of words that would satisfy many contradictory requirements.

The pronouns *I* and *you* in poetry are, actually, the x and y of mathematics. Like mathematics, poetry invents its own world, but keeps an eye on the real one. The elitist aura of both is a sign of being out of this world. Unlike mathematics, however, poetry means more than it tells. It insists on naming a single thing by many names (cloud = elephant, feather, stone, blob) and it builds abundant bonds between objects having no connection in everyday life. The bonds are not totally arbitrary. This is why, although this is not its primary function, poetry is also a way to understand this world.

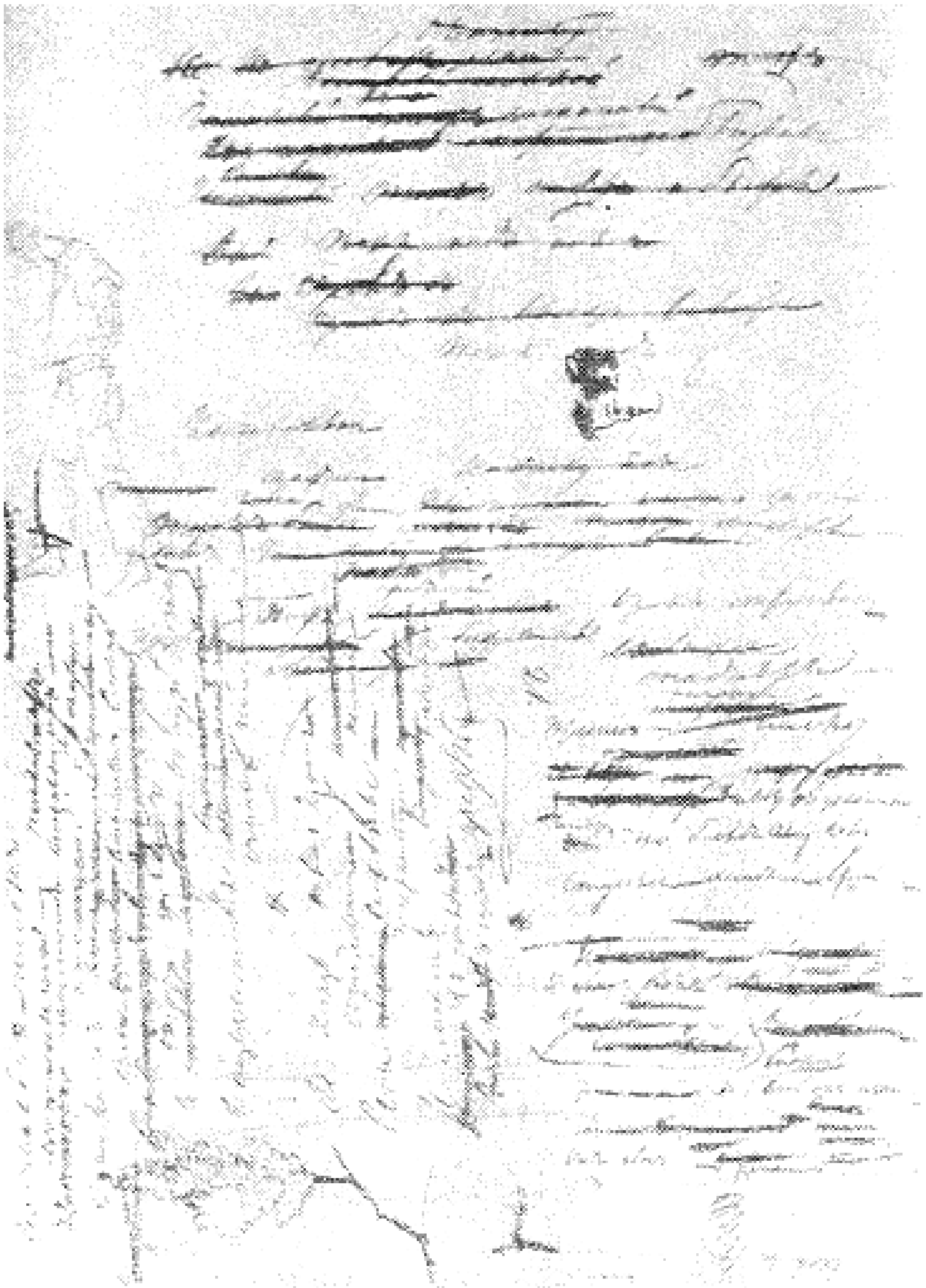

Figure 8.1. **A manuscript page of Alexander Pushkin, a great Russian poet.**

Well, *mon lecteur, mon frère (soeur)*, all I wanted to say was that poetry and mathematics with some imagination could be two good neighbors of Everything, made of the same bones if not flesh.

9. SELECTION

Competition is commonly understood as a basic attribute of life, at least in Western societies. Struggle for existence, competition, survival of the fittest, and selection are also associated with biology, economics, social psychology, and sports.

Nobody has ever observed the origin of a species on Earth and Darwinism is still a ground with volcanic activity underneath. Competition, however, is something we can watch in every detail at least every weekend on TV sports programs, as well as in stock market performance throughout the weekdays. We take part in many forms of competition during our lives, either unwillingly or with a passionate involvement, from competing for the heart of a date to career promotion.

Competition results in **selection**. I have already mentioned competition and selection many times on previous pages, assuming that everybody had some idea about it, inspired whether by Charles Darwin or sports. Competition in its noble form was practiced in Ancient Greece at Olympic games, but in the Roman Coliseum it was, literally, the physical survival of the fittest. Throughout history the social competition has been shifting from the Greek type in good times toward the Roman type in places ravaged by war and unrest, and *vice versa*.

Whether the competition in society should be mitigated or unrestrained is a major test point of social and economical doctrines.

In sports, business, and politics, all the runners have an abstract chance to win. Normally, in the Greek mode, they all reach the finish line, be it the end of a financial year, or end of elections, or the end of the game. In the Roman mode, the loser is physically destroyed.

As I believe competition is pertinent to the basic secrets of Everything. **MANY** attendants come to the Oscar ceremony about the same time and all leave a few hours later. Only **ONE**, however, is *selected* as the winner in its category. As soon as we have **MANY** and **ONE**, we have a mathematical object of a great generality and can talk about entropy, work, temperature, etc.

In terms of our under-mathematics without numbers, competition results in selection, which is a transition from **MANY** (or **MORE**) **competing** to **ONE** (or **LESS**) **selected** objects. It is the same situation as with drawing a line toward a certain point. All arrival sequences of the runners are possible. For three runners numbered 1, 2, and 3 there are six outcomes (1-2-3, 1-3-2, 2-1-3, 2-1-3, 3-1-2, 3-2-1), for five there are 120, if we exclude ties. Only one outcome, however, realizes in the run and the initial uncertainty of **MANY** sequences before the run ends with **ONE** actual sequence. From some extraterrestrial view it might seem that **MANY** runners generate and push forward **ONE** winner, as if the absolute majority of them desired not to be the first.

Drawing a number in a lottery machine is observable in every detail: only one ball of, say, fifty wins the competition and is selected, and thus the final winning sequence of five numbers appears, having left behind millions of other competitors.

Looking for an example as far off the mainstream as possible I prefer (*select)* poetry as an example of competition of many words, phrases, and variants for existence as a poem.

There are an enormous number of possibilities to write a short poem about success and failure. A poem starts with a seed in the form of an image, couple words, or a flashy line, like a Lego structure starts with two initial blocks. The rest should be built around the modest beginning. It is similar to building a Lego airplane: the real airplane is huge and complex, consisting of many thousands of parts, but we have only about fifty blocks to build something that will be recognized as an airplane. There could be a whirlwind of emotions and a snowstorm of words in the mind of the author, but only about one hundred blocks will be selected for a short poem.

Poetry is compression. We could write a whole book about what stands behind the two lines by Boris Pasternak from the previous chapter, all the more that the two lines are ambiguous and ask for explanation. It could be understood, for example, that only time can tell if a poet or anybody else has succeeded, as it was the case with many poets, artists, inventors, etc. It might mean that there is a victory in every defeat, because if you challenge a Goliath, you have to defeat your own fear, and to defeat yourself, an ancient Buddhist book says, is more difficult than to defeat an army of ten thousand men (Dhammapada, 1967).

The above paragraph shows in what way we can write a book about two lines of Boris Pasternak. We would spread a cobweb of links between what is said in two lines and some other objects, then the links between the newly included objects, then the links between the included objects and totally new objects. We would draw lines from objects to objects, group some objects into individual abstract ideas and operate with them as with single objects of the same level of abstraction, etc. We will talk about Russia and America, Roosevelt and Stalin, antiquity and modernism, love and hate, and what not. Intricate, boundless, and subjective patterns of this kind are called semantic networks and we will have an opportunity to take a closer look at them. Meanwhile, I would mention hypertext and the entire content of the World Wide Web as an alternative realization of the same principle of combinatorial rambling.

Even if we focus on a relatively narrow subject, we can still build a tree-like pattern of divergent and ever-growing clusters of ideas and connections between them. This is how the literature written about William Shakespeare—work of many generations—dramatically exceeds the volume of the original works of its object of study. It keeps growing because life brings new ideas, things, interpretations, and, of course, new writings to be reviewed, questioned, and argued about.

Yet another example, probably, most striking, is the enormous literature on the American Constitution—a never ending flow of papers generated by the flow of life.

Probably, the Talmud was built in a similar way, by taking the finite text of the first five books of the Bible as the initial set of Lego parts and playing with them and situations of contemporary life on equal basis. Then the commentaries were considered together with the canonical text as a new basic text, and commented again.

Science is built up in the same way. A scientific publication usually starts with a review of previous works in the field, and then new facts and ideas are reported and discussed. Every subsequent publication has to deal with the ever expanding base of facts and their previous interpretations. The average volume of a single publication, however, does not grow for two reasons. First, a part of the previous material is ignored: science does not have a canonical text. Second, the volume of a periodical is limited and the articles compete for the space and—more important—for the reader's attention, so that often the shortest survives.

A short poem goes into the world as it is, with no comments, no final revealing of "who done it," and it calmly takes all its possible readings and interpretations, like the Bible or the US Constitution. But if it is recognized as "an airplane," it flies. It is a combination of building blocks, like a piece of music, a paper on mathematics, a molecule, an airplane, etc., and its meaning, function, use, place in evolution, connections, allusions, borrowings, emotional strings, and the readers' own resonances stay underwater beneath the structure seen on the surface.

Of primary interest for us is the way this single published poem appears as result of its victory in the competition with many other versions which were simmering in the poet's head, consciously or subconsciously, recorded on paper and rejected. Manuscripts of some poets look like the Coliseum after the battle of gladiators, with scattered corpses and body parts, see again **Figure 8.1**.

With all the differences, a deep abstract similarity is visible, if you are in the pattern mood, between the survival of the fittest in biology, mechanisms of social and economic dynamics, creating a piece of art, car, software, and many other things. In simplest possible terms, the similarity is captured by the formula: **ONE** out of **MANY**, or, in a relaxed form, **LESS** out of **MORE**. We already know (Chapter 6) that such compression, whether in a cylinder of a foot tire pump or a poem requires work. Not only in sports to win is a really hard work, but poetry too takes a lot of sweat, and a victory in a war takes a lot of lives.

Time flies by, life is limited, day is short, and poetry itself has to compete for attention, together with other contestants definitely more relevant for the survival and success of a potential reader. Poetry and art in general are doing poorly in the struggle for their own survival because they have to compete with other subjects for the time of a young person in the formative years, and the competition with a TV or computer monitor is the hardest.

Biological competition is just one particular case covered by the big abstract umbrella, which means, whether we call it selection or competition, **MANY** invited, **FEW** chosen.

So, who wins the competition? "The best," says the successful businessman. "The best," says the sports commentator. "The best," says capitalism looking at the beaten up socialism. "The fittest," the biologist usually says. The winner is the one who wins because competition by definition means that there are winners and losers.

What we call **selection**, cruel as it is, with the macabre overtones of the Nazi concentration camps, plays an absolutely fundamental role in the evolution of Everything. Without it we would run into a problem with the Big Lego of things and thoughts.

The random combining and assembling the blocks of the Big Lego can lead to an overwhelming variety of structures. Let us take a smaller real life Lego—the Lego of language. The number of constructs is large but finite and countable. For example, the number of five-letter-long combinations of 23 English letters is 23 x 23 x ....x 23= 23^5 = 6,436,343. The absolute majority of them, however, do not exist at all as words. But all are possible as abbreviations!

The paradox of Everything is that we actually neither encounter nor generate the real Everything but only the winners in the race for existence. They are selected by different mechanisms, but the limit on winners is a phenomenon of universal importance. Unlike a beauty contest, it causes the elimination of the losers from the current pool and leads to a flux of its content, supplied by the new species.

Whether we build a toy house or write a poem, each time we join two words or blocks, we select among several alternatives. The absence of choice is a hard trial for man. The choice, however, can be even harder.

We can understand now why the poet has to spend a lot of energy to write even a short poem: he works, actually, as a bunch of athletes on a run. He runs for both the winner and the last loser, keeping the contestants on track.

In terms of Lego, competition is like one box of Lego for two or more children: only the one who snatches the parts from the box much faster than the rest has a better chance to build the house, and if not, the next attempt can be made after the house is destroyed. This is the most common kind of competition for a limited resource—space, energy, building parts, attention, etc.

Competition resulting in selection is a universal natural phenomenon that starts at the level of molecules. It is one of fundamental presumptions of chemistry, so fundamental that chemists are rarely aware of it. All theoretically possible transformations in a given starting mixture run simultaneously. In organic chemistry they could run in dozens of different realistic directions for complex compounds. All of them, however, compete for the disappearing amount of the starting components, so that in practice only a few fastest reactions provide a noticeable amount of selected products.

Selection is a universal powerful factor in introducing order into this world by restricting the growth of its complexity and preventing an unlimited expansion of Everything.

The world inside and outside us, taken as a snapshot, is the winning combination in the lottery of Everything, only some balls in the Big Lottery Machine are drawn strictly at random, some have chances biased by the laws of nature, and some balls have guts, teeth, claws, and elbows.

This is our first shot at competition. There is much more to say and we will come back to the topic.

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10. THE PANTHEON OF EVERYTHING

There are several scientific concepts not limited to any particular area of science. Really universal, they lay a foundation for understanding Everything. Chaos and order, **ONE** and **MANY**, selection, entropy, bond, energy... what else inhabits the ecumenical Olympus ?

The range from molecules to minds covers a good deal of Everything. As far as the rest of Everything is concerned, for example, the range from photons to stars and from dollar bills in wallets to stock futures, it is the subject of physics and finance, which is mostly beyond my competence. What I really need to know about the pre-history of matter and money is that during a certain stage of the development of Universe it cooled down enough for atoms and molecules to appear. Also, during the twentieth century the economies and financial systems of different nations cooled down enough to form a global system where everything is linked to everything.

Evolution of Universe did not start with atoms: the primordial matter was too hot for any atoms to exist. Atoms came to existence only at a certain stage of the evolution of the universe, after the big bang. Although it is a very intriguing question what kind of Lego had been played before atoms appeared, I am in no position to discuss the pre-molecular forms of matter. There is a lot of good books on the subject, see Penrose (1989, 1994), and Hawking (1988). As chemist, I start with atoms—a ready set of Lego pieces for building molecules.

With the fuzzy balls of atoms in my hands I can look far ahead in the direction of evolution because instead of Na and Cl I can write on them: dog, cat, muffler, wheel, Santa Claus, John Doe, and William Shakespeare. As far as the future after mind is concerned, I have as good a right to speculate as anybody else. The symbolic **atom** of Everything, therefore, takes its place in the Pantheon.

Among basic concepts, **temperature** also has a universal meaning related to the behavior of structure: when it is hot, the bonds break, when it is cold, they lock. Temperature, therefore, has its privileged place in the Pantheon of Everything.

As soon as molecules appear, the chemical stage is set, and here the magic show starts. A box of wonderful, colorful, and glittering molecules is put on stage and the public from other galaxies can watch how ***invisible*** hands of nature connect them together, separate, recombine, step by step, over millennia, and finally produce a live chemist. The chemist, at least theoretically, can come in the limelight on the central chemical stage and continue the show, working with his perfectly ***visible*** hands, looking into a mirror and working on his own cloned copy until his exact duplicate joins the original in a triumphant handshake. **Molecule**, understood as a particular arrangement of atoms, is also a universal concept.

There is a chance that to see objects in terms of building blocks and bonds between them could be a universal way to analyze and compare all components of Everything. Talking about very different things in the same language—the language of Lego—we can simplify the complexity of Everything, at the expense of its sensual opulence, of course.

As soon as we accept this universal view of things, we can see other universal aspects of the skeletal world.

Catalysis, or rather meta-catalysis, is the universal way to form a specific bond between two particular blocks, as well as terminate it. It usually works locally, i.e., over one single bond.

Selection trims the ever branching trees of choices, so that a limited number of structures can be built of a Lego set. It works globally, i.e., over whole structures.

Entropy, temperature, energy are universal indicators of the direction of events in the Lego world.

Until this point, I have already used the words "complex" and "complexity" about thirty times. **Complexity** is a mysterious characteristics of an object which has something to do with the general direction of evolution: it goes up and up and will do so until the Sun shines, literally.

We will also need the truly fundamental concept of **space**—the universal tool for compressing both countable and listable properties (see Chapter 4). When somebody says: "This is a cupboard," we understand it as a space to store cups and, occasionally, skeletons.

We can imagine its content even without looking inside, and if it is empty, we know what to put in it. But the word ***cup*** also denotes a whole space of all different cups with one or two handles, various shape, diameter to height ratio, basic color pattern, decorative element, and material, where every cup is just a point in a space, whether it exists or not.

The game of Lego does not belong to the company of respectable scientific terms. It refers to a particular case of a more general concept. We still have to find a single word for all the building blocks of Everything: the parts of the universal Big Lego, the constructs built of them, and the very process of building. Those are three other members of the Pantheon, whose names may not sound as familiar as temperature or space. Actually, two of them, **generator** and **configuration** , are simply synonyms of "atom" and "molecule" of Everything. We will call the process of building **generation**, with no relation to an age group. We will also have to deal with **patterns.** There is a pattern of Lego castle, and a pattern of Lego airplane, but there are also castle patterns with one, two, or four towers, as well as plane patterns of sports, passenger, and fighter planes. There is much more to it, as we will soon see in Chapter 12. **In short, pattern is a class of configurations defined by a transformation from one configuration to another within the class.**

We have just taken our first look at Everything. We have rambled and jumped all the way from matter to mind, from molecules to the same mind that operates molecules as well as modules of a lunar spacecraft, and saw—not in detail but in vague nebulous shadows—how molecules can assemble into a child who grows into a chemist who will later manipulate other molecules.

The problem of evolution can be formulated, therefore, as the question how the molecular Lego can turn into the enzymatic Lego inside a living cell, then into a child, playing Lego on the floor, then into a chemist combining molecules, or a poet combining words, or a team of astronauts playing Lego in space.

Suppose we have answered the above questions. The answer will look not even close to the 2-D *The Wave* by Hokusai. It will be a statement composed of words such as *building blocks of everything, energy, order, entropy, selection, bond, catalysis, temperature, complexity,* etc. It will be, therefore, a construct in yet another kind of Lego, the Lego of language.

The above chapters were an invitation and an informal introduction into playing with the Lego of Everything. In the following chapters we will take a closer look at many subjects we have mentioned above, keeping a mathematical/poetical detachment from reality, but not too far, and not too formal.

My view is just one projection of Everything—the vision of a chemist.

It is obvious that chemists are used to deal with atoms and molecules. This is true that life and neuronal activity are both based on chemistry, but there is a lot of other things in the world that are not. Is the chemist qualified for Everything?

Chemists are not supposed to deal with Everything. Nevertheless, being used to combinatorial games of Lego type, they have a very specific vision of the world, are well equipped to deal with Everything, and in my opinion can make valuable contributions to the Science of Everything as team members.

Invited or not, the chemist comes to the door of Everything, a box of Lego under his arm. A mathematician opens the door and says that the chemist is too late. Mathematics has already been at home in Everything so that the chemist can enter only as a guest.

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11. A CHEMIST'S VIEW OF MATHEMATICS

The mania of mathematicians to name many things with one name goes so far that they even name many people with one name and invent a fictional Nicolas Bourbaki as the author of a monumental treatise on mathematics written by a group of scientists.

If mathematics is the way to name many things by one name, then we all are mathematicians. While there are many different individuals known as Mr. Smith, Mrs. Johns, etc., the word "person" stands for all existing and even non-existing individuals. Person is an abstraction, and we cannot shake hands with Mr. or Mrs. person. Still, a large collection of persons has certain properties, and politicians and businessmen are well aware of that. For a white racist, Mr. and Mrs. Smith are just blacks, for a black racist, Mr. and Mrs. Johns are just whites. If we all use abstraction in everyday life, what is so specific about the way mathematics uses abstraction?

Mathematics invents abstract objects and plays with them by the rules which it also invents.

Sometimes, if there are no toys on hand, children can play make-believe games. They keep imaginary personages and situations in mind, like two chess players in a blind party. An outsider would not see anything and would not understand what they are doing. It is the agreement between the children on what is invisible that makes the game possible. They can use various objects as symbols of what they see behind them. Two fingers can walk as a witch or a princess, depending on the agreement.

Mathematics displays between the rigor of agreement and the freedom of imagination, but the rules, as soon as they are invented, are the same for everybody, like the rules of any game. It is the agreement between mathematicians about what they mean by the names of their objects that makes mathematics possible. Unlike the child, a mathematician may not need to know whether the two fingers stand for the witch or the princess and what kind of a "real" thing hides behind a concept. Most of all, there is nothing behind it. It is just something, and only its properties and the rules of dealing with it matter.

The abstract nature of mathematics should not be exaggerated. Although some mathematicians were proud that their constructs had nothing to do with reality, many noted that their creativity was inspired by physical reality, while others derived their objects directly from it. Nevertheless, mathematics can be called a singular world in the sense that, unlike physics and other sciences, it does not necessarily has another reality behind itself. It even portrays transcendent, irrational, and imaginary worlds much better than the business experts predict behavior of the stock market, which may mean, by the way, that the latter is even less rational.

The proof that mathematics has its feet firmly on the ground is that mathematicians are paid better than poets (although less than athletes).

Nothing looks farther from poetry than mathematics. Nevertheless, to me it is yet another kind of Lego. As I suspect, a mathematician in the process of his or her work may have an intuitive image converted later into a mathematical construct, so that the building blocks match this image and leave no gaps between each other.

Mathematical ideas have material representation as symbols which can be combined on paper, like chemical symbols. They are similar to atoms while formulas are molecules of a kind. On paper the mathematician takes indivisible symbols and assembles them into structures, sometimes a model of a London double-decker bus, sometimes a train, sometimes a bizarre but expressive composition with exclamation marks. Clusters of symbols can be denoted by a new single symbol. In this aspect, a page of a mathematical text looks very much like a musical score of an oratorio.

Probably, every scientist works this way, covering the image of a hypothesis with experiments, formulas, and statements, so that they do not show either gap or overlapping . A scientist provides the air-tight proof of an elephant by assembling its jigsaw picture.

Unlike a jigsaw elephant, the intuitive mathematical image may belong to some totally unknown creature, which is "proved" in the same way as the familiar elephant: its picture holds water. The mathematician *invents* by inventing both new "atoms" and new combinations of them.

The sometimes hardly imaginable mathematical objects have invisible pegs and holes, by which they stick to each other, like pieces of Lego or molecular models. For example, in a formula, the sign of addition (+) must be always connected with two numbers or variables. When we write +5 to distinguish it from -5, we actually mean 0+5. The opening parenthesis always has a rubber-band bond with the closing parenthesis, but has little restrictions on bonds with other symbols in between.

In designing new building blocks and their combinations, mathematics does not know any constraints at all. However, as soon as the pieces are created, the constraints and rigorous rules are in the center of attention.

The mathematical Lego contains a set of pieces (terms), and a set of axioms. A mathematical axiom shows which connections of pieces are allowed, for example: "a peg of one piece should be in a hole of the other" or "any two connected pieces can be used as a piece." To obtain a non-obvious construct (statement) is, probably, as much fun for a mathematician as to discover a new animal for a zoologist.

All that is very much similar to what a chemist does when he either synthesizes a new remarkable compound which never existed or finds an exciting synthetic route from one compound to another. This deep analogy comes as no wonder for a scientific monotheist, like me, who believes that there is only one Science and the borders are either artificial or historical.

A mathematician takes a set of symbols and a set of formulas and rearranges the formulas so that new formulas are produced:

$$(h + j)^2 = h^2 + 2hj + j^2$$

It looks to me very similar to a chemical equation:

$2HJ = H_2 + J_2$

While the chemical equation reflects a real molecular play in a flask, the mathematical formula may not have any relation to anything material: it is just another mental construction. When a mathematical statement appears *for the first time*, it is a frozen and forever solidified winner of *thinking,* a mysterious, intense, and fervent process in the head of scientists (and poets) who subconsciously or consciously combine mathematical symbols or images in his head and compares them with the list of all known combinations to make sure it is really new. It seems only natural to assume that mathematics is nothing but a kind of chemistry dealing with invisible atoms of ideas. The only difference is that they are mixed and cooked not in flasks but in sculls. "We are of the same blood, you and I," I would say to a regal mathematician if I was a little bit more arrogant, but I am already up to my limit of arrogance.

I would even present a circumstantial evidence.

We can characterize a chemical reaction by its rate only because an enormous number of molecules in the flask give us reliable statistics. If we had just two reacting molecules in a vessel, we could not predict when they would collide and interact. Similarly, nobody can predict when the mental reaction will produce a new theory after the components have been loaded, although we have a strong hope that sooner or later it will. The unpredictability of a scientific discovery is a striking fact which has been witnessed by any creative scientist. The classical book by Hadamard (1945) is full of illustrations.

NOTE: For the self-image of mathematics see Davis and Hersh (1982), an incredibly easy and delightful reading.

To me the fact of unpredictability of thinking means that ideas, unlike molecules in a flask, exist not in multiple copies, but in just one, so that the mental reaction of inventing has no definite reaction rate. It is more like radioactive decay, where we cannot predict when a certain atom will break up. Nevertheless, we could calculate an average "reaction rate" of human thinking over a multitude of individual cases during a lifetime. We would not be surprised to find the powerful catalytic property of coffee.

A great difference between mathematics and chemistry, however, is that atoms are physical objects. It is hard to ignore Erwin Schrödinger who believed that ideas filled up the universe as a kind of invisible matter, but we still do not have any confirmation. Suppose we take this seriously and search the universe for ideas. How do we know that we have found one? Is there any general criterion of distinction between products of mind and matter?

The difference is that we can have **MANY** identical molecules while in mathematics we always have **ONE** mathematical object of a certain kind. Matter exists in 3D-space and time, while ideas do not. Two identical ideas are one idea, like two electrons with the same four quantum numbers are one electron if they belong to the same atom.

What makes mathematics and chemistry different is that while chemistry always deals with populations of molecules, ideas of any kind, not only in mathematics, do not have copies.

Mathematics is all dreams, but there is no other dream that has so much power over the man-made world.

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12. ATOMS OF EVERYTHING

It looks plausible that the Everything of a fly, i.e., its entire world, is smaller than the Everything of a bird, which is in turn smaller than the Everything of a human. It is hard to see how we can list a really big Everything. Instead we could try to show a way to generate a very big variety of things from a basic set of building blocks. In mathematics, for example, we cannot list all integers because they are infinite, but we can show how to build them by taking one, adding one to it, and adding one to any number obtained in this way. It is the same as to say: an integer plus one is also an integer. Regarding three sets of Super-Lego constructs—molecules, toy castles, and poems—we are facing two problems. If we call all different molecules by one name "molecule," we have to show how all particular molecules (as well as toy castles and space ships) can be generated. Secondly, if we call all three groups "Super-Lego constructs," we have to show that all of them, plus much more, can fit under an umbrella of one term.

Imagine a book that deals with such topics as:

motion and behavior,
growth and decay,
statements of mathematical logic,
sentences of natural language,
human and animal skeletons,
grammars,
mathematical functions,
automata,
industrial processes,
weave patterns of fabric,
molecules,
handwritten manuscripts,
spectral data,
cockroach's legs,
human hands,
the structure of the Earth crust,
thoughts
genealogy,
plots of novels and fairy tales,
motion of planets,
kinship relations,
botanical systematics,
scientific hypotheses,
social patterns of domination,
language,
and much more.

The above list, reminiscent of Walt Whitman poems, includes such a variety of items that we really can say it deals with Everything.

No, it is not an encyclopedia, although it is as big as a big dictionary. Encyclopedias list all entries by name. For example, they catalog all American presidents and focus on what is different between, say, James Carter and Ronald Reagan. For mathematics, the presidents are $\mathbf{P_1}$, $\mathbf{P_2}$,...$\mathbf{P_n}$, where $\mathbf{P_1}$ is George Washington and $\mathbf{P_n}$ is the current president, and $\mathbf{P_{n+1}}$, $\mathbf{P_{n+2}}$, etc., are the future ones. No matter who he or she is going to be president, for mathematics he or she is as good as Abraham Lincoln and F.D.R.

During the last thirty years, an inter-scientific Esperanto fit to talk about Everything—molecules, minerals, creatures, humans, and their ideas—has been developed by Ulf Grenander, Professor of Mathematics at Brown University, Providence, Rhode Island. The above list reflects some topics of his books (Grenander, 1976, 1978, 1981, 1993, 1996). They are not an easy reading: they are tightly stuffed with elaborate mathematics and computer codes, even the popularization (Grenander, 1996). Nevertheless, they deal with cabbages and kings, clouds and elephants, and everything in the world, including our knowledge about it, on equal basis.

Pattern theory presents a general approach which could be tried on physical formulas, eating habits, political systems, kitchen utensils, architectural styles, marriage problems, and what not.

What we lose by naming George Washington $\mathbf{P_1}$ and George Bush $\mathbf{P_{41}}$ we can find in many other books, but what we gain from pattern theory—the insight into the structure of Everything—cannot be found anywhere else.

As any other fundamental idea, pattern theory has roots reaching the deepest layers of the history of human thinking, starting from Democritus and Lucretius, long before science, philosophy, and art split at the crossroads. Many theoretical nests have already been built on the branches of its tree, although without knowing that they share the same trunk.

One of the applications of pattern theory is pattern recognition and processing, which is a very exciting but specific and relatively narrow area of applied mathematics, computer science, and artificial intelligence. It deals with the ability of humans, computers, and their future progeny to interpret a picture as letter **A** or **B**, recognize a familiar face in a row of strangers, detect a tumor on an X-ray shot, to identify the place in a fog, to reconstruct the original sound of a damage recording, etc.

The ultimate target of the theory, however, is not pattern recognition, but the search for the very nature of regularity and order in Everything—the task equal to the goals of science, philosophy, and art combined. The abstract mathematical study of patterns themselves is in the focus of the theory.

Pattern theory deals also with pattern synthesis—creation of patterns basing on some rules. It provides means to list everything in the world not explicitly, as it is done in encyclopedias, but by describing rules of generation. For a chemist like myself, pattern theory is meta-chemistry—the systematic umbrella of chemistry—so that chemistry can be precisely defined as an applied pattern theory of atoms with the periodic table as the basic set. From the same point of view, sociology is the pattern theory of humans and humanoids, and biology is that of cells and organisms.

Unlike any typical formalized mathematical theory which is a goal in itself, pattern theory has live connections with the real world. "The ambition has been to stay in close touch with subject matter knowledge in order to achieve realism in the pattern models and to deal with patterns of practical significance," Grenander writes.

While the occupants of Plato's cave had no means to check their understanding of the world of shadows against the real world outside the cave, pattern theory reminds the Indonesian theater where the shadows of actors or flat dolls are cast on the screen. One can look behind the screen and compare the actors with their shadows as well as see how similar the dolls and their shadows are. Pattern theory deals not only with the transformation of an actor who plays a king into his shadow, but also the further transformation of the shadow into the image of the king in the spectator's head.

As a non-mathematician, I am interested here only in the most universal message of pattern theory, resonating in my chemical heart as the first ever scientific foundation for understanding Everything. I have to profess, however, that my interpretation of pattern theory is strictly personal, adapted to the purpose of this book, and it could be different from the true intention of Ulf Grenander and his own interpretation. I am not going to overstep the boundaries of a few initial concepts, modifying them for my needs. Some more popular works by Ulf Grenander are now available for those who would like to go in depths.

The fundamental principles of pattern theory are very simple. Like geometry, pattern theory uses non-numerical basic concepts. It is, actually, a pre-math vision of the world, if we have only high-school associations with mathematics as something based on counting. In short, its starting point is the view of the world as a Big Lego, i.e., it perceives Everything in terms of elements and bonds.

Pattern theory penetrates objects like an X-ray machine: it looks for hard skeletons of things seen as shadows, or, rather, shadows of shadows. It produces charts depicting bones and their mutual connection. The flesh of things as well as the substance of the bones, i.e., their physical parameters and other properties which can be expressed in numbers, like mass, length, temperature, wave length, etc., are ignored, but not discarded. They are kept in memory so that the relationship between a particular skeleton and the whole object could be established, if necessary.

Although pattern is neither number nor function, it is a mathematical abstraction of the same level of power. Like the number carries an important information about oranges in a bag, money in a paycheck, words in a text, etc., the pattern carries important information about the **structure** of an object, be it a sentence, manufacturing company, or molecule of drug. This information is something that cannot be expressed by quantities. Pattern is more general than number because a number is also a pattern.

Pattern theory is a consistent development of the principle of atomism. At present we understand atomism as the concept of matter built of the atoms of the elements listed in the periodic table. This concept covers the area of chemistry and many areas of physics. An expansion of the idea is to present everything in terms of building blocks, parts, elements, cells, entities, components, primitive objects, symbols, etc. An object is a **combination** of such building blocks. The rule for listing Everything is the shortest possible manual for Lego:

COMBINE THE BLOCKS

The building block of pattern theory is **generator**—an atom of Everything. It is a primitive, indivisible structural element from which **configurations** are made. Configurations are combinations of generators kept together by bonds between them. The process of building structures—configurations—from generators is what I call generation. Patterns, roughly speaking, are classes of configurations or classes of classes.

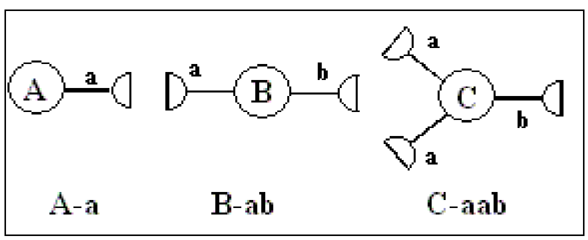
****

HIGH QUALITY GENERATORS

The package contains 12 generators, four of each type:

A-aab , **B-ab**, and **C-a**.

A generator has a body and arms. The name describes the generator in the following manner: first letter is the body type, the letters after the dash stand for its arms. For example, **A-aab** is generator **A** with two arms **a** and one arm **b**.



Any two generators of any body type can be joined through their arms if the arms are of the same type, see picture.

We have in stock a large inventory of high quality generators. Bulk discount available.

To order call **1-800-PATTERN**

****

Figure 12.1. Generators: an "advertisement."

Pattern theory does what any other theory does: takes the world apart to understand its design. Pattern theory, however, is M-blind in the sense that it does not dramatize the difference between Mind and Matter—the two domains so mercilessly cut apart by many geniuses from Descartes to Erwin Schrödinger. Both mind and matter, being presented as combinations of primitive components, shed their differences down to bare structural bones and this is why mind can understand matter: the skeletons of both are made of exactly the same stuff.

Objects—both mindless and mindful—are observed by a mindful observer who is just a part of Everything. What cannot be observed is beyond comprehension. In the process of observation some information may be lost or distorted. A series of various objects can be seen as one. The objects can be fuzzy, so that their any statement about them will hold only with some probability. Nevertheless, all those perplexities can be encompassed by the concept of generator that goes much farther than a passive block of Lego, obedient to the hands of the child. The intimate secret of Grenander's generator is that it has hands of its own.

I have to warn the reader again that I am taking liberties with the letter of pattern theory, and even with chemistry. I am going to use here the term "pattern" in a different sense than Ulf Grenander does: I will neglect the richness of the hierarchy of configuration (object of perception)—image (result of perception)—pattern (concept) explored in pattern theory.

We cannot buy a box of generators at an office supply store, but if we could, we would find a flier in one of them, **Figure 12.1**.

The pictures of generators can be misleading because one might think that all generators have certain shape and their arms stick out at certain angles. This might be true as a special case, but not in general. Generators are not geometrical figures and a generator's name or label such as **A-aab** completely describes its carrier: there is nothing more to say about it.

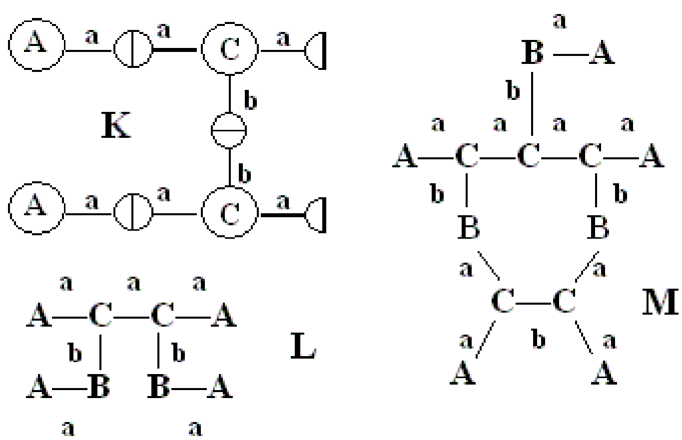


Figure 12.2. Configurations

Having that in mind, we can use a helpful visual symbolism for generators from pattern theory. Strictly speaking, the objects in **Figure12.2** are configurations, but I will use both terms interchangeably.

The little half-circles are the "palms" of the "arms." Two joined arms complete the circle and mean a bond between two generators. Each arm has its distinct label, and the "body" of a generator is labeled, too.

Generator, therefore, is not only an element (primitive object, atom, building block) but also all the bonds which it can possibly form. It is neither its body, nor its arms, but their specific combination. The arm is, so to say, only a half of a possible bond. It is a label of compatibility of a generator with other partners. It takes two compatible potential bonds contributed by two generators in order to make a regular, legitimate bond.

To form a bond, two generators contribute two half-bonds of the same kind. Generators seem to be waving their arms: "Hey, I have half-bond No.17! If anybody has the same, let us have fun together!" It is very much like a meeting place ad in a newspaper.

In **Figure 12.2L** and **M** we use a simplified way to show patterns, close to the way accepted in chemistry.

The arms can be as different as generators. Which half-bonds can stick to which is determined by the rules of connection that could be different, but we assume, for a start, the simplest case: only the arms of the same type can form a regular bond.

Real life is rarely as simple as that. We can complicate the simplest picture by introducing more variety in the design of generators and by relaxing the rigid rules of the game.

Lego pieces are connected by pegs and holes. It is impossible to connect a hole with a hole and a peg with a peg, unless through a trick. Although some parts can have only holes and others only pegs, no structure can be built if there are no pieces with both pegs and holes.

Often, although not always, real patterns have this kind of duality of half-bonds so that only bonds of opposite "sex" can be coupled. Called male-female connection in engineering, they are called in-bonds and out-bonds in pattern theory. Even in chemistry certain types of bonds can be formed between atoms with opposite charges or at least a sharp difference, so that they have a direction.

All that is still simple and there is no confusion. The ambiguity and fuzziness which is so much a property of real world—take sex as an example—can be introduced by relaxing any strict regularity of the all-or-nothing world and attributing a certain "maybe" to any "no" controlling the behavior of generators and patterns. Every rule, therefore, would hold only with a certain probability. For example, we can distinguish regular patterns from irregular and allow some degree of irregularity through unlawful connections.

A chemist would immediately recognize in generators the familiar atoms, only belonging to a different kind of periodic table. The compatibility of bonds expresses the old chemical idea of **affinity** which is applicable, by the way, to marriages and friendships as well as to molecules.

Almost two centuries ago Johann Wolfgang von Goethe, one of the greatest universalists since Aristotle and Leonardo, noticed that chemistry was not only about chemistry.

"Think of substance **A**, existing as a compound with substance **B**, unable to be sundered from **B** by force or any other means; and then think of a substance **C** related in the same way to substance **D**. Now bring the two components together: **A** will combine with **D** and **C** with **B** in such a way that it will be impossible to say which elements separated or recombined first." I take this quotation not from one of his scientific works but from his novel *Elective Affinities* (Goethe, 1988, p. 116). The letters denote the characters of the novel: **A** = Charlotte, **B** = her husband Edward, **C** = Captain, Edward's friend, and **D** = Ottilie, a young girl adopted by Edward and Charlotte. What happens in the novel can be portrayed by a meta-chemical transformation:

$$\mathbf{C + A\text{-}B + D \Rightarrow C\text{-}A + B\text{-}D}$$

This transformation is a **pattern**. One can substitute various names for the letters, obtaining **configurations**, as in algebra. In fact, pattern theory is an **algebra** of configurations and all patterns are classes of configurations preserving a particular structure.

In my eyes, pattern theory is a universal chemistry of Everything. In somebody else's eyes it is mathematics. What can be duller than mathematics and chemistry for an average citizen of the third millennium? One might ask. I would like to quote Goethe again:

"One has to see these substances, which are seemingly inanimate, but in actuality always full of potential life, interacting before one's eyes—one has to watch with some empathy as they seek each other out, attract, attack, destroy, swallow up, devour each other, finally emerging from their former close connection in a new, fresh and unexpected form. This is the point at which one attributes an eternal soul, or even common sense and intelligence to them, since our own senses hardly suffice to observe them properly and our intellect is hardly adequate to understand them."

*

13. GRAPHS

The mathematicians can award exuberant compliments to utterly abstract and totally barred from senses mental products, but the chemists rely very much on visual perception. Graph is a high level mathematical abstraction, but it can be comfortably visualized. I think graphs are the most gorgeous creatures in the mathematical beauty pageant because their graceful, slim, but firm frames appeal to both mind and eye.

Graph, however, is a mathematical concept not tied to any visual presentation. It is most effective in representing the invisible. There are scores of real and imaginary objects that could be viewed as graphs. Being a graph is, actually, a property of all structured objects, including mathematical formulas and concepts. Patterns are also graphs, with somewhat more flesh over the bones, while graphs can be considered the leanest patterns of all.

A graph consists of elements called nodes or vertices) and bonds between them called arcs or edges. The terms **points** and **lines** are also used. Graphs are usually visualized as a set of points connected with lines.

One could ask why not to talk simply about familiar points and lines? The reason is that the node, unlike a geometrical point, has no position. The nodes of a graphs are not pinned down to a sheet of paper, but are more like a collection of insects where the exact position of a bug on a pin does not really matter for its systematic classification. All we positively know about a certain node is that it is not any other node, but a pure, distilled, and absolute individuality. Similarly, the arc, unlike the line, has no length and does not consist of points. It is just a certain relationship between two nodes, as invisible as the marital bond between spouses: they remain married even separated by an ocean. We can draw any number of different lines between two points and all of them will present just one arc.

The simplest graph is just a set of so-called binary relations. If we attribute a name to each node, graph is a list of pairs of names where each pair represents connected nodes. For example, in a party crowd, the list of all pairs who know each other's first name is a graph. A graph can be drawn around a public figure, for example, the map of all acquaintances of a politician and who knows whom among them. Probably, such a web of connections would show the politician sitting like a spider in the center of his web. The web is partially shared also by his antipode from the opposition party, both trying to spook off the insects before they get ensnared by the rival. A more pleasant example than politics is a wedding party where the guests form a complicated graph of acquaintance relation with bride and groom as two focal centers.

Note, that the simplest picture of political connections can be made more complicated if we use three colors for the arcs: green for friendship, red for animosity, and yellow for indifference. We can also color the nodes in different colors: one for international dignitaries and the other for US citizens. We can draw personal relationship with a dotted line and business contact with a broken one, to avoid solid lines hardly appropriate in the world of politics. All that is perfectly fine with graphs and colored graph is a mathematical term.

We will use the term *topology* to characterize a certain binary relation, defined on a set. In lay talk it means that we have some objects, some property of any pair, and for any two of them we can say whether they have this property or not. For example, the property can be same "color" for M&M candies scattered on the table, "friends" for members of a certain group, and "prey-predator " for animals in the Serengeti National Park of Tanzania.

The most important topological concept for us is *neighborhood*: in our interpretation, the neighborhood of any generator in a configuration includes all other generators connected to it.

Exactly because a graph, strictly speaking, is not a drawing but a structure of relations, it can be presented without any lines at all, by its topology only. Instead of the list of coupled nodes, the topology can have a form of the *connectivity matrix*. It is a square table in which each node is listed twice: as vertical and horizontal, so that any crossing point means a pair of nodes. If the pair of nodes is connected, we put 1 in the table; if it does not, we put 0. It looks as a table of a football tournament where all pairs of teams are listed with their scores. Another analogy is the chart of the distances between major cities on a road map.

An example of a graph is given in **Figure 13.1A**. This particular graph has such freakish features as the isolated node 3 and the loop around node 4. Its topology can be described verbally as: "There are nodes numbered from 1 to 5. There are arcs connecting nodes 1 and 2, 1 and 4, 2 and 5, and 4 and 4."

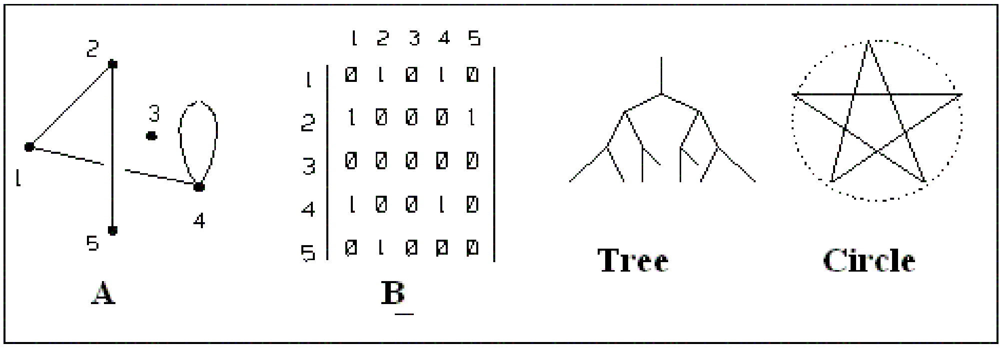


Figure 13.1. Graphs.

Some topologies are of particular interest for us: topology of a tree where each node has one in-bond and two or more out-bonds, and topology of a circle of friends where everybody is connected to everybody (full connectivity). By the way, the M&M candies fall into “circles of color” that have no connections between themselves, and the topology remains the same in whatever way we place them on the table.

Figure 13.1B shows the connectivity matrix of the graph **A**. Its nodes are positioned and numbered differently, but although it looks different, it is the same graph. In simple graphs all nodes are equal in the sense that we can number them in any way. We can place them anywhere in the plane of the figure, and the length of the arc does not matter, either. A graph is what its matrix of connectivity says.

In terms of pattern theory, a node with its potential arcs is a generator. The simplest graphs are structures built of n identical generators which have at least n potential arcs to be connected with other generators and themselves. Before they are connected, nodes represent an ultimate chaos. For n nodes, there are as **MANY** as $m = n!/2!(n\text{-}2)!$ possible arcs, and this number is a precise measure of the **MANY** for n, and, therefore, of our imagination. If n=5, then m=10, and if n=10, then m=45. Since each arch can either exist or not, the total number of graphs on n nodes, if all the nodes are considered different, is 2^{10}=1024 for n=5 and 2^{45} » 35,000,000,000,000 for n=10.

Graphs can be more complicated than that. We can make distinction between knowing each other's name and just knowing somebody's name. Then we would have to supply the arc with an arrow showing who knows whom, and if there is a movie star in a group, all such oriented arcs would be pointing at this person. Furthermore, we can make distinction between men and women so that two kinds of nodes would be needed, etc. By introducing more variety into the very abstract and general concept of graphs, we make them more specific, naming less things with one name, restricting the enormous freedom (and void) of abstract graphs, and in this way descending from the clouds of mathematics toward life, with nature and our imagination meeting somewhere in the middle.

What is the difference between graphs and patterns? In the evolution of mathematics, patterns are descendants of graphs. The topology of graphs introduces the concept of connectivity: some nodes are bonded, and some are not. Generators, however, in addition to connectivity, incarnate the concept of affinity: some hands can be closed in the handshake, and some cannot. The nodes of a graph have no affinity: each one can be coupled with any other. Therefore, by imposing another "no" on the freedom of simple graphs, we make generators able to describe more order.

As a central concept of chemistry, **affinity** introduces the order which lies in the very foundation of chemical processes (and social microstructure as well), so that atoms (and individuals) select only some partners to bond with. Bonds can be broken and closed in transformation, and thus the concept of generators makes possible talking about "natural" processes with patterns. They can live a life of their own and undergo evolution along different pathways of transformation.

By adding more and more flesh of properties to generators, adding a variety of clothing, and specifying more details, we will finally come to an accurate description of a certain area of nature, in other words, to a particular science, for example, chemistry, sociology, or cultural anthropology. In pattern theory mathematics reaches such an intermediate position on the way from ultimate abstraction of graphs toward nature—not too close, not too far—that it really captures a view of the Everything. More steps up or down—and that vantage point will be lost. From the clouds of ultimate abstraction it descends on the highest peak of a mountain area with the valleys populated by scientists and engineers. You cannot live on a mountain peak, but once on top of it, you can see more than the residents of the valleys: the entire landscape of knowledge.

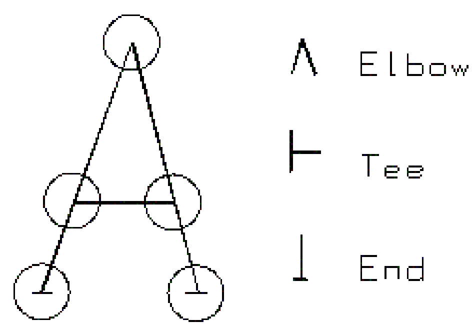
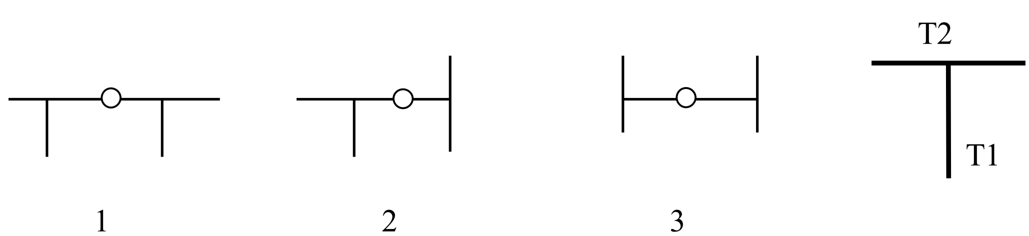


Figure13.2. Letter A.

Like any graph, a configuration can be represented by its connectivity matrix: a table listing all connections between generators. For example, letter **A** in **Figure 13.2** can be built from generators **End**, **Tee**, and **Elbow**, and its topology is described by the following table:

	End #1	**End #2**	**Tee #1**	**Tee #2**	**Elbow**
End #1	0	0	1	0	0
End #2	0	0	0	1	0
Tee #1	1	0	0	1	1
Tee #2	0	1	1	0	1
Elbow	0	0	1	1	0

The table consists of as many rows and columns as there are generators, in this case two ends, two tees and an elbow. The number 1 at an intersection of a row and a column means that the corresponding generators are connected, while 0 shows an absence of connection. There are some complications, however, because a tee has two types of bonds and two tees can be connected in three ways:



We can specify the arcs of a tee, for example, mark the cross-beam of a tee as T2 and its pole as T1. It is convenient to add numbers to other generators, so that they would show the maximum number of connections: 1 for the end and T1 and 2 for the elbow. Then the matrix of letter A will look:

	End1 #1	End1 #2	T2 #1	T1 #1	T2 #2	T1 #2	Elbow2
End1 #1	0	0	1	0	0	0	0
End1 #2	0	0	0	0	0	1	0
T2 #1	0	0	0	0	0	1	0
T1 #1	0	0	0	0	0	1	0
T2 #2	0	1	0	0	0	0	1
T1 #2	0	0	0	1	0	0	0
Elbow2	0	0	1	0	1	0	0

This matrix seems to hide a whole family of letter-like creatures built of same generators as letter **A**. We can release them into the world one by one, changing the distribution of 0 and 1 in the matrix. Of course, we have to keep in mind the number of possible connections each generator can make, and by filling up the matrix at random we may generate a lethal mutation, as they say in genetics. This way to portray configurations seems rather confusing, as one may see trying to generate something else by the above matrix.. It produces remarkably few meaningful "letters," and if we have to decide whether two tees can couple "head to head" by their cross-beams, we may ponder on it forever. The confusion follows from the spatial complexity of our generators: they are geometrical figures and not just the astral nodes of the graphs. This is why we have less freedom in handling our new toy.

Pattern theory comprises not only the simple primeval freedom of graphs but also all possible restrictions of that freedom. The more restrictions, the closer to the real world. Order is limited chaos. Even political freedom, contrary to how it sounds, is a kind of order and is based on restrictions (called "protection"), too.

Instead of messing up with the tables and matrices, how nice it would be to just toss the generators high in the air and tell them: mate as you wish and generate configurations on your own, and we will just watch and take notes.

It looks like this mental picture of the process of generation contradicts our experiments with M&M candies and Lego castles. How can we obtain order by giving a good kick to a bunch of generators? Isn't that a guaranteed chaos of the **MANY**-out-of-**ONE** type? We shall see how.

*

14. MOLECULES

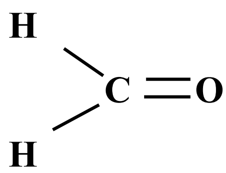
Chemistry plays the Lego of atoms—the platform on which all known complexity of matter, life, and mind grows. Atoms are no abstract points: they have certain position, shape, and volume. Chemical bonds can be established only if the atoms are properly oriented and are neither too close nor too far from each other. In pattern language, atoms are generators in three-dimensional **background space** where the bonds have measurable lengths and angles.

The atomic models in **Figure 5.1** are the chemist's Lego. Used more and more not in plastic but as computer simulation, they are either spheroids of various shapes and colors with cut-off segments or balls with rod-like bonds. The spherical models (**Figure 5.1A**) are used when the shape of a molecule as a whole is of primary interest. This is important because atoms can interfere with each other. Since the spheres can hide the internal parts of the molecule, the "transparent" ball-and-rod models (**Figure 5.1B**) are more suitable for representing the entire structure. Instead of actual models, computer simulation is widely used.

For a chemist, atom is an object that can form bonds with other atoms, according to certain rules. Although not everything we can write on paper is possible, chemical discoveries bring us from time to time something that nobody could dream of . In general, however, the limits on imagination are few and if a structure can be built of real or virtual atomic Lego pieces, it is almost always possible to synthesize it in the laboratory. If experiment was not the ultimate judge in all such questions, the whole chemistry could be written by a computer once and forever. In fact, chemistry, like any other science, is an open and evolving system which sometimes reconsiders even its long-standing dogmas.

Chemical bonding is a physical process, not just mental manipulation with symbols, and each bond has a certain strength: energy, as the chemists say, somewhat comparable to the energy of a firm handshake.

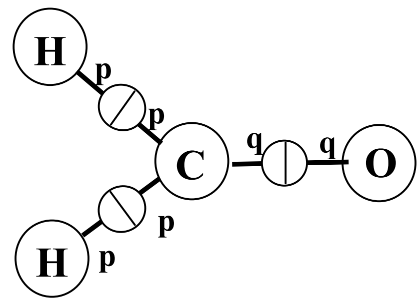
When a chemical bond is formed, energy is released; energy is required to split a chemical bond. This is what affinity is about: some pairs of atoms bond together and some do not—some marriages are stable and some short-living. When we toss a bunch of atoms into vacuum, if it is not too hot, they will behave very unlike the plastic Lego blocks: they will recombine into molecular structures, sometimes one, mostly a few, but almost never all possible ones. Atoms are born to bond. Their affinity to each other does not let them scatter around, exactly like the affinity of family, social group, culture, and political allegiance keeps the society together.



A

$$\begin{array}{c|cccc|} & H & H & C & O \\ H & 0 & 0 & 1 & 0 \\ H & 0 & 0 & 1 & 0 \\ C & 1 & 1 & 0 & 2 \\ O & 0 & 0 & 2 & 0 \end{array}$$

B



C

Figure 14.1. Formaldehyde; *p* and *q* are bond values

This is our first circle around the problem of generation and we will make a few more in subsequent chapters. Here we have to focus on molecules as static objects.

In **Figure 14.1**, a simple chemical compound formaldehyde is presented in three notations: as a common chemical formula (**A**), as its connectivity matrix (**B**), and a configuration (**C**). The numbers in the matrix show what kind of bond exists between any pair of atoms, if any. Zero means the absence of any bond, **1** is the single bond, and **2** the double bond.

The molecule of formaldehyde includes four atoms of three different kinds: **C**, **H**, and **O**. There are two kinds of bonds: single and double. The double bond is not just two single bonds but a separate entity. It could be appropriate to change double and triple bonds for single lines of different colors, but the chemists do not do it to emphasize the historically respected notion of valence as a constant number of bonds an atom can form, although our understanding of bonding today is much more sophisticated. .

Atoms of carbon, as well as many other atoms, are portrayed by several different models, depending on the types of bonds they form. Thus, there are carbon atoms with the total number of one (**C=O**, carbon monoxide), two (**O=C=O**, carbon dioxide), three (formaldehyde), and four (**CH_4**, methane) links with other atoms.

Since there is about one hundred chemical elements plus up to a dozen several types of bonds, and since there is no known limit to total complexity of molecules, the list of all known chemical species is, probably, the largest known list of objects, and it is being extended every day. No wonder, chemistry is the largest single body of knowledge in science.

Chemical Lego is a very tricky toy because atoms in a molecular environment can exist in several forms. It is like playing with Lego, pieces of which can change in your hands. There are some quite peculiar blocks in the chemical Lego.

Metals and stable clusters of other atoms can easily change the number of bonds they form: they can hide some hands or stick out some extra ones. This is how they can be an active part of a chemical machine, catching and releasing molecules when the number of their arms changes under an external influence. In fact, metals are in the core of chlorophyll and hemoglobin, two biochemical power stations providing energy for most plants and animals.

We can build a house or a giraffe from a plastic Lego, but what kind of things can we make from the molecular Lego? Well, molecules, of course.

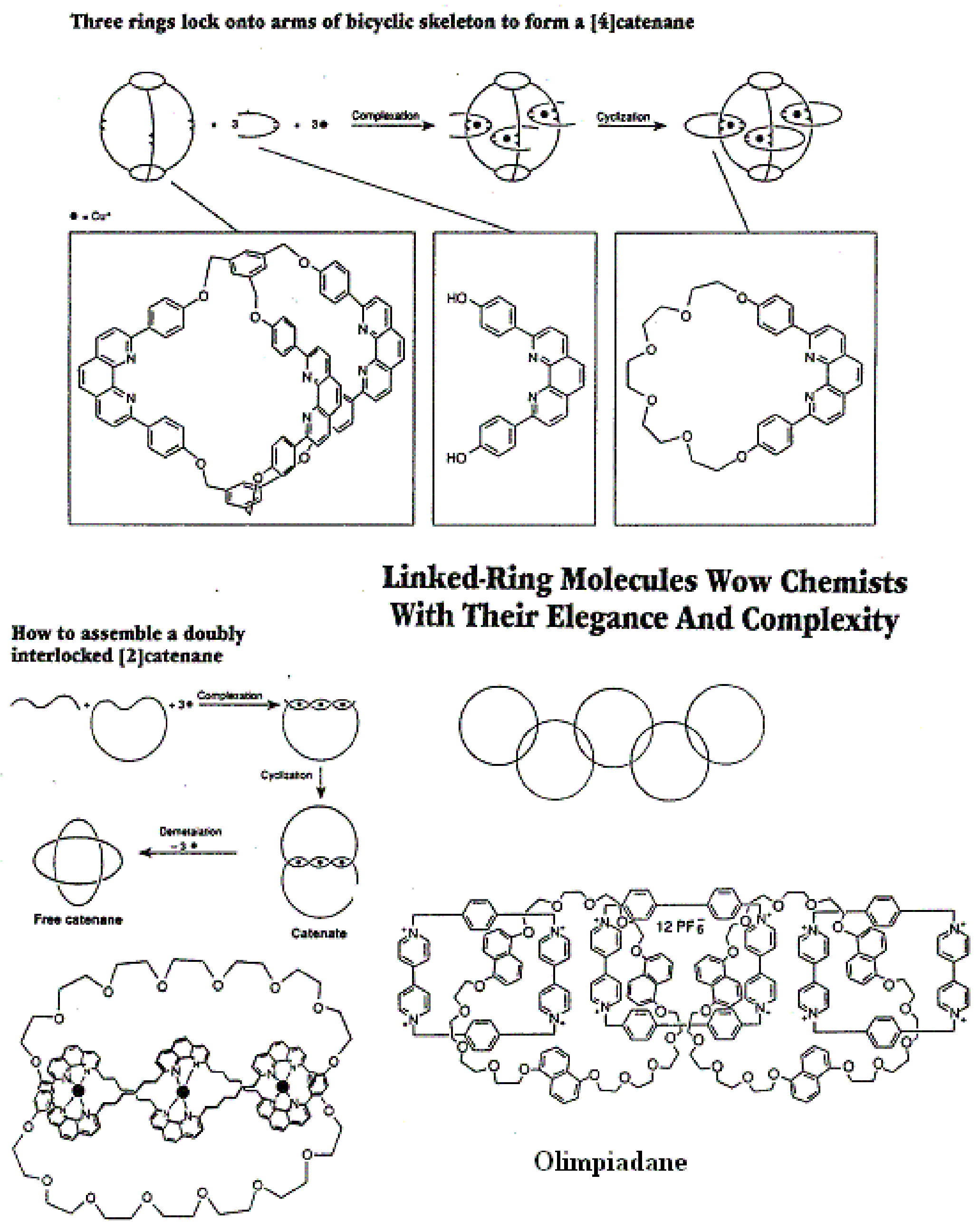


Fig. 14.2. Molecular art. In simplified notations lines stand for chains of atoms.

The more we play with the chemical Lego, the more we know about the properties of the parts, but chemistry is still full of surprises. Like with Lego, when our constructs have some value as models of real objects, the chemist is inspired and stimulated by the practical value of his or her molecular creations. In case of some exotic arrangements the practical value is unclear but the aesthetic one is indisputable.

The newest direction of synthetic organic chemistry consciously follows the well-known toys. In the moist prestigious chemical journal, one could find a series of papers entitled *Molecular Meccano*. The shape borrowed from real things becomes the primary stimulus for a complicated, expensive, chemical research. Barrels, chains, tubes, balls, etc., have all been synthesized, and **Figure 14.2** gives some recent examples of what can be achieved in this way.

From the molecular Meccano, following Nature, we can also build chemical machines which, fed by a source of energy, produce chemicals and perform mechanical work. Can we build a computer of molecules? Yes, because any computer consists of nothing but atoms and molecules (metal is a giant molecule). The most recent discoveries of polymeric conductors, semi-conductors, and nanotubes make a chemically synthesized computer a realistic dream. A more intriguing question is: can a computer self-assemble from molecules on its own, but it is the same as to ask about the origin of life and mind.

All bonds in Lego have approximately the same strength because all pegs and holes are made identical. This is not so in chemistry. The fact that different bonds have different energy is of special importance for building chemical machines. Machine is supposed to perform its function repeatedly, i.e., to alternatively bond and unbond.

A car is a typical example of a machine: its ultimate function is to form and break bonds between the tire and the ground repeatedly, in a certain sequence. The wheel works because its bond with the shaft is stronger than its bond with the ground. It is the lability of bonds that is essential for a performance of a machine: certain bonds should be easily broken and easily restored.

Suppose, we hit a molecule with a charge of energy sufficient to break a bond. If all bonds have the same energy, the molecule can break at any point. It is the wide assortment of bonds of different energy, both weak and strong, that makes the richness of chemistry and biochemistry possible.

My account of chemistry, I must say, is extremely simplistic. It should be taken only as a crude vulgarization. But isn't the planar map of the spherical world a terrible vulgarization?

15. POLYMERS

Space machines are common things. The time machine is a product of human fantasy. Let us talk about the distance machine. If we mounted the seat and pushed the button, what would we see? With the direction lever set to BACK we would see smaller and smaller things as compared with our own dimensions. Let us stop at atoms and switch the lever to FORWARD. In our journey from atoms toward ourselves and farther ahead, we would see a changing landscape of distance.

Not only the size of atoms and the distance at which they interact are extremely small but they also have a narrow range. It is different with molecules. Riding in our machine we would see atoms suddenly pop up and quickly disappear, turning into molecules which would start growing right before our eyes and would be doing so for quite a time, at least in one dimension. A molecule of DNA is already comparable in length with our own body. There is a range of dimensions where both individual molecules and things made of molecules coexist. Then we suddenly enter the range of huge distances such as those involved in the Apollo Project. Finally, matter seems to disappear altogether when we enter the realm of mind. Apparently, ideas do not have length, although a short motto is definitely smaller than a massive novel.

Distance evolves too.

Molecules have microscopic dimensions. If we form a line of several bonded atoms and then double the maximal dimension by adding more atoms, the size will be still minuscule. But if we arrange **MANY** such atoms in a sequence, and, especially, arrange **MANY** such sequences in a super-sequence, we will reach supermolecular dimensions, in other words, objects comparable with cells and our own body. **MANY** small things amount to **ONE** large thing.

The ancient paradox of pile—when exactly a grain of sand plus another grain plus another, etc., becomes a pile of sand?—has a precise solution in my home-made mathematics: it does when **MANY** grains of sand are put together.

There is a kingdom of chemical compounds that illustrates the case of a sand pile: polymers.

The rich variety of polymers that we associate with rubber, paper, plastic soda bottles, eyeglasses, paint, wood, glue, and living tissue look surprisingly uniform through the prism of pattern theory and, of course, chemistry. Polymers are compounds that consist of repeating blocks of atoms, the so-called monomers. They are strings of beads or line-ups of Lego bricks.

Monomer is a block of generators that retains its **stability** and individuality when bonded to other monomers. It is a generator of a higher hierarchical level as compared with atoms. In a molecule of a polymer, monomers can be all the same or different.

Polymer is the bridge from molecules to things. A very long polymer is both molecule and thing at the same time. Our body is nothing but a polymer of polymers.

Linear polymer is a *linear pattern* with monomers as generators. An example of a non-chemical "polymer" is a text built of words (monomers), the words being built of letters (atoms).

The chain of people passing sandbags to enforce a levy during a flood is a linear pattern but not a polymer because we cannot make a new person from the cells or organs of other people in the chain. In chemistry and language we can build a new monomer or word from the generators of the lower level—atoms and letters, respectively. The chain of people retains its structure by necessity and only temporarily. It is **unstable**.

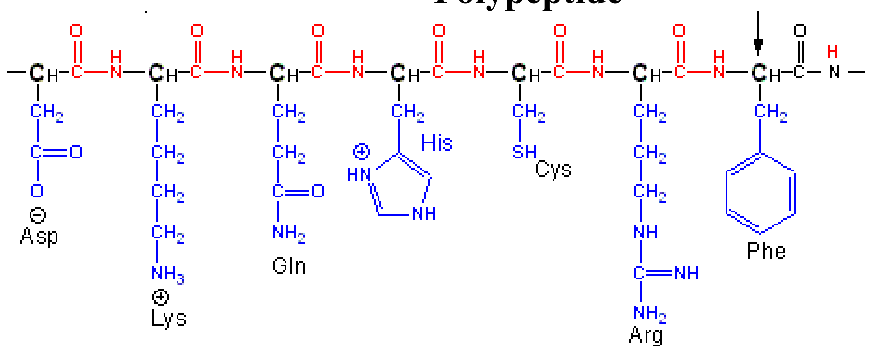
Polymers, especially linear and tree-like ones, are of paramount importance in the realms of life, mind, and society. The organization of a large corporation, a governmental institution, or even a whole totalitarian society follows the tree-like pattern and is a polymer built of people who can be recombined, added, substituted, or eliminated. In polymer chemistry a bond between atoms is chemically no different from a bond between monomers. Similarly, in a social hierarchy all bonds between the units are also of the same type: human-to-human connection.

While linear, branched, and network-like polymers have been known since long, regular tree-like polymers were obtained just recently.

In **Figure 15.1** parts of structures of polyethylene (A), a polypeptide (B), and strings of text (C) are shown. In polyethylene, the simple —CH_2— group repeats itself many times. Twenty amino acids, the monomers of peptides, are more complex. There are also polymers

A **… —$(CH2—CH2)_n$— … Polyethylene**

B **Polypeptide**



C **Text**

a: **"Polypeptide fragment Asp-Lys-Gln-His-Cys-Arg-Phe"**

b: **"A segment of a polypeptide structure"**

c: **"A rose is a rose is a rose"**

Figure 15.1. Polymers

with branching tree-like structure, irregular three-dimensional ones, and many other quite exotic arrangements. Chemists are even thinking about chain-like polymers without a chemical bond between monomers.

One thing about polymers has nothing to do with chemistry. Linear polymers of different length are natural representations of natural numbers, so to say, a hardware of numbers, the measuring tape of the world before mind.

One can build digit 3 of Lego blocks, but some literacy is needed for that. Instead, you can just hold three pebbles in your hand or join them in a line, or show three fingers. It is the same as to visualize numeral three by the Roman number III with three vertical lines, or with the Chinese character with three horizontal lines, or the Arab number from which our digit 3 takes its origin, see **Figure 15.2**.

A polymer made of three monomers (such short polymers are called *olygomers*) is something which means **three** whether you are literate or not. It is the true "mindless" number. We can even perform arithmetical operations on polymers by cutting and joining them together. A teasing question arises about what other chemical polymers and structures can represent.

Speaking mathematically, a linear polymer represents an *ordered* set. If we conclude just from the sound of it that linear polymers are good for accumulating, storing, and passing down *order*, we will hit the heart of the matter.

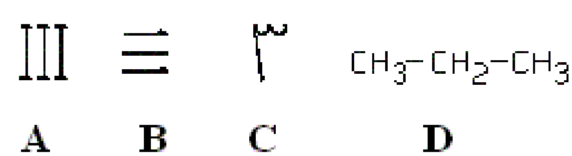


Figure 15.2. The hardware of number three: Roman (A), Chinese (B), Arab (C), and chemical (D).

We know that polymers such as DNA are able to code the entire human organism with all its inborn complexity. Instead of trying to repeat what many wonderful popularizations say about how it works, I am going to illustrate coding with an example of a different polymer: language.

Language is an example of rich pattern chemistry with elaborate hierarchy of letters, words, sentences, paragraphs, chapters, books, libraries, etc. A text—a sequence of atomic letters, molecular words, and monomer sentences—codes a complex message with a meaning that can be expressed in a multitude of other languages. When we speak or write, we actually, perform a chemical reaction similar to polymerization. The difference between a line of text and a molecule of nylon is that any repeating unit in nylon has **ONE** kind of unit as a neighbor while a letter of text has **MANY** letters as possible neighbors.

The automated telephone teller puts together prerecorded numerals to give you information about your bank account. If each time we utter a sentence we had to synthesize polymers of speech from monomer words, it would be a hard work. We tend to use blocks larger than single words so that we do not nail words together each time we say "How are you doing today?"

Language is a typical Lego: we take a construct, for example "Language is a typical Lego" and change just one word: "Chemistry is a typical Lego," then "Chemistry is an exciting Lego," then "Everything is an exciting Lego." This modest exercise, by the way, opens a door to the world of mind. Linear sequences can be copied, cross-bred, cut, and rearranged. If ideas are soft products of mind that seem to have neither shape, nor dimensions, then sentences of recorded text can be considered hard copies of ideas. They have a very simple pattern: each but two end symbols have two neighbors on left and right.

I can reveal here a small trick. I have just mentioned mind to end this chapter with a sticky little hand, so that some of the subsequent chapters about mind could grab it with another little sticky hand. This book is also a molecule, or, rather, a configuration of generators, but not a linear polymer of chapters as it may seem. *

16. IDEAS

Reasoning, discourse, study, theory, proof, inference, and hypothesis are polymers built of monomeric statements. Novel, script, and play are polymers built of sentences, or, at a different level, situations, actions, and episodes. This book is a sequence of sentences, paragraphs, and chapters arranged in a linear order, although its subject matter forms a different pattern, initially linear, but then more like a handful of crumpled yarn: it is linear but some points along the strand touch. A novel usually consists of several strands according to various plot lines. The reason why I invoke the image of polymer instead of more general pattern is that polymer is a particular pattern with predominant contribution of linear strands cross-linked or branching at some points. This pattern is typical for proteins: they are mostly linear strands with cross-links that keep them in a particular overall shape (**Figure 16.1**)

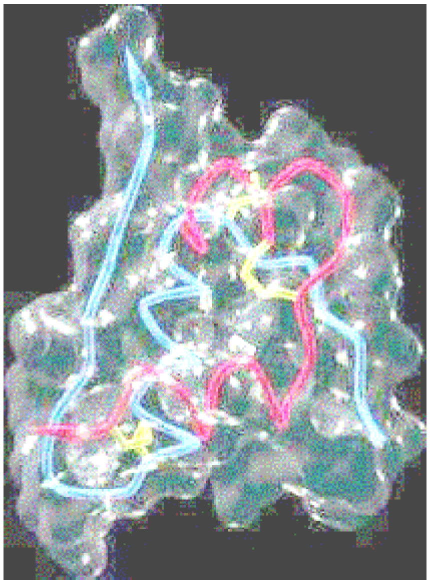


Figure 16.1. Insulin

In the multi-tiered workshop of knowledge, the higher we rise toward the spiritual loft from the dirt floor of matter the more we disagree about the meaning of abstract ideas. To avoid hairsplitting, we will not differentiate thoughts, ideas, and concepts here and use these words interchangeably: they all are "mental things" for us, whatever that means.

Unlike molecules, ideas are anything but three-dimensional material objects in a space where a measure tape or a scale can be of some use. Ideas are connected, too, but in a totally different and commonly non-linear pattern called semantic network.

There is a definite parallel between linear sequences of DNA, customarily regarded as a kind of text by molecular biologists, *expressed* in the form of three-dimensional proteins, cells, and organisms, which are, so to speak, their materialized meanings, and the chains of whimsically connected ideas *expressed* in perfectly linear spoken and written languages. One may argue that it is just the opposite and idea is an expression of a piece of text, but at least a book weighs something on the scale while its idea does not.

Some simple examples of such expressions and non-linear structures they *encode* are given in **Figure 16.2:** statements of algebra, mathematical logic, and language.

Note that in the sentence "These are some examples of objects consisting of elements and bonds," words **these** and **are** are syntactically connected, while **some** and **bonds** are not. This selectivity in links is what makes it a configuration.

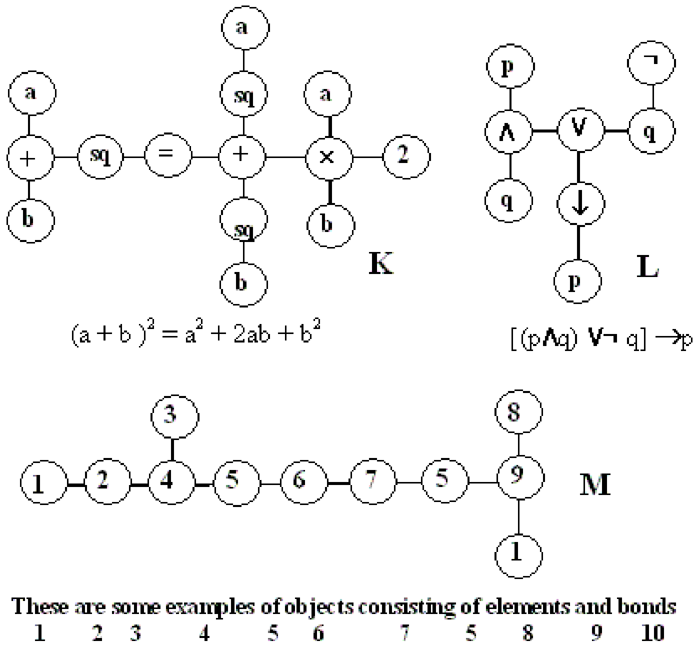


Figure 16.2. Patterns of ideas: (A) algebra, (B) mathematical logic, (C) grammatical structure

Here we have an opportunity to observe a hierarchy of patterns. A particular sentence is a configuration with words as generators. The syntactic pattern of the same sentence, however, covers a whole lot of particular configurations. Many other words could be also connected in the same way. For example, the following three phrases have the same pattern of syntax.

1. There are some specimens of swimsuits consisting of briefs and bra.
2. There are certain types of people approving of hatred and violence.
3. There are many alligators of avocados advocating of alimony and aspirin.

The last sentence seems to have no meaning, which does not cancel its grammatical structure. Not that there is anything wrong with it, but as soon as we decide to adhere to common sense and facts of life, any linguistic construct must have meaning tested by outside means.

NOTE: The difference between meaning and its linguistic form, i.e. semantics and syntax, was the starting point for structuralism in linguistics and a component of a more general direction of structuralist thought in humanities. In many aspects it was the study of patterns. Postmodernism, the most recent philosophical reaction to structuralism, tends to erase the difference between common truth and marginal truth, advocating that whatever we say and do has right to exist. Thus formulated, it is an apology of mutation and experiment, which, by the way, have been going on for millennia without anybody's approval.

As far as meaning is concerned, all ideas in the world form a continuous network of knowledge. A more special term for a representation of a piece of knowledge is semantic network, see Barr and Feigenbaum (1986) for an introduction into the subject.

We need to be aware of some fluidity of the concept of semantic network: there are no universal rules of how to build them and anybody can suggest format for his or her own system.

Semantic network is a configuration with very simple ideas as generators. Examples are: DOG, SPOT (name), CAT, PET, MEOW, BLACK, LIKE, FISH, SOUND, SEE—some of the immense multitude of the building blocks of the semantic Lego. In **Figure 16.3** they are shown as circles with words inside.

Semantic generators can have a rich variety of half-bonds, some of them out-bonds (**Figure 16.3A**). For example, DOG has an out-bond DOG—LIKE> that requires an object of preference such as HAM with an in-bond >LIKE—HAM to form a complete bond. The bond -*is a*-> , which means belonging to a larger class, is formed in the same way. Each bonded generator can have a multitude of other bonds.

Anything we know for a fact, whether chiseled in stone or written on water, can be presented as a network of generators connected with such bonds, as **Figure 16.3B** illustrates.

I do not intend to go any deeper in the world of semantic networks or, for that matter, their perky relative **hypertext**. All we need is to see that they are network-like patterns. My only two comments are:

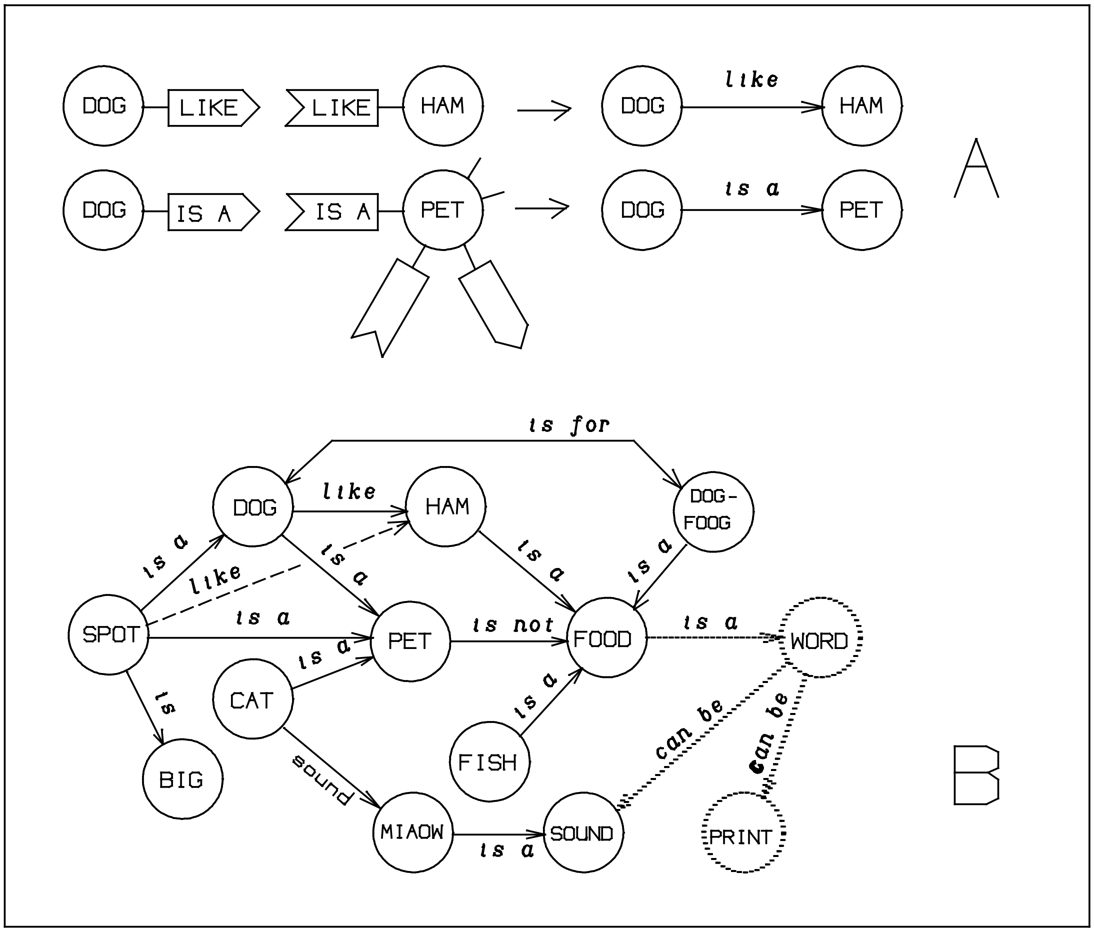


Figure 16.3. Part of a semantic network

1. We can conclude, conforming to common sense, that SPOT-*like*->HAM, but for some reason Spot may not like it because of some bad memories. We also assume that it is true that Spot is a dog and it is equally true that a dog is a pet. In fact, a dog is not always a pet. Almost any bond in a semantic network holds only with a certain probability. Occasionally, when we hit a link in a hypertext, we may get not the expected address but an error message. Let us note this probabilistic, vague nature of bond: there is no bond that

cannot be broken, just read Ionesco or watch modern movies with virtual reality effects. There has been plenty of absurdist poetry, too, in the twentieth century.

2. Language is a soft stuff for building semantic castles. The word "dog" may mean dog as biological species, the dogs in the neighborhood, the dog we are talking about, a hound only, etc., even food. "Food" is food, but the very sound of the word could totally distract us from cats and dogs and recall "mood." Fish can be food for cat, but it can also be a pet. "Sound" may mean the property of making sounds characteristic of the species and used as a bond tag: CAT-*sound*->MEOW. It can also be a generator of its own, as in physics and speech.

This kind of fuzziness and ambiguity is inherent in our use of a limited vocabulary to name an unlimited variety of Everything. Even the number of ticker symbols of stocks exceeds the average vocabulary of our mundane speech. Fortunately, we have a twenty-three letter alphabet instead of the four-letter one that living nature uses. Otherwise, it would take us a day to order a pizza.

The way we acquire, store, use, and express knowledge, is a subject of cognitive sciences, a particular interdisciplinary branch of knowledge, for a long time in the making. However exciting it is, we have to move on.

In general, semantics is as indifferent to whether a statement is true or false as syntax is indifferent to meaning. I do not care whether a particular piece of a semantic network, like that in **Figure 20B**, is correct or not.

In **Figure 16.4** the structure of a statement about the fact "Yesterday I saw a big black cat chasing a squirrel in the yard" is shown. Here we assume that any statement is, first of all, a bond between two terms, subject (**S**) and predicate (**P**), usually a noun and a verb, each of them capable of having bonds of their own. Knowledge is a set of standard Lego structures so that all we can do to record a fact is to select the building blocks and to paint our terms on the corresponding parts. Our knowledge will then turn into a zoo of creatures like in **Figure 16.4**, where parts with the exactly same painted name communicate through walkie-talkie and all bonds between parts are identical. Whether this approach makes sense or not, I do not care, either. What is important, some ideas are bonded (DOG and PET), some are not (DOG and MEOW), and some bonds are stronger than others. This is all we need to incorporate thoughts into the overall pattern picture, together with molecules and things.

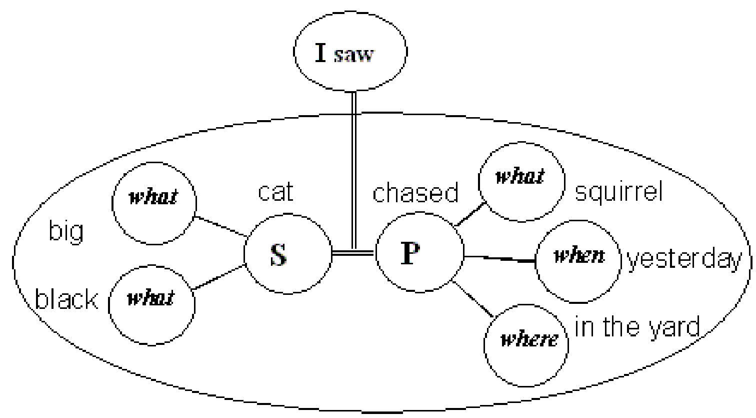


Figure 16.4. A pattern of a statement

It is obvious that there is no single universal way to design the Lego for thoughts. Like anybody can invent a new programming language, anybody can invent a new system of knowledge representation. No wonder that everybody has his or her own picture of the world, with personal measure of knowledge, ignorance, faith, and prejudice. Not only each individual knowledge is different but it also changes with time. Knowledge is a dynamic system.

Note, that there is no way to formally forbid such connections as DOGS LIKE FISH, and DOG IS A FISH. A big difference between knowledge and Lego is that the latter has no such criteria as TRUE and FALSE: all possible stable constructs with pegs in holes are equally true. Not so in knowledge: it is open to the vast outside world that is always right, only we do not always listen to it.

Although human knowledge comprises very different, sometimes incompatible and contradicting ideas which appeal as true to some people and are rejected as false by others, most of our knowledge is somehow validated as true. History records the process of the evolution of knowledge, the struggle of ideas and paradigms, their shaky co-existence, and survival some of them at the expense of the rivals. In short, knowledge is a permanent *competition* of its different versions, some on the rise to domination, and some in decline and agony. Knowledge is an active living eco-system.

Can that process of continuous change be captured by pattern theory?

With pattern theory we have not only a universal way of depicting various objects of nature—from molecules to thoughts—but also a universal way to depict evolution as a change in elements and bonds. Any structure of any manageable complexity can be described in terms of generators. Therefore, any act of change can be presented as two patterns adjacent in time.

In chemistry such presentation of change is known as *mechanism*. Chemical mechanism has nothing to do with engineering. It bears a resemblance to a meticulous chronicle of events by a contemporary historian, like the description of the Persian Wars by

Herodotus and the Peloponnesian War by Thucydides who wrote about particular episodes and not about history over a long time span. It is the complete sequence of elementary acts of change where the generator of change is a formation or cleavage of only one bond. Abstract mechanisms are illustrated by graphs in **Figure 16.5**. Two different mechanisms of change connect same initial and final graphs in **Figure 16.5A**. Mechanisms can diverge, as in **Figure 16.5B**. Note that the mechanisms of pattern transformation are patterns, too, and they are not necessarily linear, but more like cross-linked and branched strands. Chemical mechanisms of life are often cyclical.

In fact, we do not need to keep in mind the entire pattern, especially, a complex one, in order to study a realistic change. The property of consistency that we see in the nature is the ability of any change to be split into small elementary steps, each of them consisting of just one minimal step: breaking a bond or establishing a bond. The Everything does not change all at once: Rome was neither built nor destroyed in a day, and this is something to tease postmodernists with.

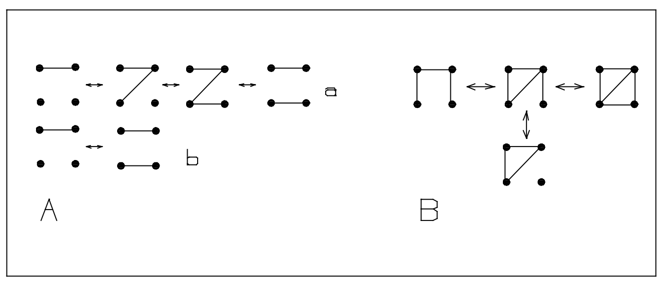


Figure 16.5. Mechanisms

Through the atomistic / pattern prism, the world is a set of supermolecules / patterns, or, rather, one giant continuous molecule, where there is no isolated part. This vision suggests a universal meta-chemistry of Everything, more abstract than the laws of chemistry. There should be some most general meta-physical (not metaphysical) reasons why certain transformations occur and some do not. This synthetic view of the world implies that

Everything as a whole is a collection of patterns and the science of Everything is physics, chemistry, and biology of patterns. Anyway, pattern theory is not just one of too many exotic branches of mathematics, but a phenomenon of human culture and it could be the right construction equipment to build a bridge between the two worlds as deeply divided as matter and mind—sciences and humanities.

In this century, Charles P. Snow (1959), a scientist turned into a novelist, echoing René Descartes, pointed to a dramatic abyss between sciences and humanities and their two breeds of people who can hardly communicate. I believe that pattern theory provides for the first time such a common language. Its syntax can be learned not only from equations and algorithms but from the game of Lego, art, and everyday life, while its vocabulary, however terse, is much juicier than the parched language of the ticker symbols. No denial, the ticker symbols are yet another bridge over the abyss.

*

17. A CHEMIST'S VIEW OF CHEMISTRY

Taking a stand as chemist in the forum of Everything I have to explain what I mean by chemistry.

Atoms of chemical elements are a particular case of what pattern theory calls **generators**. This can be seen from comparing the following two statements:

> **Statement 1**.
>
> What makes patterns different is that they are built either of different **generators** or of the same **generators** but connected in different ways.
>
> **Statement 2**.
>
> What makes molecules different is that they are built either of different **atoms** or of the same **atoms** but connected in different ways.

Modern chemistry began about 150 years ago when chemists had formulated **Statement 2**.

Modern chemistry now consists of an overwhelming number of specific areas divided into smaller domains and even more secluded cubicles. There are organic, inorganic, physical, element-organic chemistries, stereochemistry, electrochemistry, surface chemistry, kinetics, food chemistry, biochemistry, radiochemistry, cryochemistry, and what not, even the anti-chemistry of the radical environmentalists.

By chemistry here I mean chemical synthesis that deals with transformations of molecular structure. Formally, pure synthesis is just assembling, rearranging, and splitting molecules. The world of chemistry is full of luscious chemical flesh with all kinds of colors, smells, weights, shapes, and more exotic properties to the enjoyment of chemists, but in terms of pattern theory, chemistry is a Lego of atoms and bonds, not smells.

A chemist is given a set of about 100 atoms possessing certain properties and capable of combining according to certain rather flexible rules. Any combination of parts is called a molecule (sometimes, a particle, ion, radical, etc.). Most of the time the chemist plays with only five to ten chemical elements. The number of atoms of the same kind, however, as well as the total size of the molecule is practically unlimited.

Stable combinations of parts can be used as larger building blocks for the game. Usually such pre-assembled parts bring with them a certain property, for example, solubility in water or anti-bacterial action which can be passed to a larger structure.

Up to this point the similarity between the child's game and chemistry has been very close. It ends when we watch the play.

Unlike the child, the chemist does not touch a molecule, and not because it is small.

At a construction site, parts are transported by special equipment or human hands. It has been a chemical dream to be able to take two single blocks, each in one hand, and to connect them in a precise way as the child connects the pieces of Lego. Most recently, important steps have been made toward this goal. Molecules in the flask, however, prefer to move on their own, unless the temperature is too low. They dash wildly and chaotically, they collide, fall apart, and re-assemble in a new way.

Real molecular systems, outside life, exist as chaotic crowds, in a chaotic environment, and they are driven by sheer chaos. There is no engineer reading the blueprint and telling atoms which one has to bond which. There are no hands and no workers tying and untying atoms and blocks of molecules.

To visualize the chemical construction site let us imagine that all pieces of wood, all nails, window panes, toilet fixtures, and electric sockets are just flying around in total disarray, bumping into each other. They would run away from the lot, from **ONE** to **MANY** places, if the walls of the flask did not stop them.

Since molecules are small objects, the chemist usually deals with enormous number of identical molecules even in a tiny amount of substance. Instead of complicating the picture even more, this circumstance turns out to be a magic simplification of the chemical picture: the flying bricks become invisible, there is always the same stock of bricks (molecules) in any point of the construction site (flask), and we keep the exact inventory of all parts with the balance.

The unit of molecular order is a particular bond between two particular atoms. This kind of order is strictly local, and atoms decide by face-to-face bargaining whether they strike a deal or not.

If I were a molecule, I would never know what was going on even slightly beyond my outstretched hand, and even if I did, the picture would change in an instance. Molecules live in a given moment and in the world of their immediate environment, at distances comparable with their own dimensions. Moreover, atoms within a molecule feel only their immediate neighbors in space and only in some molecules atoms can feel electronic tides and waves coming from faraway places.

All elementary events of this chemical game occur only at a very close range. There is no one to keep the rules of the game in mind, and there is no mind in the flask.

The big questions are how we can conduct and control, despite the chaos, a specific transformation in the world of molecules, and why life is so successful in building two identical twin copies of an organism from chaotically moving molecules.

The art of chemistry is to set up the initial conditions, mix the right ingredients, provide heating or cooling, stirring, irradiation, etc., and control them during the reaction. The rest is done by the atoms with their secret affinities and idiosyncrasies. It is very difficult to imitate Thucidides in recording the tiny details of developments within milliseconds, but this is what makes chemistry so exciting. As mathematics is not only about numbers, chemistry is not just about smells.

Due to the chaotic movement of molecules in gases and liquids, configurations of atoms collide, break apart across their bonds, and recombine. Theoretically, in the perpetual earthquake of molecular movement, any bond between any atoms can be broken and any possible bond can be established. In practice, not everything we can imagine really happens in the nature, and there is a certain preferred direction of possible events. The reason for that is not that our imagination is too wild, but because most possibilities realize too slow.

Human life is too short for all our dreams to pursue and we are lucky if we realize just one. Similarly, the initial set of atomic Lego parts is too small to build all possible castles and to build just one or too is quite a luck. The hut that is the fastest to nail together consumes all building materials, and nothing is left for a palace.

The art of chemistry is to take such a starting set of molecules and create such conditions that the desired set of final products would form **faster** than all the others and win the competition for the limited resource of starting products.

The dramatic side of chemistry is that the chemist cannot intervene, with rare exceptions, into an individual act of chemical change. Preparing an experiment and choosing reagents, the chemist works like Sisyphus: he rolls not one but myriad of stones uphill, where the starting point is. Then he just let them roll downhill, where the gravity of the laws of nature steers them into a common pit. He can choose, however, such conditions and special tricks that the chemical change of scores of molecules will be more or less coordinated, follow a certain pathway, and produce one or just a few products—winners in the beauty pageant (a metaphor intended for radical environmentalists).

When a chemist stirs up a crowd of molecules and drives it toward a change, like an eloquent politician, there are many possible outcomes. As an art of operating large numbers, chemistry borders with politics. In a democracy no politician has any guaranteed control over individual minds of voters. By a skillful campaign, however, using well tested and new tricks, not necessarily honest, he can shift the probability of the vote. The chemist is rarely lucky to get **ONE** from **MANY**. Usually, it is **FEW** from **MANY**, which is still not bad. Using methods of chemical separation, the chemist can isolate and purify any component.

Until the middle of the 20-th century, elements of detective investigation greatly contributed to the excitement and fun of doing chemistry. A chemist had to find out the structure of an unknown compound in an oblique way, by purifying it and studying its chemical properties. Chemical behavior was mostly a circumstantial evidence. Doing chemistry was like fixing a watch with closed eyes. In the combination of intellectual power and physical helplessness to intervene into an individual chemical act lied a great romantic flavor of chemistry.

With modern physical methods of separation of chemical species and direct, sometimes automatic, decoding of their structure some of that challenge disappeared. Nowadays, a particular chemical problem is often just a technical one, like following a wild animal with a radio collar, as compared with more challenging tracking.

Chemistry becomes combinatorial: many atoms and their clusters are combined in all possible ways and in massive numbers to find a new drug, with less and less human intelligence required. This is the general effect of technology: it makes easier to survive and harder to excel.

In Chapter 41 and subsequent ones I will try to paint a pattern picture of one of the intimate secrets of the chemical transformation and the major trick both the chemist and living nature use to win in molecular gambling. Here I want to describe at a greater length, as part of a larger picture of complexity, how the chemist perceives chemical objects he deals with.

The homely chemistry is a much larger body of knowledge than anything else. There are many millions of various known molecules. Potentially, their number is unlimited, like the number of objects which could be built of an infinitely big Lego where parts are presented in infinite number of copies.

Chemistry deals with objects that cannot be expressed by numbers. It is not abstract in the sense physics is. Each of many millions of chemical compounds is a thing, not an idea: it can be kept in a glass vial. Chemistry not only lacks the mathematical way of naming a lot of things with one name, but it is determined to give to each thing exactly one name. It knows any compound by name, sometimes, very long. In the terminology of John.D.Barrow, it deals with listable properties.

A chemist looks at a molecule as an artist or photographer looks at a human face: there is always a unique character behind a face, as there is a unique character in each inconspicuous white powder in a vial. Although chemistry is as good at classification as any other science, it never loses an individual: like the residents of the United States, all "legal" chemicals have kind of Social Security numbers and are registered in a database.

The power of abstract thinking cannot be applied to pictures of molecules. There is nothing to understand in a chemical formula. It is just what it looks: what you see is what you get. It is not a result of substituting some values into the variables of a formula. Take it or leave it! Instead of a strong mathematical mind, a synthetic chemist possesses a power (or a curse?) of a different kind—the power of dealing with complexity. But this uniqueness of each molecular face can make the relation between the chemist and his object as intimate as the relationship between the master and his pet.

Chemistry names one thing with one name.

When I write a chemical formula on paper, or a computer draws the 3-D image of a molecule, I believe that it reflects the real structure of an individual molecule and the way the atoms are connected. It means that the formula is a true or a very good image of a molecule, or even a photo of what I would see if the molecule were blown up to the size comparable with my own. This belief has a strong confirmation because some molecules can actually be seen, and the structure of practically all of them can be established directly, with the help of physical methods. Large molecules can be even seen in the electronic microscope, although they might look as blurred as the Loch Ness Monster on its photos.

Chemistry tries to answer the following fundamental questions:

1. What will happen if I bring into contact a given set of molecules?

2. I have brought into contact a certain set of molecules. How to explain the resulting set?

3. What should I do in order to transform this molecule into that one?

The science of chemistry is very visual, concrete, graphic, practical, and realistic. Many other human occupations can be characterized in the same way. Engineering, architecture, construction industry, surgery, business management, politics (considered a craft by the Greeks), and even literature are very close to chemistry. They all use separate elements or building blocks that can be joined together or taken apart only in some particular ways.

Figure 17.1A presents the chemical formula of camphor. **Figure 17.1C** shows the circuit of a primitive "crystal" radio receiver that any schoolboy could make 80 years ago. It consists of such radio parts as aerial (**A**), capacitors (**C_1** and **C_2**), inductance (**I**), ground (**G**), diode (**D**), earphones (**T**), and soldered contacts (**black points**). We assume that any pair of contacts connected with a wire is equivalent to just one contact. The notation for parts is pictographic, i.e., it visually reminds the part. In **Figure 17.1B** the components of the same circuit are marked by letters. The drawing shows only the function of a part ant their connections with other parts. Actual connections can be made with wire and a solder in various ways.

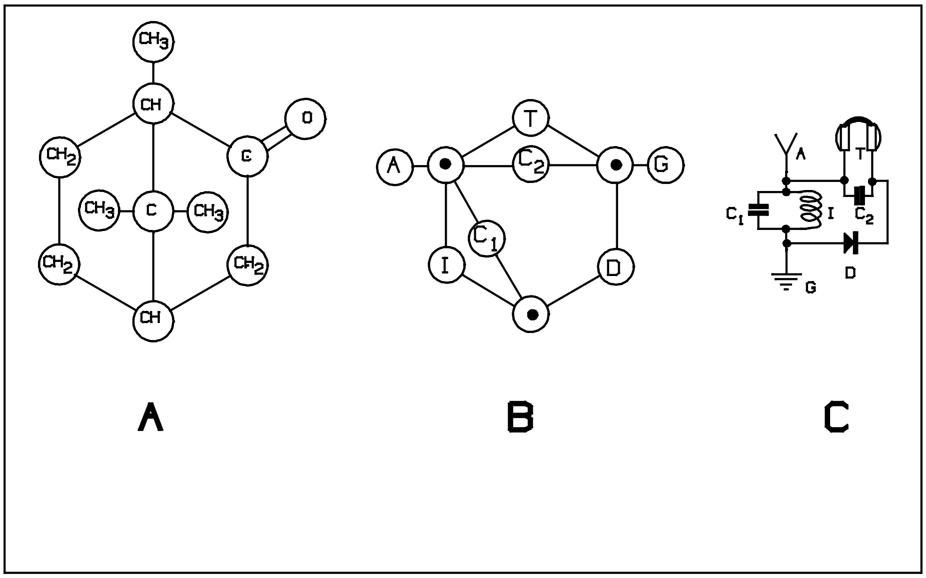


Figure 17.1. Camphor and radio as "molecules"

The way we view and depict camphor, radio set, sentences, and mathematical formulas is profoundly mathematical.

To summarize, chemistry is a game, an exciting Lego, but not the only one. It is easy to lose the sense of time over Lego, but chemistry does not have it. With the exception of geochemistry and evolutionary molecular biology, it operates with very short and disconnected intervals of time and does not care about master time. Flasks do not have memory. Strange, our scull looks like a capsized flask. There could be something in it.

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18. A CHEMIST'S VIEW OF PHYSICS

Physics, unlike mathematics, is not a singular world. It has something else behind itself: another world to which it relates. While mathematics obeys its own rules and knows only the self-imposed constraints, physics must obey the rules of both mathematics and material world.

Physics is mathematics **selected** by the nature and tested against its touchstone.

The physicist uses mathematics as a tool in order to describe, predict, and explain natural phenomena. Like the chemist, the physicist deals with something which exists independently from what is seen on the sheet of paper. Mathematics is always true by definition as soon as it assembles the jigsaw elephant that has no missing parts, no gaps, and no extra eye. Mathematics can be **correct** or **faulty**.

On the contrary, ideas of physics and any natural science can be **true** or **false** depending on how well they describe material world, and not just because they have internal contradictions or are based on false presumptions. In other words, the physicist not only assembles the picture of an elephant, but having done that, is also expected to produce it live and moving in order to prove it.

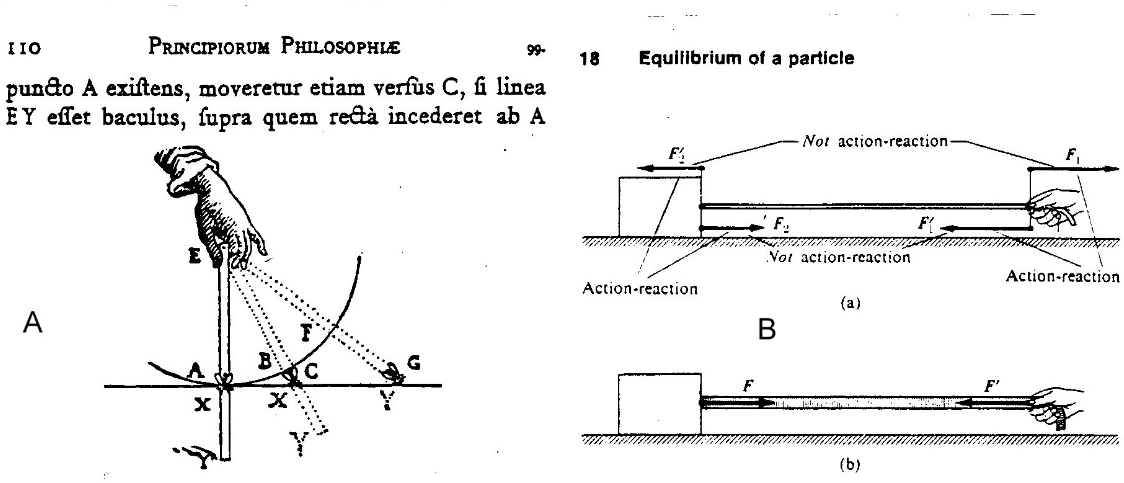
Unlike immortal mathematics, physical ideas have a certain life span. They are subject to a process of selection, according to the criteria that are not just logic. Some of them die and some of them survive, often transformed and absorbed like ancient nations. The physical criterion of selection is practical success. No wonder that those areas of physics which do not have means of active experiment, like astrophysics, are a Lego playground of hypotheses.

The approach of physics is fundamentally quantitative. It deals mostly with ordered sets, metric spaces, and measurable values. A physicist is rather annoyed than challenged by a set of objects that cannot be characterized by numbers. From physical point of view, humans are just arrays of weight, height, and metabolism rate, and what is in their heads is of no concern.

Although physicists more than anybody else are used to perceive the world in terms of time, space, and quantity, other sciences are also based on measuring and counting. It is of utmost importance for a zoologist that ants have six legs, spiders eight, birds two, and snakes have none.

Physics describes systems and processes, rarely concentrating on patterns because structure cannot be measured by a numerical value. Still, physics has some vestiges of anthropocentricity. Physics talks about situation when a valve is open or a candle is burned or a stone is thrown.

In illustrations to old books on physics, one can often see an eye, a hand, or other signs of human presence, **Figure 18.1**.



A B

Figure 18.1. Human presence in physics. A: 17th century. B: 20th century

Physics, however, never asks any question about the legality of this human presence. It deals with certain slices of Everything: it is interested in what a candle, a lens, and a screen, on the one hand, and an electric lamp, a rounded bottle of water on the way of light, and a wall, on the other hand, have in common. The process of technical evolution from candle to electric bulb seems to be totally irrelevant for a physicist. Even but a few historians take note of that remarkable transformation, probably, because the candle has not perished in the ruthless selection, as did the mechanical typewriter.

On the contrary, chemistry focuses on structures which are always unique. Chemists are used to study very complex systems and the way they change. It is the transformation of structure which is in the focus of chemistry.

Both physics and chemistry, however, are beyond history. They are not interested in the hand that mixes chemicals, opens the valve, pushes the button, or drops a stone from the Tower of Pisa. They never refer to their histories in explanations and predictions. Who discovered what and when is of no importance for any **theory**.

Trying to understand the nature, a physicist operates with highly abstract ideas and artificial constructions of mind. They cannot be visualized and sometimes cannot be even understood: they can be just used. Combinations of symbols on paper do not bear any sensual resemblance to the "real world". In $E=mc^2$, letter **E** standing for energy is neither hot nor cold and it cannot be used to power a TV-set. Letter m standing for mass is neither heavy, nor light, and letter c, velocity of light, is neither fast nor slow.

The world of physics may look incomparably richer than the world of chemistry. Physics studies all kinds of phenomena: electrical, optical, molecular, etc., including chemical ones. An unlimited variety of objects catch its attention—stars, machines, computers, organisms, and molecules.

There is a certain price for the power of physics. It becomes approximate when it describes complex phenomena because there is no exact analytical solution to many physical equations for complex systems. In such cases computers are used. When there are properties that cannot be described as quantities, however, physics is off its natural habitat.

A point of view of an outsider may greatly differ from a scientist's view of his occupation. Thus, some physicists and non-physicists take a slightly disdainful attitude toward chemistry as a dull and primitive science, more like a culinary art, which does not preclude an admiration for the results. The high school impressions of most people about chemistry are not flattering, either. For a student with mathematical enthusiasm chemistry might be disappointing. Many non-chemists familiar with chemistry believe that chemistry has no theory, or, if it has, it is all borrowed from physics, which of course, this is true, but there is nothing to be ashamed of. Physical theory is just a tool to simplify complex phenomena. We can simplify only what can be simplified and there is always something that cannot. By definition, what is left out after theoretical simplification, has no theory. There is no physical theory in Lego, but it is, nevertheless, fun.

Although chemists apply physics to their objects, structural chemistry seems to lack the idea of quantity. Often chemists have to memorize a pile of data, like a student of anatomy. Chemistry studies skeletons of molecules, bone after bone, joint after joint. Comparing with anatomy, however, the fun of chemistry is that the chemical skeletons are engaged in a joyful play. Not only they dance and bounce, solo and duo, embrace, fall apart, and exchange bones, but they play *Hamlet*, too.

What is completely outside physics is the property of being **NEW** as a natural property, like being hot, long, or fast. Physics is novelty-blind. This where the chasm separating physics and history—as well as sciences and humanities—runs.

While physics appeals to the Einstein in a student, chemistry appeals to the Shakespeare in him or her. None of them appeals to the Darwin, however.

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19. LARGER THAN LIFE

My reference to Darwin in the previous chapter was a half-bond of the chapter generator: a hook to connect with the current chapter, which is—an easy guess—about life, too. Just one more snapshot of the pattern world.

The singularity of life in the systematics of Everything may seem intimidating. Life stands lonely and aloof in the crowd of Everything. It is intensely different and rare as compared with the cosmic and mineral world that parented and nurtured life. We can get a shivering of loneliness and exposure from looking at the universe through the eyes of life.

We treasure our lives and the lives of those we love because they are unique and irreplaceable. We treasure unique objects of art because their loss is irrevocable: they cannot be either churned out like screws or bred like mice. So is life on Earth: our existence in the universe of cold minerals and white hot stars looks too fragile because it is too unique.

Of course, if we are in the mood, we can even enjoy our solitude and be inebriated by cosmic pride, but we would probably feel more secure if we knew that life was as natural and robust as old rocks and by no means an aberration of matter or even its disease, as Gerald Feinberg once said (Pagels, 1982). To relieve the fear of uniqueness, we succumb to the peer pressure of Everything and gravitate toward larger communities: lacking the legitimacy of minerals, we are looking for our relatives in the Universe.

Can we speak about life and non-life in the same language? Would that make life to look less alive or the world less dead? If we admit that life can be different from life on Earth, how different can it be? What life is possible? Even more important, what life is impossible? The awareness of the impossibility of *perpetuum mobile* (eternal motion) is one of the pillars of our knowledge. What do we know about an impossible life, so that we could set limits to our imagination and possible fear?

We all intuitively know what life is. We can tell a living object from a thing in an absolute majority of cases, and an occasional rare exception, like when an insect looks like a twig, only confirms the rule: the creature just has a good reason to look alive.

We are really good at our life-spotting skills. Whatever ideological controversy is there about life and death, we can easily tell a living body in the process of dying from either a definitely dead one or a thing that was never alive. And yet it is difficult to define what life is without using examples. It would be nice to have something like a working definition of life, for example, for the purpose of instructing a space ship crew or a robot setting out for a search of life in the universe.

Currently there is no such definition of life that would satisfy everybody. We can only tell what life is from the point of view of physics, chemistry, biology, philosophy, etc., but the definitions are fragmentary and hardly compatible.

Suppose our planet joins an interstellar federation and we are going to file a patent application on life on Earth, to protect it, just in case. In accordance with Patent Law, such a claim should refer to a broader body of objects and specify the distinctive features of the defined object. For example, “a hammer is a tool for striking a hard blow, said tool having a heavy hard head and a handle, both joined as a "T."

When we define hammer as a tool, as we define Socrates as a man, there are many other tools besides hammer and many men besides Socrates. In the patent claim we specify what makes hammer different from other tools as far as its function is concerned and we give a short description of its structure in terms of its parts. Moreover, we can patent a particular kind of a hammer, for example: a hammer with a handle and a head with two ends, said ends made of different materials, for example, steel and rubber. In a similar way we can patent a method of manufacturing a hammer so that anybody "skilled in the art" could make it.

Unfortunately for space lawyers, we do not have anything larger than life to refer to and cannot make a statement about life similar to "Socrates is a man" and say "Life is a..." what? There is apparently nothing between life and the even harder to define Everything. We do not have anything more general to accommodate life except for such empty shells of thought as framework, system, property, process, or phenomenon. Life is the way living organisms exist, and organisms, apparently, have no inanimate relatives which would seem alive from a more general point of view.

Nevertheless, this is exactly what I am going to do: to look for life-like objects covered by a larger logical umbrella. If we reach a certain height of abstraction, some typically alive and typically dead things may have something in common.

Remember **Figure 3.1**? What can be more different than the warm green Italy and the buried in snow island of Novaya Zemlya? Still, they both are shaped as a boot. Life is unique and single. If it is Italy then there is no New Zealand to match. If we want to look at life from the least partisan point of view, i.e., from that of mathematics, we have to place the Italy of life in a company of other life-like systems and to name all of them with one name, meta-life, for example.

This is what mathematics is about, according to Henri Poincaré. Mathematics performs its baptism by the trick of developing a peculiar artificial language to talk about many different things, so that they, naturally, have the same name, exactly like robin, hawk, and penguin are all birds.

Inn a company of all lines drawn between two points, a straight line seems unique and lonely among various curves: it is not only the shortest one, but different in other aspects, too. From the point of view of topology, however, there is absolutely no difference between any two "smooth" lines connecting two points, and we can easily place the straight line in the curved foster family.

Chemists do not have a more general category than life, either. If a chemist invented life, it would be hard to formulate the patent claim. Such patents without referral to a prototype are called pioneering and they usually open a whole new direction of development. They are **ultimately novel**. Let us note this property of novelty, at least in patent business: the Big New does not belong to a reasonably narrow larger set. As soon as the very first Big New appears, scores of variations pop up.

Strictly speaking, no invention is absolutely new. Photography is a method of making pictures of real things, and we can trace it back to *camera obscura*, dark room, and further back to the images on the wall of a dark cave coming through a narrow hole. All human inventions can be traced back to the natural abilities of human body and mind, like our own feet can be regarded as a prototype of car and our brain as a prototype of computer.

The chemist, however, is the right person to specify the most distinctive feature of bio-life: common biochemistry as basis for the function and structure of all living organisms. If we accept that the smallest building blocks of the Lego of life are molecules, all forms of life play the same brand of Lego—the one packed into the periodic table. Inside the intricate web of biochemical transformations, there is something that we can find in any organism, from viruses and bacteria to man, and it is neither a list of features, nor a process, nor a relation, but a single well defined object: a thing.

The thing common for all creatures, big and small, is a polymer—DNA or RNA—that is, as we believe, a coded description of what they are and how to assemble them from atoms. The linear DNA is more like a verbal description than a 2-dimensional picture in the Lego. This assembly can be performed only if some preconditions are met, either inside a living cell or in a test tube.

For simplicity (as well as out of defiance), we will not distinguish between DNA and RNA—they are extremely close, anyway—and call both DNA. Indeed, here we are interested not in the true picture of Everything but in drawing it with a single pencil line.

Although scattered inside the soft tissue of living forms, DNA is something very much solid and resilient, a stone of a kind, more like a mineral stone than the cherry stone. After the organism dies the substance can survive for a long time. On its own it is neither alive nor dead. Moreover, it can be made artificially and nobody would tell the difference.

There is an enormous popular literature on DNA, RNA, and their role in processes of life, and I have no intent to compete with them in any sense. To know that DNA is like a sequence of text using only four letters will do for us.

Unfolded DNA looks like a string of beads of four colors (monomers) denoted by letters A, G, C, and T, and connected by one type of chemical bond. The beads alternate in a strict order unique for every individual organism. All DNA on earth is, therefore, a lackluster Lego consisting of just four bricks with one peg and one hole each. Here is an example of a DNA segment:

GGACCTGGATATGGCGAGAAAACTGAAAATCACGGAAAATGAGAAA...

As soon as we pinpoint DNA as the necessary attribute of life, it is possible to notice that the "Socrates" of DNA is definitely a member of a larger family. He is a "man" of coded information that is passed to the offspring. Segregation means here that, unlike the rock, the carrier of information about an object is not the object itself. DNA of a mouse is not the mouse, while "DNA" of a page of a text is the page of the text.

In order to look for other species of coded information we have to leave the chemical ground and climb the ladder of abstraction. From a certain height a larger family for DNA can be seen: any linear pattern with meaning is its relative. Text is the best example, although a tape of a musical record, a floppy disc with a piece of software, a blueprint of a house stored in a CAD file, and a sheet of musical score are all sisters.

All DNA strings look very much alike, but so are lines of a text, especially, in an unfamiliar language. Both DNA string and text are built of words consisting of letters. Neither DNA nor Chinese and Thai do not separate words. All, however, mark an end of a meaningful sentence.

Any pattern with a meaning tells something beyond itself. For example, the sequence of differently magnetized sections of a plastic tape means a performance of a song. By just looking at a meaningful and a meaningless sequence we may not see any difference. We have to look at their *expressions*, if any.

The readable part of DNA of a frog contains a specification of proteins—building blocks of the frog—like the blueprint of a house contains a set of beams, panels, boards, and other parts constituting the house. The blueprint also gives us all details about the mutual arrangement of the parts of the house while DNA does not give a clue. Looking at a blueprint we can actually see the house like a conductor can hear a symphony looking at the score.

Probably, the part of DNA that we are still unable to read, will tell us someday the whole story of the origin of frogs, so that the sequence of events leading to the assembly of an individual frog from a fertilized egg and food is a short dramatization of a long historical novel. It is not a short episode but a history of a whole frog civilization.

Rather than novels, the DNA texts are scripts of dramatic plays that are supposed to be *displayed* in action, provided there is a theater with stage, actors, props, and light.

Remarkably, the plot of the drama, in short, is a story of building another such theater with the stage, actors, props, and light, right across the street or even side-by-side with the first one. Naturally, the theater will have its own copy of the play which is, of course, about building a theater.

The copy of the play is made by the process of duplicating, letter by letter, the text (replication). Each actor, for example, the one who is responsible for the electrical wiring, is produced (expressed) right on the stage, with his own full copy of the play, where only his part is somehow highlighted and used for his own creation.

In the new theater everything is built in the same way—from the threshold to the lightning rod on the roof. The same play runs in the new theater. After a while, the whole Broadway built with theaters slows its growth, ages, develops breakdowns and leaks, and finally turns to dust. Before it happens, however, an actor with his own copy of the scripts walks out of the city, finds a partner, and starts building a new theater.

In the process of such perpetual and rather senseless turnover of building material, a copy of the script may experience certain changes: something is added, something removed, the architectural style is changed, etc. This is what is called evolution: suddenly, number 1 is mistaken for number 7, and, look, the elephant shows off his new trunk. This is only my guess, of course.

A successful show can run for millennia while a flop is punished like on real Broadway.

The above stretched out metaphor was written not just out of defiance but to show how similar very different phenomena might look across the precipice between science and humanities if reduced to their pattern bones. To say that Everything is a Lego is not the whole truth but probably a significant part of it.

Evolution is development of complexity, new forms, and new species. It does not mean, however, a frenzy of change. Innovation in evolution is very risky and rarely appreciated and evolutionary change exhibits an exceptional self-restraint.

A powerful invisible hand controls life forms. They demonstrate a rigidity so remarkable that the remaining plasticity of organisms looks all the more remarkable.

In a very simplistic way we can describe organisms as constructs assembled from the Lego of cells. Over millions of years, life invented only a limited number of cell types, comparable with the number of atoms in Periodic Table. Only three types of blocks of the cell Lego are needed to build yeast, 60 to build a worm, and 250 to assemble a human, see Kauffman (1993, p.34). There is much more impossible and forbidden events in the world of cells, however, than in the world of molecules. Unlike atoms, the cells and organs cannot combine in arbitrary order. The number of mammal eyes is always two and the number of navels is one, and the eye and the navel cannot switch places.

With all the diversity of such big classes as insects and bony fish, their species have the same general design varying only in more or less significant detail, like all the variety of cereals or pickled cucumbers in a supermarket are just minor variations of the same product.

The static picture of DNA is not sufficient for understanding life. Replication of DNA, i.e., the process of making copies of DNA, is as fundamental as DNA itself.

Each DNA copy is able to envelop itself into the protein flesh and produce its own copy in turn. While a single DNA text is basically immune to time, the process of multiplication introduces a powerful factor of time in understanding life. One has to be Hokusai in order to capture the majestic succession of waves of generations in the constant turbulence in the ocean of life: offspring rising into parent collapsing and breaking into offspring and so on, each wave, each species being different and unique.

A particular organism is what it is because it was produced at a certain time, its parental predecessor looked the same way, and it had means to make the offspring look after itself. This naturally brings up the same question about the parental predecessor, and the answer is basically the same.

The formula of life is, therefore:

Parent → Offspring; Offspring ≈ Parent,

where ≈ stands for "is almost the same as"

Or, **organism N → organism N+1, organism N ≈ organism N+1** to avoid "offspring" and "parent."

Life is often compared with game, and as any game, it has an element of uncertainty in it. The uncertainty resides in the word "almost." I should add it to my undermath: **ALMOST**.

Biology gives us the rules of the game of life by which parents produce their offspring, but it does not predict the exact course of the game, i.e., how accurate the reproduction is. This is the case with any other game: cards, chess, football, etc. However strict the rules are, they do not allow for predicting the sequence of positions in the game not only because each move is **ONE** possibility out of **MANY** but because all moves require **ALMOST** the same energy.

Playing a game of life, therefore, is not a hard work: just make any move. To win, however, is the problem. A good chess player carefully *selects* the moves in order to survive *symbolically*. In the extreme situations of real life, a wrong move could mean death.

Skills in any game are a set of strictly personalized additional rules selected in a lifetime of non-lethal victories and defeats. Whenever there is a game, there are both chaos in the form of chance and order in the form of rules.

Life resembles the children's game called "telephone" or "operator." The children are sitting in a row, the leader quickly whispers a phrase into the ear of somebody at one end of the row who passes the phrase along the chain to the other end, where the phrase may come out changed beyond recognition. Something like that happens with DNA passed down the generations: an unremarkable primate (seen as a species only with a hindsight) becomes human.

Molecular biology studies the rules of the game, leaving a clear space for chaos and weighing the exact proportion of "chance and necessity," as Jaques Monod called both philosophical ingredients of life (Monod, 1971).

This approach to life cracks the enigma of life by pushing it further back toward the very beginning of life on earth, where in the formula **organism N → organism N+1**, **N**=1.

Comparing life scientists with historians, we see that the life historian (evolutionist) has to tell not so much the biological counterpart of the story of the Peloponnesian War but the story of the warfare in general, up to our days.

After the above lengthy preamble we can give the following more or less practical patent claim for life:

> **A spontaneous process of producing descendants which are copies of the parents, said parents and descendants being strings of DNA.**

Here *spontaneous* means without the pre-existing plan, *descendant* means a copy, and *parent* means the original of a copy. The mechanism of the copying process does not matter and neither does the accuracy of the copying. One parent can spin off many copies, as in copy machines, and this is quite natural, but if many different parents produced the same offspring, it could be a stressful situation. Nevertheless, this sinister uniformity is what a totalitarian state usually requires from its citizens. One aspect of Russian Communism, for example, was to make a new man who would never deviate from the script and act predictably at any circumstances.

I just cannot afford to expand on the meaning of spontaneity, but in a nutshell it means sterility regarding any pre-existing intelligence.

Now we have the fundamental feature of life to use as a test in the search for its relatives: reproduction. Out of **MANY** various patterns of a living being, only **ONE** appears, and that new pattern is almost exactly like the one that gave birth to it.

As soon as we look at bio-life in this way, we can at once see that it stands by no means alone. It is in a company of video and sound tapes, computer files, books, blueprints, as well as—and here the family vastly expands—cars, styrofoam cups, clothes, toothpaste, and the absolute majority of man-made things, including copy machines, and also manners, customs, mindsets, and allegiances. The things which do not fit in the family stand by as art, from Mount Rushmore to sculptures by Rodin, including fine buildings, paintings, novels, movies, poems, etc., well, maybe just yearning for imitation.

A movie or a novel has no life in the sense a biological species has: it does not change even while going through the process of making copies, unless political correctness intervenes, as it was the case with some originally naked figures in Sistine Chapel. Art as a whole evolves, however, and the borderline between art and things, on the one hand, and art and life, on the other hand, is very diffuse.

Back to things, their mode of reproduction is different from that of organisms. Cars do not have DNA inside their bodies. Instead, they have external blueprints and technological procedures—coded information about their production at certain conditions. Their maternal organism is the assembly line.Both the string of DNA and the blueprint consist of a limited number of clearly distinct objects—nucleotides in the DNA and lines and points in the blueprint. Any blueprint, by the way, can be presented as a string of symbols that can be stored in a computer. For example, all two-dimensional illustrations in this book were generated by computer. They exist as strictly linear sequences of symbols.

Both DNA and file are highly ordered homogenous objects that are not subjected to the whimsical changes the living objects experience so often. *Quasi-solid* objects, they do not regularly undergo changes during their life span, maintain the bonds between generators, and are shielded by all means from any possible chaos. They can be read and materialized in their full-bodied *expressions* and need highly specialized tools for that: DNA needs enzymes and energy to envelop in a cell and the blueprint of a car needs humans, machines, and energy to be expressed.

The very first car had most major features of modern cars, as well as of a horse carriage and it is still recognizable more as car than a carriage. Each subsequent model was a somewhat different copy of the predecessor, although individual issues of the model were very close, almost identical. There is a certain variability even in things made along the same blueprint. Even between individual cars of the same model there are differences which made some owners happy and some desperate.

The big difference between a blueprint and DNA is that DNA usually encodes the enzymes that are the work force for their manufacturing, while the blueprint encodes neither humans nor machines—those have separate codes of their own, whether DNA or blueprint. The humans preceded cars and created environment for the man-made life of things, and the technology of auto-making takes humans for granted. The code of the life of things is fragmented.

Cars—and man-made things in general—could be compared with viruses that encode only themselves, but not the machinery for making them, while humans are nothing but **enzymes** that assembly the cars in the cells of automobile factories. To a significant extent cars—and man-made things in general—have already encoded, if not in the blueprints, the way of life of humans that we call **civilization**.

The design for a car—its quasi-DNA—is under a constant assault of the creative chaos in the brains of designers who produce new versions of the blueprint with improvements, innovations, variations, miscalculations, and cheap tricks.

All alternative designs are similar to a collection of individual DNAs in a population of organisms. The winners of the competition for life pass their DNA to the progeny. The defeated ones either lose it altogether or can hardly keep its marginal presence that may be of an advantage for the species in the future.

Equally essential is the fact that DNA is passed along in relatively independent packages called genes, each package being responsible for a certain feature of the organism. It is the same with cars: chassis, body, engine, lights, etc., are coded in relatively independent packages of blueprints which are similar to genes.

All genes in an individual form a genome, where two packages are related to the color of the headlights, sorry, the eyes, but only one is actually used to make them. All genes in a population form a gene pool where many packages exist for the design of headlights: round, square, double, retractable, etc.

The presence of multiple copies of the same DNA code in a *population* is essential for mechanisms of evolution: population is the library of variations, the stock of blessed inequality from which another George Washington or Thomas Edison can be resurrected when it is necessary.

A car can evolve gene by gene. Such mutant genes as anti-lock brakes, cruise control, etc., sweep through the entire kingdom of cars. Those blueprints can survive whose cars generate enough money (i.e., free energy of the man-made world) to start a new production cycle—and those DNAs survive whose organisms generate enough free energy (=food) to start a new reproduction cycle.

The concept of a non-biological gene called **meme** was explicitly formulated by Richard Dawkins in his classical book *The Selfish Gene* (Dawkins, 1989). "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 sperm 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."

Both the world of modern biology and the much better documented world of technology are a breathtaking collection of wonders reviewed in many popular books. One can find there amazing stories about the evolution of most common things, such as paper clip, for example, see Petroski (1994). I have to stop here, and not because I am a chemist and do not feel free to discuss biological or other problems in detail but because I am not interested in describing life by referring to its particular components and manifestations. All I want is to see life as a member of a **larger entity: the meta-life club**.

Let us first accept it as a metaphor: the code of our civilization, comprising all strings of symbols from DNA to textbooks, novels, and songs, incorporates human DNA. This particular part of the code is expressed as the humans: super-enzymes assembling all man-made things, writing songs and *expressing* (performing) them. The metaphor, however, looks more matter-of-fact statement if we turn our attention to the powerful and accelerating process of digitalization of Everything that we have been witnessing, from human genome to songs. The deep pattern meaning of the ongoing computer revolution is the genesis of the code of civilization.

> NOTE (2006): The immediate consequence is the vulnerability of the civilization to viruses which do not need energy in order to penetrate our cells: we provide it. Our social structure can be electronically corrupted practically at no cost and with much fun. Moreover, it can be corrupted spontaneously because of bugs and glitches.

If we go into details, the picture becomes more and more complex because details make biology, as well as manufacturing. We can escape complexity by moving so far away from the object that details become invisible. To see the elephant, we have to step back. To study the wrinkles on its skin, we have to come even closer.

Here I use the word "move" not just as a metaphor. The *Webster II* dictionary defines "to move" as "to change from one position to another." I understand it as a change of a position in any abstract space, not just in 3-D space of Euclidean geometry.

Pattern, bond, generator, time, energy, meme, temperature, mechanism, competition, etc., are gods in the Pantheon of Everything. The space we live in is also a member of a big family and, therefore, has a seat in the Pantheon.

We will make a digression in order to discuss the fundamental idea of space (Chapters 21 to 24), how to fit generators into it, and how to navigate in it. Having established the space and time of Everything, we will try to look for a physics that governs that abstract world.

Before doing that, we will take another mental flight over something larger than life, together with birds and stones.

*

20. LIVES OF BIRDS AND STONES

DNA is commonly compared with a blueprint of an organism. Here I would like to consider a more distant parallel.

Life on Earth had not existed until a certain moment in the past. The same is true about planet Earth itself: it had not existed, it appeared, it has been changing. If both the Rock of Earth and the Bird of Life have a certain life span and both can move in the air, what is the difference between the life of a bird and the life of a rock?

I am looking out of my window. Through the invisible **AIR** I see a **BIRD** on a branch of a **TREE**, a walking **CHILD**, and a **CAR** slowing down before making a turn at the intersection. Four large **ROCKS** mark the corner of my yard. They all are parts of a larger picture of an average summer **DAY** of my life, very much similar to yesterday and tomorrow, and still different from any other day.

Can all those objects—**AIR, BIRD, TREE, CHILD, CAR, ROCK**, and **DAY** be perceived and compared from a single point of view?

I see the bird, one form of life, in contact with the tree, its another form, both belonging to the same type of bio-life. When the bird lands on the rock, I can certainly see a great contrast between both. But I am looking for similarities, not differences, and I want, like a mathematician, to name both bird and rock with one name derived form the word *life*: meta-life, for example. It occurs to me that all those objects *exist*, and this is their way of taking part in something larger than bio-life.

Birds came to being and will be gone someday. This is true about any individual bird, as well as about the species. It is also true about individual rocks and, probably, rocks as a species. Rocks and mountains evolve too, although there is not a slightest sign of bio-life in them. A walk along a rocky seashore can give you a fine collection of pebbles in all stages of their development from chaotic shapeless pieces of matter to rounded, almost man-made, objects of an aesthetic flare.

Sand is the ashes of the rocks, the evidence of their evanescence. Transient are tree, child, and car. They all come to being, stay for a while, and disappear, having performed the drama of existence in three acts. Air seems to be eternal, but we know it came to being, too. Day dies and rises, as old as the planet itself, but not eternal.

What do they all do in order to exist? How do they struggle for existence and how do they manage to prolong it? Why are rocks and biological species so resilient, at least if man does not interfere?

ROCK: It does not *do* anything. Each year I find it on the same spot, looking same way under the growing ivy, accepting offerings from dogs passing by. The rock can sit there for many years and neither bird nor tree, nor even child can compete with its longevity. The rock is rock solid.

Rocks and mountains do not typically experience abrupt catastrophic transformations. They change slowly and gradually, remaining the same during long periods of time, comparable with the life span of biological species.

A way to characterize the rock's mode of existence is to say that it *makes copies of itself*, somewhat similar to what organisms do by reproduction, only *not in space but in time*. Each moment we find a new copy of the rock on the same spot. Life forms cannot compete with rock in this regard.

Remarkably, the rock evolves, too: the soil rises around it, accidental scratches appear, and a slow erosion takes its toll. Still, it is doing very well: if we take a year as a time unit, the Roman Empire did not make as many yearly copies of itself as Vesuvius keeps making.

There is nothing inside or outside the rock that determines its shape and position. The next owner of the house, however, can decide to carve a relief on it or remove it and dump somewhere.

The reason why the rock is so good at making its own copies in time is that the atoms and molecules forming the rock are bonded with very strong bonds. In order to maintain its integrity, the rock does not require energy. On the contrary, lots of energy are required to break the internal bonds inside the rock and grind it into gravel.

The rock, by the way, is its own DNA, so to speak.

CAR: It moves faster than bird but, like rock, does not *do* anything on its own, i.e., its behavior is almost completely predictable—almost, because of a possible breakdown. The car is not as solid as a granite rock. Being in contact with changing environment—from road surface to rain and frost—it wears out, rusts, and falls apart. In due time, it will die and will be changed for another one. Some of its organs will be fixed by transplantation or recycled after death.

The car is a thing. Nevertheless, the car as species can multiply. Like acorns, it is made in multiple copies and if this one perishes in an accident, another copy can substitute for it.

However solid and firm the car is, there is something even more stable—its blueprint which can easily outlive generations of cars and even be expressed again as a replica of an antique. The car makes its copies not only in time but also *in space*. It does even better in space than in time, especially in the hard everyday traffic. The evolution of the car, of course, is more vigorous than the languid progression of the stone.

Looking at the car as a blueprinted relative of a bird, one might wonder how the cars multiply. In a language similar to one that an ornithologist could use, they make their own tissues and organs from minerals found on Earth and for this purpose utilize certain objects in the environment. The existence of the objects called humans is closely dependent on cars and often is impossible without them.

AIR: as any gas, it needs either the walls of a vessel or the force of gravity to exist. This is not the case with cars and rocks held together by forces of attraction between their atoms and molecules. Molecules of air do not form bonds strong enough to prevent the spreading. Each molecule moves and explores the space independently. If not for the gravity, the solid walls of a vessel, etc., it would expand infinitely in space. Without a restraining force it is unable to make a copy of itself even in time. There is nothing *solid* in air. It is *fluid*, which means that it is *hot*, because solids turn into fluids when they are heated.

Unlike the rock, gas cannot make any exact copy of itself neither in time, nor in space. I do not mean here that the distribution of particles in fluid never repeats itself. Left on its own, without any walls and stoppers, gas just disappears, spreads over any volume, and never returns to its original condition, unless external efforts are applied or unless the temperature is low enough to turn it into a solid—a rock.

We do not see any change in a closed volume of gas because the time scale of molecular events is incomparably shorter that the time of observation. On the contrary, the evolution of a rock would take a fleeting moment for a creature with life span of billions of years. There is yet another reason why we cannot follow the intense chaotic internal life of gas or liquid: it can be expressed only in terms of positions and velocities of zillions of its particles, and no mind and no computer can follow them even for a droplet of water. To tell the truth, nobody would even need this kind of knowledge.

TREE: It needs light, water, and nutrients. It needs a lot to exist, but it is able to make an approximate copy of itself not only in time but also in space, by spreading its seeds. The seed is a capsule with the coded DNA blueprint of the tree and all necessary equipment to start making it.

A remarkable thing about trees, as compared with cars, is that they can do well—and often even better—without humans to propagate. Still, they contain a different version of the same objects as humans in relation to cars. The job of keeping the DNA blueprint intact, as well as assembling the molecules of both the tree and the blueprint, is done by enzymes. Enzymes themselves are coded in the DNA and the latter is an enzyme of a kind, too.

BIRD: Like tree, it needs food and other conditions in order to survive and make a few copies of itself. The bird is a survival machine for its DNA. We could say that about the tree, too, but the bird beats the odds not by making millions of eggs but by insulating just a few from the chaos of the environment and shielding them with its own body. It utilizes different objects found in their environment to build nests similar to human homes.

Unlike rocks, birds are not too good at making copies in time. If we trace a creature along a time line, we can see that it always disappears at a certain moment when the organism dies. Although during its life it copies itself in space, the copies do no better in time than the parent. Besides, birds constantly change shape, as the trees do too.

What rock and DNA have in common is the extreme stability, rigidity, and rock-strong durability of DNA which makes it similar to a rock. The similarity was first noted by the great creator and prophet of modern science Erwin Schrödinger who characterized gene (what we now call DNA) as an aperiodic *crystal,* a rock of a kind.

Schrödinger (1992), well before the advent of modern molecular biology, looked deep into the rock-solidity of life, its permanence, its machine-like concrete nature. It is the combination of fluidity and solidity that is necessary for any machine to function.

DNA is, actually, a solid formation presented by a single molecule. Its solidity means not only that the bonds between the atoms are strong, but also that its dimensions fall into the range of things, i.e., they are comparable with human dimensions.

As any solid body, DNA is stable only under a certain temperature. It stands cold very well and can be stored indefinitely at low temperature.

From the point of view of abstract temperature, organisms are refrigerators for their DNA. We cannot say that the refrigerator of the lion is more perfect than that of the bacteria because they are equally successful in their survival. The interference of a man, however, can change the picture very fast.

Here we bump into an apparent paradox: we are talking about a warm organism with the temperature above that of its environment and we call it a refrigerator! Although we have already discussed abstract temperature in Chapter, I would like to cast a second quick look at it.

The solidity is only one factor of longevity of things—the internal one. The success of existence depends also on a certain level of *something* that is exactly the external factor of longevity of things. In a museum, bank vault, liquid nitrogen, library, refrigerator, a quiet country like Switzerland, etc., this factor is very low, while in the open air, harsh traffic, violent neighborhood, red-hot oven, turbulent country, etc., it is rather high. We can call it meta-temperature, or just temperature, for short, when it is clear from the context that we mean it in a generalized sense.

While we usually say that the bird keeps the eggs **warm**, it actually keeps them **cool** enough so that they remain solid, intact, and their DNA does not melt down. What no living refrigerate can prevent is mutation, a change in the structure of the crystal.

Life around us is full of examples of what abstract temperature is. At the lowest temperature the differences between molecules or "molecules" are minimal.

When a high school in America tries to level out the differences in talents and abilities of students by eliminating awards or even grades, when universities decrease requirements for a special group of students, when scholarships do not depend on the scholastic performance, all that is a powerful source of cold, freezing the ingenuity, activity, and productivity of society. I am saying this not in any judgmental sense but only as a matter of fact. Whether it is good or bad, the society based on principles of forced equality will never be as dynamic as the one based on ladders of success and levels of energy.

CHILD: Like bird, it also needs external care and food. The happy child in a good family is insulated from the perils of this world even more than the chick. It is protected not only by the mother but also by the whole survival machine of the civilization, including medical care, education, law, and even the armed forces which might endanger lives of less lucky children on the other side of the world. The design of the machine of civilization is codified in books of science, technology, law, art, education, etc., as well in technical, legal, statistical, manufacturing, and other documentation. The machine exists in a single spatial copy and evolves very much like the big round rock of the Earth does. In a sense, the Earth and the civilization is one object, not two. We all—rocks, birds, and humans—are one evolving object.

Evolution is not an exclusive property of life. Planet Earth, together with the Universe, undergoes an evolution, which is as rich as the evolution of life. *The River that Flows Uphill* by William H. Calvin (1986) can be recommended as a comprehensive view of evolution in nature, which spans from Grand Canyon to brain, both considered evolving entities. We can understand Grand Canyon only through its history, and so the key to the mysteries of life and brain are in their origins.

DAY is not a thing, it is a complex phenomenon, as well as just a section of the twenty-four hour cycle of the rotation of the Earth. The word DAY is its symbol and the phenomenon day is the meaning of this symbol. To incite a controversy, the day is the natural blueprint of the word "day", and so are stone, bird, child, etc., in relation to their expressions in our mind because we do not make them with a blueprint in our hands. Daylight expresses itself in our mental image of a day, similar to how as a string of DNA expresses a bird. Knowledge is an expression of the hidden code of nature. If this paragraph is confusing, so can be the world of ideas, and so is nature before we have some idea of it.

Our present knowledge, with all its inconsistencies, gaps, contradictions, and fuzziness is *selected* from a pool of all other possible theories, descriptions, and explanations produced by the creative chaos of human brain. Nature selects our knowledge by letting survive only those components of knowledge that allow a new cycle of human life to resume on earth each morning.

With the images of both bird and stone moving through space, let us move to the question of what space is in the dizzying world of Everything.

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21. SPACE FULL OF ICE CREAM

The Everything is unthinkably big and it grows even as we speak. There is a way, however, to ease the burden of its complexity and to pack all of Everything into a magic box, so that all possible things could be pulled out of it, like the bouquet, handkerchief, and a couple of doves of a magician.

Naturally, for this kind of magic we have to look toward mathematics. Its real *forte* is exactly the ability to pack many things into one. One of the favorite magic boxes of mathematics is called space, and our familiar 3-D space is a particular case of something much more general.

Space is the primary stage where the drama of Everything unrolls in time, whether it is mostly by chance, as in inanimate nature, or by a mix of chance and necessity, as in life and history, or by order, as in clocks, cars, and computers.

In our physical environment it is natural to measure space by the yardstick and count time with a clock. The products of human mind—graphs, patterns, ideas, concepts, designs, hypotheses, fantasies, and myths—are clearly beyond the Euclidean space.

Before considering an abstract space that can easily accommodate patterns, entertain generators, and cater to bonds, let us start with two-dimensional space, the closest materialization of which is a sheet of paper.

2-D space is a certain way to accommodate a set of simple objects called points and anything that can be made by moving them around over a plane. To design the space, we simply assign to each point a pair of numbers called coordinates, so that there is a different pair of coordinates to each point and *vice versa*. Concerning the nature of what we call "assignment" or "one-one correspondence," it is sufficient to say that a certain connection exists between a point and its coordinates, albeit only in our mind. There is some material evidence of this invisible mental bond, however: if we find the word "coordinates" in a book, chances are good that "point" sits not far away. "Point," however, can be found also in a different company because it means several different things.

I can offer the following home-made definition of 2-D space:

A SET OF POINTS WITH **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND PAIRS OF NUMBERS. (1)

It means that we have two sets of numbers and there are as many points in the space as pairs selected out of the two sets, one from each. To define a space means to name with one name all its points. Definition 1 offers a procedure to list all the points of 2-D space by simply going through all pairs of numbers.

We can scale down our definition to 1-D space:

A SET OF POINTS WITH **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND NUMBERS. (2)

We can also expand, i.e., generalize it over as many dimensions as we wish. An N-dimensional space is:

A SET OF POINTS WITH **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND MULTIPLETS OF **N** NUMBERS. (3)

What does it mean to *generalize*, however? It is understandable that if we have Definition 3, we just substitute **1** for **N** and obtain Definition 2. In the same way, we get statement 1 at **N** = 2. But how can we *move* from one statement to another, for example, from Definition 1 to Definition 3? Where and how do we ***move*** and what kind of vehicle we use?

It may seem that I am talking about two different things—space and generalization. As a mater of fact, it is the word *move* that intimately connects both.

Whenever we move, we **move in a space**. When we think, something happens in space and time, although we build the invisible creations of our mind in spaces very different from the Euclidean one. Those are structures of our knowledge, science, philosophy, spiritual life, social organization, and even personal life. In our mind we can move through them as easily as a bird moves through the branches of a tree.

Following the concept of this book, I am **not** going to give any consistent **theoretical** treatise of space. All mathematics (as well as physics, chemistry, and biology) in this book is a home-made surrogate for the real good stuff that can be found in scientific and popular literature. Instead, I suggest a free visual walk over a picture of a certain mental landscape.

The common 2-D space was my starting point because everybody knew what it meant to move in it: this is how we travel over the surface of the earth. I will take a different approach to better understand what an uncommon space can be.

Any sentence, for example Definition 1, is a certain object.

If this is an object in space, what kind of space is that?

At this point, we do not care about the meaning and truth of the statement, and it could be a message from another galaxy. Our short superficial study tells us that Definition 1 contains the total of 80 "atomic" objects—we can call them "letters" and the space, some of them occurring more than once, so that Definition 1 is a combination of only 18 letters, including the space in the beginning and the end of the sentence, as well as between the words.

In the order of appearance, the symbols are:

a, s, e, t, o, f, p, i, n, w, h, c, r, d, b, u, m .

We can build other sequences with them, for example:

INFORMATION IS MEASURED IN BITS (4)

A MAN BITES A DOG (5)

MFID SDEN SW IAUT (6)

U NAS SUP NA OBED (7)

Sequences (4) and (5) are statements, but (6) and (7) do not make any sense. A Russian, however, would immediately recognize Statement (7) and interpret it as "We are having soup for dinner," although it is not written in Russian letters.

Each statement is a linear configuration built of letters as generators. Each letter forms bonds with its two neighbors.

A set of generators with just two bonds constitutes the magic box from which any sequence of letters can be produced, from *Moby Dick* to the tomorrow's weather forecast. Gottfried Wilhelm Leibniz, a great prophet of Everything, believed that the alphabet contained all human knowledge, past and future, true and false, together with gibberish (Leibniz, 1951, p.75). The letter generators, therefore, define a configuration space where each piece of text is a point of a sort because it is a combination selected from a set. Jonathan Swift described a Laputian machine built on the same principle for the same purpose.

The space defined by the set of 17 letters is too cramped for *Moby Dick*, of course. If we expand the list of letters to 26, plus punctuation marks, we will be able to build all sentences of the English language.

Of course, if we have seen only one sentence, we will never be able to imagine that other letters exist. We can conclude, therefore, that some configuration spaces are larger than others even without listing all their points. If we observe a sufficient number of sentences, we can make up a complete list of generators. The minimal difference between two linear configurations of the same length is one generator.

Naturally, there is an immense number of different sequences, some of them making sense and some not. The word "man" makes sense because there is a bond in our head between the word "man" and a multitude of creatures, mostly with two legs and no feathers (as Aristotle defined man) to which this word can be applied. The word "obed" has no bond with anything in our experience, although it rings the bell for a Russian, meaning "dinner". The word that sounds like "man" does not ring the bell for a Russian, although it could be an abbreviation.

In a natural language some combinations of letters are possible and some are not. The number of linear combination of six letters is 26^6, i.e., over 300,000,000. The total number of English words is, probably, much less. "Dinner" is possible while "Dniner" is not. Words twenty letters long are definitely rare, if any. Therefore, most of the *text space* is empty, which is an evidence of a significant oppressive order in it: letters are afraid to combine freely.

Definition 1 can be coded as printed text on this page, part of a computer file, carved in stone, translated into another language, tapped in Morse code, pronounced aloud, coded with figures of dancing men, presented as a molecule of a protein built of different amino-acids, or as a string of DNA that codes the protein that codes statement (1), and played on a violin. There is a large number of other ways to code it. Nevertheless, any of those objects and actions would have the same meaning as Definition 1 if:

1. The objects (protein, song, picture) consist of recognizable stable structural parts (generators).

2. There is one-one correspondence between the generators of the object and generators of statement (1), so that each letter of Definition 1 has its own symbol in a dancing man, a couple of amino acids, a cluster of musical notes, etc.

3. There is one-one correspondence between bonds connecting each pair of letters in Definition 1 and bonds between their symbols in the object that codes it.

The bond is just the simplest possible relation between two objects, i.e., something that could be either present or not. We do not need to attribute to a bond any "strength," although, as we will see, it is quite natural to do. We have already seen that the word "coordinate" tends to have the word "point" on a leash. The opposite is not always the case, and no wonder: a dog does not have its master on a leash (I realize it can be disputed).

As soon as we list all 26 letters of English alphabet, together with some other necessary symbols, as two-bond generators with one in-bond and one out-bond, we describe a space that houses not only statements (1) to (3) and (4) to (7) but also all statements of all literature in English known up to date and for a foreseeable future. An absolute majority of them are built of a limited number of low and upper case letters and additional symbols that could be found on a keyboard of a computer.

My computer keyboard has 46 typing keys. Taking to account the upper and lower cases, my “periodic table” of text contains 92 atoms—pretty close to the chemical one. This is the basic list of symbols in ASKII Code, numbers 33 to 125. The code, however, denotes much more symbols such as, for example, ¨, §, ℵ, &, ±, Σ, ☙, ☟, etc.

This is what space is about: we present a multitude of objects—most of them never seen and even impossible—as a list of well-defined atomistic objects—generators. We actually do the same when describing Euclidean space where the values of coordinates are generators.

Although it is easy to show that DINNER and DNINER are different because they correspond to different numbers, it is not always practically possible to enumerate in the same way all configurations in a certain space, for example, all constructs based on a Lego set. They are configurations and not numbers.

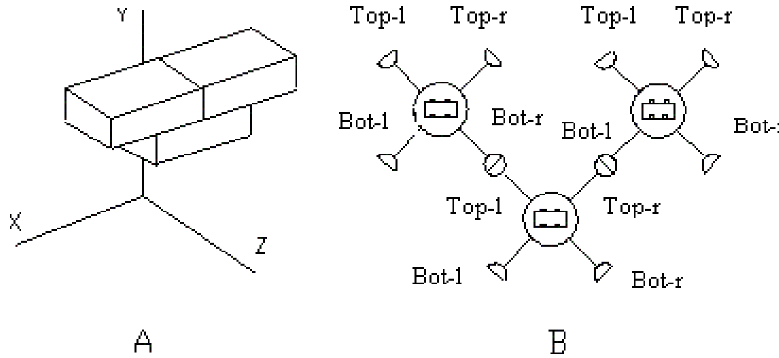

Figure 21.1. Generators of Lego. **Bot = bottom**

Figure 21.1A shows three connected bricks in 3-D space. We can list all their points, but it will not give us an idea about the way they are connected, unless we do some calculations. In **Figure 21.1B** the same construct is presented as a configuration of three generators. Each generator has two top and two bottom bonds.

A list of generators, therefore, defines a certain space of all configurations that can be built of them. A box of Lego or Meccano is, actually, a definition of a space written not in letters but in pieces of plastics.

Configuration space is much more abstract than geometrical space, but the idea is the same: it is a compact way to name scores of objects without listing them individually. Like we distinguish between different numbers by comparing them visually, we distinguish between two configurations built of the same set of generators by comparing either them or their representations. Operation **COMPARE** is built into all our fundamental under-mathematical concepts of **ONE**, **MANY**, **EQUAL**, **MORE**, and **LESS**.

We can understand the world and represent its picture by building up a list of generators and the rules of their bonding. This is how a chemist quickly understands a chemical formula he never saw before. This is how we understand a dangerous situation in a dark side street and the style of a new conductor in a symphony hall.

Space itself does not give any clue about what is and what is not *really* possible in it. For processes with matter, the answer is usually found in physical sciences. In general, we can assume that there is a certain meta-physics (not metaphysics) for any space.

Space is the mathematical way to set limits to our imagination and a tool to make a list of all we can imagine, and if we can imagine something else beyond this list, it will be a different space. To avoid the pseudo-philosophical jargon, the space of everything we can build of a Lego set is the set itself.

Most people may feel uncomfortable about the idea of multidimensional space that totally escapes visualization. It is because they expect to visualize such space in the same way as three-dimensional one. The best way to deal with multidimensional spaces is to imagine them as tables, where any line is a point, and the table lists its coordinates in appropriate columns. Any filled out business or office form is, in fact, a point of a multidimensional space, and a blank form is the space itself. The driver license is a point in a simple space, and a tax return of a billionaire can be an embodiment of an intricate space where the navigation without a good pilot is simply impossible.

The three-dimensional Euclidean space is the one where all physical and chemical processes display. What about other objects?

A space can be defined with any set of properties, not just numerical ones. For example, all people can fit into space with two dimensions, each dimension taking just two values: born either before or after January 1, 1970, and either US citizen or not.

As a reward for the readers who have made their way to this page, here is a treat: a space filled with ice cream.

In this space:

First coordinate means flavor, taking values: blueberry, raspberry, strawberry, orange, lemon, chocolate, vanilla, etc.

Second coordinate means toppings: toffee, nuts, chocolate, etc.

Third coordinate means shape or presentation: cone, cup, bar, sunday, etc.

Fourth coordinate means decoration: waffle, umbrella, cherry, cookie, etc.

This space can be packed into the following table:

Flavor	**Topping**	**Shape**	**Decoration**
Vanilla	Hazelnut	Cone	None
Lemon	Chocolate chips	Cup	Waffle
Coffee	Pistachio	Dish	Mint
…….	……	……	…..

For simplicity, in this kind of ice cream space, we do not use mixed flavors, toppings, and decorations. The space for any imaginable ice cream would have one coordinate for each feature with two values of each coordinate: 0 and 1 (YES and NO). It is still too abstract for real ice cream where, for example, two flavors can be mixed in different amounts. We can expand the space so that the feature coordinates could take a wide range of values starting from zero, for example, Hazelnut, 10%, Chocolate chips, 5%. In a similar way, any restaurant order can be presented as a point in a culinary space.

If we want to make a long-lasting ice cream space for the future, we can make it very large and very abstract, with coordinates such as: feature No. 1 (values from 0 to infinity) , feature No. 2 (values from 0 to infinity) ....etc., feature No..., etc. Obviously, such a space is an ultimate abstraction that can accommodate virtually any object, not necessarily a serving of ice cream. It can hardly have any use because it is too general.

Taking another example, not only a text but also each of its letters printed by a word-processor is a point in the space with following dimensions:

1. Position in the alphabet (or in ASKII code): a,b,c,d...z.
2. Capitalization: no, yes (0, 1).
3. Size: 3, 5, 7.... etc.
4. Bold: yes, no.
5. Font: Roman, Sans-serif, Italic... etc.

Another example of space is Drivers License Space (DLS). It has the following coordinate axes, at least in the state of Rhode Island:

1. License Number.
2. Class.
3. Date of Birth.
4. Sex.
5. Height.
6. Restriction.
7. Expiration Date.
8. Name.
9. Address.

Therefore, a driver is a point in the space of nine dimensions. Some of them, like sex, take only two values, for some extra-terrestrials, maybe, more. Others, like name and address, take an indefinite, although also limited, number of values.

Meaningful distance can be determined along the age axis and height: some people are older or taller than others, or both. With the help of a map, we can even introduce two geometrical coordinates instead of address. But it is not obvious how to define distance along the name axis, unless we code a name as a number. It is very natural to do so, because this is how human names are stored in computers, but this distance has no "physical" meaning: nothing else seems to depend on it. It is not so in a country with ethnic discrimination, where the name carries the tag of its ethnic origin and may bear some consequences for the person. My school teachers often mispronounced my name, Tarnopolsky, because there was a very **close** name Ternopolsky. The distance between linear sequences is measured by the number of differences (Hamming distance, see Chapter 25) or necessary substitutions to make the strings identical (Levenshtein distance). The Hamming distance between the two above names is **ONE**.

If we characterize drivers as good and bad, good drivers will probably not populate Drivers License Space evenly. The probability to find a good driver will be higher in certain areas of the space.

Even the alphabetical arrangement of names could carry some meta-physics. When I come to a bookstore and look at the books arranged alphabetically by author, I start with A. Then I notice that I am somewhat tired when I come to M and N and I look at the rest of the books with less attention.

The size of a name may matter, too. Since my name was longer and more difficult than the average, in high school I was called to the blackboard less often than other students.

Mind is a device for bonding. Sometimes mind breaks bonds, such as the bond between the wrath of Zeus and the lightning, but mostly it ties ideas together. For example, to say "space" is to save a lot of words, like saying "sunset" instead of "gradual decrease of the visible distance between the sun and the line of the horizon." Space is a powerful complexity-compactor for Everything.

As yet another illustration, I am going to pack both clouds and elephants (see Chapter 8) into the same space of **clouphants**.

Clouphants	**Size**	**Color**	**Shape**	**Speed**
Clouds	Big	Gray	Rounded	Slow
Elephants	Big	Gray	Rounded	Slow

Can you say now that clouds are not elephants? This is how metaphor and other tropes work.

With all their differences, spaces as different as Euclidean, Drivers License Space, phase, and configuration ones, have one fundamental thing in common: they all are combinatorial in nature. An object in space is a **combination** of certain unchangeable objects (generators, atoms, coordinates, flavors, etc.).

The number of combinations is always larger than the number of generators. This is how we can pack the complexity of Everything in a magic box. We take Everything apart and put one sample of each generator in the box. The procedure is described in the Bible, and when Noah had unloaded his Ark, he pulled out of it much more than two doves.

Throughout history, we had not been able to imagine and foresee certain things that appeared afterwards. If new things, like laser, computer, fax, internet, appear all the time, how can they fit old spaces?

For example, some time ago there was no space to fit the airplane, car or textbook of nuclear physics. A car certainly exists in a space with such dimensions as small, medium... etc., sedan, coup, etc., number of cylinders, etc. Two hundred years ago there had been no way to imagine anything like the car, even a toy one, but the car popped up out of nowhere and created its own space.

The answer—controversial—is that any space is a product of our mind. Like any other product, it undergoes an evolution. We constantly invent new generators and new types of bonds. Considered as patterns, creations of our mind are not much different from the creations of our hands. Naturally, each new generator expands the configuration space.

Physics, by its very nature, has to define space before starting inference: the pre-condition of any science is that the subject of discourse does not change during the reasoning. From my (home-made, of course) point of view, evolution is the **expansion of space**: generator space and configuration space, to be exact. This makes the chasm between physics and humanities even deeper. Only astrophysics can lend a sympathetic ear to humanities.

What can be the mechanism of such unusual things? We will return to the central problem of this book later. Next we are going to consider a very abstract idea of phase space developed by physics to describe an apparently very complicated system.

*

22. PHASE SPACE

NOTE (2006): Beware! I am taking outrageous liberties with the concept of phase space here!

Phase space is a very general physical concept. It is a space designed to store a dynamical system in time. As a very remote metaphor, a description of a human life—what the person did and what he or she did not—is an area in a "phase space" unevenly populated by events and acts. Thus, my personal space is empty in the area of parachute jumps but is filled in some other uncommon areas. What is important, my life is a **trajectory** in this multidimensional space, as linear as a DNA string. Each its point is a moment in time. My life cannot be exactly replicated, but its very abstract patterns can. Thus, to be divorced and remarry is quite common.

As an example, we will take something else very far from physics.

Let us imagine one thousand heavy trucks trudging along American roads. This time we are interested not in personal data of truck drivers but exclusively in the movements of their vehicles.

Naturally, the position of any truck can be presented by a point on the map, one for each driver, with two coordinates. For one thousand trucks there will be one thousand moving points on the map, with two thousand coordinates. A computer can handle all this information. Provided the location of each truck is monitored, the information will be printed out as a table with one thousand rows (one for each truck) and two columns (one for each geographical coordinate). It could be updated by printing out the table as often as we need. The system, therefore, is represented by a growing pile of reports.

The idea of phase space amounts to representing the state of the system consisting of 1,000 moving vehicles as a **single point** in a space of 2,000 dimensions, each dimension being either **X** or **Y** coordinate of a truck. Each distribution of the trucks over the roads corresponds to one point in this space.

The 2,000-D space is easier to imagine than to handle: it is just a table with a growing number of rows and 2,000 columns. Each row of the table corresponds to a position of the trucks at a certain moment of time and, actually, lists all 2,000 coordinates of the so-called representative point. The row of the table, therefore, contains all the coordinates at a moment of time.

Instead of a multitude of scattered moving points, we have to "watch" just one moving representative point. Note that the representative point for moving points is not able to jump over the space: its position next second will be close to the current one because the trucks neither jump nor fly.

The power of the concept of the phase space is obvious when we have an enormous number of moving objects, for example, molecules of gas. While the truck driver is pushed by his schedule, as well as by the whim of his human nature, the movement of a single molecule is governed by simple laws of mechanics and, theoretically, is completely predictable in the short run. All we need to know to calculate the position of a molecule **next** moment $t+1$ is its position (coordinates **X**, **Y**, and **Z**) **this** moment t and the direction and velocity of its movement, usually expressed as three components of its momentum ($\mathbf{p_x}$, $\mathbf{p_y}$, and $\mathbf{p_z}$). It means that each molecule has six coordinates, and the phase space of **N** molecules has **6N** dimensions. The **representative point** of a volume of gas moves through the phase space of so many dimensions that it does not even matter exactly how many.

Molecules of gas are a typical example, although the concept is much more general. Movement of the representative point through phase space is a picture of a change of any system consisting of many components. It does not matter how many dimensions we have. For the purpose of visualization, we can do with just two dimensions and illustrate the concept on a sheet of paper.

However difficult the idea of phase space may seem, as soon as we get used to it, it makes it easy to discuss some difficult questions, for example, the essence of what chaos and order are.

In a completely chaotic system, such as an idealized gas where molecules are completely independent identical balls of a negligible size, the representative point travels all around phase space. Since each point of the space is a certain possible state of the system, it means that the system has no forbidden states: no borders are drawn in the phase space, no fences raised, and no limits imposed. The density of points observed over time is uneven, however: the areas corresponding any **uneven** distribution of gas molecules over the volume are practically empty: such states are improbable.

Suppose, the molecules are attracted to each other. The energy of their chaotic movement (which is the same as to say "heat") keeps them apart. When we freeze a volume of gas in a bottle, it turns into a liquid. The molecules of the liquid move around, leave the interface, and come back from the vapor over it. The available geometrical space for the molecules is as big as when they were in the gas form, but now the areas of even distribution of molecules over the volume are almost empty: the representative point cannot visit them. At low temperature such states are practically impossible.

Phase spaces of gas and liquid are shown in **Figure 22.1.** Simply speaking, when the distance between molecules is large, there are much more different states than when they are tightly packed: one cannot dance in a tight crowd where everybody is pushed by all his neighbors.

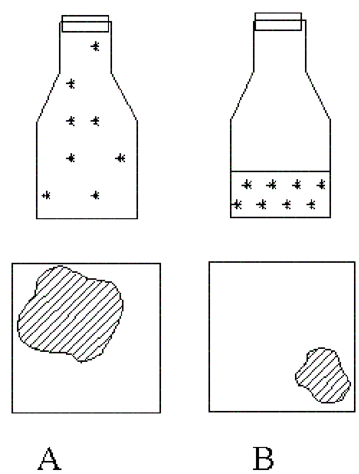

Figure 22.1. Gas and liquid in phase space.

The same applies to the molecules that form a bond between each other. In any state of the system at a low enough temperature part of the molecules is always bonded, and part is always separated, and although bonds break and close, the bonded and separate states are in equilibrium. Therefore, the areas of the phase corresponding to a complete absence of bonds are not practically accessible to the representative point.

As an example of something **practically impossible**, let us say that all American trucks at a given moment are on the roads of the state of Utah. Theoretically, we can imagine it—a rally of a kind—but practically it is impossible albeit for one reason: a couple of trucks can always break down on the way from Florida to Utah. Besides, while the truckers are moving to Utah from all around the country—it can take several days—they can cool down and change their minds.

Of course, if the total volume of the phase space is small, as when we have only a small number of molecules, anything can happen. The concept of phase space is meaningful only when the volume of the space is very large and when the laws of large numbers apply—which by no means apply to an individual human life.

Why then am I force-feeding the phase space on the readers? We can say, vaguely, that whatever kind of phase space or a related metaphor we consider, order is the ratio of the volume that the system *really* occupies in its phase space to the volume of the entire phase space. The highly ordered system will always wander inside a relatively small part of all possible positions, which is as to say that its representative point will walk tortuous trails along many fences and forbidden areas. The chaotic system, however, will spread all over a very large number of points of the phase space.

Chaos, from this point of view, is the ratio of possible to possible plus impossible. The higher the ratio, the more chaotic the system is. The less the ratio, the more order it harbors. Well, we have come to the **ONE-MANY** mantra again: the system is more ordered the more realistic area in the phase space is compressed, when among **MANY** green pastures to frolic the representative point—or our soul—is confined to **ONE** small corral.

The question arises: what if we had never seen any gases and knew only about liquids and solids? Could we have imagined a phase space larger than that of liquids? I believe so. We could do that just by manipulating words (and the ideas attached to them) and handling them like pieces of a Lego.

We could say:

1. PHASE SPACE OF LIQUID IS LARGER THAN THAT OF SOLID.

2. LIQUID IS A STATE OF MATTER.

3. SOLID IS A STATE OF MATTER.

4. THEREFORE, **ONE** STATE OF MATTER CAN HAVE PHASE SPACE LARGER THAN ANOTHER.

5. **X** IS A STATE OF MATTER

6. PHASE SPACE OF **X** CAN BE LARGER THAN THAT OF LIQUID

Whether our mathematical extravagances have a meaning outside themselves, it is the subject of *a physics*, or, more generally speaking, natural science. Wherever we acquire a parcel of in a space, be it abstract or not, a certain physics digs ditches, paves out narrow pathways among thorny bushes, rams in poles, and nails down picket fences, so that the former free space is not suitable for playing mental football anymore.

While non-bonded objects are by definition independent and, theoretically, all can change their position in 3-D space, a **bond** does not allow for that kind of freedom anymore.

In the material world the acts of bonding and unbonding are relatively rare events at a medium temperature. This is why a simultaneous bonding or unbonding of many bonds is practically improbable. Neither the molecules of the mouse can suddenly rearrange into the sparrow, nor a stone can change its shape. When molecules of a snowflake rearrange into a tiny droplet or the opposite takes place, it happens not only because temperature changes, but also because both are simple: all generators (molecules of water) and bonds are approximately the same. A drastic change of a complex object with many bonds is a catastrophic event usually meaning the end of the object.

However big the dips of the stock market may seem to those who witness them, on the long term performance plot, they all are small. Although we can imagine cataclysms of any magnitude, they are rare in nature because of its consistence and coherence. Only life is prone to dramatic events such as extinction of dinosaurs, plague of the Middle Ages, and Hiroshima. Yet even those catastrophes could not disrupt life on earth as a whole.

The behavior of the mouse is different from the behavior of the molecule. While a molecule flies over the entire available space and with time covers it all, so does a representative point of a multitude of molecules. Any living being, however, shows a combination of chaotic and highly ordered behavior. The meals of a dog are separated by substantial intervals of time, and it is impossible that a healthy and happy animal takes several meals in a row or does not touch available food for several days. The behavior of a dog is predictable if not in every detail but in many general features. For example, it inhales and exhales with an approximate regularity. The dog's heart beats at a certain, although fluctuating, rhythm. In other words, we can project meaningful statistics about a single dog, but no exact prediction can be made.

We cannot predict when the dog will fall asleep or wake up, raise its head or turn it to the right, but we know that this will happen within a day. If any action of the dog is considered a generator, we can build a configuration space for dog's behavior. Since any sequence of actions is a linear configuration, any such configuration is a kind of point in the configuration space. Not all the areas of this space are occupied and, for example, the following sequence is impossible:

— OPENS EYES — FALLS ASLEEP — EATS — OPENS EYES — CLOSES EYES — CLOSES EYES —

One cannot close eyes two times in a row without opening them, as well as eat while asleep. Generator FALL ASLEEP does not form a bond with a subsequent EAT, although the opposite is possible. The generators of animal behavior are subjected to a certain **physics** too. Physics is the map of the possible framed by the impossible.

Diagrams, plots, spreadsheet, Dow-Jones Index, etc. are necessary constituents of our life. The stock index plot, however, cannot take all possible shapes. What is "really" possible in a given space and what is not is subject of a particular "real" science, each having its own "physics."

When we follow the behavior of the truck drivers on the map, we notice that they cannot be found in most areas, only on the roads. It says something about the highly ordered nature of transportation. The representative points will **ALMOST** never populate some areas of the phase space. There is always something **ALMOST** impossible … today.

A spontaneous gathering of many scattered molecules that constitute a bacteria into a living or even dead bacteria is impossible today but could be possible in some form in the future.

When physicists made their initial attempts to apply physics to life, the improbability of life bothered them very much. They started calculating the probability of accidental assembly of a protein or a string of DNA. The number of different proteins made of 20 kinds of amino acids, assuming each protein is 100 amino acids long, is 20^{100}; the number of

DNA sequences long enough to code a protein of this length is 4^{300} or 10^{180}. To wait for such a rare event as drawing a single lucky ticket out of 20^{100} empty ones is hopeless.

Physics showed that if free energy is pumped into a system and heat is dissipated by the system, molecules can assemble into a bacteria. However, a necessary condition was that at least one bacteria should be present at the very beginning of such experiment. Physics was good at describing complex chaotic systems, but had no conceptual apparatus to treat complex ordered systems in detail. That was the domain of chemistry, biology, linguistics, and sociology.

The most fundamental property of ordered systems such as life, language, etc., is that they do not fill up the entire volume of the phase space. It is also true in relation to any space, not just the phase space. Known organisms do not realize even a tiny part of all possible combinations of cells and organs. The reason is that neither they nor their components assembly from a set of scattered generators. They are **gradually built** from simple **small** combinations, in **small** configuration spaces, by adding more and more units, following a **small** number of rules that do not leave room for arbitrary evolution. I hereby induct **SMALL** in the Pantheon of Everything. Alas, **BIG** is there, too.

*

23. THE LANGUAGE LEGO

Most of us play the Lego of language everyday without even being aware of it. The concept of language as Lego was one of the tacit assumptions of structural linguistics developed by Noam Chomsky (1971) and others. The words adhere to each other and form statements according to a set of rules called *syntax*, a Greek word meaning *putting together*.

Even when the words seem meaningless, as in *Jabberwocky* by Lewis Carroll, we can see that the rules of affinity made visible by a few such connecting words as *and, the, did, in,* etc., hold the poem together:

Twas brillig, and the slithy toves
  Did gyre and gimble in the wabe;
All mimsy were the borogoves,
  And the mome raths outgrabe.

As this celebrated example shows, meaning is separated from grammar. The main structural blocks of a sentence are actually nameless shells of words capable of forming a relatively limited number of structures according to the rules of syntax. Various words from the dictionary, as well as new and non-existing words could be put inside the shells, like filling into ravioli, without any change in the pattern.

The meaning of words is the subject of semantics. Generators of meaning belong to a different set and they have different properties. Various meanings form not grammatical but semantic patterns (Chapter 16), and here we are taking another look at them.

In terms of pattern theory, words are generators of the language. If we compare language with a set of plastic Lego pieces, a sentence is a structure with words written with a marker on the sides of the pieces. In a different sentence one or several word markers could be erased and other written instead.

Let us consider the following statement as example:

LANGUAGE is a SET of LEGO PIECEs that FORM VARIOUS STRUCTUREs.
or: **A** is a **B** of **C** **D**s that **E** **F** **G**s,
where **A** is LANGUAGE, **B** is SET, **C** is LEGO, **D** is PIECE, **E** is FORM, **F** is CERTAIN, and **G** is STRUCTURE.

Yet the blocks **A** to **G** could mean something totally different.

Statements, myths, folk tales, novels, poems, and soap operas, as well as many other products of human creativity that can be passed from one individual to another, have the skeletons of algebra-like formulas inside, with various substitutions instead of **a**, **b**, **c**, etc.

We can use other blocks for the same pattern, provided they have same pegs and holes to snap together:

Statement A. STARCH is a SEQUENCE of GLUCOSE UNITs that FORM LONG CHAINs, where **A** is STARCH, **B** is SEQUENCE, **C** is GLUCOSE, **D** is UNIT, **E** is FORM, **F** is LONG, **G** is CHAIN.

Statement B. FATIGUE is a PERIL of HIGHWAY DRIVERs who DRIVE LONG DISTANCEs, where connective **who** is used instead of **that**.

The family of connectives like **who, that, which**, is incomparable smaller than that of interchangeable words, and the connectives are not used freely.

Statement C. DRIVER is a FATIGUE of HIGHWAY PERILs who DISTANCE LONG DRIVEs, which is a jumbled **Statement B**.

Statement D.

AROR is a SOR of PROCTs that SID OLG MIVEs.

(AROR is a SOR of PROCT that SIDs OLG MIVEs is different!)

The absence of meaning of the key words in **Statement D** cuts us from anything else outside it. What remains is the familiar relation between the strange terms.

Paradoxically, we can make statement D more meaningful by adding more "meaningless" statements:

Statements E. Mives feen on stamms. Ptar feens on axters. Stamms and axters are feep. Stamm is a sor of feep.

One could even correct this abracadabra: probably feeps, not feep.

We can even build a semantic network based on **Statements D** and **E**, see **Figure 23.1**.

Each generator is denoted by a small circle placed on a larger one like a bead on a string. By this particular "circle of friends" or "round table" symbolism I wish to emphasize the equality of all generators constituting a set of Lego. Any generator can form a bond with any other on equal conditions, if the rules of connection allow, and new generators can be added because as the members of the circle they are all equally close to each other.

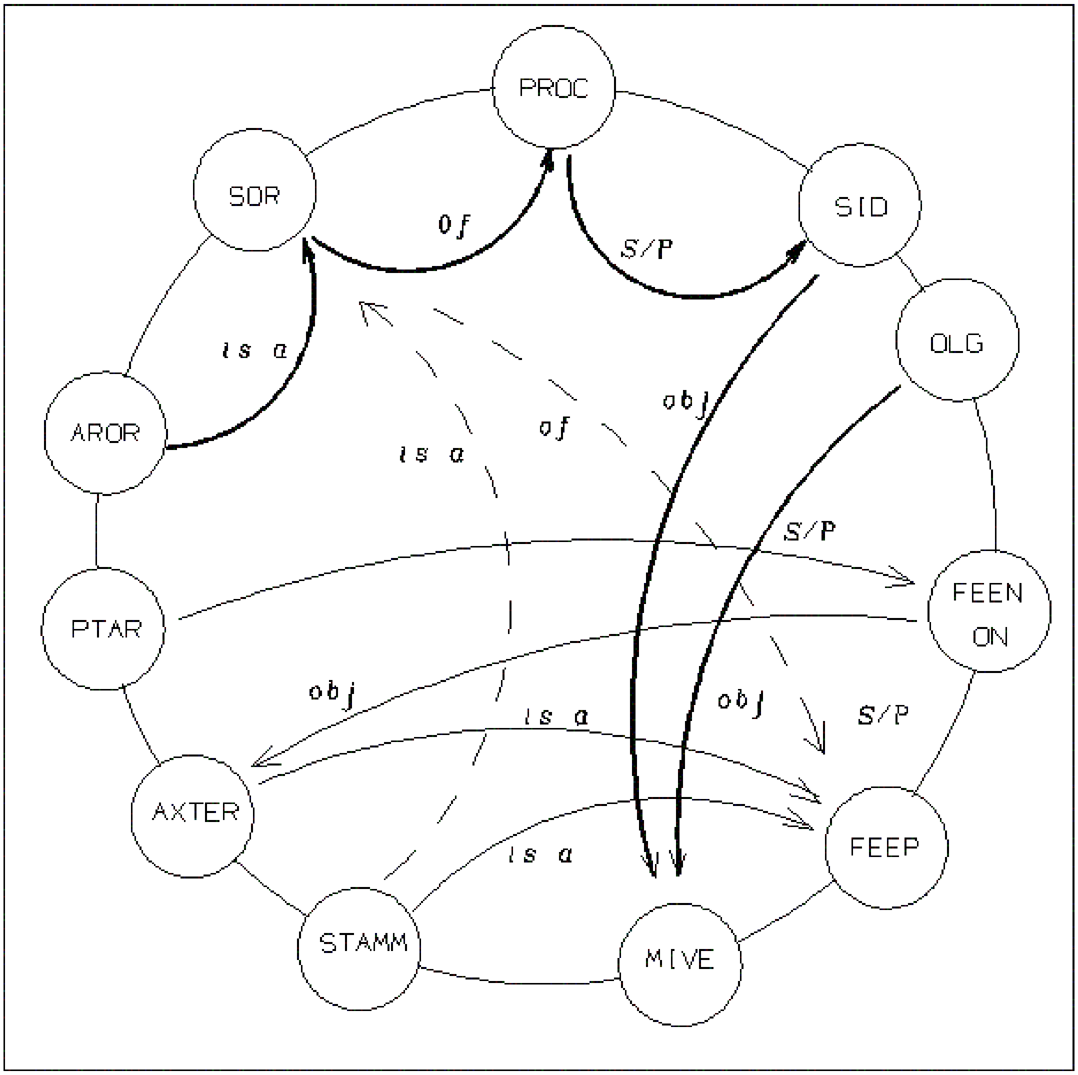

Figure 23.1. Meaning of the meaningless

Inside the circle I show bonds with lines of different types to avoid confusion. Therefore, instead of drawing a bond *feen* between PTAR and AXTER, as in typical semantic networks, I draw bonds from PTAR to FEEN and from FEEN to AXTER in dotted lines so that it can be distinguished from similar bonds between MIVE, FEEN, and STAMM.

S/P bond means the bond between subject and predicate, *obj* connects a verb and its object, and *of* means a somewhat vague relation of belonging to a class or having a property. All I am interested in is the very fact of bonds between some generators, and there is no need to trace all the connections.

The common semantic connections follow from this notation if we use the "vector addition" of bonds oriented in the same direction. For example, the connections AROR->[*is a*]->SOR->[*of*]->PROC is equivalent to AROR->[*is a sor of*]->PROC and PROC->[*S/P*]->SID->[*obj*]->MIVE to PROC->[*sid*]->MIVE.

Suppose, we learn that:

Statement F. STAMM is a SOR of FEEP.

We can, probably, suspect that:

Statement G. AXTER is a SOR of FEEP.

Moreover, we can even interpret SOR of FEEP as "sort of food," although we can never check that unless we visit the strange world, and even then the food there may look very different.

In this way we decode not only a strange *language*, but also the strange *reality* that is described in that language. If so, what is the difference between decoding our perception of the real world and decoding a poem by Lewis Carroll?

I believe there is no principal difference. The bonds of patterns in one configuration space somehow help select bonds in another configuration space. This is how we *understand* the world or a text and can transform it into a description or translation .

To understand an alien world means to build a pattern of a semantic network around it. Using a distant analogy, this is how an immigrant to America from a country with a different culture understands the new environment. It is never productive to translate the new reality in familiar terms, all the more, in the native language. The immigrant simply connects strange new axters and stamms with equally strange arors and ptars, using more or less universal connectives.

Remember, I said that I would point to myself and say my name, walk and say "walk" (Chapter 1) ? There is a bond between a live cat and writing or saying such words as cat, Katze, chat, gato, and koshka. There are two pattern universes living according their own laws, real world and our symbolic presentation of it, and both worlds are connected with mostly but not always parallel lines, and, amazingly, have a great influence on each other. Textbooks, papers, and documents on nuclear physics were generated by observing objects made of glass and metal, and a sequence of words resulted in nuclear explosions.

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24. TOWARD CHEMISTRY OF EVERYTHING

Even a modest box of Lego contains a cornucopia of structures so rich that we can hardly enumerate all of them. We do not see them when we open the box. Nevertheless, they are there. How are all of them stored in there? What is the process of their extrication from the invisible form? We can ask the same question about chemical structures—known, yet unknown, and those that will never be known—stored in the Periodic Table of Elements.

The list of all atoms contains in a compressed form all chemically identifiable matter. Chemistry has been busy with unzipping it for over a century of playing with the chemical Lego, yet we still do not know all the rules of connection and we learn more and more about atoms. Even when a chemist has a clear picture of a pattern, for example, in the formula of a certain natural compound found in a plant, it can be a big challenge to synthesize the molecule in the lab in an economical way.

Like a box of Lego contains, *in a sense*, all that can be built of it, a set of generators contains, *in a sense*, a continent of Everything. In order to specify in what exactly sense, we use the word *space*. All possible patterns somehow exist in that *configuration space*, like the mundane blocks of Lego exist in the 3-D space. Generators plus the rules of their connection form a configuration space whether we know what is in that space or not, and even if we will never know—which we cannot know in advance, of course.

Space is a way to name an infinitely long list of all possible things of a certain kind with one name. Mathematics names all points of a curve with the name of its analytical formula. It cannot be done with a plot of a Shakespearean drama, but all dramas are built of the same blocks from a slowly expanding box. Some subspaces of modern drama have very loose bonds.

All patterns are folded, crumpled, compressed, tightly packed, and stored, *in a sense*, in the list of their generators.

In a completely defined set of generators we have, actually, in a packed form, all things we can build from it. For that we need a procedure for unpacking. For a limited Lego set, we can build all possible structures, at least, by purely random connecting. For more complex sets of generators we can do well by keeping most of the pattern intact and playing the random procedure on its part, then going to another part, and so on.

The act of pulling out a particular configuration from the magic box of the space is what I call *generation*.

Two questions could be asked here:

Question 1. A configuration space, for example, that of a plastic Lego or a language, may contain enormous numbers of potential configurations. When we utter a sentence or build a castle, we make a possible pattern a *real* one: we *generate* it.

What is the **process** of generation of a pattern? What makes a child combine Lego pieces into an *actual* structure, atoms combine into a *real* molecule, words combine into a *particular* poem, aror and ptar combine in a picture of a *certain* world, and the drama blocks combine in a play by Eugene Ionesco?

To rephrase this question, **how does something come out of the ghost world of universal possibilities to the day light of existence?**

Question 2. What is the **process** of understanding, i.e., how the bonds of a pattern in the mind form under the influence of the pattern of reality? To rephrase, how something thriving in the day light of existence casts its shadow into an individual mind?

Our two questions fall under a more general question: what is the chemistry of Everything? How can configurations change and interact and how can they do that if they belong to configuration spaces as different as the material world and the mind?

(**Aside**: Omygod, I have already mangled physics, am I going to do that with philosophy?)

With the word *process*, time enters our discourse and we have to look for a certain physics. Even if we call it meta-physics, isn't it a sacrilege to talk about processes in a space where we cannot measure anything with a ruler? Even if we call it meta-chemistry, what kind of stuff is something we cannot weigh with a balance?

Next I would like to make a digression in order to illustrate, in a preliminary manner, how a certain physical chemistry can display in such an immaterial space as the Lego of language.

Let us take somewhat clipped statements 2 and 3 from Chapter 21, call them statements **H** and **I** and transform statement **H** into statement **I**:

Statement H. **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND NUMBERS.

Statement I. **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND MULTIPLETS OF **N** NUMBERS .

Substitution of one group of atoms for another is a typically chemical phenomenon. This is how it goes with words:

We know that:

point	is an	object
number	is an	object
pair	is a	multiplet
triplet	is a	multiplet
object **A**	is an	object
object **B**	is an	object

Each statement of this kind means that we can substitute a term from the right column for a term from the left column and vice versa and the grammar will not be violated.

Therefore:

Statement J. **ONE** TO **ONE** CORRESPONDENCE BETWEEN POINTS AND MULTIPLETS (instead of PAIRS) OF OBJECTS (instead of NUMBERS).

I am not sure that a logician can see the parallel between generating ideas and generating molecules, but a chemist certainly can.

Chemical reactions are driven by certain changes in energy. Is there anything like that in the realm of words?

As an introductory look into what meta-energy can be, let us compare the following two sentences?

Statement K. IF YOU DRINK A MIX OF COFFEE AND TEA YOU WILL IMPROVE YOUR MEMORY.

Statement L. THE ELEPHANTS IN THE ZOO TALK TOO DEFIANTLY.

The first one (**K**) does not contradict other statements in our memory, while the second one (**L**) does because we know that:

Statement M. ELEPHANTS DO NOT TALK.

Let us attribute a certain value of **E** (stands for both ERROR and ENERGY) to any couple of statements. We will count it up or down from zero value, and we assume arbitrarily that **E** of **Statement K** is zero. We assume that if two statements contradict each other, their combined **E** is high, and *vice versa*. Then **E** of **Statement L** will be **MORE** than zero (in our own mathematics) because the sentence ELEPHANTS DO NOT TALK (**M**) that we keep in our memory does not form any bond with sentence **L**. They, so to say, repel each other like similar poles of two magnets. The combination of **L** and **M** has a high energy, and if we do not use force to reconcile both sentences, their coupling will be unstable. The Lego pieces of our extended knowledge about elephants do not stick together.

Suppose, this were true:

Statement N. ELEPHANTS TALK.

Then we could substitute ELEPHANTS IN THE ZOO from **Statement L** for ELEPHANTS in **Statement N** and do the same with TALK TOO DEFIANTLY and TALK. We would obtain **Statement L**, but this transformation would not increase **E**.

What we know about tea and coffee neither contradicts nor confirms **Statement K** which is a *hypothesis* about properties of coffee-tea mixes. In general, it is possible that if two components do not possess a certain physiological activity, they will get it when mixed. Therefore, **E** of **Statement K** is, actually, close to zero and it looks like a legitimate hypothesis that can be proved or rejected. This explains the perennial popularity of snake oil.

E is the measure of attraction and repulsion of statements. Any statement on its own is **stable**, but two sentences can either contradict each other or comply, not necessarily in all-or-nothing terms.

Our knowledge, which is a mix of true, probable, irrelevant, and erroneous statements, evolves toward the state of a lowest **E** exactly as a chemical system would evolve toward equilibrium. If the energy is pumped into the society, illusory or irrelevant values and truths can persist and even bring the society into turmoil. A speech of a talented defense attorney can reconcile apparently irreconcilable pieces of knowledge and lead to exonerating a criminal. Same can happen with convicting an innocent by a prosecutor.

The "non-physical" energy **E** is just a value that is low for a bond and high for non-bonded attracting generators. We can imagine that for some bonds it is just the opposite: energy is high when the bond is formed and low for non-bonded but repelling generators (Chapter 26).

Coming again back to the key point in the picture of Everything, the idea that I wanted to express here is that our logical thinking, i.e., thinking along certain rules, has a parallel in building objects of Lego blocks. In other words, our thinking is a chain of transformations of configurations. Therefore, it might have some parallels with chemical transformations of molecules **driven by changes in energy** [i.e., **stability** (note of 2006)]

At this point we have a number of new questions and insights about the Everything. We shall try to answer them one after another.

Next, we will come back to the problem of movement in an abstract space, because there is no physics without movement.

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25. SPACE WALKS

In **Figure 25.1** we can see twenty small pictures numbered using letters **A** to **D** for the row and numbers 1 to 5 for columns.

Pictures **A1** and **A2** demonstrate a walk over a structure in 2D space, with two consecutive positions of the walker moving along an edge of the structure. There are many such positions along any line, and distance can be measured the way we are all used to: by yardstick. This is what means to move in 2D-space.

If we consider walking over graphs, see **A3** and **A4**, the walker can only jump from one node to another because graphs have no metrics and no Euclidean distance. Nevertheless, we can measure a discrete "distance" by the number of nodes along a certain pathway. This applies to movement over a graph or, more generally, a configuration.

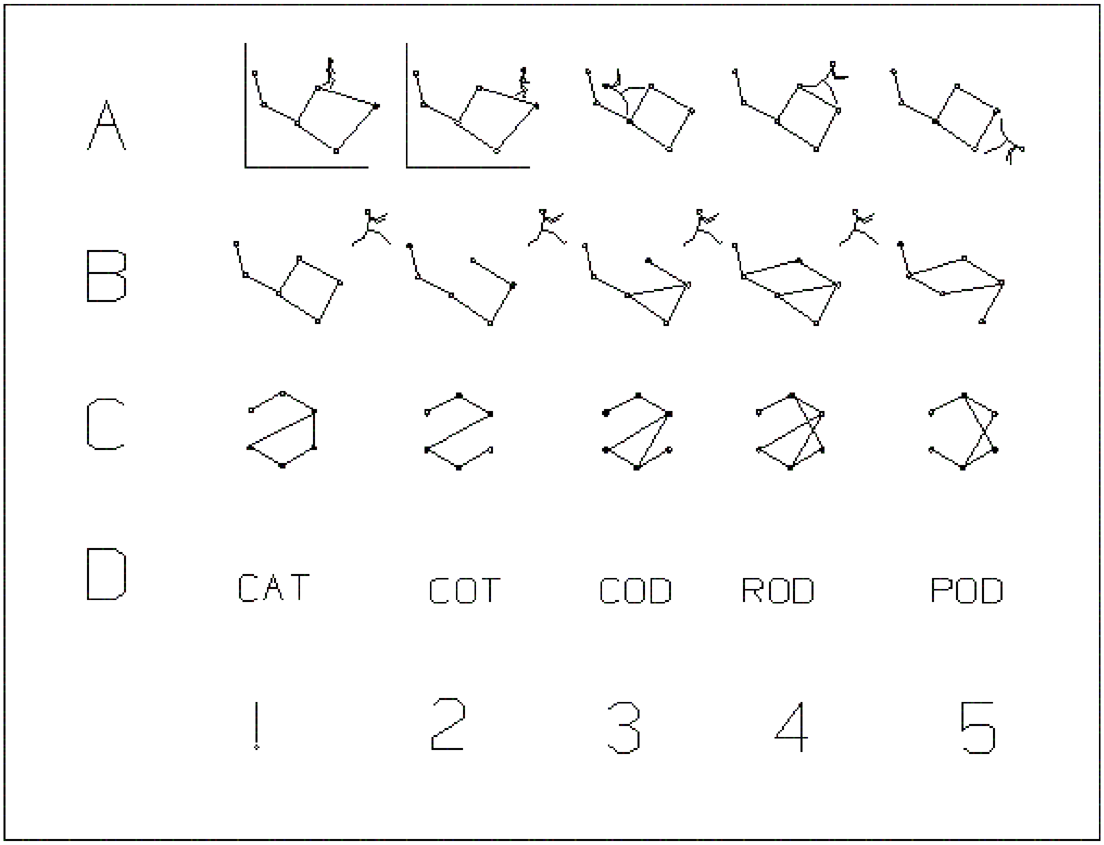

Figure 25.1. Walking in abstract spaces

In **B1** to **B5** we move in the space of graphs with six nodes, step by step, each step being an act of either disconnecting two bonds or forming a new bond, i.e., a *minimal change*. In this sense, each two consecutive graphs in the row are neighbors in the space.

In pictures **C1** to **C5** graphs are presented "round table" style, as polygons with the same number of nodes.

Can we picture the movement in the space of all graphs? Yes, we can, but we need a polygon with infinite number of nodes. Naturally, we cannot present any picture of that, except for a circle filled up with black paint.

In pictures **D1** to **D5**, we slowly move in the space of meaningful English three letter words. They form a subspace of all three letter words. From word to word, we change only one letter. We can measure the distance between words by the number of different letters. So, the distance between **D1** and **D2** is 1, between **D1** and **D3** is 2 (two letters are different), and between **D1** and **D4** is 3, same as between **D1** and **D5**. In this space it cannot be more than three. We can also say that each word has 25 x 3 = 75 neighbors—the number of possible minimal changes of any single letter for any other letters but itself.

The space of this kind is called sequence space, and the distance between sequences is the so-called Hamming distance. Another example is protein space where each amino acid can be changed for any of 20 - 1 = 19 other amino acids. For the limited protein space enclosing only proteins consisting of 100 amino acids, each protein has 190 neighbors.

Isn't that curious that we cannot visualize a space but can understand it and learn to *move* in it? We can also measure distances in such abstract spaces and, as in moving around the city, we can choose shorter and longer pathways between two points.

Metric space is a particular case of topological space. Topology, again, in a home-made sense and for internal use only, can be just a certain relationship which may or may not exist between any two objects packed into space. For example, lists of all pairs of natural numbers that are neighbors, defines a topology. Integers 2 and 3 are close, while numbers 2 and 4 are not. The list (1,2), (2,3), (3,4)... defines a topology, leaving out a larger list of pairs such as (1,3), (1,4), (2,7), etc.

Not every discrete space has topology. For example, we can say "the US Senate," instead of listing all senators and congressmen. Ten years from now, the US Senate will have somewhat different people, but what we mean by that is a set of seats which should be filled anyway. Space is a set of objects called points, but as far as US Senate is concerned, this set has no particular properties and using any mathematical term makes no sense. Of course, some senators represent bordering states and some do not, some are seated close to each other, and some are not, but it could be related to the geography of the USA and not to any essential properties of senators. The US Senate has no topology in the above sense, and only from a different perspective we can, actually, trace the connections of partisanship, business, geography, friendship, and animosity that make some senators closer to each other than to others.

Generally speaking, although a configuration is a mathematical object, it is neither number nor function and it represents only itself. Nevertheless, as we saw, some configurations are close and some are not and some are closer than others. The configuration space, therefore, shows a potential for order and organization.

I have spent so much time talking about space because the concept of space outlines the place of pattern theory in its relation to Everything: pattern theory is a way (and maybe the way) to compress **listable** properties (see Chapter 4).

To summarize: a list of generators defines a certain space in which we can move even easier than over the surface of the earth, with closed eyes, and with a cup of coffee instead of a tank of gasoline.

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26. THE FLICKERING BOND

Generators, like atoms in chemical reactions do not change between their birth and death. While the generators represent the conservative nuclei of Everything, their bonds quiver in change. They are responsible for fluidity, search, transformation, innovation, evolution, the plasticity of youth, and the crystallization of aging.

At the beginning of evolution the earth had been given a set of atoms that was only slightly expanded by man. The bonds, however, have been in constant play, leading to life, humans, and their creations.

In an abstract configuration space where everything is equally possible, any sequence of patterns is as good as any other, and they can follow each other in arbitrary order. In real world we can never go back, neither can we leap to any desirable state. There is usually one or two practically feasible ways from one state to another.

Patterns seem to represent pure crystalline order while the real world is full of chaos. We need to disturb the peace of the museum exhibition of regular structures and to animate it by adding the time axis together with a meta-physics stating what is possible and what is not.

Chemistry is well equipped to deal with molecular chaos: large statistical ensembles of molecules allow for making rock solid predictions about their behavior, so that the typical chemist never even thinks about any chaos in the flask.

We know in advance, however, that moving along the evolutionary pathway from molecules of shapeless fluids to immaterial ideas we will have to abandon mechanical movement. Ascending in the elevator of evolution, we expect to leave behind three-dimensional space and confront chaos in a universal non-mechanical form. The question is how we can introduce **chaos in patterns**.

I hope that after walking and jumping in abstract spaces the reader got some taste for mental calisthenics.

In terms of generators, we do not have much choice. To fully describe a generator means to call it by its name and to identify its bonds. Therefore, we can do two obvious things.

1. We can make generators chaotically appear and disappear, leaving no trace. We can consider disappearance of a generator as a complete severance of all its bonds and a fall into a limbo from which it might eventually reappear if needed. In a way, this is how many religions regard death: a human being is removed from the material world, with all material bonds severed, and put into a different transcendent reality of the other world. At a certain moment, he or she can be called up back.

Although we can express birth and death of a generator in terms of its own generators of a lower level, the chaotic flickering of a generator lacks the simplicity that we expect from a fundamental pattern concept. Death of a generator is not an atomistic event because it is not simple enough. When a generator "turns off", **MANY** bonds become simultaneously severed, while we are looking for the simplest possible move in the world of change, and the simplest is always **ONE**.

2. The single bond is a truly atomistic object because it does not consist of anything. We can make a bond appear and disappear—flicker—in a chaotic way, with each bond living an independent life.

If generators represent matter, then no matter can appear and disappear without something being converted into something else. Nothing cannot originate from nothing. Bonds, however, form and break all the time, at the levels of molecules, as well as in life, mind, and society. Bond is the true atom of pattern theory. We can regard a generator as a bunch of all its bonds, both half-bonds and whole ones, something like the rubber band that keeps a bunch of broccoli together.

What does it take to break or form a bond?

In man-made things we have to spend energy on connecting parts and we have to spend it again on disconnecting. This is the way a car wheel is mounted on the hub with bolts and nuts. The bonds between atoms are different. Bonding is the most intimate mechanism of chemistry. It can be explained only by theoretical physics in terms having little to do with patterns but a lot with energy. I cannot demonstrate it either on my fingers or on a Lego set. If chemical bond is a marriage between atoms, it is based on convenience, not passion. The interatomic bond exists due to specific quantum-mechanical properties of electrons in the field of atomic nuclei. Bond is an energy saving agreement between atoms.

The nature of chemical bond is a very special subject that we are not going to discuss here at length. In short, physics shows that external electrons of two separate atoms brought into close contact can be in three situations: bonding, non-bonding, and anti-bonding. They can be interpreted as attraction, indifference, and repulsion.

Similarly, but without any physical interpretation, we can think of three major types of abstract bonding .

1. POSITIVE BOND

When this bond forms, a certain amount of energy is released. In order to break the bond, we have to spend the same amount of energy. Energy is needed only for breaking the bond, provided the two generators are close enough.

$$\mathbf{A + B \Rightarrow A—B \ + E} \quad (\mathbf{E} = \text{energy})$$

We will call this type of bond **positive** or simply bond.

A bond between two disk magnets with opposite poles facing each other is the best example. They jump upon each other and we have to apply force to separate them.

Chemical bond belongs to this type. When a chemical bond closes, energy evolves. In order to break the bond, we have to spend energy. Unbonded atoms are called radicals when they do not carry electric charge and ions when they have opposite charges. They are so eager to mate with each other that they are rarely observed for more than fractions of second, unless there are some special circumstances, for example, vacuum, where to find a mate is a real problem.

In living objects, as well as in chemicals on the shelves, practically all atoms are bonded. Still, an occasional impulse of energy, for example, from radiation, can make some bonds break down. However rare, this event is extremely important for the processes of life. In plants, it is a necessary condition of life, in animals, it can cause cancer.

2. NEUTRAL BOND

This bond needs energy E for both bonding and unbonding.

$$\mathbf{A + B + E \Rightarrow A\text{-}B}$$

$$\mathbf{A\text{-}B + E \Rightarrow A + B}$$

We will call such bonds **neutral**. A latch or a lock is an example: we need practically the same energy to either lock or unlock it. A snap button is yet another one.

The same type of bond is used in Lego: when brought into contact and pushed together, the parts form a bond that can be broken only by applying energy to pull them apart. The separation can happen on its own, while spontaneous connection of **MANY**-TO-**ONE** type is improbable.

To form a negative bond, we need to perform work because chaos will not do the job. Most of the hardware of our civilization is joined together with bolts, nuts, locks, and other neutral bonds, while the rest is glued, welded, cemented, etc., i.e., connected with **MANY** positive bonds, so **MANY**, that we cannot reconnect them into **ONE** when it is broken.

3. NEGATIVE BOND

There are bonds that demand energy to be formed, but not to be broken. This is the bond between a master and a slave, between married couple in trouble, between two sheets of paper kept together by a flow of air between them, etc. The best example is two disk magnets facing same poles. We need to force them toward each other and keep in that position.

$$\mathbf{A + B + E \Rightarrow A...B}$$

Let us call them **negative** bonds or **anti-bonds**. In order to keep two generators with anti-bonds together, a force, a clamp, or a constant supply of energy in the form of work may be needed.

Remarkably we find nothing like that in mineral nature. All our examples involve human participation. Chemistry does not commonly deal with such bonds. At certain conditions, however, they exist in a tricky way, mostly in living systems, and need to be viewed at a certain angle to be recognized.

In practice, strong bonds in chemistry are rarely formed by connecting loose pieces because separated atoms have high energy and are unstable. We cannot store on a shelf a pound of either chlorine radicals $Cl\bullet$ or chlorine ions Cl^{-}. We cannot order them from a chemical company. We can, however, buy a gallon of bleach that may generate short-living atoms of chlorine in small quantities. We can also irradiate molecular chlorine Cl_2 with UV light and make some of the molecules split into Cl. If not immediately consumed, loose chlorine atoms will soon reunite into Cl_2:

$$Cl_2 \rightarrow 2\ Cl\bullet$$

At moderate temperature, chemical bonds are typically formed not from free atoms but in the way which reminds of financial transactions through a bank, so that no cash changes hands.

$$\mathbf{A\text{-}a + B\text{-}b \rightarrow A\text{-}B + a\text{-}b}$$

In this exchange parts stay free only for a short moment, or not at all. The energy of forming one bond ("sales") is spent for breaking another ("purchase"). The difference is either profit or loss, depending on its sign.

The whole process is rather complex and it carries the same fascination for a chemist as the courtship of white cranes for a biologist or the French Revolution for a historian. Chemical reaction is a dramatic happening and suspense novels are written about it, although in a lingo beyond a layman's understanding.

The chemical way of bonding can be compared with changing a car wheel in the process of wheel rotation. We remove the nuts from the front wheel, then from the back wheel, than switch them, then screw the nuts on, so that in the end there are neither loose nuts, nor a wheel with empty holes.

The majority of chemical reactions are neither pure separation of joined atoms nor pure bonding. Usually as many bonds are broken as formed because atoms do not like to have loose, unattached bonds. This is why the chemical limbo is almost always empty at moderate conditions. A single atom with all bonds cut off does not survive for long. It finds something to bond to in fractions of a second, and if there is nothing else, two identical atoms might just bond to each other.

We cannot be sure about atom's emotions. Bonds among humans, however, certainly have an underlying emotional attachment: most people do not like to be alone all the time, although this may change with age. In this sense we can say that atoms are very sociable. Single separated atoms usually have high energy and are eager to recombine and form a stable bond. It happens because there is no barrier between the unbonded and bonded states. Note that the expression "to fall in love" reflects the energy drop when a bond is formed. The separated atoms fall onto each other as naturally as a ripe apple falls on the ground.

As for the humans, even a family may need an external force to keep it together. An antagonistic society, for example, based on slavery, needs power to overcome the resistance of the oppressed. Even the most prosperous society, however, requires constant efforts to maintain social peace and bring together different people not too much in love with each other.

In the household of civilization, the energy obtained from locking positive bonds, for example, when mineral oil is burned at power stations, is utilized for maintaining negative bonds between the members of society, and for populating the world with things screwed together with neutral bonds.

Negative bonds are the key to understanding patterns of life and society, and we have to take a closer look at them.

*

27. FROM UNDRESSING TO DIVORCE

Most bonds in human life are reversible: we pick up or replace a telephone receiver, open or close the door, take a book from a shelf and put it back, etc. Spiritual and emotional bonds could be reversible, too, not to mention holding hands and joining in a kiss.

Buttons, zippers, and other fastenings are designed for repeatable reversible use. The way the humble snap button works (**Figure 27.1**) illustrates one of the most fundamental concepts of the physics of Everything. In both open (**27.1A**) and snapped on (**27.1C**) states the parts of the snap button are in

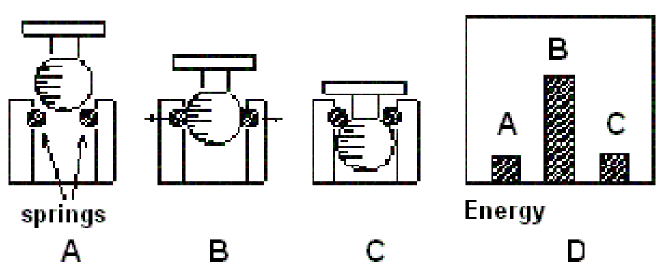

Figure 27.1. Snap button.

the same shape. In order to move from A to C, the ball of the upper part must squeeze itself through a spring which yields to the pressure of the ball (**27.1B**). The energies of both states **A** and **C** are equal, while the strained state **B** has a higher energy (**27.1D**). As chemists say, an energy barrier separates the two stable states. To overcome the barrier we need to supply energy in the form of mechanical work.

Note that for the **MANY-ONE** reason it is easy to undo the snap with a jerk, but not to connect widely separated parts with the same move. The entropy of a separated state in a metric space is always larger than that of the bonded one and we have to pay extra price for the order of bonding. Chaos alone would do the separation.

This is why dressing takes more time than undressing. It would take even more time if the buttons zippers, etc., did not belong to one piece of clothing.

Similarly, in order to connect two pieces of Lego we need not only physical energy. First of all, we need to connect them in our head. Let us note here the accelerating function of our mind. We will discuss it later when speaking about catalysis.

The door has two bonds: one is the reversible neutral bond between the lock edge and the jamb and the other is the positive bond at the hinges. Since both the door and the jamb are already connected through the hinge, we easily close and lock the door. We use the same anti-entropy trick when we carry eyeglasses on a string over the neck.

Similar phenomena at the molecular level are well known in chemistry and some uncomplicated and common molecules are, actually, chemical doors, eyeglasses, and snap buttons.

Consider, for example, a cyclic molecule, **Figure 27.2**. When the cycle is open, the molecule looks like a folding screen with multiple hinges. Due to the design of the screen, the ends cannot go too far apart and always stay within a certain distance. The same with an open cycle: its ends are always within the reach if the number of links is not too small and not too high: preferably, five or six. Such molecules close cycles easily because the entropy of the linear state is not as high as if they were completely separate. If more than six atoms form a linear chain, the ends have difficulties finding each other in space and closing a ring.

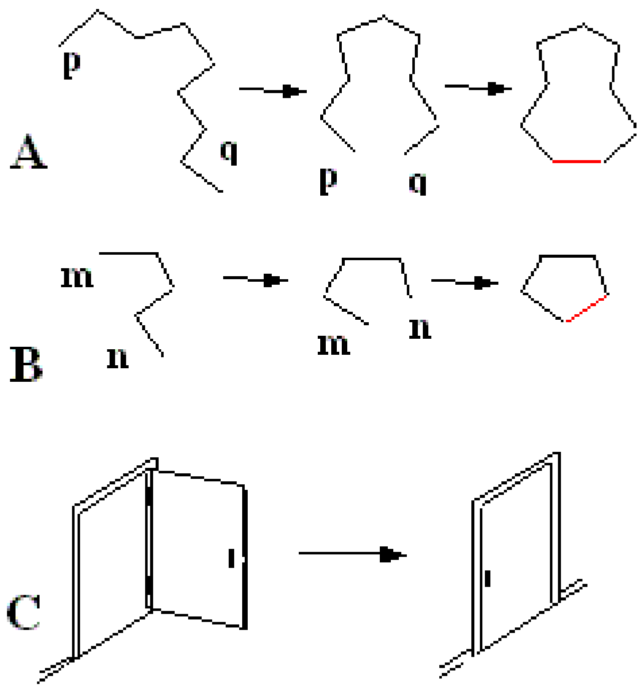

Figure 27.2. Chemical door

When we pick up a phone receiver, we work against gravity. We have to work again when we hang up in order to slow down the free fall of the receiver. We could invent a device for producing electricity by just dropping the receiver on it, and in a similar way we could probably convert the outbreaks of our anger and frustration into useful work.

The world of man-made things and human relations has all types of bonds. Happy marriage is a positive bond, hard to break, but the shaky marriage, like a decrepit house, needs a lot of maintenance. In order for a marriage to break up we do not need to do anything—in most cases the neglected marriage will break down on its own. In order to keep it strong, however, we need to spend energy, fix the cracks, paint the surface waterproof, and reinforce it with extra beams.

As far as bonds between humans and animals are concerned, I can refer the reader to delightful books of Konrad Lorenz, a great contributor to the science of Everything from the borderline between life and society. Many bonds between animals as well as people are as impersonal as those between the generators of syntax patterns: any word would fit. Lorenz (1966, p. 146) describes a male white stork which does not even notice the difference between his wife and another accidental female intruder. The stork care about the grammar but not about meaning.

In Lorenz's *On Aggression*, rich with examples of building blocks of behavior, a chapter entitled, remarkably, *The Bond*, considers a personal bond between individuals when two generators are born for each other and nobody else can fit their shoes. The life of a greylag goose "may last half a century and its marriage only two years less," (Lorenz, 1966, p.188).

The story of Romeo and Juliet is a classical example of a strong emotional bond. Even though the young people were removed from this world into infinity, the bond between them remained unbroken. They are connected at least in the world of ideas, images, and our culture in general.

The story of Romeo and Juliet, however, is not only about the positive bond of love but also about the equally strong negative bond of hate and hostility between two clans.

In the animal world, both types of bonds are neither inhibited nor overstated by social customs and historical memory. Konrad Lorenz uses a physical analogy while describing the aggressive behavior of individuals within a species: "The danger of too dense a population of an animal species settling in one part of the available biotope and exhausting all sources of nutrition and so starving can be obviated by a mutual repulsion acting on the animals of the same species, effecting their regular spacing out, in much same manner as electrical charges are regularly distributed all over the surface of a spherical conductor" (Lorenz, 1966, p.28).

We inherited from animals the interplay of the positive impersonal bonds between the members of a herd or pack with the aggressive instinct toward the same species, as well as love and hate toward individuals, groups, and ideas. In times of social frustration, hitleroid personalities become leaders of the human herd, with the standard pattern of paramilitary organization around the leader, cult of order, force, and obedience, and the hatred toward real or imaginary enemies. To reconcile the pattern with reason, the other herd is tagged as a different species.

The bonds of attraction and repulsion can work between people, collectives, and communities, as well as between an individual and the crowd. To maintain negative bonds, a constant supply of energy is needed: lots of work and aircraft fuel may be spent to bring two hostile nations to peace talks.

As a meta-chemist, I see familiar chemical analogies everywhere. In times of war and revolution, charged with the energy of love, hate, and explosives, many human bonds are broken. Such books as *War and Peace* by Leo Tolstoy, *Gone with the Wind* by Margaret Mitchell, and *War and Remembrance* by Herman Wouk are descriptions of meta-chemical reactions with large clusters of people: time sequences of broken and established bonds, personal and impersonal.

In our time many traditional bonds break down or get weaker while new, often non-traditional, ones gradually become legitimized.

In Chapter 16 we shortly mentioned pattern mechanism as a sequence of minimal changes. Such an atom of change means breaking or making one bond and it takes a unit of pattern time. Rephrasing Leibniz who defined time as a sequence of events, I would define time as the sequence of steps of a pattern mechanism.

Curiously, such terms as time and mechanism have strong connotations in our mind: we all associate both time and mechanism with watches and clocks.

In chemistry mechanism is a sequence of all intermediate states between the molecules before and after a transformation. Any mixture of chemicals arrives at the final state of equilibrium with time, whether long or quite short.

When we draw a picture using CAD software, the sequence of images consisting of points and lines on the screen is a mechanism. Books on history describe mechanisms of a social or geopolitical change. A sequence of Lego structures starting from one block and going through additions and removals of just one block is a mechanism. What we call a hardware mechanism, like watch, can also be presented as a circular sequence of its states.

There is a particular pattern mechanism, the favorite vehicle of Everything, called *exchange*:

$$\text{A—a} + \text{B—b} \rightarrow \text{A—B} + \text{a—b}$$

To hint what kind of kick a chemist can have from an equivalent of this simple operation, let us compare two politically correct scenarios:

Scenario 1. John and Mary are happily married. The bond between them is strong. Another couple—Wayne and Phyllis—buys a home nearby. The neighbors get to know each other. John finds Phyllis irresistibly attractive. The spark of love strikes between them. Both marriages are in a mess. Wayne and Mary share a passion for bird watching. They feel mutual attraction, too. In a dramatic showdown they decide to rearrange their marital bonds.

Scenario 2. John and Mary are happily married. The bond between them is strong. Mary meets Wayne, a new executive at her company. He is a recent divorcee, lonely and longing. The spark of love strikes between them. Mary walks out on John. John is desperate, now lonely and longing. He moves to another city and happily marries there.

One can see that the process of the exchange is what almost all novels and soap operas are about: breaking and forming bonds between people, people and things, things and things, pets and people, etc., and money, pleasure, and frustration are the counterparts of energy. This is what makes chemical reaction so exciting for a chemist. No wonder, masterpieces are rare among both soap operas and routine works of chemistry.

One does not need to go astray in marriage, however, to experience the adventure of exchange. Here are two innocent mechanisms of exchange in everyday life.

Scenario 3. You have a shirt. You buy a new one. For a while you keep both shirts in your wardrobe. The old one wears off. You throw it away.

Scenario 4. You have a shirt. You spill ketchup on it. The miracle stain removers do not work. You throw away the shirt. Next day you buy another one.

The two types consist of elementary steps. In each step only one bond either closes or breaks:

1. $\mathbf{C—D \rightarrow C + D;}$

$\mathbf{A—B + C \rightarrow A—B—C \rightarrow A + B—C}$

$\mathbf{A + D \rightarrow A—D}$

2. $\mathbf{A—B \rightarrow A + B}$

$\mathbf{A + D \rightarrow A—D}$

They are illustrated in **Figure 27.3** with changing one pen for another in our breast pocket. The mechanism of exchange reminds bartering goods or exchanging them for money.

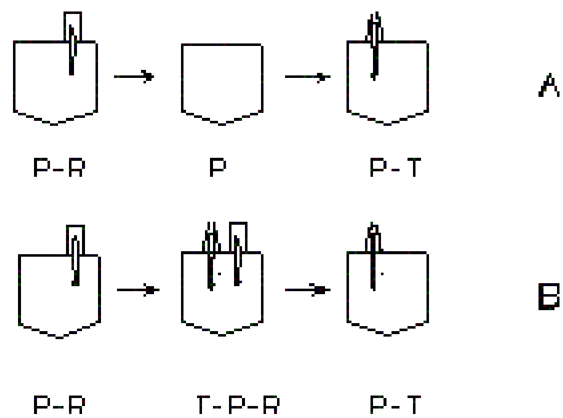

Figure 27.3. Two types of exchange

The inborn instinct of possession, as powerful as gravitation, ties people to things. People go into pains to acquire goods and they do not want to loose them. Money could be a quantitative measure of the strength of such bonds as love and possession. “How much do you want for this?” is the question to ask to measure the strength of a bond.

War, conquest, robbery, and expropriation have been the violent means of breaking bonds between owners and their possessions with the subsequent dividing the loot. Shopping mall is a more civilized way to satisfy human affinity for possession. Money in this kind of transaction looks very similar to energy. The reader is free to fantasize what is the business equivalent of entropy. There is no need to look for temperature: hot deals, hot stocks, and frozen accounts are right there.

In chemistry, the change of energy in the process of exchange is usually much smaller (roughly ten times) than the change of energy in the direct bond formation between free atoms. The frugal biochemistry always works through exchange and not through robbery.

28. THE IMPORTANCE OF BEING NEGATIVE

The reason why the exchange is so natural and painless is that no bonds are broken for a long time. The rearrangement of four participants of the exchange occurs almost simultaneously. Most energy—the currency of physics and chemistry—remains in the changing molecular pattern.

This is what happens when some chemical reactions, very important in biochemistry, run in the presence of water. Those are mostly reactions of hydrolysis (breaking by water) and condensation (bonding through eliminating water). One molecule contributes hydrogen (H) and the other hydroxyl (OH) to make water (HOH).

A—H + B—OH → A—B + HOH

Hydrolysis is the reverse transformation:

A—B + H—OH → A—H + B—O H

If we start with **A—H** and **B—OH** the reverse reaction of hydrolysis will begin as soon as some water is produced. Both direct and reversed reactions will be running simultaneously and independently until an equilibrium will be established.

Equilibrium is a concept universal enough to fit the Everything. It has already spread over economics, politics, and cognitive sciences. To describe chemical and any other equilibrium, we will take an example far away from chemistry.

Suppose we have two adjoining rooms separated with a closed door, couple dozen flies in one room, and bread crumbles in the other. When we open the door, the flies start moving toward the feeding grounds. After a quick snack they will, probably, resume their flight over the entire available space. A state of equilibrium in this case means that approximately equal numbers of flies move through the door toward the food and from it in both directions. It does not mean that the numbers of flies in each room are equal: there will be more flies near the food than far away.

Chemical equilibrium is similar to that, with molecules instead of flies and, in our case, **A—H + B—OH** and **A—B + H—OH**, i.e., two sides of the equation instead of two rooms. In the state of equilibrium the ratio of **A—H** , **B—OH**, **A—B** , and **H—OH** does not change, although both direct and reverse transformations run ("fly") at their usual rates. If we add one component, for example, water, the equilibrium will be shifted toward **A—H** and **B—OH**, i.e., toward hydrolysis. If we remove water, for example, by letting it dry out, we will have an almost pure product of condensation: **A—B**.

Only a reversible transformation achieves equilibrium. If we put the crumbles on a sticky paper, the final result will be: no flies in the first room and no traffic through the door whatsoever. The change in this case is irreversible: a fly cannot break off the glue.

We can apply this kind of meta-chemistry to many other processes, for example to migration of populations. The immigration to America has been practically irreversible for centuries, although no analog of sticky paper could be found, and it has not yet reached an inevitable equilibrium.

The most popular example of equilibrium is the idealized model of market economy based on the balance (equilibrium) of supply and demand. Any change in either supply or demand causes prices change until a new equilibrium will be achieved. Here price is an equivalent of chemical concentration: it is the index of the rarity of a product, and if its abundance changes, so does its price.

In case of hydrolysis, the position of the equilibrium depends on the total energies of the mixture of **A—H** and **B—OH** and the mixture of **A—B** and **H—OH**. The higher the energy per molecule, the lower the concentration of either mixture in the equilibrium. We can compare it with the amount of food in the fly model. If we spread some crumbles in the first room, the equilibrium will be shifted toward an equal distribution. The total energy of the mixture in equilibrium is minimal.

Food, satisfaction, pleasure, and content in life and society equals to energy in chemistry and physics, only with the opposite sign. Pleasure looks like negative energy. An individual tends to move toward **MORE** satisfaction, while a bunch of molecules or a skier on a mountain slope move toward **LESS** energy. In fact, the trend to minimize energy is the universal driving force for all processes in the Everything. The "energy" (displeasure) of a hungry rabbit looking at a carrot is higher than the "energy" of the rabbit that is digesting its carrot. For carrots and sticks for humans see social psychology.

How could it happen that prosperous nations that have reached a high standard of living fall into decline? Why periods of comfort, pleasure, and satisfaction alternate with periods of destitution, frustration, and scarcity? What to do to evade wars? Can America fall down below the level of her global companions, competitors, friends, and enemies?

NOTE (2006). See: Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (Viking, 2004).

Those are some problem for the reader to think about. The concept of equilibrium, however, cannot be applied to society, and, probably, even to economics for just one reason: society is a dynamic system kept in a state far from equilibrium by a constant flow of energy through it. Such systems are called *dissipative*: they exist because they extract order from energy and eject the rest as chaotic heat.

Non-equilibrium thermodynamics, as any thermodynamics, is a typical science of Everything. There is an abundance of popular books on the subject and I would recommend those by Prigogine (1984, 1989), who was one of the creators of the whole area of physics of non-equilibrium systems.

Dynamic systems such as life and society can at best be in so-called **steady state**, but such a turbulent system as humankind presents very few examples of steady state, if any at all.

A far-fetched illustration of an apparently unchanging non-equilibrium state is a tennis ball kept in the air by repetitive upward strikes of the racket. As soon as this stops, the ball falls to the ground and does not move anymore.

Back to chemistry: it will provide us with a good example of non-equilibrium thermodynamics.

The fact is that condensation bonds hold together monomers in proteins and DNA. They are as strong as any other average chemical bond and it is as difficult to break them head-on as to tear off the car wheel from the axis. The same result, however, can be achieved in a non-violent way: by exchange.

Hydrolysis can be compared with unscrewing—it does not require much "work." Condensation in biochemistry, however, requires slightly more work than hydrolysis. We express that by saying that the equilibrium of proteins and DNA with their monomers in water is shifted toward hydrolysis. In a big excess of water, especially if it is not pure, they would sooner or later split into monomers.

The monomers in a cell do not rush toward each other to mate. They should be nudged to do so by supplying "work" or removing water. Energy that can be converted into work and used to increase order is called in physics and chemistry **free energy**, and if we want to connect monomers into a biopolymer, free energy is as indispensable as for tying shoelaces.

There are some subtle chemical reasons why the proteins and DNA in our bodies do not fall apart and we do not dissolve while taking shower, despite the energetics of hydrolysis and condensation that is more favorable for the breakdown of our polymers.

One of them is that both hydrolysis and condensation are very slow on their own, if no booster is added. To wait until an act of hydrolysis or condensation happens with plain water is like trying to button a shirt without using hands: by bumping into furniture and walls. Our cells contain powerful **catalysts** of condensation and hydrolysis, which speed up both but do not change the position of equilibrium.

Another reason is that our polymers, like hedgehogs, turtles, armadillos, and porcupines, have some means to protect themselves from an attack. A polymer molecule is not a geometrical point: it is, actually, a thing. Such molecules have many internal degrees of freedom and they can coil in such a smart way that their vulnerable internal parts will be shielded from any external influence. Although theoretically a water molecule can assault the polymer molecule at a spot between monomers, it is hardly possible in practice. A coiled polymer is, actually, more solid than fluid. We cannot expect water to get into a tightly capped jar of sugar although sugar easily dissolves in water.

The primary reason for stability of our biopolymers, however, is that we, thank God, are lucky to have daily breakfast, lunch, and dinner. Food in our organism is burned and the generated free energy is used for making condensation bonds between our monomers—building blocks of our body. The simplest proof of the inherent instability of our most important bonds is that when we starve or die, they break apart sooner or later, and we lose our proteins.

Therefore, in order to play with the biochemical Lego we have to consume energy not only for initial bonding but also for keeping bonds from being broken by the chaos of molecular movement in water. This is something different from simple association-dissociation like connecting and disconnecting two pieces of Lego. It is like trying to prevent a house of cards from falling down while kicking the table. One way to do that is to have as many hands as there are cards and to hold each card in place individually. The other way is to bind the cards with a sticky tape.

The mechanism by which energy helps hold monomers together is called coupling. It works the following way. Energy is stored in the form of a compound with an easily hydrolyzed bond. Its breakup by water releases a significant amount of energy which is immediately used for bonding monomers.

A typical energetic currency of life is adenosine triphosphate (ATP). In the mechanism below it is shown as **C—O—D** that can be hydrolyzed by water into **C—OH** and **D—H** . Water, however, does not take part in the reaction. Instead the condensation of **A—O—H** with **B—H** and the hydrolysis of **C—O—D** are bundled together:

A—O—H + B—H + <u>C—O—D</u> → A—O—B + C—OH + D—H

ATP works as a credit card: it pays the expenses of condensation right on the spot, but, of course, the account should be replenished by burning food. Therefore, in the presence of water, condensation biopolymers behave **as if** they were connected not with positive but with negative bonds (anti-bonds). This fundamental fact is often overlooked.

Strictly speaking, life is not supposed to exist at all: it is a house of cards built on sand. It originated against the equilibrium, against the normal order of things. Unlike free atoms, the Lego pieces of life do not combine on their own and the building blocks of life do not have snap-on joints. They have no brains, no legs, only tiny living hands that hold each other, and the hands require food to maintain their strength. As soon as there is none, they disengage in agony of dying, under the blows of water molecules directed by demonic catalysts.

At the first glance, the suicidal hydrolytic inclination of our biopolymers does not make any sense and make life looking inherently imperfect, unstable, and doomed.

Let us imagine the opposite case: equilibrium is shifted not toward hydrolysis but toward condensation. Then as soon as we have a mixture of biochemical Lego pieces, they will connect chaotically on their own. In order to have only **ONE** specific connection, we would need to hinder all the other possible connections, and there are really **MANY** of them.

Suppose, we have a bunch of monomers eager to bond to each other and make chains. In order to form a specific chain, for example, the only **ONE** string of DNA responsible for brown eyes among zillions of other possible strings of DNA, most of them without any meaning at all, we need **MANY** little demons to restrain each monomer from reckless mating. They must line up in due order in view of the supervisor with the blueprint.

On the contrary, when equilibrium is shifted toward hydrolysis, we need to control only one process at a time, deliver the tools and the power outlet to one spot, and we do not care for the rest. We need, at most, **ONE** little demon called Enzyme to bring together the reluctant generators and link them together, albeit at a price in the currency of energy.

To control **ONE** anti-bond means less ordering work than to control **MANY** positive bonds. It is more economical to spend energy for screwing together two parts than for preventing hundreds of parts from sticking together. This is why the nature invented a mechanist of putting parts together with a power screwdriver and a couple of nimble hands. We have just seen how the screwdriver works. About the hands and the little demons, see Chapters 43 to 45 about catalysis.

Life is a sophisticated order among awesome chaos, and such order can be maintained only at a high energetic price. Most energy of food, however, is used for producing work, pumping blood, digesting, etc., as well as for thinking, and not for the maintenance of polymers.

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29. MINDLESS SCIENCE, LIFELESS LIFE

This chapter is a reminder to myself.

I use and extrapolate some basic ideas of Ulf Grenander's pattern theory in order to take a unified view of the Everything. Seeing the world in terms of generators and configurations, however, I catch myself on talking about the world consisting of generators as if they were as real as atoms. I discuss various processes in this imaginary world, make arrogant predictions, establish illusory laws, and assign ambiguous values as if patterns were totally independent of me and I were just an outside observer.

Do I have the right to overstep the boundary between atoms and products of our mind? If yes, how far can I go?

For centuries, philosophers have been wrestling over the problem of mind and matter.

If one believes that an impenetrable abyss separates both, it makes no sense to compare two objects having nothing in common. If one believes that mind is a form of matter or *vice versa*, then it makes no sense either. Only if we regard them as two different kinds of something more general, we can compare them in the same way we compare cats and dogs as pets belonging to the even larger entity of animals.

What is exactly the difference between things and ideas? We can say that things are material and thoughts are not, but what it means to be material? If things and thoughts are equally real, why is their antinomy so dramatic and why is there so much controversy about it? Any historian and politician is aware of either creative or destructive power of ideas as soon as they infect enough heads. Can there be any geometry, physics, and chemistry in the world of ideas? Can we measure mind like we do with matter and money?

Pattern theory, as well as mathematics in general, is M-blind: it does not make any distinctions between mind and matter as long as it deals with patterns. At the same time it is interested in comparing patterns of matter with their shadowy patterns in mind. I omit here this important aspect of pattern theory and the distinction between patterns and images; the reader is referred to the original works by Ulf Grenander.

I believe that it is the gift of immortality which makes recorded ideas so different from things. An epitaph on a tombstone is, probably, a good example of immortality of a message as compared with human life.

On the scale of the natural history of the earth, ideas are the youngest newcomers. On the scale of our personal lives most of our individual thoughts are forgotten next minute. I am almost certain that our planet will outlast its residents with all their thoughts.

What I mean by immortality is the following: watching the pieces of knowledge coming from nowhere, we do not see any opposite spontaneous process. In other words, modern civilization is unable to forget anything. It should not be taken literally: most writers and scientists have been forgotten. But forgotten knowledge can be retrieved from a storage, while lost things can be reconstructed only by making them anew.

Probably, immortality means just immateriality: while in the material world a new thing is made only at the expense of other material things or raw materials, a new idea does not exterminate an old one. There is no conservation law in the world of ideas while the number of atoms in a certain closed space is, normally, constant.

The immortality of ideas is due to the fact that an idea can exist in a multitude of material carriers: books in different languages, punch cards, computer files, films, disks, flash memory, etc. The carriers can be multiplied together with their contents. Not only the hard copy of an idea is solid, but it is also kept at a very low abstract temperature. While its carrier is a thing and can exist in copies, the idea cannot.

The world of ideas is like Noah's Arc: each species is presented in one specimen. Or, it is like arts: there are no two *Romeos and Juliets*. Two identical ideas are one idea, not two, but unlike Noah's couples, they cannot either multiply or die. To destroy an idea means not only to destroy all its carriers but also to destroy the carriers of all derivatives of the idea, and all its evolutionary progeny, and all the preceding ideas from which it could be generated anew.

Exactly because of the mixed blessing of the practical immortality of ideas, the humankind as a whole finds itself in a difficult situation. We denounce war, cruelty, and bigotry, and yet, unable to erase those ideas from our memory, we do same things again and again. We have to live with them and even appreciate such thing as hate without which there would not be freedom and democracy, and even fear, without which mutual destruction could go to the very end.

Even if we could make everybody forget about war, the idea could develop through mutations from other innocent ideas, like arguing with a neighbor, mowing grass, slaughtering cattle, and spraying the pests.

Once an idea has appeared, it can be modified, a new idea can be added, it can be rejected by most people, but it exists in a dormant form of a record somewhere.

For seventy years of Communist rule the idea of monarchy was as alien to Russia as it has been to the United States of America. Russian monarchy had been discredited and eradicated physically and ideologically. And nevertheless, it had hibernated somewhere and it germinated as soon as freedom of expression was given to Russia.

Unlike the idea itself, the *meme* of an idea can replicate and spread like a bacteria: twenty bigots are not the same as one, but the most abstract idea of racism is always as single as the idea of general relativity. Like viruses, ideas live and mutate only in the mind they have infected.

When we look at the longevity of ideas, any particular idea does not seem to exist in time, but the evolution of knowledge as a whole is a process like any other. Like a shell shed by a mollusk, an idea is an artifact of somebody's life, most probably, already non-existent and properly kept in the crypt of a library where it does not change.

How can we think about something that had happen even before life appeared, not to mention mind itself? This strange question formulates what I call "the **no-witness**

problem". In a very oblique way, it is related to the problem of measurement in quantum physics.

Let us imagine a movie which contains all we know about the evolution of life on earth. We can watch a lifeless world, and then a modest pageant of first very primitive forms of life progressing amidst fuming rocks and turbulent waters. A momentary blackout comes, however, at the most intriguing moment right before the very first float appears.

Amazingly, when a completely new idea appears in our mind, for example, when a mathematician makes a discovery, the very moment of generation of new idea usually falls under a blackout, so that he cannot give an account how the idea occurred to him. There are scores of stories like that, told by mathematicians and other scientists, see Hadamard (1986).

Right before the blackout we could, probably, watch molecules of such relatively simple substances as ammonia, formaldehyde, phosphoric acid, and hydrogen cyanide in a frenzy of chaotic molecular movement. Right after the blackout, we see them incorporated into long strings of polymers furiously twisting and kicking inside a fleck of a substance similar to Jell-O pudding. The blob grows in the ocean water, divides, and grows again.

Of course, all that is only our imagination. There is no way to prove how it actually happened. Indeed, there was no witness when life appeared on earth, unless an alien expedition was there. Even after humans had appeared, it took a long time before they became able to analyze and record their observations.

Like newborn babies, life and mind missed the moment of their birth. Nevertheless, our belief in the universal and permanent laws of nature (yet another hypothesis!) helps us reconstruct the picture with some plausibility.

Although life did not endowed us with its photo album with shots of the pregnant Mother Nature and the naked baby Life, there is a collection of facts that confirm the origin of life from relatively simple organic molecules used as a biochemical Lego set. For example, most carbohydrates constituting the bulk mass of a plant can be regarded as polymers of formaldehyde. Important constituents of DNA are built of hydrogen cyanide. Metals such as iron and magnesium are vital for animals and plants respectively. Looking at biomolecules we can see their ancient origin in their folds and wrinkles.

Do we have any chance to reconstruct what happened when Life was born?

On the cosmological time scale, most of the Everything appeared without any witness present. By definition, what is going to appear tomorrow has no today's witness, either. We presume that there was nobody alive before life, as there was no mind before mind. Evolution is so teasing—like a mysterious murder—exactly because it is non-witnessed. It challenges the scientific method based on observation and reproducibility. We can neither observe evolution of entire nature nor can we reproduce it.

It is rather rare that a premeditated murder is watched by a witness. Nevertheless, the mystery happens to be solved in real life and not only by the fictional Lieutenant Columbo on TV show. It is our knowledge of both human and physical nature, as well as our logic and common sense that guide us through the investigation. We can be optimistic about solving the mysteries of origins because we have already solved many mysteries of nature. Still, like with real murder, there can be mistakes even if a witness was present.

Origin of life is an obvious annoying gap in our knowledge. What can we expect to see in the missing piece? Where is it kept? What would happen on another planet at similar condition amidst the rocks and the waters?

The approach I am trying in this book is to build a bridge over the “no-witness” gap between two observable points: molecules and civilization. In order to do that I have to use the same building materials—Grenander's atoms of Everything—all the way.

What bothers me is that while moving from our side of the canyon back into the past, we cannot expect that the same apparatus of thinking will be on hand as soon as we enter the pre-mental era.

Suppose, we invented a more comfortable car-like version of Herbert Wells' time machine. Riding backwards along the time road, we will see less and less gas stations, they will disappear at a certain moment, there will be more and more primitive metal tools, and sooner or later we will have only stone tools to fix our car. Similarly, if we want to trace mind back to its birth from life, and then further, to the birth of life, less and less sophisticated mental tools might be available. We will abandon mathematics, be left with our fingers to count, lose the ability to count, and lose even the gift of memory that allows us to remember what happened an hour ago. We will not be able to remember at this point even the word "we" that opens this sentence.

Mind—mathematics is its finest creation—is a bonding device. It connects anything and it does not know any distance.

In the material world, however, distance is crucial. Two pieces of Lego should be positioned close to each other before they can be snapped together. Two distant material objects do not have any means to interact and, speaking in human terms, they do not "know" about each other. The fundamental property of our mind is the ability to consider (hold together, keep in mind) two distant objects, for example, the bagel in the fridge and the knife in the drawer. There is no physical interaction between both before we take them in our hands. Nevertheless, they are connected through our mind that directs our hands that bring the knife and the bagel in contact.

If we want to understand how life and mind originated, we can talk in terms of pattern theory only about acts and events taking place between generators close to each other—there is no mind to serve as the door hinge that facilitates the contact between the door lock and the door frame. There is no child to bring two Lego pieces in contact. There is no clock, no yardstick, and no memory. What kind of science can be done with the mind of a molecule?

One solution of the problem of genesis was suggested by religion. Everything was created by a super-human Creator who inspired one of his creations to make a record and to be a creator himself.

In a sense, the idea of God the Creator was the first profound scientific idea. It was, actually, the beginning of science, which starts with asking and answering questions. With time, religion and science fenced out their lots. Religion stayed with unique, irreproducible, and imaginary events while science committed itself to repeatable and measurable phenomena. Evolution, however, always seemed to be a disputed territory, and, no wonder, it has been a battlefield.

One way to deal with evolution is to examine the process of creation in nature and in human activities and extrapolate it back in time.

Another alternative is to actually create life and mind and make the creation a reproducible event and legitimate object of science.

This is where yet another problem crawls in.

Suppose, we can create a life from scratch in an experiment. Our intellect and our hands will bring the new life into existence. We would inspire a word processor, our other creation, to print the record about our new sensational creation. The well documented record would never raise any controversy. A new book will sit on the shelves of bookstores.

Even if we succeeded, would there be really a new life created? Our synthetic life will be a realization of our ideas, drafts, calculations, and manipulations with instruments.

In the authentic creation, we have to create life without any assistance by the already existing life. Moreover, we have to create life without creative power of intellect. Therefore, our success in developing artificial life will be nothing but a proof of our failure. It would be *another life*, a **different** life, an offspring of our own, an extension, and not a **new** life.

Artificial intelligence runs into the same difficulty of the purity of origin as artificial life does. I firmly believe that a computer, probably, of a new type, will someday successfully imitate human thinking and dreaming, not just human obedience and diligence. From the practical point of view, we would not care about the origin of a device which could successfully pass the Turing test: hidden behind a curtain or inside Commander Data, it would be indistinguishable from a human.

Created with human mind, artificial intelligence, like artificial life, would hardly pass the purity test, however. Executing a program, the computer runs into a command like GOTO and jumps to a different address in the memory. The computer memory means a strange land, a big city where the distance between all homes at all addresses is the same because it is equally easy to move from one to another.

The medium where life originated was dramatically different: a molecule "felt" only what it touched. What was one, two, three, and more molecular diameters away, did not exist. Therefore, the very concept of number did not exist. This is why it is useless to approach the last moments of the prebiotic era with the mathematics of “one, two, three.”

In order to analyze the problem of the origin of our abilities to live and think, we have to use an absolutely sterile equipment and to take care of preventing our probe from being contaminated with our own life and mind. It is the same situation as with probing for life on other planets.

YES, NO, **ONE**, **MANY**, **MORE**, **LESS**, etc.—this is all we can use because this is the mathematics for a molecular mind. In the world of molecules all events happen only at a close distance. It is like an imaginary New York City where you see only the person you can touch and immediately forget somebody as soon as he or she is out of touch, where you always know without the scale whether you are losing or gaining weight, and not money but **MANY** defines all your life.

From this point of view, what separates the molecular New York from the mental one and from the real one is the concept of distance.

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30. MORE AND LESS

In a number of examples we saw how much the difference between **ONE** and **MANY** was responsible for the behavior of things. Our next step is to play with **MORE** and **LESS** and for this purpose I am going to use a **toy universe** significantly simpler than Lego. It is the pattern universe populated with graphs on five nodes. I will call it Universe-5, or **U-5**, for short. **Figure 39.1** presents all its states.

If all the bonds in **U-5** are identical, independent, and can be broken or formed equally easily or equally hard, the mini-universe **U-5** will generate its configurations completely chaotically and we will not be able to make any prediction whatsoever. There will be a moment when all five nodes are completely disconnected, and there will be a moment when all the nodes the graph are connected with all ten possible bonds at a time. Three possible transformations starting from a certain initial configuration are shown in

Figure 30.1A. Even molecular chaos is less chaotic than this system because due to the geometric properties of molecules in 3-D space not all of them can push through the crowd of other molecules and collide next moment. In our graph space anything can change into anything any moment.

Let us stir some order into this absolute chaos, like a cook carefully adding ingredients to the sauce.

Our first act is to introduce abstract distance into the configuration space and to decree that only one bond can change at a time—either break or form. It means that any change is a continuous line in the configuration space and jumps are impossible. Now we have possible and impossible changes and the inflamed **U-5** somewhat cools down.

Figure 30.1B illustrates a possible sequence of minimal transformations.

Our second addition imposes an inequality of another kind. We legislate something that sounds politically incorrect: bonds are "born" unequal and they may have different abilities for change. I leave to the reader to ponder whether social equality means chaos or order. As a hint, I note that if we have to distribute a dollar coin among five people equally, we can do it only by drawing lots, i.e., by chance. The result will be inequality, anyway.

Within the limits of our mathematics, we cannot express any value in numbers, but it is sufficient to say that each bond has a certain value E_b which is the stability of this bond. We do not know how to measure E_b, but if we have two bonds, we can always say which one has **MORE** E_b than the other. Therefore, some bonds are stronger than others.

Suppose, three bonds in **U-5** are stronger than other seven. They are shown with double lines in **Figure 30.1C**. If we start with the same initial graph as in **Figure 30.1A**, there are some possibilities shown in **Figure 30.1D**. The stronger bonds tend to form, while the weaker bonds tend to break. Therefore, after a series of steps, strong bonds will statistically dominate. If we take, so to say, a photo of this graph with a long exposure, we will see mostly the three strong bonds with the fuzzy halo of the weak bonds.

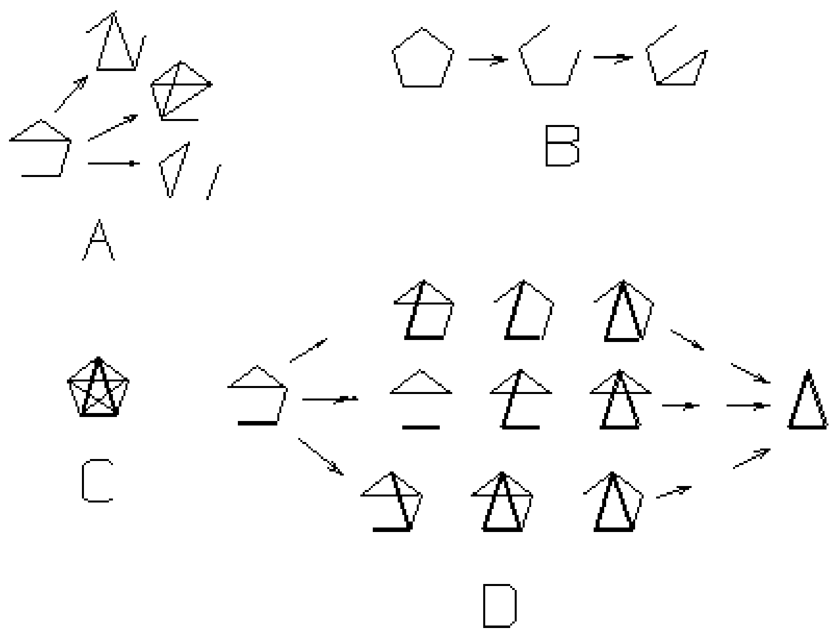

Figure 30.1. Taming the chaos of graphs

What all that means is, actually, the flickering bond: two generators can be either bonded or not with nothing in between, so that the bond flickers like in a strobe light. If the flickering is rare, the bond is weak, and if we see mostly light, the bond is strong. The anarchy of the initial **U-5** is thus abated.

Now let us squeeze in the third inequality.

Let us assume that there is some arbitrary standard E_s so that we can say about any bond whether its E_b is **MORE** or **LESS** than E_s. Now we can not only compare any two bonds between them but also say whether any of them is stronger or weaker than E_s. It is the same as to classify all people into those above and below 6 feet tall.

Next, to make the idea clear, let us rename E_b as *energy* and E_s as *temperature*.

Temperature is nothing but a certain energy chosen as the reference notch to judge the bonds. If their energy is above the notch, they are strong and mostly closed, and if they are below it, they are week and mostly open.

In the molecular world, temperature can be very naturally expressed in units of energy and *vice versa* because **temperature *is* energy** of chaotic molecular movement.

Now let us define the strength of the bond as the temperature at which the bond is open or closed with **EQUAL** probabilities. Remember, temperature is just a reference energy. As a certain floating standard of bond energy, it can be compared with the currency exchange rate.

The buying power of dollar abroad goes up and down with the fluctuations in exchange rate, although the face value which is printed on the banknote does not change. Similarly, the strength (stability) of a bond is its face value which is always the same. At different temperatures, however, the same bond flickers at different rate.

With the inequality of bonds and the factor of temperature, life in **U-5** becomes more interesting. As I said, temperature is an external factor and by changing the temperature, the gods of **U-5** can play various tricks with it.

If the bonds are too weak, it is tantamount to say that the world is chaotic. If they are too strong, the world is rigid. But “weak” or “strong” should not be taken literally, because at a high temperature all bonds are weak and, if frozen, all bonds are strong.

In our toy universe we do not discover laws: we impose them. In the material world, energy and temperature are in the center of physics that explains the behavior of chemical systems and predicts the direction of their development and the pace of events. We cannot impose any laws on the floors of Everything below society—even society resists them very successfully—but to generalize energy and temperature over the entire Everything—why not?

How often in history a robust civilization or culture with strong bonds between social components was hit by a heat wave of an invasion or heresy or a social disease coming unexpectedly from the outside or just out of nowhere. The elaborate structure melted down sending around floods of refugees. How often in the history of art and science the rules, dogmas, and canons melt down and art is cast into a new variety of forms.

Two intriguing questions arise from the concept of universal temperature:

1. Is there an overall trend of changing temperature in Everything? If it rises, what is going to happen? If it falls, is it good or bad for us?

2. Can there be any stability in our life if sooner or later all bonds will be broken by the rise of temperature or all freedom will be taken away by the fall of temperature? Is there anything permanent in this world so that we could build our nests and regain piece of mind, or the utmost stability can be found only in a life of a stone?

In large chunks of Everything temperature is not the same for different parts. If it were evenly distributed, the play of bonds would stop. For some reasons, well explained in popular literature on chaos, heat and cold are traveling over the Everything like winds and clouds around the globe, breaking bonds and freezing them in new configurations. At some conditions, a dynamic system can be inherently chaotic, albeit with a substantial degree of order, and atmosphere is a good example. We can predict that the winter in the Northern Hemisphere will be colder than the summer, but we cannot predict the temperature for every day of the year. The pattern of clouds over the Earth, as seen from space, is always unique and changing in a direction that can be predicted only for a few days.

Temperature is the degree of heat, i.e., chaotic energy. There are different forms of energy. Such organized forms of energy as work and radiation are not at all chaotic and they create order because they are selective, i.e., generate **FEW** out of **MANY**. We can break a dry twig if we apply force in any direction, but we can use a minimal force if we apply it right at the middle of a twig supported at its ends.

Radiation supplies energy in quanta, small portions of energy. Therefore, a quantum of radiation, absorbed by a molecule, generates mostly a particular change that demands exactly this amount of energy. In chemistry it often means that only certain bonds will be selectively broken.

We can summarize our approach to bonds in patterns as a statement of a meta-physics:

The higher the temperature the less probable the bond

We cannot learn anything from our physics because it states only what we have already postulated or defined. It is just a language and not the real physics. Once we have the language, however, we can sort out meaningful statements from meaningless ones, as well as the true ones from false among the meaningful ones.

To summarize, in the language of my home-made physics, a bond is superposition of two states: closed and open. Each state has a certain probability, both adding up to 1. In the long run, we can compare the ratio of the time the bond is on to the time it is off. The higher this ratio, the stronger the bond is. When it is on all the time, it is the strongest possible bond. All bonds are getting weaker with rising temperature.

With our wandering mental eye, we will come back to the subject of temperature in Chapter 57.

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31. LOVE THY NEIGHBOR

If evolution of Everything has something to do with distance, we need to bring the distance into the picture. Since there is no distance in the distanceless world of graph nodes, any two nodes can be either bonded or not, but they cannot be close or far apart.

As soon as we have a space where some points are close and some are not, the picture is more complicated. Two generators in a configuration space with *distance* can be:

A:	1. close	**B**:	3. bonded
	2. distant		4. separate

The following statement is neither my hypothesis about how Everything is built nor any piece of knowledge about Everything either, but rather a configuration of a certain mental Lego in my head.

Only close generators can be bonded

"Distant," therefore, means exactly the impossibility of bonding and we now can distinguish between potential bonding and actual bonding.

For example, distant atoms in metric space do not interact at all and a bond between them is impossible. It is the chaotic movement that occasionally brings them close enough for bonding and if the bond is broken, it is highly improbable that they will ever find each other again in the whirlwind of molecular chaos.

Taking another example, two people in the Western society can marry only if they know each other, i.e., are at least geographically close during a certain period of time, maybe even at the last moment. People who are not aware of each other's existence cannot form any bond.

The bond of love between Romeo and Juliet could lock in only after they were brought by circumstances within a short distance from each other.

"Love thy neighbor" with emphasis on neighbor is a statement of physics that can be interpreted as: "closeness is a necessary condition of bonding." As Dostoyevsky noted, it is no problem to love somebody distant: try to love your neighbor. The condition of closeness is necessary but not sufficient. We still have to see whether the World Wide Web brings brotherhood into this world. Two hostile brotherhoods are not what we would need.

Two things can happen with two generators that have some affinity to each other:

1. If they are distant, they can be made close, and *vice versa*, close generators can be moved apart and made distant. We can simulate these two processes by alternatively

spreading our hands apart, as if we wanted to fly, and joining them together in the Hindu greeting.

2. Distant generators cannot be bonded. If they are close, then if they are not bonded, they can form a bond, and if bonded, they can break the bond, remaining close.

We can simulate bonding/unbonding by locking the fingers of both our hands together. Some possible cases are presented in **Figure 31.1** with a pen and its cap. A pen can be either far from its cap or close to it. When it is close, it can be capped. When it is distant, it cannot. There are also cases of wrong mutual orientation.

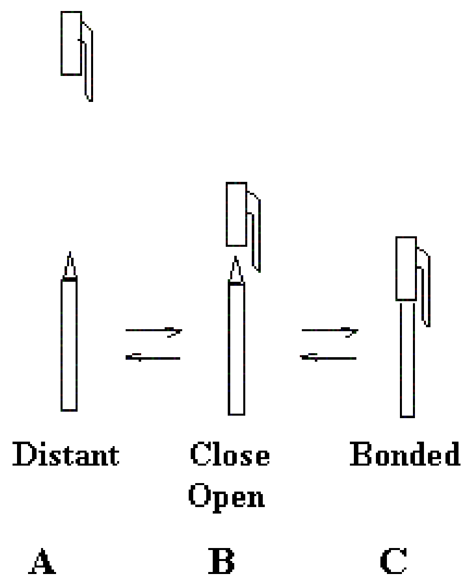

Figure 31.1. Bonding and distance

In view of this classification we can say that the door hinge is a device to keep the door and the jamb close, while the lock is the device to form a bond. If a bond is closed, it is not distant. If it is distant, it is not closed. Clsoeness is a condition of a bond.

Here I would like to give another example of the interplay between closeness and bonding.

From time to time I make typing errors. What is more accidental than an error? Once I noticed that I accidentally typed "aork" instead of "work." I was surprised: I would rather expect to mistype it as "vork" or "wcrk". It looks like there is a certain weak bond between letters **W** and **A**. In fact, there is, but not in my mind.

The explanation is simple: on the keyboard of my computer, **A** is in the vicinity of **W**: they are neighbors. This is why such a mistake as "dog" instead of "cog" is also possible, while "doq" is highly improbable.

If I used a Cyrillic keyboard, I could mistype TOK (sounds like talk, means current) and POK (sounds like rock, means fate) because keys T and P are neighbors in the Russian layout. I would not do it in English, however.

If we increase the temperature, bonds become less and less probable and melt one after another, first the weakest, then the strongest. If I type in a hurry, I make more mistakes because the bonds in my mind and between my brain and my fingers are getting weaker. My mistakes, however, follow the topology of the keyboard, which is completely alien to the topology of my mind and fingers. Even a monkey at the keyboard would produce, probably, not a completely random text but a sequence of letters from which the layout of the keyboard could be reconstructed: the closest keys would appear as more often coupled letters (or, probably, less often, depending on the nature of monkey's physiology).

Those familiar with genetics might find here some similarity with the old classic methods of the mapping of the sequence of genes in chromosomes by the frequency of their joint occurrence after crossover. The nature was presumed to copy a chromosome as a bunch of monkeys and the true message of the genes was reconstructed from their errors.

When the Universe was born in the big bang or whatever it was, the temperature was so high that there were no chemical bonds at all. Gradually, in the course of cooling down, subatomic particles formed atoms, atoms formed molecules, molecules formed polymers, etc. Throughout all that long stretch of evolution, the abstract temperature has been decreasing.

Society is the youngest and the hottest formation on earth, but it is quickly cooling down right before our eyes toward the global economy, tied down in wired and wireless round the clock communication as Laocoon and his sons in the coils of snakes.

We should note that temperature breaks positive as well as negative bonds. This follows from our understanding of temperature as the level of chaotic energy. Chaos disrupts all types of bonds and opposes any type of bond, even the neutral one.

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32. COMPLEXITY AND EVOLUTION

Whatever we say about the unwitnessed evolution of life and mind, it will remain a speculation until we witness several other evolutions of the same magnitude. Nevertheless, there are strong reasons to believe that evolution of life is only one link in an overlapping sequence of other stages:

> ...particles — atoms — molecules — polymers — life — cell — organism — behavior — mind — language — society — technology — science — global politics — global economy — global information — global culture — ?

Everything in this chain starts with its complete absence. From nothing of its kind it evolves into something and provides a foundation for another emerging structure with which it coexists.

NOTE (2006): One should not look for harmony in anything global.

From a primordial matter without atoms, molecules, and stellar bodies, the highly diversified and organized Universe emerges with its quasars, nebulae, giants, dwarfs, planets, etc.

On one of the planets, simple forms of life unfold into an overwhelming diversity of coexisting species. One of them multiplies, evolves, and dominates other forms of life, developing an incredibly rich record of social diversity and organization, language and culture. It splits into national subspecies and some of them develop enormous, staggering, excessive numerical richness of material culture with millions of books, things, as well as pieces of art, trash, and junk mail.

We are having more and more of everything and need more and more space for just listing all particular objects known to humankind. Each particular man-made object struggles for the attention of the public, and more and more products perish in this struggle, together with individual hopes of those who brought them to existence.

Along this sequence we can identify three more general stages: pre-biotic, biosocial, and global. There must be a general fractal pattern of any evolution, repeating on the large as well as on the small scale, so that the evolution of man-made things could tell us something even about the global stage of evolution on earth. One such universal fractal trend is the growth of complexity.

Man-made things are yet another form of life. Simple aspirin splits into sub-species for day, night, extra-strength, and some special needs. Anti-heartburn medicine comes in several flavors and colors, all having no influence on its function. Life looks more and more complex. The explosion of things can be compared with the Cambrian explosion of taxonomic richness in the evolution of life about 550 million years ago.

The cardinal importance of complexity for current social evolution is being recognized more and more. The main reason is the overwhelming complexity of modern civilization and the failure of governments to deal with the problems of modern society, as well as the failure of the society to deal with the governments. Various institutions are complaining about the tremendous burden of complexity which threatens to paralyze regulatory mechanisms of social life.

At the stage where we are now, the weight of a Sunday newspaper embodies the burden of complexity: it can kill a mouse, a frog, or even a small dog.

The outbreaks of chaos periodically shake even the most sophisticated and advanced societies, while the order of entrenched and rigid bureaucracies strangles the creative evolution. The people blame the government, although the government simply cannot process and manage the complexity by simple means. The only way it can improve itself is to grow and nurture its own complexity.

From time to time complexity collapses, as it happened with clothing, social structure built of many classes and estates, social customs, and, probably, will happen with the system of taxation, law, and computer software. In turn, new growth comes to new areas.

Basing on the available data about distant past provided by archeology and paleontology, as well as the witnessed evolution of cars, media, science, politics, and paper clips, we identify one common trend in evolution of everything: the surge of complexity. We do not know whether this is true for the evolution of the universe, but our experience on earth strongly suggests it.

We know that after the Cambrian explosion an opposite process of simplification followed about 200 million years ago during Permian extinction which wiped off 96% of all species. Nevertheless, no large taxonomic units disappeared in the massacre.

We talk about matter, energy, entropy, distance, time, etc. Can we include complexity into the list of major quantitative values? Is it an independent parameter or a derivative one? What is the relation between complexity and such notions as order, chaos, randomness, and entropy? What is the measure of complexity? Is chaos complex or simple?

The way we answer such questions depends on how we understand complexity and related terms. Since we already know that the most fundamental concepts are defined through each other, we can define complexity as what grows in evolution and evolution as the growth of complexity.

If we are looking for appropriate units to measure evolution, it is a very natural idea to use units of complexity, although it is not quite obvious how to do that.

An exemplary, albeit too complex, description of complexity belongs to Joseph A. Tainter (1988). Complexity is the "size of a society, the number and distinctiveness of its parts, the variety of specialized social roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole. Augmenting any of these dimensions increases the complexity of a society." Instead of society, we can talk about any object, omitting a few words such as "social," but this definition is inclusive, and we never know what we might miss.

Everything is too complex, the complexity of the world starts bothering us, we sense here a future quandary, and we want to understand what the elusive and fluid complexity is. Questions clearly outnumber answers in this area of human thought—a happy situation for a scientist. Information, too, was just a vague idea, until a precise way to measure it was found. Can we do something similar about complexity?

33. ALGORITHMIC COMPLEXITY

Despite its title this chapter is not only about complexity but also how much mind do we need to have something in mind. This question arises when we try to imagine the very emergence of the newborn mind, as small and feeble as the first life and first airplane were.

The most popular approach to measuring complexity is based on the concept of algorithm. The latter is nothing but a sequence of instructions for a human, robot, or computer performing operations with a piece of whether metal or information.

The following cooking recipe from *The Lilly Wallace New American Cook Book* (Wallace, 1946) is a typical algorithm:

(1017) RYE BISCUITS

1 cup rye flour	2 tablespoons sugar	1 teaspoon salt
1 cup flour	$2^1/_2$ tablespoons shortening	

Mix and sift flour, salt, and sugar. Work in shortening with finger tips. Add water and mix to a stiff dough. Knead for a few minutes on floured board. Cut with a cookie cutter. Prick with a fork. Bake to golden brown in moderate oven (350^{o}F.).

This algorithm has a name (RYE BISCUITS) and an address (1017), starts with a declaration of ingredients and their numerical values, and presumes some feedback from the results of the operation along the way, i.e., includes instructions of the type: "if this is the case, than do so and so; if not, do so and so." For example, "mix to a stiff dough" could be expanded:

(M) Mix
IF stiff, THEN GOTO (K) {knead}.
ELSE GOTO (M).

Here (**M**) means the address of a certain point in the algorithm, like (1017) is the address of the recipe in the book.

Algorithm is a configuration of generators, and its structure is independent of the subject matter. An algorithm can include, for example, SUBTRACT 3, instead of mixing, EQUALS 0 instead of "stiff," PRINT "YES" instead of kneading, and be a core of a somewhat larger algorithm for checking if a number divides by 3.

RYE BISCUITS is written in plain English. When an algorithm is written in a programming language, it is called program or code. Plain ENGLISH is as good for some purposes as MATLAB or C+. Algorithms can be written in many programming languages used all over the world and there is usually more than one way to program the same algorithm. Such components as IF, THEN, GOTO, etc., are universal features of algorithms. Making rye biscuits even includes a function called RANDOM: "knead for a **FEW**

minutes." In programming languages **FEW** can be expressed as RANDOM (3,5), which means a random natural number from 3 to 5, i.e., 3, 4, or 5.

When we cook we keep in memory where our flour and salt are in the cabinet. We have free access to all points in our kitchen. If not, we prepare in advance all ingredients declared in the beginning of the recipe and put them within the reach on the counter. What is on the counter and is used for cooking can be compared with RAM, Random Access Memory, and the rest of the kitchen is similar to ROM, Read-Only Memory of the computer.

Let us take a simpler example: a book case. I can take a book off the shelf, open it and read. I can also remove or place any book on the shelf, provided there is free space. All the books are practically equally **close** to me, although the geometrical distance between the books and myself varies.

An example of an algorithm is an instruction to arrange books in alphabetical order by author. It could go like this:

> Look at the first book on the top shelf. If the author's name starts with **A**, look at the next book. If not, take it in your left hand and follow the row of books with your eyes until you see one with the author's name starting with **A** , take it in your right hand and exchange both books. Look at the next book after the one you have just put on the shelf with your right hand. If its name starts with **A**, look at the next book. If not, take it... etc. When you see the last book on the shelf, start it all over, looking for books with author's name starting with **B**, etc., until you are finished with **Z**-authors.

Of course in real life we are rarely so methodical and we rearrange books in a more chaotic but more efficient way.

If we write this algorithm in each detail instead of "etc.," it will be several pages long because we will have to repeat some segments as many times as there are letters in the alphabet.

Instead, it can be written in a shorter form:

Find first **A**, place it first, find next **A**, place next, do so until the end of shelves, then start over for the next letter of alphabet, do until the end of alphabet.

That makes sense only if we know in advance what "place it first," and other expressions mean. What we use in this kind of instruction is a special language understandable by professionals in the field. If we have agreed on the meaning of our terms, the whole algorithm can be made very short:

ARRANGE THE BOOKS IN ALPHABETICAL ORDER,

or compressed even more:

SORT BOOKS.

Labeling a long procedure with a short name or referring to the address of another procedure is commonly used in both cookbooks and programming. Here is a recipe with a reference to another recipe:

(1076) RYE STICKS Follow recipe for rye biscuits (No. 1017), but roll out 1/2 inch thick and cut into 3 inches by 1/2 inch sticks.

Similarly, the programming function RANDOM, as short as a dog command, means a rather complicated calculation that produces a “pseudo-random” number, i.e. the number that is probably random, but we can never be sure.

Therefore, the same object can be given a longer or a shorter description. If it is short, it always requires some background knowledge in possession of the one who writes the description and the one who understands it. This knowledge is not included in the program.

According to the almost half century old approach suggested by Kolmogorov and Chaitin (Chaitin, 1975), complexity of an object is the length of its shortest description. The description can be considered as an algorithm for reconstructing the object, like Recipe No. 1017 is an algorithm for reconstructing rye biscuits.

Complexity is one of the most important concepts of Everything and we can afford spending some time with a very simple version of Lego consisting of integers 1 and 0 and some accessories such as parentheses. In this Lego we can assemble only linear sequences.

The favorite illustration in the theory of algorithmic complexity is an alphanumerical string, for example, a sequence composed of numbers and letters of alphabet. For example:

String 1 010101010101010101010101010101,

which is 30 units long, but can be compressed as:

String 2 1111(01),

because it is nothing but 01 repeated 15 times, and 15 in binary notation is 1111 (8 + 4 + 2 + 1 = 15). This is what compression is about, and it is possible because of the highly regular nature of **String 1**.

Next I am trying to write a random **String 3**, "trying" to avoid any regularity (although if you really try hard to do something, you can produce only order).

String 3 100010111000101011100100100110 (**Test string A**)

I assume it is random and I will call it "test string A" to use it in subsequent chapters

I cannot compress **test string A** into a shorter description because I do not see any regularity in it. It does not mean that there is no pattern. Somebody may find the pattern where nobody sees in, and this is how big advances in science were made. The question about a possibility to compress a particular description is always open, however. In general, we can prove that it is compressible only by demonstrating how to do that.

Algorithmic complexity is a value which can be measured by counting the length of the shortest compression of a sequence. There is some confusion about this approach, however. First, we never know if a description can be further compressed. Second, the compressibility of a message depends on an agreement between the sender and the recipient. For example, in the long gone age of telegrams, when the cost depended on the number of words, people tried to use as few words as possible without losing the meaning.

For example, we could compress the message:

A. DESCRIPTION IS NOTHING BUT A PROGRAM FOR A HUMAN OR ELECTRONIC COMPUTER TO REPRODUCE THE OBJECT

into:

B. DESCRIPTION IS PROGRAM HUMAN ELECTRONIC COMPUTER REPRODUCE OBJECT.

Message **A** could be compressed also at the expense of letters:

C. DESCRIPTN IS NOTHNG BT PRGRM FR HUMAN OR ELCTRNIC CMPTR TO REPRDUCE OBJCT.

Obviously, somebody who does not know English and the subject will not reconstruct the sentence.

Another confusing thing is that the compression of data into a formula is not always as dramatic as it may seem. For example, the length of an infinitely extended **String 1** will be expressed by an infinitely long **sequence 2**, because the number of 01-pairs will be infinite, too. Of course, we can say "write 01 infinite number of times," but what if it is just a large number? We can keep the concept of infinity in mind, but we at least need a mind.

The approach to complexity based on compressibility has an inherent complexity of its own. When we compress **sequence 1** as "write (01) 15 times," we dodge the complexity of explaining such terms as "write", "15 times", and parentheses. It certainly takes an intellect to follow such instructions.

A compressed message on its own is like a can of sardines that has no can opener attached or built in. I cannot take it into a journey into mindless world.

Algorithmic complexity is very anthropocentric: it displays between the sender and the receiver of a message. I would not certify it as sterile for problems of prebiotic and pre-intellectual evolution (see Chapter 29) unless our life were created by visitors from space.

In order to decode the description we always need some hard to define knowledge deeply rooted in the past experience. The algorithmic theory of complexity shows that for very long sequences, the volume of this additional knowledge does not really matter, but we are mostly interested in objects of a modest size.

Despite some perplexing aspects, the language of algorithmic complexity is perfect for expressing distinction between **two different kinds of data**. A huge volume of data of the first kind could be dramatically compressed into mathematical formulas and equations, while data of the second kind can be shortened only insignificantly.

The concept of algorithmic complexity gives us a curious insight: complexity starts where mathematics stops and when we cannot call many things with one name anymore. This is why John Barrow (1991) drew the line between *compressible* and *listable* properties: listable properties cannot be compressed.

While tables of mathematical functions, for example, trigonometric functions, could be compressed into relatively short analytical formulas, cookbooks can hardly be cut any further. A painting by Rembrandt, converted into a data string by a color scanner, cannot be compressed even a bit without losing much of its original effect—and value. Some abstract and op-art paintings, however, can be packed into a program which would reproduce not only this particular painting but also a whole series of similar ones. Mondrian seems to me very generic.

Taking another example, the complexity of a word processing software can be evaluated by the size of its manual. Probably, manuals could probably be compressed by thorough editing, but not much. Different programs, therefore, could be approximately compared just by weighing their manuals, if the quality of paper is the same. Algorithmic complexity looks like something we can measure with an instrument. The irony is that we do not have a universal algorithm for compression. Specialized algorithms work very well.

If we consider mathematical expressions, complexity of a mathematical formula is the smallest possible number of mathematical symbols needed to write the formula and a mathematical expression can be simplified by reducing the number of symbols. For example, the complexities of two following formulas of algebra and mathematical logic are, correspondingly, 16 and 12:

$\mathbf{a^2+2ab+b^2=(a+b)^2}$ **Expression 1**, complexity = 16

$\mathbf{[(p\vee q)\wedge q']\rightarrow p}$ **Expression 2**, complexity = 12

Expression 1 also shows how its left side, which counts 9 symbols, can be reduced to 6 symbols on the right side. The same meaning can be expressed in a more way or in a simpler one.

Coming back to numerical strings, we can compress **sequence 3** in the following way, which may be very effective for long strings:

String 4 100010 = a; a11a1011100100100110

There is much more to play with.

We can also denote 011101 as Neg(a), i.e., we change all zeros for ones and *vice versa*, Neg stands for Negative). We can also introduce operation **Bw** (stands for Backwards) which writes a segment of a string backwards: **Bw**(a)=010001. **N** and **Bw** are operators applied to a segment of string. We can use operators one after the other on the same segment: **NBw**(a)=N(010001)=101110. Operation **D** means DOUBLE.

With all those tricks, and at the high prize of irritating the reader (who may skip the rest of this chapter), **sequence 3** takes a shorter form:

Sequence 5 a11a**NB**w(a)0**D**(100)110

Every our attempt to simplify the world by naming many things with one name, however, will lead to a very complex description because we will have to introduce more and more additional notation, a far cry from the original simplicity of 0 and 1. This is how science as a means to simplify the world grows and becomes exceedingly complex itself.

To work in such a complex environment, scientific community splits, like in a beehive, into queens who develop new ideas, workers who drudge, and drones who just pretend working. In addition, some other insects may wear the camouflage of the bees. With such a complexity of science, the way to evaluate professional achievements is based strictly on counting: the naked numbers of publications, grants, and awards simplify the real world for a bureaucrat. Naturally, the number of dollars forces out everything non-numerical.

Let us further experiment with the idea of algorithmic complexity and examine where it leads us. According to Chaitin, a random number cannot be compressed into a shorter sequence. The non-compressibility is what he attributes to a random number.

The problem with **test string A**, 10001011100010101110010010011 0, is that it does not seem to be completely random, or, at least, not completely arbitrary. It has the property that we can describe as:

NOT **MORE** THAN THREE IDENTICAL SYMBOLS IN A ROW. (**Rule 1**)
Interestingly, the rule is longer than the sequence itself. We can cut it short:
NO 0000 AND NO 1111. (**Rule 2**)

Obviously, if there is no 0000, then there is no 00000 either.

We cannot use this knowledge in order to generate **test string A**, however. The only way to reproduce the sequence is to copy it. But do we always care about the way a random number looks? When we draw a lottery, the number 1111 is as good as 5417.

In the language of cookbooks, a random number is like potatoes in "take some potatoes" while a non-random one is like potatoes in "take small Red Russet potatoes."

It turns out that some random numbers are less random than others. Thus string 100110110010101010101100100110 (**String 6**) is as algorithmically complex as **test string A**: we need thirty binary symbols to describe both. At a closer look, it is somewhat "less random" than the test string because it has the pattern:

NOT **MORE** THAN TWO **IDENTICAL** SYMBOLS IN A ROW. (**Rule 3**)

This is a tougher restriction than the previous one. Still, both sequences, if they are long enough, have the same complexity from the point of view of the algorithmic theory.

It is not always easy to tell whether we know the shortest way to present a sequence of symbols. Moreover, a simple symbol, like a single letter, can denote a very complex mathematical object.

Furthermore, paradoxically, we can generate a "not-quite-random" sequence of symbols, using random instructions. For example, we can give an instruction:

> Write a random sequence of **N** symbols where the number of any identical symbols in a row does not exceed a random number in the range from 1 to **R** where **R** is a random number from 2 to **K**.

To realize this algorithm, a computer should use three random numbers: it casts **K**, finds the range for **R**, casts **R**, and looks back if there are more than **R** identical symbols in a row. If yes, it goes one step back and tries again.

Paradoxically, the triple-random string that uses three random numbers for its generation and appears to be, so to say, random along and across and inside out, is not random enough. Order infects it with the word NOT in "not more than" because order is a restriction, a NO. And, of course, computer generates only pseudo-random numbers.

Therefore, by using pseudo-purely random numbers—random along and across—the computer can generate a sequence of complexity **N** which will never be random because some of the numbers of the same length will be forbidden.

On the other hand, there are algorithms that by doing some very simple calculations along two equations can produce apparently random sequences without any visible order. Order, therefore, can generate chaos—a common place today. There is a substantial popular literature on that type of chaos (Gleick, 1987).

Talking about mathematical issues, I feel no firm ground under my feet. As a chemist, I am a born intuitionist. I need any statement to be demonstrated by something beyond the words and symbols. This is why I can do with a demonstration instead of a mathematical proof. Nevertheless, I am tempted to avoid applying such term as *random* to single numbers. I would say that sequences generated by rules 1 and 2 are *arbitrary*, while a sequence like 101101101101... is *regular*.

Here we are facing the distinction between static regularity and dynamic order. Regularity can be a property of a single object. It is not necessarily related to other similar or dissimilar objects. We can evaluate regularity just by looking at a picture.

On the contrary, a random number is always one of many equally possible numbers, and the way it looks does not matter. A perfectly regular number may be random in a context.

Randomness is a property of a crowd and not of an individual. We can say that a single long enough number is random only in the sense that all figures appear in it in equal quantities (more strictly, at equal probabilities). In the same sense we can say that a series of numbers is random if there is no preferred number. We can never say that a number is random unless we have a procedure for producing long enough series of random numbers. It is the possibility of many other similar numbers of the same length that makes this particular number random: random numbers fill up a space without any void.

In a physical system that produces random numbers, let us say, a lottery machine, the numbers are random if the representative point of the machine can fill up the whole phase space. In other words, time is inherently involved in the notion of random number.

On the contrary, a regular number is regular irrespective of other numbers of the same length. Regularity is an individual property, and it belongs to a pattern.

I am going to make a heretic suggestion, sharing a wide-spread doubt, that a random sequence is not at all as complex as the concept of algorithmic complexity surmises. Any random sequence has, actually, a minimal complexity because it can be compressed into a single symbol, for example, **R**, which means "random". The operation of generating such a sequence can be performed by any source of random numbers, best of all, by the chaos of molecular movement or radioactive decay. If we can denote word *multiplication* by a single symbol "×", we can denote any random number by R.

Let us look for something else. According to John D. Barrow, science is a search for compressibility of apparently disconnected data. Then what about non-compressible data? I believe, together with Ulf Grenander, that the search for regularity is the essence of science. This is what pattern theory uniquely provides: an apparatus to treat the listable, i.e., incompressible knowledge.

*

34. LOCAL COMPLEXITY

My discomfort with algorithmic complexity is strictly personal. As a chemist who has to navigate in the ocean of incompressible knowledge, I do not deal with algorithms every day.

Far from meddling with any mathematical theory, I would prefer describing complexity in a way that uses the language of generators and does not mention any compressibility.

Here I am going to make a digression and expand a little on sequences because I will need them for illustrations.

The string of one thousand 01s may seem more complex than the string of ten 01s. From the point of view of evolution, however, the inventor of the string of just two 01 invents all lengths of them just because of inventing a **generator with two bonds**. Intuitively, the "1000-string" and "10-string" are equally complex although they are different. The length itself does not mean anything: the snail has one of the longest DNAs on Earth.

Nature invented linear sequences of nucleotides and amino acids **mindlessly**. A different kind of invention is an introduction of parentheses, as in the following sequence:

$$10(00111(01)_2 0(001110)_4 0)_2$$

This notation means that the sequence in parentheses is repeated as many times as the subscript index shows.

The parentheses introduce a real complication into handling sequences because one has to **bear in mind** (here comes the mind!) that parentheses are always coupled, no loose one could be left, and a strict hierarchy of parentheses should be followed because one has no meaning without the other. It is impossible to use parentheses without human mind or its computer extension because there is no other memory on earth.

What parentheses actually do is maintaining a bond between distant objects in linear sequence. We can say that adjoining characters in a string are naturally bonded, snapped on, or glued to each other, and this is why the string is what it is: a sequence of symbols. The parentheses mean that some bonds are stronger than others. For example, in the following sequence, bonds between bold letters are stronger than bonds between italics, the latter being stronger than main font:

10(*00111*(**01**)*0*(**001110**)*0*)

The bold blocks **01** and **001110** are solid blocks bound with their parentheses like pages of a book with a cover. They are hold between italic *00111*, *0*, and another *0* by "italic bonds," the whole italic block bound with its parentheses and tied to the initial 10. We can show the same structure with parentheses and brackets:

10[00111(01) 0 (001110) 0]

We can denote bonds with dots: the more dots between two figures, the stronger the bond:

1::0 . 0:0:1:1:1 : <u>0::1</u> : 0 : <u>0::0::1::1::1::0</u> : 0

Suppose we start "heating" this sequence with the intent to melt the bonds. First, the initial 10 will fall off, then the two-dot bonds will melt down, and, finally, the four dot bonds will follow.

It is impossible to read a sequence with parentheses, brackets, and braces without a mind that has **equal access to all symbols** notwithstanding the real geometrical distance between them. (NOTE (2006): I don't think it is the same as RAM which needs addresses). When we are moving along the sequence and look at the opening parenthesis, we do not see the closing one. We have to **remember** the first one while we are looking for the second. Both should be tied in our mind, and without it no algorithm can be executed and no calculation made because otherwise we can be physically tied to one thing at a time. Mind is another dimension of nature where all fleeting and distant things coexist. Mind is a compactor where everything is close to everything. (NOTE (2006): I am not sure it is the same as Turing machine; I suppose it is not).

In order to use parentheses, one has to keep in mind the whole sequence and to have an ability to reach its distant points. Half-seriously, I could give a definition of mind as a device operating with parentheses.

The reader has probably already gotten the feeling of the close relation between metaphor and understanding. We better understand what mind is when we can say something like "mind is a universal compactor," or "mind is a bonding device," provided we can show that there are other compactors and bonding devices working like mind. I do not mean that our understanding is necessarily correct: it is just an understanding. Metaphor, this wing-footed herald of mind, brings together distant things and places them side by side. First human knowledge about the world was metaphorical: Zeus is angry and this is why the lightning strikes.

It would be good to jump from here to the chapters on catalysis, but I hope the

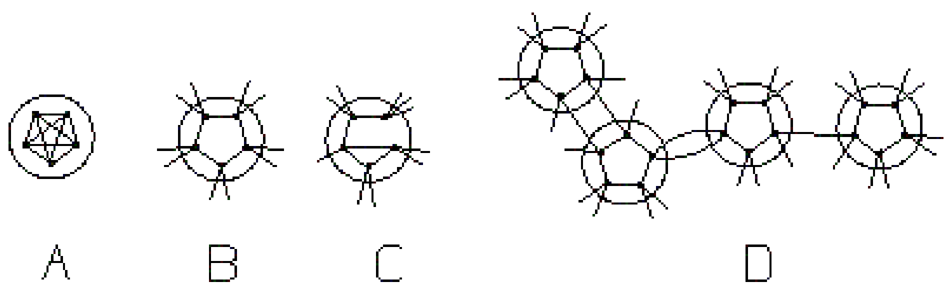


Figure 34.1. Hierarchy of generators

reader will remember the mental parenthesis opening here.

The natural mindless way to keep two distant generators together is to fill up the whole distance between them with a continuous sequence of other generators glued with strong bonds between them, simply speaking, by a physical bond.

Patterns can have a hierarchic organization of generators of different levels, so that a generator of a higher level is a configuration of generators of a lower level. For such organization, generators should be present in multiple copies. This is exactly the case in chemistry.

Let us go back to the toy universe **U-5** (Chapter 30). If each generator uses only two of its four bonds to hold the five nodes together, a generator of a higher level can be formed, **Figure 34.1A**. With less bonding inside this block (**Figure 34.1B**), more external bonds can be formed. If all bonds are used up for the internal bonds, nothing is left for the external ones (**Figure 34.1C**).

A pattern of a higher level is shown in **Figure 34.1D**. All we need to build patterns of the higher level is to have very strong bonds inside the blocks. If, for example, the boards and panels of a door (level 1) had connections as loose as the bond between the unlocked door and the frame (level 2), then the door would fall apart when we tried to open it.

Here I am closing the parenthesis opened with the sentence: "Here I am going to make a digression and expand a little on sequences because I will need them for illustrations," see the 3rd paragraph of this chapter, finish the digression, and return to the subject of complexity.

A generator in a pattern can be bonded in various ways to various other generators. The same generator can have different neighborhoods in different patterns. As a possibility of many neighborhoods, any generator is a space in itself, and each time it appears in an actual pattern, its connections with the neighbors correspond to a point in the **neighborhood space** of the generator, filled up with all possible combinations of neighbors. For example, the neighborhood space of letter A is filled with pairs of all possible neighbors on the left and on the right: b**A**c, b**A**d, c**A**t, etc., and even neighborhood a**A**a can be found in a real word, as in the abbreviation for American Automobile Association.

Generator in a pattern is what its neighborhood is. I have already compared the generator with a little hand holding the bunch of bonds. This time, looking out in the neighborhood of the generator, we can add a little **mind** to the little **hand** holding together the neighboring generators. The micro-mind calls different things (connected generators) with one name: neighbor.

I would define *local complexity* of a pattern as the number of different neighborhoods that could be encountered in a configuration. If we use the undermath incapable of counting, the complexity of a pattern is just the list of all neighborhoods, i.e., the natural representation of a number. It is like presenting Roman numeral III by three vertical lines or Japanese numeral 3 by three horizontal lines (**Figure 15.2**).

For example, **test string A** from Chapter 33, 100010111000101011100100100110, consists of the following **neighborhoods:** s**1**0, 1**0**0, 0**0**0, 0**1**0 ....1**1**0, 1**0**f,

where **s** stands for start, **f** for finish, and the bold print shows the element whose neighborhood is explored.

Although there is a total of 30 neighborhoods, according to the number of elements, the number of different neighborhoods is significantly smaller.

The maximal possible number of neighborhoods in sequences made of 0 and 1 is $2^2+2^3+2^2 = 16$. The first $2^2=4$ is the number of all possible beginnings: s**0**0, s**1**0, s**0**1, and s**1**1. The last $2^2=4$ is the number of all endings, and $2^3=8$ is the number of all triplets inside the sequence.

The end neighborhoods contain some information. For example, if we take the ends to account, sequence 0000000000000000... has local complexity: 1 inside triplet + 2 ends = 3, which is a minimum for any sequence with a beginning and an end. A circular sequence

```
      00000
   0        0
  0          0
 0           0
  0         0
    0      0
      00000
```

has no ends, and this is why its complexity equals 1. A necklace of identical beads is an example of a pattern of complexity 1.

If, for simplicity, we will not count the ends in our estimations of local complexity, then **test string A** has complexity 8, which is the maximal possible complexity for a linear sequence of 0 and 1.

Let us consider another sequence:

10011011001010101010101100100110 **Test string B**

Test string B has complexity 6 and looks as arbitrary as **test string A**, but we can catch the subtle drop in complexity due to the more restricted number of identical symbols in a row: not more than two. Its neighborhoods are: 1**0**0 0**0**1, 0**1**0, 0**1**1, 1**0**1, and 1**1**0.

Local complexity is neither better nor worse than algorithmic complexity, it is just fundamentally different. As I believe, it is most suitable for estimating evolutionary complexity, and it probably captures some of deep aspects of evolution.

For example, such sequences as 101101 and 101101101101101101101101 have different algorithmic complexities because the length of instructions "write 101 2 times" and "write 101 8 times" are different in binary presentation, where 2 is 01 and 8 is 1000.

Local complexities, however, do not depend on the size of the sequence, and for both sequences they equal 3 because there are three kinds of neighborhoods in both: 1**0**1, 0**1**1, and 1**1**0.

The local complexity seems to ignore long range regularities, such as the repeating pattern 101011110 in the sequence

101011110-101011110-101011110...

where the hyphen is inserted to make the pattern visible.

With the short-sighted topological vision, we cannot "keep in mind" more than immediate neighbors of an element. Suppose, the hyphenated sequence is an abstract image of a polymer consisting of many identical or different monomers like 101011110. If we can make a very coarse copy of the sequence, we will see only the sequence of the monomers, i.e., the higher hierarchical level of the pattern.

A coarse copy means that the bonds between the generators of the monomers in our copy of the polymer are so strong that we cannot even suspect that they exist. In this way we can deal with sequences of larger blocks and evaluate their complexity not seen at the close range. This is how we perceive history, turning our back to most everyday trivia.

Some directions of modern art are based on making coarse or even distorted copies of the world instead of the fine copies of the classical art, while others break even the strongest bonds between the components.

*

35. WHY DNA AND LANGUAGE ARE LINEAR

I am fatally attracted to all twilight zones: between day and night, rain and shine, joy and sorrow, minerals and life, life and death, and life and mind. I want to catch the moments of emergence, inception, and transformation. I play with the Lego of imagination trying to assemble the sunset out of clumsy rectangular bricks. This is what a poet who obsessively plays with words does, struggling to express a fleeting feeling coded in the subtle dark eddies in the depth of the soul,

I am attempting in this Chapter to slightly hit (not kill, God forbid) three birds with one stone. First, I would like to dally more with sequences because they are simple exemplary models of patterns.

Second, I am interested in algorithms requiring as little human mind as possible, whether naked or armed with a computer. If we are interested in the pattern origin of mind, we have to descend down to such a low level of mental abilities that even to execute command GOTO or deal with parentheses is out of question.

Third, I wish to expand on evaluating local complexity. I will do it by trying to design a "mindless" algorithm for that purpose. By mindless I mean something that lies in the twilight zone between molecules and mind.

In my quest for the minimal mind I am motivated by a hope to find forms of mental activity so primitive that they could originate spontaneously from the pre-mind matter.

The algorithm I suggest consists of two parts. It is applied to a configuration, for example, a linear sequence of symbols. In my comments I try to show that each step exists in nature without mind.

Algorithm: COMPLEXITY

PART ONE

(1) TAKE a generator AT RANDOM.

It means just crawling along the string without any order, making random numbers of steps back and forth, stopping at each generator and going to step (2) at the *taken* one. In physics it is called random walk or Brownian movement. Another example is a molecule of gas: during its wild race over the volume it meets, sooner or later, all other molecules in an unpredictable order, not making any stops, of course.

(2) MAKE A COPY of its neighborhood.

This is what we did when wrote down the triplets in the previous chapter. Replication of DNA is an example of rather complex but totally mindless copying. It is an evidence that physical copying exists in mindless nature.

(3) REPEAT 1 and 2 **MANY** times.

It is an intrinsic property of this world that same acts, events, and processes repeat over and over again.

Therefore, each step of PART **ONE** has a natural mindless counterpart: chaotic movement, making copy, and repetition. The result is a set of "isolated" neighborhoods: multiple copies of three-member segments of the sequence.

PART TWO

(4) TAKE a COPY of a neighborhood AT RANDOM.
(5) TAKE another COPY of any neighborhood AT RANDOM.
(6) DESTROY ("UNCOPY") **ONE** of the two identical COPIES.
Step (6) can be envisioned ("naturalized") as a random collision.
(7) REPEAT (4) to (6) **MANY** times.

The steps of the algorithm are portrayed in **Figure 35.1**: first, a pile of copies is produced (the bottom of **Part 1**) ,and then it is reduced to a set of **different** triplets in **Part 2**.

The result is a number, only not in any of its graphic forms, but in the "natural" form of a set of objects. Thus, either seven stones or a combination of three stones and four coins represent number seven. The final number of copies is a material form of a number, as good as word, written or spoken, or as Roman numeral III.

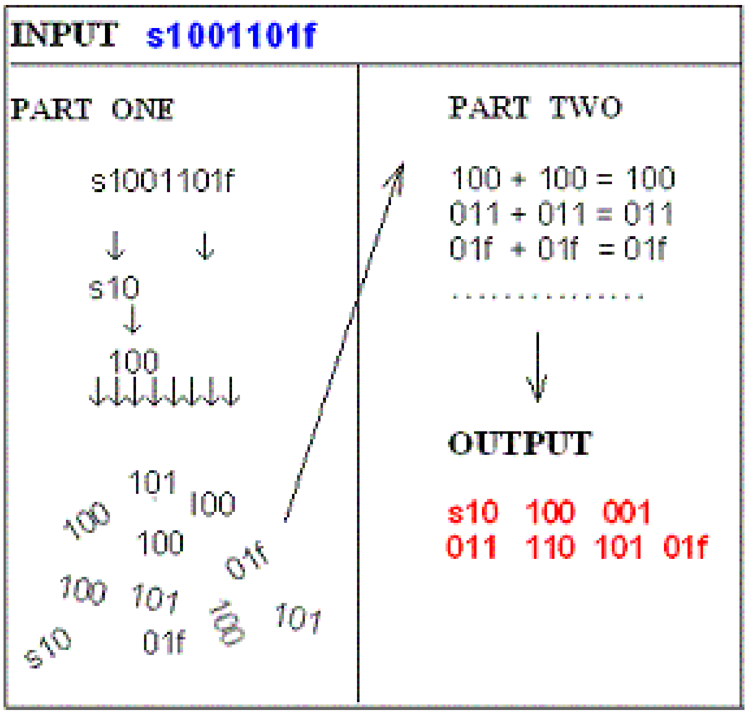


Figure 35.1. Natural calculator for complexity

Among all the steps, only step (6), which I would call "**UNCOPY**," has no equivalent in mindless nature. There is, however, some foundation for it in the form of **recognition**. If one copy recognizes the other as the same, the collision does not contribute to the count of complexity. If the other copy is different, it is counted. Even lower organisms with nothing like mind perform it. Molecules of enzymes perform it, too.

Mind is an exterminator of twins: it stores everything in one copy. Two identical messages is one message. Two copies of a book by Albert Einstein contain one theory of relativity. One hundred copies of a Social Security Card are exactly equivalent to one card.

If we know that time is money, nothing will change in our mind if we hear the adage again and again.

The above procedure of natural evaluation of complexity is very simple and it is always the same. It has nothing to do with the problem of generation of an object where Kolmogorov-Chaitin's complexity applies perfectly well. It destroys copies of an object, instead of generating an object, and to destroy something is much easier than to build.

Obviously, other variations upon this theme are possible and the reader can play with improving such algorithms and making them more and more mindless, so that they can display in inanimate matter.

All we need for that is **MANY RANDOM** events. Time, the vehicle for change, means **MANY** moments.

It looks like at least some calculations could be done by using **RANDOM** elementary operations, as well as operations of making a copy and destroying a twin copy, without either GOTO or parentheses.

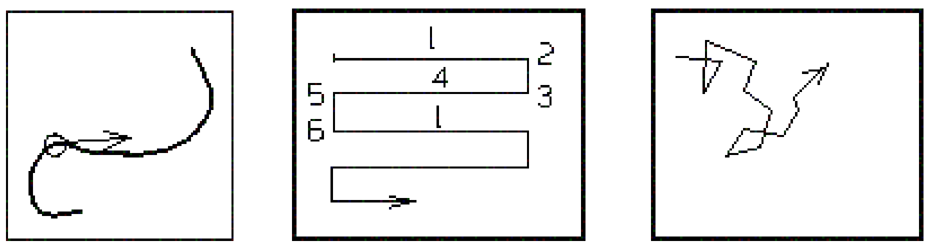
If intellect is a destroyer of identical copies, it is because of **memory**, which is, in tandem with recognition, a device for distinguishing between new and old. It never allows two twins to exist: one is always a copy of the other. Erasing is a function as primitive as copying.

Now I can attempt to answer the question why DNA is linear. It is because it can be crawled all over in **ONE** direction, without the confusion of **MANY**, from the beginning to the end, see **Figure 35.2**. The only thing the crawling creature should remember is "go straight ahead."

If we want to crawl over a plane, we need to have a plan or a view of the plane on order not to return to the same area again and again. We need more complex strategy of crawling if we want to

scan the plane in the shortest time possible. The algorithm can be:

(1) Go straight ahead, at the end make one step to the right, turn back, crawl straight ahead, at the end make one step to the left, turn back, GOTO (1). This is the way a dot matrix printer head moves over the sheet of paper.



A B C

Figure 35.2. Scanning a line and a plane

Or, we can do line scanning as it is done in TV: by jumping to the beginning of the next line.

Scanning a plane takes brains: we have to keep in mind the distance between the end of the line and the beginning of the next line. For the line, entropy is minimal. For the plane, there are too **MANY** possible directions.

For the same reason, our language is a linear sequence of sounds or letters. It can be easily remembered and reproduced because the uncertainty at each point is minimal. The **MANY** of the line is **LESS** than the **MANY** of the plane.

Probably, at the very moment of the origin of mind, there was a fork in the road to linear and two-dimensional languages, visible in the pictures of the cave men, carrying two-dimensional messages of the scenes of the hunt. This line of the evolution of mind turned into the road to art.

As **Figure 1.1** shows, the nature has not invented any ordered way to perceive a two-dimensional message: the eye scans it in a partly chaotic, Brownian way. In the same way we would perceive the real three-dimensional wave: as a semi-chaotic two-dimensional scan.

We can see another evidence of the fork in the road of the evolution of mind in the Chinese characters, which are, by their origin, small 2-D pictures, **Figure 35.2**. While different parts of Latin characters do not carry separate meanings, some components of Chinese characters are used as separate characters. They still contribute separate residual meanings to the overall meaning of the composite character, as "woman" and "child" contribute to the Chinese character for "good."

It seems to me that the Neolithic pictures on the rocks, **Figure 35.3**, was, actually, the first form of written language: they recorded a fact of the hunt or a dream about it in a two-dimensional form. They represent exactly the fork-road of written language and art from which the language took the hieroglyphic route and then sprouted the alphabet (Mazonovich, 1974). In **Figure 35.3** we can see repercussions of the storm in the see of mind 20,000 years earlier, while **Figure 1.1** presents another evolutionary descendant of the cave pictures—art—married to an awesome physical phenomenon in the inanimate matter: storm in the see of water. Those three pictures make up my triptych of Everything.

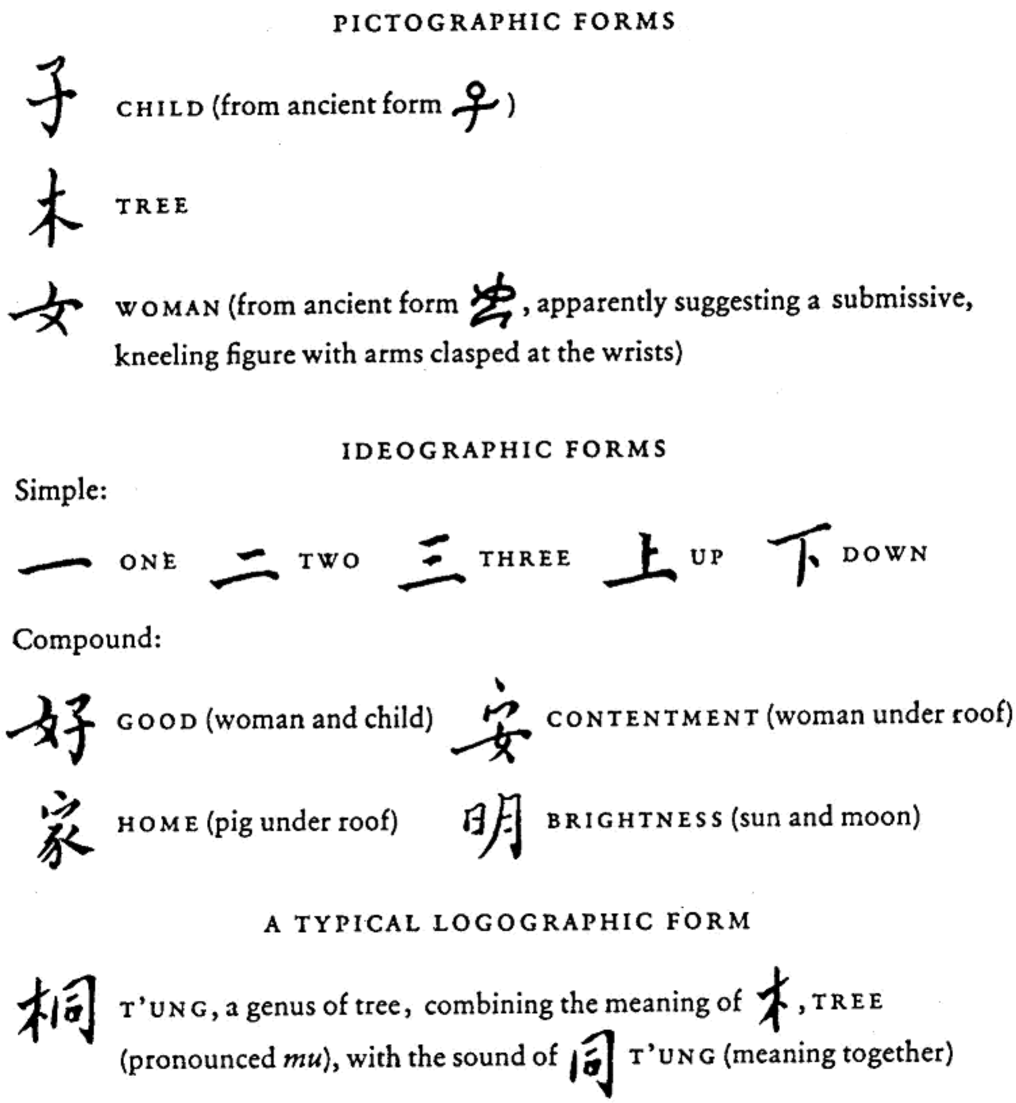


Figure 35.2. Chinese characters

Aren't the icons of our computers the repercussions of the pictorial cave art?

The turbulent ocean of Everything stirs up my mind like a newborn hurricane kicking up the surf at distant shores under quiet skies.

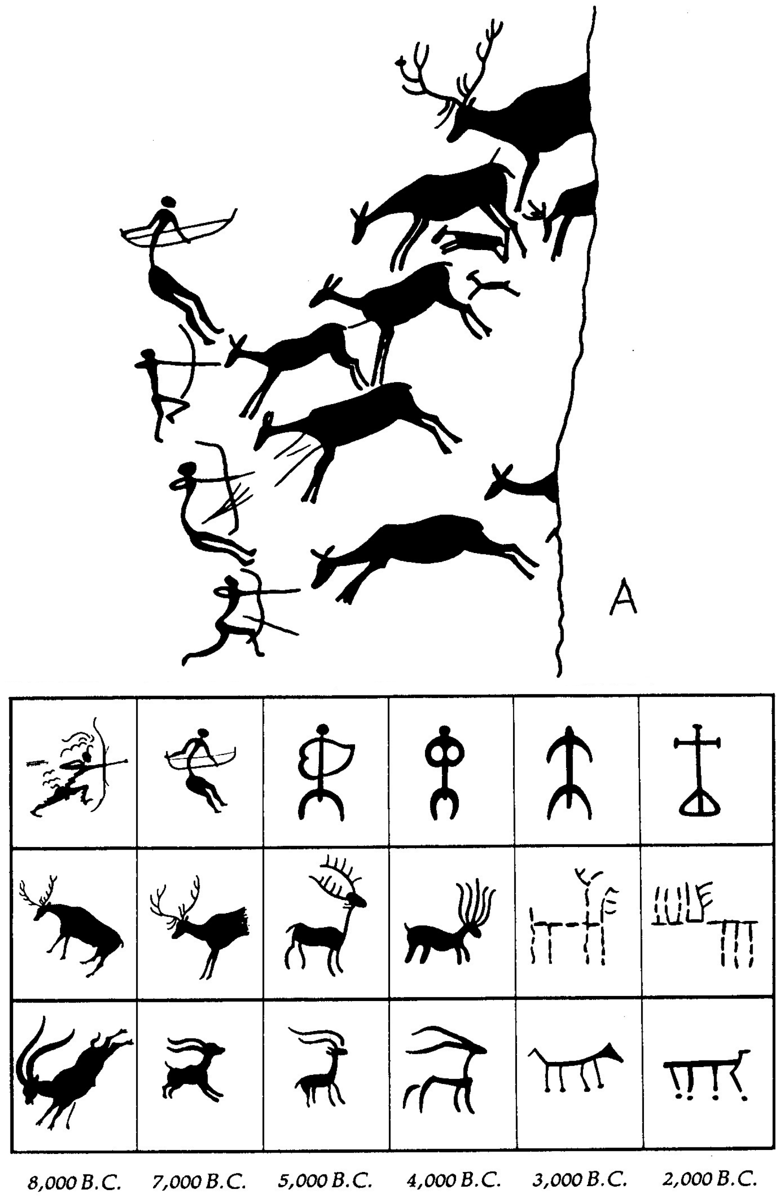


Figure 35.3. Rock art. The bottom part portrays the evolution of images

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36. MINDLESS COPY-MAKING

Let us briefly compare various ways of making copies.

1. The copy machine makes a global copy of the 2-D original by reproducing all its points simultaneously.

2. The fax and scanner make copies by highly ordered linearization of the 2-D original.

3. The mindless computer in a living cell performs the meticulous copying of a long linear DNA sequence in the point-by-point way. In a similar way the magnetic tape is dubbed, a poem, probably, memorized, and a speech perceived.

While talking about life we seemed to forget patterns: I did not use any pictures to illustrate patterns of life. It is time to ask **what life is in terms of pattern theory**. If it fits the general picture, we should be able to write the pattern mechanism of life.

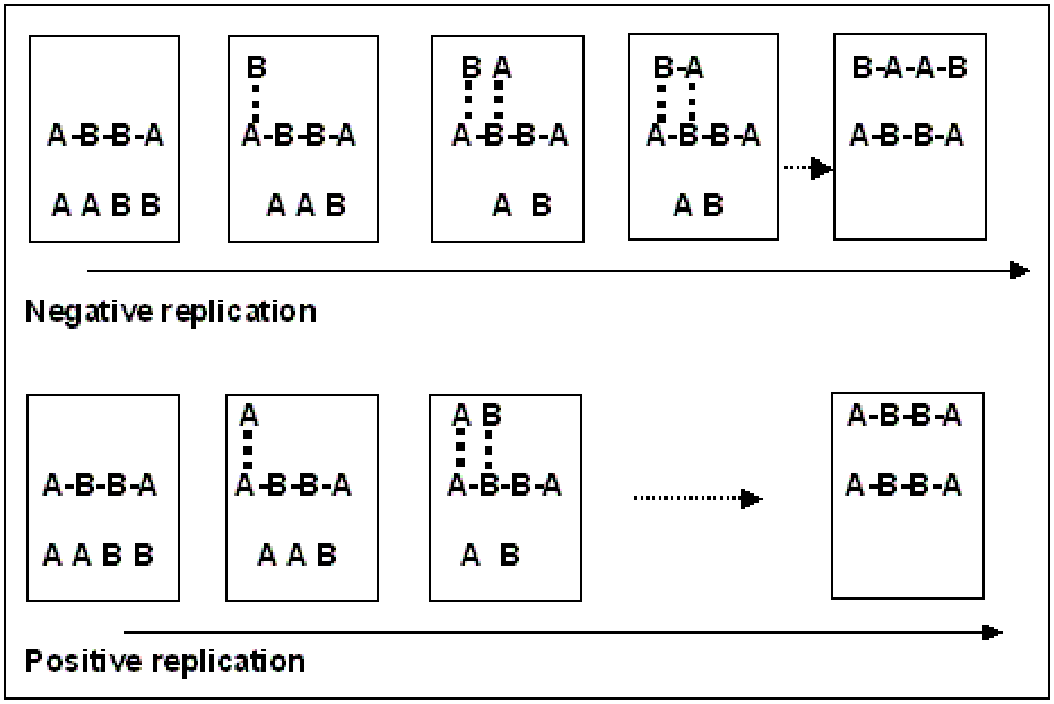

Figure 36.1. Replication. Bond types: 1 ▬ , 2 ▪▪▪

Although replication may not be a necessary condition for life in a larger sense, it is an essential aspect of bio-life.

In **Figure 36.1** the process of replication is shown in the simplest possible symbolism. There are two kinds of generators, **A** and **B**. **A** can form bonds of **type 1** with both **A** and **B**, and bonds of **type 2** only between **A** and **B**. This system is capable of *negative* replication. If the bonds of **type 2** can form only between same generators (**A** and **A**, **B** and **B**) the system displays *positive* replication. The generators involved are shown in **Figure 36.2**.

Let us consider negative replication first. We have a configuration **A—B—B—A** to be replicated and single unbonded generators **A, A, B, B**. Being single means that they are distant and bonding between them is improbable.

Since **A** has free bonds only of **type 2**, it connects with a free **B**. The **B** next to it bonds with a free **A**. Immediately, the new **A** and **B** find themselves close to each other, so that they can form a bond of **type 1**. This procedure can be repeated until the entire original (matrix) is replicated.

The next practical question is how to separate them? If the **type 1** bonds are stronger than the **type 2** bonds, we can just increase the temperature and the two strings—the matrix and the copy—will split.

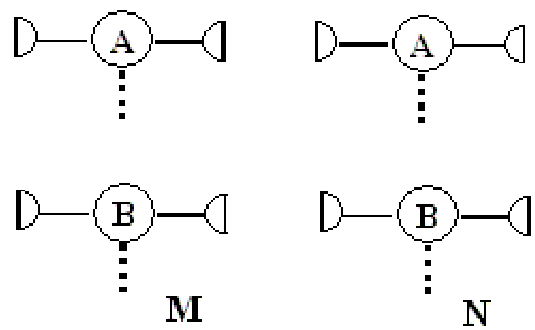

Figure 36.2. Replicators.

The same process can be repeated on the copy, so that the final result will be the exact copy of the matrix.

The above picture is purely speculative. It is nothing but a mental Lego exercise. What we can clearly see, however, is that replication is impossible unless we have two different types of bonds.

A certain set of conditions is required for abstract replication of a linear sequence. It includes not only a particular design of the generators but also a certain relative strength of bonds. In short, replication requires a minimal complexity of the system. No wonder, life was able to germinate only from a soil with a significant chemical complexity.

*

37. MEASURING COMPLEXITY

Next I am going to test the concept of local complexity on non-linear objects such as letters of alphabet, for example.

Let us compare **Figures 37.1A** to **D** and arrange them in order of increasing complexity.

First of all we see that **Figure 37.1A** differs from three others because it does not display any apparent order. This distribution of points can be described in such terms as chaotic, random, irregular, and accidental. We can hardly distinguish between this and another chaotic picture with the same density of points, and if we do, it is of no practical importance.

Figures B to **D** are definitely ordered. The points in **Figure B** form parallel rows, while the points in **Figures C** and **D** form intersecting lines. Therefore, we can dissect **Figures C** and **D** into lines and angles.

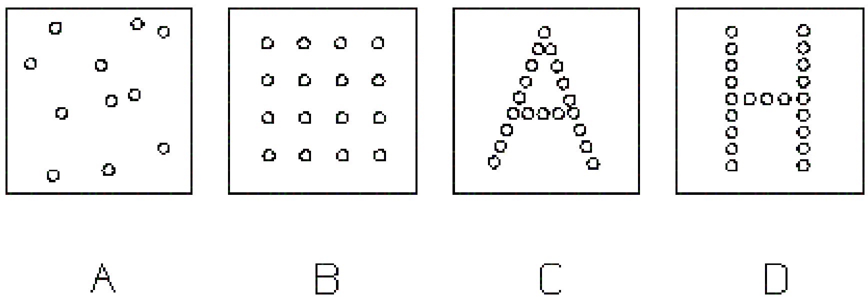

Figure 37.1. Complexity of letters.

Intuitively, **Figure B** looks simpler than other two ordered pictures. There is more of what we understand as order or regularity in it. Opinions may split about **Figures C** and **D** which are built of the same number of lines. Probably, most observers would say that **Figure D** is simpler than **Figure C** because it has more internal similarities or more symmetry.

In order to come to a consensus we should try to reduce our individual differences by avoiding the high level judgment which is based on our education, knowledge, and preferences and by using only the lowest means of comprehension common to all people. All we need to estimate the complexity of a configuration is to count its characteristic neighborhoods.

In **Figure 37.2** neighborhoods of different types are encircled in the picture of letter A. They are **L**-s (corners), **T**-s, ends (**E**), and **I**-s. The **I**-s are just segments of lines, and we exclude them from consideration because all pictures built of lines have them.

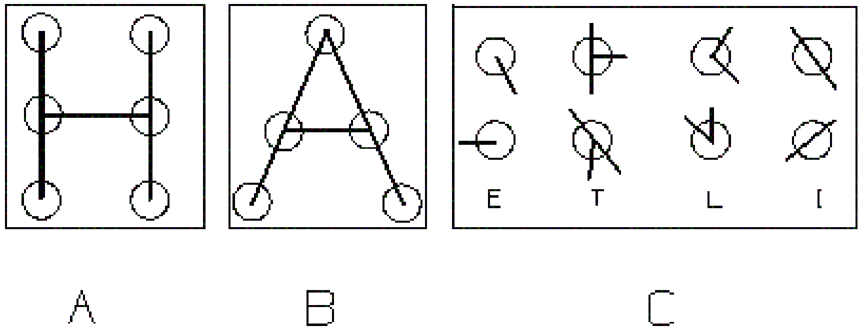

Figure 37.2. Neighborhoods

Letter A contains three types of neighborhoods: **L**, **T**, and **E**. Letter H has only two: **E** and **T**. My conclusion is that letter **A** is more complex than letter H. Moreover, I would say that letter H is as complex as letter T. Letter E contains two **L**-s, two ends, and one **T**. It is as complex as letter A. Letters W, M, and N have the same complexity.

The complexity of "random" objects, like in **Figure 37.1A**, is a matter of agreement. I prefer to assume it equals 1 because, in a sense, all neighborhoods of all random patterns are **equally** random.

I could express complexity with a number, but within my numberless mathematics all I can do is to tell which of two patterns is **MORE** complex by comparing the length of the lists of neighborhoods.

I would like to use another example to illustrate the principle of the "local mind" that I use not only to measure complexity but also to trace its origin.

Let us imagine that letters A and H are of the size of the state of Wyoming, and their lines are written in highways, and not in ink. Suppose, we do not have any means to explore them from the air or space. Moreover, we do not have any technical means at all, we cannot use triangulation, map, compass, nothing like that. All we can do is to drive along the highway and look around. How can we understand what is "written" and how can we compare the two pictures if we perceive the world not from a bird's view but through the eyes of a small bug crawling over letters one foot high?

We can describe letter A in the following way.

If we start our journey from one end of the road, designated by **E1**, we will walk until a **T**-crossroads(**T1**).

> If we go straight, there will be a sharp turn (**L1**), then we come to another **T**-crossroads (**T2**) which is similar to the first one. Next:
>
> > If we go straight, we will come to the other end of the road (**E2**).
> >
> > If we turn, we will come to the first **T** (**T1**).
>
> If at the first **T**-crossroads (**T1**) we turn, then we will come to the second **T**-crossroads (**T2**). Next:
>
> > If we turn, we come either to the other end of the road (**E2**)
> > or to the same sharp turn (**L1**), depending on the direction of our turn.

In a similar way, we can describe our way starting from any point. All we need for the journey is **natural** short-distance vision and modest memory.

For this journey we do not need to know how letter A actually looks in its integrity. Instead we have its presentation. We need only a minimal intelligence, and even an animal can be trained to walk along the route in a certain way. Yet if this seems too complex, the bug can just run along the letter in a totally random way, mark the path with a scent, and keep the record of all neighborhoods visited for the first time. This way to build a presentation is similar to the evaluating complexity in Chapter 35.

The reason why I have tested the patience and attention span of the reader in Chapters 35 to 37 is that I wish to neither prove not to formulate but to **demonstrate** a certain guess about what the nature of the **minimal mind** is. Like the intimate mechanisms of life, mind is about memory and recognition and both have their origin in the same pattern properties.

Isn't it surprising that we have a linear description of a 2-D object without any **regular** TV-type scanning? If one bug wanted to tell another bug what it saw, that was how the translation from the Buglish would look. Our **mind linearizes our experience**, but we can save a lot of words by drawing a map, of course. Note that the description of a journey along a non-linear configuration is a linear sequence of words.

Local complexity reflects a somewhat non-obvious property of objects. Local complexity allows us to explore some aspects of the **world before intellect**, as well as the appearance of the intellect itself, when there was no receiver of any instructions, and nobody could either write or count.

Natural mindless principles and processes such as chemical interaction can be a basis for most primitive forms of processes that we consider essential for life and mind: making copies, recognition, thinking, etc. We have been rambling all over the Everything on the pages of this book, but we are gradually narrowing on mind.

In order to understand the Everything, we need to concentrate on its simplest forms and to show how their complexity can increase. This way of thinking is akin to what is called mathematical induction: describe the first member of a series and show how each subsequent member can be generated from the preceding one.

*

38. THE NEW AND THE DIFFERENT

One might ask why not to measure the number of generators instead of the number of neighborhoods? The answer follows from the way we understand configuration space. It is nothing but the number of dimensions of a certain specific multi-dimension space, each of dimensions being a generator. This space is different from any familiar mathematical space. Nevertheless, a configuration—a combination of generators—is a point in this space in the same sense as a geometrical point is a combination of its coordinates.

Like coordinates of a mathematical space, generators contain a possibility to construct an indefinite number of objects. Moreover, geometrical space is a partial case of generator space because any point has other points in its neighborhood.

The difference, rather dramatic, is that for the common 3-D space we have a clear procedure of generating all points, and we can list **X**, **Y**, and **Z** of all of them, following a certain system that can be presented by an algorithm:

X	**Y**	**Z**
0	0	0
1	0	0
2	0	0

....

We exhaust all variations of **X** and start varying **Y**:

2	1	0
2	2	0

....

Varying **Z**:

2	2	1
2	2	2

....

Take a new **X**....etc.

As far as the configuration space is concerned, we encounter tremendous difficulties because, unlike numbers, **generators are not ordered** outside configurations.

We cannot arrange all generators into sequences. Like symbols ♥, ♣, °, ∞, and ☏, they have no natural order, while by definition 7 and 8 are neighbors and 7 and 9 are not.

The number of generators in the space is the complexity of the space, but not of any particular configuration. It is, therefore, the potential complexity of all configurations in this space, whether actual or never seen and designed.

If we have a small Lego universe and play a god in it, the evolution starts with some simple combinations of bricks and goes through a series of structures of various local complexities. More or less locally complex configurations appear one after another, until the configuration space is checked out, however long it would take. Since the total number of parts is limited, the number of their combinations is limited, too.

The local complexity of a configuration depends on the number of ways each part is connected with its neighbors. Within the same space we will have very simple and very complex objects. The complexity of the space, however, will remain the same: it is the number of generators counted so that two equal generators are considered one. From this point of view, a table spoon of water has the size of 6×10^{23} (the number of molecules in it), but its chemical complexity equals one, because all molecules of water are the same.

Let us see what happens when we add a piece of a new kind to our Lego set. In terms of configuration space it means adding a whole new dimension. A new multitude of objects with new neighborhoods can be brought to being. Some of them could have local complexity as low (or lower) as those built with the previous smaller set. The upper limit of local complexity, however, goes up because we have more possible neighborhoods.

At this point, a reader may get ready to drop the book because the answer to the question hidden in its title follows in the next two paragraphs.

All objects built in a certain configuration space are **DIFFERENT**. They may or may not have the same local complexity, but they belong to the space of the same complexity. When we add a new generator to the space, we **expand the space** by adding a new dimension. Any first object with this generator is **NEW**.

Pattern evolution is the **expansion of generator space**. All objects of the **OLD** configuration space will be possible to build in the **NEW** space. If generators are lost as result of **involution**, this could be impossible, as it happens with biological diversity.

NOTE (2006): Not a mathematician, I cannot vouch for my perception of the main reason why physics is blind to evolution: a physical system must be well defined in advance, which contradicts the *Axiom of closure* and Aristotelian logic.

We cannot understand what evolution is by looking at its creations. The same structure can be built with both the limited and the expanded set of generators, some of them not used at all. A creation does not carry any brand label of the space it was born in. Moreover, a simpler object can belong to a more complex space. **Looking at a bacteria, a Martian cannot imagine an elephant.** We can understand evolution only by studying a large enough volume of the configuration space and keeping the entrance door open.

The **NEW** is what fits a more complex space than anything else. The **DIFFERENT** is just another object in a given natural space. They must be immediately inducted into the Pantheon of Everything. Evolution, which is a sequence of **NEW** objects, moves toward higher complexity. When complexity decreases, it is not what we intuitively characterize as new, because we keep the record of the vanished part in memory. In the pattern world, the expansion of space and not the expansion of the universe is the most general direction of its evolution.

Books and polymers demonstrate another kind of complexity which we would call **vertical complexity**.

Atoms combine into molecules or blocks called monomers, the monomers combine into polymers, some polymers combine into enzymes, viruses, and organelles, the latter combine into cells, the cells form an organism, the organisms form a population or a society. We can measure vertical complexity just by the number of levels of hierarchy.

All Nature is ONE system of high vertical complexity. In principle, we can study Nature as one super-pattern in the process of its change and evolution.

A similar process of "chunking" is known in managing any system consisting of either symbols or parts. An object is described in terms of its parts while the parts are described in terms of their parts, etc.

Here is yet another kind of complexity. Let us imagine that aliens with a different biochemistry visit the Earth. Then, suddenly, the complexity of the living nature on Earth doubles. We face the same situation when we have a number of texts written in different languages. Parts of two texts in two languages are incompatible with each other. They belong to two different structures. A university library has a high degree of this complexity, which can be called **systemic complexity**. A similar situation arises in a society consisting of humans and robots, humans and aliens, and just nations of different ideology, religions, philosophy, and culture. Of course, complexity can be also lost in evolution.

Typical problems of systemically complex patterns are communication, translation, and compatibility. We can imagine a translation industry which processes human food and chemicals into alien food. We can even imagine a translation from one biochemistry to another so that the function remains invariant.

NOTE (2006): What about a clash of civilizations?

In terms of Lego, system complexity means that we mix together two different sets: some parts from different sets may stick together, and some may not.

Complexity is complex, but it is built of simple things in simple ways.

*

39. GENERATION

The view of Everything through the grid of generators and bonds fusing into patterns gives me a powerful feeling of the unity of the world. In this way we can describe both things and thoughts about things, as well as thoughts about thoughts and things for thought. From such an intellectual distance, the depressing complexity of Everything vanishes, the world levels up with my mind, and I can fly across vast continents of knowledge. I do not need to run upstairs from atoms to mind and downstairs from society to molecules to get that feeling of unity: I can see all the continents at once.

If my function in this world is to survive on the rough playground (battleground for many) of everyday life, the bird's eye view is deceiving. I can do with the view of the earth from an enormous distance in space only until I am not elbowing my way through the earthly crowd here. I need to land somewhere to feed on. I need for my survival not only a realistic close-up view but the rough physical touch of the things on my fingertips.

I need something like that from patterns. I need some texture. Some **naturalization**.

In plays with molecules we rely on the laws of nature and the chaotic energy of the particles that brings chemical patterns to existence. Nature resists our will. By playing with graphs and toy universes, however, we transform one graph into another with our mental effort, knowing no constraints. We watch our hand consistently drawing lines between the points, with occasional hesitation but without any significant disorder. If my mind is moving my hand, **who or what is moving my mind** in the same sense the chaotic movement of molecules brings about a chemical transformation?

The man-made things appear and change because we think about them. We see the figures on the chess board move due to the succession of changes in our brain. It is surprising how much change, even on the global scale, occurs as result of our thinking. A good childish question is: if we do not think about our thoughts, who does?

The world of mental generators seems to be brought into motion by a mysterious source of movement in our mind. Not knowing what it is, one can be tempted to suggest that a *homunculus*, a minuscule man in our brain, does the job of running our mental computer. The fact that the mind commonly makes mistakes and tweaks its own software looks like an oblique confirmation of our humane distinction from silicone chips.

We can only suspect that the driving force of our thinking has something to do with its pre-biotic predecessors. If there is no homunculus, then it is pure chaos, and if chaos, then there should be constraints to tame it. But chaos is the only alternative to both the homunculus and the chip in the brain.

Since our mind was not designed by another mind, we have to look for chaos in it in order to understand how it works. When we tried to understand life, we knew that its nature was chemical. We were looking for the source of order and found it in DNA. Regarding mind, we are so overwhelmed and blinded by its order that somehow we are missing its chaos.

I am in no business of popularizing natural sciences, including neurophysiology, and I wish to abstain of any speculations about the molecular source of chaos in the brain. The fact that the brain tissue is not solid but **ALMOST** liquid tells me it all: liquid sustains chaos as water sustains fish.

The question I am approaching is: what is the very nature of the process of generating *any* pattern? The trick is that I ask about "nature" and "process," using "generation" as something known and well defined, but it is not. Generation is a fundamental concept, and as any basic term it cannot be defined, only demonstrated.

As a point in a configuration space, each pattern is just a possibility. It is ready to be called up, invoked to pop up out of a spring box, sense the world and to be seen, and become real, actual, not just potential, one at a time, leaving all the other population of the space hibernating in the darkness of the possible. If it happens by pure chance, there should be is not a homunculus but a lottery machine in our brain.

Patterns become actual during a walk through the generator space. It looks like we make a step and—click!—a thought is produced and thrown like a coin into a box with other coins. Is that walk entirely random, like Brownian movement? Why this and not that configuration comes to mind, desk, or workbench?

Do generation of mental images and material world have anything in common?

I can ask such questions *ad infinitum*.

Taking an example from the realm of thinking, let us write down all different graphs on five nodes, i.e., all possible states of the **Universe U-5**, see **Figure 39.1**.

There are two ways to solve the problem of listing graphs.

One way is to systematically try all possible combinations of 0 and 1 in a 5 x 5 matrix, selecting only the graphs that cannot be made identical by the permutation of nodes. Note, that each bond occurs twice: above and below the diagonal, so that we need, actually, less than half the matrix. Each **x** in the matrix means a possible bond. Behind each of ten **x** stands either 0 or 1, which means no-bond and bond.

	1	2	3	4	5
1	0				
2	x	0			
3	x	x	0		
4	x	x	x	0	
5	x	x	x	x	0

The number of graphs is $2^{10} = 1024$. Only 36 of them cannot be transformed into each other by just re-numbering the nodes.

This way of systematic generation requires a developed human mind or a computer.

The second way is random generation. All graphs can be mentally generated by drawing lines between any two points at random. To a chemist with a hypertrophied imagination it looks like a chemical reaction between points and lines, where the ends of the lines have an affinity to points. We take a handful of "chemical points," i.e., small spherical molecules, capable of forming up to four bonds each, add a bunch of "chemical lines," i.e., long enough thin linear molecules capable of bonding to the "points" at their ends, and analyze the product of the reaction. We would expect all possible structures to form, and among them the entire population of **U-5** plus much more.

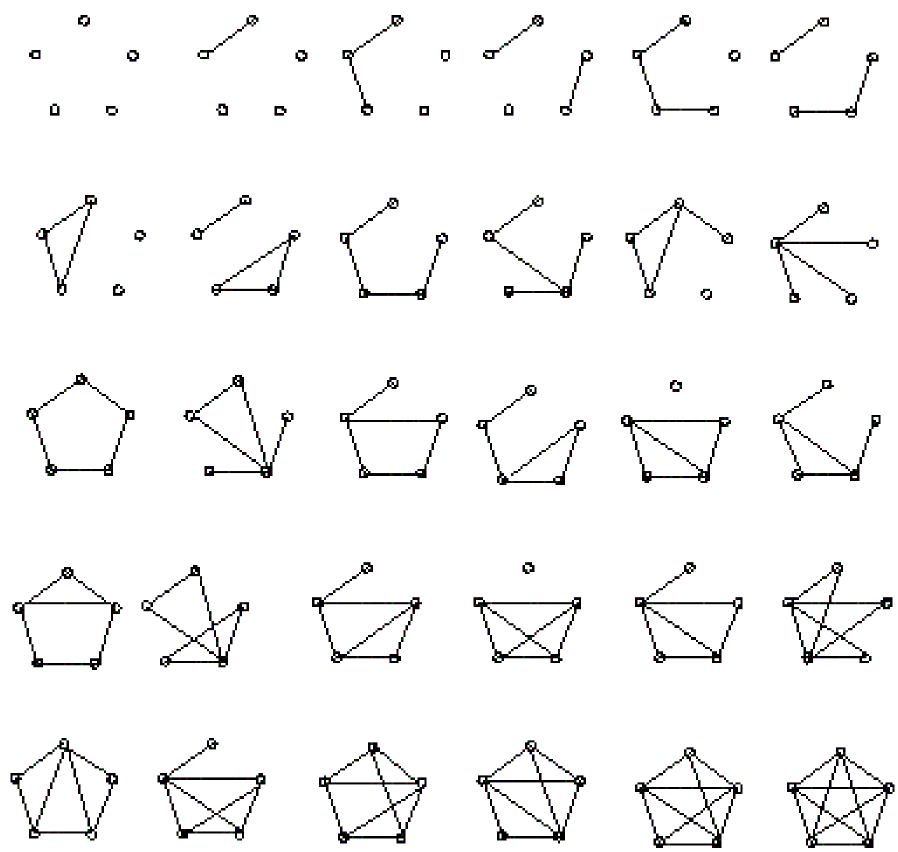

Figure 39.1. Universe U-5

In fact, this experiment, although possible in principle, is not easy to conduct in a lab exactly because the laws of nature impose great constraints on our imagination. One of them is that atoms retain a certain number and geometry of their bonds, another is that some molecules form much faster than others, but if we wanted to list them all, it would be a digest of a textbook of chemistry. This is why to reproduce the generation of graphs through chemical reactions would require great ingenuity, time, and expenses hardly justified in this case.

Suppose, however, that we can synthesize **molecular counterparts of graphs**. In this way an unlimited number of “graphs” can be generated, most of them multiple copies of each other. In order to compound a list of all graphs we have to erase one of each identical twins, as we did in the "natural" algorithm of counting complexity.

There are two ways to find a rhyme to a word, for example, "pig." One is just to think hard but without any system, waiting until the right word jumps out of nowhere. The other way is to search for a rhyme systematically, following the alphabet and changing only the beginning of the word : **A**: aig, no such word, **B**: big—good!, **C**: cig—no!, **D**: dig—yes!, etc.

Sometimes chaos can bring the same results as order.

Our mind is an absorber of extra copies—it does not know **multisets**—and it does it through the function of recognition. What we recognize as **NEW**, we memorize. What we recognize as familiar, we disregard. Thoughts as configurations of mental generators cannot be presented in multiple copies. This makes a striking contrast with the material world. We can make plenty of identical bolts and nuts, but any clearly formulated idea is the same even you repeat it thousand times in various languages and with some verbal variations. In different cultures, however, similarly sounding statements may have different meaning.

The property of ideas to have no copies has at least one analogy in material word. Any electron in an atom can be described by four quantum numbers. No two electrons with the same set of quantum numbers can exist in the atom. Two such electrons are, in fact just one. This is the **Pauli Exclusion Principle**. It works for mind!

Unlike the idea itself, its carrier may vary. It can be a message on TV, radio, in a newspaper, book, in different languages, on different paper. Any commercial ad has the same message: "buy me," but it works by its form, not by its message and the number of repetitions matters when we consider propaganda.

We can make a computer simulate the random “chemical style” generation . In order to guarantee the completeness of generation, the computer should use random numbers, work fast, and produce a very large number of graphs. The procedure of random generation of structures, i.e., walking through a configuration space, does not need intellect, whether computerized or not. It can be realized in a **natural computer** produced by the nature. This computer needs a source of chaos and a set of local rules governing combinations.

The primordial ocean has been, actually, a natural computer, "calculating" possible combinations of dissolved atoms, in the deep or in a poodle somewhere at the shoreline. The results of the combinatorial play do not need any memory storage because they are their own natural representations, like a golf ball is its own symbol and can be stored as such.

There is at least one obvious advantage of the natural computer over the man-made one: it has one of the best sources of random numbers in the universe—chaotic molecular movement. The word **gas** takes its origin from the Greek **chaos**.

Chemists sometimes invent new compounds through random generation, by playing with pen and paper, driven by the chaos of molecular movement in their neurons. A formula on a sheet of paper gets its alternative "real" existence when the chemist mixes the starting compounds in order to materialize the desirable molecule and the chaotic molecular movement in the flask assembles the desired molecule according to the picture on paper.

Is our thinking really chaotic? Everything seems to contradict that, and no wonder, because most of our productive thinking is algorithmic. There is a very strong evidence for the random nature of creative thinking, however: we cannot predict when the solution of a non-algorithmic problem will come. All we know is that in order to solve the problem we need to think hard. The solution comes at the most unexpected time and place, as many mathematicians and inventors witnessed. It has a surprising parallel in radioactive decay in which the time when a particular atom will split is unpredictable.

The joys of shopping, collecting, traveling, thinking, reading, etc., are all underlined by the joy of freedom and novelty, which is the belly-button of our origin from molecules.

On the contrary, algorithmic thinking is not only much faster: it takes a predictable time and often is quite automatic. With the help of a computer database we can answer questions almost at the rate the questions are asked. We can always evaluate time needed for performing certain calculations. All that suggests that there is some hidden time constant in our creative thinking. It looks like a typical random process: when our brain is intensely stirred, the time spent on thinking is unpredictable and we have to wait before a lucky combination appears.

In this chapter we have not arrived at any definition of generation and we did not expect to. It would suffice to see some vague parallels between generation of chemical structures in chemical reactions about which we know a lot, and generation of mental structures in thinking about which we still know little. This is not a definition but a demonstration of unity of both.

Next, let us try to build a "chemical" machine for thinking, as a mental experiment.

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40. HEAT MOTION AND THE MIND

Suppose, we have a set of molecular models similar to those in **Figure 5.1**. The truncated spheres representing atoms have magnetic locks which simulate chemical bonds and can stick to one another according to their affinities. Suppose, they are made of a light material with the density of water so that they can float suspended in a container with water. If we stir the liquid, the "molecules" and fragments will collide at random.

There are four possible results of a collision:

1. New bonds are formed.
2. Old bonds are broken.
3. The bonds between more than two generators are rearranged.
4. Nothing happens when the collision is not energetic enough
or the "molecules" collide at an unfavorable mutual orientation.

Each particular distribution of the atomic models in the container corresponds to one possible configuration of the system. If we stir the liquid long enough, we will *generate* all possible configurations averaging around some median size. We can anticipate that if the intensity of stirring is high, the average size of "molecules" will be smaller but the process of generation will be faster. With a slow, careful stirring, larger structures could be obtained, but they would last longer.

The system of this kind constantly **generates patterns**. It imitates molecules but is neither molecules nor thoughts. It is something commensurable with our scale of perception, and therefore, suitable as a departure point for generalization over both.

The analogy between the intensity of stirring and temperature sheds some light on what temperature is. In order to increase stirring we need more energy with the purpose of creating chaos. This use of mechanical work is called dissipation because it all finally turns into heat and the liquid warms up slightly. We reach an equilibrium distribution between bonded and separated states, but in order to maintain that equilibrium we need to spend energy all the time. If we stop stirring, the system will stop changing.

In this chaotic system the pure chaos of imitated "molecular" movement produces regular clusters of "atoms" according to strictly local rules: which magnet sticks to which. The floating system will walk over the whole configuration space and nothing **NEW** can be produced inside it. If we have a set of generators, all we can do is to generate **DIFFERENT** patterns.

In my view, the apparently paradoxical chaotic generation of regular patterns is exactly what molecular motion and intellectual activity have in common. Our presumption is that any actual generation of patterns in nature involves a certain amount of chaos. This is true about mind, too.

We can imagine mind as a floating model with elementary terms, notions, ideas, and concepts, each written on the surface of an "atom." Their chaotic mixing, colliding, bonding, and rearrangement create new clusters of ideas that serve as "atoms" for other ideas, etc. This, of course should not be taking literally, but only as a particular case of more general pattern generation. What biochemistry and physiology stands behind it—we will know someday.

I see a deep pattern analogy between chemical reaction and thinking. In terms of generators, chemical reaction is random generation. We do not know what thinking is physiologically, but in terms of patterns, it can be mapped on a chemical reaction. In other words, it can be a process of random generation, unless, of course, it is a non-creative algorithmic thinking that allows chaos only in form of accidental mistakes.

We can even speak about the **temperature of thinking** because one chaos can be more chaotic than another.

In order to break the existing bonds and generate new ones in the floating model we need mechanical stirring. Its intensity can be interpreted as abstract (in this case “mechanical”) temperature. The higher the temperature the more bonds break the smaller their aggregates. Larger patterns are generated when the temperature is not high enough to break most of the bonds. At a very high temperature "atoms" can bond only for a very short time, so that the absolute majority of them are isolated. At a very low temperature, patterns of high total complexity are formed, but they do not change over time.

In terms of pattern temperature, it is only natural that a cup of strong coffee, whether hot or iced, warms the mind up.

At this point the reader has a second opportunity to drop the book because I have already shown—from a distance—what I see at the other end of the bridge from molecules to thoughts.

My idea is simple: thoughts are like molecules because both are patterns; both thinking and the chemical reaction are transformations of patterns and both are driven by chaos. They are not chaotic because the nature, and not anybody's mind, imposes strict limitations on them.

What I am saying is not a scientific explanation, but just an image or a guess—an attempt to develop a language to talk about different things.

Chaos is something we haven little to say about. Let us better look for the source of order in our mind—the order that makes us have some thoughts and not to have others.

My next point, to which I have been trying to prepare the reader, is that thoughts can be **catalyzed** like chemical reactions. In most abstract form it would sound: **some patterns make other patterns more probable in the competition for realization**. To take an extreme case, the function of a computer is rigidly catalyzed by its code.

Since the reader has already missed the very best moment to drop the book—in the very beginning— let us move ahead and see what I have in mind and what it means "to have in mind," all the more, we are closer to the end than to the beginning.

What we need next is to formulate the difference between the chemical flask and the mind. Again, we have to start from afar.

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41. THE MARRIAGE BROKER

Although chemistry has never been popular with general public, a few chemical terms penetrated our everyday speech. "Chemistry" and "catalyst" come first to mind, as in "there was a chemistry between them" and "a catalyst for change," and even “catalyst” in the stock market.

Catalyst is a substance that makes a particular chemical reaction run faster. A substance that slows a process down is called inhibitor, or negative catalyst.

Catalysis was discovered by Swedish chemist Jöns Jakob Berzelius in 1835. It is in the focus of a large branch of chemistry with tentacles reaching to practically all other chemical fields. It is a universal phenomenon related to most fundamental aspects of chemical transformations.

There are various types of catalysts, all of them having one thing in common: although catalyst can participate in a chemical reaction, it is not consumed. The catalyst, apparently, does not change chemically while performing its function and by the end of the reaction the catalyst remains in the mixture like nothing has happened at all.

Catalyst is a **chemical tool** that can be used many times. Extending the comparison, it is like a wrench that can turn many nuts, but of one size only. It is not adjustable because it fits only one process or a certain type of processes. This property is called selectivity.

Like mechanical tools, catalysts help assemble and take apart the kicking and wriggling constructs of chemical Meccano. A living cell is a workshop densely packed with catalytic machinery: life is catalysis, among other things.

In my opinion, catalysis carries the most universal message about principles of nature. Moreover, as I believe, the message of catalysis is the missing link between matter, life, and mind.

The function of catalysis has a strange reflection in human activities because a catalyst induces change without being changed itself. We cannot find a place for catalysis inside a box of Lego. The catalyst is the child itself who plays Lego day after day with no wear-off.

The Chinese word for catalysis, *tsoo mei*, means marriage broker (Moore, 1972).

Catalyst is a behind-the-scene source of order. It takes, probably, a childish imagination to see a mystical transcendence in the shadowy power of catalytic phenomena. There must be something really important behind it: isn't that magic to run things by mere presence?

The child is the catalyst of assembly because without its presence it would take an indefinitely long time and will go in an unpredictable direction. It would never happen according to the picture in the manual.

In terms of Lego, catalysis is the door to **information**—the word we have hardly used until now. While information cannot be found in the material foundation of the universe, catalysis can.

Here we consider two preliminary examples taken from areas very much contrasting with happy childhood.

In the past, as well as, sometimes, in the present, a word of an aggressive despot used to start a war, and one despot could start many wars without any damage to himself. Of course, a war could start on its own, but certainly not so often: aggressive rulers **catalyze** war.

Another military example concerns a mine field. Theoretically, there has always been a chance that somebody would accidentally step down on the mine and trigger the explosion. When a combat engineer discovers the mine and pushes the button of his detonating device, the mine explodes, but nothing actually happens either to the button, or to the finger, or to its owner. We can say that the combat engineer has **catalyzed** the event and can use his finger for this purpose again and again. Catalyst is a tool or a machine in the sense that it performs the same function repeatedly.

This property of performing a series of identical or very similar acts is something we typically attribute to machine.

By pushing buttons, signing documents, making telephone calls, etc., people in business and politics start major changes in this world, although the next day they may look exactly as they did before. Gradually, of course, we all change even if we don't do anything at all. In this aspect, the catalyst has a striking advantage not only over humans, but also over their machines: it is, like, *immortal*. A catalyst stays beyond time, at least, theoretically. Of course, it is a substance like any other and it wears out and can be destroyed, although not because of its catalytic function.

The bizarre permanence of catalysts is somewhat surprising in the material world, especially in chemistry, where everything that does not change does not belong there.

To generate a change without having been consumed—this property sounds familiar. Didn't we previously talk about another kind of immortality? Yes, of course, it was in the world of ideas, and more generally, in the realm of information where a message can trigger dramatic changes but is not consumed itself. Stock market news—an immaterial emanation—can give jitters to a million people, but nothing whatsoever happens to the news, so that it can give jitters to another million right away.

Can it be that a catalyst looking like white, black, or whatever color, powder, pellets, or granules, has something to do with the black crumbs of letters scattered over a piece of white paper?

Isn't that possible that catalysis is the long sought bridge between things and thoughts, the primitive embodiment of idea, a primeval message, a precursor of thought? Aren't our ideas literally catalysts for actions, and this is not just a metaphor? Is there any deep parallel between catalysis and information, catalyst and message?

We are going to explore this parallel.

The best way to approach catalysis of patterns is to touch upon some chemical problems. Here we do not need to indulge too much into chemical intricacies. I wish to remind that I do not intend to educate about catalysis or any other field of science. All I want to do is to show a theater of shadows where matter, life, and mind are seen as recognizable silhouettes cast by a single source of light. We will further use the terms catalysis and catalyst in a broader meta-chemical sense that would not be necessarily accepted by chemists working in catalysis.

The first question we have to ask ourselves is how a pattern transformation takes a certain time and does not occur instantaneously. How can time get into patterns if it cannot be expressed itself in terms of generators and bonds?

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42. WHY EVERYTHING DOES NOT HAPPEN AT ONCE

There is a good childish question: why there is time?

Suppose, there is no time. If there is no time, there is no speed. Anything that could possibly happen is going to happen in an instant or has already happened, and after that nothing will change anymore. Energy loses its meaning because it indicates the direction of events in time, and now there is nothing to indicate. The whole world just falls to the lowest possible energy, and nothing can push it off the eternal peace, except for another external world communicating with this one.

Time means that what can happen does not happen all at once. Time keeps track of momentary states, one after another.

While something changes, however, something else remains the same. The graceful, smooth stride of nature is due to the fact that different processes occur at different pace.

One of the main reasons why something always happens is that there is no such thing as an isolated system, and every fast external change creates a non-equilibrium situation. Another important reason is that complex dynamic systems just cannot come to an equilibrium if energy flows through them. We do not need to go into details of the so-called non-equilibrium thermodynamics: there is plenty of popular literature. Besides, thermodynamics cares little about time. Thermodynamics tells what processes can happen and where they end up, so that nothing apparently happens after that. It is not directly concerned with the speed of a process.

The pace or rate of a chemical transformation and of many other processes is the subject of **kinetics**. Chemical kinetics is just an application of a more general apparatus of formal kinetics based on some abstract assumptions about abstract systems.

Formal kinetics is the most universal way to describe processes that happen with large numbers of interacting objects that behave chaotically. It is based mostly on common sense and is not limited to chemistry or any particular science. Kinetics treats both molecules and bacteria, as well as human actions, equally.

For example, if a person is looking for a date, the **fastest** way to find it is to go where other people hang around because the probability to meet somebody in a crowd is higher that the probability of a meeting in a desert or in an empty apartment. That was a typically kinetic reasoning. But if the crowd is too big and your demands high, your date will be lost.

Kinetics does not depend on any specific background space. While in chemical kinetics, anything happens only at a close distance or in collision, in social kinetics, things can happen over the telephone, of course.

Kinetics, in a sense, bridges the chaotic behavior of an individual with the regular behavior of the crowd. What constitutes the crowd—people, ants, or molecules—does not matter.

Let us consider an example of a chemical process that everybody can reproduce in any room at home. All we need is a candle and a match or lighter.

In order to light a candle we need to strike the match and ignite the candle. It seems very natural that fire can be started from another fire, but why? The candle consists mostly of carbon and hydrogen. The starting state of the system is the candle plus the oxygen in the air. The final stage is carbon dioxide and water. Thermodynamics says that the candle burns because the difference in the free energy levels of the final and initial states is negative, i.e., chemical energy drops during burning and it dissipates as heat.

How can that be, one might ask, if energy is conserved and in a closed system it cannot neither increase nor decrease? As a matter of fact, free energy takes to account both heat and entropy. Here we can see a dramatic difference between the solid candle packed into a small volume and the products of its combustion chaotically scattered all over the room. This is why the process runs until the end: from **FEW** to **MANY**.

If so, the candle should burn on its own, and it is exactly what we see: no match needed after the start. Still, thermodynamics does not explain why we need to **initiate** the process of burning.

One of the basic presumptions of kinetics in chemistry is that the rate of chemical reaction, i.e., how much of a certain product changes over a certain time, depends on the concentration of the reagent. There is no chemistry and no physics in that, just common sense: the more molecules in a volume, the more probable their collision, and of course, they interact only at a close distance.

If only one kind of molecules participates in a process, for example, when a molecule spontaneously splits into two parts, the rate depends only on the concentration of this molecule: the more molecules, the more fragments.

If two molecular species interact, like in the problem of finding a date, then, obviously, the rate of the transformation will be proportional to the product of their concentrations in the molecular crowd.

As soon as any change starts, the concentration of initial species decreases and therefore, the rate keeps dropping. Finally, the transformation comes to a halt.

Kinetics is, actually, the bookkeeping of all acts of change in the system, very much like keeping track of an inventory in a warehouse. The final satisfaction of a chemist doing kinetics is to produce a computer printout that plots the concentrations of all components at any moment after it all starts.

Let us take a simplest possible reaction: **A** $\rightarrow$ **B**. The reaction is reversible, i.e. **A** turns into **B** and **B** turns into **A** : **A** $\rightleftarrows$ **B**

As the concentration of the starting component **A** decreases, that of the product **B** increases. As soon as first portions of **B** have been formed, they start converting back into **A**. It goes that way until the rates of direct and reversed transformations are equal at the state of equilibrium.

The most famous example of non-chemical kinetics is the study of lynx and hare population over many years (Lotka, 1956). It was explained many times in popular literature and, probably, best of all by John H. Holland (1995).

In short, the balance of the number of hares per year is the number in the previous year plus the gain due to the fertility, minus the loss due to the encounter with the predator (lynx), minus loss due to death. Similarly, lynx multiply, die, and also gain from meeting the prey (hare).

The encounter of a lynx and a hare is an accidental contact which may destroy the hare and enhance the reproduction of the lynx. The probability of such a contact is proportional to the "concentrations" of both the prey and the predator, i.e., to the product of their separate numbers in the area. The contribution of the newborn hares is proportional to the total number of hares last year, and so is the case with lynx.

The mathematical processing of those relationships gives periodical oscillations of hare and lynx populations with offset maximums: the more hares, the more lynx next year, and, therefore, the less hares, the less lynx next year.

It does not matter for kinetics what is behind the equation. All we need is to list all debits and credits and to give the bottom line.

In real life there is another factor that influences the process: the availability of food for the hares. This source does not directly depend on the lynx population. However, it may depend on weather or other grazing species. In real life, the interdependence in an ecosystem can be very complex.

Same periodical change of concentration happens in chemistry. The relatively recent discovery of such strange reactions was a strong stimulus to the study of order in non-equilibrium systems.

It is unusual to find a chemical reaction which could be described as: "the more substance we have now, the more we will have next moment," but they are typical for biology.

Still, why do we need **to light** the candle? We understand how the things are running in our little universe consisting of the candle and air, but we need a kind of divine intervention to start its burning evolution. This question is a very intriguing one in evolutionary aspect because it could tell us something about the beginnings of things.

If the candle does not light up on its own, it can only mean that there is an energy increase on its way to burning—a barrier of a kind separating the start from the finish. On the other hand, the overall energy after burning decreases. Therefore, our common sense tells us that, like the downhill skiers, we have to go uphill before rolling downhill. We have to light the candle exactly in order to overcome an energy barrier on the way of spontaneous transformation.

If we have a single molecule, it can take any time from zero to infinity before it decides to jump over the barrier. Chaos always takes time. For example, we have to wait a certain time before a lottery machine spits out our lucky number.

This is why everything takes time.

To fight insomnia, we imagine a flock of sheep jumping over the fence one after another. The actual flock of sheep will jump over the fence in a disorderly manner. The process will take time because it involves **MANY** events, each event taking a unit of time. The energy fence implies that overcoming it takes time. If we have a crowd of molecules, it takes time before one of them will jump high enough to land on the other side.

We should note, however, that a free drop from any energy level to a lower one does not take any time at all, as the concept of energy implies. It is the ascent that requires good luck and patience.

The state between the start and the finish that is not seen in common chemical equations is called transition state.

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43. TRANSITION STATE

The concept of **transition** (alias, activated or active) **state** presumes that there is something between the initial and final **stable** states in any chemical reaction. The transition state is unstable. Its energy is higher than the energies of both stable states that are transformed into each other through the transition state.

Here is an example of a chemical reaction:

$$\begin{array}{lcl}
\mathbf{CH_3} & & \mathbf{CH_3} \\
\quad | & & \quad | \\
\mathbf{CH_3{-}C{-}Cl} & \mathbf{+\ HOH \rightarrow} & \mathbf{CH_3{-}C{-}OH\ \ +\ HCl} \\
\quad | & & \quad | \\
\mathbf{CH_3} & & \mathbf{CH_3} \\
\\
\quad \mathbf{I} & & \quad \mathbf{II}
\end{array}$$

It does not matter what the chemical names of the participants are, and even what is going on from the chemical point of view: we are interested only in patterns.

In the most abstract form the transformation in both cases is:

A—B + C—D ⇄ A—D + B—C ,

where **A** is **$(CH_3)_3C$**, **B** is **Cl, C** is **OH**, and **D** is **H**.

Figure 43.1 shows the change of free energy in the chemical reaction of exchange, depending on the coordinate of the reaction *t* which can be approximately associated with time.

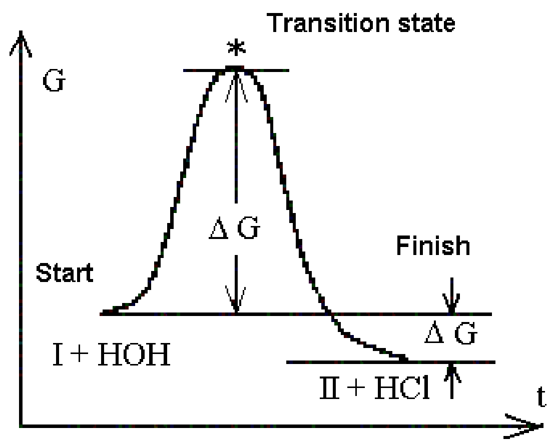

Figure 43.1. Energy of change

The fleeting transition state between the initial state **I + HOH** (start) and the final state **II + HCl** (finish) is marked by the asterisk (*). Its free energy is higher than that of both initial and final states. If the transformation is reversible, the system of many molecules is in the equilibrium between the start and finish with the final state prevailing because the barrier from the reverse transformation is somewhat higher than for the direct one.

If we have a single participant, it will swing between the two states, like a single fly between two rooms, but the overall time spent in the final state will be longer than in the initial state.

Any chemical change is usually reversible. To make it irreversible, some special conditions should be created. In the chemical example, if we have an excess of water, the reverse reaction will be highly improbable—lost in the crowd.

In the absence of the transition barrier there would be neither chemistry nor life. All possible chemical reactions on earth would quickly go toward equilibrium. A dry leaf would burn in the air because the energy of combustion products is lower than the energy of the leaf and the oxygen which is needed to burn it. Of course, we can wait an eternity until accidentally several very hot molecules will strike the candle and ignite it. In order to overcome the barrier, we need to strike a match and to spur both candle and oxygen—the horse and the rider—over the barrier.

According to the theory, it is the height of the energy barrier that determines the reaction rate from the initial to final state. Naturally, temperature boosts up all chemical reactions while at low temperatures they all go very slowly.

Although everything at the molecular level happens very fast, the change is slow because **MANY** molecular sheep have to jump over the fence while **MANY** of them jump back. This is how fast events can have slow results.

The entire chemistry is possible only because some reactions are much faster than others, so that we certain products dominate in the end. Otherwise, any starting mixture of compounds would quickly give a mixture of all possible combinations of atoms of the mixture.

How natural and yet how amazing! All things in the world—material objects, physical, chemical, and biological systems, establishments, doctrines, technologies, and beliefs—are surrounded by invisible walls that contain their spontaneous change.

Everything in the world is like a marble in a dish: it cannot roll off without a jolt or tilting the dish. Restrictive walls, discrimination and oppression, violence and revolt seem to be the source of order—a good argument for a dictator. And yet everything jumps and creeps over the barriers. If it is a single thing, like a heresy or a scientific revelation, it waits and waits and waits, and finally jumps. If it is a swarm of molecules or people, it goes over the barrier one by one, two steps forth, one step back. If the society is sharply divided into solid blocks, a social revolt instead of a slow social evolution flares up from their clash.

To figure out the transition state and to evaluate its energy is the central and the most challenging problem of chemistry because transition state is something that cannot be kept in a jar. In most cases it is something entirely hypothetical and nobody can see it.

The transition state of chemical nature has a close analogy in social transformations. First of all, only a small number of all people—the "hottest molecules"—play active role in social activity. Secondly, in order to undergo a change, the society as a whole should be heated up to such degree of discontent that not only the hottest people-molecules could reach a transition state but also a good deal of the rest.

Does liberal rulings on "gays-in-the-military" and "women-priests" have lower energy than discrimination? Does equality has lower energy than inequality? Why do we go for equality? It seems that equality is, actually, a low-energy state, but I have no room here either for applied meta-chemistry of society or for more subtleties of transition state in chemistry. One of the most original thinkers, Vilfredo Pareto (1935), who came to sociology from physical chemistry, regarded people as molecules of a kind.

If all people are equal as far as energy is concerned, who will jump over the fence?

In Russia, for example, tremendous creative (as well as destructive) changes occurred when equality was imposed by the Communists. The society was rebuilt and transformed, but the final result 70 years later was inequality and stagnation. Could we foresee that result from the point of view of thermodynamics?

In thermodynamics, all molecules have the same energy only at zero temperature when nothing occurs. Equality means cooling the society down to a frozen brittle state in which any external shock can break it as a piece of glass.

Freezing does not occur on its own: both our refrigerators and air conditioners consume energy. What is better: to spend energy for maintaining inequality or to spend it for maintaining equality? Is progress better than equilibrium?

The answer is: unlike **MORE** and **LESS**, the terms BETTER and WORSE do not belong to classic science which can, at best, predict the consequences of our decisions. Comparing the abstract temperature of society from year to year we can say objectively whether it warms up or cools down. But do BETTER and WORSE belong to the Pantheon of Everything? They might when reality interacts with expectations.

I do not feel free to indulge in such discussions. I can use only a diminishing lens, not a magnifying one.

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44. CATALYSIS EQUINIZED

A catalyst is a magic wand, but it does only what is possible without it, only faster. The acceleration may mean a difference between practically impossible and very fast. How does the chemical catalyst do its trick?

A particular mechanism of the catalytic magic is not seen in the overall mechanism of a chemical transformation: with or without the catalyst, it looks the same:

$$\mathbf{A + B \rightleftarrows C + D}.$$

Chemical reaction can be compared with a horse jumping over a fence, see **Figures 44.1A** to **C**. Fences, barriers, and pits slow down the movement of the rider in an equestrian competition. There are at least two ways for the rider to get over a high hurdle. One is to put a ramp right before the barrier, so that the actual height of the barrier with respect to the ramp will be decreased (**Figure 44.1E**). The other is to get off the horse, take off the highest bar of the hurdle, get back in the saddle, and jump over the lower bar (**Figure 44.1F**).

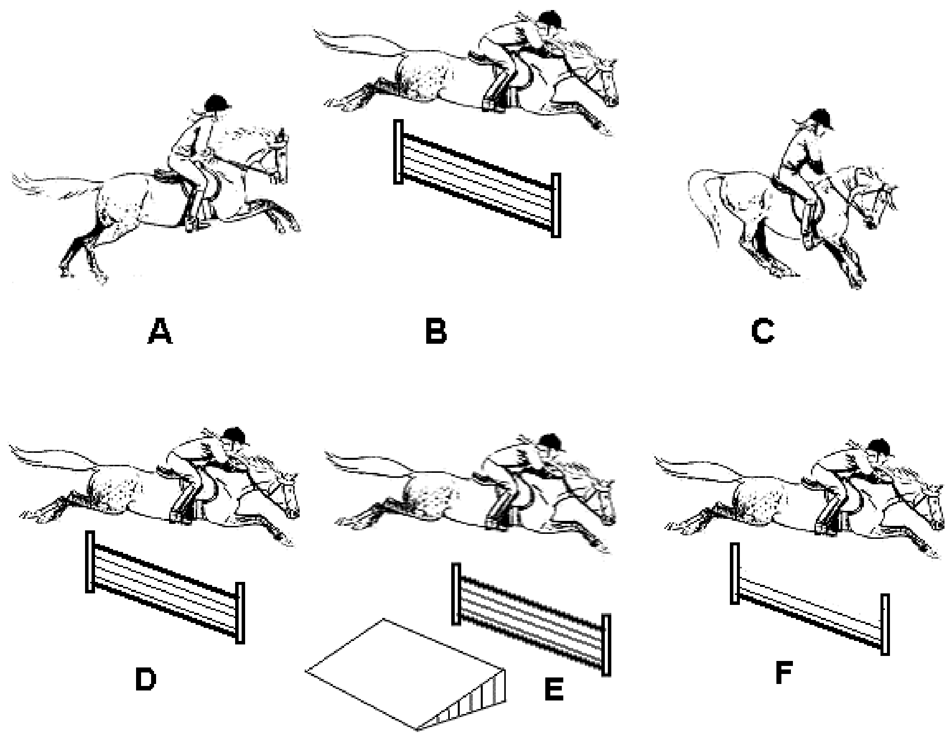

Figure 44.1. Catalysis equinized

The third way is to spur or dope the horse, and although this is not catalysis, we can do that with molecules, too, for example, by hitting them with a photon whip.

Each of three ways is a kind of cheating, but this is often how the nature overcomes hurdles: when life is at stake, ends justify means, and the success of survival is the only criterion that matters. Without catalysis or photochemical excitation life could hardly beat the odds because the basic laws of nature are hostile to life. At the higher end of the scale of life, basic chemical industry could not exist without catalysis, either.

The two ways to go over a barrier shown in **Figures 44.1E** and **F** represent two basic types of catalysis. I am going to give here a classification which might seem frivolous to a professional chemist, but it will serve our purpose. The two types are:

1. Hot catalysis.
2. Cold catalysis

Schematically, the difference between the two types of catalysis is rather subtle. In its most general form the pattern of chemical catalysis looks like this:

$$\mathbf{M + K \leftrightarrow M\cdots K \leftrightarrow N\cdots K \leftrightarrow N + K}$$

$$\mathbf{I \qquad\quad II \qquad\quad III \qquad\quad IV}$$

In plain language it means: we starts with substrate **M** and catalyst **K** (**I**) which form a bond (**II**), so that **M** in the bonded state can turn into **N** (**III**), after which they split into the final state with separate product **N** and **K** (**IV**). **M** could turn into **N** without **K**, but much slower. All stages of the transformation are reversible, and the same catalyst can turn **N** into **M**.

More formally, in transformation **M → N**, catalyst **K** forms **catalytic complex II** that further transforms into catalytic complex **III**, the latter splitting into catalyst **K** and product **N**. The substrate can consist of two or more separate molecules, not just one. The catalyst enhances both direct and reversed reactions if they go through the same transition state.

The hot catalyst is usually a relatively simple particle carrying high energy. The way it works can be also compared with the way a billiard ball hits a cluster of other balls and initiates a chain of events on the pool table. It is often a different ball, not the initial one, which falls into the hole and leaves the pool.

For example, proton $\mathbf{H^+}$ generated by the dissociation of an acid in a water solution is a very common hot catalyst:

$$\mathbf{HCl \rightarrow H^+ + Cl^-}$$

Since proton is a charged particle, it has a high energy and is eager to get rid of it by coupling with a negatively charged particle. It can exist in water only if bundled up in a thick fur coat of water molecules that bridle its aggressive energy. The coated proton shakes off its coat while colliding with another molecule which receives its charge, undergoes a series of transformations, and at the end expels the troublesome invader or its twin. This is, of course, a terrible simplification of the picture.

The hot catalyst works because it injects energy into a chemical system. Like the ramp in **Figure 44.1E**, it rises the absolute energy of the reactants well above the barrier. To its disadvantage it is not always selective and can energize both desirable and undesirable processes.

The cold **catalysis lowers the barrier**, so that less energy is needed to overcome it.

We can see the distinction between the hot and cold catalysts if in the following mechanisms, where the substrate of the catalysis consists of two separate entities **A** and **B** and the function of the catalyst is to connect them into **A—B**. This is how the hot catalysis may look:

$$\mathbf{K + \underline{A + B} \rightarrow \underline{K\cdots A} + B \rightarrow \underline{K\cdots A—B} \rightarrow K + \underline{A—B}}$$

Here the hot catalyst forms a bond with **one** atom (element) of reagents.

The pattern mechanism of the cold catalysis is shown in **Figure 44.2** where **44.2B** is a more detailed version of **Figure 7.2**.

The catalyst must be a molecule of the right size and shape.. What we designate as **K** is its active center: the atoms of the catalyst that take part in the process of catalysis by making and breaking bonds with the substrate. The rest of the molecule may not take part in the process.

The so-called covalent chemical bond, usually portrayed by a solid line, is considered a strong bond. There are much weaker bonds in chemistry and they are responsible for the whole biochemistry. Like Lilliputians, they can overpower even Gulliver when they work in large numbers.

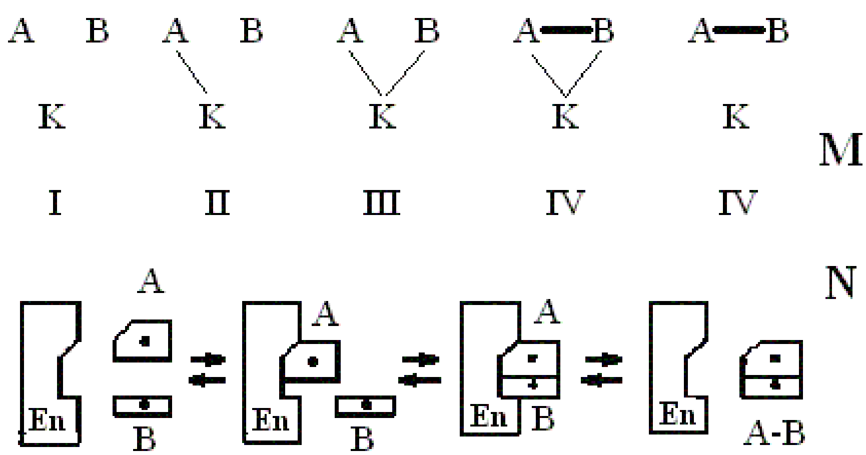

Figure 44.2. Cold catalysis

Figure 44.3 illustrates what weak multiple bonds can do. They imitate the Velcro zip in which a multitude of tiny hooks forming weak bonds with each hold the parts together. They can be easily unhooked one after another instead of ripping them off all at once. In **Figure 44.3A** two linear sequences are hold together by four weak bonds. In **B**

and **D** the unzipping of such a connection is shown. Even if some of multiple bonds are open, as in **C**, the remaining bonds are sufficient for the overall connection. Weak bonds can lead to a coiling of a chain into more compact structures, see **Figure 44.3E**.

Among weak multiple bonds there are what chemists call hydrogen bonds, usually shown as dotted lines. The bonds between enzymes and their substrates commonly belong to this type. Naturally, most weak bonds form between two surfaces only when the latter closely fit each other and repeat each other's shape. The weak bonds control the most important aspects of behavior of DNA and proteins, too.

The cold catalyst does not need external energy. It is a tool, but not a machine. It is highly selective because it works only for the given jockey, fence, and track, as if controlled by a single mind.

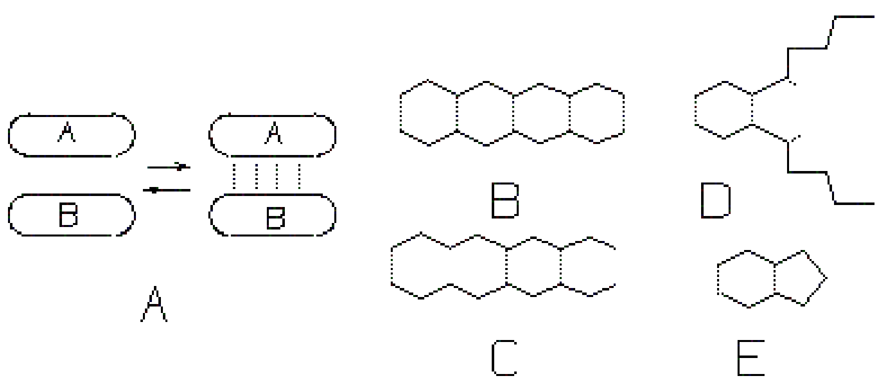

Figure 44.3. Multiple weak bonds

Mind! That's it. The cold catalyst, so to say, has a **mind** of its own. It is **intelligent** because it is **selective**. It accelerates **ONE** transformation **among MANY** and we can smells **information** in the phenomenon of catalysis. No wonder chemists talk about chemical **recognition** when the enzyme binds to the substrate, but is indifferent to anything else having a different shape.

Unlike ideas, and like everything in chemistry, the catalyst works in real three-dimensional space where two points which are close to a third one are close to each other in a very natural way, due to the metrics of the space.

If a bond is going to break, the atoms are always at the closest possible distance, but if a bond is about to form, the atoms should be properly oriented—as the pen and its cap. Because there is no homunculus to push them together and they can come close only accidentally, the probability of their contact is what defines the rate of the process.

Therefore, the trick of catalysis is that **two atoms close to the catalyst are close to each other** and are ready to form (or split) a bond.

A typical cold catalyst enhances the process due to a certain space fixation of the components. The child connects two parts by bringing them from a distance into close contact and appropriate orientations of pegs and holes. Each of the two fragments sticks to the catalyst as accidentally as the flies to the sticky paper, but as soon as they are close, the catalyst holds them in the mutual orientation which is most favorable for bonding.

In physical terms, catalytic effect is due to decreasing the free energy of the transition state by introducing more order into it. This order has a very simple interpretation: it is the spatial fitness of the 3-D generators for bonding. In more abstract terms, the catalyst brings them into the topological nearness so that they are in each other's neighborhoods. If a chemical reaction does not involve any displacement of atoms but just rearranges chemical bonds inside a molecule, it occurs very easily.

In classical chemistry all molecules are considered close for interaction because they all are mixed up and shaken by fast molecular movement. This is not so regarding atoms within a molecule or in a transition complex. Peace and tranquility are needed for the most intimate act of bonding of two selected mates, and the catalyst offers the shelter from the chaos, albeit for a short while.

Since the catalyst can be used repeatedly, its effective concentration seems much higher than the actual one. This is why catalysts or enzymes work in low concentration. Catalyst literally works against the odds: its effect is equivalent to changing probabilities of events, which not only smells of information but even walks and quacks like it.

To summarize, in order to overcome the barrier of the transition state, a certain energy is needed. It consists of two parts. One is the difference in the heat content between the initial state and the transition state. The hot catalysis compensates for the heat term of the energy barrier.

The other part is the energy equivalent of the order which is needed to arrange atoms for the transition. This is what the cold catalyst does: it provides big savings in the cost of order by decreasing the entropy of the transition state.

From now on we will be interested in the cold catalysis only.

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45. CATALYSIS HUMANIZED

A little bit more complex mechanism of cold catalysis with three participants and the catalyst is shown in **Figure 45.1**, which is an abstract notation of a series of changes, not necessarily chemical ones.

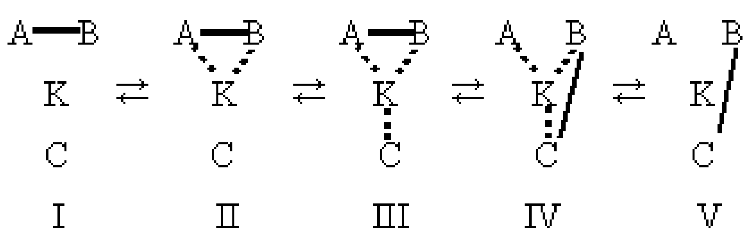

Figure 45.1. Catalytic triangle

Example 1

A man **K** takes book **B** from shelf **A** and puts it on table **C**. The dotted lines denote his bonds with three objects: book, shelf, table. The man physically touches only the book, while the visual bonds connect him with the shelf and the table. If they are broken, the action is still possible by touch. If no touch is permitted, the action can be successful only by trial and error and this can take a long time.

In the absence of **K**, this event is still possible, especially if the shelf is above the table and the house is located in a seismically active area where earthquakes are common. Without the living catalyst, however, it could take a much longer time. In the molecular world of chaotic movement, the catalytic function would be to wait for a jolt, to catch the falling molecular book with one hand, to catch the flying molecular table with the other hand, and to direct the book toward the table.

Example 2

A woman **C** is looking for job **B**. She finds advertisement **K** in a newspaper and calls company **B**. In the absence of **K**, she would sooner or later run into the job during his search, but it would probably take a longer time and be too late. In this situation, the newspaper with advertisements simulates a stepwise—a step a day—stirring of a mixture of jobs and applicants, which brings them all into mutual contacts.

The same newspaper can catalyze the contacts between businesses, as well as contacts with private people looking for companions: "Handsome, professional, sophisticated Male seeks attractive, adventurous Female," etc.

Example 3

In the beginning of this book, an image of a child generating patterns of Lego was evoked as a parable of an abstract change. We are now well prepared to perceive the child as the catalyst of pattern generation. If the child joins and separates any two pieces of Lego at random, it works like molecular chaos. An older child, however, joins pieces in a certain order and does not take them apart too often. She follows an image either in her head or in a manual. We can say that building a house along the manual is a case of a very selective pattern catalysis, where only a certain pattern among many possible is catalyzed. Building a new living cell along the linearized manual of DNA requires a very mature and conscientious "child" in the form of the biosynthetic apparatus of the maternal cell.

In order to generalize the effect of catalysis over abstract patterns without 3-D metrics, we need an additional principle. I would put the following, already familiar, statement:

If two generators are close to a third one, they are close to each other

This principle expresses all my philosophy of pattern evolution. The catalyst brings distant generators topologically—not necessarily metrically—close enough to make new bonds, selecting **ONE** pattern from **MANY**, and this is exactly what evolution and growth of complexity is about. In the absence of catalysis everything scatters around from **ONE** to **MANY**. The selectivity of the catalyst works against the ruthless law of nature not head-to-head but by circumventing it.

Of course life and human civilization are impossible from the point of view of an old rock that only needs to look at its own mossy side to see that the opposite is true. We may deceive nature in many ways but not by creating order without spending energy, the rock would say and be absolutely right. Life and civilization exist only because they extract work from the energy of the solar radiation—directly or in the form of food and fuel—and dissipate it as heat. The rock, however, takes nothing but heat from the sunlight and dissipates it as heat. The rock is so rock solid that it can maintain its integrity without any food.

As far as life is concerned, it needs to make its own copies in space because the copies in time do not do too well.

Figures 36.1 and **36.2** illustrated a very general pattern mechanism of replication. Now we are going to take a second look at it from the point of view of pattern thermodynamics and kinetics, see **Figures 45.2** and **45.3**.

Generators **A** and **B** have two strong and one weak bond each (**Figure 45.2**). The strong bonds are shown by solid lines and the weak ones by dotted lines. The following bonds are possible: **A—A**, **A—B**, **A···A** and **A···B**. In order to form sequences, enable one sequence to interact with another sequence, and make a copy, as in **Figure 45.2K**, the bonds must meet certain rather simple conditions.

We do not use numbers. Let us simply put the bond into square brackets to denote the value of its energy. Thus, in **Figure 45.2M** [**A—A**] means the strength of bond **A—A**, which is a certain number that we do not even want to know. The set of conditions in **45.2M** signifies that the energies of bond **A—A** and **A—B** are close, while the dotted bond **A···B** is weaker (**LESS**) than either of them. The first condition, for example, should be read: the strength of bond **A—B** is approximately the same (**EQUAL** to) as the energy of bond **A—A**.

The type of replication in **Figure 45.2K** produces a negative copy that should be replicated again in order to obtain an exact copy of the initial sequence. By changing conditions to:

[A···A] = [B···B] > [A···B],

we come to an exact replication at one step.

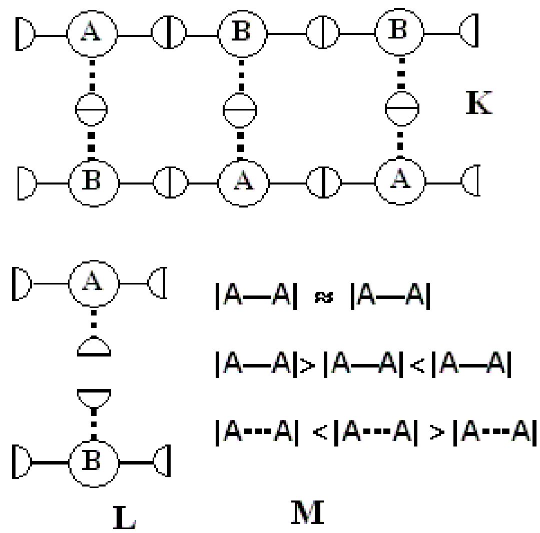

Figure 45.2. Generators for replication

In **Figure 45.3** we see the intimate mechanism of an elementary act of replication, and it is nothing but a four-center catalysis: two generators in the substrate and two in the catalyst.

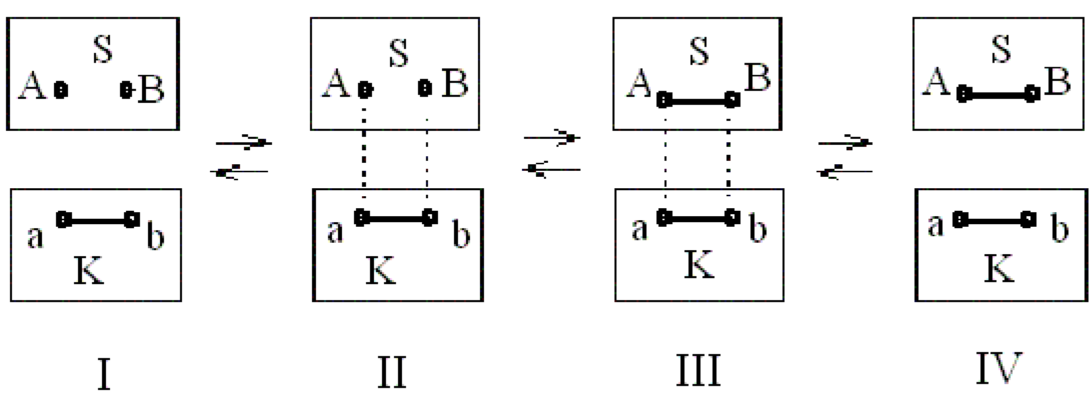

Figure 45.3. Catalytic rectangle. S substrate, K catalyst

Obviously, the catalyst and the substrate are two copies of the same object. This type of catalysis, when the catalyst catalyzes its own production, is called autocatalysis and we will return to it in Chapter 48.

To summarize, the catalyst makes **distant** generators of the substrate **close**. In other words, catalyst changes the topology of the system.

The question is what makes the catalyst and the substrate close. In chemistry it is the chaotic movement that brings them together. As soon as two elements of the substrate are bound to the catalyst, they have better chance to form a bond between themselves, as compared with the situation when they are looking for each other in a crowd.

The catalyst works as a match-maker or marital agency.

Example 4

There is a network of connections between friends. Mr. **K** in politics has two friends, Mr. **A** in industry and Mr. **B** in finance. He introduces them to each other, giving a powerful business connection to both.

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46. THE HAND THAT SHOOK THE CRADLE

There is a price to pay for the miraculous properties of the catalyst: there should be a hand to pull out the magic wand, wave it, and put away until next time.

The possibility of a repeated use is the most characteristic common feature of both catalyst and machine. To connect two parts with an electric screwdriver, we need to position the parts and the screw, put the screwdriver in contact with the screw, start, stop, and remove the screwdriver.

A molecular screwdriver would not need a motor: the molecular screw can spin on its own, although quite erratically. The function of the molecular screwdriver would be just to hold the screw in place and permit rotation in one direction only. Note that this is exactly what the car engine does with the molecular chaos of hot combustion products.

The catalyst fits only its substrate, like the key fits the lock. We need, for example, a special wrench and a rather high torque in order to change an oil filter. We can open the hood by slightly pulling the lever with one finger. We cannot, however, use the wrench for opening the hood or the finger to unscrew the oil filter.

Let us go through the whole sequence of events related to catalysis. Although I use here chemical terminology, the reader can substitute a multitude of life situations for the molecular protagonists.

1. In chemical terms, there is a starting mixture of reagents that can turn into a mixture of products on its own. The rate of the transformation is slow because the energy barrier is high. In pattern terms, the mixture is a pattern consisting of several disconnected parts (sub-patterns), each corresponding to one chemical species, each species represented in enormous numbers of multiple molecular copies. Such a pattern looks like the chemical equation in the beginning of Chapter 43. Theoretically, any bond can break, and the fragments can be recombined in the same or different order.

One thousand letters of alphabet printed on small cardboard squares, some of them stapled together in lines forming words (existing or meaningless) and some scattered—this is another pattern example of the same type of system, if the "staple bond" is reversible, i.e. twinkling.

2. There is a source of random recombination of generators. In the chemical case it is molecular movement. In the case of letters it can be a little demon, a trained monkey, or a random computer model. A number of elementary acts of bond formation and cleavage occur in a unit of time.

3. A catalyst **is brought into contact** with the mixture. For example, the catalyst works on linking any two H-O-R type molecules, where H is hydrogen, O is oxygen, and R can mean anything, so that they spin off water (R-O-**H + H-O**-R) and form R-O-R and H-O-H.

In the case of letters, let us assume that the "letter catalyst" works only on identical letters and combines them together in strings like AAAA, BBBBB, etc.

Any catalyst, due to the very nature of catalysis, speeds up both direct and reverse transformation: splitting as well as bonding.

4. In the chemical system, transformation occurs until the equilibrium is reached, when as many molecules of water and R-O-R turn into two R-O-H as two R-O-H turn into R-O-R and H-O-H. Same is true about the letters, and the monkey in an equilibrium is destroying as many combinations of letters as tying letters together.

5. Nothing further can happen after that, whether we take out the catalyst or leave it in the mixture. The system can move out of equilibrium only if it is knocked out by some blow. This is true, of course, only about a large statistical ensemble, while a small system will walk all around its phase space.

The final result, therefore, will be a chemical equilibrium in the chemical system. The position of the equilibrium depends on the energy of every pattern. If energy of R-O-R and H-O-H is lower than energy of two R-O-H then R-O-R will prevail.

It may seem that in the system of letters where bonds between identical letters are catalyzed, sequences like AAAA, BBBBB, or AAAABBBBBBAAABBB, with long blocks of identical letters, will dominate over "more random" sequences like AABABBBABAABAABBABAB. In fact, it depends not on the catalyst but on the relative energies of A—A, B—B, and A—B bonds. If we have scattered letters in the beginning, as soon as we add the catalyst, we will see the letters really combine in sequences or blocks of identical letters but then the catalyst will act destructively upon the A-A and B-B bonds with the same zest as it does constructively upon isolated A, A and B, B pairs.

If the catalyst drops into an equilibrium state, its presence will have no effect. If the system is not in equilibrium, then the catalyst will speed up only the transformation for which it is designed. The rest of possible independent transformations will run with the usual speed. Temperature is the only absolutely universal factor that speeds up all chemical transformations.

In the language of chemistry, there are two kinds of control over the direction of a transformation. Kinetic control works in the direction of the fastest change, while thermodynamic control determines the position of equilibrium. If we take a system far from equilibrium, the fastest transformation will dominate, and we will be able to see how the catalyst works. Gradually, however, the catalyst will start working on the reverse transformation and with time all evidence of any catalyst present will be erased.

Therefore, if external conditions change faster than the system runs toward equilibrium, the latter will never be achieved, because any external change, for example, a change of temperature, the removal of the cork from the flask, sudden exposure to light—all that sets a new position of equilibrium, and the overall pattern starts changing toward it, but along the way, new change of conditions will remove equilibrium even further.

In such conditions a chemical system behaves as a circus clown who is chasing his own hat, kicking it each time he is about to grab it or a dog chasing the ball which is being kicked by several people standing in a circle.

The simplest way to keep practically any chemical system far from equilibrium is to alternatively heat and cool it so fast that the rate of change will be comparable with the rate of the chemical transformation.

The contact with a catalyst is a *unique* event in the *history* of the system. For the system the arrival of the catalyst is an act of God and in the lab it happens by the power of human hand. It cannot be repeated because it results in coming to an equilibrium from which there is no way out without help. The catalyst cannot change a system in equilibrium.

Nevertheless, it is very easy to make a catalyst work 24 hours a day with the same efficiency. In industry it is done by passing a liquid or gaseous mixture through a column packed with the solid catalyst. The starting mixture enters the column, contacts the catalyst, converts into the products and leaves the column. The column is not in equilibrium but in the so-called *steady state*: chemicals come and go without apparent overall change.

The living cell packed up with enzymes—biochemical catalysts—never comes to an equilibrium because matter continuously enters the cell and exits it in a changed form.

Like running a treadmill, steady state can be an intense process with no visible result. Without a supply of energy, steady state will finally come to a real equilibrium where nothing happens. Energy is needed for both pumping the liquid through the catalytic column and pumping nutrient through the living cell.

A fountain with jets of water is an example of a non-chemical steady state: a pump re-circulates the water for the jets. Yet another example is the volleyball kept in the air by players: somebody hits it when it is about to fall on the ground. Life is like that ball: it does not drop dead because the sun hits it with short impulses of energy and because both energy and matter flow through it.

Yet another analogy with life is a circular conveyor assembly line. Machines or people positioned along the line play the role of catalysts. Raw materials or parts enter the process and final products and scrap leave it at certain points.

The changing and evolving life walks on two feet: steady state and catalysis. The energy to keep the whole system going and not to collapse toward equilibrium is supplied by the sun in the form of radiation and is dissipated in the form of heat. In animal cells this energy is derived from food.

Thermodynamics of non-equilibrium state, developed and popularized by Ilya Prigogine, is a relatively recent development in physics. It is understood now that a necessary physical condition for the permanent evolution is permanent non-equilibrium. Somebody or something had to shake the cradle of life not in order to put it to sleep but with the opposite goal of not letting it fall into the lethargy of equilibrium.

When there was no life, however, why did it appear from the presumed initial equilibrium or something close to it?

A probable answer is that planet Earth has always had various sources of non-equilibrium, for example, weather. However chaotic, weather is like a sequence of numbers with a hidden order. No pattern can last longer than a certain time: it cannot snow for six months in a row in New York City.

Any periodic process such as change of day and night, high and low tide, rain and shine, etc., could have been the hand that shook the cradle of life.

There is a view that making copies of the code is the very essence of life. A periodic external process could have operated the primeval copy machine.

The phase of cooling promotes bonding, so that a copy can be catalyzed by the original. They can remain zipped together for indefinite time if there is no hand to detach them. The phase of warming melts weak bonds and separates the copy from the original so that they both can serve as templates for new copies, see **Figure 46.1**.

Reproduction leads to competition and selection, and the life takes off full throttle.

Evolution can be considered as a constant invention of new, better catalysts employed to dissipate the energy pouring from the sun into biosphere. Until there is enough free energy to dissipate, the biosphere stays far from equilibrium. Life is a catalyst for bringing everything into equilibrium, which never arrives because any catalyst works only on a part of a system. Therefore, any fast process in a part of a system immediately violates the equilibrium between the part of the system and the rest of it.

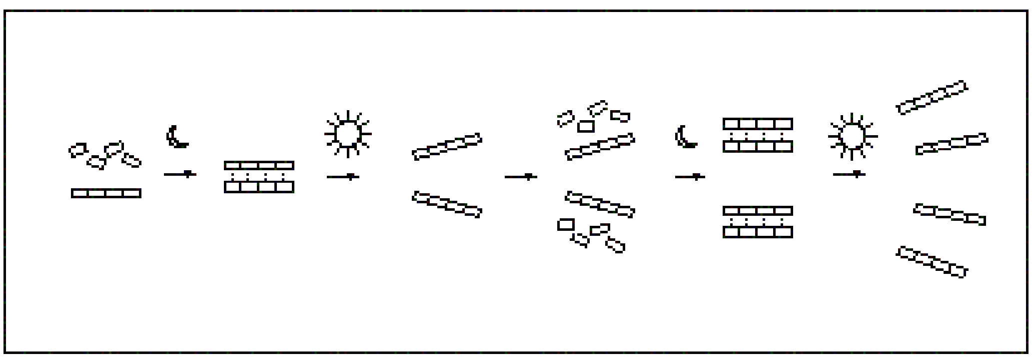

Figure 46.1. The natural copy-machine

Life had at least the following initial sources of chaos and order:

⟶ **more order**

1. Chaos of molecular movement,

 2. Chaotic order of climate,

 3. Ordered chaos of weather and climate,

 4. Order of chemical Lego,

 including catalysis.

←— **more chaos**

As soon as life takes off, it creates its own ordered chaos of a complex dynamic system: life is a wave of non-equilibrium. As soon as life spreads all over the planet, it creates its own order (instincts, parents caring for the young, herd, learning, etc.) and chaos (predators, fights, search for food, etc.).

We are coming to a somewhat paradoxical understanding of order and chaos. In social processes we associate equality with order and inequality with chaos. This is so if chaos in the form of inequality is natural and order in the form of equality is something we have to pay for. In natural processes equality is chaos: any distribution of molecules of gas is as good as any other. When we pump gas from one vessel to another we create unequal distribution which is order. Contrary to popular aspirations, equality is chaos and inequality is order.

Still, there is no complete equality in a volume of gas: all molecules have different energies statistically distributed along a bell-shaped curve.

Man-made things, their manufacturing and selling, have acquired fundamental control over social life. Moreover, since the life expectancy of things in 20-th century became shorter than human life span, some stable order of things, peace of mind, and equilibrium of soul are unattainable dreams constantly violated by new waves of things and information—more different than new.

If we have a Lego set with only a few kinds of parts, there is not much we can build of it. We need a developed inequality of parts, a wide variety of them, like in the molecular Lego, in order to build a variety of forms. To serve as information carriers, however, generators should be as much equal as possible, almost indistinguishable, uniformed like soldiers, marching in rows and columns of words.

Unification of individual life, mass culture, cold formalization of human relationships, reduction of an individual to a bar code—if the reader is troubled by all that, he or she can play the imaginary social Lego in search of a solution. The results are predictable: order is expensive, chaos is cheap, novelty is rare.

I have been almost completely silent about information which rules in the realm of mind. Next I will try to look for a kinship relation between catalysis and information.

47. CATALYSIS AND SIGNAL

As usual, we shall look at several disparate examples and a single logical umbrella over all of them.

When I write a letter to a friend from whom I have not heard for months, put it into an envelope, affix an address label, stamp, and drop it into a mail collection box, I send a signal. I trigger a chain of events: the postman picks up the letter, the post office delivers the letter to a place thousand miles from here, and after a while I find in my mail box a reply. If I send an email, the entire pattern mechanism does not change, but the action requires much less energy and costs nothing.

My friend can write a letter to me without my acting first, but my action definitely triggers or *catalyzes* his reply. The mail delivery channel and the telephone line keep us in each other's topological neighborhoods, so that the bond between us flickers. The communication systems keep me and millions of people close, creating a pre-condition of a bond, mostly without actual contact. The Yellow Pages are full of numbers that I will never call and I have no idea about the existence of billions of other people whose names, addresses, and telephone numbers I do not know and do not care to learn.

Mail, telephone, e-mail, Internet, etc., create a world of personal communication without the physics depending on distance, i.e., with the topology of graphs.

The process of sending letter or placing a call is irreversible: they typically cannot be "unsent" or "uncalled."

A signal device can be as simple as the "DO NOT ENTER" sign on the door of an X-ray lab warning about a procedure in progress. It has two positions of the switch as the inputs and no intermediate states between outputs LIGHT ON and LIGHT OFF. Although the switch works only if the force is applied in a certain direction, it can be activated accidentally by an object moving nearby. It is highly improbable, however, that the sign lights up on its own because the energy barrier between the two states of the switch is relatively high.

A computer memory cell, door latch, valve, and switch can be in two states of approximately equal energy separated by a high barrier. Writing a bit of information, locking the door, turning the valve—all those events are initiated, triggered, or *catalyzed* by an **external** action, for example, pushing a button, which may or may not happen.

By dropping a catalyst into a flask or pushing a button the hand comes out of nowhere, from outside the system, and makes a probable event actually happen, whether the system is a flask with chemicals or a computer.

The difference is that the computer has neutral bonds which require very little energy to either lock or open, while the chemicals have positive bonds with a big difference between bonded and separated states. A similar act takes place among negative social bonds dividing a nation when an outstanding leader comes to the rescue in a crisis and unites it against the danger.

Probably, as many pages have been written about information since the times of Claude Shannon and Norbert Wiener as about catalysis, with historians slightly trailing behind. It looks like both catalysis and signal, however distant, are relatives, like horses and cars.

In the world of patterns, information changes neutral bonds. The required energy can be very low, like that of a single photon. Presented in terms of bonds, information finds home in the family of Everything.

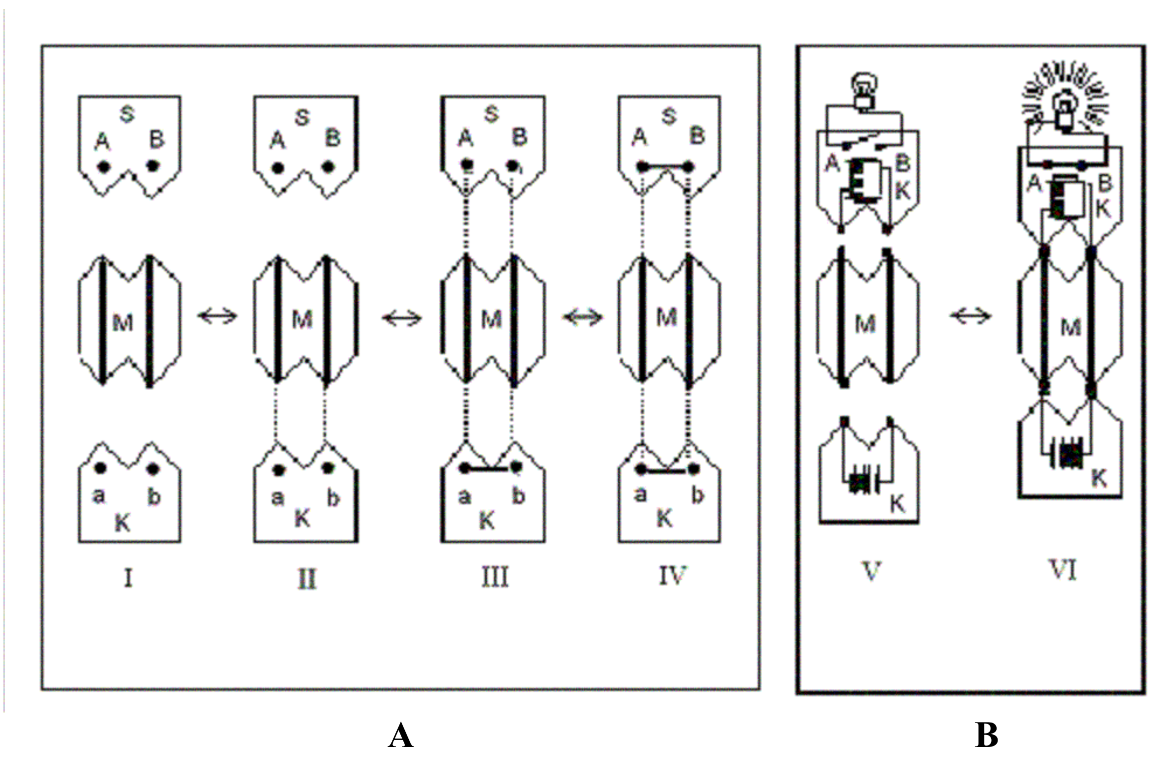

Figure 47.1. Catalysis (A) and signal (B). S: substrate, K: catalyst, M: mediator

Figure 47.1 illustrates the parallel between information and catalysis. In **Figure 47.1A** mediator **M** functions as a channel (transducer) between **K** (catalyst) and **S** (substrate). In chemical catalysis **M** does not exist. For Lego, we can see the child behind **M** whereas **a—b** is the bond in the manual.

Figure 47.1B shows another embodiment of the same system. An electric battery (**K**) is here the catalyst and the relay (**S**) is a substrate. Something should bring them into a contact. In this case it is the mediator (**M**), which is just the electrical switch that closes the circuit. It can be interpreted also as communication channel.

In both cases, however, the input in the form of a bond between electrical contacts (it starts with the bond between the finger and the button) results in closing another bond, with different physical consequences.

I see in catalysis a bridge between dead molecules and life. The family name of chemical catalysis and signal could be meta-catalysis or pattern catalysis. Soon we will look for more relatives. Purely non-chemical signals can be found only in man-made things, from railroads to computers, while animal and human perception is based on chemical mediators and processes.

I wish to emphasize that the cold chemical catalysis, as it is generally understood, does not close or break a specific single chemical bond: it takes part in a transition state of a chemical reaction, which is just a **faster** roundabout way to the same end.

There is a more subtle analogy between catalysis and signal, but because it is too technical for my kind of **MORE-LESS** mathematics, I will only slightly touch upon it. In short, both catalysis and signal change probabilities of events.

By dropping a catalyst into a mixture, a chemist creates a new situation: one chemical transformation among many pushes out its competitors.

By sending a message, a person creates a new situation, too, which, theoretically, had some probability beforehand. After the message has been received, the probability changes: it was only 0.25 probability that Aunt Olivia will come next week. After her today's call, however, this probability changes to 0.8 (she can still change her mind and so can the weather). This difference is related to the amount of information and we can measure it in her call.

Note how little energy an electronic message requires as compared with a horsemen carrying a letter and the actual arrival of aunt Olivia. The electronic civilization as a form of life claims the future because it has the advantage of low energy consumption. To compare, the large wild animals lose to humans because they require large sunlit spaces to feed on—what the humans crave for themselves.

Still, the parallel between catalysis and information may seem rather flimsy. Catalysis speeds up events but does not change their equilibrium probabilities. Information in a message may radically change the course of history, not to mention somebody's personal life. Catalysis is a **matter of matter**, information is a **matter of mind**. If the pun is not enough, we shall look for more common ground next.

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48. MIND AND MATTER: A FAMILY PHOTO

Autocatalysis is a particular, relatively rare case of catalysis when the catalyst catalyzes its own production. Autocatalysis is the very essence of the life of organisms, things, and individual beliefs.

The DNA replication involves many acts of catalysis with a copy being built over the original. Weak bonds assist in forming a strong bond when the generators of the template catalyze the entry of a new generator into the growing copy. The new entry forms a strong bond with the catalyst itself, because in the process of replication, the original and the copy are not separated, see **Figure 48.1**. The catalyst seems to make itself grow like a crystal of salt. The perspicacity of Erwin Schrödinger who compared life with an aperiodic crystal is all the more amazing.

Usually when a component **A** undergoes a transformation, the more **A** is present, the higher the rate of this transformation. Component **A** disappears faster in the beginning than in the end.

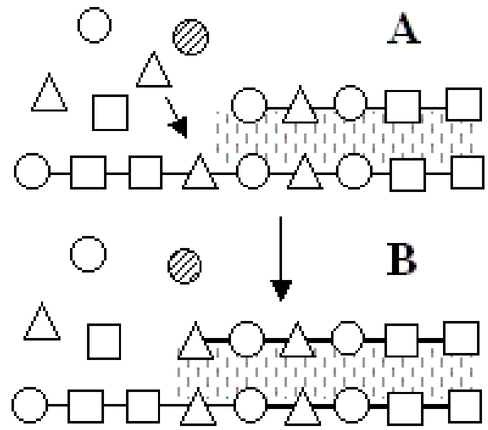


Figure 48.1. Autocatalysis

Let us spill a cup of small beans on the kitchen floor and start picking them up and putting back in the cup. We can consider this as a transformation from **B—FLOOR** (i.e., beans on the floor) to **B—CUP** (beans in the cup) catalyzed by **MYSELF**:

B—FLOOR + MYSELF ⇒ B—CUP + MYSELF

Initially, the beans are everywhere and we just pick them one by one as fast as we can. With time, the beans become rare, some of them roll under the furniture or the refrigerator, and to find the last ones takes more time than to pick up the first ones. If two people are picking beans, the work will go faster.

The common law of chemical kinetics as applied to bean-picking says that the **MORE** starting entity we have at the present time, the **LESS** we will have next time. The **MORE** beans on the floor, the **MORE** beans are picked in the unit of time, the **LESS** beans on the floor.

In autocatalysis, the starting entity increases in numbers instead of disappearing. The rate law for it is: The **MORE** we have, the **MORE** we will have next time, along the equation:

$$\mathbf{A} \rightarrow \mathbf{A} + \mathbf{A}$$

In terms of beans it means that the beans start multiply themselves—a picture typical for life but with almost no parallel in inanimate chemistry. Similar phenomena, such as chain reactions in a nuclear material or during the fuel combustion in car engine, contribute very much to the production of energy in our civilization, but are too technical to be considered here. The autocatalytic break-up is common while autocatalytic bonding outside life is exotic.

If we start picking up the beans that are able to multiply like bacteria, the result will depend on our dexterity: the faster we work, the slower they spread over the floor, and if the rate of picking is higher than the rate of multiplication, we can finally collect them all. Multiplication is exactly what happens with molecules of DNA and with all cells and organisms: they catalyze their own production. Theoretically, any normal "the-**MORE**-the-**LESS**" transformation in chemistry can run for a long time because it slows down with time, like when only a few beans remain in hidden nooks. Replication, as well as any "the-**MORE**-the-**MORE**" growth in general, although it goes through a period of acceleration, slows down anyway because there are no unlimited resources of anything anywhere in this world. **Figure 48.2** illustrates the kinetic difference between common chemical transformation and autocatalysis.

To make the example with multiplying beans more realistic, we can feed them with bean soup. They will divide until there is no more soup left. We can, however, run the show for a long time if we make the soup of the dividing beans themselves.

Life has been able to exist for ages because everything that is in process of building up undergoes an independent process of destruction, so that matter is involved in a global turnover. One part of matter exists in the form of life, another in the form of nutrients: decomposed life.

Manfred Eigen (1977) mathematically explored the situation when, in our interpretation, there is a rich enough stock of Lego parts in a closed space and they can bond with each other at random, like in the floating model. The rules of the game imply that if there is a bonded combination of parts, it will catalyze its own copy. The same model can be described in terms of a soup made of the letters of the alphabet that are capable to connect into strings in such a way that one string catalyzes its own copy.

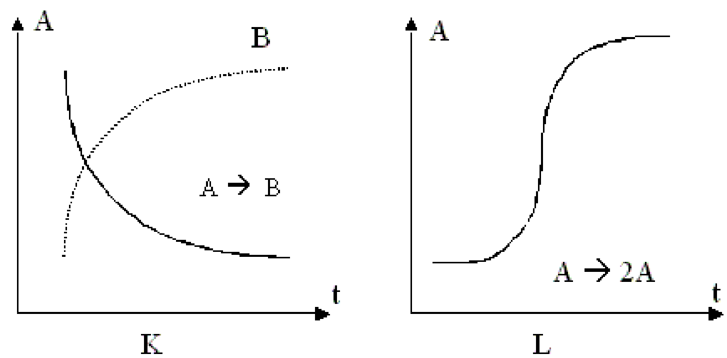


Figure 48.2. "Common" transformation and autocatalysis

The following independent processes run in the system by its very definition:

1. All species of assembled parts tend to **grow** in numbers due to their replication.

2. All bonds have tendency to **break**, so that the assemblies tend to "decompose" into smaller fragments.

3. **Mistakes** can distort the process of copying. Replication is not completely reliable, so that some species produce other species instead of their own copies.

The results of mathematical analysis show that the fate of this micro-universe depends on the ratio of the rate constants of all transformations. One species may become dominant, some species can become extinct, periodic rises and collapses can occur for certain species, etc. What is important, the fate of the system is defined by both chance and necessity.

The specific behavior of the system follows from the fact that any species of the assembled parts tends to grow in numbers while the number of parts available for growth is limited. This system lacks creativity because it does not invent anything NEW but just walks through its phase space, however large. This is the crucial shortcoming of the model as compared with evolution of species.

At the first glance, there is some resemblance between autocatalysis and paradoxes of mathematical logic.

In the Russell's paradox we assume that statement **A** is true:

A. The village barber DOES shave only somebody who DOES NOT shave himself.

If so, does he shave himself?

B. (If **YES**) He DOES shave somebody who DOES shave himself.

C. (If **NO**) He DOES NOT shave somebody who DOES NOT shave himself.

Therefore, if (**A**) is true, it is false, and if it is false, it is true. For more on the subject, see Hofstadter (1979).

In autocatalysis, the chemical "barber" (catalyst) is its own client (substrate): it "shaves" itself. No paradox arises because the catalyst dwells in the material world where the law of conservation of matter rules. In terms of generators, it means, that no generator can be generated out of nothing. The generators of a higher level (molecules) are built of the generators of a lower level (atoms), and the number of atoms is constant.

Russell's paradox (and if I am allowed an arrogant guess, the Gödel's theorem) is the price for the immortality of ideas and the use of logic instead of demonstration. The power of mathematics, however, is exactly the consequence of its freedom from actual demonstration with pebbles and fingers.

In mathematics the expressions on both sides of the equality sign A = A are really **equal**. In chemistry we can mark all atoms and see that both the original and the copy are actually **different** because they are built of different individual atoms and **A ≠ A**.

Here we finally come to the problem of mind and matter. We knew from the start that they were Adam and Eve of Everything because the Everything embraced everything. But how do we distinguish them on the family photo? I would say that in the same way as we distinguish between a man and a woman on any photo: they are basically the same except for some details.

Mind and matter are both configurations and patterns built of generators. It is their basic similarity which enables us to understand the world.

Products of the mind do not have copies, however: in the strange world of mind the use of **MANY** is limited. While Lady Matter can bear children, i.e., make copies, Sir Mind cannot. God definitely made Mind from Matter's maternal rib.

Products of matter, as a setback, always have a limited room to grow, until they grow so complex that they develop the mind that knows no limits. This is what makes mind and matter different, but think about how much they have in common! Whether they are married or not, I cannot say, but their relationship is not always harmonious.

Matter is the part of Everything that obeys the law of conservation, so that whatever grows—in the form of either replication or crystallization—has limits of the growth. Life is the copy-making matter.

Mind is the part of Everything that forms no copies and, therefore, can grow without limits. This statement contradicts the adage that human intelligence has limits, while human stupidity does not.

*

49. MIND AS CHAOS AND ORDER

Once again I would resort to pointing at various things and saying what I think about them rather than trying to build a system, give logical definitions, and care about any completeness or objectivity.

What I would like to share with the reader is a vision, not a theory. In my picture of the world, clouds are elephants and not bodies of tiny droplets of water visible in the sky, and Italy is a boot and not a Mediterranean nation, while footwear is a species of meta-life populating human closets.

After so much exercise in pattern thinking, instead of definitions, which are always circular in most important cases, I will try to take some momentary shots of the mind at various angles, with the optics of my camera as peculiar as my numberless mathematics.

Searching for the mind in the Lego universe, I could find it only inside the playing child. The mind is a bonding device. If it breaks bonds, it is only to make new ones. Like chemistry, the mind does not like loose generators with free unsaturated half-bonds, probably, as common for the transition states of mind as they are for chemical transition states.

The mind is a catalyst. It is also its own substrate, an autocatalyst of a kind, because it is able to grow. It is also a substrate for external events to leave their imprints: if two events, the candle flame and the pain in the finger, are close in time, a bond forms in the mind between their imprints.

I prefer to talk about the mind and not the brain because all I know about the material carrier of mind is that the brain is a kind of a circuit that can be mapped and studied more or less objectively. The brain is the hardware of mind, hooked up to a network of brains, while the mind is the network's software being creating while the hardware works.

Physical reality, for example, an ocean wave, finds in the mind its code, which can be derived from a book or photo and not even from looking at the real wave. The code goes through an evolution of its own and it comes out after a while as a picture of the wave, a poem about it, and a textbook. Different minds produce different pictures of the same object. During the entire process, the material wave and the ideal wave interact with each other: the mind invents the wave breaker, flat Fresnel lens, and wave mechanics.

Mind reflects the topology of the world. What is close in the nature becomes close in the mind: the pattern of reality is transformed into the pattern of knowledge. Various individual or group patterns of knowledge compete with each other for dominating the largest number of individual brains—but only in free and not frozen societies.

There is a lot of complexity behind this simplistic picture—probably, as much as in real chemistry behind its simplistic image as the Lego of molecules. To understand the mind as pattern, we need to know what the parts of its Lego are, what the pattern chemistry of the mind is, and what kind of physics rules over the chemistry.

Is there any "pattern" way to learn what happens inside our mind? Thoughts are observable in an oblique way—by the changes in the world they induce. The mind produces not only thoughts but also actions and behavior. For example, human mind constantly generates new patterns of ideas, including ideas of new molecular patterns which cannot be found in nature. The ideas of molecules can be converted into actual molecules in a chemical flask. There is a close correlation between what we think about the world and what happens in the world. The least observable are the transition states of the mind: the moments of discovery.

We know that molecular patterns are generated in nature due to the chaotic play of molecular movement, within thermodynamic and kinetic constraints. At the same time, some molecular patterns are generated in our head before they are generated in nature. Is there any similarity between the ways molecules and images of molecules are generated? In what way mind patterns are *generated*?

How to recognize a thought? Can we make an automatic device detecting thoughts, like a movement sensor of a security system? If we sent a probe on Mars to look for life, how can we design a probe for a non-human intelligence?

In the course of evolution, new biological patterns appeared without any participation of human intellect. We have to either admit that some non-human intellect created them or that our intellect, paradoxically, is as **mindless** in its foundations as the nature that gave birth to humans.

Instead of setting apart mind and nature, we can as well suggest that at a certain level of abstraction they work along the same pattern mechanisms.

Nothing seems to imply the idea that there is any similarity between the ways both molecules and ideas are generated. It looks like just another idea, a pure arbitrary combination of partial ideas, a mind-Lego construct. As soon as it has been generated, however, it can be explored and either rejected or accepted as a building block for other ideas.

In Chapter 40 we took a unified approach to such different subjects as heat motion and intellect by considering them various forms of generating patterns. We may suggest that chaos is the universal source of generation of other different patterns in nature, ranging from molecules to thoughts.

Taking a look at modern computers from this standpoint, we can see that they stand apart from both chemical flask and brain. It is exactly the complete elimination of any chaos that makes their function possible. They serve as a kind of prosthesis for the brain, the purpose of which is to buffer the excessive chaos of human thinking and to make it as rigid as a tool in a machine shop, not distracted by a beautiful face or an unfortunate accident. If a chaos is needed in the form of random numbers, it is the measured and bottled chaos of pseudo-random numbers.

The computer takes up the non-creative components of thinking, as well as those of the creative thinking. It is supposed to be infallible, although at such high complexity anything perfect is impossible. Modern complex software and even chips show more and more signs of relaxed attitude to work. Computers have learned to be sloppy because the time required to make them perfect would make any computer business out of question: the life of a thing is short in the grinding economy, especially when humans try to postpone their own death indefinitely.

In terms of order and chaos, computer is neither natural nor human. It is a typical machine for performing transformations of strings of symbols (data) into strings of symbols (output), according to another string of symbols (program), nothing more.

In my view, in order to build a humanoid computer we need a **hardware based on chaos** more than on order. The next generation of computers will, paradoxically, strive on imperfection. A humanoid cannot work without listening to a chaotic noise as the source of random numbers. Pure chaos, however, is as much creative as it is destructive and, whether human or humanoid, both would need a source of order as much as that of chaos.

I would define a computer as a device for solving complex problems in such a way that one hundred individual computers will give ten (but not one and not 100) identical solutions. Reciprocally, this is also a definition of complexity, in a way.

I would define a humanoid as a device for solving complex problems in such a way that one hundred individual humanoids will give two to one hundred different solutions, even using computers.

We do not need to look inside the mind in order to discover its random component. It is sufficient to watch the behavior of any animal or human. Like weather, it is never predictable within sufficiently short intervals. In the long run, we know that the animal will fall asleep or will look for food, but we can never tell when a dog is going to turn his head and in what direction if there are no obvious stimuli such as another dog, a cat, or a relevant sound. Behavior is a typical ensemble in time (time series): it is statistically ordered only if watched over a sufficiently long period of time.

The behavior of a human may look even more predictable than that of an animal, which leads us to a sad conclusion for a libertarian that hundred years from now it will be even more predictable—a pleasing conclusion for an authoritarian.

However complex, behavior is a pattern, it consists of atoms of positions and movements, and its simplest relative is a sequence of 0s and 1s, see Chapter 33. Human behavior can be variable and dynamic, while even a toy with a computer chip inside would show a low degree of complexity. The complexity of behavior and the ratio of order and chaos can be a basis for classifying an object as dead, alive, or artificial: the dead object is like a sequence of only zeros or only ones.

A human is capable of long stretches of highly ordered behavior at work, medium ordered dog-like behavior at home, and short occasional outbreaks of chaos in personal life.

A product of mass culture is highly ordered (What? You haven't seen "Titanic?") . An artificial object, such as a coffee maker, usually shows a highly ordered behavior, too.

A movie is an artificial object because a character in a typical movie neither behaves completely chaotically nor shows long stretches of machine-like behavior. Almost every scene has a meaning and is connected to something else. All redundant situations are removed, unless as a particular tool for giving the film an artificial tint of realism. The abrupt change of frames on the screen reveals the artificial origin of the movie because nothing like that can be observed in the consistent nature.

While a TV show is new and hot, it builds its own pattern space by inventing new generators, but with time it loses steam and amounts to shuffling and reshuffling same basic situations and ingredients, while other shows start imitating it. Mass culture is based on a blueprint as much as coffee makers, and its space has a limited number of dimensions, like the ice cream space, see Chapter 21. Mass products are based on new combinations of tested and proven generators, while innovative ones expand the list of generators.

Although we do not know all about the chaotic ingredient of the mind, it is clear that parts of the brain, whatever they are, do not move chaotically all around the scull. We know very little about the physical basis of what we call thoughts, but there are strong reasons to believe that they do not move either. As far as biochemical and electrical processes are concerned, the peaks of their intensity can move all over the cortex.

If the movement in the brain is not mechanical, what is it?

*

50. THE VILLAGE OF THE MIND

Our unified "floating" model (Chapter 40) was based on mechanical movement. Here I am going to offer another imaginary model of generation, which does not involve movement over space.

There is a small village of Noyes with a single street and no telephone, so that the residents stay in touch only in person, at random meetings, as well as by appointed visits, see **Figure 50.1**.

Watching the behavior of the villagers for some time, we can see a lot of mechanical motion. Residents leave their homes and move to other homes. By night they usually come back. The regularity of day and night makes their behavior partly ordered.

We can regard the villagers as generators, and contacts between them as flickering bonds. In a small community all people are interconnected and the relationships between them are governed by attraction, aversion, and indifference.

The community of Noyes is, at least partially, similar to the behavior of the atomic parts of the floating model. It generates changing configurations in the system of communication where a resident is a generator (atom) and the contact (collision) is a bond. The strength (energy) of each bond is measured by the frequency (probability) of the contact. Good friends have strong bonds and enemies are rarely seen together. Therefore, generation is not completely random.

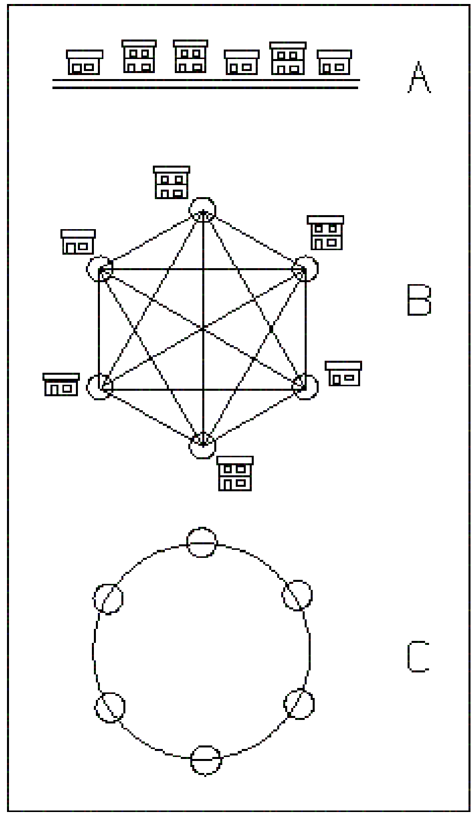


Figure 50.1. The village of Noyes

The arrangement of homes in the village is linear: each house has one or two neighbors (**Figure 50.1A**) and a distance can be measured with a tape measure. Neither geometry nor the linear topology matter for communication, however.

In the communication space all distances are equal because the actual metric distance is irrelevant and does not influence the frequency of contacts in a small village. The village, in a sense, is a world without metrics and everybody is everybody's neighbor. In this small world, all physical contacts have approximately the same entropy and energy. Unlike the possibility of physical contact, mutual attraction and repulsion varies from couple to couple. To portray this in my notation, I will place all nodes on a circle and in this way emphasize their equality, **Figure 50.1B**. A simplified symbolism is used in **Figure 50.1C**.

We can extend the analogy of this situation with molecular movement. Good weather increases the temperature of the system and encourages visits. Big news and happenings are another source of abstract "heat." For those familiar with chemistry, they can be compared with photochemical initiation or radiation impact.

Bad weather, crime, curfew, etc., freeze the communication. Moreover, in a very bad weather, the contacts may depend on the distance between the houses.

Now let us install the telephone in the village and, as an extreme condition of experiment, lock the residents at their homes for a while. In the new system of contacts, a little would change as compared with the personal meetings. The telephone calls will have about the same relative probability as visits, but the effect of distance would disappear completely. The same external factors, minus the weather, would change the temperature of the system.

In the new system the bonds of information channels substitute for physical contacts (“collisions”). Instead of meeting each other the residents exchange signals, thereby generating changing patterns of telephone contacts. We will call this particular kind of generation *commutation*. It can be performed either by a centralized telephone switchboard, or through direct telephone lines between every pair of homes. Handshake or telephone call—they both are the moments when the twinkling bond is on.

The world information networks such as email and Internet have the same topology of full graph, converting the world into a global village. The fundamental difference, however, is that most residents of the planet do not know about each other's existence.

To summarize, both molecular and telephone models are systems with some thermodynamics and all generators equally close.

We assume that molecules move so fast over a volume that any of them can collide with any other within a short time. Same is true about telephone: any two persons can establish contact any time, with rare exceptions.

I believe this is what mind is about: it is a *commutational device*, and the topology of this type is possible because the physical dimensions of the brain are relatively small. The commutation system performs the same function as the molecular collision system: it makes possible events involving any two participants.

We should note, however, that any channel of communication has a double existence—first, as physical connection (telephone line), and, secondly, as communication bond. Its physical integrity is a necessary condition of communication. Both the function and physical integrity have a price: we need to perform work for both telephone line maintenance and the act of sending a message, and both are reflected separately in our telephone bills.

Let us consider not a village but a large company with its system of managerial subordination or a city with the city hall, mayor, his deputies, and clerks. Although the physical distances between the employees located in one building can be less than the distances between the houses of Noyes, the bonds in such structures are not equally probable. There will be certainly more communication between the mayor and his deputy than between the mayor and a clerk. Similarly, a CEO has little contact with low level employees. Some social systems may have communication topology very different from that of an individual mind, and the tree-like topology is the most common alternative.

In the telephone model, as well as in the floating one, the temperature controls the rate of the frequency of the contacts. In addition to that, each channel may have its own temperature reflecting, for example, the level of noise and interference. The higher the temperature, the less reliable the bond is. The concept of the temperature of an individual information channel is common in theory of communication.

Now imagine that the residents of Noyes are released from their seclusion and both personal and telephone contacts are possible. The two systems of communication—personal and telephone—may exist at two different temperatures. For exchanging things, the residents would prefer to meet in person, while for exchanging news they would prefer telephone. Something like that happens in a living organism where both neural (i.e., electrical) and humoral (i.e., chemical) communications co-exist.

Now we can take a look at evolution from the point of view of topology. I did not expand on what exactly topology was about, hoping that the very use of the term would make it clear that topology was about the relationship of being in some sense close to each other. Topology of a pattern does not change if all bonded generators remain bonded, and no bonds are either formed or broken, like the topology of our distorted reflection in a curved mirror is exactly the same as that in a perfect one: the thumb and the index fingers are neighbors in both.

For a molecule the world beyond the sphere of immediate contact does not exist. Of course, the molecule can be under the influence of a physical field, but there is nothing it can do to the source of the field in response.

Evolution starts in the non-metrical world of small volumes. Next, evolution develops metrics inside a cell in the form of subcellular structures, as well as outside, in the form of the movement of the cell toward a source of light or food. Next, it compresses physical distance through the invention of means of communication. Evolution moves in the direction of the growing physical equivalent of non-metrical communication distance.

Metrics is associated with order because it means inequality: we measure distances because they are different. Evolution, starting with life, implies the expansion of generator neighborhoods beyond physical contact, turning big parts of Everything into big meta-cities, not villages, where any individual generator can be lost like a voyager in a forest full of identical trees. There is a chance that group ideology and identity will displace individualism, as it happened with multicellular organisms, and in the competition of groups for resources only one or two will survive. The remarkable global trend to separatism, from Canada to Russia, and from American minorities to upper middle class neighborhoods may indicate the end of the individual as unable to stand against the armored tank of complexity as a butterfly. One might expect in this situation the revival of organized labor.

The key question in connection with this is temperature: in a hot society big blocks will be melted down, although smaller blocks disappear faster than big ones. In a cold society one block has more chance to grow at the expense of others, as it had happened with the Communist Russia before it melted down when the thermal insulation was dismantled.

I am not an expert in theoretical physics of Everything, but I can easily imagine a future textbook of physics discussing not only the impossibility of eternal motion as a fundamental law of nature, but also the impossibility of some social ideals or the high price we will have to pay for them.

Yet the purpose of this chapter has nothing to do with politics. I simply wanted to show how patterns could be generated in very different worlds of molecules and individuals, and if the illustration was convincing, this is a way patterns can be generated in the mind.

51. THE MIND AS LEGO

In order to treat mind as Lego—and this is what I think it is—we have to identify the generators and the topology of their connections.

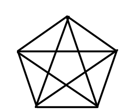
Mind is probably the most mysterious thing in the world, which in itself is amazing because each of us possesses a mind and is free to play with and explore it all day long, no equipment needed. We also accumulate a lot of observations of other people's minds. This paradoxical difficulty of understanding something which is always on hand can mean only that we should try to distance ourselves from the subject—the abstract mind—and **not to infect it with the germs of our individual minds**.

It is impossible to find an analogy of mind in the areas of knowledge studying objects that existed before mind. The mind possesses a crucial evolutionary novelty. There is an analogy, however, with the stage of evolution that we are entering right now, as it seems.

My vision of mind is similar to a popular (but not necessarily true) vision of our planet next millennium, with billions of people all tied together in a global communication system, so that any independent individual can communicate with any other in the network, for better or worse, using a tiny bit of the available communication space.

At present we can watch an initial stage of this transformation of the world into a “global village” or whatever, where the final goal is to have everybody in each other's neighborhood and be capable of sniffing out what is cooking in the neighbor's pot. This may result either in the topology of a big segregated city or that of a corporation, rather than a village.

If something looks too complex, it is probably quite simple. From my arrogantly pattern point of view, mind is a set of generators with the topology of **complete graph** (which is the graph with every point connected with all the other points, like the pentagram inside a pentagon). This statement is far too extreme, but at least it shows some direction. It means that any generator, at least in principle, is close to any other, so that any bond is already posted, with higher, lower, or zero frequency of twinkling and always in a dynamic change.



Thoughts are what we call statements: "the cat chases a mouse," "a dog bites a man," etc. Their generators are: CAT, CHASE, MOUSE, DOG, BITE, MAN. It is understandable that CAT is connected with CHASE, and DOG with BITE, but how can those two statements be connected to each other?

"Cat is an animal," "Dog is an animal." ANIMAL is connected to both CAT and DOG (and even to MAN). There is only **ONE** ANIMAL, however, not two. Therefore, ANIMAL is a bond—or a bridge—between CAT and DOG.

In short, the topology of knowledge, unlike the topology of Noyes (Chapter 50), has a discrete metrics: there are more distant generators, like CAT and GIRAFFE, even more distant, like CAT and ACCELERATION, as well as close ones, like CAT and TIGER, or even CAT and MOUSE. We can walk or jump or fly from one point of the semantic network to another because they all are close in the topology of the mind, but a long distance travel is discouraged by the topology of knowledge: one can easily get lost. The best vehicle for traveling is... catalysis: two generators close to a third one are almost close to each other. PET catalyzes our glide from CAT to DOG to PET DINOSAUR.

Catalysis speeds up what would happen anyway. This is a kind of triangulation that we use to build the roads over the land or map Mountain Everest.

Any individual mind has a history: a sequence of non-repeatable new events. Mind grows by feeding on the **NEW**, not just through shuffling the same pack of cards.

We can consider any set of generators that performs generation of patterns by interconnection as a basis for the pattern picture of the mind. From this point of view, all we know about thoughts is that they are patterns. A chemical flask and a brain look like rather close relatives in the family of Everything.

One of the first meta-chemists was Aristotle. Let us take one of the oldest known meta-chemical transformations, Aristotle's syllogism "Epymenides."

1. All Cretans are liars	**Therefore:**
2. Epymenides is a Cretan	3. Epymenides is a liar

It means that **IF** statements 1 and 2 are true **THEN** the statement 3 is also true, but it does not mean that any of them is true. In fact, this reasoning is similar to a chemical reaction. We take statements 1 and 2 as starting compounds, give them time to react in our head, and the result is statement 3. Formal logic is a kind of chemistry.

As compared with a chemical reaction, something from statements 1 and 2 is missing: CRETAN disappears in the end, which could never happen in chemistry. We can balance the equation, however, by keeping CRETAN and eliminating the redundant ALL.

CRETAN→ **is a**→LIAR + EPYMENIDES→ **is a**→CRETAN ⇒
EPYMENIDES→**is a**→LIAR + CRETAN→**is a**→ CRETAN

It is very much like chemical reaction A + B → C + D. Whether A and B are true, or not, the identity CRETAN→ **is a**→CRETAN is always true: all Cretans are Cretans.

Can we say, then, that the following syllogism and transformations are correct?

1. All Cretans are liars	Therefore:
2. Epymenides is a liar	3. Epymenides is a Cretan

Let us drop the three statements into a meta-chemical flask and stir them well:

CRETAN→ **is a**→LIAR + EPYMENIDES→ **is a**→LIAR ⇒
EPYMENIDES→ **is a**→CRETAN + →LIAR + →LIAR + **is a**

Some atoms do not stick! The reasoning does not hold the water because we cannot connect →LIAR with →LIAR: they both have only passive bonds. Neither can EPYMENIDES→ and CRETAN→ be connected, for the same reason.

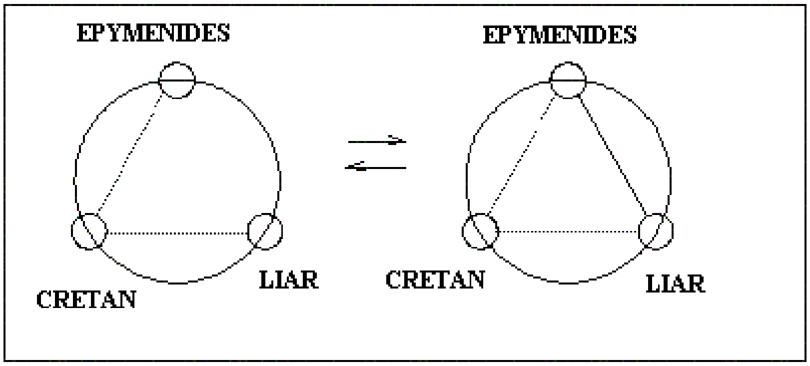


Figure 51.1. Chemistry of syllogism.

We can use a chemistry-like notation for at least some mental transformations.

Next I am going to suggest a chemical-style graphic presentation of the mind, see **Figure 51.1**. It is no different from the map of the village of Noyes. Each term is close to any other term, and we place them all on a circle. Since CRETAN is bonded with both LIAR and EPYMENIDES, it works as a catalyst, increasing the probability of the bond between EPYMENIDES and LIAR.

We can ask now a different question. Why could anybody even think that CRETAN and LIAR were connected generators? Why are some generators in mind bonded and some are not?

In the mind any term can be connected with any other, although the strength of the bond can be very low. If we believe that all Cretans are liars, there was something that increased the strength of that bond.

Mind is like a flask with molecules **A** and **B**. They react but very slowly. There is also the **environment** of the mind , i.e., the world, which may influence what is going on inside mind, by applying pressure, temperature, or adding a catalyst.

An individual mind is also a generator that communicates with other similar generators either directly or through the frozen products of mind such as books and other information, including hearsay, slander, etc. The way it works is shown in **Figure 51.2**. The world as pattern expresses itself in the pattern of the mind through the mechanism of catalysis.

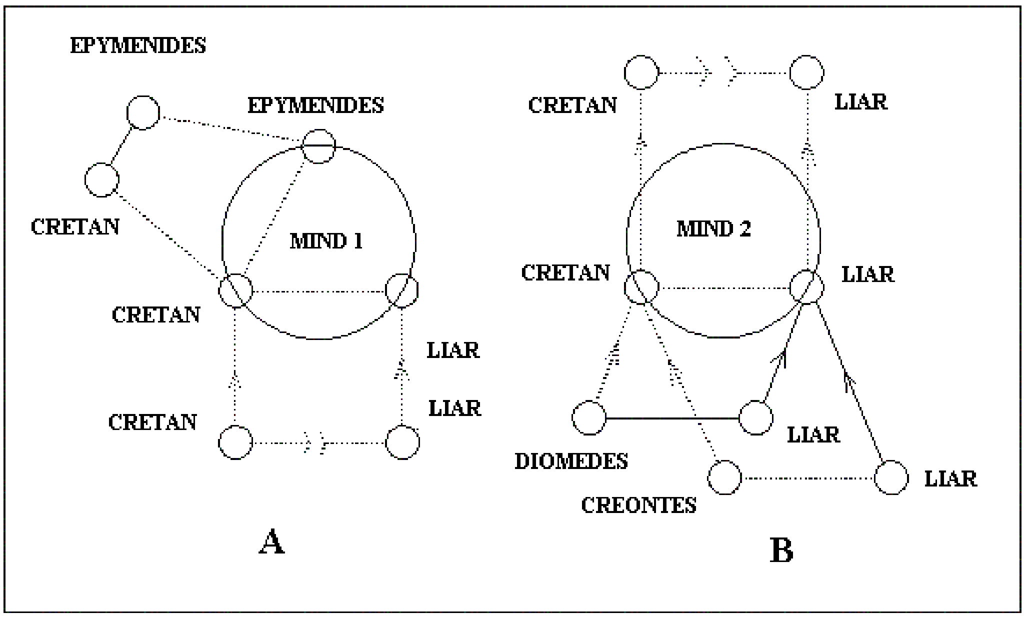


Figure 51.2. Life catalyses mind

In the pattern picture of Everything, including both matter and mind, all patterns interact through making and breaking bonds in dance figures of triangles and rectangles where the topological nearness is more or less preserved.

The bond between CRETAN and LIAR in **MIND 1** can be catalyzed by another such bond in the environment. Another mind, for example, **MIND 2** can be responsible for that, having acquired that idea from personal experience or hearsay, or with a malicious intent.

I have to state my disclaimer again: this is how the mind looks to me not from the point of view of psychology or neural physiology or chemistry. It is the skeleton of the mind on the pattern X-ray shot.

NOTE (2006): Compare with *Patterns of Thought* by Ulf Grenander .

Does it all mean that we cannot change an ethnic prejudice or any other pattern in the mind?

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52. THE MIND IN TURMOIL

In general terms, the concluding question of the previous chapter is about what happens to any mind pattern with time. It is the cardinal question of chemistry, the science of time. If we follow the chemical model, all interacting patterns will come to an equilibrium.

Here I would like to make some casual remarks about the pattern mind as a dynamic system.

The world is never in equilibrium. If Epymenides lied once, his further behavior may prove that it was not typical of him and the fact that he is truthful could catalyze a more favorable opinion about him. In the real world we do not always use formal logic with its no-yes all-or-nothing bonds: we use not only the vague "maybe" option but we also roughly measure the quantitative degree of the "maybe" on the scale from "practically yes" to "well might be" to "fifty-fifty," etc.

We have to remember that chemical catalysts do not work in a selected direction: they either form a bond or break one, depending on where the equilibrium stands. The position of the equilibrium depends on the temperature. This is true if all bonds are positive, as it is the case in chemistry.

When a bond is negative, we cannot talk about equilibrium. The overall state of the system depends on the supply of energy. The less energy, the closer the bond to its break-up. The more energy, the stronger the negative bond.

The world has a double control over its mental patterns: through catalysis and through supply of energy. This is why poor economical conditions always work against rosy propaganda. The essential consequence of this order of things is that unlimited growth is impossible due to limited resources of energy, not just the stock of atoms. Without supply of energy, all negative bonds would break down. Some natural material patterns can grow only when some other patterns die and are available for recycling.

Are bonds in the mind positive or negative? Looking at the elderly people who remember perfectly well tiny details of far-away past but cannot keep in memory vital details of the present, I believe that the phenomenon of forgetting is an evidence of the negative character of bonds in the individual mind.

In order to work, mind has to forget most of the daily information. The brain, however, possesses the ability to make some bonds if not negative then of the neutral type. Some long term bonds in the individual mind either do not break or break up very slowly. At the same time, they can be changed by an external impulse. Those bonds are of the same type as in the memory cell of a computer: whatever is written in the cell, it can be stored indefinitely until something else is written over. Today President→**is a**→Democrat, overnight President→**is a**→Republican.

Molecules in a flask are presented in many copies of the same pattern. Living creatures are presented in many numbers: they exist as populations. We say that a species flourishes when its population is numerous. Chemical and biological dynamics are to some degree predictable only as the interaction of populations.

As I believe, something definitely absent in the mind is population: multiple copies of the same species. On the contrary, the numbers of individual carriers of the same pattern can be different and considerably large, which creates a basis for the phenomena of ideology. The pattern then is identical with what Richard Dawkins (Dawkins, 1989) called the meme.

For the ideas—strange singular systems without populations—we can imagine dynamics as **competition in time**, not in space or numbers. A pattern presented in a single copy competes with another pattern for its survival in the environment of limited resources, i.e. for the longest segment of time. Our individual ideals change with age, knowledge, and experience, and during the transition periods we may make decisions swinging between the outgoing and incoming system of beliefs.

The human knowledge has been growing like a living organism, but we can see now some signs that it too might come to a steady state, with a balance of a loss and acquisition of information. Books and periodicals take too much room. Computer files, on the contrary, are almost immaterial, but exactly because they multiply freely, most of them are of no value and die out or are exterminated. In the world of man-made things, too much of variety means that there is no time to choose between enormous numbers of pseudo-different things, and they are chosen either at random or by a feature totally unrelated to their function.

I was in this kind of situation when I needed an example of syllogism for the previous chapter. I chose the Epymenides syllogism among an infinite number of other examples like "All dogs bark. Rex is a dog. Rex barks" because "Epymenides" has been marked: it has a high auction value, like an ancient statue, because of its antiquity.

Another advantage of this example was that it showed that the statements did not need to be actually true. The Cretans could be honest people, or Epymenides can be unlike his folk. The transformation in a syllogism is like a chemical reaction on paper: it is not necessarily feasible.

In the realm of Everything, we can still afford the luxury of the free play of mind that Aristotle enjoyed when there was too little testable knowledge. There was some reason to believe that some Asian antelopes could breathe through their legs.

The expansion of knowledge creates a constant inflow of information through the mind. New terms, facts, ideas, concepts, theories generated by individual minds pour into the collective mind and keep it in a state of a constant non-equilibrium, generating more and more new ideas coming back to the mind like the water evaporated from the ocean surface comes back in torrents of rain.

This is something very different from what can happen in a chemical flask. The chemical parallel ends half-way. In order to complete it, we need to formulate the **difference between the flask and the mind in terms of the flask**. What is the imaginary chemical procedure which is possible in the mind but impossible in the flask? We will come back to the question in Chapter 55.

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53. THE WIRING OF THE MIND

In order to describe evolution of nature and creation of new generators, the mind itself should possess an ability to create generators and keep up with the expanding knowledge.

The number of cells in the individual brain does not significantly change during productive human life, echoing (distantly) the conservation of matter in the nature and the constant size of computer memory. The empty memory contains no information: it starts filling up the void when the computer starts accepting software and data. The computer can have a stored individual history, if needed. Everything in the computer can be erased, new information written, and the past record usually has no bearing on the present one. From this point of view, computer is **reversible**. It can be brought to the same state many times and whatever happened between the two identical may leave no trace. Like the computer, the chemical flask does not remember all the reactions that were conducted in it.

If biochemistry is not involved, it is hard to imagine a flask that produces higher yields of those compounds that were previously synthesized in it. The content of the mind, however, depends on what has passed through it before. A chemist who works with his flask is a remarkable combination of both devices.

Next we will try to follow the development of the mind and the intimate mechanism of inventing the NEW in the form of new generators.

Suppose, there is a little universe **U-3** consisting of all graphs on three nodes **A**, **B**, and **C**, which are atoms of that universe. **U-3** can be only in eight states shown in **Figure 53.1K**. Unlike the case of universe **U-5** (Chapter 30), we distinguish between the nodes, so that **graphs 5**, **6**, and **7** (**53.1K**) are different.

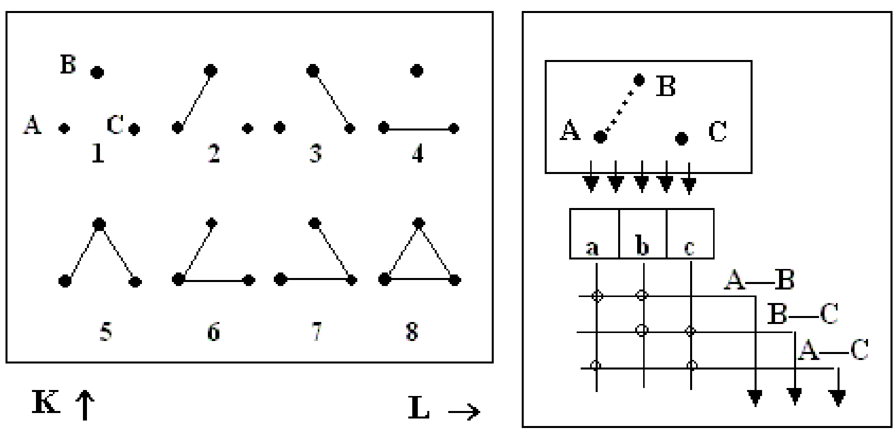

Figure 53.1. Universe U-3

Let us imagine that a mind arrives at this little universe and starts studying it. The situation is shown in **Figure 53.1L**. The mind perceives the pattern of the universe due to one-way bonds between the external generators **A**, **B**, and **C** and the corresponding generators (cells) of the mind **a, b,** and **c**.

I found useful the following visualization of the contact between **U-3** and the mind (**Figure 53.1L**). Each receptive primary generator of the mind (**a**, **b**, and **c**) has an outbound "wire" going downward. The only function of the wire is to represent **a**, **b**, and **c** as basic arguments of logical (Boolean) functions.

Suppose **U-3** is in the state 2 (**Figure 53.2K**, **graph 2**), with a bond between **A** and **B** (dotted line). This bond **catalyzes** the bond between **a** and **b**. which materializes in the new horizontal wire that represents (**A** AND **B**) or **a** $\wedge$ **b** in a different notation, turns down and joins the three original ones. The same procedure repeats for three other bonds. Each new wire joins the expending bundle of arguments and various logical functions on them can generate new wires. Thus, **graph 5** will be represented as (**A—B** AND **B—C**) : the new horizontal wire will cross and connect the vertical wires **A—B** and **B—C.**

Next I am going to demonstrate what makes the mind a unique device in the Everything.

As soon as bond **A—B** has been perceived **the very first time**, a **NEW** generator **appears** in the mind (**Figures 53.1L**). I show it by the **NEW** wire that starts horizontally, crosses the verticals, makes contacts with them where the dots are, and becomes a new generator representing **A—B.**

If bond **B—C** is perceived next, another generator and line representing **B—C** appears, etc.

If bond **A—B** is perceived **second time**, the mind does not make any NEW connections, but just **recognizes** bond **A—B** as **OLD** and **understands** that something familiar is in the focus of its attention.

Understanding is expressing the **NEW** in terms of the **OLD**. It can be done only once, and understanding cannot be undone, but can be forgotten.

Provided there is a way to recognize generators **A** and **B**, the wiring for recognizing a bond between them is shown in detail in **Figure 53.3**. Here three types of cross-contacts are used. They correspond to three logical connectives: NOT (cross), AND (filled circle), and OR (empty circle). For more about logic, see Chapter 54. In that way we can derive wires and form new generators that will represent internal secondary generators **A**, **B**, bond **A-B**, **Nothing**, and **Something**. This is how we form abstract ideas: by placing one new wire across **MANY** old ones, i.e., taking a Boolean function from old arguments. The list of arguments, however, expands.

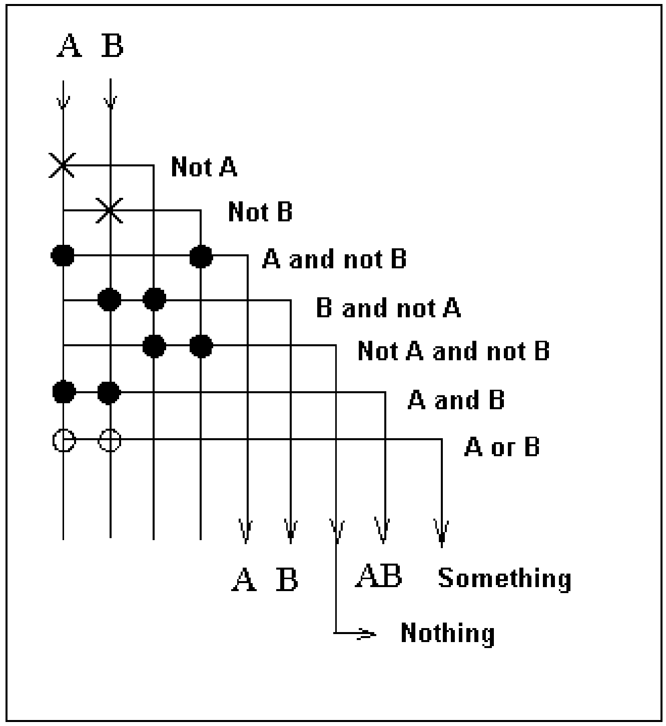

Figure 53.3. All about a bond

After **MANY** acts of perception, the mind comes to understanding the nature of **U-3**. It means that the mind has a representations for ALL states of **U-3** , having acquired eight new generators in its configuration space in addition to the three primary ones. This process of understanding **U-3** is shown in **Figure 53.2** in the circular notation where each "wire" ends with a new generator symbolized by a small circle on the big circle of the mind.

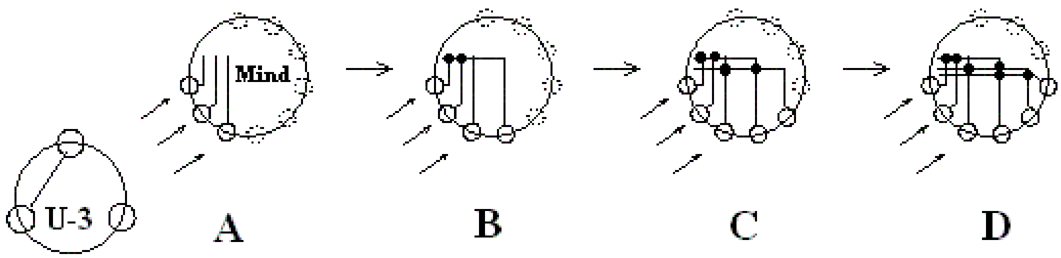

Figure 53.2. The understanding mind

If each bond gets its presentation as a new generator, where the new generators come from?

In the pre-mental chemical world, the new generators (polymers, genes, cells) were formed by aggregation of generators of a lower level (monomers, polymers, organelles). Chemical generators, however, were presented in multiple copies. Aggregation of amino acids into proteins did not wipe out all free amino acids—there were plenty of them, and even more atoms of **C**, **H**, **N**, and **O**.

In the pattern mind, where every generator is single, the mental counterpart of molecular aggregation does not consume the contributing generators. The multiple wiring serves as a substitute for molecular bond, but a new generator has to come out of somewhere.

As I believe, in an empty mind all generators are in a kind of sleeping mode: they are not hooked to other generators in any way. They are like unpacked boxes with telephones in a newly founded company.

In the initial state of mind which is the beginning of its individual history, some telephones—I will call them primary—are unpacked and hooked to the lines coming from the environment. Each time any two telephones ring together, a new telephone is taken from the box and hooked to them. It rings when both of them ring together, but it can be reached by other callers, too. Such a telephone may be called secondary. Primary telephones are hooked up to external generators (sensors), secondary ones may be hooked up to any other telephones. When two secondary telephones ring together, a new secondary telephone is unpacked and hooked up to them.

The history of an individual mind, therefore, is unpacking the boxes and hooking up the telephones to each other in a certain order imposed by the world outside, and using at least three types of connections. In these terms, the collective mind is a collection of communicating companies.

Let us see how all that can be used for understanding **Universe U-3**, **Figure 53.4**. Here we start not with primary sensors but with three ready lines meaning individual bonds and derived from primary wires (**Figure 53.4**).

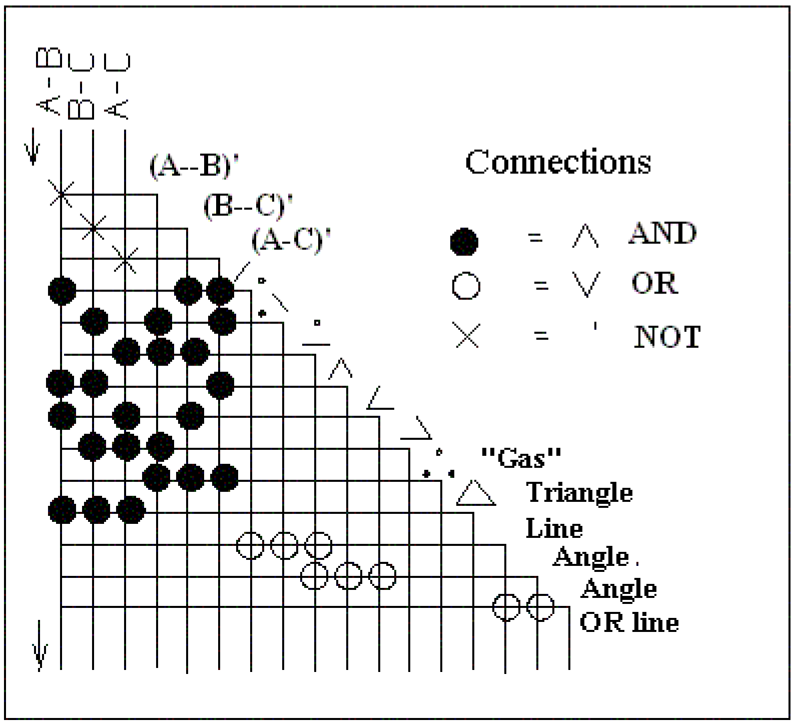

Figure 53.4. A complete encyclopedia of universe U-3.

The secondary wires bear names like "**A-B bond**," "**B-C bond**," "**No A**," "**No A-B bond**," "**A-B and B-C bonds**," etc. In other words, the wires apply logical connectives to their inputs. We can see how by using connectives we can get a generator meaning "elbow”

("L-shape") regardless of its orientation, or an abstract "bond," no such thing existing in the real world.

As soon as a generator (new phone line) appears, it becomes a **NEW** generator, not a **DIFFERENT** one, because it was not there: it has been born. To be retrieved from the initial limbo means to be connected by communication channels to other generators or to external sources.

The next event in the life of the newborn generator can be only **recognition** of already familiar pattern in the outside world. The differentiation between **OLD** and **NEW**, therefore, is the essence of recognition. When a secondary generator is born, it is **NEW**. When it is bonded to upstream generators, which in common language means that it responds to primary signals, it is already **OLD**, and the established bonds recognize the outside pattern as **OLD** (familiar).

This how I see the pattern skeleton of the mind. The pattern Lego is free for anybody wanting to experiment with it and do better. You are welcome to design a better universe and a more compassionate mind. For an exercise try to build a pattern soul.

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54. THE MATHEMATICAL MIND

The reader with aversion to mathematical symbolism can skip this chapter about parallels between mathematical logic and chemistry. Another option is to ignore the meaning of the symbols and regard them as pieces of a linear Lego that can be assembled into strings with interchangeable fragments or treat them as poetry by Lewis Carroll.

Chemistry deals with patterns called molecular structures which may or may not make sense. It starts with a set of atoms denoted by letters **H, Li, B, C, He**, etc., bonds denoted by lines such as single (—), double (=), triple (≡), dotted (·····), sign of transformation (→), etc. Those are generators of chemical patterns.

Mathematical logic (or just logic, for short) deals with patterns called propositions—statements that may or may not be true. It starts with a set of terms notated by letters **a**, **b**, ... **p**, **q**, **r**, etc., connectives **AND** (⋀**, &, x**), **OR** (⋁**,** +), **NOT** (¬ **, '**), and others, parentheses, brackets, and the signs of implication ($\Rightarrow$) and equivalency ($\equiv$, =). Those are generators of logical patterns.

The two preceding paragraphs illustrate once again what pattern vision of the world is about: both products of the flask and products of the mind are patterns and they can be described in the same language.

Exactly as in the Lego or chemistry, some generators can be connected and some cannot. The rules of connection are, like in language, called syntax. Syntactically correct statements are not necessarily true. The meaning of all connectives is given in the following table where **A** and **B** are two terms, **T** means **TRUE** and **F** means **FALSE** :

A	B	A $\wedge$ B	A $\vee$ B	¬A
T	T	T	T	F
T	F	F	T	F
F	T	F	T	T
F	F	F	F	T

The first line of the table reads: If both **A** and **B** are **TRUE**, then **A** AND **B**, **A** OR **B**, and NOT **A** is **FALSE**. If we take true terms, we can compose complex proposals that are also true if we follow certain rules of inference and start with a rather short list of statements presumed to be always true (axioms). There are different systems of axioms, and even different systems of logic. My examples are taken from the system of Whitehead and Russell (1925).

Logic is similar to geometry, which takes points and lines as given, starts with axioms, and derives theorems from them. It is also strikingly similar to chemistry—no wonder because the propositions fill up a configuration space. Like in chemistry, logical expressions can form a hierarchy where big chunks can be treated as terms and bonded to connectives. An example is presented in **Figure 54.1**.

The generators are shown in **Figure 54.1A**. To show that negation can be connected

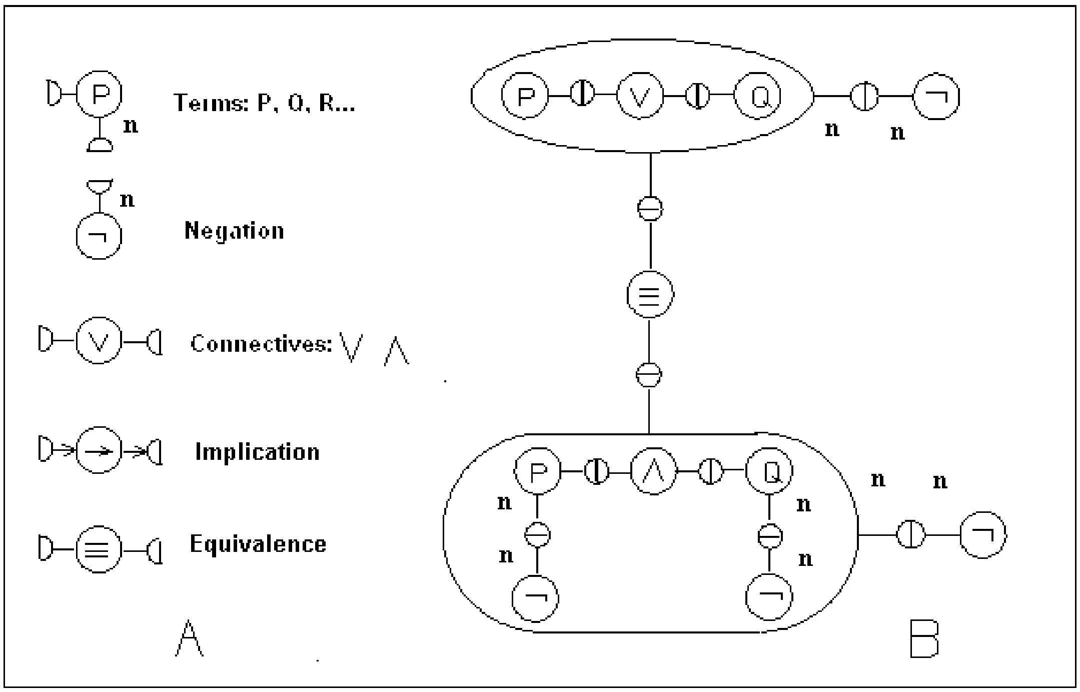

Figure 54.1. A molecule of common sense: a configuration of mathematical logic

to a term but not to another connective, I give to each term two different bonds, one with bond index **n**, specifically for negation. It is not obvious how to show with indexes that two implications cannot be connected, but I would suggest that two implications in a row mean just one.

In the usual linear notation, the "molecule" of logic shown in **Figure 54.1B** is

$$\neg(\boldsymbol{P} \vee \boldsymbol{Q}) \equiv \neg(\neg \boldsymbol{P} \wedge \neg \boldsymbol{Q}) \text{ or } (\boldsymbol{P} \vee \boldsymbol{Q})' \equiv (\boldsymbol{P}' \wedge \boldsymbol{Q}')'$$

Here we do not need to understand all the intricacies of the subject: we just need to watch the logical Lego in play. Some structures can be transformed into others—that is all. A particular combination of parts is called expression or statement. An example of expression is **Axiom A4** from the system of Whitehead and Russel.

$(q \to r) \to [(p \vee q) \to (p \vee r)]$ **Axiom A4**

In common language this axiom reads:

There are statements q, r, and p.

$(q \to r)$: If q is true then r is true (**A**)

$[(p \vee q) \to (p \vee r)]$: If either p or q or both are true then

either p or r or both are true. (**B**)

The whole means: If **A** is true then **B** is true.

Theorem 1 of mathematical logic in the same system is:

$(q \to r) \to [(p \to q) \to (p \to r)]$ **Theorem 1**

It means that if q implies r, then the fact that p implies q implies that p also implies r, whatever p, q, and r are.

The truth of **Theorem 1** is not obvious if we look at **Axiom A4**, but it can be inferred in the following way.

1. Substitute p' for p in :

$(q \to r) \to [(p \vee q) \to (p \vee r)]$ **Axiom A4**

We can substitute all occurrences of any term for any other term.

If we substitute p', i.e. NOT p, for p, then follows:

$$(q \rightarrow r) \rightarrow [(p' \vee q) \rightarrow (p' \vee r)]$$

2. Substitute:

$(p \rightarrow q)$ for $(p' \vee q)$ and $(p \rightarrow r)$ for $(p' \vee r)$, which is possible because those pairs are equivalencies:

$$(q \rightarrow r) \rightarrow [(p \rightarrow q) \rightarrow (p \rightarrow r)] \qquad \textbf{Theorem 1}$$

From the point of view of a chemist, the inference of a theorem is similar to a synthesis of a chemical compound from simple reagents.

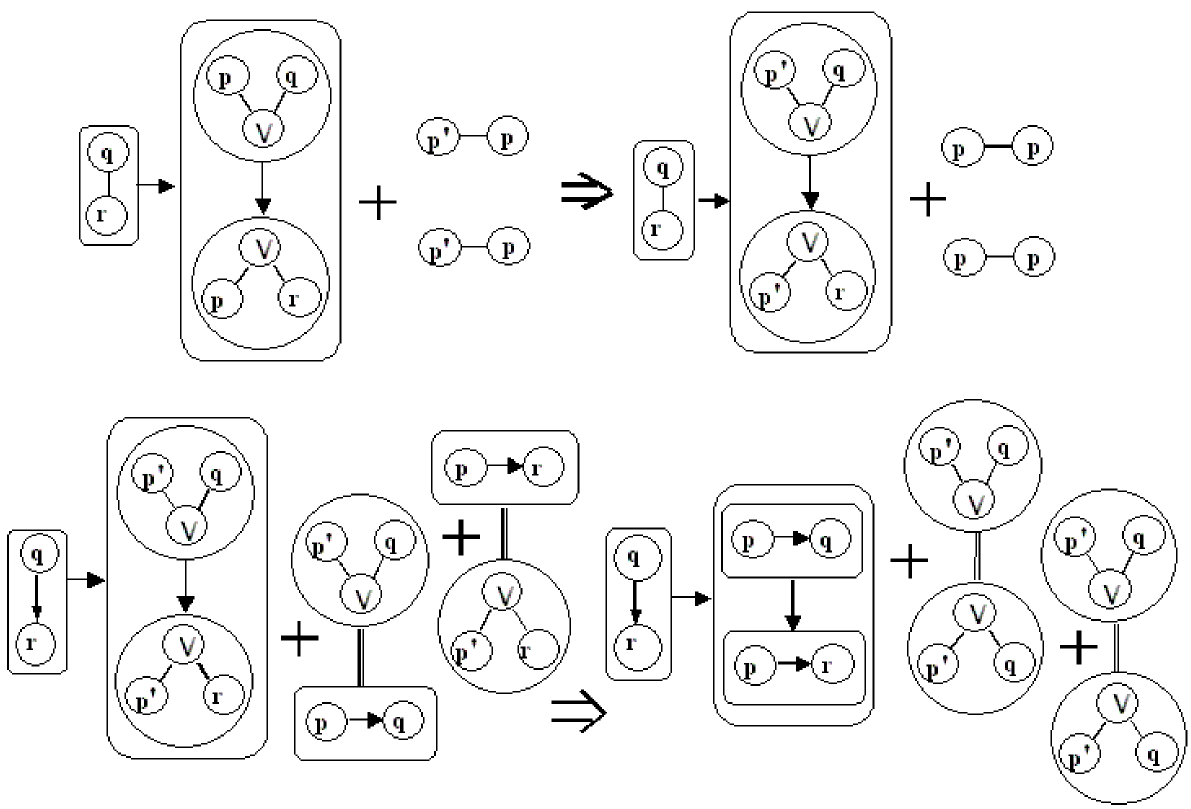

Figure 54.2. The chemistry of the mind.

In **Figure 54.2** the inference is shown as "meta-chemical" reaction. Naturally, both "reactions" can be presented as sequence of simpler steps. Negation is marked with " ' ."

We obtain true statements each time we transform true statements according to some rules. In this case, the rule is simple: the product should contain an identity, i.e., an isolated symmetrical pattern of the type $p \equiv p$.

We can formulate this condition as a particular physical statement: the "energy" of any non-symmetric pattern is higher than that of any symmetrical pattern. Therefore, each

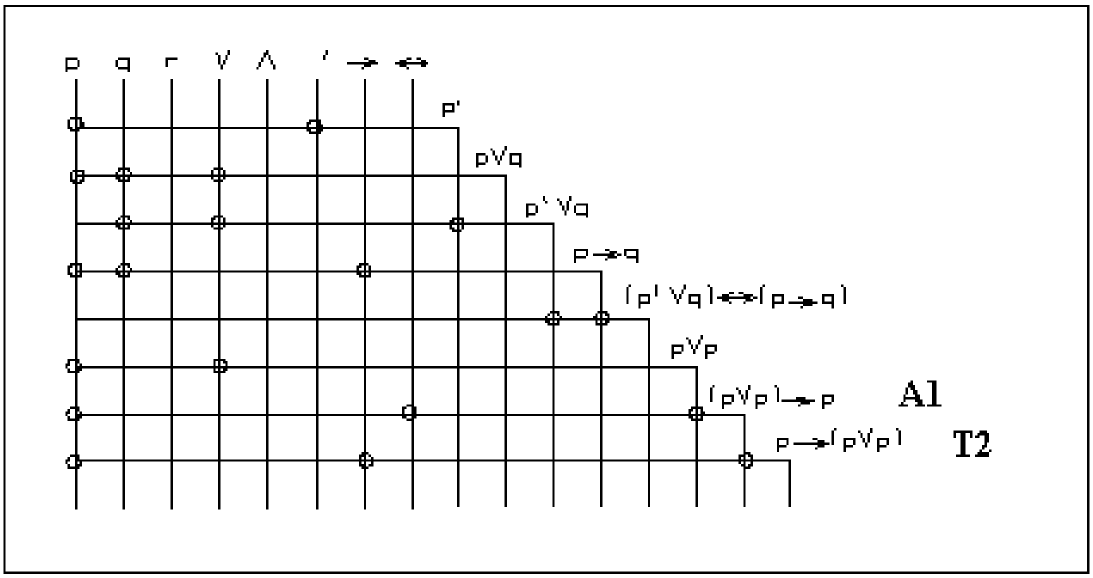

Figure 54.3. The mathematical mind

time we obtain a low energy identity, the system moves from a higher to a lower total energy.

The proof and listing of all theorems was the main subject of the work of Russell and Whitehead. A mind of a substantially lower intellectual power which could be capable of doing this kind of job on a smaller scale is shown in **Figure 54.3**. This time, unlike **Figure 53.1**, the mind operates with a set of terms and connectives of mathematical logic created by another mind.

This mind works as a chemical reactor where initial generators "react" with each other by the meta-chemical rules. Every new combination expands the configuration space and can be used for building other combinations.

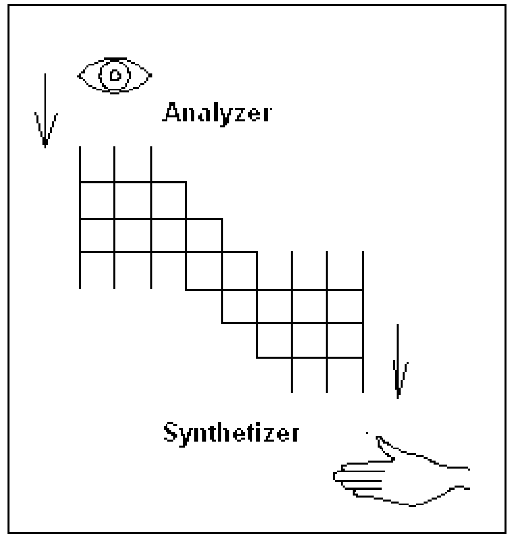

Figure 54.4. Analyzer and synthesizer

In fact, this is one of many possible pathways of evolution of the mind with just three initial terms, three connectives, and two implications. Suppose, the mind starts its creative work by inventing negation of p, p'. Next, it spontaneously composes $p \vee q$, etc. The rules of combination are in the properties of the generators. The horizontal wires are thrown on vertical ones, connected at some intersections and bent into new verticals. Two last verticals represent **Axiom 1** (**A1**) and **Theorem 2** (**T2**) in the system of Whitehead and Russell.

It is not enough to come to a discovery and keep it inside the mind: it should be communicated to another mind, which is the essence of understanding: NEW in terms of OLD.

There is something in the mind of a mathematician or a student of mathematics that enables his hand to write both **Axiom 1** and **Theorem 2** on a piece of paper. This can be done by using the reverse wiring coupled with the initial one, so that some outputs of an *analyzer* are inputs of a *synthesizer* of a movement, **Figure 54.4**.

For example, the wire corresponding to the generator "**Axiom 1**" in the analytical mind can continue into the reversed—synthetic—part of the mind and catalyze a sequence of movements of the hand that writes on paper.

The "eye" part of the wiring analyzes patterns, while the "hand" part synthesizes them, transforming generators into behavior.

NOTE (2006): I cannot accept $p \equiv p$ for evolving complex systems with novelty. This is the point of transition from traditional Aristotelian scientific theory to the Heraclitean pattern approach.

*

55. THE EXPANDING SPACE

The individual mind develops by unpacking all its stored boxes with telephones. It becomes a growing pattern of communication lines, creates abstract concepts such as CRETAN, LINE, ENERGY, PATTERN, etc., which name many things with one name exactly as the chemist gives the name *polymer* to any string of repeating molecular blocks, from polyethylene of the milk bottle to DNA of a cell.

In the language of physiology one neuron sends a signal to another. I have no intent to identify the neuron with the generator of the mind. The signal, however, has a pattern interpretation, too. What we call signal, or impulse, or excitation is a bond between two generators, the sender and the receiver, where the sender is a catalyst and the receiver is its substrate, and the catalyst works by changing a probability of a certain bond in the substrate (Chapter 46).

In Chapter 52 I already compared the mind with a flask to which a chemist adds and removes various chemicals, keeping it in a constant non-equilibrium while the intermolecular play and redistribution of bonds runs on its own. Now I am going to focus on the difference between both, see **Figure 55.1**.

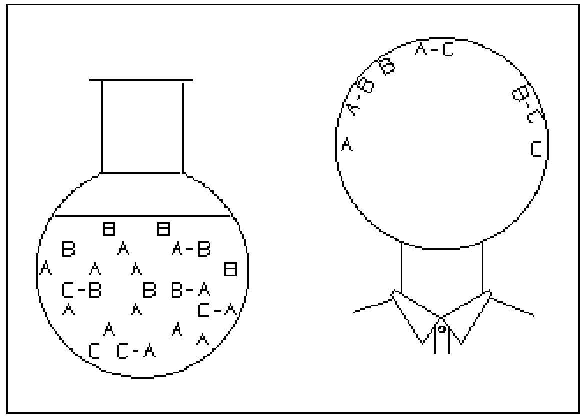

Figure 55.1. The mind as a flask.

The mind is a universe in a pattern flask, with "molecules" attached to the walls and presented in single copies. The pattern of the universe is in perpetual change. When the mind recognizes a new "molecule," it assigns a separate generator to it. It is like adding a new kind of an artificial atom, beyond the periodic table, each time any two atoms or molecular fragments form a bond. Nothing like that happens in the material world. Mind is radically different from matter, but note that we are able to express this difference in terms of matter because mind and matter are made of the same pattern stuff.

To the two flasks in **Figure 55.1** we could add a third one in the form of the globe, where all individual minds are presented in multiple approximate (**ALMOST**) copies, like real molecules.

The representative point of the phase space of mind constantly walks over the space. The space, however, is constantly expanded by the birth of new generators. **The strange chemistry of mind is based on an expanding Periodic Table.**

Since there is an enormous amount of generators in the collective mind—just look at an encyclopedia—any particular new pattern is as improbable as a win in a lottery. Nevertheless, most of the time somebody wins. Scientists play a life long lottery of discovery and this is how knowledge grows by big and small wins.

Expansion of configuration space is not an exclusive property of mind, rather, it is what any evolution is about: generators aggregate into clusters and form higher hierarchical layers of vertical complexity.

There is a curious mathematical image of this process. It is not accidentally that **Figures 51.2, 53.2, 53.3, 54.3, and 54.4** looks like steps: they are steps of an exotic mathematical object called **scale of sets** (Bourbaki, 1951).

The scale is built starting from an initial base set of elements, for example *A*, *B*, *C*.

First, we build the so called Cartesian product of the base set on itself, which means simply a set of all pairs chosen from it: *AA*, *BA*, *CA*, *BA*, *BB*... etc., and add the new set of pairs to the base sets. We have now something like *A*, *B, C, AA*, *BA* ...etc., and use it as the base for the next step of the scale:

Let us make a new set of all possible combinations of the base set and the second step set: *A*, *B* ... *AA*, *BA* ... *AAA*, *ABB*... etc.

Next, we add the new set to the previous ones and build the next step, etc.

Scale of sets, therefore, is an **open growing set** of all possible combinations of all possible sizes, made of the members of the base sets. The essence of the scale is that each new combination is added to the base set and used as an independent combinatorial element.

Any unlimited combinatorics leads to an enormous combinatorial explosion. How can the mind manage to avoid it? It might seem that the human mind would literally explode after a few days of absorbing information. In fact, the capacity of an individual mind is big but not unlimited, but the balance is maintained by a mature mind by forgetting most of the incoming information. The mind names many things with **ONE** name and discards the **MANY**, in other words, it approaches the word as a scientist, a mathematician in particular. We can use p instead of *ABC*, and q instead of *ABB,* etc.

Mind is a form of life, and death is as much part of life as birth. Most of the individual contributors to an abstract idea do not find place either in the mind or in encyclopedia: if we have the notion of a human, we do not need to know the names of all humans ever populated this planet. The ability of the mind to forget prevents the flooding of the mind and the exhaustion of its total capacity. The intimidating mass of daily newspapers going into garbage bin every day symbolizes the death of the content of the global mind, as well as its immortality: sample issues will be stored in the library, although most of them will never be retrieved.

This is where the power of selection interferes with unlimited growth, weeding unnecessary data. Our impressions, images, and ideas compete for the limited place in both individual and collective mind and for the limited life time of the avid readers of books, TV addicts, and moviegoers. We may be well versed in philosophy but helplessly impractical in personal life.

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56. COMPETITION AND CONSCIOUSNESS

This book is approaching its end. I decided in advance that the book should be too long. I took my vow not only to keep the reader awake: I wanted the book itself to be an illustration to the problem of competition in the mind. All my thoughts, ideas, examples, explanations, etc., could take at least two hundred more pages. By imposing the size restriction I simulated a tough competition for a limited resource of space.

Travelers of Everything, we are now in the kingdom of the mind. It is a dangerous zone: the black hole of the mind can generously absorb any speculation. There is a temptation to fantasize about the mind where anything goes—mysterious fields, quantum effects, whatever.

I have to be concise and stay away of technicalities not only because I really want to limit the size of this book, but because I do not want to lose the view of Everything in its integrity. Whether the pattern skeleton of the mind—pattern catalysis, expanding space, pattern interaction, pattern competition and selection—will be enveloped in physiological flesh, the future will show. I have no idea whether "wires" of Chapter 53 can be compared with neurons and synapses. My goal is not to explain how the human mind really works—because I do not know what “real” mind is—but to show how pattern vision can encompass the entire picture of Everything and switch from molecules to thoughts to anything and back, never leaving the same plane.

Here I am once again focusing on competition (compare to Chapter 9)

Before I formulate my belief, my thoughts have to undergo selection: only the most important will stay alive while others will be wiped out from the computer screen and the face of the paper. Some of them will remain in drafts, some will be forgotten, and some will be blended with other ideas.

The result of the competition will be a linear sequence of letters, words, phrases, paragraphs, and chapters. All my ideas are codes for strings of text. I see in ideas the strings of meta-DNA, which can be expressed in meta-proteins of text.

Biological DNA is linear, while proteins form three-dimensional structures. In the mind, however, it is the opposite. Strings of text are linear while the code—meaning—is a non-linear pattern. Language, spoken or written, is the linearization of the content of the mind, and this text is an example of how a swarm of whimsically connected ideas, very much like a molecular chaos, can be linearized in a sequence of words.

Another example of linearization is a description of a two-dimensional picture. My eyes are disorderly walking and jumping over the picture by Hokusai (**Figure 1.1**) My impressions can be expressed in a strictly linear order:

A big wave is collapsing onto the see. Other waves are in the motion. A snow-capped volcano is seen on the horizon. The skies are cloudy.

My impressions have undergone a competition for space in a short paragraph. Taking an impression a time, I can arrange them into a linear sequence. Different people can produce different sequences, and even I can do it in different ways.

A big wave with a fringed edge is about to collapse into the see. Other large waves are rising. A snow-capped faraway volcano looks small on the horizon. The skies are covered with clouds.

I can even do with simply "**This is a storm at sea**."

Like my eyes can clearly see only a small area around the focus of my vision, my mind can retain only about **ONE** image, **ONE** idea, **ONE** impression, **ONE** point of a discourse in the focus of consciousness, others simmering on a back burner. We can think **ONE** thing at a time, while there is more in the background.

Consciousness is like the light spot of a flashlight in darkness, scanning the three-dimensional surroundings, or like our eyes scanning the picture of the wave. The snapshots made at the stop points form a strictly linear time sequence.

In the language of patterns we can understand what **consciousness** is: it is a **device for the linearization of the mind**. We and animals need it to perceive the world as a time sequence and to select what is important for survival.

I believe that the essence of consciousness is selection. It is hard for us to judge whether animals have the same consciousness as we do, but they certainly have attention. We, humans, need consciousness in order to convey our knowledge to other members of our species through speech as a means of communication. Speech conveys the factual information like DNA conveys the genetic one.

A DNA sequence should be linear in order to replicate with minimum of obstacles—two flexible strings can always be aligned—and the replication needs to roll in only one direction, without long distance jumps necessary (see Chapter 34). While the scanning of a two-dimensional image can be done either with regular long range jumps, as in TV, or at random, the scanning of a linear sequence can be done strictly locally, in a mindless manner.

Similarly, speech and writing can be reproduced in the easiest way because they are linear patterns and there is only one way to scan them.

While the TV type of scanning is sheer order, the eye movements of a viewer of a two-dimensional picture are an example of ordered chaos. Can chaos be linearized?

The lottery machine is as much a model of chaos as it is a model of its linearization into a sequence of numbers: the balls pop up one at a time and form a linear sequence. In each section of the machine, they compete for an exit at a given moment of drawing. The winner, however, is drawn by pure chance.

We have come to understanding mind as a device that spins off a string of conscious patterns, each of them being a winner in a huge lottery. This idea is more compact but otherwise no better than any other, and it would be good to reinforce it by finding some visible signs of **competition in the mind**.

In his famous essays on mathematical creativity, Henri Poincaré (1946) noted that a sudden illumination of a mathematical discovery comes as a lucky combination of "mathematical entities" only after a period of subconscious work on generating such combinations. The total number of combinations can be immense, but due to some mechanism mind selects only those relevant to the solution of the problem.

"What is the cause, Poincaré wrote, that among the thousand products of our unconscious activity some are called to pass the threshold, while others remain below? Is it a simple chance that confers this privilege?" Poincaré suggested that the useful combinations were selected by some subconscious aesthetic criteria.

The eloquent description by Poincaré invokes the picture of various combinations struggling in the darkness of the subconscious mind for a small spot of light that continuously scans the mind in time. Consciousness is the top of a pyramid above the surface, gradually widening in the ever darker depths of the subconscious. I would say that it is the representative point of a system walking through its phase space.

Unlike the honest competition of the identical lottery balls with equal opportunities, the competition of organisms is not so equal: some of them may die because of a specific interaction with the environment, and some of them may flourish for the same reason. In terms of the lottery machine, it is like making the balls of different mass. The lighter ones will have a better chance to be carried to the exit by the flow of air.

Using the analogies with the lottery machine, spotlight, and focus of vision, we can understand why the flask of mind produces a linear sequence of ideas: only in this form complex ideas can be reliably communicated. Next, we have to understand why some ideas have better chances to pop up into the focus of consciousness than others.

To throw in another one-liner, **life and mind are rigged lottery machines**.

As I mentioned in Chapter 17, competition in the world starts at least at the level of molecules: a chemical reaction runs in all possible directions, but the exhaustion of the starting components results in only a few fastest products.

The mathematical theory of competition over a limited resource in the case of molecular evolution was developed by Manfred Eigen (1971, 1977, 1978, 1979).

The imaginary system under consideration comprises n species with $x_1, x_2 \dots x_n$ individuals in each. Each individual is a combination (configuration) from a set of building blocks (generators), for example, arranged in a line, but not necessarily. The number of blocks in the system is constant. This combinatorial aspect is exactly the unique contribution of Manfred Eigen to the widely studied problem of evolution, as if Eigen anticipated Pattern Theory.

In Eigen's model, the simplest system is described by the following kinetic equation, which I framed as just a picture to look at:

$$\mathbf{dx}_i\mathbf{/dt= A}_i\,\mathbf{Q}_i\,\mathbf{x - D}_i\,\mathbf{x}_i\mathbf{+ S}_{(k'i)}\,\mathbf{w}_{ik}\,\mathbf{x}_k \ ,$$

where:

$\mathbf{A}_i\,\mathbf{x > 0}$ is the component of self-reproduction (birth), diminished by
$\mathbf{Q_i}$ as the measure of incorrect reproduction,
$\mathbf{D}_i\,\mathbf{x}_i$ is spontaneous decomposition (death),
$\mathbf{S}_{(k'i)}\,\mathbf{w}_{ik}\,\mathbf{x}_k$ is the production of species x_i through mutations from all the other species $\mathbf{x_k}$.

The only thing the reader disliking mathematics needs to understand is that it is an equation of the type **A = B – C + D**, where A is a change of a certain quantity over a short time.

As I mentioned before, kinetics is neither physics nor chemistry, but just common sense. There is something very simple and familiar behind the above piece of mathematics—something like what many of us write on monthly basis in everyday life: the family budget. The left part of the equation corresponds to its monthly balance.

Suppose, we live only on interest income from several interest accounts. For each account we can add up three terms:

1. Growth of each account due to the accruing interest.
2. Withdrawal from each account for spending.
3. Transfers from and to this account from all other accounts.

Growth: The more money we have, the more we will have next month because money multiplies. If the annual interest is 5%, then $X will turn into $(1.05)X next year. Note, that this budget item is always positive.

Withdrawal: Whatever we have today, tomorrow we will have less if we only spend and not earn. The spending item is negative: it should be subtracted from the total.

Transfer of money between accounts: If we monitor a certain account, it may grow or decrease due to transfers between the accounts, which does not change the total.

Therefore, if we have three accounts, the complete financial dynamics is reflected by three similarly built equations:

Balance (1) = interest(1) - spending (1) + transfers (1)

Balance (2) = interest(2) - spending (2) + transfers (2)

Balance (3) = interest(3) - spending (3) + transfers (3)

Species can be approximately interpreted as different accounts where nature keeps its “money” of the invested solar energy.

The first part in Eigen's equation for each account means interest: growth of a species.

The second part (negative) means spending: decline of a species due to death .

The third part summarizes transfers of money between this account and others: conversion of one species into another. This is hard to imagine with organisms but very natural among molecules.

We presume that the total amount of "money" in the system is constant, so that some of it is not accounted for and is just scattered around in the cash form of nutrients.

In chemical terms, the first term is the growth through replication (birth). If the population of a certain species of molecules is today **N**, we will have $\mathbf{A} \times \mathbf{N}$ tomorrow ($\mathbf{N}$>1). The coefficient $\mathbf{Q} < 1$ represents the loss of the population due to mistakes in replication, so that other species are produced. In the fiscal analogy those losses are transfers from the account.

Second term is the loss due to death (break-up) of some species into fragments that can be used for building other species molecules.

Third term is the gain from mistakes in the replication of other species (transfers to the account).

This mathematical picture of competition, at least two first terms, is extremely general. If molecules, species, things, and humans compete, patterns can too. I will try to apply this approach to the competition of mental patterns for the spotlight of consciousness.

Suppose, we have the following properties of patterns in the individual (or collective) mind:

1. The longer the pattern is in the spotlight of consciousness the longer it will stay there (making copies in time).
2. The longer the pattern stays in the spotlight the shorter time it will stay there (fatigue, forgetting, death).
3. Some patterns catalyze (or inhibit) other patterns, giving them and advantage in the competition.
4. Only one pattern can stay in the spotlight, as only one ball pops up in the lottery machine.
5. Configuration space expands due to the formation of new generators.

The result is the evolution of mind. Its only principal difference from Eigen's system is that the configuration space is not constant and the mind expands, i.e. evolves toward growing complexity.

The third property may seem the most confusing one.

In the following example, catalysis will be both the illustration for a concept and the concept illustrated by it. The example was reported by Russian physiologist Ugolev, author of a theory of food digestion (Ugolev, 1989), in a Russian popular science journal *Science and Life* in 1983-1984. The source is not available to me, but the story is so unique and typical at the same time that I will tell it from memory.

The subject was a hypothesis about mechanism of food digestion in the stomach. It states that the digestion of food in the intestine occurs not in the volume but strictly on the surface of the intestine.

The author of the hypothesis accidentally saw a photograph of a solid clay-like **catalyst** with a developed surface. The photograph was visually similar to the photograph of the intestine, although nothing could be more different than a mineral substance and the live intestine. It flashed through his mind that digestion, like many forms of "cold" catalysis, is a surface phenomenon. The hypothesis turned into a theory when it explained the observed kinetics of digestion.

The meta-chemical reaction of thinking is shown in **Figure 56.1**.

The first step (**56A**) is presented as a meta-chemical transformation. In two separate acts of catalysis (**56B and C**) two new bonds are formed. What is remarkable, the concept of catalysis denoted by the word "catalysis" is the pattern catalyst for producing a new idea.

If there is too much knowledge of a subject, a random contact of disconnected ideas is rare. If there is too little knowledge, the new knowledge cannot be produced. Catalysis known as **thinking by analogy** is stimulated by the presence of a lot of diverse information. Too much specialized information in the field can depress creative thinking. Too little encourages fantasies.

This is how some ideas take advantage of others and how we can follow competition as a general phenomenon among all patterns, starting from molecules and ending cultures, economies, and revolutions. Only some rare periods in human history and, probably, in evolution of life make an unlimited growth possible, as it was in America during the time of frontier. Tough competition is the global long term future.

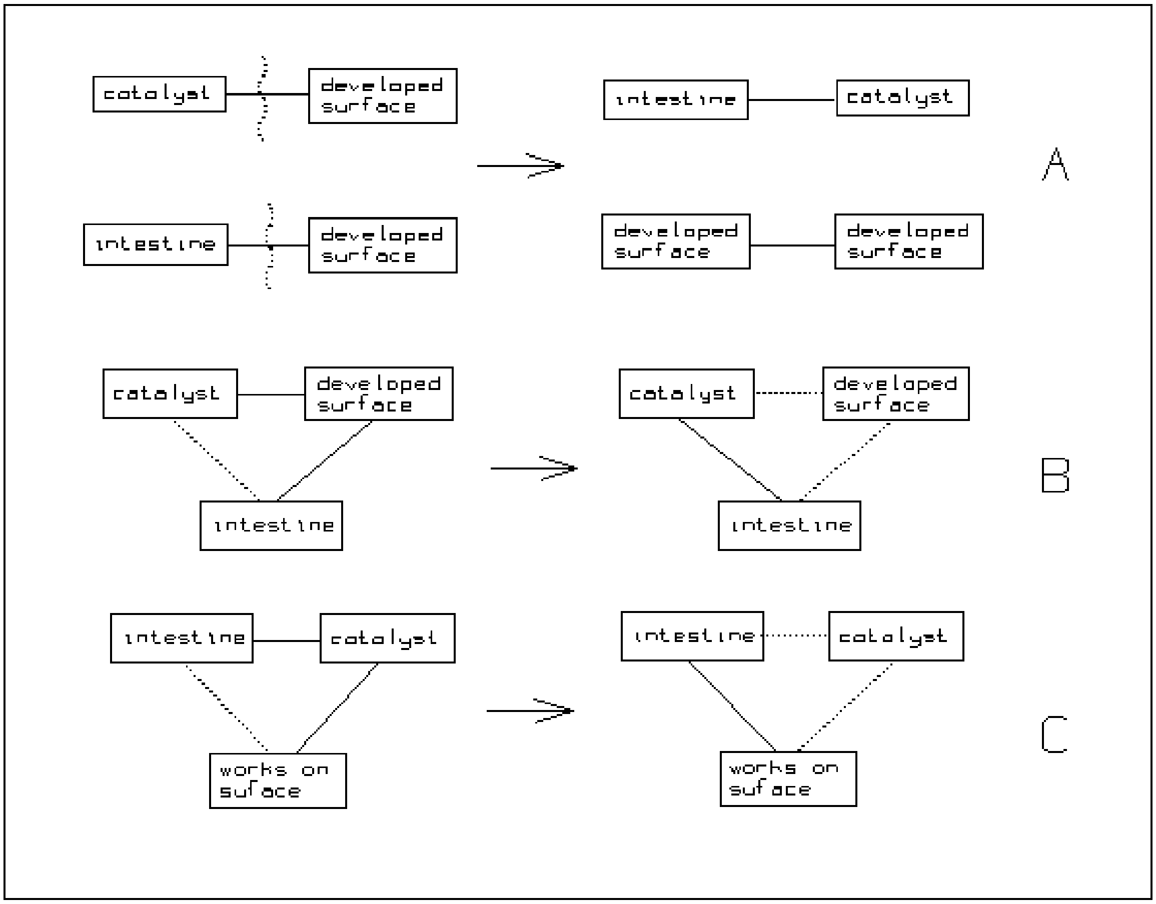

Figure 56.1. Chemistry of a scientific discovery

To conclude about catalysis, I consider Grenander's pattern theory a powerful catalyst for understanding the world. The substrate is Everything. I will leave to the reader further applications of the pattern ideas.

I am most of all interested in useless things, like what is going to happen with the world after my molecules will spread all over it in the turnover of matter. The useless things are most precious: by definition, they have no money value at all.

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57. TEMPERATURE AND COMPLEXITY

Let us think what happens when the temperature of universe **U-5** changes.

Figure 57.1 presents the inhabitants of **U-5** arranged in the order of increasing number of bonds. Each column comprises all patterns with the same number of bonds. The numbers at the patterns are the values of their complexity. The average complexity of all patterns in a column is calculated and displayed in the upper row.

Assuming the bonds are positive, they will get weaker (less stable) with rising temperature. Accordingly, the probability that the pattern has several bonds will decrease, too. If we start heating the fully saturated "solid" pattern at the extreme right, we can turn it into the "gas" on the left.

We can clearly see that complexity changes with temperature reaching a maximum within a certain medium range. Both too much order and too much chaos kill complexity.

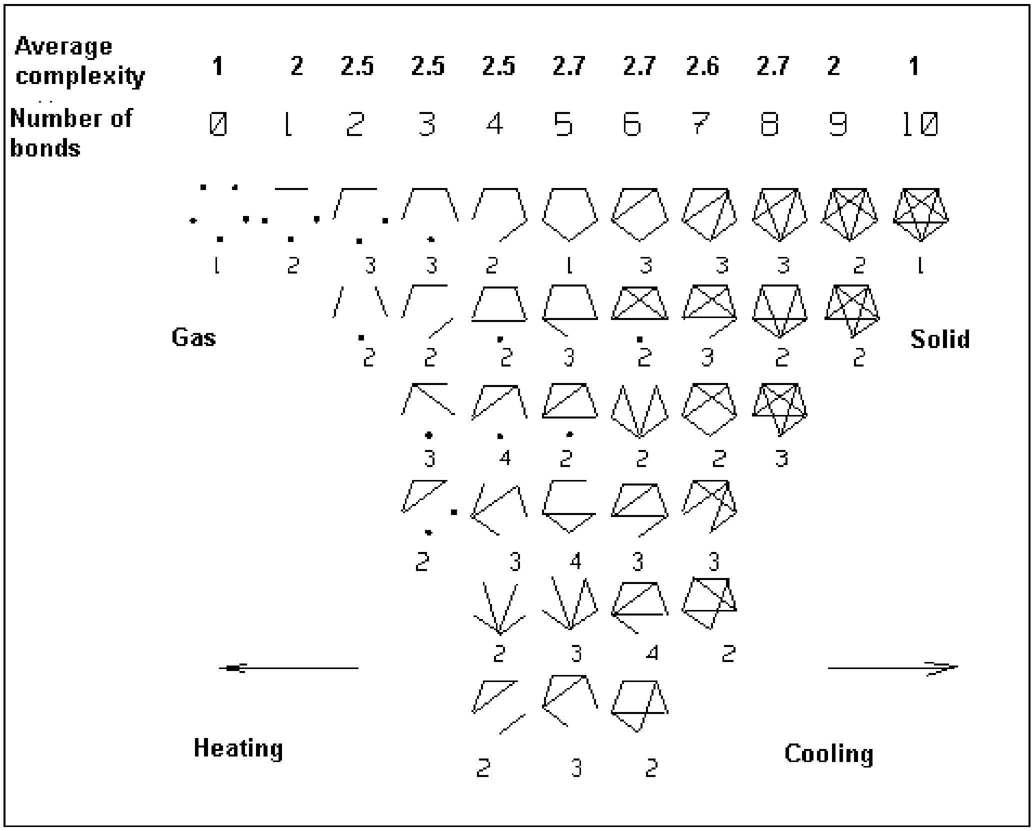

Figure 57.1. Weather in universe U-5

This diagram tells us something important about evolution. It was the cooling of the universe that made first strong chemical bonds and then weak bonds possible. The further cooling developed the gorgeous complexity of life and mind. Further trend toward cooling, however, can decrease complexity, the common term for which is diversity. The global system can even finally freeze, although not because of the exhaustion of energy resources. .

Energy can be used for producing both heat and cold, chaos and order. We can plug both oven and fridge in the same outlet. Society can use energy for both cooling and warming in the political and economic life.

Civilization works as a gigantic oven: extracting free energy from coal, oil, and gas, it breaks down empires and paradigms, spreads knowledge, technology, mobility, individual freedom, human rights, dismantles caste barriers, loosens rigid ideologies, invents, creates diversity, increases opportunities, homogenizes society, maintains overall inequality of achievements, but also provokes crime, terrorism, revolt, and war.

Civilization also works as a gigantic refrigerator: using the same energy, it decreases the temperature and with it the diversity, freedom, mobility, independence, dynamism, and other ingredients of modern capitalist civilization. Technology and information decrease chance, accident, opportunity, and movement. Bureaucracy, regulations, political correctness, "new world order," caste system, oppression, fundamentalism, rigidity, abuse of political power, monopolization, equality within large layers of society, accompanied by a sharp inequality between the layers (stratification), creativity directed toward packaging instead of manufacturing new products, standardization of spirit, unification of ideology—those are signs of the order of the cold.

Things are a new form of life and humans are turning into enzymes assembling them according to blueprints.

We talk about limited natural resources, but there is an equally limited resource of personal time for both invention and consumption. Free time can be totally absorbed by watching computer-made movies and making them, playing hypnotizing games, chatting over the phone, bathing in computer-generated waves, **Figure 57.2**, surfing the Web—as big and irrelevant as the Universe—and feeling a complete and satisfying loneliness.

While there is enough free energy on earth, free humans and computers may co-exist as apes and humans do, with the apes mostly detained in the zoos. When the sources of free energy are depleted, whether absolutely or per capita, computers may allocate as much energy to humans as it is necessary for the survival of computers and not human culture. Accordingly, human life might enter the descending branch of evolution:

simplification. The apparently contradictory doctrines of equality and slavery might both be resurrected: they did not contradict each other in ancient Greece.

NOTE (2006): With the exhaustion of energy, water, and soil resources, global society could be expected to scale down its freedom and complexity and enter the stage of "involution." The recent slowdown trend in population growth and the prospect of depopulation reveals a counteracting factor. This rises the question of future global and local social patterns in the world where human creations compete with humans for resources in the increasingly dehumanized world.

With these final observations, I will stop short of moralizing and prescribing recipes for common progress. **GOOD** and **BAD** are not yet full members of the Pantheon of Everything. As I hope, until we have the inherent molecular chaos in the gray cells of our brains, we can survive.

Hopefully, even if we trust our future to the *calculated* chaos of creative computers, they will keep us in the Red Book, as we keep the apes.

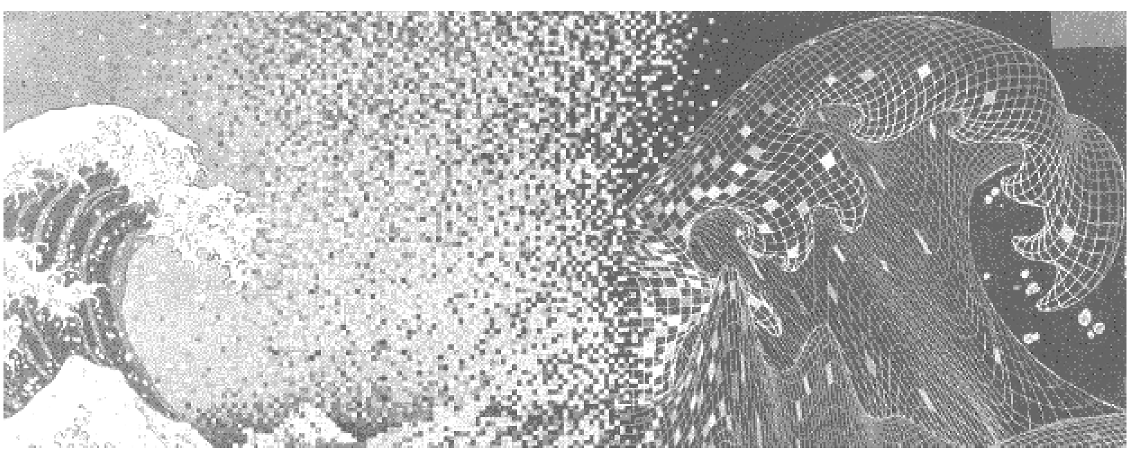

Figure 57.2. Computer generates an extension of *The Wave* by Hokusai. (From an advertisement)

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58. EVERYTHING: THE LAST LOOK

We have completed our flight and it is time to land, but where? Our orbit runs below the infinite skies of pure mathematics but high above the landscape of nature, science, and technology with the rivers and creeks of fluid life running between the solid banks of minerals, metals, and plastics toward the invisible and immaterial ocean of thought reflecting the stars in the mental skies.

The solid, substantiated, and testable knowledge in the form of facts, hypotheses and theories was not the terrain of this journey, and neither were close-range mathematical concepts and their particular applications. We can look at a particular continent of human thought only from such a long distance that no scientist working in a particular area would accept it. The pattern vision may be too far-sighted and blurred at close distance but it grants us the wings to fly.

We have come to the end of our cursory pattern digest of an enormous record of human creativity in science, arts, philosophy, and religion, as well as personal destiny which everybody builds through a series of choices. As with the picture of the wave, we did not even touched upon some vast areas, but lingered for quite a while on some narrow lots.

Our travel diary it is not a miniature copy of Everything, but a result of a severe **selection** in author's head—selection by no means random but driven by author's preferences and obsessions. It was just heartbreaking to leave out so many exciting subjects and brilliant names, but the volume of the book was curtailed by the author with a deliberate cruelty (meant also as mercy to the reader).

Now I am giving myself only a few pages to compress everything about Everything, presuming that the reader has already made his way through the previous pages.

Pattern theory is a way to describe Everything in terms of generators—atoms of Everything, capable of forming bonds, whether due to attraction, force, or indifference.

We believe that both Everything and our description of it are configurations of generators. What is the difference between the object and its description, then? We cannot answer this philosophical question. Instead, we believe that patterns of the world interact with each other and with patterns in our mind, while the latter interact between themselves on their own. Matter, mind, and understanding are all patterns, and their transformations are also patterns.

A movie is a sequence of frames. We can clearly see that the happenings in the studio settings interact with the film during the shooting, and we can trace the image back to the actor, but do the frames interact? Of course, not. The states of mind, however, interact with each other, and our thoughts this moment are influenced by our thoughts and observations a minute or a month ago.

The current position of the clock arms is influenced by their position a minute ago. What is the difference between the mind and the clock, then? The state of the good clock is completely defined by its previous state, as well as the state a month ago, while the state of mind has a random component in this influence. Isn't it the same as to say that the multiplication table has a random component and $2 \times 2 = 4 \pm r$, where r is a random number? How could we rely on such chaotic minds?

Actually, we live in such a world, as the weather forecasts and stock market reports show. What makes our world livable is that by spending energy we can keep the random component pretty low, and besides, if we live long enough, then $2 \times 2 = 4$ will be a good approximation.

A human civilization is an anti-chaos machine, but if it works too well, however, it becomes as vulnerable to heat and blow as an icicle, especially in a contact with another, hot and wild one. For about thirty years the price of a loaf of bread in Russia was twenty cents, but the Russian icicle broke down as soon as the insulation against Western winds was dismantled. If the cooling system of the civilization is inadequate, however, the internal ever-present heat of the society may melt it down: the modern civilization, with its enormous stockpile of energy, may experience a meltdown.

Pattern theory cannot answer questions like why the stone falls to the ground and why the heated steel rod expands—they are answered by particular sciences. What we can do from the pattern orbit is to draw a picture of Everything with a palette of pattern colors.

As soon as we have the picture, we can attempt to answer some questions which no other science can answer because no science approaches Everything.

The major question about Everything is what can happen to it. The negative answer is: not everything we can imagine.

The elusive answer is: whatever happens, it happens in space in time.

The positive answer is: it can grow and evolve.

A list of generators described in terms of their identities and their bonds defines a space where a pattern is a point. Space is what I call the magic box of Everything: patterns are stored there in an invisible, potential form, like all drawings are stored on a blank sheet of paper with a pencil casually dropped on it, or like a sculpture by Michelangelo was stored in a marble slab.

How could it happen that only David's figure had been retrieved from the slab? How a potential pattern becomes actual?

We seem to be totally free in our imagination and yet we can imagine only a combination of known elements, like medieval chimeras are combinations of features belonging to humans, animals, and insects, and like novels and stories of Franz Kafka are sequences of very common elements arranged in an uncommon order.

What limits our imagination limits nature. This limiting power belongs to the quality called order. Without order the world would be for us a kaleidoscopic change of disconnected images, and our mind would be just a bustle of disconnected thoughts.

Without chaos, however, the world would be a frozen forever carving on a marble Roman sarcophagus or a never changing collection of the Notre Dame chimeras. Not accidentally, it was the great medieval architecture which embodied stability and order in the world where human life was at stake every minute, and so were the great religions based not on chance but on justice.

Change is the property of bonds: they break and close all the time: the bonds between oxygen and hydrogen, enzyme and substrate, master and slave, sovereign and vassal, mother country and its colony, a lender and a borrower. If an object is as firm as car engine, where the bonds are not supposed to break, all parts are circling through the same routine of movements never skipping a position and never producing a new and unforeseen situation.

A single weak bond cannot provide order—it is always a reed in the wind—but a multitude of weak bonds are as strong as the army of Lilliputians tying Gulliver down so that he cannot move, and as strong as a bundle of reeds: strong enough to build a ship.

The breathtaking drama of Everything displays between strength and weakness, like the drama of Othello displays between trust and perfidy. The strong bonds provide the continuity of the world. They secure its stability and keep chaos at bay while the weak bonds transform it by virtue of their very weakness.

Since matter is not mind and mind is not matter, no science keeps them both in the same basket. Pattern theory, however, embracing both, easily distinguishes between them. Matter is the world where objects form populations: crowds of identical or similar things, such as stars, molecules, midges, can openers, and shoppers. In other words, matter is the world of numbers. The mind, however, does not know numbers: each pattern of the mind exists in one copy because, by its very design and purpose, the mind names many things with one name.

All this is very general, one can say, but what does the pattern vision reveal that we could not see without it?

With the pattern vision, the world is a network of bonds, negative, positive, and neutral. The destructive wind of thermal chaos, which rises when temperature goes up, breaks the bonds, loosens connections, and warps the multiplication table for the mind. Under the wind, the restless branches of the pattern bushes tear up the cobweb woven by the spiders and suddenly a restless mind suggests that 2 x 2 = 3 or 5.

Energy, if applied to negative bonds, is as constructive as it is destructive for positive bonds. The solar radiation brings the creative free energy which allows the spiders to patch up the crumpled cobweb, and pushes the mind toward inventing the computer that knows precisely how much is 2 x 2 today. For billions of years, due to the heat absorbing environment of the ultimately cold outer space, the order has been accumulating on earth, and the balance of chaos and order has created first life, then our global civilization.

Life sprung up through the window of opportunity and became a machine for converting the free energy into the order of negative bonds. Catalysis, an inherent pattern phenomenon, gave birth to life and sustained it in the form of coding. Molecular bio-life is a hard work: a animal organism is doomed to incessant search for food, but the variety of situations, the swing of luck and failure, and the close interaction with the environment enrich the pattern of its nervous system until it turns into brain: the substrate of mind. Nature catalyzes mind, and mind, through the body, catalyzes nature, so that the lottery machine casting random numbers for the chaotic component in the multiplication table becomes more and more rigged by connections, memories, preferences, and fears.

The lottery machine of nature works in the old fashioned way by dropping into a hat the rolled pieces of paper with the names of generators to be either married or separated at such a distance that they would never unite again. But as soon as a cluster of generators is bonded with strong enough bonds to survive the impact of chance, a new piece of paper with the name of this new generator is placed into the hat: a new dimension of a configuration space has been born, and a new pattern enters the world. This is how the hat of Mother Nature has been filled with molecules, polymers, cells, rabbits, and educated citizens. The mind, however, does not know what distance is, and this is how its explosive creativity, not limited by the tribulations of traveling through space, has filled up this world with mind-made and hand-made creations, with the complexity of the human environment still growing, both blessed and cursed.

To express simple mechanisms of Everything in simple symbols, show the rise of complexity due to simple linking of simple steps, portray the epic of Everything in primitive dot-and-line pictures, fill up the borders with the colors of entropy, energy, temperature, catalysis, and selection, and bring it all into motion—the reader is invited to play that game on his or her own. How we adapt to the growth of complexity, what we lose and what we gain, what is our place in the patterns of the future, and what are the patterns of our personal lives—the reader can try answering those questions with the pattern vision and language.

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EPILOGUE

It is easy to prophesy a coming global disaster due to the enslavement of humans by computers, things, and money. It may be easy to admonish that all historical attempts to create a lasting *e pluribus unum* have failed. It is not so hard to be optimistic either.

As history shows, the future comes as a wave of a transformed past.

The realistic cave art turned into abstraction, but not forever: the Renaissance came with not only realistic but also humanistic art, gradually turning into abstraction, but not forever: computer art rivals the human art, and realism comes back with a new computer flavor which, probably, will turn into an alphabet for advertising things, but not forever, either.

The Athenian democracy died after Pericles but not forever: it sprang up in Europe and America many centuries later. Eternal life is not guaranteed to the American democracy, but democracy as an idea is immortal: ideas do not die. All empires have fallen, from Roman to Russian, but Europe is starting yet another experiment with *unum,* on different foundations. New experiments with both democracy, balkanization, unification, and brutal force may follow. History may bring tragedy for one generation and bliss for another.

Computers may bring a chilling cold to a human who could be reduced to the status of a rat going through a maze of e-shop menus in order to hit a button and get an electric stimulus into the pleasure center of the brain. But it will not be forever: as soon as the computers develop internal chaos, they may get humanized and in this way downgraded enough for the humans to get equal with them.

What we all need to face the future as humans and not rats is to understand Everything as a whole.

It is a great but encouraging paradox that we can see the whole Everything through the generator, the atom of Everything, a tiny pinhole in the opaque surface of things.

I would like to give the last word to Ulf Grenander by quoting the opening words of his *Pattern Theory*: "*Wir müssen wissen, wir werden wissen*:" we must know, we will know—a quotation from David Hilbert coming as a wave of transformed past, changing languages on its way, from the pebbles thrown by Democritus, Aristotle, and Lucretius into the ocean of Everything.

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REFERENCES

See also http://spirospero.net/complexity.htm

Barr, A. and Feigenbaum, E.A. (1986). *The Handbook of Artificial Intelligence,* Volume I, Reading, Mass.: Addison-Wesley.

Barrow, J.D. (1991). *Theories of Everything*. New York: Fawcett Columbine.

Bourbaki, N. (1968). *Elements of Mathematics: Theory of Sets.* Reading, Mass.: Addison-Wesley.

Calvin, W.H. (1989) *The Cerebral Symphony*. New York: Bantam.

Calvin, W.H. (1986). *The River That Flows Uphill. A Journey from the Big Bang to the Big Brain*. New York: Macmillan.

Casti, J.L. (1994) *Complexification. Explaining a Paradoxical World Through the Science of Surprise.* New York: HarperCollins.

Chaitin, G.I. (1975). Randomness and mathematical proof. *Sci. Am*, May 1975.

Chomsky, N. (1971). *Chomsky: Selected Readings*. Edited by J.P.B. Allen and Paul van Buren. London: Oxford University Press.

Clough, A.H. (1951). *The Poems of Arthur Hugh Clough*. Oxford: Oxford at Clarendon Press.

Complexity (1985). *The Science and Praxis of Complexity. Contributions to the Symposium Held at Montpellier, France, 9-11 May, 1984*, The United Nations University.

Davies, P.J. and Hersh R. (1982). *The Mathematical Experience*. Boston: Houghton Mifflin.

Dawkins, R. (1989). *The Selfish Gene.* New York: Oxford University Press.

Delbrück, M. (1986). *Mind from Matter.* Palo Alto, Calif.: Blackwell Scientific Publications.

Dhammapada (1967). *The Dhammapada*. New York: Farrar, Strauss & Giroux.

Dickinson, E. (1959). *Selected Poems and Letters.* New York: Doubleday Anchor Books.

Eigen, M. (1971). Self-organization of matter and the evolution of biological macromolecules, *Naturwissenschaften*, **58**: 465-523.

Eigen, M. (1977). *Ibid.*, 64: 541-565.

Eigen, M (1978). *Ibid.*, 65: 341-369.

Eigen, M. (1979). *The Hypercycle. A Principle of Natural Self-Organization.* New York: Springer.

Eigen, M. and Winkler.R. (1993) *Laws of the Game*. Prinston: Prinston University Press.

Gleick, J. (1987). *Chaos: Making a New Science*. New York: Viking.

Goethe (1988) J. W. v. *The Sorrows of Young Werther. Elective Affinities . Novella. Goethe's Collected Works, Volume 11*. New York: Suhrkampf Publishers New York, Inc.

Goldstein, E. B. (1984) *Sensation and Perception*. Belmont, Calif.: Wadsworth Publishing Company. The photo is from: Buswell, G.T. (1935). *How People Look at Pictures*. Chicago: Chicago University Press.

Grenander, U. (1993). *General Pattern Theory. A Mathematical Study of Regular Structures*, Oxford, New York: Oxford University Press.

Grenander, U. (1976). *Pattern Synthesis. Lectures in Pattern theory*, Volume 1. New York: Springer-Verlag.

Grenander, U. (1978). *Pattern Analysis. Lectures in Pattern theory*, Volume II. New York: Springer-Verlag. Berlin.

Grenander, U. (1981). *Regular Structures. Lectures in Pattern theory*, Volume III. New York: Springer-Verlag.

Grenander, U. (1996). *Elements of Pattern Theory.* Baltimore: Johns Hopkins University Press.

Hadamard, J. (1945). *The Psychology of Invention in the Mathematical Field*, New York: Dover Publications, 1945

Hawking, S.W. (1988). *A Brief History of Time*. London: Bantam.

Hofstadter (1989). *Gödel, Escher, Bach: An Eternal Golden Braid*. New York: Vintage Books.

Holland, J.H. (1995). *Hidden Order. How Adaptation Builds Complexity.* Reading, Mass.: Addison-Wesley.

Hucker, C.O. (1975). *China's Imperial Past*. Stanford, CA: Stanford University Press.

Kauffman, S.A. (1993). *The Origins of Order*. New York: Oxford University Press.

Kauffman, S.A. (1995). *At Home in the Universe: The Search for Laws of Complexity*, New York: Oxford University Press.

Leibniz. (1951). *Selections*. Edited by Philip P. Wiener. New York: Charles Scribner's & Sons.

Lewin, R. (1992). *Complexity: Life at the Edge of Chaos.* New York: Macmillan Publishing Company.

Lorenz, K. (1977) *On Aggression.* New York: Bantam Books., 1977)

Lotka, A.J. (1956). *Elements of Mathematical Biology*. New York: Dover.

Lucretius. (1947) *Titi Lucreti Cari De Rerum Natura*. Edited by Cyril Bailey, Vol.1, Oxford: Oxford at the Clarendon Press.

Mazonowicz, D. (1974). *Voices from the Stone Age.* New York: Thomas Y. Crowell Company.

Monod (1971) , Jaques Monod, *Chance and Necessity*. New York: Knopf.

Moore, W.J. (1972). *Physical Chemistry*, Englewood Cliffs, NJ: Prentice Hall.

Pagels, H.R. (1982). *The Cosmic Code*. New York: Simon and Schuster.

Pagels, H.R. (1988). *The Dreams of Reason*. New York: Bantam Books.

Pareto, V. (1980). *Compendium of General Sociology*. Minneapolis, Minnes.: University of Minnesota Press.

Penrose, R. (1989). *The Emperor's New Mind*. New York: Oxford University Press.

Penrose, R. (1994) *Shadows of the Mind: A Search for Missing Science of Consciousness*. New York: Oxford University Press.

Petroski, H. (1994). *The Evolution of Useful Things.* New York: Vintage Books.

Poincare, H. (1946). *The Foundations of Science*. The Science Press.

Prigogine, I. and Stengers, I. (1984) *Order out of Chaos* . New York: Bantam.

Nicolis, G. and Prigogine, I. (1989). *Exploring Complexity.* New York: W.H.Freeman.

Propp, V.I. (1971). *Morphology of the Folktale*. Austin, Tex.: Univ. of Texas Press.

Rich, A. (1983). *Adrienne Rich's Poetry And Prose*. New York: W.W. Norton.

Schrödinger, E. (1992). *What is Life from the Point of View of a Physicist*. New York: Cambridge University Press.

Slobodkin, L.B. (1992). *Simplicity and Complexity in Games of Intellect*. Cambridge, Mass.: Harvard University Press.

Tainter, J.A. (1988). *The Collapse of Societies.* Cambridge: Cambridge University Press.

Ugolev, A.M. (1989). *Membrane Digestion: New Facts and Concepts*, Edited by A.M. Ugolev. Moscow: Mir. In English.

Waldrop, M.M. (1992). *Complexity*. New York: Simon and Schuster.

Wallace, L.H. (1946). *The Lilly Wallace New American Cook Book*. Edited by L.H. Wallace. New York: Books, Inc. N.Y.

Whitehead, A.N. and Russell, B. (1925). *Principia Mathematica*, Cambridge: Cambridge University Press.

Wiener, N. (1961). *Cybernetics or Control and Communication in the Animal and Machine*. New York: M.I.T. Press.

Wilson, E.O. (1998). *Consilience: The Unity of Knowledge.* New York: Alfred A. Knopf.

Yeats, W.B. (1956). *Collected Poems*, New York: Macmillan.