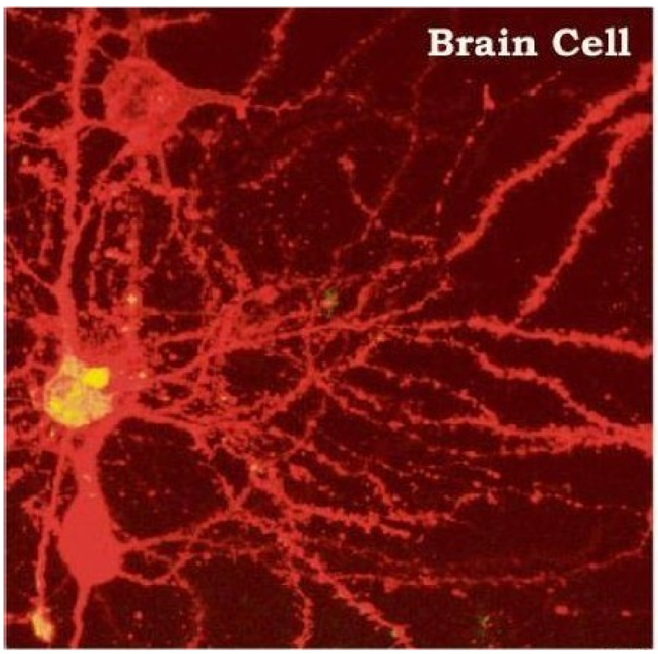
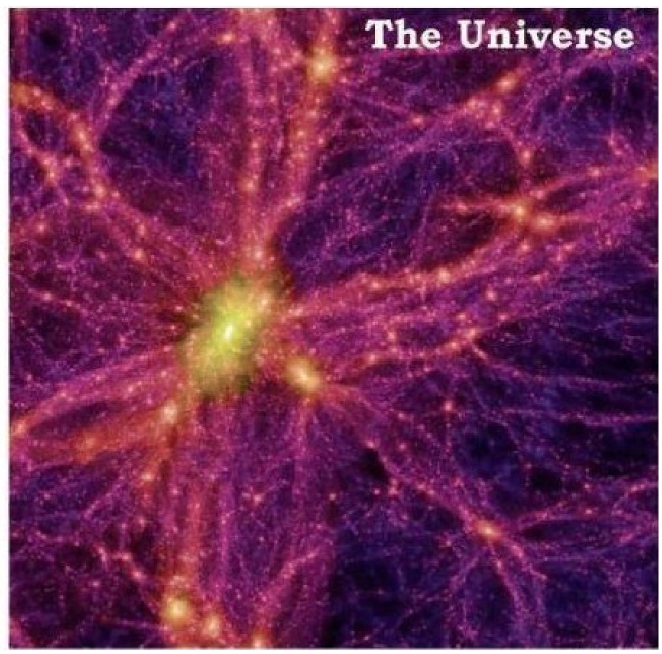
NEURAL NETWORK NATURE

Fractal Hierarchies of 'Perceptrons' from Clusters of galaxies to the World Wide Web

a small handbook

Peter Winiwarter





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"*Things arise in Space as Thoughts arise in Mind"*

Parmenides

"The Universe is a vast system of systems which strikingly resemble one another in the details of their structures and processes. Among theses systems, or realms, are matter, life and mind"

George Perrigo Conger in *A World of Epitomizations*

"Life and mind have a common abstract pattern or set of basic organizational properties. The functional properties characteristic of mind are an enriched version of the functional properties that are fundamental to life in general. Mind is literally life-like. "

Godfrey-Smith, P. (1996). Complexity and the Function of Mind in Nature. Cambridge: Cambridge University Press.

Introduction

Every creation in the field of science or art is the realization of a child's or juvenile's dream.

I received my high school education at the "humanistic gymnasium" at Linz, Austria. Since the age of nine our mind was formed with Latin lessons six days a week during every school year. Daily lessons in ancient Greek were added at the age of eleven. The major goal of this education was to form our minds in the old tradition of Greek-roman culture without neglecting mathematics and philosophy.

At the age of fourteen we had to choose between two additional subjects: music or art. I played the violin and should have been attracted by music, but I had not the least ear – tuning my instrument was a daily nightmare. I liked to draw and to paint so I chose Art as my additional subject for the remaining years of my education.

At the final exam of graduation, which in German speaking countries is called Matura or Abitur, we had three compulsory subjects: Latin, Greek and Mathematics and one subject of our choice. I was always a fan of the "principle of least effort" so I choose Art as fourth subject. For the exam we were questioned on the history of Art but we also had to produce one work of art corresponding to a given topic.

The topic of the exam was "Big fish eat small fish" to be realized as a painting in four hours.

I liked the subject and at the end of the four hours I admired my creation. The biggest part of my painting was filled with a big monster fish, who was about to swallow a medium sized fish. The medium sized fish was about to swallow a small fish. On the left side of the painting two more medium sized fishes were busy swallowing small fishes and the rest of the painting was filled with all sorts of small fishes swimming around. For an animated version see http://www.funny-games.biz/fishtales.html

Fish Tales

Meet Sunny, a small fish in a vast ocean. Use YOUR MOUSE to help Sunny survive in these dangerous waters. To win you have to follow these rules. Eat the fish smaller than yourself, avoid the fish bigger than yourself and eat enough fish to grow up. Have fun!

This was just a juvenile's dream.

Today, waking up during my years of research I often had this image in mind “big fish eat small fish”.

This book is a scientific answer to the question. From a science point of view the painting is called an aquatic ecosystem showing the food web for the biggest organisms fish. There is a strict hierarchical order in the systems with the constraints “who swallows whom” which follows a power law. A few hubs, the biggest fishes, swallow almost everything, while a few medium sized fish modules are constrained on the feeding of a great number of small and very small fishes. There is also a fractal like feature in the image; independent of the scaling we see the same building block a big fish swallowing a small fish.

Todays studies of ecosystems go further down in the scaling hierarchy to plankton and bacteria over more than ten orders of magnitude in size. What is noteworthy that virtually all observed ecosystems reveal power law biomass size distributions.

Why do we observe these Pareto-Zipf-Mandelbrot (PZM) regularities not only in ecosystems but also for complex networks on virtually every level of the evolutionary hierarchy from stars to the World Wide Web?

This book has a simple aim: to get you to think “real world” complex networks in terms of Neural Nets, that have memory, are learning and could be considered as intelligent, since they strive to reach a goal.

The intelligence is not only located in brains, its located out there in the topology and weighted links of the numerous small world networks ranging from massive stars to the World Wide Web.

Hierarchy Theory

To grasp the key idea put forward in this book, that the universe can be understood as a self similar hierarchy of neural networks some basic concepts like hierarchy, self-similarity, fractal, network and neural network have to be understood by the reader.

When we found a suitable Wikipedia entry we have cited the article in extenso to avoid for the reader the necessity to be on line to the Internet while reading the book. When the reader desires to deepen his understanding he can follow the links in the text when connected on line.

Likewise several sections like the one on operator hierarchy and compositional vs. subsumption hierarchy have been written by the authors and been included in the book with their permission. Why rewrite when the authors or an encyclopedia can say it better?

What is a Hierarchy? Wikipedia

A **hierarchy** is an arrangement of objects, people, elements, values, grades, orders, classes, etc., in a ranked or graduated series. The word derives from the Greek **ἱεραρχία** (*hierarchia*), from *ἱεράρχης* (*hierarches*), "president of sacred rites, high-priest" and that from *ἱερός* (*hieros*), "sacred" + *ἄρχω* (*arkho*), "to lead, to rule"[1][2]. The word can also refer to a series of such items so arranged. Items in a hierarchy are typically thought of as being "above," "below," or "at the same level as" one another.[3][4]

This is as opposed to anarchy where there is no concept of higher or lower items (or people) -- everything is considered equal.

The first use of the word "hierarchy" cited by the Oxford English Dictionary was in 1880, when it was used in reference to the three orders of three angels as depicted by Pseudo-Dionysius the Areopagite. Pseudo-Dionysius used the word both in reference to the celestial hierarchy and the ecclesiastical hierarchy. [5] His term is derived from the Greek for 'Bishop' (hierarch), and Dionysius is credited with first use of it as an abstract noun. Since hierarchical churches, such as the Roman Catholic and Eastern Orthodox churches, had tables of organization that were "hierarchical" in the modern sense of the word (traditionally with God as the pinnacle of the hierarchy), the term came to refer to similar organizational methods in more general settings.

A hierarchy can link entities either directly or indirectly, and either vertically or horizontally. The only direct links in a hierarchy, insofar as they are hierarchical, are to one's immediate superior or to one of one's subordinates, although a system that is largely hierarchical can also incorporate other organizational patterns. Indirect hierarchical links can extend "vertically" upwards or downwards via multiple links in the same direction. All parts of the hierarchy which are not vertically linked to one another can nevertheless be "horizontally" linked by traveling up the hierarchy to find a common direct or indirect superior, and then down again. This is akin to two co-workers, neither of whom is the other's boss, but both of whose chains of command will eventually meet.

These relationships can be formalized mathematically; see hierarchy (mathematics).

Computation and electronics

Large electronic devices such as computers are usually composed of modules, which are themselves created out of smaller components (integrated circuits), which in turn are internally organized using hierarchical methods (e.g. using standard cells). The order of tasks in a computational algorithm is often managed hierarchically, with repeated loops nested within one another. Computer files in a file system are stored in an hierarchy of directories in most operating systems. In object-oriented programming, classes are organized hierarchically; the relationship between two related classes is called inheritance. In the Internet, IP addresses are increasingly organized in an hierarchy (so that the routing will continue to function as the Internet grows).

Computer graphic imaging (CGI)

Within most CGI and computer animation programs is the use of hierarchies. On a 3D model of a human, the chest is a parent of the upper left arm, which is a parent of the lower left arm, which is a parent of the hand. This is used in modeling and animation of almost everything built as a 3D digital model.

Biological taxonomy

In biology, the study of taxonomy is one of the most conventionally hierarchical kinds of knowledge, placing all living beings in a nested structure of divisions related to their probable evolutionary descent. Most evolutionary biologists assert a hierarchy extending from the level of the specimen (an individual living organism — say, a single newt), to the species of which it is a member (perhaps the Eastern Newt), outward to further successive levels of genus, family, order, class, phylum, and kingdom. (A newt is a kind of salamander (family), and all salamanders are types of amphibians (class), which are all types of vertebrates (phylum).) Essential to this kind of reasoning is the proof that members of a division on one level are more closely related to one another than to members of a different division on the same level; they must also share ancestry in the level above. Thus, the system is hierarchical because it forbids the possibility of overlapping categories. For example, it will not permit a 'family' of beings containing some examples that are amphibians and others that are reptiles — divisions on any level do not straddle the categories of structure that are hierarchically above it. (Such straddling would be an example of heterarchy.)

Organisms are also commonly described as assemblies of parts (organs) which are themselves assemblies of yet smaller parts. When we observe that the relationship of cell to organ is like that of the relationship of organ to body, we are invoking the hierarchical aspects of physiology. (The term "organic" is often used to describe a sense of the small imitating the large, which suggests hierarchy, but isn't necessarily hierarchical.) The analogy of organ to body also extends to the relationship of a living being as a system that might resemble an ecosystem consisting of several living beings; physiology is thus hierarchically nested in ecology.

Physics

In physics, the standard model of reasoning on the nature of the physical world decomposes large bodies down to their smallest particle components. Observations on the subatomic (particle) level are often seen as fundamental constituent axioms, on which conclusions about the atomic and molecular levels depend. The relationships of energy and gravity between celestial bodies are, in turn, dependent upon the atomic and molecular properties of smaller bodies. In energetics, energy quality is sometimes used to quantify energy hierarchy.

Language and semiotics

In linguistics, especially in the work of Noam Chomsky, and of later generative linguistics theories, such as Ray Jackendoff's, words or sentences are often broken down into hierarchies of parts and wholes. Hierarchical reasoning about the underlying structure of language expressions leads some linguists to the hypothesis that the world's languages are bound together in a broad array of variants subordinate to a single Universal Grammar.

Hierarchical verbal alignment

In some languages, such as Cree and Mapudungun, subject and object on verbs are distinguished not by different subject and object markers, but via a hierarchy of persons.

In this system, the three (or four with Algonquian languages) persons are placed in a hierarchy of salience. To distinguish which is subject and which object, *inverse markers* are used if the object outranks the subject.

In music, the structure of a composition is often understood hierarchically (for example by Heinrich Schenker (1768–1835, see Schenkerian analysis), and in the (1985) Generative Theory of Tonal Music, by composer Fred Lerdahl and linguist Ray Jackendoff). The sum of all notes in a piece is understood to be an all-inclusive surface, which can be reduced to successively more sparse and more fundamental types of motion. The levels of structure that operate in Schenker's theory are the foreground, which is seen in all the details of the musical score; the middle ground, which is roughly a summary of an essential contrapuntal progression and voice-leading; and the background or Ursatz, which is one of only a few basic "long-range counterpoint" structures that are shared in the gamut of tonal music literature.

The pitches and form of tonal music are organized hierarchically, all pitches deriving their importance from their relationship to a tonic key, and secondary themes in other keys are brought back to the tonic in a recapitulation of the primary theme. Susan McClary connects this specifically in the sonata-allegro form to the feminist hierarchy of gender (see above) in her book *Feminine Endings*, even pointing out that primary themes were often previously called "masculine" and secondary themes "feminine."

Hierarchies in programming

The concept of hierarchies plays a large part in object oriented programming. For more information see Hierarchy (object-oriented programming) and memory hierarchy.

Containment hierarchy

A containment hierarchy of the subsumption kind is a collection of strictly nested sets. Each entry in the hierarchy designates a set such that the previous entry is a strict superset, and the next entry is a strict subset. For example, all rectangles are quadrilaterals, but not all quadrilaterals are rectangles, and all squares are rectangles, but not all rectangles are squares. (See also: Taxonomy.) A containment hierarchy of the compositional kind refers to parts and wholes, as well as to rates of change. Generally the bigger changes more slowly. Parts are contained in wholes and change more rapidly than do wholes.

- In geometry: {shape {polygon {quadrilateral {rectangle {Square (geometry)|square }}}}}
- In biology:subsumption hierarchy {animal {bird {bird of prey|raptor {eagle {golden eagle}}}}}
    - compositional hierarchy: [population [organism [biological cell [macromolecule]]]]
- The Chomsky hierarchy in formal languages: recursively enumerable, context-sensitive, context-free, and regular
- In physics: subsumption hierarchy {elementary particle {fermion {lepton {electron }}}}
    - compositional hierarchy: [galaxy [star system [star]]]

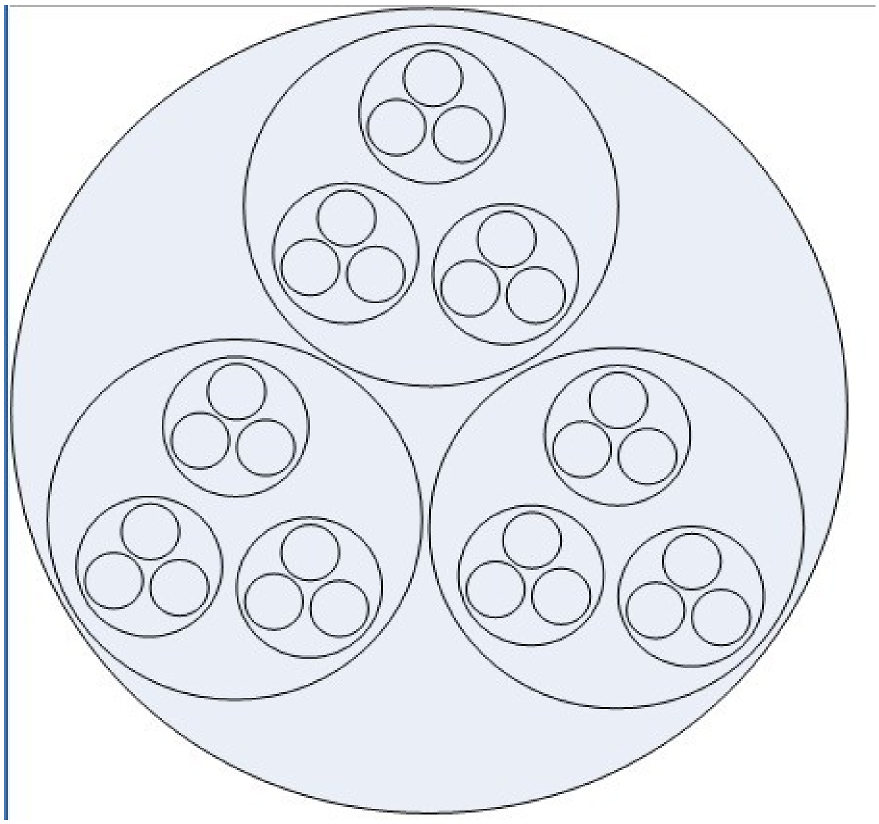
Social hierarchies

Many human organizations, such as governments, educational institutions, businesses, churches, armies and political movements are hierarchical organizations, at least officially; commonly seniors, called "bosses", have more power. Thus the relationship defining this hierarchy is "commands" or "has power over". Some analysts question whether power "actually" works in the way the traditional organizational chart indicates, however. This view tends to emphasize the significance of the informal organization. See also chain of command.

Retrieved from "http://en.wikipedia.org/wiki/Hierarchy"

Hierarchy of Holons (1968 Koestler)

Some 40 years ago, Arthur Koestler proposed the word "holon" [Koestler 1968]. It is a combination from the Greek 'holos' = whole, with the suffix 'on' which, as in proton or neutron, suggests a particle or part.



Selfsimilar hierarchy of holons

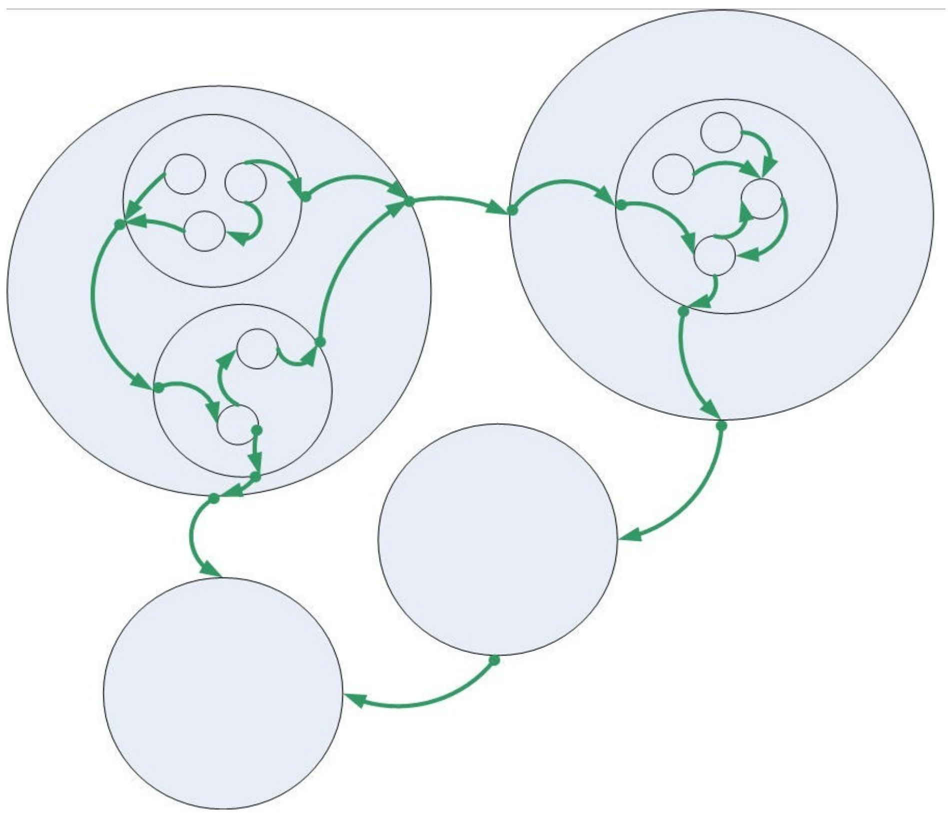
Two observations impelled Koestler to propose the word holon. The first comes from Herbert Simon, a Nobel prize winner, and is based on his 'parable of the two watchmakers'.

The Parable

There once were two watchmakers, named Hora and Tempus, who made very fine watches. The phones in their workshops rang frequently and new customers were constantly calling them. However, Hora *prospered while Tempus became poorer and poorer. In the end, Tempus lost his shop. What was the reason behind this?*

The watches consisted of about 1000 parts each. The watches that Tempus made were designed such that, when he had to put down a partly assembled watch, it immediately fell into pieces and had to be reassembled from the basic elements. Hora had designed his watches so that he could put together sub-assemblies of about ten components each, and each sub-assembly could be put down without falling apart. Ten of these subassemblies could be put together to make a larger sub-assembly, and ten of the larger sub-assemblies constituted the whole watch.

From this parable, Simon concludes that complex systems will evolve from simple systems much more rapidly if there are stable intermediate forms than if there are not; the resulting complex systems in the former case will be hierarchic.



Dynamics of of a holarchy

The second observation, made by Koestler while analyzing hierarchies and stable intermediate forms in living organisms and social organization, is that although it is easy to identify sub-wholes or parts 'wholes' and 'parts' in an absolute sense do not exist anywhere. This made Koestler propose the word holon to describe the hybrid nature of sub- wholes/parts in real-life systems; holons simultaneously are self-contained wholes to their subordinated parts, and dependent parts when seen from the inverse direction.

Koestler also establishes the link between holons and the watchmakers' parable from professor Simon. He points out that the sub-wholes/holons are autonomous self-reliant units, which have a degree of independence and handle contingencies without asking higher authorities for instructions. Simultaneously, holons are subject to control from (multiple) higher authorities. The first property ensures that holons are stable forms, which survive disturbances. The latter property signifies that they are intermediate forms, which provide the proper functionality for the bigger whole.

Finally, Koestler defines a holarchy as a hierarchy of self-regulating holons which function (a) as autonomous wholes in supra-ordination to their parts, (b) as dependent parts in sub- ordination to controls on higher levels, (c) in co-ordination with their local environment

What is a Holon? Wikipedia

General definition

A holon is a system (or phenomenon) that is a whole in itself as well as a part of a larger system. It can be conceived as systems nested within each other. Every system can be considered a holon, from a subatomic particle to the universe as a whole. On a non-physical level, words, ideas, sounds, emotions—everything that can be identified—is simultaneously part of something, and can be viewed as having parts of its own, similar to sign in regard of semiotics.

Since a holon is embedded in larger wholes, it is influenced by and influences these larger wholes. And since a holon also contains subsystems, or parts, it is similarly influenced by and influences these parts. Information flows bidirectionally between smaller and larger systems as well as rhizomatic contagion. When this bidirectionality of information flow and understanding of role is compromised, for whatever reason, the system begins to break down: wholes no longer recognize their dependence on their subsidiary parts, and parts no longer recognize the organizing authority of the wholes. Cancer may be understood as such a breakdown in the biological realm.

A hierarchy of holons is called a holarchy. The holarchic model can be seen as an attempt to modify and modernise perceptions of natural hierarchy.

Ken Wilber comments that the test of holon hierarchy (e.g. holarchy) is that if a type of holon is removed from existence, then all other holons of which it formed a part must necessarily cease to exist too. Thus an atom is of a lower standing in the hierarchy than a molecule, because if you removed all molecules, atoms could still exist, whereas if you removed all atoms, molecules, in a strict sense would cease to exist. Wilber's concept is known as the doctrine of the **fundamental** and the **significant**. A hydrogen atom is more fundamental than an ant, but an ant is more significant.

The doctrine of the fundamental and the significant are contrasted by the radical rhizome oriented pragmatics of Deleuze and Guattari, and other continental philosophy.

Types of holons

Individual holon

An individual holon possesses a dominant monad; that is, it possesses a definable "I-ness". An individual holon is discrete, self-contained, and also demonstrates the quality of agency, or self-directed behavior. [3] The individual holon, although a discrete and self-contained is made up of parts; in the case of a human, examples of these parts would include the heart, lungs, liver, brain, spleen, etc. When a human exercises agency, taking a step to the left, for example, the entire holon, including the constituent parts, moves together as one unit.

Social holon

A social holon does not possess a dominant monad; it possesses only a definable "we-ness", as it is a collective made up of individual holons. [4] In addition, rather than possessing discrete agency, a social holon possesses what is defined as nexus agency. An illustration of nexus agency is best described by a flock of geese. Each goose is an individual holon, the flock makes up a social holon. Although the flock moves as one unit when flying, and it is "directed" by the choices of the lead goose, the flock itself is not mandated to follow that lead goose. Another way to consider this would be collective activity that has the potential for independent internal activity at any given moment.

Applications

Ecology

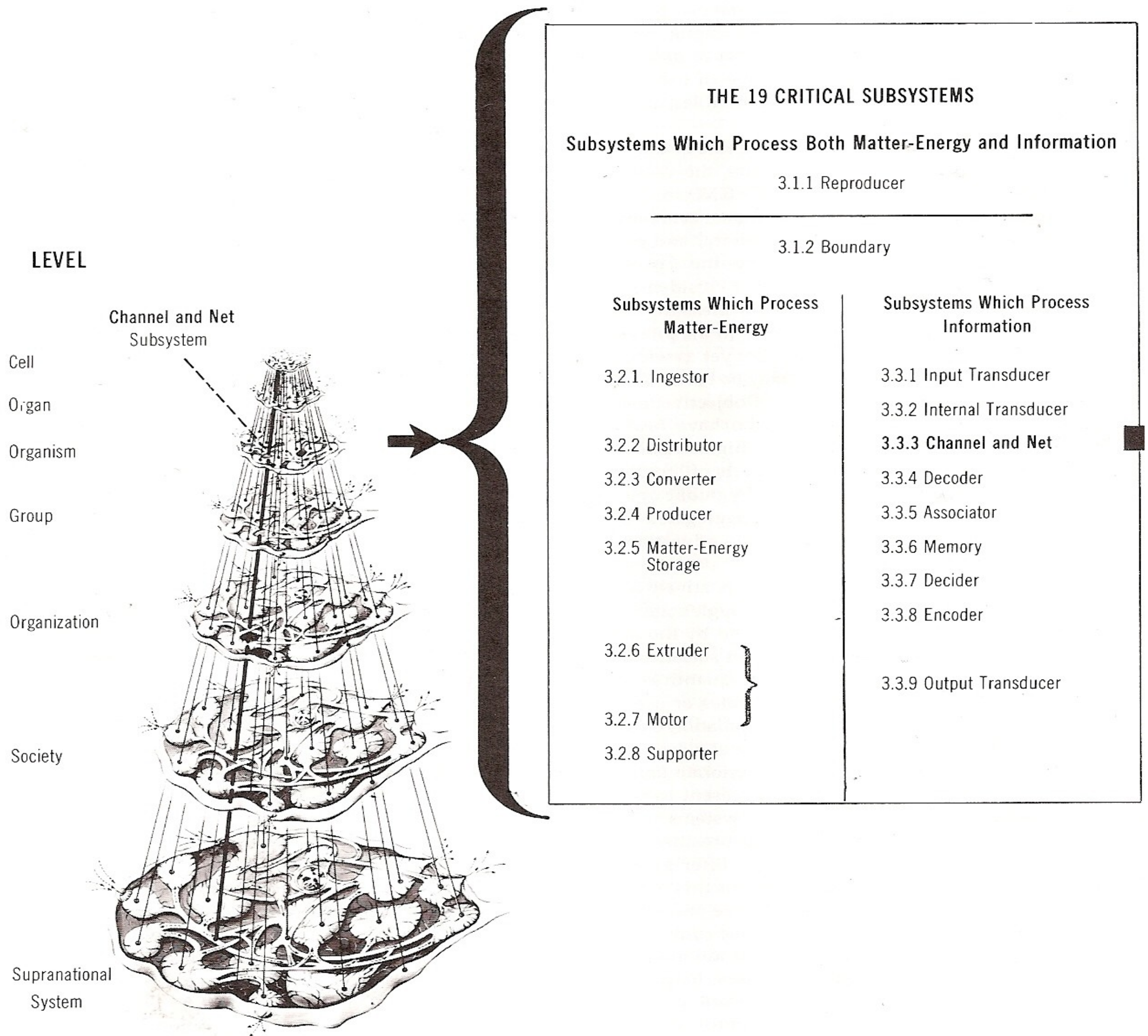
The concept of the holon is used in environmental philosophy, ecology and human ecology. Ecosystems are often seen as holons within one or many holarchies. Holons are seen as open subsystems of systems of higher order, with a continuum from the cell to the ecosphere.

Philosophy of history

In the philosophy of history, a holon is a historical event that makes other historical events inevitable. A holon is a controversial concept, in that some reject the inevitability of any historical event. A special category of holon is technology, which implies a perspective on how technologies have the potential to dictate history.

Living Systems (1978 Miller)

In 1978, together with his wife and collaborator Jessie, Miller made the case for a unified approach to the biological, psychological and social sciences in the book "Living Systems" a compilation and synthesis that he regarded as the capstone of his career, 25 years in the making[2] which founded the field of Living systems theory.



The self-similar nested hierarchy of living systems from the cell to the supranational system: on each level we identify the same 8 subsystems processing matter energy and the 9 subsystems processing information.

Living systems Wikipedia

Miller considers living systems as a subset of all systems. Below the level of living systems, he defines space and time, matter and energy, information and entropy, levels of organization, and physical and conceptual factors, and above living systems ecological, planetary and solar systems, galaxies, and so forth.[1].

Living systems are by definition open self-organizing systems that have the special characteristics of life and interact with their environment. This takes place by means of information and material-energy exchanges. Living systems can be as simple as a single cell or as complex as a supranational organization such as the European Economic Community. Regardless of their complexity, they each depend upon the same essential twenty subsystems (or processes) in order to survive and to continue the propagation of their species or types beyond a single generation.[2].

Miller said that systems exist at eight "nested" hierarchical levels: cell, organ, organism, group, organization, community, society, and supranational system. At each level, a system invariably comprises 20 critical subsystems, which process matter/ energy or information except for the first two, which process both matter/energy and information: reproducer & boundary.

The processors of matter/energy are:

- Ingestor, Distributor, Converter, Producer, Storage, Extruder, Motor, Supporter

The processors of information are

- Input transducer, Internal transducer, Channel and net, Timer (added later), Decoder, Associator, Memory, Decider, Encoder, Output transducer.

Miller's Living systems theory

James Grier Miller in 1978 wrote a 1,102-page volume to present his living systems theory. He constructed a general theory of living systems by focusing on concrete systems—nonrandom accumulations of matter-energy in physical space-time organized into interacting, interrelated subsystems or components. Slightly revising the original model a dozen years later, he distinguished eight "nested" hierarchical levels in such complex structures. Each level is "nested" in the sense that each higher level contains the next lower level in a nested fashion.

His central thesis is that the systems in existence at all eight levels are open systems composed of 20 critical subsystems that process inputs, throughputs, and outputs of various forms of matter/energy and information. Two of these subsystems—reproducer and boundary—process both matter/energy and information. Eight of them process only matter/energy. The other 10 process information only.

> All nature is a continuum. The endless complexity of life is organized into patterns which repeat themselves—theme and variations—at each level of system. These similarities and differences are proper concerns for science. From the ceaseless streaming of protoplasm to the many-vectored

activities of supranational systems, there are continuous flows through living systems as they maintain their highly organized steady states.*[3]*

Seppänen (1998) says that Miller applied general systems theory on a broad scale to describe all aspects of living systems" [4]

Topics in living systems theory

Miller's theory posits that the mutual interrelationship of the components of a system extends across the hierarchical levels. Examples: Cells and organs of a living system thrive on the food the organism obtains from its suprasystem; the member countries of a supranational system reap the benefits accrued from the communal activities to which each one contributes. Miller says that his eclectic theory "ties together past discoveries from many disciplines and provides an outline into which new findings can be fitted".[5]

Miller says the concepts of space, time, matter, energy, and information are essential to his theory because the living systems exist in space and are made of matter and energy organized by information. Miller's theory of living systems employs two sorts of spaces: physical or geographical space, and conceptual or abstracted spaces. Time is the fundamental "fourth dimension" of the physical space-time continuum/spiral. Matter is anything that has mass and occupies physical space. Mass and energy are equivalent as one can be converted into the other. Information refers to the degrees of freedom that exist in a given situation to choose among signals, symbols, messages, or patterns to be transmitted.

Other relevant concepts are system, structure, process, type, level, echelon, suprasystem, subsystem, transmissions, and steady state. A system can be conceptual, concrete or abstracted. The structure of a system is the arrangement of the subsystems and their components in three-dimensional space at any point of time. Process, which can be reversible or irreversible, refers to change over time of matter/energy or information in a system. Type defines living systems with similar characteristics. Level is the position in a hierarchy of systems. Many complex living systems, at various levels, are organized into two or more echelons. The suprasystem of any living system is the next higher system in which it is a subsystem or component. The totality of all the structures in a system which carry out a particular process is a subsystem. Transmissions are inputs and outputs in concrete systems. Because living systems are open systems, with continually altering fluxes of matter/energy and information, many of their equilibria are dynamic—situations identified as steady states or flux equilibria.

Miller identifies the comparable matter-energy and information processing critical subsystems. Elaborating on the eight hierarchical levels, he defines society, which constitutes the seventh hierarchy, as "a large, living, concrete system with [community] and lower levels of living systems as subsystems and components". [6] Society may include small, primitive, totipotential communities; ancient city-states, and kingdoms; as well as modern nation-states and empires that are not supranational systems. Miller provides general descriptions of each of the subsystems that fit all eight levels.

A supranational system, in Miller's view, "is composed of two or more societies, some or all of whose processes are under the control of a decider that is superordinate to their highest echelons" [7]. However, he contends that no supranational system with all its 20 subsystems under control of its decider exists today. The absence of a supranational decider precludes the existence of a concrete supranational system. Miller says that studying a supranational system is problematical because its subsystems

> ...tend to consist of few components besides the decoder. These systems do little matter-energy processing. The power of component societies [nations] today is almost always greater than the power of supranational deciders. Traditionally, theory at this level has been based upon intuition and study of history rather than data collection. Some quantitative research is now being done, and construction of global-system models and simulations is currently burgeoning.[8]

At the supranational system level, Miller's emphasis is on international organizations, associations, and groups comprising representatives of societies (nation-states). Miller identifies the subsystems at this level to suit this emphasis. Thus, for example, the reproducer is "any multipurpose supranational system which creates a single purpose supranational organization" (p. 914); and the boundary is the "supranational forces, usually located on or near supranational borders, which defend, guard, or police them" (p. 914).

Strengths of Miller's theory

Not just those specialized in international communication, but all communication science scholars could pay particular attention to the major contributions of LST to social systems approaches that Bailey[9] has pointed out:

- The specification of the 20 critical subsystems in any living system.
- The specification of the eight hierarchical levels of living systems.
- The emphasis on cross-level analysis and the production of numerous cross-level hypotheses.
- Cross-subsystem research (e.g., formulation and testing of hypotheses in two or more subsystems at a time).
- Cross-level, cross-subsystem research.

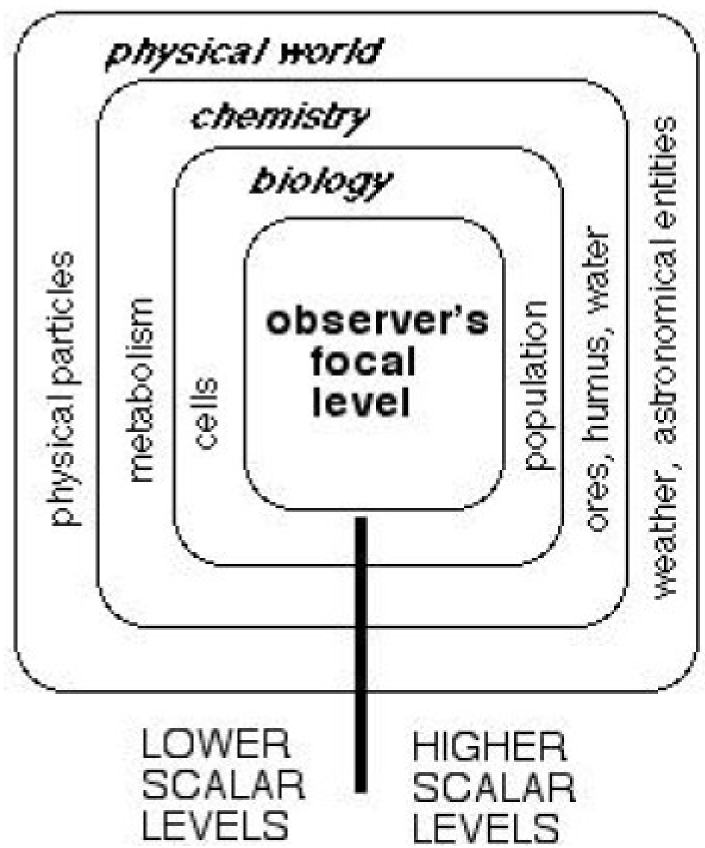
Bailey says that LST, perhaps the "most integrative" social systems theory, has made many more contributions that may be easily overlooked, such as: providing a detailed analysis of types of systems; making a distinction between concrete and abstracted systems; discussion of physical space and time; placing emphasis on information processing; providing an analysis of entropy; recognition of totipotential systems, and partipotential systems; providing an innovative approach to the structure-process issue; and introducing the concept of joint subsystem—a subsystem that belongs to two systems simultaneously; of dispersal—lateral, outward, upward, and downward; of inclusion—inclusion of something from the environment that is not part of the system; of artifact—an animal-made or human-made inclusion; of adjustment process, which combats stress in a system; and of critical subsystems, which carry out processes that all living systems need to survive.[10]

LST's analysis of the 20 interacting subsystems, Bailey adds, clearly distinguishing between matter/energy processing and information-processing, as well as LST's analysis of the eight interrelated system levels, enables us to understand how social systems are linked to biological systems. LST also analyzes the irregularities or “organizational pathologies” of systems functioning (e.g., system stress and strain, feedback irregularities, information-input overload). It explicates the role of entropy in social research while it equates negentropy with information and order. It emphasizes both structure and process, as well as their interrelations [11]

Limitations

It omits the analysis of subjective phenomena, and it overemphasizes concrete Q-analysis (correlation of objects) to the virtual exclusion of R-analysis (correlation of variables). By asserting that societies (ranging from totipotential communities to nation-states and non-supranational systems) have greater control over their subsystem components than supranational systems have, it dodges the issue of transnational power over the contemporary social systems. Miller's supranational system bears no resemblance to the modern world-system that Wallerstein (1974) described although both of them were looking at the same living (dissipative) structure.

Compositional hierarchy vs. Subsumption hierarchy (2002 Salthe)



This figure from Salthe [Salthe, 2005] can be taken as a mandala, suggesting the relationship between the scalar levels of extensional complexity and the integrative levels of intensional complexity. The observer arises out of the physical – chemical and biological realms as the peak of a pyramid rising from the left, but at the same time is embedded in these containing realms as a thought from the right.

In order to underline the crucial difference between compositional hierarchies (extensional complexity) and subsumption hierarchies (intensional complexity) we extensively cite Salthe [Salthe 2002 revised 2008]:

Hierarchies have two known logical forms:

1. the **compositional hierarchy** (including a synchronic map of the command hierarchy), which in applications I have called the 'scale hierarchy'. The picture of macromolecules inside of a living cell inside of an organism is a familiar image of one important application. This form is suited to synchronic modeling of systems as they are at any given moment.

- the **subsumption hierarchy** (including a diachronic model of the trajectory of a given command), which I have called the 'specification hierarchy'. The Linnaean hierarchy in biological systematics has this form. This form is suitable to diachronic modeling of emergent forms.

- Cliff Joslyn has provided the following comparative table of logical properties:

Meronomy	Taxonomy
Whole/part	General/specific
is-a-part-of	is-a-kind-of
Composition	Subsumption
Containment	Inheritance
Modularity	Specification

General properties:

Hierarchies are examples of 'partial ordering' in logic. That is, the items being ordered could be ordered in other ways as well. Hierarchies order entities, processes or realms into a system of levels. The ordering principle ('is-a-part-of' or 'is-a-kind-of') is transitive across levels. In both of these hierarchies, when used to model systems, higher levels control (regulate, interpret, harness) lower levels, whose behaviors are made possible by properties generated at still lower levels. So higher levels provide boundary conditions on the behaviors of lower levels -- behaviors initiated by still lower level configurations (see below for the usage of 'higher' and 'lower'). It is important to realize that only some users of hierarchical forms would insist that particular levels exist in actuality. Levels are discerned from hierarchical analysis, aimed at constructing / discovering Nature's 'joints' with respect to given projects. Hierarchies thus provide models of systems that are susceptible to analysis into different levels.

(a) To use the compositional hierarchy we need to stipulate a focal level, as well as a lower and a higher, making up a 'basic triadic system' -- as, e.g., when the behavior of living cells is initiated by chemical events, and controlled by organismic events. The three level form insures stability because with it in place (a third level always anchoring relations between the other two), the focal level cannot be reduced either upward or downward by assimilation into a contiguous level. Here we should note that this hierarchy has been invoked to explain how the world manages to be as stable as it is. The triadic form reflects the putative way in which levels would have evolved, by interpolation between primal highest and lowest ones, as when biology would have emerged as organizational forms between chemical activities in an environmental energy dissipative configuration.

(b) In the subsumption hierarchy the highest relevant level is always the one in focus, with all the lower levels of the hierarchy providing cumulative initiating conditions simultaneously upon it. This reflects the fact that this hierarchy is implicitly evolutionary, with the levels being viewed as having emerged consecutively from the lowest, or most general (or generally present), up -- as with, e.g., biology emerging from chemistry, both historically and at any given moment. The two-level form is unstable, allowing new levels to emerge at the top of the hierarchy. Use of this form provides us with a model allowing for emergent changes in the world.

Hierarchical analysis is always driven by a given problem or project.

Formal relations between levels:

(a) The compositional hierarchy is one of parts nested within wholes, as, e.g., [... [species [population [organism [gene [...]]]]]], where [higher level [focal level [lower level]]]. The logic reflects Russell's logical types. In principle the levels just keep going, receding at both ends from the focal level. (It may be noted that this structure probably is rooted in our visual experiences.)
If the parts are functional in some given analysis, they are referred to as components, if not they are constituents. As one goes down the hierarchy, the relative number of constituents per level increases, giving a measure of the 'span' of the hierarchy.

(b) The subsumption hierarchy is one of classes and subclasses, as e.g., {material world {biological world {social world }}}, where {lower level(s) { highest level}}. The focus of analysis is always the highest level, which is the innermost level of the hierarchy. The logic reflects Ryle's categories. Higher levels inherit all the properties of the lower levels.

(c) A note on levels terminology: The levels in a subsumption hierarchy have been referred to as ‘integrative levels’ inasmuch as the higher levels integrate the lower levels’ properties and dynamics under their own rules. ‘Levels of reality’ and ‘ontological levels’ have been used in subsumption as well. One sees other labels, such as ‘levels of organization’ or ‘levels of observation’ used for either kind of hierarchy. I have used ‘scalar levels’ or ‘levels of scale’ for application of the compositional hierarchy to material systems for dynamical reasons (see below under ‘Criteria’).

Style of growth of the hierarchy:

(a) A compositional hierarchy adds levels by interpolation between existing levels. In this way the system must be an expanding one. Therefore, an assumption required for application of this hierarchy would be the Big Bang (or other expanding system). The actual process of formation of a level would involve the cohesion of entities out of lower level units guided by higher level boundary conditions. This process is little understood since this hierarchy has largely been used for synchronic analyses.

(b) In the subsumption hierarchy new levels would emerge from the current highest one. So this system too can grow -- but not in space. Growth here is by the accumulation of informational constraints, modeled as a process of refinement by way of adding specification. New levels, marked by subclasses reflect thresholds of system structural reorganization.

Criteria:

(a) In application of the compositional hierarchy to actual natural systems, components at different levels must differ in size roughly by orders of magnitude. Otherwise components at different levels would interact dynamically, in which case there would not be different levels functionally.

(b) Levels in a subsumption hierarchy mark the qualitative differences of different realms of being, as in 'physical realm' versus 'biological realm'. This hierarchy is open at the top; the innermost level is unbounded above, and so free to give rise to ever higher levels.

Complexity:

(a) A compositional hierarchy provides a model of ‘extensional complexity’, the sign of which is nonlinear and chaotic dynamics, allowed by the fact that at any locale at any level in this hierarchy there could be a mixture of different kinds of information (relations, variables, constants of different kinds, attractors) which are not governed by a single overall structure. It is useful here to contrast complexity with complication. A flat hierarchy with few levels could tend to show more complicated behavior than a hierarchy with more levels, which would have more constraints imposed top-down.

(b) A subsumption hierarchy embodies intensional complexity, which characterizes a system to the degree that it is susceptible to many different kinds of analyses.

Dynamical relations:

(a) A compositional hierarchy represents a single moment in space, so its dynamics represent homeostasis, not change. Large scale moments "contain" many small scale moments. It is often suggested that scalar levels fundamentally signal rate differences rather than component size differences. We may note that the two most often go together. The problem appears in cases that are said to be non-nested, where, e.g., a much slower rate in a component of a cycle would regulate the rate of the entire cycle. It would be rare, however, for such rates to differ by orders of magnitude, and so many of these examples are likely not hierarchical at all. If we allowed mere size differences rather than scale differences to be the criterion, then the constraint of nestedness would be lifted. In any case:

Because of the order of magnitude differences between levels in the compositional hierarchy, dynamics at different levels do not directly interact or exchange energy, but transact by way of mutual constraint (i.e., via informational connections). The levels are screened off from each other dynamically. Because of this dynamical separation of levels, informational exchanges between levels are non-transitive, requiring interpretation at the boundaries between levels.

So, if focal level dynamics are represented by variables in an equation, then the results of dynamics at contiguous levels would be represented by (nonrecursive) constants. Larger scale dynamics are so slow with respect to those at the focal level, that the current value of their momentary result appears relatively unchanging at the focal level. Cumulated results of lower scale dynamics also appear relatively or statistically unchanging at the focal level, as it takes a very long time in lower scale moments to effect a change detectable at the focal level -- these points are the essence of dynamical 'screening off' in compositional hierarchy models.

Note that, because of these relations, thermodynamic equilibria would be more rapidly achieved per unit volume at a lower scalar level, delivering an adiabatic principle relating to screening off. While change of any kind (development, acceleration, diffusion) is relatively more rapid at lower levels, absolute translational motion is more rapid at higher levels. Thus, higher levels provide modes of convection for the dissipation of energy gradients, which would otherwise proceed by slow conduction instead. Related to these matters, we should note that metabolic rates and development are absolutely much faster in smaller dissipative structures (organisms, fluid vortices, etc.), and their natural life spans are shorter than in larger scale ones.

One sometimes sees the term ‘heterarchy’, posed in opposition to the scale hierarchy because of supposed failures of actual systems to conform to hierarchical constraints. One needs to recall here again that hierarchy is a conceptual construction, an analytical tool, and use of it does not imply that the world itself is actually hierarchically organized. It does seem to be so in many ways, but to suppose that this is the sole principle needed in understanding the world would be naive. It is one tool among many. But often this ‘hetero’ opposition to hierarchy is based merely on faulty understanding. For example, the tides are affected (partially controlled) by gravitational effects associated with the moon; yet the oceans are not nested inside the moon. As in classical thermodynamics, it is important to see the whole system correctly. The oceans are nested, along with the earth itself, within the solar system, and from the hierarchical point of view, these effects on the tides emanate from the solar system, not merely from the moon. (Demurrer: As we descend in applications through the realm of fundamental particles, it may be that some of these rules would break down [via nonlocality, etc.]. Hierarchical constructs model events and informational transactions in the material world, defined as the realm of friction and lag in the affairs of chemical elements and their compositions.)

(b) Dynamics in a subsumption hierarchy are entrained by development, which is modeled as a process of refinement of a class, or increased specification of a category. It is important to note that this process is open-ended in the sense that there could be many coordinate subclasses of a given class. That is, the potentials arising within any class form a tree. So, in {physical realm { material realm { biological realm }}}, or {mammal { primate { human }}} each hierarchy follows just one branch of a tree. Rylean categories can branch into new distinctions (and this forms a link with the scalar hierarchy because this would give rise as well to new logical types). Evolution (unpredictable change) is one -> many, and thus we have been able to picture organic evolution using the Linnaean hierarchy.

The fact that functionally this is a two-level hierarchy makes it susceptible to change, because, without the anchoring provided by a third level, it could be reduced to a single level. How is its direction into new subclasses insured (giving rise to the hierarchy)? In models of the material world this is afforded by the fact that information, once in place (or once having had an effect), marks a system irrevocably. Marks in material systems are permanent. If a system continues to exist, it must march forward if it changes; there can be no reversal of evolution. Since change in the material world is entrained by the Second Law of thermodynamics, we have here a link between the two hierarchy models because the Second Law can be seen to be a result of Universal expansion being too fast to allow the global equilibration of matter. As noted above, this expansion is also what affords the interpolation of new levels in a compositional hierarchy.

So, development of a subsumptive hierarchy model requires a two-level basic form. Yet these hierarchies involve more than just two levels. Why do not the more general levels prevent change, as by the weight of their accumulated information? Here we are led to note another aspect of development, which is perfectly general. The amount of change required to launch a new level is ever smaller as a hierarchy develops -- refinements are just that. The more general levels do continue to exert their influence; e.g., biology is a kind of chemistry, and humans are a kind of mammal. The key to understanding this situation is that in the subsumption hierarchy informational relations between levels are transitive. Thus, physical dynamics are fully active players in a biological system. This means that we can fully understand development in this hierarchical model using only two contiguous levels. New levels may branch off anywhere in the hierarchy, potentially giving rise to collections of coordinate subclasses.

Informational relations and semiotics:

(a) As noted above, informational relations between levels in a compositional hierarchy are non-transitive. The levels are screened off from each other dynamically, and influence each other only indirectly, via transformed informational constraints. Signals moving from one level to another are transformed at boundaries between the levels. When this is not the case, as when a signal from a higher level occasionally transits to a much lower level, that level suffers damage (as when an organism is hit by lightning, or, going the other way, if a given cell affects the whole organism, this could only be if its effect is promoted by the likes of cancer). Here we can note again the idea that levels different in scale dynamics deliver stability to a system, via the screening-off effect.

The interpolation of a new level between two others can be viewed as involving the appearance of a capability at the uppermost level (via fluctuation, self-organization and/or selection) for making a significant (to it) interpretation of events at what then becomes the lowermost level of the three. The upper level effectively disposes -- facilitates cohesion among -- some of what the lower level proposes. This requires energetic screening off between levels. As the arena of the upper level's interpretants, the new level acts as a filter or buffer between upper and lower. This allows us to see levels succeeding each other by a classification procedure whereby topological difference information is converted to (or coheres as) typological distinction information in an essentially top-down procedure.

(b) In a subsumption hierarchy the lower levels also make possible the emergence of a new realm, in an epigenetic process. And here too the process is top-down, but in a different sense, involving finality. Thus, e.g., we can see that organism sociality implies biology in the sense of material implication or conceptual subordination. Then, as organism sociality implies biology, biology implies chemistry, and so, because this is a process of refinement, only a very narrow set of possibilities could imply organism sociality. That is, chemistry could give rise to many kinds of supersystems, biology to fewer, and sociality to even fewer as the epigenetic system develops. Developments (in distinction from evolution) are always entrained by final causes, and approach them asymptotically with each emergence of a new realm. Involved here, as in all developments, is the process of senescence, a condition of information overload (recall that information in this hierarchy is transitive across levels), leading to overconnectivity, leading in turn to functional underconnectivity, leading in its turn to inflexibility and habit driven responses (loss of requisite variety), leading ultimately to loss of adaptability (inability to produce interpretants of novel situations).

Operator hierarchy (1999 Jagers op Akkerhuis)

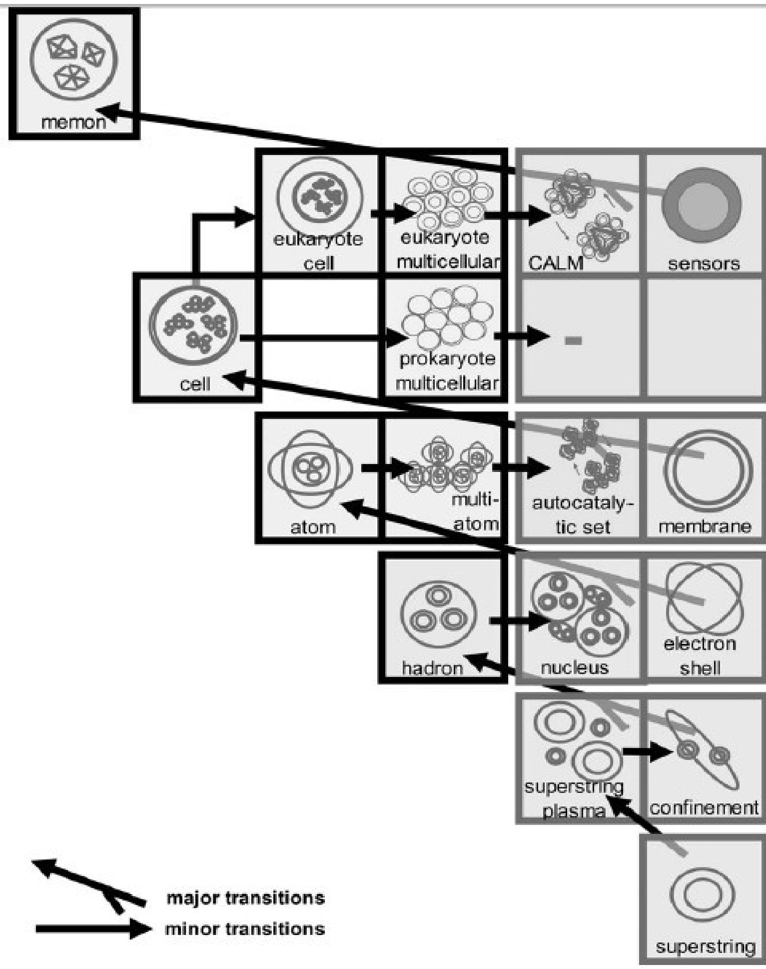


Fig. 1. The ranking of system types according to the operator hierarchy (Jagers op Akkerhuis & van Straalen, 1999; Jagers op Akkerhuis, 2001). Grey boxes indicate non-operator systems that play an important role in the operator hierarchy as intermediate closure states. Black upward arrows represent major transitions creating a new operator that shows a completely new type of closure. Black right-pointing arrows represent minor transitions. Empty cells and dashes indicate stages that have not yet evolved, but according to the logic of the hierarchy may potentially exist. Systems in the same vertical column share a common closure type. Titles above the columns indicate closure types. 'Interface' represents an emergent boundary. 'Hypercycle' represents an emergent second-order interaction cycle. 'Multi-operator' represents an emergent recurrent interaction between operators of the preceding type. 'Hypercycle mediating interface' (HMI) represents an interface that mediates the interactions of the hypercycle of the system involved with the world. 'Structural copying of information' (SCI) represents the property of systems to autonomously copy their structure and in this way reproduce their information. 'Structural auto-evolution' (SAE) represents the property of systems to improve, while living, the neural structures that contain their information. CALM stands for a Categorizing And Learning Module, representing a hypercyclic neural interaction pattern.

Network hierarchy (2002 Barabási)

“To build a modular network we started with a single node (see Figure 16.1 A) and created three copies of it, connecting them to the old node and to each other, obtaining a little four-node module (B). We next generated three copies of this module, linking the peripheral nodes of each new copy to the central node of the old module, obtaining a sixteen node network (C). Another “copy and link” step again quadrupled the number of nodes, resulting in a sixty-four-node network (D).

While we could have continued this process indefinitely, we stopped here and inspected the intricate structure of the network.

First it was modular by construction (self-similar fractal). At the lowest organizational level it was made of many highly connected four-node modules. These modules were the building blocks of the larger sixteen-node modules, which in turn were the major components of the sixty-four-node network.

Second, a highly connected central hub with thirty-nine links held the network together. The central nodes of the sixteen-node modules served as somewhat smaller local hubs, with fourteen links. Numerous nodes with a few links only accompanied these hubs, resulting in the familiar hierarchy of many small nodes held together by a few large hubs, a signature of scale-free networks. Indeed, the number of nodes with exactly k links followed a power law, confirming the model's scale-free nature. For the construction described above, the degree distribution follows a power law $P(k) = k^{\alpha}$ with alpha ~2.26.” Source: Barabási 2003.

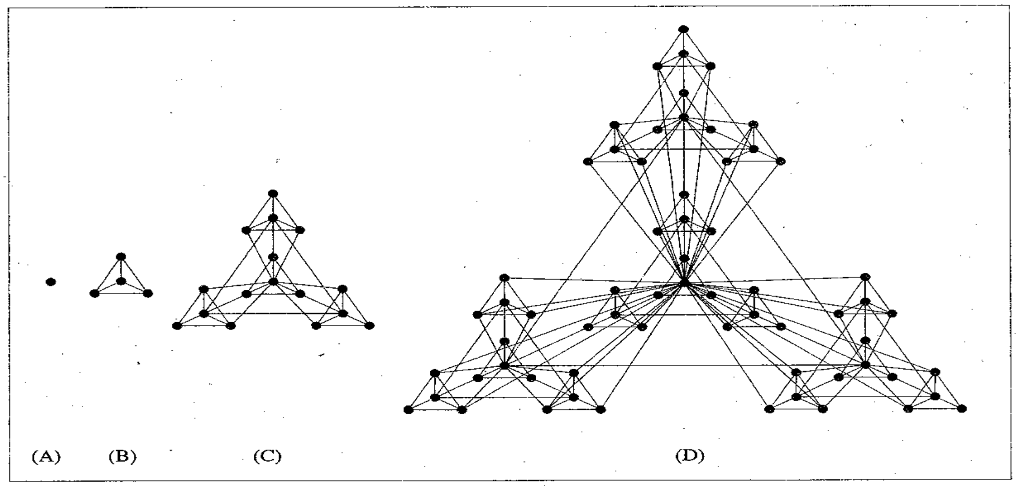


Figure 16.1 *We can generate a hierarchical network by starting from a single node (A) and making three copies of it, connecting the new nodes to the old node and to each other, obtaining the four-node structure shown in (B). In the next step we make three copies of our four-node structure and place them around the old module, connecting the peripheral nodes of the new modules to the central node of the old module and linking the central nodes of the new modules to each other. The obtained network will have sixteen nodes, as shown in (C). We can repeat the same process, creating now three copies of the C module and placing them around the old one, connecting the peripheral nodes to the center of the old module and the central in (D). The process can be continued indefinitely, each time generating a four-times-larger network. The obtained network is scale free: One can clearly distinguish a hierarchy of many small nodes, held together by a few large hubs. It is also modular, made of a hierarchy of larger and larger modules. Indeed, one can easily deconstruct the network shown in (C) into sixteen four-node modules, or four sixteen-node modules. An interesting property of the network is that it displays hierarchical clustering: It is made of many highly interlined four-node modules, which in turn form less interlinked sixteen-node modules, which are the building blocks of an even looser sixty-four-node module. Recently we learned that such hierarchical clustering is a generic property of a large number of real networks, from the cell to the World Wide Web.*

Note that the modular construction of the network follows a self-similar fractal like algorithm and suggests the fractal nature of scale-free networks. Hierarchical modularity is a generic property of most real networks accompanying scale-free architecture from cells over language to the Internet.

The Figure below shows an example of modular clustering in social networks. Small clusters of nodes interlinked with strong ties are interconnected with weak ties in a larger network.

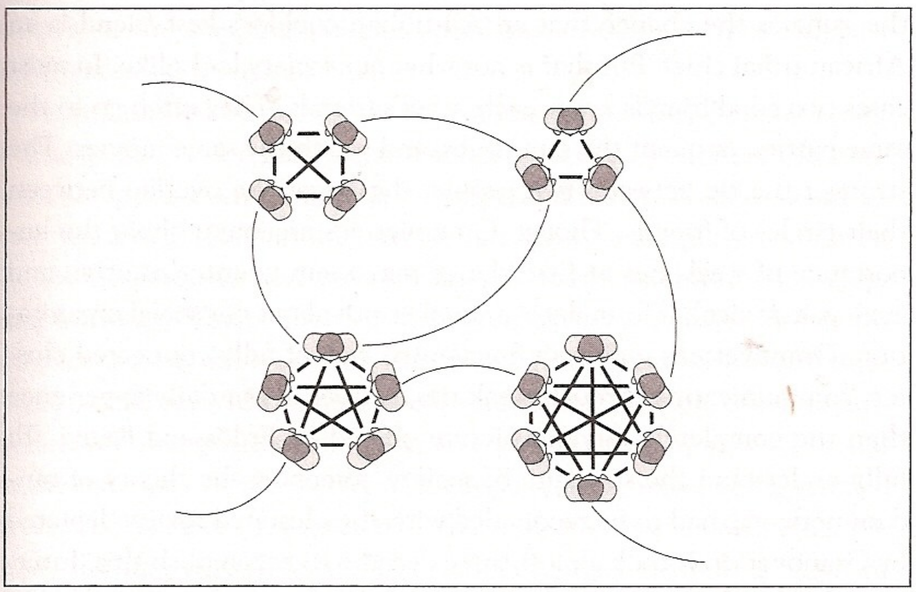


Figure 4.1 Strong and Weak Ties. *In Mark Granovetter's social world, our close friends are often friends with each other as well. The network behind such a clustered society consists of small, fully connected circles of friends connected by strong ties, shown as bold lines. Weak ties, shown as thin lines, connect the members of these friendship circles to their acquaintances, who have strong ties to their own friends. Weak ties play an important role in any number of social activities, from spreading rumors to getting a job.*

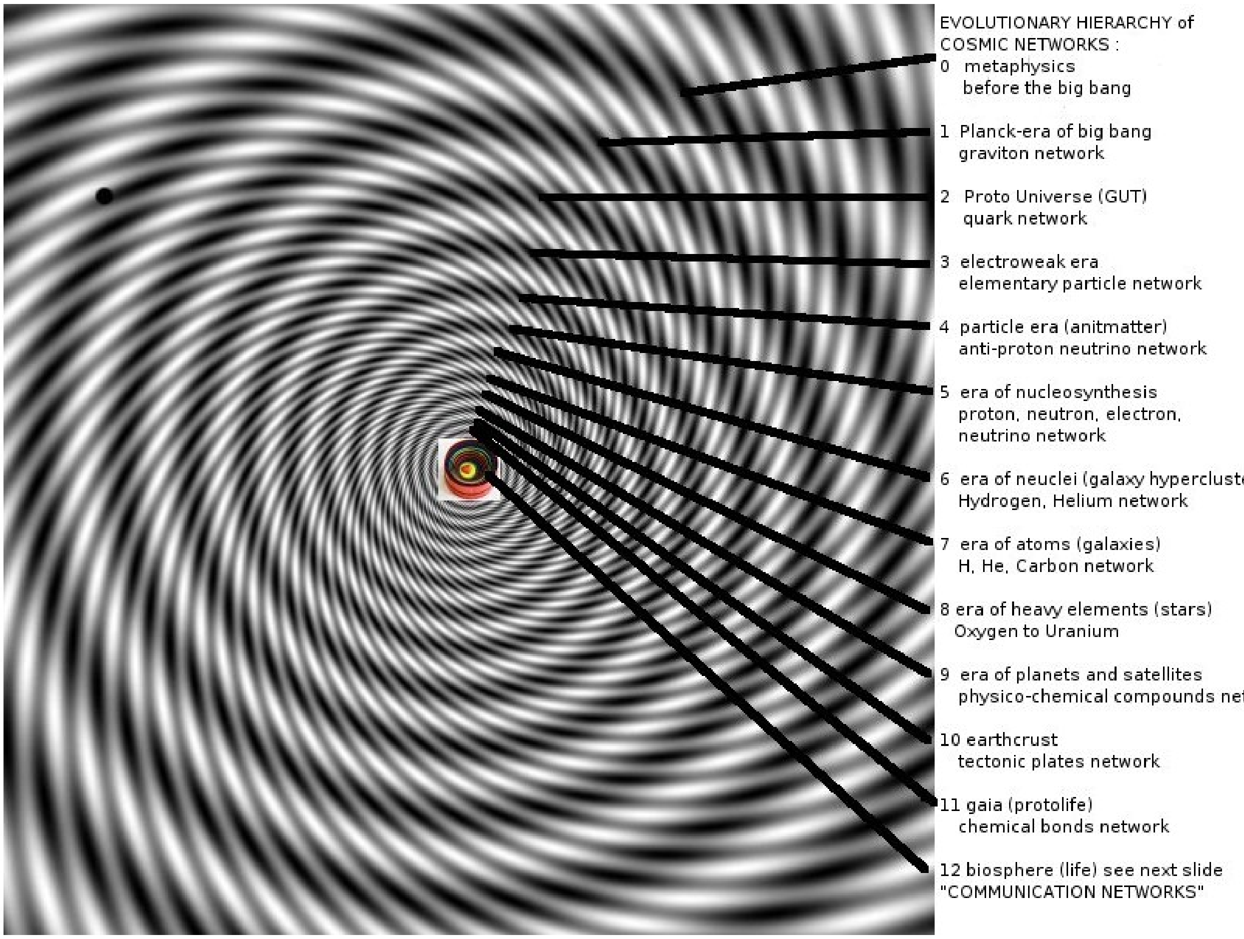
“Thanks to the high interest in clustering generated by Watts and Strogatz's unexpected discovery, the scientific community has subsequently scrutinized many networks. We now know that clustering is present on the Web, we have spotted it in physical lines that connect computers on the Internet; economists have detected it in the network describing how companies are linked by joint ownership, ecologists see it in food webs that quantify how species feed on each other in ecosystems; and cell biologists have learned that it characterizes the fragile network of molecules packed within a cell".

This citation of Barabási (Barabási 2003)shows that clustering is ubiquitous and a generic property of empirically observed complex networks.

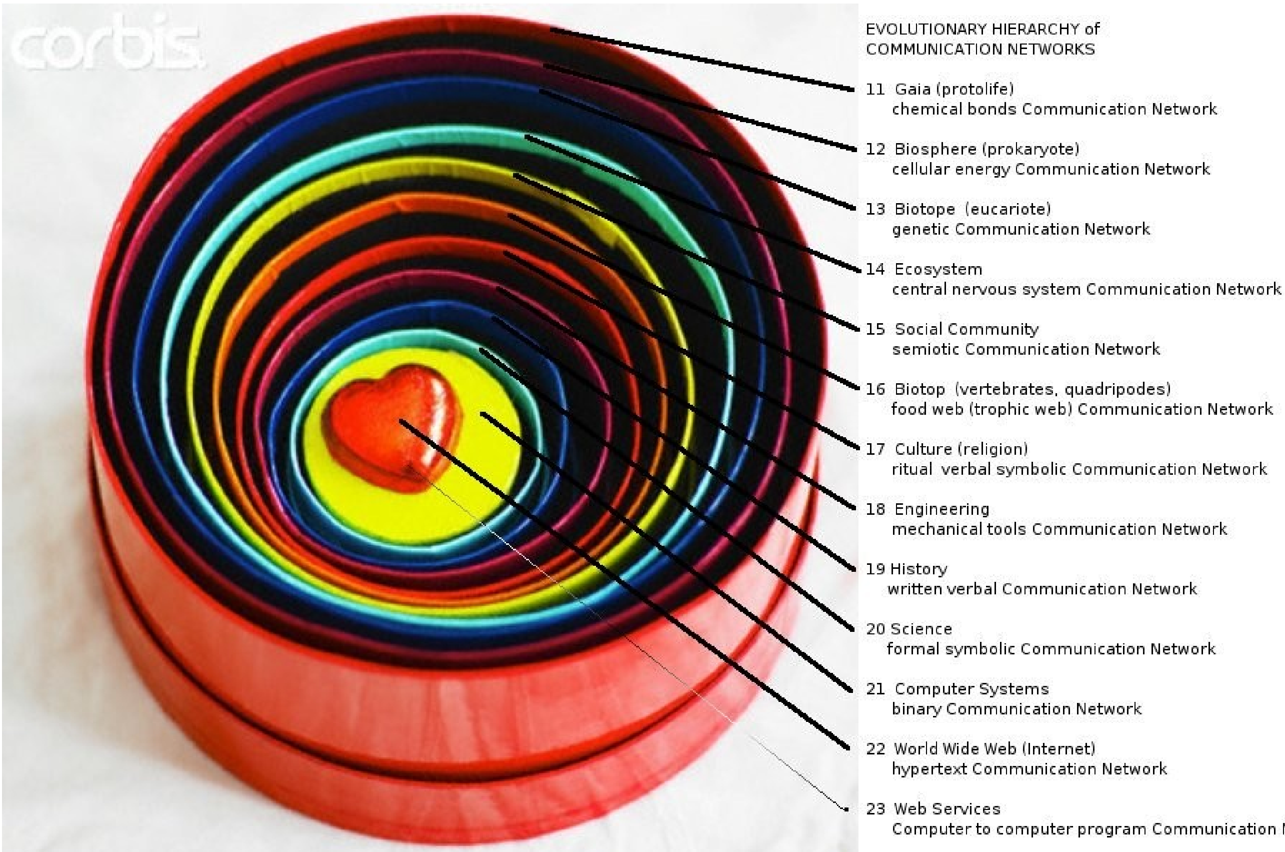
As we will show in the chapter on Neural Networks a modular network of the above type can be mapped on an Artificial Neural Network of a multilayer feed-forward network with back-propagation called also multilayer perceptron. While the above network limits itself to the description of the network topology the ANN model comprises the internal dynamics and information flow within the network: bottom up integration of inputs and top down differentiation through error back-propagation.

Levels of evolutionary hierarchy (2008 Winiwarter)

Hierarchies are ubiquitous. You find them in any science and in any field of research.
In fact the hierarchical "vision" of a system is a way to put a *static* order into the view of a complex system.
Networks are everywhere. You find them from galaxies to the World Wide Web. Again the networks don't exist, they are only a mental framework to put a *dynamic* order into the view of a complex system.
The Universe is a hierarchy – most people agree that it is not a flatland – but it can also be seen as a hierarchy of networks. How to put an order into this complex mess of viewpoints, points of view and world views?
We attempt to establish an evolutionary hierarchy based on clearly stated criteria.
A hierarchy is an ordered set - ordered according to an order criterion.
As order criterion for the universal evolutionary hierarchy we propose the time of emergence during evolution as observed by todays science.
By time of emergence we understand the first observation during the process of evolution of a given hierarchical level. Such the nested hierarchy of levels corresponds to the temporal sequence of their emergence.



The number of levels is arbitrary. For simplicity we choose 24 levels : 12 levels for the astrophysical evolution (deceleration and expansion of the universe from the big bang to the origins of biological life) and 12 levels from the early biosphere to the present of the Internet and Web Services (acceleration of evolution).



Evolutionary hierarchies are imbricated or embedded like "Russian dolls"

— *Humans have a natural tendency to find order in sets of information, a skill that has proven difficult to replicate in computers. Faced with a large set of data, computers don't know where to begin -- unless they're programmed to look for a specific structure, such as a hierarchy, linear order, or a set of clusters*. ScienceDaily (Aug. 28, 2008)

We introduced a zero level (background zero) for the metaphysical foundations of the model based on the standard big bang hypothesis.
Below an overview of astrophysical and biological hierarchical levels and the corresponding networks emerging at this level:

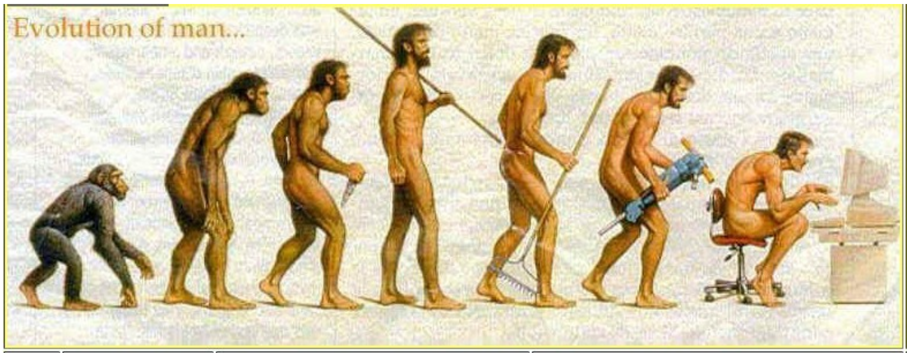
Such the 24 levels are imbricated like Russian dolls. Any other partition into a greater or smaller number of hierarchical levels would be equivalent as long as the partition respects the single order criterion, which is first time of emergence.

With this view, the higher levels in the hierarchy of complexity have autonomous causal powers that are functionally independent of lower-level processes. Topdown causation takes place as well as bottom-up action, with higher-level contexts determining the outcome of lower level functioning, and even modifying the nature of lower-level constituents.

Each of the hierarchical levels can be described as a complex interactive network. Each level having its characteristic "interaction units" or processors emerging from the prior level in the process of evolution.

Table of Evolutionary Hierarchies

	phase of evolution	Microscopic energy / information processor type	emerging energy / information field bonds linking the network	time scale since big bang	scientific discipline, link to empirical data	comments
0	metaphysics	man	consciousness	?	metaphysics	Short before the big bang?
1	Planck-era of big bang	graviton	super-grand-unified field	???	astrophysics theory	
2	proto-universe GUT era	quark	GUT, gravitation	10^{-43} sec	astrophysics theory	
3	electroweak era	elementary particles	strong force	10^{-35} sec	astrophysics theory	strong forces become distinct, perhaps causing inflation of the universe
4	particle era	antiproton, antineutrino antimatter	electromagnetic and weak force	10^{-10} sec	astrophysics theory	electromagnetic and weak forces become distinct
5	era of nucleosynthesis	protons, neutrons, electrons neutrinos	electromagnetic and weak force	10^{-3} sec	astrophysics theory	matter annihilates antimatter
6	era of nuclei	Hydrogen, Helium, electrons	strong nuclear	180 sec	astrophysics theory	Fusion ceases; normal matter is 75% hydrogen
7	era of atoms	H, He, C	carbon hypercycle	300.000 years	astrophysics	Atoms form, photons fly free and become background radiation
8	era of stars	H, He, C O, ... U	nuclear binding energy in atom (nuclide)	1 billion years	astrophysics	first galaxies form
	today			13.73 billion years	astronomy	humans observe the cosmos



				time scale from today		
	big bang			- 13.73×10^9 years *billion*		age of the universe
9	era of planets and moons	physico-chemical elements	trajectory bonds of planetary network	-4.54×10^9 years *billions*	astrophysics	
10	earthcrust	land-water agglomerates	geophysical bonds network	-3.8x10^9 years *billions*	geophysics	islands
11	gaia	macro-molecules hypercycles ATP	chemical bonds, trophic bonds in network (foodweb)	-3.5x10^9 years` *billions*	physics, phys-chem geology, geoscience, meteorology	mountains, lakes, rivers, floods
12	biosphere	proto-cells, selfreplicating unicellular metabolism (prokaryote) RNA	genetic network	-3.3x10^9 years *billions*	bio-chemistry	hypercycle, cell
13	biotope	cell (eucariote) DNA	energy transportation network, genetic network	-2.5x10^9 years *billions*	bio-chemistry, biology	genetic tradition, first photosynthesis by blue-green algae
14	ecosystem	multicellular organism	central nervous system network	-2.0x10^9 years *billions*	biology, plant, animal, ecosystems	oxygen from photosynthesis
15	social community	communication symbols, rituals	social communication network	-1.0x10^9 years *billions*	social systems; ethology,	first nucleated cells with organelles/ bacteria colonized single cells

16	Land plant animals	vertebrates	trophic web network	$-500x10^6$ years *millions*	plant, animal,	-200 to -100 million years Age of Dinosaurs
17	culture, religion	*homo economicus verbalis :* words	formal symbolic (verbal) communication network,	$-2x10^6$ years *millions*	economics linguistics, religion	oral traditiion, homo economicus
18	engineering & design	*homo mecanicus*: tools, buildings, machines	oral tradition and tools, mechanical systems network	-10.000 years	mechanical systems	it's in the cities that new forms of social interaction and mechanical systems emerge, (water, road)
19	history	*homo letteris*: icons, ideograms, letters	written communication network	-5.000 years	paleontology, history, communication systems	written tradition, communication networks, energy transportation networks (water, roads ... railroads, electricity, airports)
20	science	*homo scientificus*: formulas, laws	formal written symbolic community / network	-500 years	history of science,	formal written tradition; humans observe the cosmos
21	computers	*homo cyberneticus*: systems theories, systems laws	binary systems network	-50 years	cybernetics, science of science	transdisciplinary tradition
22	world-wide-web	*homo networked:* URL universal resource locator on computer networks	man computer internet network, artificial neural networks, scientometrics	-18 years	computer tech, neural networks scientometrics metaphilosophy	putting it all together on the web, this site
23	Semantic WEB	*computer communicans*	WEB services network	-2 years future	Amazon(Amazon Web Servicies), Google Semantic Web	computers communicating directly with computers

The network of processors create a field specific to the level, which is the interaction of all processors specific to the hierarchical level.
For a level to exist, all prior levels are necessary, since they constitute the environment of the new emerging level. There is no science without language, there is no language without semiotic communication, there is no semiotic communication without central nervous systems ...
There are no chemical compounds without atoms, there are no atoms without nucleons, there are no nucleons without quarks ...

A general process of emergence is described in the paper Autognosis, the theory of Hierarchical self-

image building systems (Winiwarter 1986). In this paper we advance the hypothesis of an underlying isomorphic self-organizational core process by which learning and evolutionary processes in general take place.
The core idea is that evolution is a simultanous process of global top down differention of the environment and local bottom up integration of elements or processors. As a generic example we describe the evolution of nucleosynthesis in a massive star with the emergence of nested cores. In each core there is synthesis of nucleons from protons to helium, from helium to carbon ...

A Summary of Principles of Hierarchy Theory

The Hierarchy theory is a dialect of general systems theory. It has emerged as part of a movement toward a general science of complexity. Rooted in the work of economist, Herbert Simon, chemist, Ilya Prigogine, and psychologist, Jean Piaget, hierarchy theory focuses upon levels of organization and issues of scale. There is significant emphasis upon the observer in the system.

Hierarchies occur in social systems, biological structures, and in the biological taxonomies. Since scholars and laypersons use hierarchy and hierarchical concepts commonly, it would seem reasonable to have a theory of hierarchies. Hierarchy theory uses a relatively small set of principles to keep track of the complex structure and a behavior of systems with multiple levels. A set of definitions and principles follows immediately:

Hierarchy: in mathematical terms, it is a partially ordered set. In less austere terms, a hierarchy is a collection of parts with ordered asymmetric relationships inside a whole. That is to say, upper levels are above lower levels, and the relationship upwards is asymmetric with the relationships downwards.

Hierarchical levels: levels are populated by entities whose properties characterize the level in question. A given entity may belong to any number of levels, depending on the criteria used to link levels above and below. For example, an individual human being may be a member of the level i) human, ii) primate, iii) organism or iv) host of a parasite, depending on the relationship of the level in question to those above and below.

Level of organization: this type of level fits into its hierarchy by virtue of set of definitions that lock the level in question to those above and below. For example, a biological population level is an aggregate of entities from the organism level of organization, but it is only so by definition. There is no particular scale involved in the population level of organization, in that some organisms are larger than some populations, as in the case of skin parasites.

Level of observation: this type of level fits into its hierarchy by virtue of relative scaling considerations. For example, the host of a skin parasite represents the context for the population of parasites; it is a landscape, even though the host may be seen as belonging to a level of organization, organism, that is lower than the collection of parasites, a population.

The criterion for observation: when a system is observed, there are two separate considerations. One is the spatiotemporal scale at which the observations are made. The other is the criterion for observation, which defines the system in the foreground away from all the rest in the background. The criterion for observation uses the types of parts and their relationships to each other to characterize the system in the foreground. If criteria for observation are linked together in an asymmetric fashion, then the criteria lead to levels of organization. Otherwise, criteria for observation merely generate isolated classes.

The ordering of levels: there are several criteria whereby other levels reside above lower levels. These criteria often run in parallel, but sometimes only one or a few of them apply. Upper levels are above lower levels by virtue of: 1) being the context of, 2) offering constraint to, 3) behaving more slowly at a lower frequency than, 4) being populated by entities with greater integrity and higher bond strength than, and 5), containing and being made of - lower levels.

Nested and non-nested hierarchies: nested hierarchies involve levels which consist of, and contain, lower levels. Non-nested hierarchies are more general in that the requirement of containment of lower levels is relaxed. For example, an army consists of a collection of soldiers and is made up of them. Thus an army is a nested hierarchy. On the other hand, the general at the top of a military command does not consist of his soldiers and so the military command is a non-nested hierarchy with regard to the soldiers in the army. Pecking orders and a food chains are also non-nested hierarchies.

Duality in hierarchies: the dualism in hierarchies appears to come from a set of complementarities that line up with: observer-observed, process-structure, rate-dependent versus rate-independent, and part-whole. Arthur Koestler in his "Ghost in The Machine" referred to the notion of holon, which means an entity in a hierarchy that is at once a whole and at the same time a part. Thus a holon at once operates as a quasi-autonomous whole that integrates its parts, while working to integrate itself into an upper level purpose or role. The lower level answers the question "How?" and the upper level answers the question, "So what?"

Constraint versus possibilities: when one looks at a system there are two separate reasons behind what one sees. First, it is not possible to see something if the parts of the system cannot do what is required of them to achieve the arrangement in the whole. These are the limits of physical possibility. The limits of possibility come from lower levels in the hierarchy. The second entirely separate reason for what one sees is to do with what is allowed by the upper level constraints. An example here would be that mammals have five digits. There is no physical reason for mammals having five digits on their hands and feet, because it comes not from physical limits, but from the constraints of having a mammal heritage. Any number of the digits is possible within the physical limits, but in mammals only five digits are allowed by the biological constraints. Constraints come from above, while the limits as to what is possible come from below. The concept of hierarchy becomes confused unless one makes the distinction between limits from below and limits from above. The distinction between mechanisms below and purposes above turn on the issue of constraint versus possibility. Forget the distinction, and biology becomes pointlessly confused, impossibly complicated chemistry, while chemistry becomes unwieldy physics.

Complexity and self-simplification: Howard Pattee has identified that as a system becomes more elaborately hierarchical its behavior becomes simple. The reason is that, with the emergence of intermediate levels, the lowest level entities become constrained to be far from equilibrium. As a result, the lowest level entities lose degrees of freedom and are held against the upper level constraint to give constant behavior. Deep hierarchical structure indicates elaborate organization, and deep hierarchies are often considered as complex systems by virtue of hierarchical depth.

Complexity versus complicatedness: a hierarchical structure with a large number of lowest level entities, but with simple organization, offers a low flat hierarchy that is complicated rather than complex. The behavior of structurally complicated systems is behaviorally elaborate and so complicated, whereas the behavior of deep hierarchically complex systems is simple.

Hierarchy theory is as much as anything a theory of observation. It has been significantly operationalized in ecology, but has been applied relatively infrequently outside that science. There is a negative reaction to hierarchy theory in the social sciences, by virtue of implications of rigid autocratic systems or authority. When applied in a more general fashion, even liberal and non-authoritarian systems can be described effectively in hierarchical terms. There is a politically correct set of labels that avoid the word hierarchy, but they unnecessarily introduce jargon into a field that has enough special vocabulary as it is.

Power laws and the laws of Power

> "Power laws are emergent general features of complex systems. Despite the complex and idiosyncratic features of organisms and the ecosystems where they occur, there are aspects of the structure and function of these systems that remain self-similar or nearly so over a wide range of spatial and temporal scales. Empirical power laws describe mathematically the hierarchical, fractal-like organization of these systems. Presumably these power laws reflect the outcome of simple rules or mechanisms. On the one hand, simple mechanisms that determine the structure and function of the fundamental components at the smallest scales constrain how these parts function when they are assembled in progressively larger subsets or hierarchies.
> On the other hand, simple mechanisms constrain the structure, and dynamics at the largest scales also place powerful limits on how the components interact and assemble in the large, complex system. Together, these bottom–up and top–down mechanisms give rise to power laws and other emergent features."

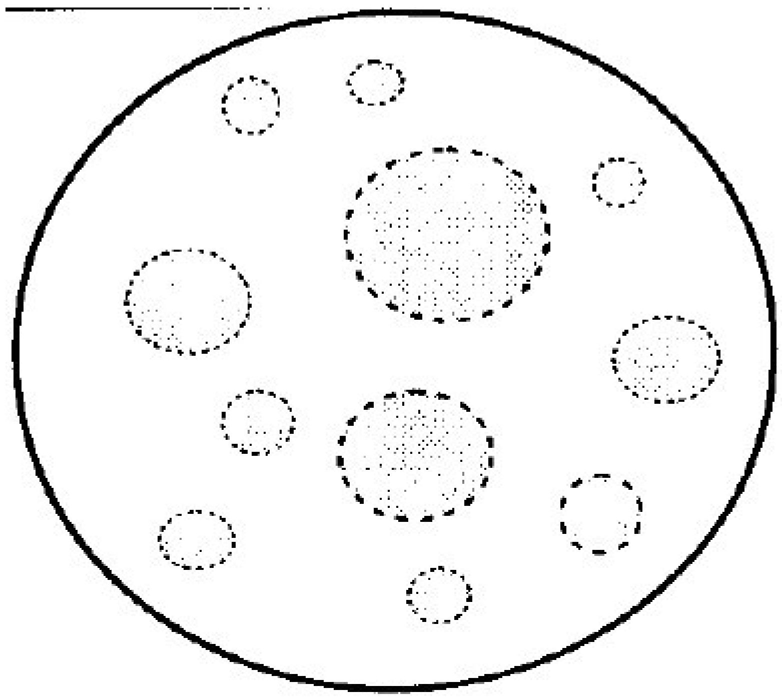
The fractal nature of nature: power laws, ecological complexity and biodiversity
James H. Brown, Vijay K. Gupta, Bai-Lian Li, Bruce T. Milne, Carla Restrepo and Geoffrey B.West
http://www.fractal.org/Bewustzijns-Besturings-Model/Fractal-Nature.pdf

"It is an interesting possibility that the power laws followed by so many different kinds of systems might be the result of downward constraintes exerted by encompassing supersystems."

Stanley N. Salthe, ***Entropy*** 2004, **6**, 335

Common 3-level hierarchical structure

Power laws of the Pareto-Zipf-Mandelbrot (hyperbolic fractal) type are observed for class-size distributions of virtually all evolutionary hierarchical levels ranging from the field of astrophysics to the Internet.



All observed regularities are based on a 3-level hierarchical description, see figure below:

Figure. The three-level hierarchy of a Pareto-Zipf-Mandelbrot PZM distribution: local processing units (small dots), processing unit classes (dotted circles) and global interaction system (fat circle)

Let us have a closer look at this hierarchy at hand of and example.

City-size distribution show PZM regularities for any country of the world.

Interaction units

Interaction units – small dots in the figure – are the third and basic level of the 3-level hierarchy: interaction system, equivalence classes, interaction units. In our example the basic local interaction unit is an inhabitant, which is assigned to a class (city) during the snapshot of the system.

The class size distribution of the system changes only due to three possible interactions:

- birth of an interaction unit (new inhabitant)
- death of an interaction unit (disappearance of an inhabitant) and
- migration of an interaction unit from one class (city) to another class (city) within the network during two consecutive snapshots (US census)

Interaction units may be closed energy information processors or operators as defined in the operator hierarchy approach.

In our example above the basic interaction units are human inhabitants, better households or oikos in our terminology. Basic households are the building blocks for aggregates on a town or city level.

Equivalence classes of interaction units

Equivalence classes – dotted circles in the figure – are aggregates of interaction units, cities in our example. The interaction units (inhabitants) belonging to the same class (inhabitants of the same city) are equivalent for the statistical analysis. The class sizes, number of operators per class, show the characteristic PZM distribution at a census measurement, that is a count of all individual inhabitants during a snapshot of the system.

There are few very big agglomerations like New York and Los Angeles with millions of inhabitants, few big agglomerations of hundred thousand inhabitants and very many small agglomerations in the range of 10.000 inhabitants. In quantitative geography this regularity is called rank-size rule

Interaction system, closed network of interaction units

The global system – fat circle in the figure - for which we observe a PZM regularity we call interaction system. This system is delimited within a boundary, frontier of the US in our example. This boundary or frontier is more or less impermeable to the interaction units of the network, while movements of interaction units (inhabitants) between equivalence classes (cities) within the system are frequent and relatively free.

Note that PZM regularities are observed only within a closed boundary of an interaction system. We observe PZM regularities for the entire United States but also for each individual state with the exception of Texas. An explanation for this exception may be the fact, that the frontiers of Texas are arbitrary straight lines on a map not corresponding to a quasi impermeable membrane.

The same approach of description of a 3-level hierarchy can be applied in astrophysics to massive stars for which we observe PZM regularities.

The **interaction system** level is the entire massive star (e.g. the sun or) with its surface as boundary. Within this system we have interactions between local **interaction units** called atoms (nuclei), which can be classified into **equivalence classes** called chemical elements. The sizes of the equivalence classes (frequencies of chemical elements) follow a PZM regularity. See figure later in this chapter.

Likewise we can analyze **any** interaction system revealing PZM regularity.

Let us take another example, a national economy.

The **interaction system** is the entire economy (e.g. a country or the entire world). Within this system we have interactions between local **interaction units** called monetary units (Dollars or Euros), which can be classified into **equivalence classes** called firms (turnover of a firm or assets of a firm). The sizes of the equivalence classes (firm sizes) follow a PZM regularity.

A short history of discovery across the disciplines

1897 Wilfredo Pareto, income distribution

The first extensive discussion of the problem how income is distributed among the citizens of a state was made by Vilfredo Pareto in 1897 [Pareto, 1987]. On the basis of data collected from numerous sources Pareto arrived at the following law:

In all places and at all times the distribution of income in a stable economy, when the origin of measurement is at a sufficiently high income level, will be given approximately by the empirical formula

(1) $n = a S^{\gamma}$

where n is the number of people having the income S or greater, a and .y are constants.

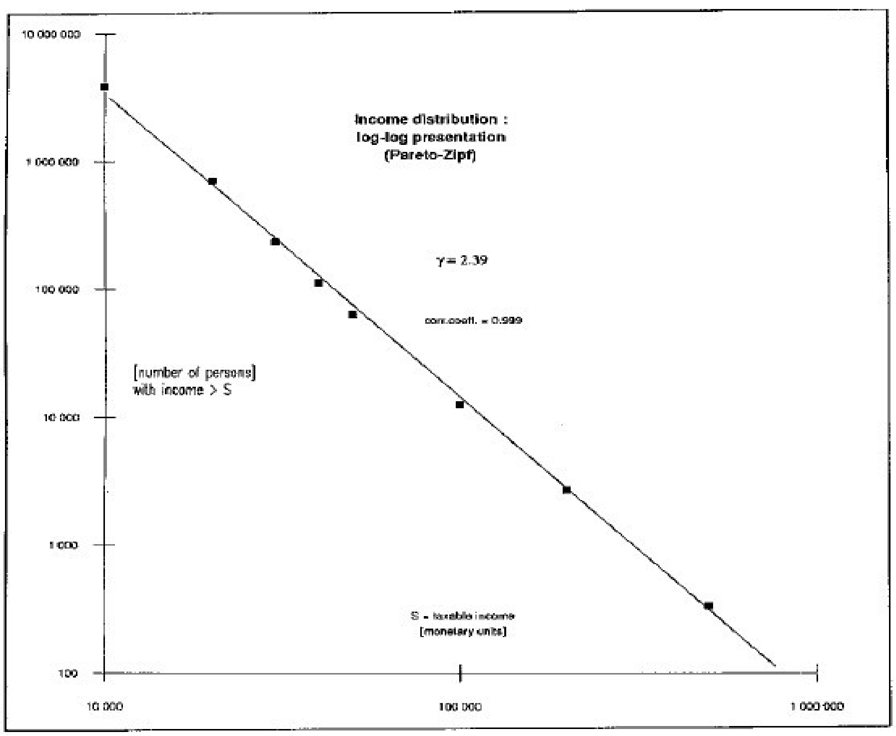


Figure. It is difficult to represent the data graphically within ordinary arithmetic scales . The data are taxable incomes of 1937 in France, but any other country and year yields distributions of the above type. Note the almost perfect correlation coefficient. Data Source [Winiwarter, 1992]

It is extremely interesting to note, that empirical observations of Pareto distributions are:

i) not markedly influenced by the socio-economic structure of the community under study

ii) not markedly influenced by the definition of "income" .

The Pareto law holds for a few hundred burghers of a city-state of the Renaissance up to the more than l00 million taxpayers in the USA. Essentially the same law continues to be followed by the distribution of "income", despite the changes in the definition of this term.

Note: this empirical evidence is a contradiction to any ideology striving for equal distribution of incomes. As we shall see below, this goal is just as unrealistic and unnatural as the goal to make all cities of a country of the same size i.e. the same number of inhabitants. Likewise it is 'unnatural' to make all business firms of equal size or to use in a text all words with equal frequency.

Pareto was intrigued by the generality of his discovery: "These results are very. remarkable . It is absolutely impossible to admit that they are due only to chance . “There is most certainly a cause, which produces the tendency of incomes to arrange themselves according to a certain curve.”

1913 Auerbach, the distribution of city sizes in countries

Looking for a new measure for population concentration, Auerbach [Auerbach, 1913] analyzed the distribution of cities within a country. He ranked the cities in decreasing order of inhabitants and discovered a relationship between rank and size of the type

(2) $S(j) = a \; j^{\beta}$

with S(j) the size of the city ranked j, a and β are constants.

As an example let us consider the city-size distribution of France.

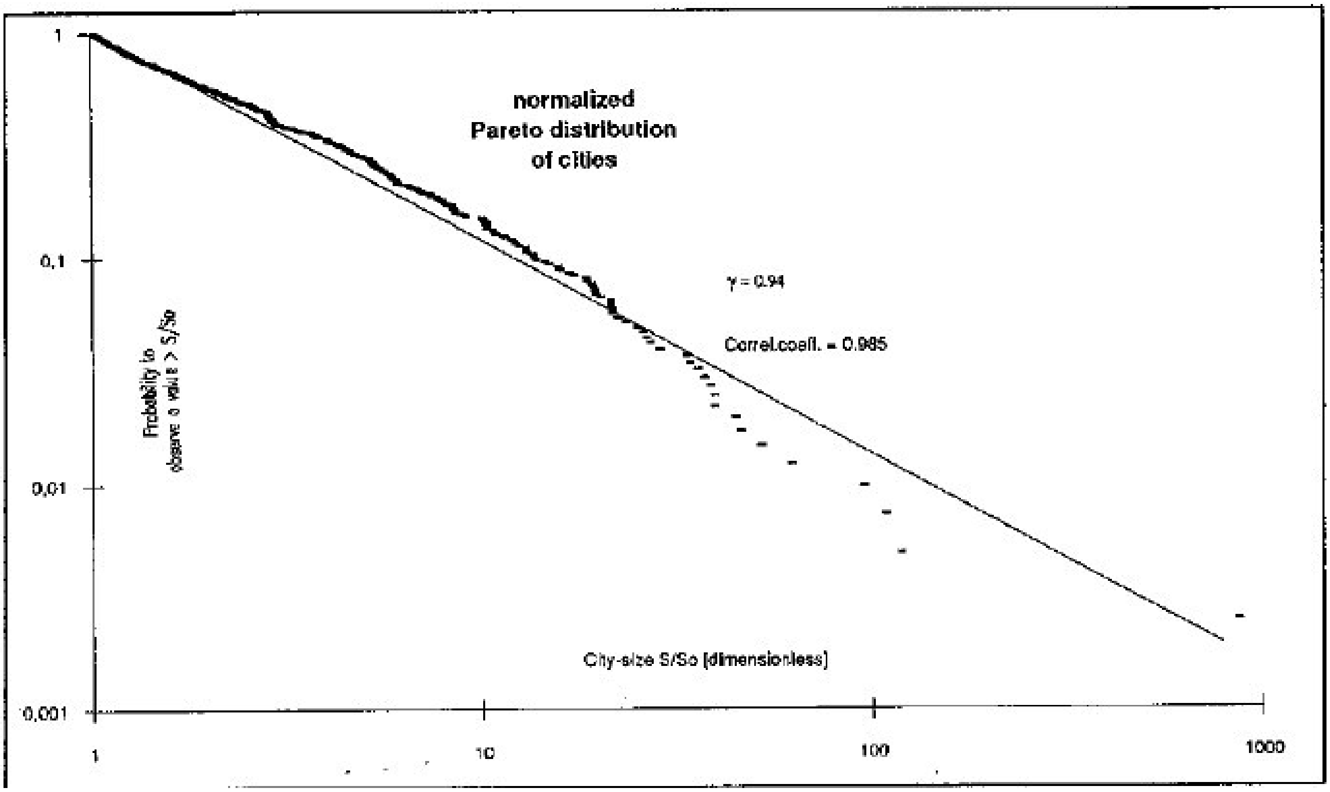


Figure. The cumulative probability as a function of the dimensionless symptom S/So. S is the city size and S_0 the smallest or threshold size for of the observed set of cities (here 10.000). Data Source [Winiwarter, 1992]

1912 Willis-Yule, the distribution of species, genera and families in biological systems

Based on field observation in Ceylon in Willis [Willis, 1912] first noticed, that the distribution of species within the genera of an ecosystem follows a regularity, which is of the Pareto-Zipf type.

“ this type of curve holds not only for all the genera of the world, but also for all the individual families both of plants and animals, for endemic and non-endemic genera, for local floras and faunas ... it obtains too, for all the deposits of Tertiary fossils examined ."

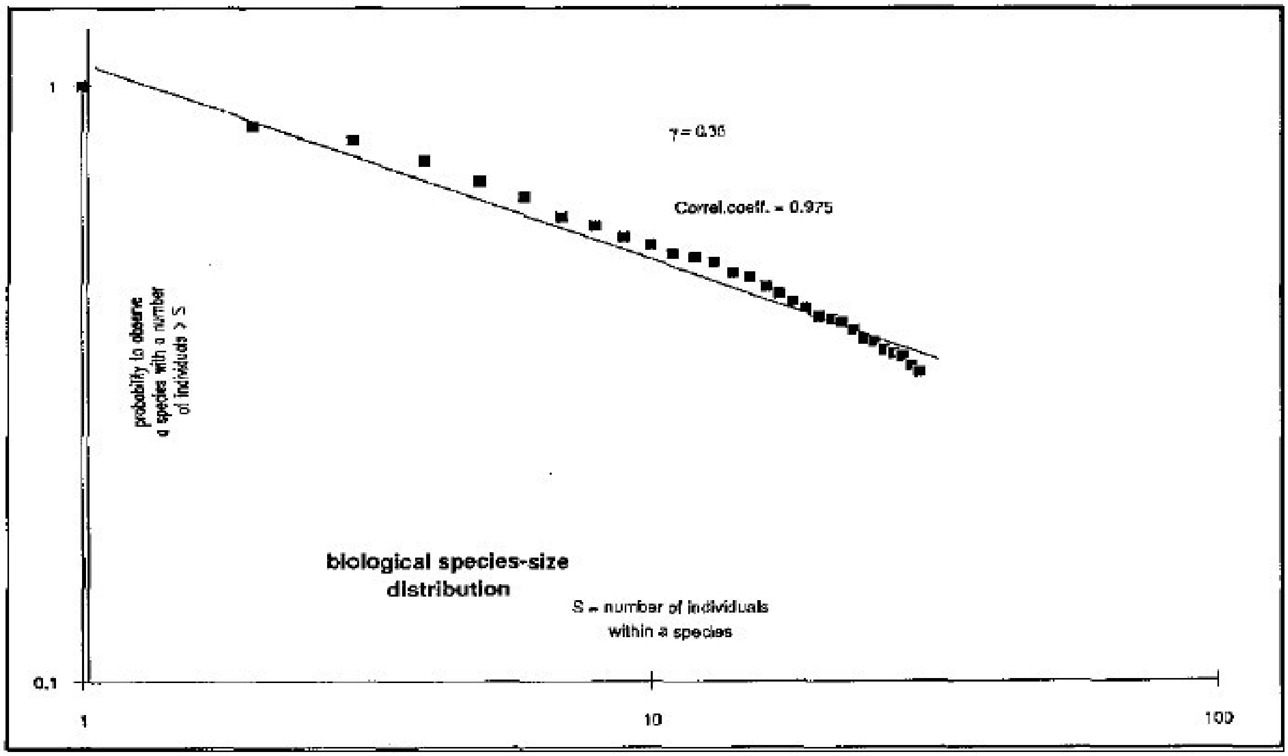


Figure. Species-size distribution of Macrolepidoptera. 15 609 individuals were captured belonging to 240 species. Data Source [Winiwarter, 1992]

Further analysis of data have shown, that similar regularities hold also for the distribution of parasites on hosts, the distribution of individuals within species and the distribution of genera within families of any observed ecosystem at any time.

1948 George Kingsley Zipf the linguist, word frequencies

In his magnum opus Zipf [Zipf, 1948] reports regularities of the above type for a wide variety of fields, but his main interest is human language for which he analyzed word-frequency distributions.
James Joyce's Ulysses is the "richest" known text with almost 30 000 words and word occurrences ranging from 1 to 2 653. The empirical data can be approximated almost too perfectly by a Pareto-Zipf distribution.
Zipf found regularities of similar type for all types of English text, for all types of languages and for all times, even for Chinese text and also for spoken language of children of different ages. The exponent is in all cases close to 1.
The only exceptions reported by Zipf are texts written by schizophrenics and scientific English.

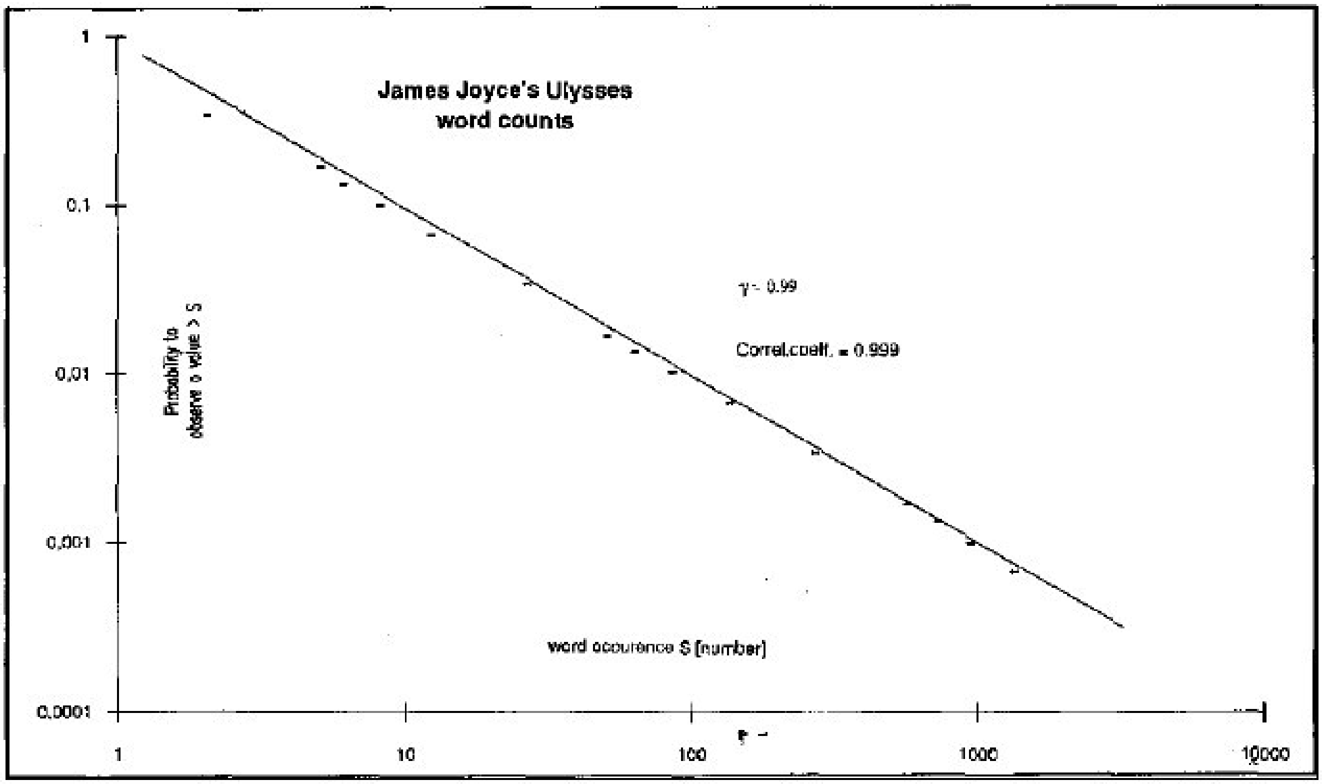


Figure. Word counts for texts in any language yield Pareto-Zipf distributions. In normalized form the graph shows the probability of a word to occur more the S times in the text. Data Source [Winiwarter, 1992]

Zipf also reports, that the distribution of scientists within a research discipline is of Pareto-Zipf type. The observed "symptom" of a scientist is measured as the number of citations in the physical or chemical abstracts.
As a side remark we note that the author [Winiwarter, 1992] has discovered that the size-distribution of programs on the hard disk of a computer are of Pareto-Zipf type.

1955 Herbert Simon, firm size distributions

Herbert Simon, who won the Nobel prize for economics in 1978, has intensively studied firm-sizes: Whether sales, assets, number of employees, value added, profits, or capitalization are used as a size measure, the observed distribution always are of the Pareto-Zipf type. This is true for the data for individual industries (economic sectors) and for all industries taken together. It holds for sizes of plants as well as of firms.
Take any annual number of the Fortune 500 magazine and you can verify this assertion, which also

holds for any national economy and also for multinational companies on a world level.
We have analyzed the Fortune data over a period of 30 years [Roehner, Winiwarter, 1984] and found, that the parameter γ of the size-distributions remains almost constant over the entire period of observation. This self-similarity of the distribution curves holds in periods of overall economic growth as well as in periods of economic recession and despite the fact, that firms appear and disappear. From the 50 largest industrial firms in 1954 only 20 can be found among the 50 largest 3 decades later, the other 30 have declined in size, been absorbed in mergers and acquisitions or simply have gone out of business . On the other hand, 12 of the 50 largest firms were not even ranked among the 500 largest in 1954 or did not even exist at that time.
To observe a constant size-distribution despite this intensive shuffling around within the system is quite remarkable .
As Herbert Simon stated in the conclusion of his paper: "We need to know more about the relations between the distributions and the **generating processes"** .
Since the graphs oft the empirical data are monotonously similar, we will not burden the reader with examples.
Over time, the Pareto-Zipf line seems to act as an ***attractor*** for "deviating points" . For example in the computer industry we had a similar situation as in the case of the largest French cities. IBM, the number one, was "too big" and the next ten following companies were "too small" deviating from the attracting straight line. The evolution of the following 10 years has brought the "deviations" almost back in line again due to:
i) a relative decline of the growth rate of IBM reducing its "deviation"
ii) an above average growth rate of DEC, the number two follower bringing it closer to the attractor
iii) several mergers and acquisitions among the top computer companies reducing the overall deviations.

1956 Gutenberg-Richter the distribution of earthquakes

In 1956, the geologists Beno Gutenberg and Charles Richter (the father of the seismological scale of the same name) discovered [Richter, 1958], that the number of important earthquakes is linked to the number of small earthquakes :
the law of Gutenberg-Richter states, that the number of annual earthquakes as a function of the liberated Energy, is a Pareto-Zipf-distribution . The exponent $\gamma = 1.5$ is universal and does not depend on the geographical region!

1983 Winiwarter, the distribution of chemical elements in cosmic systems

The analysis of chemical element distributions within stars or within the entire cosmos is traditionally presented as relative abundance versus the mass number of the elements.

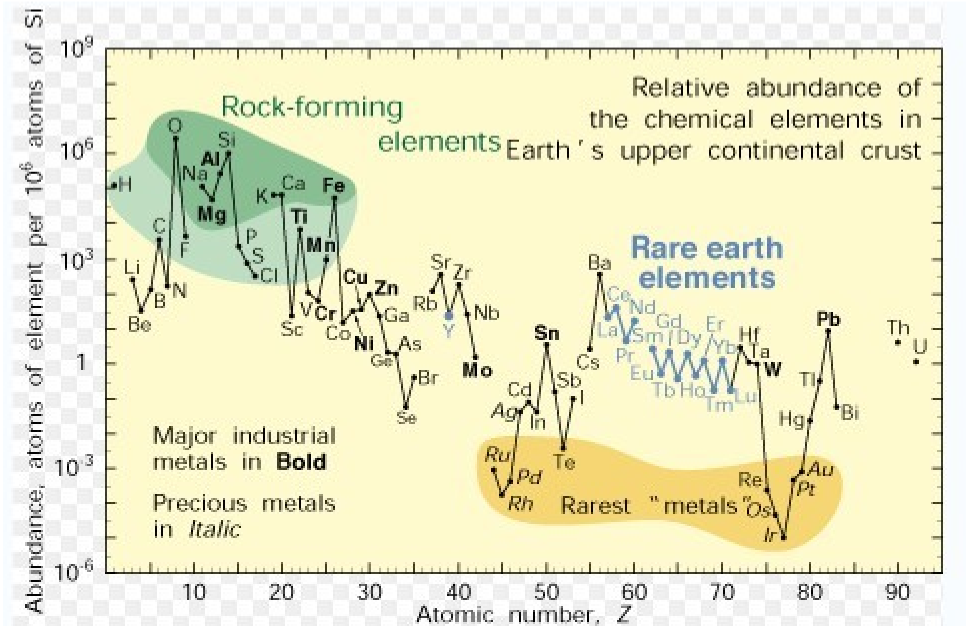


Figure. Relative abundance of chemical elements in the universe as a function of atomic mass. This graph does not allow to deduce any quantitative regularity except a decrease of abundance with mass number with peaks around the "magic numbers". Data Source [Wikipedia]

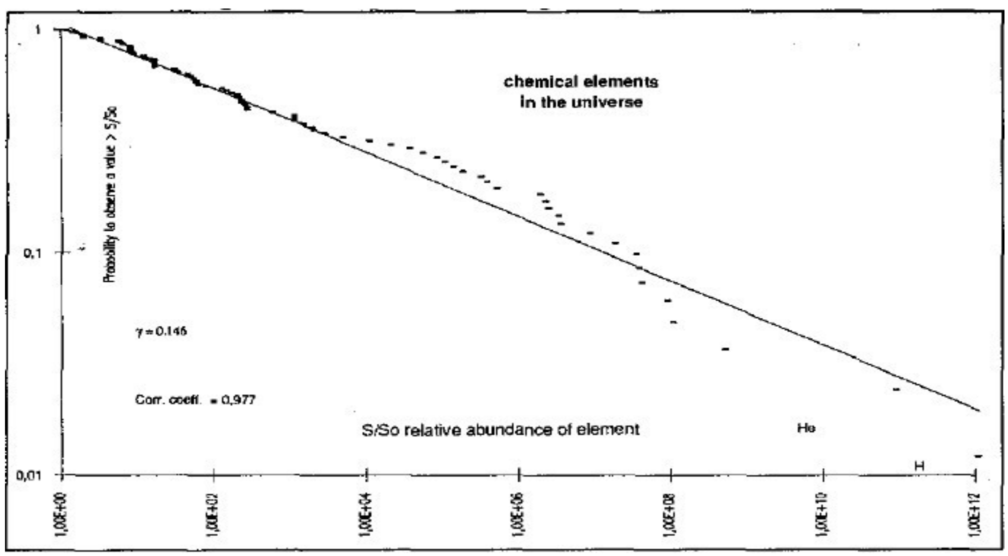


Figure. The same data as in the figure above presented as a normalized Pareto-Zipf distribution revealing a distinct quantitative regularity. Data Source [Winiwarter, 1992]

This type of regularity for the abundance of chemical elements can be observed for the universe, for single stars, for meteorites, for the lithosphere ...
Similar regularities can be observed for star-size distributions in galaxies, for the planet-size distribution in our solar system, for the moon-size distributions of the Jupiter system ...

1991 Cempel, the distribution of vibration amplitudes in mechanical machine systems

Research in the field of vibration diagnostics [Cempel, 1991] has revealed, that long-tailed Pareto-like distributions are a good approximation for the data yielded by empirical measurements of vibration symptoms for a set of "running" machines :
the regularities are observed independently of the machine type (electro motors, diesel engines ...)

Do we live in a Pareto-Zipf world?

This short historical overview showed the discovery of similar regularities for incomes, cities, species, words, earthquakes, chemical elements, machine vibrations. How can this possibly make sense without postulating similar underlying structures and processes of the observed systems?
With the rapid development of complex network theory in the 1990ties Power laws have been observed in almost all systems of research ranging from protein networks to the World Wide Web.
In the following chapter we will give some illustrated examples of the systems, for which we observe Pareto-Zipf-Mandelbrot Power laws.

Pareto-Zipf-Mandelbrot (PZM) and parabolic fractal distributions

There exists a great variety of names for the same type of empirically observed distributions in self-organized systems:

long tail , "*longtailed* "/ "*heavy tailed* "/ "*skewed*" distributions, Pareto law, Zipf's law, Zipf-Mandelbrot law, lognormal distribution , Yule-Simon distribution, Frechet Weibull distribution, rank-size rule, parabolic fractal distribution, 80/20 rule, the law of the vital few ***and the principle of factor sparsity*** ...law of Gutenberg-Richter, Lotka's law, Bradford's law , Benford's law ... selforganized critically ***power laws***, scaling laws, scalefree networks, ...

all are synonyms of the same statistical **power law structur**e called **PZM** (***Pareto-Zipf-Mandelbrot***).

The common statistical feature of all the distribution types cited above are simple, they yield more of less straight lines in log log coordinates.
The mathematical forms of the distributions are more or less complicated. Statisticians have done extensive studies http://arxiv.org/PS_cache/arxiv/pdf/0706/0706.1062v1.pdf, trying to find out which distribution yields the best fit to a given data set. But they show, that if one distribution yields a good

fit, then all the other distributions yield good fits also. (Error type three in the inquiry question, which is not what distribution is best, but why do we observe always similar distributions).
Let's apply Occam's razor and say that the most simple distribution will do it (the simple Pareto power law, which is equivalent to Zipf's law or the rank size rule by simple inversion of coordinates. For discrete distributions (which are the case in most real examples) the Zipf-Mandelbrot or parabolic fractal distribution is the most simple form to prefer to complex constructs like Yule-Simon or Frechet Weibull.
In the following we therefore speak of PZM (**Pareto-Zipf-Mandelbrot or parabolic fractal distribution**).

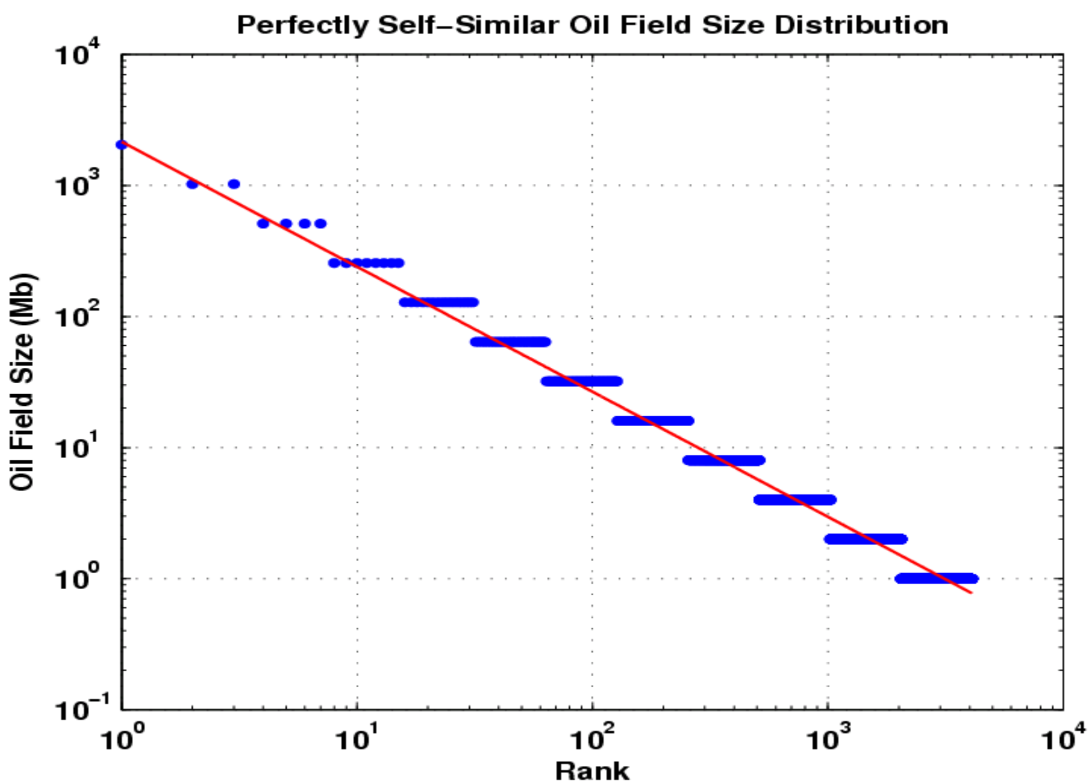


Figure. Parabolic fractal distribution, the logarithm of the frequency or size of entities in a population is a quadratic polynomial of the logarithm of the rank.

How to explain this to a non-mathematician?
Very simple:

Let's take the income size distribution of any country. There are very few very rich billionaires, there are few rich millionaires, there are many middle class people and the remaining vast majority are just plain poor. This inequality can be described by a mathematical distribution, which yields a straight line in log-log coordinates. (Pareto law).

Another example for PZM Pareto-Zipf-Mandelbrot regularity. Let's take the city size distribution of a country and rank the cities in decreasing order of number of inhabitants. There are a few very big metropolis, there are a few big cities, there are many cities of medium size and the vast number of agglomerations are small towns. This inequality can be described by a mathematical distribution, which yields a straight line in log-log coordinates. (rank size rule). etc...

This asymmetric distribution is very different from the well known Gaussian bell shaped symmetric distribution.

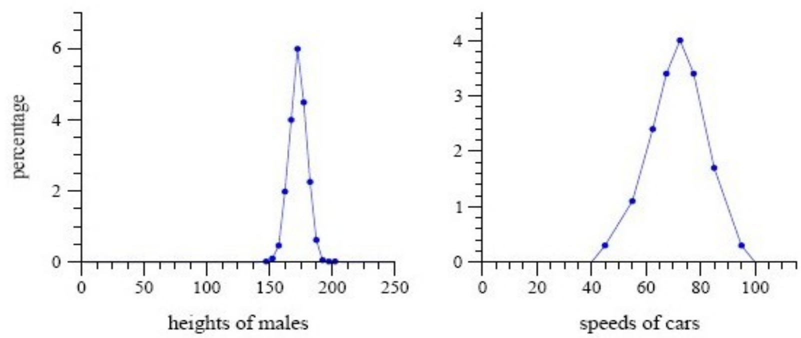


FIG. 1 Left: histogram of heights in centimetres of American males. Data from the National Health Examination Survey, 1959–1962 (US Department of Health and Human Services). Right: histogram of speeds in miles per hour of cars on UK motorways. Data from Transport Statistics 2003 (UK Department for Transport).

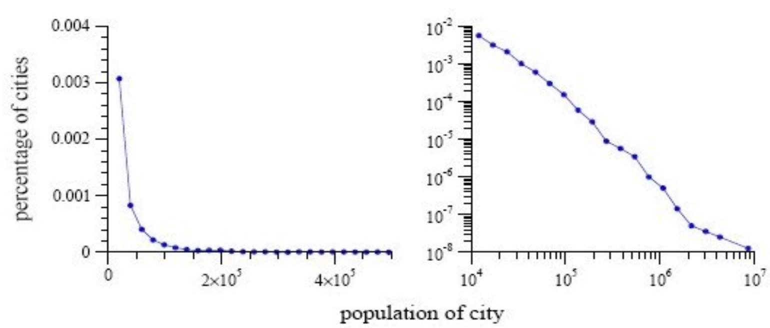


FIG. 2 Left: histogram of the populations of all US cities with population of 10 000 or more. Right: another histogram of the same data, but plotted on logarithmic scales. The approximate straight-line form of the histogram in the right panel implies that the distribution follows a power law. Data from the 2000 US Census.

normal Gaussian distribution versus Pareto-Zipf distribution

For those who persist to say they are the same mathematical structures, there is a major difference even in the second and third degree of a Taylor development.

Pareto-Zipf-Mandelbrot (parabolic fractal) distributions are scalefree.

In the PZM or parabolic fractal distribution the right tail of the poor is very much longer than the short left tail of the rich. Therefore the term longtailed. For these distributions there is no such thing calculable like a mean or average income, since there is no symmetry and a value would be different for every arbitrary cutoff point in the ranking.

Note that there are only two families of mathematical distributions which do not change their form after the merger or split of system distributions :
1) the Gaussian *(Gauss folded with Gauss yields Gauss).*
2) the Pareto-Zipf-Mandelbrot distribution *(Pareto folded with Pareto yields Pareto).* *see the chapter on stability under addition.*

For all the following examples in the next chapter we observe similar regularities of the Pareto-Zipf-Mandelbrot (parabolic fractal) type in the fields of:

astrophysics, geophysics, geology, geoscience, physics, meteorology, physico-chemistry, biochemistry, biology, plant, animal, ecosystems, environment, social systems, transportation systems, economics, sociology, religion, linguistics, mechanical systems, computer technology, world wide web, scientometrics, brain, neural networks ...