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Fundamentals of Complex Evolving Systems: A Primer

Ekke Weis

Es ist gewiß gefährlich, wenn man die kalte wissenschaftliche Forschung bis zu einem Punkt treibt, wo ihr Gegenstand einen nicht mehr gleichgültig läßt, sondern einen vielmehr versengt. Das Sieden, das ich untersuche und das den Erdball bewegt, ist auch *mein* Sieden. So kann das Objekt meiner Untersuchung nicht mehr vom Subjekt geschieden werden, genauer noch: *vom Subjekt auf seinem Siedepunkt*.

Georges Batailles (1975) *Die Aufhebung der Ökonomie*[1]

Die Naturwissenschaft wird später ebensowohl die Wissenschaft von dem Menschen wie die Wissenschaft von dem Menschen die Naturwissenschaft unter sich subsumieren: Es wird *eine* Wissenschaft sein.

Karl Marx (1844) *Ökonomisch-philosophische Manuskripte aus dem Jahre 1844*[2]

Vienna, May 27, 2007

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[1] It is certainly dangerous when one takes cold, scientific research to a point, at which the subject of such research does not leave one indifferent any longer but, instead, gets one cooking. The cooking which I investigate, and which moves the Earth, is also *my* cooking. Hence, the object of my investigation can no longer be separated from the subject, or rather, from the *subject at the point of cooking* (Georges Bataille 1975:*Die Aufhebung der Ökonomie*)

[2] Later on, the natural sciences will subsume the human sciences under itself, in the same way that the human sciences will subsume the natural sciences under themselves. They will be *one* science (Karl Marx 1844: *Ökonomisch-philosophische Manuskripte aus dem Jahre 1844*.

Abstract

Complex Evolving Systems (CES) are definitely not everyone´s bag – they are certainly not on the menu list of the favourite subjects of so-called "Mainstream Economics". There are reasons for that, but they are not good enough. Therefore, this Primer is intended to help economists cover a deficit in understanding which is not only glaring but – given the current state of the world - has become patently unacceptable. The paper proceeds logically, and does so step by step, viz. by (1) Explaining WHY systemic approaches are, indeed, urgently required, (2) Explaining WHAT distinguishes Systems from Non-Systems, (3)&(4) Explaining the Distinction between Closed, Partially Open, and Open Systems, (5) Giving an Introduction to Autopoietic Systems and Key Elements involved in the Process of Evolution. Throughout, the language is largely non-technical, at the same time that the paper extensively quotes the relevant Standard Texts. Some fundamental properties of CES – such as the Second Fundamental Theorem of Thermodynamics - are formalized as well.

Preface and Acknowledgments

The current paper is designed as a Primer i.e., as an elementary introduction to a subject which has enjoyed increasing attention, especially over the past couple of decades. Every decent writer starts out with apprehension – especially of the apprehension associated with trying to avoid "belabouring the obvious." While Complex Evolving Systems are ubiquitous – they include both every writer and his or her audience – they are, generally speaking, largely ignored, misunderstood, unheard of, unheeded, unnoticed, unstudied, and unvalued. In short, they are treated - especially so by hardcore Mainstream Economics - as "suspect". While mainstream economics has some merits, it is certainly not devoid of grave omissions, misperceptions, mistakes in its reasoning and analytics, and outright prejudice. This paper was written to clarify what is at stake here, and do so by a method which has definitely become increasingly popular and vogue, globally, in recent years – a clean, surgical strike. That means, the paper extensively quotes from the standard literature on the subject, and is fully referenced.

While the text will speak for itself, I want to express my deepest appreciation and thanks to the staff of the Institute of Social Ecology at the Viennese Faculty for Interdisciplinary Studies (IFF), where I had the pleasure to study, do research, and teach as an independent researcher and copy editor, over various periods since 1995. The current paper would have never seen the light of the day, had it not been for the trenchant discussion, lively critique, fantastic atmosphere, and (occasionally, wonderfully sarcastic) humour that is at home there.

These days, conventional – or, "mainstream" – traditions of practicing science, or doing research (and, especially, economics ...) has largely become a drab, dreary, and increasingly boring business. From the vantage point of complex systems theory, mainstream economics – while certainly qualifying as a complex system – seems to qualify as a species which should be put, immediately, on the red list of species threatened by extinction. As every economist will testify, mainstream economics is obsessed with equilibrium, preferably saddle-point-stable equilibrium. In fact, mainstream economists mistake equilibrium for the blood of life. Hence, thanks and praises must go to Philip Mirowski of Notre Dame University at Indiana, IL, for having diagnosed economics with a potentially lethal disease, viz., notorious disinterest: After having ranted *Against Mechanism* in 1988, he wrote a legendary sequel in 1991, in which he charged mainstream economics with producing *More Heat Than Light*. To put it in the nutshell of the old Italian saying: Mainstream economics – while notoriously being concerned with "*fare una bella figura*" - is producing, in fact, "A Lot of Hot Air", at the same time that it conspicuously lacks substance. After the "Second Crisis in Economic Theory", diagnosed by Joan Robinson in her legendary Richard T. Ely Lecture before the American Economic Association in 1972, the discipline is facing another predicament that was exposed, clearly, and ruthlessly, in the very same year, by Sir Nicholas Kaldor, then President of the British Economic Association: Sir Nicholas heaped his scorn on his "dear fellow economists" in style, and in appropriate settings, by way of a Presidential Address – the verdict was duly, and promptly, published in the *Economic Journal* under the ominous title "The Irrelevance of Equilibrium Economics."

Having largely banned evolution from its curriculum, the science is verging ever closer to thermodynamic equilibrium – i.e., certain death, and sooner rather than later. Well, yes, every decent systems analyst knows that there are always forces which may push a system over critical thresholds, cause disturbances, and even (systemic) instability. Such instability, in turn, may end in pure chaos, and finish the system (for good) - preferably by taking it into some nice variety of deterministic collapse. Thank God, there is a way out of such predicaments – viz. "spontaneous evolution" by way of generating "emergent properties". And this is the subject to which we will turn, *con amore* ...

Given this dismal state of economic (and other) affairs, such rays of enlightenment as are provided by the Department of Social Ecology must almost be worshipped. Therefore, I want to give thanks and praises to everyone in the Institute – to the Dean of the Department, Univ. Prof. Dr. Marina Fischer-Kowalski, the Research and Teaching Staff, the Library, to its wonderful Secretarial Staff, and – not to forget – to several of the visiting professors and researchers whom I had the occasion to meet while they were here in Vienna. I clearly remember that the subject of this paper was *not* always considered an unmixed blessing by the (mostly) Social Ecologists at home at IFF/SOZÖK, and that, occasionally at least, well-meaning staffers mused about the fact that I was reading – to quote MIT´s Paul Krugman – "a surprising amount of fringe literature". Nevertheless, while my business may have been considered somewhat esoteric, a bit lunatic and, occasionally at least, a bit "suspect", I could always rely, and bank, on receiving a decent, and thorough, discussion and critique, as well as a good laugh – what more can one want ...!.

In 1976, the legendary Jamaican Reggae singer Jimmy Cliff came out with a song that has never left the world again since:

"Let´s Seize the Time Now,
Let´s Seize the Time ...
Let´s Make the System
Pay for its Crimes !
If the Power of the People
Is Worth the Time,
Let´s Do Our Thing Now,
Let´s Seize the Time !"
(Jimmy Cliff, 1976)

„Rev It Up, Rev It Up, Rev It Up ...
Hit the High Waaay ...!"

❖

This paper is the first installment of a **Trilogy**: Part 2 – already "in the tube" – will concern itself with the key macroscopic entities which are at stake in the current discussion, viz. (i) Ecosystems, and (ii) the Biosphere. That paper will be titled **Super-Organisms, Gaia, and Other Friendly Spectres**.

Part 3, then (also "in the tube"), will concern itself with the "usual suspects" that have successfully tried to "create a world after their own image" (quote: Marx) – an endeavour which, as we all know, was not to remain without dramatic consequences. Thus, we will come full circle – "As It was in the Beginning, so shall it be in the End!" Needless to say, "Surgical Strikes" – especially under conditions of "Emergency Interventions", and lacking appropriate anaesthesia – must be expected to be somewhat painful. Nevertheless, there is no other way to rescue a moribund patient ... That paper will be titled **"More Heat than Light." The Dismal Science On and (Mostly) Off Complex Evolving Systems**.

Contents

1. Science, Reality, the Whole, and its Parts

All Beginning is difficult, this is true for each science.[1]
Karl Marx (1867) "Vorwort zur ersten Auflage des *Kapital*", in Marx (1890/I:11).

That which has been left lying around, which is off limits, within which there is no trace of analytical work, criticizes that which already has been worked out. The beginning of every critical work is marked by a change in perspective.
Oskar Negt & Alexander Kluge, *Geschichte und Eigensinn* (1981:87).[2]

19th century epistemology was well-nigh unequivocal when it came to answering the perennial question about the proper subject of science: "Science *begins*", or *starts*, „when one deals with the **thing itself**, i.e., with the real cognizance of *what truly IS*: The content, or subject of [science or] philosophy is nothing else but that which has been brought forward originally, and which is continually bringing forward itself: That which has become both the *external world* AND the inner world of consciousness – *reality*" (Hegel 1970/3:68,47).[3]

Everyone knows - even if (s)he does not know anything else – that, "In the Beginning, God created Heaven and Earth. And the Earth was Barren and Empty, and the Spirit of the Lord Hovered above the Water" (1 Mose 1:1-3). This all-embracing reality which is the first and the ultimate subject of science, therefore, is - in and by itself – the **Cosmos**, ort he **Universe**.[4]

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[1] Original in German in Karl Marx (1867) "Vorwort zur ersten Auflage", *Das Kapital. Kritik der Politischen Ökonomie*, Bd. 1 *Der Produktionsprozeß des Kapitals* (= *MEW* 23), Berlin: Dietz, S.11. Translation mine.

[2] Negt & Kluge (1981:87). The subject of Human, or Social Ecology is „the relationship between society and nature" (Fischer-Kowalski & Haberl 1997a: 3) and, therefore, that which is neither comprehended by the concepts and categories of both biology and ecology, nor by those of the Human and Social Sciences. This change of perspective implies new conceptions of both the Natural and the Social Sciences and, therefore, the critique of these concepts and categories. With regard to the Critique of Political Economy, cf. Karl Marx´s Letter to Ferdinand Lassalle: "The first thing that must be done is to criticize the categories of economics or, if you like, to work out a critical presentation of the System of bourgeois Economics (quoted in the original German on the back cover of Winfried Vogt´s (1973) Reader). Generally speaking, cf. Friedrich Engels "Preface to the English Edition" of volume I of Marx´s *Kapital* (Marx 1867:37): "Each new conception of a science includes a revolution of the scientific concepts of that science." On the concept of "What is Real", cf. Negt & Kluge (1981:154)

[3] Cf. Marx (1845/46:26): "Real, positive science – the analysis of practical human activity, of the practical process of human development – begins, where speculation ends." Needless to say, science does not end with human beings. „The phrases concerning awareness end, and real knowledge must take their place."

[4] Cf. the answer that Haug (1985:37-38 *passim*) gives to the question: „What is he starting point of science?" „What are the requirements one must fulfil at the beginning of science? The absolutely primary requirement that must be fulfilled at the very beginning of each and any scientific endeavour is: *Everyone must be Familiar with the Beginning*. If the General Public is not to be excluded from the very Beginning, one must start at some point at which everyone meets everyone. One must start with something that everyone is familiar with – i.e., with some *Commonplace*", which is not permitted to presuppose anything but "what everyone knows, even if (s)he does not know anything else." The commonplace *par excellence*, the place which is common to everyone, or which is the *general* place of their common existence, is **Reality**, or the **Cosmos** – The Universe subsumes under

When one prejudices the interest of cognizance and restricts, or constrains, scientific work taking on *reality* to particular *Moments*, *Elements, Parts*, or *Components* of the whole, one always excludes all other components or moments of matter from the analysis which are not identical with the current *object* of scientific desire. However, it is not only possible, in principle, but also highly probable that these moments, elements, or parts are, in fact, complex systems which maintain mutual interactions with one another. If these mutual interactions are ignored in the analysis of whatever is the *object* of scientific work, or rather its *subject*, it is not analyzed and presented in the way it *really*, or *truly* is: "The *true* thing" - as G. W. F. Hegel made sure to remind us - "is the *whole* thing“ (Hegel, 1970/3:24).[5]

Thus, science is concerned with *reality* as a *whole*: What belongs together must be analyzed AND presented together - Everything is at stake! The *de facto* common practice of constraining scientific research to a choice set of *parts* of reality to the wilful exclusion of all others, therefore, is found to be deficient, and unpardonable. If the objective is to analyze and present reality as it truly is, this implies, *a priori*, to present the *whole* reality. This vindicates that science is not allowed to respect any limits except those set by reality itself.[6]

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itself, in *reality*, all natural and social systems and is, therefore, the most concrete "common being", the most common system *par excellence* or, **The General**.

[5] The whole thing, or whatever is the entity under analysis, always consists of several parts, elements, or components the properties of which are, at first, completely unspecified. A language is „the product of a particular community - very much like, in another sense, it is part of the existence of this community, and the self-understanding existence of that community (Marx 1953:391). Therefore, let us briefly touch on some connotations of the terms in question here:

In Middle Old English, the *whole* was *hool* = healthy, unhurt, entire, similar to Old English *hal* or Old High German *heil*, also in Old Dutch and Slavic: Free of wound or injury: UNHURT. Recovered from a wound or injury: RESTORED. Being healed. Free of defect or impairment: INTACT. Physically sound and healthy: Free of disease or deformity. Having all its proper parts or components: COMPLETE, UNMODIFIED. Constituting the total sum or undiminished entirety of something: ENTIRE. Constituting an undivided unit: UNBROKEN, UNCUT. Constituting a person in his full nature or development. A complete amount or sum: A number, aggregate or totality lacking no part, member or element. Something constituting a complex unity: A coherent system or organization of parts fitting or working together as one.

Component derives from Latin *componere* = to put together, putty clay, e.g., as Gods like to do. A constituent part: INGREDIENT. Any one of the vector terms added to form a vector sum or resultant. A coordinate of a vector.. ELEMENT.

Element derives from the Latin *elementum*. One of the four substances air, water, fire, and earth formerly believed to compose the physical universe. A constituent part. The simplest principles of a subject of study. A part of a geometric magnitude. A generator of a geometric figure. A basic member of a mathematical class or set. One of a number of distinct groups composing a human community. One of the necessary data or values on which calculations or conclusions are based. One of the factors determining the outcome of a process. Any of more than 100 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter. A distinct part of a composite device. MEMBER. Synonyms: Component, Constituent, Ingredient, Factor. Shared meaning element: One of the parts, substances, or principles that make up a compound or complex whole. (Source: *Webster´s New Collegiate Dictionary* 1976).

[6] Cf. Adorno (1973:22): In his *Transcendental Teaching of Method*, Kant says: "As the term says by itself, `to *define* something´ actually implies only that one should present the comprehensive concept of something within

Since reality is, in fact, a *complex*, *living System* or *Subject*, it continuously transgresses or *transcends* these limits:[7]

> Die Knospe verschwindet in dem Hervorbrechen der Blüte, und man könnte sagen, daß jene von dieser widerlegt wird; ebenso wird durch die Frucht die Blüte für ein falsches Dasein der Pflanze erklärt, und als ihre Wahrheit tritt jene an die Stelle von dieser. Diese Formen unterscheiden sich nicht nur voneinander, sondern verdrängen sich auch als unverträglich miteinander. Aber ihre flüssige Natur macht sie zugleich zu Momenten der organischen Einheit, worin sie sich nicht nur nicht widerstreiten, sondern eins so notwendig als das andere ist, und diese gleiche Notwendigkeit macht erst das Leben des Ganzen aus (Hegel 1970/3:12).[8]

Just like the whole Universe and the Earth within it, Mankind as well as Science find themselves at the end of their whole evolution up till now. Since her earliest beginnings – i.e., since time immemorial – science has gloriously evolved into the currently existing complex system of the sciences, or a historical subject. She is a living component of reality, pursuing a boundless range of cognitive concerns, as well as objectives, and disposing, with sovereignty, of a phenomenal arsenal of means to pursue her interests and objectives. Currently, mankind knows more than ever before in her whole history and, in the meantime, has increasingly also become aware of it. While the whole accumulated knowledge about reality available to mankind may seem vast and chaotic to the individual, it does exist, *de facto*, in the form of the contemporary scientific system. This system exists – *potentially* at least – as a historical *subject* that is capable of *acting*!

Reality must be presented as it *truly*, or *really*, *IS*. This mandates, a priori, that it must be presented as a *whole*. Given the current state of affairs, it may be as understandable as it is ubiquitous that - for whichever pragmatic reasons - scientists throw themselves into the arms of specific partial scientific disciplines and research paradigms, or restrict their work to analyzing particular moments, or aspects, of reality. Irrespective of the fact that there may be

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its own limits. According to such a demand, an empirical concept" – i.e., a concept which denotes some content originating in experience, an „experience concept" (= „Erfahrungsbegriff") – cannot be defined, but only explicated."

[7] *Sensu Strictu*, every living, coherent complex system is a *Transcendental Subject.* It was Hegel who did prove this proposition by way of rigid philosophical argument. We will see, further down the road, that this proposition is a quite natural presupposition in sciences which – like Ecology and the Theory of Complex Adapting (Evolving) Systems – are geared towards the „totality" of their subject and, hence, are considered „holistic" sciences. The fact that every evolving process involves qualitative change and transformation sets limits to formalizing these processes mathematically.

[8] "The bud disappears with the opening of the blossom, and one might say that the first is being falsified by the latter. In like fashion, the blossom is "proven" to be the "wrong" form of existence of a plant, as soon as it transforms into a fruit – and the fruit substitutes the blossom as the "true form of existence" of the plant. These various forms do not only differ from one another, but also displace one another as mutually incompatible. At the same time, however, their fluid nature transforms them into moments of the same organic entity, within which they are NOT incompatible with one another: Instead, each individual moment is as necessary as any of the others, and it is their very equal necessity which, indeed, gives life to the whole.

substantial arguments in favour of such widely practiced restriction, history has proven that, taken by itself, such common practice is far from reasonable!

Whoever ignores – in addition to such voluntary self-constraint – the *real* process of *evolution* and, thus, the *dynamics* of the real world, will fail to arrive at a dynamic concept of the real world. Moreover, whoever acts in this way will ignore the dynamic evolution of the sciences from their earliest beginnings all the way through to their current state. Hence, the subject of *science* is the *scientific* system of reality together with its *evolution* or its *becoming* – its dynamics, or what philosophy calls the *Spirit* of the Whole: "That what is *true* is only real as *system*, or that *substance*, essentially, is a *subject*, is expressed in the idea which conceives of the Absolute as *Mind* (Hegel 1970/3:28).

Admitted, this may still sound somewhat *esoteric* for the time being – it will definitely become clearer in what follows.

Our starting point, therefore, must be the current state of scientific discussion concerning the „state of the world“, “the course of things“, or reality as a whole. Everyone knows that this discussion is as old as humanity, or man kind. However, this discussion only gained its present acrimony with the transformation of man kind into a veritable spectre of a beast!

The human population on Earth vitally depends on its *metabolism* with Nature. However, for quite a while now mankind has been organizing and running this metabolism in ways which CANNOT, and thus WILL NOT, remain without dire consequences falling back, not only on the human species, but on ALL species on Earth constituting the biosphere, as well as on the Earth herself. The Evolution of the so-called *Modern Market Economy – vulgo* **Capitalism** – has produced radical transformations in the anthropogenic forms of metabolism. These transformations, in turn, have changed the biosphere in ways, which have systematically ruined the very preliminary conditions required for the continued survival of the part of mankind obsessed with the economic **Regime** currently ruling supreme. As if this was not enough, the same fatal processes have been at work for decades in the etatist *Alter Ego* of Capitalism, viz. “**Real Existing Socialism**” (Peterson 1993).

Populations which produce, and metabolize, in these ways will ultimately – and, as far as we can tell, this will happen in the *not too distant* future – destroy themselves. They are about to face a stern choice: If they continue their all-too-well-trodden trajectory, they will crash in *collapse*. Alternatively, they will be *forced - on pain of extinction* - to *evolve*, i.e. to transform the Mode of Production currently ruling supreme on Earth, and evolve it into a more highly developed form that MUST BE ECOLOGICALLY SUSTAINABLE.[9]

[9] The literature on the topic is vast, ubiquitous, and available in any decent bookshop, as well as via digital media. It is fully sufficient to point to the channels and media of information which are available in ANY HOUSEHOLD. Beyond that, *vide* the continuously increasing flood of scientific contributions worldwide, concerning these issues, and published in the international media, the press, as well as in the established science journals. Very much as with the Nazis, nobody will be able afterwards to exculpate him- or herself by arguing that they “did not KNOW about it.”

This fundamental insight – or rather, the *concession* that this insight may *possibly* correlate closely with the *real* facts and, therefore, *might* be true rather than wrong – gradually seems to diffuse, inconspicuously, even into the most secret closets of the Cathedrals of Learning. Ever since the 1972 publication, by the Club of Rome, of the report on *The Limits to Growth* (Meadows et al. 1972), doubts about the unmitigated blessings heaped on mankind as a result of unending and ever-lasting exponential growth have stubbornly refused to leave the public discussion, irrespective of admonitions to the contrary. In most recent years, these doubts have gained ample support by the increasing certainty that the anthropogenic metabolism entertained by the so-called „Modern Industrial Societies" – the **Capitalist Mode of Production –** is **unsustainable as a matter of principle**.[10]

2. Systems as Entities with Emergent Properties

Non-systems are *collective entities*, or *un-ordered Sets*: A Set consists of *Elements* which do not maintain relationships with one another – a number of randomly assorted sand corns positioned next to one another without forming a sand **pile** do not maintain any relationships with one another, although they are exposed to the effects of exogenous physical and chemical forces. Sets are entities which display collective properties, but are no systems: One may form alternative sub-sets, change or substitute these sub-sets, separate the elements, increase or decrease them or change their ordering without changing any of the fundamental properties of sets.

Capitalist Society not only creates colossal productive forces which, in the end, mutate into destructive forces. Much more, it documents – not to say, celebrates – LIVE, with phenomenal technical expenditure, and in the most glowing colours, its own demise and collapse. The opulence with which capitalist societies meticulously, and in the most minute detail, document the destructions and havoc they wreak – destructions which they have been taking into account while being fully aware of them – justly remind one of the lunatics of that strange totalitarian regime which, not too long ago, went about to bring about God ´s Empire of the Thousand Years, here on Earth. Since time immemorial, all totalitarian regimes have shared the same obsession with meticulously documenting their colossal crimes. This ist rue for all such regimes, irrespective of whether one talks about the palace dynasties of the ancient Civilizations, Ancient Rome, the repressive Austrian-Hungarian police regime of Sedlnitzky („in China, behind the walls ..."), National Socialism, Fascist Dictatorships from Mussolini to Pinochet, the former Soviet Union, or just plain Capitalism. In the late 1970s, then President of the United States, Jimmy Carter, commissioned the *Global 2000 Report to the President of the United States*. This report went far enough with documentary evidence to induce his successor – the former third-rate actor and later Governor of California („God´s Own Country"), Ronald Reagan – to firmly forget it within closed drawers.

Just for he sake of completeness, we would like to point the honourable reader to a choice selection of standard references, viz. Marsh (1864), Thomas (1956), Kapp (1963), Mishan (1967), Meadows et al. (1972) Jänicke (1979), *Global 2000,* Wicke (1986), World Commission on Environment (1987), Leipert (1989), Turner (1990), Leggett (1991), Peterson (1993), the publications of the World Watch Institute, The Earth Policy Institute, Brown (2005, 2006), Gore (2006), Meadows et al. (2006), IPCC (2007), and Stern (2007).

[10] This will be developed and elaborated *infra*. For standard classic references, cf., *inter alia*, Clark & Munn (1986), World Commission on Environment and Development (1987), Pearce et al.(1989), Pearce & Turner (1990), Baccini & Brunner (1991), Pearce et al. (1993), Daly (1993), Daly & Townsend (1994), Ayres & Simonis (1994).

With a *System*, such procedures are not possible without changing the relationships among all its elements and, simultaneously, the general character, or the fundamental properties, of the whole system in question. Systems, therefore, display certain properties which distinguish them, first of all, from Non-Systems.[11]

Systems likewise generally consist of several different elements which, however, now function as *Parts* or *Components* of the system in question. In contrast to pure sets or non-systems, therefore, the elements are components, or parts, of more or less complex *entities*. Whenever they function as such components, or parts, these elements do not lie randomly, or indiscriminately, side by side with one another. Instead, they are *organized* in certain ways, they are *linked with one another* in a particular *Web of Relationships* and a particular *Internal Structure*, and are organized within an *Ordered Structure of Mutual Interaction*.[12]

Vester (1985:27) explicates this by way of using the example of a *Set* of a certain quantity of randomly assorted sand corns. As long as these do not form a coherent sand *Pile*, such a random set of sand corns cannot be classified as a system. In contrast, each of the molecules which, together, form a single corn of sand, IS a system. A *System* differs from a *Non-System* in the fact that it consists of a number of elements which are linked with one another as *Components*, or *Parts of that System*. It is NOT mandatory, however, that the web of linkages

[11] What follows did originate from a method of assembling quotes, and excerpts, from Vester (1983a,b; 1985), Jantsch (1992), Capra (1996), and others, to compose a concentrated Primer on the fundamental properties of systems. The concept of system is a commonplace by now, because everybody has to deal with systems everyday – although they are, therefore, „generally familiar", we will see that people are a far cry from having a clear concept of them. When ecologists, economists, historians, sociologists, and other people talk, e.g., about *cities* as specific systems, they may talk about the same thing. As a general rule, however, they will talk about different *concepts* of cities which will vary among one another. Hence, we are well advised not to forget Hegel:

„Let us call the *Knowledge* of a thing its *Concept*, at the same time that we call the *Essence* of the thing in question – i.e., that *Being* which is *True* – the *Object*. Under these circumstances, the proof consists in examining whether the concept corresponds to the object. However, let us now call the *Essence* of the thing – i.e., the thing as it is *in itself* – the *Object*, at the same time that we consider the thing as an *object* the way it appears *to something different from itself*. In this case, the proof consists in examining whether the object corresponds to its concept. It is plain to see that both procedures are one and the same. What is fundamental (and not to be forgotten) for the whole analysis is, that both of these moments – *Concept* and *Object*, *Being for Something Else* and *Being in Itself* - immediately fall into the very knowledge which we are examining. Therefore, it is patently unnecessary for us to apply our own criteria, or our own ideas and thoughts, in this examination. By abstaining from such procedures, we can indeed attain that we look at the thing in question the way it is in and by itself" (Hegel 1970/3:77).

[12] With respect to the concept of *Organisation*, let us presuppose, for the moment, nothing more than what can be found in any dictionary: **organize 1:** to cause to develop an organic structure, **2:** to arrange or form into a coherent unity or functioning whole: INTEGRATE, **3:** to undergo physical or organic organization, **4:** to arrange elements into a whole or interdependent parts (*Webster´s New Collegiate Dictionary*). The concept of *Structure* originates from Latin and was originally applied to the construction of buildings. A Structure is an entity which displays a certain pattern of organization of its elements. This particular organization and the mutual relationships among the different parts of this entity is determined by the particular properties of the higher-order entity.

is visible – instead, it may consist of cause-and effect relations which originate by way of communication, i.e., by way of pure exchange of information.[13]

Everybody knows that organisms, biological systems, and anthropogenic social systems are different kinds of living systems which – just like the Earth herself – are part of a larger system, i.e., the *Solar System*. Since time immemorial, man kind has known that the Earth herself is a complex entity, or a system – notwithstanding the fact that people could not care less about the casual, and frequently mindless, ways in which they actually deal with an infinite number and variety of systems in the real world that are in continuous interaction with one another. Once again, this is clear evidence of the fact that systems are, indeed, ubiquitous and ever-present, at the same time that they remain largely unknown.

The casual everyday-„handling" of the incredible variety of systemic entities squares with the stern efforts invested in clarifying the origins, genesis (*Emergence*), and evolution of existing systemic forms of order. The volume of literature on systems theory has literally become unmanageable – the number of publications concerned with explicating a vast arrear of divergent systems, and with their functional specification, is legend. Nevertheless, the casualness with which it is generally accepted that such systemic entities have literally been with us since time immemorial, is increasingly disturbed by the question HOW such systemic forms of order *emerge*.

❖

Systems Theory starts out by distinguishing, for the sake of plain logic, between *Systems* and *Non-Systems* – with neither of them being assigned, *a priori*, logical or historical priority. The actual evolution of life on Earth since the origin of the Solar System, however, is a process in which un-ordered matter has organized itself, spontaneously, in an evolving sequence of ordered structures of mutual interactions. The *Genesis* (*Emergence*) *of Systems* – of increasingly complex organized entities – occurs under specific conditions, i.e., by way of *specific processes occurring in un-ordered (chaotic) Non-Systems*.

A simple example for the Genesis, Emergence, or Origin, of a System is the Formation of a Sand Pile out of a continuously increasing set of individual Sand Corns. Let us take an experimental setting in which there is a circular plane and a device which permits dropping individual sand corns into the centre of this plane from a pre-determined height. Initially, the first few sand corns dropping on the plane will disperse and settle in various positions without

[13] The suggestion that a pile of sand (or indeed, a waste disposal site) is just a Set, but not a System, is true only under certain conditions:: *Sets*, or *Non-Systems* are defined by the fact that their individual elements (sand, waste, water, gases) are NOT LINKED with one another as system components in a web of mutual relationships, nor are organized within an ordered structure of mutual cause-and-effect. The probability that the individual elements of a set maintain mutual relations with one another is low within sets consisting of elements which are more or less *Homogeneous* and *Inert*, and which display a *Low Density*. In *Heterogeneous Sets* (such as waste dumps) – the elements of which are, by themselves, complex, open and, in part, highly reactive systems – mutual interactions are self-evident. It was Bak & Chen (1991), and Bak (1997) who demonstrated that continuously adding sand corns to an already existing *pile* of sand may procure situations which are pretty critical, and chaotic (sand pile dynamics lead to supra-critical systemic instabilities which may ensue in deterministic chaos, and collapse).

touching one another – a single corn of sand does not make a sand pile, and several of them only form a Set.. With a continuous increase in the number of elements in this set, they will enter into ever closer relation with one another. Once the number of sand corns reaches a critical density and concentration (threshold!), physical forces (gravity, frictional resistance) generate spontaneous interactions and relations among the elements which generate the formation of a sand pile – i.e., a particular spatial structure.

Originally, the elements of sets (which may potentially also be systems themselves) are separate from one another. Once a rising number of these elements begin to enter into close mutual relations of cause and effect, this may trigger the emergence, or genesis, of a new system of higher order. Thus, individual atoms may form a molecule, cells form an organism, and the interaction of animals, plants, and microbes, generates an eco-system. When many small parts, elements, or systems, come together, they may either generate a *Set* – in which they remain separate from, or side by side with, one another – or some larger *System*, e.g., a social system (e.g., chicken, bees)(Vester 1983b:19; 1985:27). Thus, original urban cores may emerge from the spontaneous agglomeration of smaller and larger concentrations of human settlements which *grow together* (for Vienna, cf. Brunner 1994: 400).

Vester (1983a:23; 1985:27-28) argues, moreover, that humans and the artificial systems they generate on this planet (such as roads, settlements, factories, mines, land used for agriculture) were relatively spaced from one another for a long period of time. With small populations distributed over a vast terrain initially, and for a prolonged period of time, there was but little interaction among these systems far enough away from one another. With increasing population and density, however, these artificial systems have come into close range from one another. This, in turn, has generated a wide variety of physical, chemical, energetic, and social interactions among them, between them and human populations, and between them and the biosphere. These mutual interactions have generated a new system overarching them – i.e., the system of human civilization on Earth.

Such a system need not be stable, i.e. sustainable, by necessity – the individual parts may affect one another in ways which may eliminate the system (and all partial system which are linked to one another within it). (…) In close analogy with this, the evolution of human civilization on Earth has generated new systems of mutual relations of cause and effect – systems which are characterized by exponential growth and, by necessity, increasing density and an increasingly global network of interactions.

As long as the relations and interactions among the elements within a set are negligible, the entity is NOT a System. The transition to a System occurs when a certain critical state is reached, in which the mutual interactions among the elements lead to a process, in which the set of elements in question organize themselves as a *Whole*, in the form of a *new entity*, i.e., as an *ordered structure of interactions* or a *System*. This new, or *emergent*, systemic order behaves totally different from the way in which these elements did before: Within the emergent system, they have become parts, or components, of the system. The components and parts of a system are linked with one another in a web of interactions, depend on one another and, in doing so, form a complex unified *Whole* or a new *Entity*. Each such combination of parts into a new whole, viz. an individual entity, not only possesses certain *Collective*

Properties which result from the sum of its components. Instead, a System exhibits completely *New* or so-called *Emergent Properties*. These properties are specific *Systemic Properties* and *Behavioural Characteristics*, which DO NOT result from the properties and the behaviour of the individual parts of the system.[14]

A system is always an entity, or an integrated *Whole*, the properties of which cannot be reduced to the properties of smaller parts. The behaviour of a system, therefore, cannot be explained by studying its individual parts, or by the collective sum of the individual properties of these parts. And that, in turn, does not imply anything else but that a system – while it may consist of many parts – is a separate *Individual*.

The whole spectrum of all existing systems within reality is hierarchically ordered, just like the partial spectrum of biological systems is. All real systems are more or less *hierarchically organized Entities* which exist on various – more or less complex – *Levels of Organization* or *Degrees of Complexity*. In *hierarchically ordered* or *organized* systems, each level subsumes all lower levels within itself, at the same time that the parts or components of a system may be systems themselves.[15] Hierarchically organized systems are, from their very beginning, themselves systemic components of the total spectrum of existing systems and, hence, parts of higher ranking systems with which they are connected:[16] Thus, all systems exist within higher-ordered systems which, themselves, are once again parts of more comprehensive systems – and so forth, all the way down to the *complete*, or *total*, system which is the *totality* formed by *reality itself* (Vester 1985:27; Jantsch 1982:65).[17]

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[14] The concept of *Emergent Order* or *Property* does not only point to *systemic properties* of organized entities which are novel and appear for the first time, but also to the fact that that systems, literally speaking, are *composed of elements* which, therefore, become Components of the system in question.

[15] As already mentioned, this is not just true for molecules in a sand pile or other things. The same is true, e.g., for parts of certain technical installations, for cells within organs, for organs within organisms, individuals within populations, farms and houses in a village, households, firms, systems of communication and infrastructure in urban agglomerations, or for cities and other living beings embedded within ecosystems. Odum, e.g., distinguishes genes, cells, organs, organisms, populations, and communities as different levels of organization of biotic entities. Needless to say, ecosystems these days subsume a wide variety of other living beings as well, apart from trees and forests – one may just think of villages, cities, firms, banks, governments, networks, industries and industrial sectors, oligopolies, conglomerates, financial and other markets, economies, and other niceties. For more detailed expositions of the concept, cf. (*inter alia*) Odum (1983:5-7; 1991:38-49), Lewin (1992), Nicolis & Prigogine (1989), Waldrop (1992).

[16] The concept of *Hierarchy* refers to a structure, or sequence, of (functional) entities which is ordered in several layers, shells, or levels (Odum 1991:38).

[17] Individual human beings, e.g., are not only a hierarchical system of organs, cells, enzymatic systems and genes. Human beings are, at the same time parts of hierarchic systems which transcend the particular individual, such as populations, cultures, and ecosystems. Of course, any science will fail that tries to understand phenomena by way of *reductionist* analysis, i.e., by way of analyzing ever smaller particles. Instead, science must also begin to understand – by way of synthetic and *holistic* analysis – large components as functional entities (Odum 1983:xiv).

Each level of organization has its own specific, distinctive, and generally valid, characteristics. This means that not all properties of a more highly organized system can be deduced from the properties of systems of a lower degree of organization. It is not possible to predict the properties of water from the molecular properties of hydrogen or oxygen. In like fashion, the specific properties of ecosystems can not be predicted from the knowledge we may have of isolated populations within it.[18] Systems which emerge from the combination of components or component entities (systems) are entities which exist at a higher level of organization or complexity than did the individual components before their combination. On each new and higher level of complexity or organization, systems display completely new or emergent properties which either did not exist at the previous lower level of organization, or were inconspicuous. Such newly emergent properties of particular levels, or entities, of organization result from the functional interaction of their components. By studying isolated or detached components, without taking their mutual interaction into account, it is impossible to predict the specific properties of the more highly organized entity (Odum 1983: xiv-xv, 7; Salt 1979; Edson 1981; Odum 1991:42-43).[19]

It is in the nature of systems that they cannot be described by the *sum* of individual properties. Cartesian science argued that, with each complex system, the behaviour of the whole system could be analyzed by way of analyzing the properties of its individual parts. Systems science demonstrates, instead, that systems cannot be understood by way of *analysis*. The properties of the parts of a system are not properties which inhere in themselves, but can only be understood within the context of the larger whole of which they are part (Vester 1983:17-20; 1985:27-29; Odum 1983:5; Capra 1996:34, 38, 52):

> The system problem is essentially the problem of the limitations of analytical procedures in science. This used to be expressed by half-metaphysical statements, such as emergent evolution or *the whole is more than the sum of its parts*, but has clear operational meaning. *Analytical procedure* means that an entity investigated be resolved into, and hence can be constituted, or reconstituted from, the parts put together, these procedures understood both in their material and conceptual sense. This is the basic principle of *classical science*, which can be described in different ways: resolution into isolable causal trains, seeking for *atomic* units in the various fields of science, etc. The progress of science has shown that these principles of classical science - first enunciated by Galileo and Descartes - are highly successful in a wide realm of phenomena.
>
> Application of the analytical procedure depends on two conditions. The first is that the interactions between *parts* be nonexistent or weak enough to be neglected for certain research purposes. Only under this condition can the parts be *worked out*, actually, logically, and mathematically, and then be *put together*. The second condition is that the relations describing the behaviour of parts be linear; only then is the condition of summativity given, i.e., an

[18] One needs to analyze both the forest and the individual trees – the whole as well as its parts. Whoever restricts him- or herself to looking only at the trees, will inevitably fail to see the wood for the trees (Odum 1983:7).

[19] This principle (called, in English the *emergent property principle*) is a somewhat more formal version of the old saying „The Whole is *more* than the *Sum* of its parts “, or, in other words: „A forest is more than just a collection (or set) of trees “ (Odum 1991:42).

> equation describing the behaviour of the total is of the same form as the equations describing the behaviour of the parts; partial processes can be superimposed to obtain the total process, etc.
>
> These conditions are not fulfilled in the entities called systems, i.e., consisting of parts *in interaction*. The prototype of their description is a set of simultaneous differential equations which are nonlinear in the general case. A system or *organized complexity* may be circumscribed by the existence *of strong interaction* or interactions which are *nontrivial*, i.e., *nonlinear* (Bertalanffy 1968:18-19).

The most essential or *systemic* properties of a system, therefore, are properties of the entity as a *whole* which do not inhere in any of its parts.

Systems have characteristic *Patterns of Organization* – i.e., a specific *Network of (self-) organizing Relations* of their components, a specific *Configuration of ordered Processes or Relations* which are *mutually linked to one another*. The *Pattern* in which these processes and relations are organized is characteristic, and specific, for a particular class of systems at each level of organization.[20] Systems possess, therefore, characteristic *Patterns of Relations* or *Organization*, a specific *Network* of *Mutual Interactions*, and *Mutual Relations of Cause and Effect*, which are characteristic for the *Structure* of the system in questions and inhere in it.

These systemic patterns or organization are either determined *exogenously*, or they are organized by the system itself, i.e. *self-organized*. They are different, and specific, for each individual system.. Therefore, systems differ from one another by the specific ways and modes in which they *are organized*, or in which they *organize themselves*. Systemic properties are properties of a specific pattern – this pattern is destroyed when the system gets dismantled into elements which are isolated from one another. While the components of the original system are still there, in such a case, the specific configuration of the relations among them – the pattern of their (self-) organization – is destroyed, and therefore the system dies (Capra 1996:51, 98-100).

Systems, therefore, essentially differ from Non-Systems because they are (*Self-*) *Organized*, because their parts, or components, are linked in a *Web of Relations*, and are *organized* in a specific *configuration*, i.e. a specific internal *structure* in which these components form an *ordered structure of mutual interaction*. They differ from Non-Systems in that their components exhibit specific *patterns of integration* (*interconnectedness, networking*) and *organization*, i.e., specific *structures*, or *configurations of cohesion* (*coherence*, *mutual*

[20] What is particularly important is cyclical (circularly *closed*) organization of processes. The biological systems which we are most interested in here are *dissipative Systems* or *Structures* which, generally speaking, are organized in what Manfred Eigen called a *Hyper-cycle*. A hyper-cycle is a *closed* circuit of processes of transformation or of catalytic processes, in which one, or several participants function, moreover, as autocatalytic (self-augmenting) participants. In order for this process to rotate in a specific direction, it is required that the system is in a state of disequilibrium. The "interior" cycle of processes regenerates itself continuously and, in doing so, functions as a catalyst which transforms inputs into outputs (Jantsch 1982:64). Vgl. Ayres & Simonis (1994:9): "Evidently, biological evolution responded to inherently unstable situations (open cycles) by `inventing´ new processes (organisms) to stabilize the system by closing the cycles. This self-organizing capability is the essence of what has been called `Gaia´."

relations, *contiguity*), both *internal* and *external reciprocal interactions* (*interdependencies*) and organizing relations.

The concept of the ***Structure*** *of a System* originally referred, first of all, to its *spatial* configuration. *Static*, or *fixed* spatial *Systems* or *Structures* consist of components which are configured in a spatial dimension in a certain way, yet do not maintain mutual interactions with one another – generally speaking, one can take these systems apart and putt hem together again. Most of the time, it is possible to reduce them to combinations of but few standard components, or modules. Macroscopic properties such as weight, stability, firmness (fixity, resistance, rigidity, solidity) can be reduced, in this case, to the properties of the components and their specific configuration.

As already explicated, there is a wide variety of systems in which macroscopic properties do not result from the properties of their components and their combinations. Systemic properties often do not result from *Static Structures*, but from *Dynamic Interactions*, both *within* the system in question, AND between the system and its *Environment*.[21] This, however, implies that a *systemic approach* is bound up, by necessity, with a *dynamic* perspective, since a system can be generally observed, and defined, primarily by way of its *interactions*.

Dynamic Structures, or *Systems*, typically never consist of solid and permanent components. Instead, they are entities which are characterized by certain forms of (Self-) Organization: Their components engage in mutual interactions, i.e., they participate in certain *Processes*, and do so jointly with other components. All together, they are integrated within a *network* and within a certain *pattern of organization*: Therefore, it is not only the quantity of components and elements, and their logical organization, which is characteristic fort he properties of systems, but the pattern of *Processes* which occur both within the system in question, as well as between this system and its environment. Dynamic structures or Systems consist, therefore, of components which, in fact, are *Processes* – Systems, therefore, are so-called *dynamic Regimes*, i.e. pure *Structures of Processes*, *Process Chains* and *-Networks*, or ***Process Structures*** (Jantsch 1982:51-52,55,64).

For the Social Sciences, as well as for Biology, it was the macroscopic analysis of the dynamics of ***Coherent Systems*** which became ever more important. *Coherent Systems* are Systems whose structure does not remain rigid, fixed, and unchanged, but changes in coherent ways. Organisms of all different kind, and Ecosystems are coherent systems, in the same way as cities, communities, economies, financial markets and a host of other forms of social organization (Jantsch 1982:54-55). Human Beings, the entities within which they organize themselves, and other living systems, therefore, are *Self-Organizing*, *Dynamic*, *Coherent* and *Evolving Systems*.

[21] For example, an *Organism* is NOT defined by the collective sum of the properties of its individual cells – very much like no city can be defined by the sum of its administrative units. In chemical reaction systems, certain molecules which do not enter into reactions themselves can exert, under specific circumstances, catalytic effects which may decisively influence the dynamic system at large. Individual human beings influence, and may transform, the life of the community of which they are part.

The overall characteristic of all self-organizing processes taking place – i.e., the internal organization of the system, as well as its interaction with the environment, the kinetic characteristics (dynamics) of the individual processes as well as their mutual interaction – is called the ***Function*** of a System. This includes the internal process organization of the system, as well as the structure of the processes which it maintains in its interaction with the environment – and, moreover, the kinetic characteristic of the individual processes taking place as well as their mutual interaction. Hence, the logical pattern of these relations is framed within the structure of their temporal sequence.

If the Function of a System is determined exogenously, as in the case of a machine, the system is an ***Allopoietic*** *System* (Jantsch 1982:65-66). Whereas a machine produces a certain output for which it is designed, a living Cell, or any other living system for hat matter, first of all produces itself. Living Systems are geared to regenerate (repair, replace, rebuild, renew, recondition, remake, restock, renovate, revive) themselves – just think of a biological cell which remakes itself, continuously, by maintaining a carefully orchestrated structure of catabolic (composing) and anabolic (decomposing) reaction chains, and which does not exist, for an extended period of time, of the very same molecules. Such Systems are called ***Autopoietic*** *Systems*.[22] Autopoietic Systems are self-organizing and are oriented, first of all, towards themselves – therefore, they are also called ***Self -referential Systems***.[23]

According to Jantsch (1992:64-66), all entities which are called Systems are characterized, first of all, by the fact that they separate, and distinguish, themselves from their surroundings (environment), at the same time that they are themselves parts of this very environment. They may either be closed off from their environment (*closed*, or *isolated Systems*), or they may maintain relations with it: Living Systems, however, continually maintain mutual relations of exchange with their environment – which, apart from matter and energy, may involve, first of all, also Information – and are Open towards whatever is New, or something that appears (emerges) for the first time. Such systems are called *Open Systems*.

3. Closed, and Partially Open, Systems

In a *closed* System, a given quantity of *free*, *ordered* Energy in a particular form transforms itself, in the process of its transformation, irreversibly into an equal quantity of *bound*, but *disordered* Energy - free Energy "dissipates" into the total system within which it was transformed. In a closed system, this process irreversibly increases *Entropy*, i.e. the share of energy within the system which is no longer freely available but bound and disordered. In the

[22] The concept originates from Ancient Greek and implies as much as „Self-Creation“, Self-Production, or Self-Regeneration and –Rejuvenation - cf. the classic papers edited in the reader published by Maturana (1985).

[23] Cf. Ebeling (1989:39, 41): „Self-organization is only possible when the distance of the system from equilibrium passes certain critical thresholds. It only occurs when systems are in states that are far from equilibrium, and its occurrence is bound up with discrete transitions. (...) Processes of Self-Organization are frequently made up of sequences of kinetic transitions which, with increasing distance from equilibrium, occur under certain parameter values. This implies analogies to phase transitions from one particular state of equilibrium to another.“

long run, any such system must, by necessity, tend towards a thermodynamic equilibrium, and disintegrate: The so-called Entropy of an isolated system can only increase to the point at which the system has reached its thermodynamic equilibrium.

It may suffice here to explicate the complex concept of entropy by defining it as a measure fort that part of energy which is not freely available and cannot be converted into a directed flow of energy, or work. Entropy is a measure fort he quality of the energy within a system. In contrast to a mechanical description, this introduces *Irreversibility* (Non-Reversibility) or Directedness of temporal processes as a characteristic of such systems. Each future macroscopic state of an isolated system can only display equal or higher entropy, every past state must be characterized by equal or lower entropy than the current state. A reversal of any particular state is impossible. All irreversible processes generate entropy. More than a hundred years ago, Ludwig Boltzmann interpreted the increase in entropy as progressive disorganization, as an Evolution towards a *most probable* state of maximum disorder – hence, the dark image of the inescapable *heat death* of the world (Jantsch 1982:56-57):

> The energy level of any bounded physical or chemical system decreases with time as the system loses energy to its surroundings; in other words, such a system spontaneously changes from a higher to a lower energy state. Physical and chemical processes usually lead to transformations that release energy; those that require energy are highly improbable. The oxidation of a carbohydrate - for example, the burning of a piece of paper - releases energy in the form of light and heat, and the products of this oxidation (carbon dioxide and water, in this case) contain less energy than the reactants (oxygen and carbohydrate).
>
> Physical systems also dissipate energy. A swinging pendulum contains a certain amount of energy, some of which is transferred to its surroundings. As it loses energy, the energy initially residing in the pendulum becomes more evenly distributed throughout the larger system (Ricklefs 1990:36).

Isolated or *closed systems* – Systems without environment – belong to one the two fundamental classes of physical systems, i.e. the class of so-called *Equilibrium Systems*. An equilibrium system is defined as a system which either has already reached a thermodynamic equilibrium (maximum entropy, disorganization, and disorder) and, therefore, is in equilibrium, or is as yet on its path towards that state. In the latter case, the dynamics of the system are already oriented towards the equilibrium to be reached – equilibrium systems irreversibly move towards such a thermodynamic equilibrium.[24] This dynamics can be called *Devolution*, since it runs contrary to Evolution (Jantsch 1982:67).

Devolving, or Equilibrium Systems are called *Conservative Systems*, i.e. *Systems which Conserve their Structure*. Such are distinguished from the class of so-called *Evolving Systems* which include all biological systems (and, *eo ipso*, also financial markets, or economies)

[24] According to the systematic of Jantsch (1992:57), the more realistic case is that of a partially open system under conditions which are such that it tends to its equilibrium in a similar way (e.g., the materially closed, yet energetically open, system of a sand clock, or the disintegration of an-organic and organic structures under the influence of physical and chemical environmental influences). Once it has reached that state, any exchange with the environment ceases.

(Jantsch 1982:67). In contrast to systems maintaining a given structure, evolving systems are *open* and, therefore, far from thermodynamic equilibrium – such systems are so-called *Nonlinear Disequilibrium Systems*.

4. Open Systems

Open Systems are capable to continuously import free energy (in the form of light or other forms of potential energy, such as biomass, electricity, or fossil fuels) from their environment.[25] This enables them to do *Work*. At the same time, during this work process, these systems transform free energy into other forms of energy, all the while increasing entropy within the system. Natural Systems such as Organisms, Populations, or Ecosystems, however, are capable to generate and maintain a high degree of internal order (and, therefore, a state of low entropy). They do so by *exporting* energy forms which can no longer be used and, therefore, are no longer available or disposable, as potential energy within the system by way of "respiration". In contrast to isolated systems, therefore, entropy within the system need not increase by necessity: It may remain stationary or may decrease, with the adjustment process being attained by way of exchange with the environment. In this case, what applies is the general extension of the Second Fundamental Theorem of Thermodynamics, according to which the *Change of Entropy* within a given system, dS, is the sum of entropy produced by irreversible processes within the system, d_iS, and the flow of entropy induced by exchange with the environment, d_eS:

$$dS = d_iS + d_eS.$$

The theorem maintains that the internal component d_iS – just like with an isolated system – can only be either positive or zero, but never negative ($d_iS \geq 0$). The change of the flow of entropy between the system and its environment d_eS, however, may be either positive (import of entropy from without, or „immissions“), or negative (export of entropy, or "emissions"). The total change in entropy within the system, therefore, may be positive ($d_iS \geq 0$, $d_eS > -d_iS$), remain stationary ($d_iS \geq 0$, $d_eS = -d_iS$), or may diminish ($d_iS \geq 0$, $d_eS \leq -d_iS$). If the system, as a whole, is to remain in equilibrium, imports and exports must be balanced ($d_eS = 0$), at the same time that total entropy within the system must remain constant ($dS = 0$). This, however, is only possible if the production of entropy within the system itself stops ($d_iS = 0$). For this to happen, the system must be in thermodynamic equilibrium, i.e. must have stopped "working", and no longer maintains any transformation processes: Strictly speaking, such a system is "dead" (Jantsch 1982:56-59).[26]

[25] The import of energy may be controlled exogenously, in which case the import of energy takes place from outside. In the case of biological and other complex living systems, the process is organized by the system in question itself.

[26] Cf. The path-breaking works, *inter alia*, of Daly (1968), Ayres & Kneese (1969), Georgescu-Roegen (1971).

This implies, by necessity, that *open systems* can only be maintained, on a continuing basis, in states that are *far from thermodynamic Equilibrium* or in *Disequilibrium* – i.e., they must maintain relations of exchange with their environment. At the same time, exchange with the environment can only be sustained, if an *internal state* of **Disequilibrium** is sustained.. In a state of thermodynamic equilibrium, all processes end (Jantsch 1982:64).

No open system – hence, no organism, and no single biological system – is capable of existing by itself, or without its environment. Open systems are systems which, by necessity, must continuously maintain relations of exchange with their environment, and the systems continuously regenerate themselves. Closed systems do not exist in reality – in reality, all systems are open and cross-linked to others. Closed systems only exist as a theoretical possibility.

Living systems are, therefore, first of all, **open Systems** which maintain *relations of mutual exchange*, and develop – on each particular level of organization - characteristic *Functional Systems* (Odum 1983:5): All *biotic Components* of the biological spectrum only become real, living, *biological Systems*, or *Bio-Systems* only because they take in, and process, *abiotic Components*, i.e. material and energy.[27] The same is true for all anthropogenic social systems – they only become the real living systems which they are, by continuously maintaining relations of mutual exchange with their environment.

Living beings are complex systems which can only keep themselves alive by maintaining a continuous inward flow of material and energy from their environment (Capra 1996:64).[28] They cannot live by themselves, or without their environment (Odum 1983:11), are inseparably connected with their environment, and influence one another (Odum 1983:10):[29] Living beings or complex living systems, therefore, maintain some form of **Metabolism**.

[27] With respect to exchanging material with her environment, Planet Earth is a factually closed system – apart from the occasional meteorite (sometimes pretty BIG ones, too …), the Earth does not maintain material exchange with the Solar System, or with the Universe at large. With regard to energy, however, the Earth is an *open system*: The whole evolution of global Eco-Systems and of the complex systems existing within them is conditional upon a *directed* and, therefore, *irreversible* flow of energy in the shape of cosmic radiation. All these systems depend on such flows of energy as an indispensable and preliminary condition of their *function*.

[28] Capra (1996:64) justly credits Ludwig von Bertalanffy, who recognized that living organisms are *open systems* which cannot be described by classical Thermodynamics. He called such systems *open*, because they must be nourished by a continuous flow of material and energy from their environment in order to stay alive: „The organism is no static system which is closed off from its external world and always contains the same, identical components – it is an open system in a (quasi-)constant (changeless, consistent, continual, continuous, durable, endurable, fast, firm, indestructible, invariable, perennial, permanent, persistent, resistant, solid, stable, unvarying), or *steady state*, (...) in which a continuous exchange of material and energy takes place between the system in question and its external environment " (Bertalanffy 1968:121).

[29] *Sensu strictu*, living beings or complex living systems of all different kinds are *Subjects*: Subjects are living beings which are characterized by certain properties and relations, which depend on the biosphere for their survival, and which are *subordinated* to biological laws – they are *children of life*, not its *master*.

> To sustain the processes of life, a typical *cell* carries on thousands of biochemical reactions each second. The sum of all biological reactions constitutes *metabolism*. What is the purpose of these reactions - of metabolism? Metabolic reactions convert raw materials, obtained from the environment, into the building blocks of proteins and other compounds unique to *organisms*. *Living things* must *maintain themselves*, replacing lost materials with new ones; they also grow and reproduce, two more activities requiring the continued formation of macromolecules. (...) Metabolism is the totality of the biochemical reactions in a *living thing*. These reactions proceed down **metabolic pathways**, sequences of enzyme-catalyzed reactions, so ordered that the product of one reaction is the substrate for the next. Some pathways synthesize, step-by-step, the important chemical building blocks from which macromolecules are built, others trap energy from the environment, and still others have functions different from these (Purves 1992:113,130).

Human beings, other living systems, and all complex living systems, therefore, are systems which continuously transform,[30] i.e., *work*. Hence, they are not static, or unchanging structures of components which are arranged in some spatial order or structure, and do not maintain relations of mutual interaction. Instead – as already mentioned – they are in fact *Structures of Processes* in which certain forms of energy are transformed into other forms: They are *Process-Structures* (Jantsch 1982:52,55).

> Life depends upon the physical world. *Living systems* require the purposeful expenditure of energy to keep the organism *out of equilibrium with and distinct from* its *physical surroundings*. *Organisms* maintain their integrity as *open systems* by continually exchanging materials and energy with the physical environment.
>
> Motion and reproduction are the two most evident of the properties that distinguish *living organisms* from inanimate objects. Motion expresses a fundamental property of life, the ability to perform work directed toward a predetermined goal; biological reproduction derives its need from the mortality of the individual and ensures the continuation of life. Although distinct from physical systems, *living beings* nonetheless function within constraints set by physical laws. Like internal combustion engines, they transform energy to perform work. The organism´s metabolism of carbohydrates and its movement of appendages follow the chemical and physical principles (at work in physical systems). The biological world is therefore not an alternative to the physical world, but an extension of it.
>
> While *biological systems* operate on the same principles as physical systems, there is an important difference. In physical systems, energy transformations act to even out differences in energy level throughout the system, always following the path of least resistance. But *in biological systems, the organism purposefully transforms energy to keep itself out of equilibrium with the physical forces* of gravity, heat flow, diffusion, and chemical reaction. The goal of keeping itself *distinct* from the physical world applies [whatever the organism does]. [Organisms constantly expend energy and perform work to maintain themselves against physical forces](...) The ability to act against external physical forces is the one common property of all living forms, the source of animation that distinguishes the living from the nonliving.

[30] Cf. Ebeling (1989:39): Self-organizing systems are characterized by chains of processes in which energy gets transformed. The development of ordered structures is bound up with high-quality forms of energy. A part of the energy conveyed to the system will always be transformed, within the system, into some specific high-grade form (flow energy, concentration differences, tensions, etc.)."

The ultimate source of energy for life is the light from the sun. Pigments in the green tissues of plants absorb light and capture its energy; that energy is then converted to food energy through the production of carbohydrates from simple inorganic compounds - carbon dioxide and water. This energy-trapping process is called *photosynthesis* - literally, a putting together with light. Energy locked up in the chemical bonds of sugars - and thence of proteins, fats, and other organic compounds - is used by plants and by animals, which either eat plants or eat other animals that eat plants, and so on, to fire the engines of life (Ricklefs 1990:31-32).

❖

5. Autopoiesis and Evolution

As we have seen, human beings – just like any other living biological systems - and anthropogenic social systems are *open dynamic systems*, *disequilibrium systems* (or disequilibrium *structures*). In order to survive, they *must*, by *necessity*, maintain continuous interaction with their environment – i.e., *Metabolism* – and, in specific ways, *work*. The preliminary condition for the continuous dynamic existence of such disequilibrium structures is that they are partially open with respect to their environment, and that they maintain some macroscopic systemic state which is far from equilibrium (...). Thermodynamic Equilibrium is equivalent to cessation, standstill, shut-down, and death. The high degree of disequilibrium - which is required to sustain the self-organizing processes at work within the system (as well as between the system and its external environment) – is maintained by the sustained maintenance of the exchange of material and energy with the external environment - in other words, by way of metabolism.

As already mentioned above, the dynamic of such a globally stable, but never inactive, structure was called ***Autopoiesis*** (Self-Production or Self-Regeneration). An autopoietic system strives, in the first instance, not after producing some form of output, but after continuously maintaining and regenerating itself in the same *process structure* (Jantsch 1982:37). Under certain circumstances, such systems also generate new, or emergent process structures. In such systems, constitutive (anabolic) and decomposing (catabolic) processes are continuously at work simultaneously. In doing so, these systems not only dissolve their *evolution*, but also their temporary *existence within a particular structure*, into *processes*. In the sphere of life, there is little that remains solid and unchanged. An autopoietic structure ist he result of the interaction of many processes (Jantsch 1982:33,37) – hence, it is a *structure of transformation processes*, or a *process structure*.

However, autopoietic systems (or, structures) are not only geared do reproducing their particular given structure and, by way of doing so, reproducing themselves: Under certain circumstances, they are also capable of rebuilding (reconditioning, regenerating, reintegrating, remaking, renewing, renovating, replacing, reviving) themselves. They are able to change – i.e., to *evolve* – and to *spontaneously* generate new (*emergent*) *properties* or *process structures* in this process. Open systems which are in states far from thermodynamic equilibrium, and which *evolve* through an open sequence of structures (Jantsch 1982:67), therefore, are logically called ***complex evolving systems***. They are *coherent systems*, the structure of which does not remain unchanged, but changes in a coherent way. All biological Organisms, communities, and ecosystems, are dynamic, self-organizing, autopoietic, coherent, or complex, evolving systems – in the very same way as the complex anthropogenic systems so beloved in economics, sociology, or political science: Households, firms, governments, oligopolies, networks, markets, economic systems (regimes), and other niceties (Jantsch 1982:54-55).

Complex evolving systems are open *disequilibrium systems* of a particular kind which – in contrast to *conservative* systems geared to *conserve* a particular *structure* – maintain so-called *dissipative self-organization*, and are generally called ***dissipative systems*** (or ***structures***) (Jantsch 1982:56-59,115).

As dissipative structures, complex evolving systems produce entropy which, however, does not get accumulated within the system. Instead, such entropy is part of a continuous exchange of energy with the external environment.[31] By maintaining this continuous exchange of material and energy (metabolism), the system maintains its internal disequilibrium – and this very same disequilibrium maintains the processes of exchange that it requires to survive.[32] In doing so, dissipative structure continuously regenerate themselves, and maintains a specific dynamic regime i.e.,, a globally stable space-time-structure. Such structures seem to be exclusively concerned with their own identity and self-regeneration (Jantsch 1982:63). Hence, dissipative systems are not characterized by the static measure of the amount of entropy which, at a particular moment, is within the system: Instead, what is decisive is the dynamic measure of the *rate* at which entropy is being produced within the system, and the rate at which it maintains exchange with its environment. Thus, the crucial parameter characterizing dissipative systems is *intensity* of their throughput, as well as turnover, of energy.

Dissipative structures display two kinds of behaviour: When they get close to a state of (thermodynamic) equilibrium, their internal order[33] gets destroyed (just like that of closed, or isolated, systems). When they are in states that are far from equilibrium, they maintain

[31] In a simple such system – e.g., some chemical reaction system – one can already discern what ist rue for all dissipative systems: Free energy and new elements participating in reactions are being imported, at the same time that entropy and the products of reactions are being exported – this is *metabolism* of a system in its most elementary form.

[32] Jantsch has in mind, e.g., people who trip, lose their balance, and are only capable of holding their balance by continuing their stumbling (colloquially, this happens in what is typically called “pub-crawling”). One may equally well think of any anthropogenic system (households, firms, cities et al.) which can only sustain themselves by continued exchange with their environment.

[33] In the current case, the concept of the *Order* of a system refers to the (Self-) Organization of the Process Structures – the particular way in which the transformation processes of the system are cross-linked into a particular configuration and a particular internal *structure* and a particular *dynamic regime*, and organized within a systemically ordered structure linking cause and effect, and mutual interaction. The term *Evolution* of dynamic systems, or regimes, therefore, implies the transformation of a particular state of order into one that differs from the original – the emergence of new forms of order, of (self-)organization, of process structures, functional systems, or dynamic regimes. Cf. Appendix I at the end: *On the Concept of Order*.

ordered structures by way of *instabilities* and *fluctuations* (exogenous, or endogenous, shocks), out of which *new* (*emergent*) *order* may evolve (coherent behaviour):

> Dissipative structures which, at first, emerge spontaneously and transcend the original thermodynamic order, do not constitute the ultimate end of evolution. As long as they maintain exchange of energy with their environment, and as long as the fluctuations which occur (emerge, appear, arise, develop) are absorbed within the limits (scope, bounds) of the dynamic regime in question, the structure is stable, in principle. However, no structure of a disequilibrium system is stable in and by itself. Each system may be forced, or driven, over a point of instability, into a new regime, once the fluctuations exceed certain critical thresholds. This, in turn, corresponds to a *qualitative* change of the dynamic regime of the system in question. The transition to a new dynamic regime renews the capacity of the system in question to produce entropy – a process which may be associated with life in the widest sense of the term (Jantsch 1982:77).

The spontaneous creation of new forms of order, or *emergent* (process-) structures occurs only under specific conditions. In the case of the most simply hydro-dynamic or chemical dissipative structures, their evolution can be precisely specified and formalized – as a matter of principle, they equally apply to all such structures that are more complex –The transition from a laminar flow to a turbulent flow when one turns up a faucet, the emergence of new macroscopic phenomena of order such as the Bénard-instability in certain liquid systems, or dynamic phenomena in certain chemical reaction systems of the Belousov-Zhabotinsky (BZ) type, requires *openness* toward the exchange of energy and material with the environment, a state *far from (thermodynamic) equilibrium*, and both *auto-* or *cross-catalytic processes*, and/or *auto-catalytic self-augmentation of certain process stages* (Jantsch 1982:51-64).[34]

Thus, there are two *Factors*[35] which are decisive fort he evolution of systems, viz. (1): The *Intensity* of their throughput of energy, material, and information must increase and transcend certain critical thresholds, and/or (2): The systems must have auto- and/or cross-catalytic components and/or processes – this implies that either the systems at large grow, or they have certain components which grow.

[34] At the level of dissipative chemical reaction systems this implies that, e.g., certain groups of molecules participate in reactions, in which they are necessary to produce molecules of their own kind (auto-catalysis) or, first, to produce other molecules and, subsequently, molecules of their own kind (cross-catalysis). This results in a form of behaviour which is called, based on its mathematical counterpart, *non-linear* – one can best compare it with *taking off in a gallop*. In technical cybernetics, such behaviour is called a *positive feedback* – a divergence from a pre-given reference value is not reversed but, instead, causes ever more massive divergence. Population growth on Earth, like many other growth factors, is an example of such auto-catalytic nonlinearity. Cf. Anderson et al. (1988), Arthur (1988, 1990, 1994), Bak (1997).

[35] The concept of *Factors* is qualitatively defined as an ingredient, as something which actively contributes to the production of some result, or participates in some production process, hence acts, or operates, productively. In quantitative respect, factors are defined as terms which serve in multiplications and divisions. It is in this form that, e.g., technical progress is defined as a growth factor in neo-classical production functions, such as $q = A(t)f(K,L)$ (Nicholson 1995:325): Output q is defined as a function of capital (machine hours), K, labour (hours of work), L, and technical progress, A. In general form, the standard neoclassical Cobb-Douglas production function including technical progress and two factors of production, x_1 and x_2, is defined as $f(x_1,x_2) = Ax^a{}_1x^b{}_2$ (Varian 1996:308). Over time, technical progress increases, which implies that factor A grows over time – thus, as already explicated, technical progress is a nonlinear, autocatalytic factor.

Living, or complex evolving systems continuously transform energy, and are characterized by chains, or networks of processes which transform energy. In doing so, they *work*, or *produce* in certain ways. The development of highly ordered structures is always dependent on high-grade forms of energy - with part of the imported energy always transformed into some specific high-grade form (Ebeling 1989:39): Such systems, therefore, are not static, or invariant, structures of components which are configured in a specific spatial order and do not maintain interaction with one another. Instead, as already mentioned, they are *structures of processes*, in which specific forms of energy are transformed into other forms – hence, they are *process structures* (Jantsch 1982: 52, 55). The evolution of such systems, therefore, implies the transformation of existing structures of processes in which energy is being transformed.

Such spontaneous, self-organizing transitions to new process structures are dynamic processes which vary among systems depending on their degree of organization and complexity. The most elementary case is the case of so-called *Equilibrium Phase Transitions* taking place in physical systems (Krammer 1990:59): Water changes its aggregate state (frozen-liquid-gaseous), depending on temperature, and on reaching certain critical thresholds – something that is valid for a host of chemical elements and groups of materials. Hydrodynamic systems change their structure, depending on the quantity of throughput (laminar-turbulent flow), or temperature (Bénard-Convection), chemical systems of the BZ type evolve because of auto- and cross-catalytic processes which are triggered by the addition of new elements which participate in the reaction.

In dissipative physical and chemical systems, the (continuous, or discontinuous) transitions from one macroscopic state of order to another one occurs because of changes in the throughput of energy and material which are exogenously caused. In contrast to this, the process structures of dissipative physical and chemical systems (d)evolve, when certain parameters of order which are specific to the system in question exceed (or fall below) certain *critical* thresholds. This is caused by an increase, or decrease, of the throughput of energy, material, and/or information.

Although the evolution of biological systems of Life on Earth has been the subject of the most intensive scientific research, the topic is definitely beyond the scope of the present paper. Therefore, we will briefly refer to a few recent comprehensive analyses by Kauffman (1991, 1993, 1995) and others, who have extensively studied, and documented, the role of natural selection and the spontaneous emergence of order in self-organizing systems. In this approach, the evolution of Life is conceived as a continuous evolution of increasingly more complex process structures which occurs spontaneously, and by way of self-organizations:

> Darwin [reduced] the sources of the overwhelming and beautiful order which graces the living world to a single singular force: natural selection. This single-force view fails to notice, fails to stress, fails to incorporate the possibility that simple and complex systems exhibit order spontaneously. That spontaneous order exists, is hardly mysterious. The non-biological world is replete with examples, and no one would doubt that similar sources of order are available to living things. What is mysterious is the extent of such spontaneous order in life and how such

> self-ordering may mingle with Darwin´s mechanism of evolution - natural selection - to permit, or rather, to produce what we see.
>
> Biologists have not entirely ignored the spontaneous emergence of order, the occurrence of self-organization (...), but the sheer imponderable complexity of organisms overwhelms us as surely as it did Darwin in his time. We customarily turn to natural selection to render sensible the order we see, but [to explain] the origins of order [it is necessary to consider certain] kinds of spontaneous order or self-organization. (...) [While] molecular biology is driving us to the innermost reaches of the cell´s ultimate mechanisms, complexity, and capacity to evolve, mathematics, physics, chemistry, and biology reveal how far-reaching the powers of self-organization can be. These advances hold implications for the origin of life itself and for the origins of order in the ontogeny of each organism. Recent work in molecular biology with these new insights into spontaneous order in complex systems (...) promises to transform our understanding. The order in the busy complexity within the cell may be largely self-organized and spontaneous rather than the consequence of natural selection alone. Therefore, to combine the themes of self-organization we must expand evolutionary theory so that it stands on a broader foundation and then raise a new edifice. [First] we must delineate the spontaneous sources of order, the self-organized properties of simple and complex systems which provide the inherent order evolution has to work with *ab initio* and always (Kauffman 1993:xiii-xiv).

What is true for dissipative physical and chemical systems is also true for biological systems – whether it is human beings, complex anthropogenic systems (such as cities, markets, or other complex evolving systems, the (continuous or discontinuous) transition from one macroscopic state of order to another one occurs by way of changes in the throughput of energy or matter. Such changes may result from random exogenous shocks as well as endogenous causes. The evolution of process structures of biological systems occurs, when they are driven over a threshold into some new dynamic regime by fluctuations which exceed (or fall below) certain *critical* reference values (Jantsch 1982:77). This is the case, when certain parameters of order - which are specific to the system in question - exceed (or fall below) *critical* thresholds as a result of an increase (or decrease) in the throughput of energy, matter, and/or information. Under such circumstances, the system in question is incapable of absorbing any further instability, shocks, or fluctuations (caused exogenously or endogenously).[36]

> The fluctuations which we are talking about here in no way refer to concentrations, or other macroscopic parameters, but to fluctuations in the mechanisms which result in modifications of kinetic behaviour (such as rates of reaction, or diffusion). Such fluctuations may hit the system, more or less at random, from outside – e.g., by way of adding new participants in reactions, or by changing the quantitative relations within the existing original reaction system. On the other hand, they may be generated within the system itself, by way of positive feedbacks which – in this case – is called *evolutionary feedback*: → Instability, Formation of a new dissipative

[36] Every system which is made up of large numbers of nonlinear elements that are diffusely cross-linked and, therefore, almost interact like a continuum, may be driven into high disequilibrium by way of increased throughput of energy. Once this occurs, the system in question may display the typical behaviour of dissipative structures, viz. autopoiesis, and system evolution. Autopoietic modes of existence, and evolutionary self-organization by way of autonomous increase in fluctuations is what mainly characterizes most biologial, socio-biological, and socio-cultural systems (Jantsch 1982:93).

> structure → Increase in the production of entropy → Critical Threshold → Instability → Formation of a new, emergent, dissipative structure → ... (Jantsch 1982:77-78).

As a general rule, the evolution of complex evolving biological systems involves the transition to more complex dissipative regimes characterized by higher rates of energy throughput, production of entropy, increasing complexity, and increasing volume of metabolic processes (increase in the intensity of work). The spontaneous formation of new forms of order, or *emergent* (process-) structures in dissipative systems results from fluctuations and instabilities which can no longer be absorbed, and are caused by random exogenous shocks, or **endogenous growth** (auto-, and cross-catalytic processes, positive feedback). The decisive parameters of control for the particular systems in question, therefore, are (i) the **Growth rates** of the mass of energy, matter, and information, which these systems convert in their metabolism, and (ii) the growth in the extent (volume, turnover) of these systems (by way of increasing numbers of systemic component, participants in reactions, or e.g., of organisms in populations).

This can be explicated by way of a few examples: Vester (1985:27), e.g., takes a pile of sand as an example for a non-coherent quantity, a set, or a non-system (note 22). In doing so, he starts from a (relatively) closed static system – from a given quantity of more, or less, homogeneous components which, for all practical considerations, do not maintain mutual interactions with one another. If one continuously increases the quantity of these homogeneous components and, by doing so, transforms this system into an open dynamic system, the very same pile of sand proves anything else BUT "simple", as Bak & Chen (1991) convincingly demonstrate:

> A pile of sand is *a deceptively simple system* which serves as a paradigm for *self-organized criticality*: A pile of sand is a *composite system* containing millions and millions of elements that interact over a short range: many composite systems naturally evolve to a critical state, in which a minor event starts a *chain reaction* that can affect any number of elements in the system. Although composite systems produce more minor events than catastrophes, chain reactions of all sizes are an integral part of the dynamics. According to the theory of self-organized criticality, the mechanism that leads to minor events is the same one that leads to major events. Furthermore, composite systems never reach equilibrium but instead evolve from one meta-stable state to the next (Bak & Chen 1991).

In the case of sand piles, linear growth of system components eventually takes the system to, and beyond, critical thresholds, and into a critical state - Bak & Chen distinguish sub-critical, critical, and supra-critical states of systems. They do so by focusing on the number of system components, their concentration within a given space, and the number of their (potential) interactions: Apart from the example of a growing sand pile, the classic example for the development of critical systemic states is, e.g., the ordered set („population") of vertically placed Domino stones in a specific area: As long as there are but few stones, which are randomly placed and within a distance from one another that exceeds their potential reach, the exogenous import of energy (destabilization, random exogenous disturbance of the existing equilibrium) will practically have NO effects on all other elements of the ordered set. Just as with a dispersed quantity of sand, it is even subject to discussion whether this set of elements even constitutes a system.

When the number of stones within the same perimeter is increased, this implies, *pari passu,* that both their *concentration* and their *density* must increase. This, in turn, increases the probability of interactions among the system components in the case of disturbances. Moreover, if the stones are arranged, not randomly, but systemically, exogenously caused local disturbances of a given static equilibrium will initially only induce local events,, without triggering a global catastrophe of the system at large. If the number of system components is further increased, this will, *pari passu*, also increase the range of effects, within the system, which are caused by disturbances and exogenous shocks – they will affect an ever-increasing number of system components. This increases the probability that the system will be induced, by way of exogenous disturbances, to develop a higher level of activity: In turn, this will increase the probability that the system is driven over critical thresholds, and global instabilities, into a potential catastrophe – such systems are called *supra-critical*.

A growing sand pile is a complex evolving system which consists of relatively few, and homogeneous, components. It is situated at a much lower level of organization and complexity than complex biological or anthropogenic systems. Examples for the emergence of spontaneous order and the self-organization of new process structures in socio-biological systems are, e.g., the generation of new macroscopic phenomena of order in animal populations (amoeba, ants, termites, bees): Under specific conditions and circumstances, this may be caused by chemo-taxis, i.e., by way of autocatalytic enzymatic processes (Jantsch 1982:102-104).[37]

Finally, auto-catalysis and growth processes play a decisive role fort he evolution of the social systems of populations and, therefore, for the evolution of ecological communities as well as ecosystems: *Populations* are auto-catalytic systems which, in any environment with virtually unlimited resources, follow **exponential growth**. If resources are limited, and the macroscopic dynamic of the system remains unchanged, the growth process of the population takes a **logistic** form and flattens off, asymptotically, at a certain level of saturation. If mutations, or new varieties emerge which have a higher capacity to utilize given resources than the original population, the probability is high that they will prevail (assert themselves, establish themselves, hold sway, stand up) against the original population, and displace them – such a process can be understood as the emergence of *ecological fluctuations* which result

[37] Generally speaking, amoebae act with complete independence from one another. Once the density of an amoeba population, however, increases beyond certain levels and causes a deficiency of food, amoebas stop dividing and spontaneously change their behaviour: They spontaneously form aggregations, the cores of which emit, in regular intervals (pulsating) adenosine mono-phosphate, which results in rhythmical chemo-taxis. In this process, the autocatalytic enzyme system becomes unstable - its behaviour enters a limit cycle. At the same time, these processes intensify via positive feedback – the amoeba coalesce in compact clots, take over various new and different functions, and form a new organism – a slime mould which, at the same time, is constituted solely by amoebas, and changes its structure: Over a period of 20-50 hours, the initial pseudo-plasmodium (10-500.000 cells) transforms into a fungoid structure which, in the end, dissolves again. Once again, we are faced with a structure in which, suddenly, and spontaneously, the individual components which are originally separate from one another become cross-linked in a network of mutual interactions. For the whole structure to remain alive, however, it is necessary that it evolve into some system of higher order (i.e., is situated on a higher level of organization or complexity) (Vester 1983a:22-24; Jantsch 1982:103-104).

in a sequence of overlapping growth processes of individual species. Since populations exist, a priori, in ecological community with other populations, their development and growth is substantially determined by the interactions with other populations of organisms (*co-evolution*), as well as by environmental changes. These changes in the environment are determined, not least, by the behaviour of the populations within the respective ecological communities (and ecosystems), as well as by their mutual interactions.

Each population which increases rapidly – especially, the human species which does not just grow by itself, but *together* with a host of artificial anthropogenic systems which it has generated - will eventually cross critical thresholds of density - must adapt to this new level of density, and to the global cross-linkages of all partitions. These processes have resulted in a supra-critical state of the global anthropogenic system which is characterized by increasing instabilities, fluctuations, and turbulence. When such supra-critical systems cross certain critical thresholds, they tend to generate unexpected, and unpredictable, modes of behaviour: Local – endogenously, or exogenously caused – disturbances of the system may have global repercussions and either lead to catastrophes, or may generate chaotic processes which result in the spontaneous formation and emergence of new macroscopic states of order.

Whenever anthropogenic systems - which are growing exponentially on a limited globe - exceed certain thresholds of density, they must, on pain of extinction, develop new, and different, modes of macroscopic behaviour which are sustainable. If they fail to develop adequate new modes of self-organization, they will inevitably face some catastrophe which will force them back to earlier levels of density. And, if that does not suffice, and they do not respond adequately to such a trial, they will be unceremoniously extinguished.[38]

6. Man (and Woman) Kind, and Order – Planned, and Spontaneous

As already mentioned, human beings are a truly peculiar race: They have not been around for long in the Universe – while Planet Earth has been around for some 4,600 million years, the phylogenetic evolution of humans started between four and a maximum of 10 million years ago. The phylogenetic evolution of *Homo sapiens sapiens* is generally held to have ended at the beginning of the Palaeolithic, i.e., approximately some 50,000 years ago. Expressed as a percentage, the time period during which “Mother Earth” evolved without any human populations worth mentioning covers a full 99.99913 per cent of the total time which has elapsed since the origin of the Planet.

Taking a time horizon of 50,000 years, it is quite impressive (not to say, frightening) to see the transformations that human beings have been capable of wreaking on Earth. It is even more telling, if one shortens that time horizon to the past 200 years, i.e., to the time span covering the Industrial Revolution and the emergence of so-called “Modern Economic

[38] Cf. The so-called *Collapse* of Maya-civilization, the transformations in Early Medieval Europe after the Fall of Rome, or the so-called Crisis of the High Medieval Age which reached irs climax in the catastrophe of the Black Death Epidemic in 1347/48. Temporarily, such crises lead to a regression of human populations to lower levels of organization and complexity. It is 2007, and the world is in a state that can only be called supra-critical.

Growth" – vulgo **Capitalism**: Taking a comprehensive balance of the rather nonchalant way in which a human race obsessed by **Capital** has gone about to "create a world after its own image", such musing regularly transforms into awe, outright shock, and appalling horror.

Now, we have heard that the Earth is an open system with respect to energy. For all practical matters, however, Planet Earth is a closed system when it comes to the exchange of material with her "environment", i.e., the solar system. Not so with human beings which, like any other *organisms*, or all other biological systems, function as biotic components of the biosphere.

The so-called *anthroposphere* includes the complete spectrum of all systems created by humanity – i.e., all *anthropogenic* components, including all anthropogenic *social*, *economic* and *cultural* systems in which human populations organize themselves. Of course, the *dynamic* anthropogenic systems are, by their very nature, complex systems which maintain internal process structures as well as interactions and mutual relations with their respective environment. Just like any other complex system, anthropogenic systems are capable, under specific circumstances, to evolve. Although social ecology is concerned with the whole spectrum of anthropogenic systems, it is mainly concerned with the partial spectrum of anthropogenic *social*, *economic* and *cultural* systems, in which human populations organize themselves. However, these systems are heterogeneous and, therefore, do not only contain biological systems and natural living beings, but increasingly also abiotic components and systems. Hence, they are called ***anthropogenic*** **living systems** or ***anthropogenic*** **living beings**.

Humans, human populations, and the anthropogenic systems in which they organize themselves, sustain certain process structures internally (metabolism). They can only do so by continuously sustaining material and energetic processes of exchange with the environment.

As everyone knows, anthropogenic systems have displayed – especially over the past 200 years or so - a phenomenal capacity for change, dynamic adaptation, growth, evolution, and development. The almost casual and mindless pleasure of humans – and, especially, CAPITAL - "to create a world after its own image", has resulted in a dramatic increase in disturbances, instabilities, and a host of critical phenomena, in a continuously increasing number of both anthropogenic and natural systems. These critical developments, in turn, have resulted in processes which have a tendency to turn chaotic and, if taken to their logical conclusion, to their bitter end. The dramatic increase and aggravation of critical developments on Earth is amply documented in ravaging floods of data, in meticulously formalized reams of statistical information, in a flood of more or less complex models, and in the continuous evolution of knowledge concerning the phenomena in question: The capitalist world proceeds happily, superbly informed, and straightforwardly, right into its own collapse, and demise (Marsh 1864, Thomas 1956, Turner II 1990, Sieferle 1997:7-11, Brown 2005, 2006, Meadows et al. 2006, Gore 2006, IPCC 2007a,b,c):

> Humans are more effective than other species in attempting to transform their physical environment, in order to satisfy their own immediate needs. In doing so, they increasingly destroy those components of nature which are essential preliminary biological conditions for

> their own survival. Humans are heterotrophic and phagotrophic organisms - hence, belong to the final links in the complex food chain. Notwithstanding their capacity for technological development, their dependence on the natural environment persists. Anthropogenic systems (such as economies, giant cities, et al.) are, therefore, left as **parasites** in the biosphere: The bigger they become, and the higher the volume of their material and energetic turnover (just think of so-called "vital" raw materials such as air, water, and foodstuffs). The more they take out of their natural environment, the more menacing the danger that they damage the natural environment. Human beings were so concerned with the "conquest" of nature that they rarely thought of, nor took care of, solving the inherent conflicts which resulted from their twin role as both "creators" and members of natural ecosystems (Odum 1983:31).[39]

At the present (preliminary) end of all human history so far (Fukuyama 1992) the much-heralded *blue Planet* - *Mother Earth*, *Gaia* (Lovelock 1991:43; 1992:6-11; Sahtouris 1993; Capra 1996) –proves to be a Living Being that is virtually **possessed** by mankind and her anthropogenic systems. Despite the fact that human societies have "chosen", to fail, or succeed, many a times before (Diamond 2005), this predicament has never been as comprehensive and global as in our own time! Historically speaking, therefore, it is of utmost importance to stress that, by now, the Earth has come to be possessed of the so-called *Modern Market Economy* or, *vulgo*, by ***Capital***. It is plain to see, and well documented, that the long-run development, and dynamics, of the relationship which growth-oriented social systems maintain with the natural environment, undermine the capacity of natural systems to sustain themselves: *Pari passu* this process has led to the fact that an ever-increasing number of natural systems themselves are in *critical* conditions, i.e., in *crisis* – basically, an ever-growing number of natural systems are *on the edge of catastrophe*, at the edge of the abyss in which – as everyone knows - ***Chaos*** rules supreme. The continuous (and, mostly, *exponential*) increase in instabilities and fluctuations - in critical, by tendency chaotic, and catastrophic processes - in ever more natural and anthropogenic systems have resulted in a crisis which is unprecedented in the total history of mankind:

> After largely having escaped from immediate dependence on nature, humans evolved into a species which maintains a controlling stake in nature. By now, this relationship of „control and subjection" has become an uncontrolled natural force which threatens to put in question the continued existence of the human race. The Earth cringes under the roaring of human societies and their irrepressible urge to acquire. In many place on the planet, the Earth is poisoned, and excoriated, having become inhospitable. The crimes of today are casting wide, and dismal, shades. The horsemen of apocalypse have come sallying forth. Nature is fighting back – be it in the way of the feverish expansion of deserts, and the malign growth of cancerous cells in the human body (Armanski 1978:83).

[39] With respect to urban agglomerations, e.g., cf. Girardet (1992:11): "The history of early cities shows that they often depleted their local hinterlands, draining their fertility without replenishing it. They exhausted the forests, watersheds, and farmland that had enabled their existence. The ancient cities of Mesopotamia are now surrounded by bleak wastelands, covered in crusts of salt. Are we repeating this tragedy today, but on a planetary scale? The word´s largest cities now have the whole planet as their hinterland; they draw on resources and dump their wastes all around the globe." Critical tendencies in contemporary urban agglomerations are documented, *inter alia*, by Vester (1983a); Odum (1983,1991); Schweizer (1987); Berry (1990); Sassen (1991,1994); Girardet (1992); Elsom (1996); Zimm (1996). For exemplary contributions to historical urban ecology, cf. Te Brake (1975), Newcombe et al. (1977, 1978), Bilsky (1980), Glick (1980), Boyden et al. (1981), Cronon (1991), Girardet (1992).

> Throughout most of history, the interactions between human development and the environment have been relatively simple and local affairs. But the complexity and scale of these interactions are increasing. What were once local incidents of pollution shared throughout a common watershed or air basin now involve multiple nations - witness the concerns for acid deposition in Europe and North America. What were once acute episodes of relatively reversible damage now affect multiple generations - witness the debates over disposal of chemical and radioactive wastes. What were once straightforward questions of ecological preservation versus economic growth now reflect complex linkages - witness the feedbacks among energy and crop production, deforestation and climate change that are evident in studies of the atmospheric „greenhouse effect“. (...) Humanity is thus entering an era of chronic, large-scale, and extremely *complex syndromes of interdependence* between the global economy and the world environment (Clark 1986:5)

Since the good old times, when humans began to distinguish themselves from animals, by beginning to *produce* their means of existence, the Earth has transmogrified dramatically (Turner II 1990) – at the end of her whole history so far, humanity is facing a global environmental crisis hand-made by man. Still unconceivable, and beyond even the wildest expectations only a few years ago, this scenario is exactly what happened – and everyone knows it is true (Fischer-Kowalski & Haberl 1997a:3).

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Thus, nobody can deny that, what is necessary to realize, is the long-run *sustainability* of anthropogenic metabolic processes. What is at stake, therefore, is the long-run ability of mankind on Earth to evolve modes of production which must be modified, on pain of extinction, vis-à-vis the capitalist mode of production that is ruling supreme (at least, for the time being ...)!

Recent ecology is well aware that it does, indeed, start from this preliminary condition. Ecologists have repeatedly pointed out, that the specific system, or *network* of metabolic exchanges maintained by the Advanced Industrial Societies, is a dynamic **open cycle of metabolic processes**. There is no discussion that these social formations must **close** these open cycles – on pain of their physical extinction:

> The hydrological cycle, the carbon cycle, and the nitrogen cycle are familiar concepts to earth scientists. The major way in which the industrial metabolic system differs from the natural metabolism of the earth is that the natural cycles (of water, carbon/oxygen, nitrogen, sulphur, etc.) are *closed*, whereas the industrial cycles are *open*. In other words, the industrial system does *not* generally recycle its nutrients. Rather, the industrial system starts with high-quality materials (fossils, fuels, ores) extracted from the earth, and returns them to nature in degraded form.
>
> This point particularly deserves qualification. The materials cycle, in general, can be visualized in terms of a system of compartments containing *stocks* of one or more nutrients, linked by certain *flows*. For instance, in the hydrological cycle, the glaciers, the oceans, the fresh water lakes, and the groundwater are stocks, while rainfall and rivers are flows. A

system is *closed* if there are no external sources or sinks. In this sense, the earth as a whole is essentially a closed system, except for the occasional meteorite.

A *closed system* becomes a *closed cycle* if the system is also in steady state, i.e. the stocks in each compartment are constant and unchanging, at least on average. The material balance condition is that the material inputs to each compartment must be exactly balanced (on average) by the outputs. If this condition is not met for a given compartment, then the stock in one or more compartments must be increasing, while the stocks in one or more other compartments must be decreasing. It is easy to see that a closed cycle of flows, in the above sense, can only be sustained indefinitely by a continuous flow of *free* energy. This follows immediately from the second law of thermodynamics, which states that entropy increases in every irreversible process. Thus a closed cycle of flows can be sustained as long as its external energy supply lasts. An open system, on the contrary, is inherently unstable and unsustainable. It must either stabilize or collapse to a thermal equilibrium state in which all flows, i.e. all physical and biological processes, cease.

The natural system is characterized by closed cycles, at least for the major nutrients (carbon, oxygen, nitrogen, sulphur) - in which biological processes play a major role in closing the cycles. By contrast, the industrial system is an open one in which "nutrients" are transformed into "wastes", but not significantly recycled. The industrial system, as it exists today, is therefore *ipso facto* unsustainable.

(...) Evidently, biological evolution responded to inherently unstable situations (open cycles) by "inventing" new processes (organisms) to **stabilize the system by closing the cycles**. This self-organizing capability is the essence of what has been called „Gaia“ (Ayres & Simonis 1994:5-9, passim).[40]

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In his Introduction to his Study on the Development of the Theory of Complex Systems (titled „Visions of the Whole“), Mitchell Waldrop (1992:11f.) sketches these systems as follows:

A system is *complex*, in the sense that a great many interdependent agents are interacting with each other in a great many ways. Think of the quadrillions of chemically reacting proteins, lipids, and nucleic acids that make up a living *cell*, or the billions of interconnected neurons that make up the brain, or the millions of mutually interdependent individuals who make up a human society.

In every case, moreover, the very richness of these interactions allows the system as a whole to undergo *spontaneous self-organization*. Thus, people trying to satisfy their material needs

[40] Cf. Marx (1890:528): "With the ever growing preponderance of the urban population agglomerating in great centres, capitalist production amasses, on one hand, the historic power of society to act, at the same time that it disturbs the metabolism between man and nature – i.e., the return of the components of nature which humans use to make food and to produce their means of livelihood. Thus, they tend to destroy the eternal natural condition of sustained soil fertility. In doing so, humans destroy both the physical health of urban workers, and the spiritual life of the agricultural workers. However, by destroying, quasi "naturally", the external conditions of their own metabolism – which, itself, has evolved by its own nature – they are forced to establish these natural processes in systematic ways, as a regulating law of social production, and to do so in ways that are adequate to accomplish the full development of human beings." (translation mine)

unconsciously organize themselves into an economy through myriad individual actions (...); it happens without anyone being in charge of consciously planning it. (...) Organisms constantly adapt to each other through evolution, thereby organizing themselves into an exquisitely tuned ecosystem. (...) In every case, groups of agents seeking mutual accommodation and self-consistency somehow manage to transcend themselves, acquiring collective properties such as life, thought, and purpose that they might never have possessed individually.

Furthermore, these complex, self-organizing systems are *adaptive*, in that they do not just passively respond to events the way a rock might roll around in an earthquake. They actively try to turn whatever happens to their advantage. Thus, the human brain constantly organizes and reorganizes its billions of neural connections so as to learn from experience (sometimes, anyway). Species evolve for better survival in a changing environment - and so do corporations and industries.

Finally, every one of these complex, self-organizing, adaptive systems possesses a kind of dynamism that makes them qualitatively different from static objects such as computer chips or snowflakes, which are merely complicated. Complex systems are more spontaneous, more disorderly, more alive than that. At the same time, however, their peculiar dynamism is also a far cry from the weirdly unpredictable gyrations known as *chaos*. (...) Instead, all these complex systems have somehow acquired the ability to bring order and chaos into a special kind of balance. This balance point - often called *the edge of chaos* - is where the components of a system never quite lock into place, and yet never quite dissolve into turbulence, either. The edge of chaos is where life has enough stability to sustain itself and enough creativity to deserve the name of life. The edge of chaos is where new ideas and innovative genotypes are forever nibbling away at the edges of the status quo, and where even the most entrenched old guard will, eventually, be overthrown (Waldrop 1992:11f.)

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