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Six Levels of Complexity; A Typology of Processes and Systems

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Abstract

A closer examination of the position of processes and systems on a scale of complexity is a precondition for the simulation of (biotic and) social processes and systems.

It is possible to distinguish 6 levels:

1st level of complexity: the process takes place mainly between 2 concrete participants (simple movement). Control by the environment, not yet a system (solidum).
2nd level of complexity: the process orders the movements, it is horizontally (temporally) oriented, and passes in each case through 4 stages (movement project). The system is the sum of the elements and orders itself through its elements (equilibrium system).
3rd level of complexity: the process distributes energy (demanded products), it is vertically (between superior and inferior environment, market) oriented and passes in each case through 4 bonding levels (flow process). The system is more than the sum of its elements, it regulates itself as a whole (flow-equilibrium system).
4th level of complexity: the process converts energy into products, it is horizontally (temporally) oriented, and passes in each case through 8 stages (7 by overlapping) (process sequence), it is based on division of labour. Each system organises itself structurally as a whole (non-equilibrium system).
5th level of complexity: the process is vertically (hierarchically) oriented and in each case passes through 8 hierarchical levels (7 by

overlapping)(hierarchical process). Each system generates itself structurally by organising its elements and subsystems (hierarchic system).
6th level of complexity: process is horizontally (spatially) oriented, and probably passes 16 spheres (13 by overlapping) in each case (universal process, universal system). Each system within the spheres generates itself materially: autopoiesis.

Keywords:
Autopoietic systems, energy flow, Pecos (New Mexico), process sequence, self organisation

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The problem

1.1
In the 1980s, research into complexity developed from the discipline of chaos research. By means of simulation it successfully attempted to represent the complex structures which distinguish our reality. Models were developed which were intended to illustrate the emergence of, for example, biotic and social systems. In this way, new fields of research such as Artificial Life and (particularly important in our context) Artificial Society, came into being. Epstein and Axtell (1996) in particular were able to use simple mathematical formulae to demonstrate how "agents" move within an artificial "landscape" (cellular automata), how they spread out, thereby forming patterns, how they concentrate locally, arrange themselves according to different aspects etc. Interesting formations are created which demonstrate a spatial differentiation of society. Whereas previously, under the influence of behaviourism, deterministic and probabilistic models predominated, which attempted to explain the processes of movement and arrangement "from the top down", so to speak, this approach shows how important processes leading to changes in society can be traced "from the bottom up".

1.2
However, to date, it has not yet been possible to define processes which create lasting self-organising systems such as we encounter everywhere in the social world, i.e. populations such as families, companies, communities, states etc. (see ¶ 2.20). It is these which, integrated in hierarchies (see ¶ 2.29) shape cultures, form cultural landscapes and provide the driving force for social change. In this connection, the term autopoiesis, originally developed in the field of biology, also appears in the literature. Hence the question arises whether the processes which shape social reality are perhaps autopoietic processes. It is questions and difficulties such as these which prompt us to reflect on the connection between model and reality. The creation of a link between complexity research, which is based on simulation, and empirically obtained results appears to be more necessary than ever because indications are increasing that researchers who are engaged in work with mathematical models on the one hand and those whose work is based on empirical data on the other, are understanding one another less and less.

1.3
The author of this article works in the field of social geography. Consequently, it is social processes and systems on which his reflections are based. The drawback in working with social systems is that (with very few exceptions) they do not permit experimentation, i.e. it is not possible to corroborate results by means of repetition. On

the other hand, with their assistance, it is possible to trace contexts on the same scale as our day to day experience ("Mesocosmos"; Vollmer 1985, p. 57) from inside, so to speak, which would otherwise be very difficult to identify, or which can be followed only with the assistance of costly equipment.

From solidum to universal system: the levels of complexity

Introduction: the way to understanding complexity

2.1

The social and historical-geographical studies carried out by the author in the 1960s and 1970s identified concealed spatial tendencies in migration and traffic movements as well as periodically recurring processes in the development of settlement, which it was not possible to explain in isolation. The systematic study of the abandoned Indian Pueblo Pecos and the area in New Mexico settled by the Spaniards (Fliedner 1975; Fliedner 1981) showed then that the settlement processes are carried out by populations, i.e. by centrally controlled and distinctly delimited social groups (tribes, communities, ethnic groups etc.; see ¶ 2.20). This discovery stimulated investigations to obtain a more detailed understanding of the internal processes of populations, which in turn allowed conclusions to be drawn with regard to the systems involved in processes and (from a systemic point of view) to the groupings within human society (Fliedner 1997).

2.2

This forms the basis for the conclusion that the above mentioned problems can only be seen in the correct systematic context when phenomena are approached not from the point of view of structure, but of processes. The following is an attempt to develop step by step a systematic approach to the complexity of processes and systems (see ¶ 2.1 to ¶ 2.60; Fliedner 1999). Our starting point is human society, and more specifically, the settlements in New Mexico.

Simple movement and Solidum

2.3

At the beginning of the 20th century, geographers still regarded concrete forms (e.g. forms of settlement) and their spatial distribution as the actual object of their research (outlined by Fliedner 1993, p. 30). Seen this way, the Pueblo Pecos appears as a structure several storeys high, consisting of thick walls of clay, which is now decayed and protected as a national monument. It was probably inhabited by thousands of people, who found protection there from the heat of the sun as well as from their enemies. They were sedentary Indians, cultivating maize, squash, beans etc. as well as collecting plants, berries, nuts and roots and hunting wild animals such as elk, deer, coyote, and turkey. The utilisation of the land was - in this dry climate - extensive, as irrigation was only introduced after the arrival of the Spaniards (around 1600), and even then, only in a very rudimentary form.

2.4

Pecos was only one of many Pueblos in the dry country of New Mexico. In the course of their settlement, the Spaniards built mission stations to convert the Indians to Christianity. They introduced cattle breeding and built haciendas. Besides this, they founded numerous settlements of their own and used the land for agriculture by irrigating the ground around the few perennial rivers. The houses in these settlements were either constructed around central plazas, in rows, or in irregular villages. The building material they used was adobe brick, i.e. available directly from their surroundings. Administration, trades and services were concentrated in the small towns.

2.5

In this brief description, the settlements of the Indians and Spaniards appear as concrete objects, i.e. "solida", especially in their dependence on the forces of nature. This view of things is to be found in numerous regional-geographical publications, which characterised the subject up to the 1920s (from a methodical point of view, see Hettner 1927). The object, i.e. the country or a specific phenomenon (e.g. a settlement) was regarded in its shape as an effect, whose cause and causal forces had to be studied. The processes as such were left aside and activities such as settlement and cultivation were treated without temporal differentiation. One may even say that the temporal sequence represented the sum of action motions or simply "movements" in which two elements participated, the moving (agents, i.e. the humans engaged in settling and cultivating) and the moved (parts of the natural environment which is changed). The explanation is causal. In the scale of complexity, movement and solidum are located at the beginning, and although neither a complex process nor a complex system is involved, we will refer to it as the 1st level of complexity for the sake of uniformity of scale.

Movement project and equilibrium system

2.6

As mentioned above, the Indians of Pecos were engaged in extensive agriculture. In the immediate vicinity of the Pueblo, it was slightly more intensive, as is shown by the greater density of the artefacts found in this area (field houses, ceramic shards etc.). The intensity of cultivation declined with increasing distance from the settlement. In the outer areas, hunting was practised (stone tools used for hunting and dismembering game) as well as gathering of edible products from the surrounding bush and forest areas. This decline in the intensity of utilisation from the centre towards the periphery is attributable to the time budget available to each inhabitant. This budget included such things as social communication, rearing of children, construction of dwellings, ritual activities, defence against hostile tribes etc. as well as recuperation (sleep, rest intervals etc.). Most of these activities involved overcoming distances (e.g. journeys on foot, transport of goods). The time required to cover the distance had therefore to be added to the time needed for work. The greater the distance from the Pueblo, the fewer Indians were prepared to undertake arduous field work. Thus, the land at a greater distance from the Pueblo was utilised less intensively.

2.7

The work on a specific task (e.g. field work, construction, warlike expeditions) along with the effort involved in covering the distance to carry out the task represent an action project or, generally, a "movement project". It consists basically of four stages (stimulus, acceptance of stimulus, energy expenditure and execution). Pauses for recovery or recuperation should be added at certain intervals, since individuals had to ensure that they did not "overstrain" themselves, i.e. an equilibrium had to be found between the work and the energy available to carry it out. If all the similar individual movement projects of this type are added together, one is able to conceive that the plurality of humans in their daily and yearly work had come to terms with their environment and, with regard to physical labour and yield, had achieved an equilibrium with it. We are now dealing with "equilibrium systems". In the case of Pecos, this is demonstrated by a greater intensity of land utilisation close to the pueblo and a lesser intensity in the peripheral areas, and the separation of activities (agriculture in the inner and hunting and gathering in the outer areas). In specialist literature, this process of separation is known as Thünen's rings (see v. Thünen 1826/1921).

2.8

To take a further example, the Spaniards living in the villages of New Mexico depended administratively and economically on the central town of Santa Fe and, at a later date, on Albuquerque, as it increased in economic importance. This process of centring on towns and the greater density of settlement around the towns can be explained by the dependence of the country dwellers on the services available there, and on the dependence of the town dwellers on the goods produced in the country. Here too, there is a separation of activities in relation to distance. In principle, the same applies in a much altered form to the systems formed by modern city-hinterland systems, in spite the extensive and complex transport networks which have come into being in the course of "globalisation".

2.9

Equilibrium systems are linear systems inasmuch as the individuals engaged in movement projects are linked together cumulatively as their elements. The system orders itself according to the possibilities of the participants (elements). The equilibrium system represents the 2nd level of complexity.

2.10

In the 1920s, sociologists and geographers gave much attention to this type of system (Burgess 1925/67; Christaller 1933; outlined by Fliedner 1993, p. 78). As with the solida, it was not the processes as such which were studied. Instead, greater emphasis was devoted to the functional relations between central places and surrounding areas and therefore to the separation of activities, i.e. the (horizontal) time-space link. Clearly, this approach was destined to be adopted by other sciences. Most prominent among these were the economic sciences, which developed a number of different models (Lösch 1940). Generally speaking, the human sciences were able to resort to deterministic models originating from the natural sciences, e.g. Newton's Law of Gravity.

Flow process and flow-equilibrium system

2.11

The term "complex process" and "system" can only be applied from the 3rd level of complexity. The system acts independently as a system and not just as the sum of its elements. To return to the example of the pueblo Pecos, the settlement was founded around 1300 and abandoned in 1838. Precise studies of the terrain indicate that the cultivated land was extended and reduced at intervals of approximately 30 years (oscillation), and each time, the centre of mass of the cultivated terrain shifted (in the average) tangentially, with the result that a rotational tendency is seen.

2.12

This indicates a close connection between the number of people and the amount of food available. The people and the land (with its resources) form a self-regulating flow-equilibrium system. Considered more closely, a distinction has to be drawn between the quantity of people as a biotic system demanding nourishment and the system procuring the nourishment. More people have to be supplied with nourishment than actually carry out work. The systems consist of many individuals which may be seen as elements to the extent that they are engaged as participants (i.e., in their roles). In relation to the social system, the biotic system is the demanding "superior environment" and the land the "inferior environment" providing the nourishment. Thus, information (i.e. the demand) flows from the superior environment through the social system, which has to carry out the task, into the inferior environment. Then the energy (i.e. the nourishment, the supply) comes in the opposite direction to the superior environment via the social system carrying out the task. Thus, both the flow of energy and the flow of information cross the social system in a vertical direction. In the social system, four structural levels can be seen in the flow of information:

1. the whole of the social system accepting the demand from the "superior environment" (the biotic system as the "market"),
2. the whole of the social system in contact with the participating individuals as the elements,
3. the accepting elements of the social system and
4. the elements in contact with the energy resources in the "inferior environment".

2.13

These levels are called "bonding levels". This downward travelling flow of information (demand) is opposed by an upwardly travelling flow of energy (supply) which uses the same levels, only in the opposite direction.

2.14

The entering of the demand and the offer of the supply do not occur simultaneously. This is because both environments change. On the one hand, the number of demanding individuals and therefore the demand for nourishment (superior environment) increases or decreases. The social system can only respond to these changes by increasing or reducing the supply with a certain delay, resulting in oscillations. On the other hand, the land as inferior environment loses its productivity in the course of time and is damaged by erosion, thereby leading to occasional shifts in the main areas under cultivation (rotation, see above). Four different stages can be identified:

1. The number of demanding individuals (biotic system) increases, but the social system cannot yet provide sufficient food;
2. The number of individuals (biotic system) decreases, as not sufficient food is available; the social system extends the land under cultivation (into areas not yet damaged by erosion);
3. The number of individuals (biotic system) continues to decrease, although the social system now supplies sufficient, or even too much food;
4. The number of individuals (biotic system) again increases, while the social system reduces the area under cultivation (and because of the decline in fertility, moves it to another area not yet damaged by erosion); foodstuff again becomes scarce.

2.15

In this way, the system regulates itself. Many such oscillations are attributable to basically the same reasons. For example, the Spanish colonisation of New Mexico between ca. 1600 and ca. 1850 (when the USA took possession of New Mexico) was due to an exponential increase in the number of inhabitants. The land was colonised in a number of stages which lasted around 50 years each and produced new forms of settlement. The periodic increases and decreases in the speed of expansion were probably due to the delayed reaction of the social system (with regard to provision of nourishment) to the growth in the number of participants (the biotic system). This was return reflected in the process of colonisation.

2.16

In most cases, when population groups or parts of an economy (as in this case, the agriculture of a region) working in the same sector are stimulated by the market to procure demanded goods, we are dealing with such flow processes and flow equilibrium systems. Oscillations normally occur as a sign of self-regulation, as the participants must procure the demanded goods from the inferior environment, and that takes time.

2.17

Flow equilibrium systems have been extensively studied since the 1950s (outlined by Fliedner 1993, p. 122). Geography should be mentioned in this context, in particular diffusion research (Hägerstrand 1952). The economic sciences should also be seen in this connection (Forrester 1969). Ecology has also developed especially through the concept of flow equilibrium systems. The results obtained in this science have contributed to revealing the precarious state of the system "earth-humans" (Meadows et al. 1972).

2.18

The theory of sociological structuring developed by Giddens (1984/97) should also be mentioned. With Luhmann's social systems (1984) it is not quite clear how they are internally structured. They involve at least partially flow equilibrium systems. No process sequences or systems based on division of labour are described, and certainly no autopoietic systems (see ¶ 2.38 to ¶ 2.60).

2.19

Chaos research and synergetics (Prigogine 1979; Haken 1977/83) are also based on the model of flow equilibrium systems, as well as the studies based on cellular automata (complexity research), as applied, for example, in the Santa Fe Institute (see ¶ 1.1). Interesting patterns are generated, but no real self-organisation of elements is achieved. This only becomes possible within the framework of the following type of system.

Conversion process and non-equilibrium system

2.20

The flow processes serve to procure and distribute demanded goods. The flow equilibrium systems (see ¶ 2.11) consist of more or less numerous smaller system units, the companies, farms, workshops, organisations, plants etc.. We call these units (from a social point of view) "organisates", which for their part belong to the group of "populations". Populations absorb the raw goods from the inferior environment and process them to form products. From the point of view of the system, these are non-equilibrium systems. They represent the 4th level of complexity.

2.21

For example, the whole of the working members of a Spanish colonist family in New Mexico is an agricultural organisate. The oscillations mentioned in the flow equilibrium system (see ¶ 2.11) also express themselves within the populations and determine the rhythm of the processes at work in them. Here too, four stages are recognisable:

1. the demand from the superior environment (market) is absorbed as information in the social population ("adoption"),
2. the "production" by the social population (i.e. cultivation and harvest) takes place in accordance with demand. The supply to the superior environment in

relation to demand is fed back; e.g. it is noticed that supply and (now altered) demand do not correspond.

3. The "reception" of this result (information) takes place, and therefore the stimulus to adopt the structure of the population to the changed circumstances by means of investment, and,
4. "reproduction", i.e. the implementation of the adaptation. In this way the system organises itself.

2.22

Supply and demand take place in interaction with the market, i.e. adoption and production are market-oriented - "induction process". Reception and reproduction on the other hand concern the system itself and its structure. They are system oriented - "reaction process". Self organisation shows that this system is a non-equilibrium system.

2.23

These systems too are characterised by the contradiction between the whole and the elements (i.e. the participating individuals in their specific roles). For this reason, we can see four bonding levels here too, as in the flow equilibrium systems (see ¶ 2.11). They are passed through in temporal sequence one after another, with the result that the (horizontal) process receives additional structuring from these. In this way, all four stages mentioned (adoption, production, reception and reproduction) receive their specific characteristics.

2.24

During the adoption stage, the demand from the superior environment is accepted and incorporated into the system, which stimulates the whole (1st bonding level, "perception"). The decision is then taken whether to accept the stimulus (2nd bonding level "determination"). The third bonding level is distinguished by the contact with the elements, i.e. their integration and control ("regulation"), and finally, the spatial organisation of the elements takes place in relation to the contacts between them, and with the inferior environment, the resource basis (fourth bonding level, "organisation" of adoption). Here the production stage also begins, in which the energy or the raw goods from the inferior environment is passed upwards via the bonding levels and is processed into products. First of all, the energy from the inferior environment is absorbed by the elements (fourth bonding level, "organisation" of production) and fed to the system as an whole (third bonding level, "dynamisation"). Only then does the actual implementation i.e. processing (second bonding level, "kinetisation") take place. Finally, the finished product is offered to the market and it is noted whether it is accepted in the expected quantity or not (first bonding level, "stabilisation").

2.25

The result of the above-mentioned contact with the market, i.e. of the comparison between demand and supply at this point (feedback) determines as well the stimulus for the next induction process as for the reaction process, i.e. whether the size of the system and its structure should be changed. The reaction process (self organisation) takes place according to the same pattern.

2.26

In the review, it is shown that specific tasks (perception to stabilisation) are resolved gradually in the various stages. This is the "process sequence". (The individual task stages are represented by formulae, but this cannot be dealt with in detail at this point, see Fliedner 1997, appendix). The 4th and the 5th stages (organisation), and the last stage (stabilisation) and the 1st stage of the next sequence (perception) overlap temporally. Thus, the induction and the reaction processes each consist of 7 stages and the entire process of 13 stages. All the tasks of the sequence must be fulfilled, even if this is not generally possible in a separate stage each (in less differentiated systems), with the result that several tasks are included in one stage. The process sequence forms the basis for the systems of higher complexity levels and therefore has considerable significance for the structure of the processes and systems.

2.27

The self-organisation takes place in such a way that the system aligns the elements (e.g. individuals in their roles) to make it possible for them to carry out the process sequences. As these systems produce by means of the division of labour, elements of the same task are joined in a way which is most favourable to the production process. Thus, the system consists of different parts which communicate with one another. The elements are not generated materially themselves, i.e. the individuals as such, as is the case with autopoietic systems (see ¶ 2.38). Instead, only the artefacts necessary for the work are manufactured (such as tools, earthbound artefacts such as houses, fields, roads) as well as the products for precise transfer to the demander. The system also limits itself from the inside outwards, with the result that it is identifiable from the outside.

2.28

Because they constantly procure energy from outside and release it in form of products to the outside, non-equilibrium systems are the actual centres of activity in our reality. They include all the populations of mankind (see ¶ 2.29) and ecosystems, and the cells and organs which constitute living beings. Perhaps they even include the social systems as understood by Maturana (1998) (see ¶ 2.40). At any rate, humans and all living beings belong to them, as well as atoms, molecules and solar systems in inanimate nature. At the same time, they should be assigned to a higher level of complexity, the sixth (see ¶ 2.38).

Hierarchical process and hierarchical system

2.29

Pecos can be described as a community. Its inhabitants belonged to the tribe of Towa-speaking Indians. Also the Spanish settlers were divided into village communities. In the middle of the last century, they formed (as a whole) an ethnic group distributed between city-hinterland systems with Santa Fe and Albuquerque as their centres. Today (after their war of independence), the Mexicans appear as a people (or as population of a state). Communities, tribes, ethnic groups, and peoples represent different types of population, i.e. non-equilibrium systems. They are identifiable as such all over the world. To these should be added other types of population, cultural populations (e.g. that of the Pueblo Indians, or that of Europe), organisates (see ¶ 2.20) and families.

2.30

These populations are arranged hierarchically. We should distinguish two types of hierarchy while referring to the above statement (see ¶ 2.12) that we must regard humans both in their biotic and their social aspects. In the course of cultural evolution (since the late Palaeolithic era) a highly differentiated hierarchical system, mankind as society organised by division of labour, developed from the biotically defined mankind as a species. The populations assigned to mankind as society represent the social and economic aspects of mankind. Mankind as a species took much longer to become differentiated than mankind as a society. Thus, two strands of development to independent hierarchical processes and hierarchical systems can be distinguished, which are founded on individuals in their roles (see table 1):

Table 1: The hierarchies of mankind as species and mankind as society

Mankind as species		**Mankind as society**
	Mankind as population	
Small cultural population		Large cultural population
Tribe, people		State population
Ethnic group		City-hinterland population
Community		Community
Family		Organisate
	Individual	

2.31

The populations, i.e. the non-equilibrium systems as structural units, were created in the course of cultural evolution with the developing hierarchic system of mankind as society. This is the same as saying that the hierarchic system gradually generated its elements and therefore itself, and (as cultural evolution is not yet concluded) is still in the process of doing so. However, this takes place only structurally (i.e. humans are not created as materially shaped living beings; (see ¶ 2.46) but only adapted to the system in their roles).

2.32

Each type of population is embedded in a flow equilibrium system, i.e. the individual populations compose the flow equilibrium systems. Mankind as a society, with which we wish to deal more closely, is a vertically oriented system, i.e. the directions are passed from the top downwards (demand) and compliance with these directions, i.e. the flow of energy (supply) takes place from the bottom upwards. All populations are integrated. These vertical processes take place in accordance with the process sequence, i.e. at every level tasks are resolved for the entire hierarchic system. Regarded structurally, the horizontal process sequence of the non-equilibrium system (see ¶ 2.20) is brought into a vertical position. And thus we enter the 5th level of complexity.

2.33

The tasks of the non-equilibrium systems in the hierarchic levels take their concrete form in basic institutions (see table 2; we are here not able to give reasons for this. Cf. Fliedner 1997). In this way, a qualitative thematic specialisation is achieved. Thus the processes at the various levels are screened off from one another. Unnecessary noise is avoided in the transfer of information, as well as the unnecessary dissipation of energy.

Table 2: Populations, tasks and basic institutions within mankind as society

Population types	**Tasks**	**Basic institutions**
Mankind as population	Perception	Science, art
Cultural population	Determination	Religion, view of life

State population	Regulation	Rule, authority
City-hinterland population	Organisation	Transportation
Community	Dynamisation	Infrastructure
Organisate	Kinetisation	Implementation
Individual (role)	Stabilisation	Labour, consumption

2.34

The populations located at the lower hierarchical levels supply those at higher levels. The duration of their process sequences must therefore be shorter.

2.35

Generally speaking, through differentiation, mankind as a society is able to exploit the multifarious resources available in the ecumene and (through world trade) to transport them to those areas where they can undergo further processing. The fact that this leads to unfair distribution (demonstrated by the contrast between industrialised and developing countries) is just one of the drawbacks of a world economy.

2.36

Hierarchies constitute our reality. Through hierarchies, the production of the non-equilibrium systems can be co-ordinated, the processes, i.e. the flows of energy can be controlled and the energetic resources of the environment to a great extent optimally exploited. Perhaps the global ecosystem also structured itself as a hierarchical system for this reason. After all, mankind as a species is part of this system and as such, embedded in its vertical flow of information and energy. Then it would be possible to assign the non-equilibrium systems in the hierarchical levels to the tasks in the same way as the populations to mankind as a society. The following is an attempt to do so.

1. Perception (perception of the environment): the living world is distinguished from inorganic nature by certain specific characteristics (metabolism, reproductive ability). The living beings perceive the advantages and disadvantages of the environment to their own advantage. Carrier: the living world as a whole.
2. Determination (decision on the type of exploitation of the environment): the plant and animal kingdoms define themselves as antagonists through their position in the flow of energy (see ¶ 2.46). Their independent existence is dictated by this. Carrier: the kingdoms.
3. Regulation (control of the flows of information and energy): the absorption of nutrients and reproduction are specified by the fact that living beings belong to certain species. This permits a control of the vital processes of life. Carrier: the species.
4. Organisation (contact with the inorganic inferior environment, transition of flow of information to flow of energy): the living beings define themselves as independent objects in their environment and give the vital processes spatial order internally. Carrier: the organism.
5. Dynamisation (division of energy from the inferior environment in the system): the internal flow of information and energy involved in the metabolism is carried out by the organs. Carrier: the organs.
6. Kinetisation (transformation of energy into useful substances or products): the various (metabolic) products are manufactured for the body in chemical working units by a process based on division of labour. Carrier: the cells.

7. Stabilisation (organic substance preserves life): the construction of organic substance and its release from the inorganic environment are controlled at molecular level. Carrier: the organic molecules.

2.37

One has to assume that hierarchical structures have also formed in the inorganic world, e.g. in the creation of the macro- and microcosmos (see ¶ 2.52.). However, the hierarchies are normally much less differentiated, i.e. at the various levels several tasks have to be resolved in the vertical process sequence.

Universal process and universal system

2.38

However, we can also approach the ecosystem in another way. As mentioned above, mankind as a species is part of the global ecosystem. It uses its niche to survive and to make its existence as comfortable as possible. The breeding and maintenance of cultured plants and domestic animals, as well as their utilisation, can be controlled by farmers through their work. They make use of the potential of biotic processes but they cannot change these as such. They may manipulate certain details in biotic processes, but they cannot eliminate them altogether. The fact that plants and animals require certain nutrients to survive, that they have only a limited life span etc. is outside a farmer's sphere of influence. Here, we cross the threshold to the next, or 6^{th}, level of complexity. The processes in this level can only be understood if we regard them against the background of the universe as a whole. The universal system forms the framework in which life and inorganic matter are created.

2.39

This sixth level of complexity is characterized by autopoietic processes and systems. In order to understand this correctly, a slight digression is necessary.

About the question of autopoiesis

2.40

In the 1970s, Maturana and Varela developed a theory of autopoietic systems. The term autopoiesis is a combination for the Greek work autos (self) and poiesis (creation, generation). According to Maturana (e.g. 1998, p. 106) an autopoietic system can be interpreted as a network which creates its components and its organisation recursively itself, through interactions, and which defines its own limits and therefore constitutes itself as a unit in space. In addition, the system maintains itself as an independent structure in the surrounding milieu. It is open for the processing of energy, accepts stimuli from outside, which may cause structural changes in the system, but the internal processes take place on their own in accordance with a program of their own (Maturana 1993, p. 16; Maturana and Varela 1984/87, p. 55).

2.41

The authors continued to develop this concept in various publications and I will refer principally to their most recent ones. Put briefly, autopoietic systems are distinguished by three characteristics (Whitaker 1998; Fleischaker, quoted by Capra 1996/99, p. 237):

1. Self limitation: the system creates its limit itself, the limit is a constituting feature of the network;

2. Self generation: all the components including the limits are created by the network processes themselves;
3. Self maintenance: all the components are maintained permanently by the processes in the system itself.

2.42

Maturana and Varela relate autopoiesis to "living systems" which are defined as "closed networks of molecular production processes which create their own limits" (Maturana 1998, p. 182). Apart from the fact that this term may cover many different things, its delimitation with regard to social systems is not clear-cut. Maturana (1998, p. 185) distinguishes between autopoietic systems of the first degree which have a relatively simple structure, i.e. cells, and autopoietic systems of the second degree, by which he means organisms as multi-cellular systems. As autopoietic systems of the third degree he mentions social systems (see also Whitaker 1998). These represent networks of co-ordinated actions and behaviour patterns which their components carry out through their interactions. However, Maturana only regards those systems as social systems that are characterised internally by mutual emotional acceptance (which he calls "love") (see pp. 251, 374). According to him, working systems and power systems which have not come into being on this basis, are not social systems. Here, things become more difficult. He was contradicted by Varela (1981, quoted by Mingers 1995, p. 129) who thought that organisms and human societies were completely different types of living systems, the term autopoiesis could not be used for social systems, and a more general term would be appropriate.

2.43

Luhmann (1984, pp. 43, 60, 296) on the other hand, claimed that the term autopoiesis could be used generally for social systems, as inner circularity and self-reinforcing feedback loops formed an enclosed system and reproduced new (communicative) systems. However, he did not accept Maturana's theory that social systems were also living systems (p. 298) and distinguished between organic and psychic reproduction in the case of humans. "In one case the medium and outward appearance are *Life*, in the other case, *Consciousness*. Autopoiesis qua life and qua consciousness is the precondition for the formation of social systems and that also means that social systems can only achieve their own reproduction when the continuation of life and consciousness is assured" (Luhmann 1984, p. 296; italics by author; see also Schlemm 1997/98). On the other hand, Heijl (1993) objected to transferring the concept of autopoiesis to social systems, but considered Maturana's and Varela's concept as possibly being an important precursor for a theory of self organisation and therefore the self-regulation of cognitive and social systems (p. 234; refer also to Mingers 1995, p. 152).

2.44

Other writers are of different opinions. Be that as it may, autopoiesis has been the cause of much discussion, but everything remains rather vague. New details are often added and new opinions formulated without really clarifying the situation or defining what autopoietic systems really are and how they are categorised. This is not intended as a complaint, but only as a statement of the fact that the discussion has arrived at a crucial point. The problem is that the system is not scrutinised exactly enough, that no investigation is taking place of how the networks are linked with one another, what processes (flows of information and energy) constitute them and what their significance is for the whole. In addition, there is no theoretical structure leading to an understandable organisation of systems and processes.

2.45

It is not the purpose of this essay to fill this gap, but an attempt will be made, at least in general outline, to arrange systems and processes and to assign them to their correct position within the framework of autopoiesis, at least as far as this is possible and necessary from a geographical point of view.

Living beings as autopoietic systems

2.46

In the ecosystem, living beings occupy the central position (Begon, Harper and Townsend 1996). As non-equilibrium systems (see ¶ 2.20), they transform energy, i.e. produce. They also organise themselves i.e. they structure their elements, network their processes and position themselves in such a way that the conditions of life in the ecosystem take on a form which is as free from stress as possible, above all, that the flow of energy can take place in a way which involves as little loss as possible. However, living beings also possess the ability to create themselves materially. The term autopoietic system can therefore be used to refer to them, the cells are their elements. The cells, too, exhibit the autopoietic organisation, as Maturana had already emphasised (see ¶ 2.40, also Mingers 1995, p. 18).

2.47

Creating themselves also means that living beings, in their corporeality, are integrated in the general cycle of energy, because living beings are born, grow, and die. They absorb substances from other sources of energy, and themselves supply energy for other living beings (through their death). Here, an important difference from biotic and social populations i.e. non-equilibrium systems, emerges (see ¶ 2.20). These do not create themselves substantially, they only organise themselves structurally. Thus, we may speak only of self organisation, not of self creation. Autopoietic systems may also be non-equilibrium systems, because they organise themselves, but they also belong to a higher, i.e. the 6th level of complexity.

2.48

Plants (we mean autotrophic cormophytes) select the chemical substances which they need from those dissolved in water passing through the ground. They absorb these through widely branching root systems and conduct them through tubular cells into the highest twigs and branches, transform them (metabolism) and convert them into growth. The water is sucked up by the capillary effect of the water deficit in the leaves caused by evaporation. The chemical conversion of the inorganic nutrients to organic substances takes place mainly in the leaves (but also partly in the sprouts). In addition, carbon dioxide is absorbed and oxygen released into the atmosphere. In the individual cells, the pigment chlorophyll absorbs light from the sun and converts it into chemical energy. Thus it can be said that many substances from the inorganic environment are used to create vegetable forms. Substance is converted into shape.

2.49

Generally speaking, plants are incapable of changing their location. They are propagated by the transport of seed or by layers. Wind, water or animals are used as the means of transport. In the course of evolution, the plants have continually adapted to environmental conditions and have helped to shape the process themselves.

2.50

Animals on the other hand are equipped with the means of locomotion, can orient themselves in space by means of sense organs and seek the food they require. Thus, the herbivores are able to find suitable plants and the carnivores suitable prey as well as sources of water. This means that they are in a position to use the environment to satisfy their requirements.

2.51

The animals consume plants and/or prey as food, thereby destroying the shape of these living beings, while their digestive organs extract the substances they require to build up their own structure and shape. In general, it can therefore be said that the ecosystem supplies the energy (originating from organic vegetable substance) by which the animals form themselves according to the scheme dictated by their genes. On the other hand, through the death of living creatures spatially formed and structured life is again reduced to its substance and passed to the inferior environment. Put simply, plants appear as the inferior environment to the animals and prey to the predators, while to plants, the animals represent the superior environment and to prey, the predators. We may therefore say that the substance from the inferior environment (see ¶ 2.11) is transformed in form and space, and vice versa, form and space from the superior environment is transformed into substance. The generating of substance therefore takes place in an upward direction, and the formation of form and space in a downward direction. Living creatures of the same species are organised in populations, i.e. non-equilibrium systems (areal systems; Müller 1981). This makes it easier for them to reproduce and find their own place in the food chain, to generate their ecological niche. They therefore form and maintain themselves as autopoietic systems, they create themselves, they are their own product.

The inorganic autopoietic systems

2.52

The processes take place in the global ecosystem, or, expressed spatially, in the "biosphere". The inorganic environment plays an important part in this.

2.53

In the course of evolution, life has adapted to its peculiar characteristics and dynamics through the specific formation of its living beings, and is therefore able to draw the necessary energy from its environment with special efficiency. The inorganic environment takes part in this process in two ways.

2.54

On the one hand, it supplies the material which serves forms of life as the basic material for chemical conversion in their food chain. This is the "molecular sphere", the environment which is hierarchically inferior to the biosphere. The "molecules" of which it is composed create themselves thereby forming their own product. They define themselves with reference to others, organise themselves internally in space and maintain themselves. They are autopoietic systems. The raw materials originate either from the biosphere itself, organic detritus or the inorganic inferior environment (subterranean rock, rivers, lakes, oceans etc.).

2.55

On the other hand, the biosphere is surrounded by the large compartments of lithosphere, hydrosphere and atmosphere, which, systematically regarded, also form a unit, which we may describe as the "chemosphere". It is hierarchically superior to the biosphere. Systems also form in it. These are the "chemical systems" which organise themselves as independent structures, and through their specific substantial composition, form their physical conditions (solid, liquid, gas) and their physical characteristics (temperature, convection current, eddies etc.), fora in which molecules may take shape. Through the formation of substance in the chemosphere, matter achieves a diversity such as exists in no other sphere. Only in this way can the presence of enough raw materials for the emergence of life be explained.

2.56

The chemical systems continually recreate themselves. Many of the substances mix, constantly creating further contacts, thereby stimulating the formation of new substances (occasionally with the assistance of catalysis). However, the delimitation of the individual chemical systems is generally vague and in many cases system limits are impossible to distinguish, as with living creatures or molecules. In this respect, autopoiesis is therefore incomplete.

2.57

The molecules may be regarded as the elements of chemical systems, i.e. the molecular and chemical spheres are assigned to one another in a complementary manner. Here too, the flow of energy takes place from the bottom (molecular sphere) upwards (chemical sphere) and the flow of information ("demand") from top to bottom (see ¶ 2.11). The molecules form the substance, the chemical systems the spatial framework.

2.58

Seen broadly, the chemical systems (and thus the chemical sphere) can be classed with the macrocosmos, the molecules and thus the molecular sphere with the microcosmos. The biosphere with its living beings acts as an intermediary in its order of magnitude between these two spheres, and thus between macro- and microcosmos.

2.59

The biosphere has come into being on our planet. As we know, this cannot simply be taken for granted, since the other planets of our solar system are probably lifeless. The global ecosystem depends on the two inorganic neighbouring spheres. This does not apply in the opposite direction. However, the global ecosystem does exercise a certain influence on the inorganic spheres, primarily through the exchange of gases and through its effect on the water systems and erosion processes. This may produce an added stabilising effect on these inorganic compartments. Mankind is also part of the ecosystem. Through its influence, not only is the ground subject to change (erosion, pollution, desertification etc.) but it probably also has a destabilising effect on the climate (see Lovelock's "Gaia theory" 1991/96, although it is inappropriate to refer to the earth as an organism).

2.60

As stated above, the biosphere occupies a structurally intermediate position between the macro- and the microcosmos. If one continues the scale of spheres through the chemical or molecular sphere to the macro- and microcosmos, it can be seen that the term autopoiesis can also be applied to the systems of which these are made up (earth as planet, solar system, galaxy, or ions, atoms, particles etc.). They generate themselves materially, they delimit themselves and they maintain themselves. Thus, the word "autopoiesis" should not be limited to "living systems".

Conclusion

3.1

Let us return to the questions posed at the beginning:

3.2

Firstly, the term complexity itself requires closer examination. Here, we must distinguish between two basic scales of complexity:

a. The scale of the 6 levels of complexity from solidum to universal system is superior. These stages are linked to one another by emergence processes (Fliedner 1999).

b. Within the stages of complexity, we can distinguish between systems with simple and complex structures. Thus, within the universal system, i.e. between the autopoietic systems, there is a scale from the atom via the ion and the molecule to the living creature, and within mankind as a society from the individual via the organisate, the community etc. to mankind as a population.

3.3

Secondly, the discussion (see ¶ 1.1) became more acute with reference to the terms self-organisation and autopoiesis. According to the scale of complexity we must distinguish between flow-equilibrium system (flow process) and non-equilibrium system (conversion process).

a. Flow-equilibrium systems distribute demanded energy or products (flow processes), non-equilibrium systems convert these by means of conversion processes, and they produce prducts;
b. Flow-equilibrium systems are homogeneously structured, and consist of analogous elements. Non-equilibrium systems on the other hand are heterogeneously structured and based on division of labour;
c. Flow-equilibrium systems do not delimit themselves from the inside and are often spatially diffusely distributed. Non- equilibrium systems, on the other hand, do delimit themselves from the inside outwards.
d. Flow-equilibrium systems regulate themselves and preserve themselves in this way. Non-equilibrium systems also organise themselves spatially.
e. Flow processes, as diffusion processes, are homogeneously structured. Conversion processes, on the other hand, are heterogeneous in theme and form process sequences.

3.4

Moreover, a distinction should be drawn between non-equilibrium systems and autopoietic systems. Both preserve, organise and delimit themselves. However, they are different:

a. Non-equilibrium systems:
   This system type of the 4th level of complexity is explained on the basis of populations. Populations, whether biotic (e.g. areal systems) or social, are self-organised, self-preserving and self-delimited. They are also aligned thematically, i.e. they have tasks for superior systems (for instance the global ecosystem or mankind as a hierarchic system). As structures, they require carriers (i.e. plants, animals and humans in their various roles).

   Social populations also require earthbound artefacts (houses, fields, traffic routes etc.). Both population types have in common that individuals (in their roles) come and go as elements, while the structures remain, i.e. with regard to the duration of their existence, carriers and structures are not directly dependent on one another.

b. Autopoietic systems:
   These are also self-organised, self-preserving and self-delimited, but the structures are materialised directly. They only remain in existence as long as the carriers exist, and vice versa. This applies for all systems of the 6th level of complexity, i.e. not only for living creatures and cells but also for chemical

systems and molecules, planets and ions, solar systems and atoms. The spheres are the frame. The global ecosystem is an hierarchic system (and an non-equilibrium system), which creates itself structurally (evolution) and forms the milieu for autopoiesis of the living beings. Neither the global ecosystem is an autopoietic system, which creates itself materially, nor, of course, the regional sections of the global ecosystem. The latter can be studied only as flow-equilibrium systems, consisting of numerous inferior non-equilibrium and autopoietic systems (living beings, cells). It is remarkable that, on the one hand, relatively simply constructed atoms belong to the highest level of complexity, while, on the other, highly complicated ecosystems are assignable to much lower levels of complexity.

3.5

It would be desirable if, in the simulation of (biotic and) social systems, more attention were devoted to the varying character of the systems and processes at the different levels of complexity. Each type of system demands its own explanations. The first complexity level is linked with the causal explanation, the second with deterministic (temporal and spatial) models. For the third level, probabilistic models and, in particular, simulation models e.g. within the framework of Artificial Life and Artificial Society should be used. Probably, it would not be adequate to apply the models of the third level also to conversion processes and self-organising systems of the fourth level of complexity.

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