EMERGENCE, ANTICIPATION AND MULTISIMULATION: BASES FOR CONFLICT SIMULATION

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ABSTRACT
Two major categories of usages of simulation are highlighted. They are (1) providing experience for three types of training and entertainment and (2) performing experiments. Several characteristics of emergence are reviewed, especially within the framework of the simulation of social systems: and lists of over 30 terms related with emergence as well as over 20 types of emergences are given as appendices. The importance of perception in human decision making and activities is underlined; anticipation and early detection of emergence are presented as a special cases of perception. Basis of a methodology to model emergence is explained.

Keywords: Emerge, de-emerge, re-emerge, merge, demerge, multistage model, multisimulation, types of simulation, perception, anticipation, behaviorally anticipatory systems, simulation challenge, conflict simulation

1. INTRODUCTION

Our long term interests include the development of appropriate modeling and simulation methodologies for conflict studies applicable in different types of usages of simulation. To better represent several human traits which can be best described by mostly linguistic variables, such as autonomy/quasi-autonomy, personality and emotions, agent simulation is preferred. The focus in this article is on perception, anticipation, and emergence within the framework of multisimulation. A modeling methodology to represent emergence is proposed and multisimulation is explained as a simulation methodology to allow simulation of several aspects of a system of interest.

2. SIMULATION

2.1. Types of Simulation

Simulation is useful for two major categories of usages which are (1) providing experience for three types of training and entertainment and (2) performing experiments.

In *training*, simulation is use of a representation of a system to gain/enhance competence through experience under controlled conditions. Training can be achieved (1) by using virtual equipment as it is the case in simulators and virtual simulators (i.e., virtual simulation) to gain/enhance motor skills, (2) by gaming simulation (i.e., constructive simulation to gain/enhance decision making skills, or (3) by a mixture of real system and simulation (i.e., live simulation) to gain/enhance operational skills.

In areas other than training and entertainment, simulation is used to perform goal-directed *experiments* with dynamic models. These areas include education, understanding, and decision support.

Use of simulation for decision support is done for the following main categories of activities:

- *Prediction* of behavior or performance of the system of interest within the constraints inherent in the simulation model (e.g., granularity) and experimental conditions;
- *Evaluation of alternative* models, parameters, experimental and/or operating conditions on model behavior or performance;
- *Sensitivity analysis*;
- *Engineering design*;
- *Prototyping*;
- *Planning*;
- *Acquisition* (or simulation-based acquisition);
- *Proof of concept*.

The richness of the discipline of simulation and its many facets are elaborated on in other articles, see for example Ören (2005, 2006, 2009). However, some authors, instead of benefiting from these scientific aspects of simulation which make simulation a vital enabling technology for many disciplines–including social sciences– they tend to focus either (1) on the non-technical historic meaning of the term simulation which exists in English since the 14th century or (2) on an assumption not done by simulationists.

2.2. Simulation Fallacy

In a review of a book by Buchanan (2007a, b), Feld refers to "Simulation fallacy" in the following assertion: "Furthermore, in searching for explanations for social phenomena, Buchanan repeatedly commits two types of logical errors. The first of these is the simulation fallacy. A simulation typically shows that a particular proposed mechanism "could" produce an observed pattern. However, a simulation provides no evidence that the proposed mechanism is necessarily important or even relevant in some particular situation in which the pattern is found. Identifying "possible" causes only contributes to a scientific understanding of society when the conditions under which those causes are applicable and the extent of their applicability are empirically demonstrated and understood."

The term "*simulation fallacy*" is also used to stress the fact that the simuland (the system which is simulated) is not the same as the model which is used in its simulation. This assumption is categorically not done in either type of simulation stated at the beginning of the section on the types and usages of simulation, namely in (1) providing experience for three types of training or entertainment and (2) performing experiments.

"Simulation fallacy" is also stated within a metaphysical framework, as expressed by Searle: "Given that a computer simulation of a fire doesn't burn the neighbourhood down, or a simulation of gold make you rich, why should the computer simulation of understanding, actually understand?"

According to Copeland, the term simulation fallacy is also stated as:" A closely related error, unfortunately also common in modern writing on computation and the brain, is to hold that Turing's results somehow entail that the brain, and indeed any biological or physical system whatever, can be *simulated* by a Turing machine."

2.3. Simulation Challenge

One can take the following quotations–all published in 1968–as a "*simulation challenge*." First, a quotation from Knuth (1968): "*We often fail to realize how little we know about a thing until we attempt to simulate it on a computer.* "

Second, two observations are from John McLeod (1968): *"(1) If you do not know enough about a system, a good way to find out more is to try to simulate it. And (2) A model need not be sophisticated to be useful. If it simulates those aspects of interest to the degree necessary for the study at hand, the simulation is valid*". And the last quotation which is also from John McLeod (1968): "*The smaller a man, the closer his horizons*".

2.4. Agent Simulation

"Agents are autonomous software modules with perception and social ability to perform goal-directed knowledge processing, over time, on behalf of humans or other agents in software and physical environments. The knowledge processing abilities of agents include: reasoning, motivation, planning, and decision making. Additional abilities of agents are needed to make them Intelligent, human-like, and trustworthy. Abilities to make agents intelligent include anticipation, understanding, learning, and communication in natural language. Abilities to make agents more trustworthy as well as assuring the sustainability of agent societies include being rational, responsible, and accountable. These lead to rationality, skillfulness and morality (e.g., ethical agent, moral agent)." (Ghasem-Aghaee and Ören, 2003).

Abilities to make agents human-like include representation of personality, emotions, and culture.

The term *agent simulation* denotes simulation of systems modeled as software agents.

3. EMERGENCE

3.1. Sistemic View

"It is important to draw the line between "emergence" as a mere synonym of everyday language words like "appearance" or "growth" on the one hand , and 'emergence' as the fundamental concept of emergentist theories in philosophy on the other hand." (Brunner and Klauninger).

In philosophy as well as in systems science, "emerge" and its derivatives have different meanings and these properties are very important in complex systems in general and in the simulation of social systems in particular; therefore they are elaborated in this article. For a history of emergent properties, see Stanford Encyclopedia of Philosophy (SEP-emergent). A systemic definition of emergence is given by Goldstein (1999) as: "the arising of novel and coherent structures, patterns and properties during the process of self-organization of complex systems."

Some fundamental concepts are:

- Emergence is a fundamental feature of self-organizing systems;
- Self-organizing systems are complex systems;
- Complex systems are not organized centrally;
- The complexity of a system depends on the number of its elements and connections between the elements;
- Emergence is based on non-linear causality.

There are feedback loops within a self-organizing system. Fenzl elaborates on the role of energy flow and information in emergence and self-organization of complex systems (Fenzl). "In all self-organizing (physical, biological, and social) systems the emergence of order is triggered by fluctuations that cause synergies between the elements of the systems. … There is a non-linear, complex relationship between causes and effects in self-organizing systems: It is objectively conditioned that a fluctuation will at some critical point in the system´s development result in the emergence of new order (necessity). According to Fuchs, but the exact moment and the exact form of the process of emergence and its resulting new qualities is to a large degree uncertain (chance)."

Fuchs lists and clarifies 15 principles of physical self organization.

These principles are listed in Table 1.

Table 1: Principles of Physical Self-Organization

1.	Control parameters
2.	Critical values
3.	Fluctuation and intensification
4.	Feedback loops, circular causality
5.	Non-linearity
6.	Bifurcation points
7.	Selection
8.	Emergence of order
9.	Information production
10.	Fault tolerance
11.	Openness
12.	Symmetry breaking
13.	Inner conditionality
14.	Relative chance
15.	Complexity

Appendices 1 and 2 adopted from Fuchs (pp. 206-207) and (Arshinov and Fuchs, pp. 6-8) cover some explanations of these fundamental concepts as well as types of emergences.

Bonabeau et al. (1995) provide a critical review of emergent phenomena. Deguet et al. (2006) provide a survey of definitions of emergence. A special issue of Sciences et Avenir is dedicated to discuss several aspects of emergence (S&A, 2005).

3.2. Types of Emergence: some lexical clarifications

Rey (2005) provides a good etymological clarification for the relationships of the terms emergence, immersion, and submersion. In our article, the relevance of the terms merging, de-emergence and re-emergence are also stressed since they are equally relevant in simulation of social studies, especially for conflict studies. Table 2 depicts the relationships of the terms immerge, submerge, emergence, re-emergence, de-emergence, merging (horizontal, vertical), and demerging.

Table 2. Relationships of the Terms related with "merge"

↧	—— ↓	—↑—	—— ↓	↔ ↕
Immerge immerse	Subm.	e(x)m. Re-em.	de-em.	Merge Hor.-m. Ver.- m. Dem.

Immerge, submerge, emerge, de-emerge, re-emerge, and merge are derived from Latin *emergere* which means to dip.

Original connotations were passing–totally or partially–from a medium (air) to another (water) as it is the case in *immerge* (from Latin *in-* and *mergere* "to plunge") and *submerge* (from Latin *sub-* "under"). *Submerge* means:

- to place under water;
- to cover with water, inundate;
- to hide from view, obscure.

Immerge (immerse) means:

- to plunge into something that surrounds or covers, *especially***:** to plunge or dip into a fluid.
- to engage wholly or deeply, absorb: *scholars who immerse themselves in their subjects* (AHD-emerge).

In the case of emerge (from Latin ex- "out of") the direction of the flow is reversed and original meaning was passing from a medium (water) to another (air). Later, immerge, submerge, and emerge gained additional meanings.

The term "*emergence*" can be used with its system theoretic connotation meaning appearance of a characteristic of a non-linear complex system with feedback loop(s). In social systems this feature is of primordial importance.

As it is the case with most words in natural languages, the word "emerge" and its derivatives have different meanings and some of them differ from their etymological meanings.

For example, according to the American Heritage dictionary, "*emerge*" means the following:

- to rise from or as if from immersion: Sea mammals must emerge periodically to breathe;
- to come forth from obscurity: new leaders who may emerge;
- to become evident: The truth emerged at the inquest.
- to come into existence (TAH-emerge).

According the Merriam-Webster, "emerge" means:

- to become manifest, become known: new problems *emerged*;
- to rise from or as if from an enveloping fluid, come out into view: a diver *emerging* from the water;
- to rise from an obscure or inferior position or condition: someone must *emerge* as a leader;
- to come into being through evolution (MW-emerge).

Compact Oxford Dictionary defines “emerge” as follows:

- become gradually visible or apparent;
- (of facts) become known;
- recover from or survive a difficult period (OD-emerge).

The term "*merge*" means:

- to cause to be absorbed, especially in gradual stages;
- to combine or unite: *merging two sets of data*;
- to blend together, especially in gradual stages;
- to become combined or united.

Merging, hence, mergence may end up of generating characteristics and/or structures different then previous ones and therefore is an important concept in social system simulation.

Demerge (Brit.) is to separate a company from another which was merged.

In social systems, two types of merging, namely horizontal merging and vertical merging can cause structural changes in system components. *Horizontal merger* is a merger occurring between companies producing similar goods or offering similar services. This business term can be extended to factions of similar goals. *Vertical merger* is a synonym of vertical integration which is defined as follows by Business Dictionary (BD-vi): "*Merger of firms at different stages of production and/or distribution in the same industry. When a firm acquires its input supplier it is called backward integration, when it acquires firms in its output distribution chain it is called forward integration. For example, a vertically integrated oil firm may end up owning oilfields, refineries, tankers, trucks, and gas (petrol) filling stations. Also called vertical merger.*" In conflict situations, vertical merger may mean merging of factions to complement their functions.

3.3. De-emergence and Re-emergence

In social systems, the opposite characteristic of emergence is equally important; namely a characteristic or a component of the system may disappear. Instead of using the terms immersion or submersion, the term de-emergence is preferred; since the Latin prefix *de-* also means negative and opposite. Another relevant topic is re-emergence, i.e., emergence which may occur after de-emergence.

3.4. Emergence in Simulation of Social Systems

Jin et al. (2008) provide a review of emergence-oriented research in agent systems. Dessalles et al. (2008) elaborate on emergence in agent based computational social science. Different types of emergence, i.e., emergence, de-emergence, re-emergence, horizontal and vertical merging are important in the simulation studies of conflict problems in social systems. Sawyer (2004), for example. focuses on emergence in agent simulation of social systems and simulates the mechanisms of emergence. Sawyer also addresses the question "Which social properties are emergent?"

In social system dynamics, several aspects of emergence need to be taken into account:

- Emergence studied *as a systemic characteristic of non-linear complex systems*; since social systems are both complex and non-linear;
- in addition to self-organization as a complex system, *a social system may be guided (or forced) to change* (for the good of the citizens or for the group who may have an interest for the change). This way, external and internal inputs/events/ processes affect the social behavior. For example, conditions may be activated to cause, in the long run, a new feature in the society. This new feature may change the nature of the society even radically and may appear to have emerged out of nowhere. However, if the citizens and/or those working for them (e.g., representatives and media) would be proactive and anticipate the consequences, they could have foreseen that the initial events/processes/inputs would be resulting with such effects. Most often, the change occurs at several stages. Hence, in social systems, leading to conflict, especially the first two principles of self-organization as listed by Fuchs may be useful in simulation modeling. They are: "(*1) control parameters*: a set a parameters that influence the state and behavior of the system. (*2) critical values*: if certain critical values of the control parameters are reached, structural change takes place, the system enters a phase of instability/criticality (Fuchs, pp. 206-207).
- Also, *disappearance* of some social characteristics may also be conceived and hence, modeled and simulated as "emergence."

4. PERCEPTION, ANTICIPATION AND BEHAVIORALLY ANTICIPATORY SYSTEMS

4.1. Perception

Perception is very important in our activities; since the way we perceive reality affects our decisions, feelings, emotions, and activities. We can perceive three categories of entities which exist, which may be anticipated, and which may emerge or which may cease to exist. In modeling existing, anticipated, and emergent systems, we represent goal-directed abstractions of objects, their attributes, and relationships among themselves as well as with their environments.

4.2. Anticipation and Anticipatory systems

Most human activities and simulation models are reactive; therefore according to causality, the value of the current input and current state determine the value of the next state. Special Interest Group in Anticipatory Systems of BISC (Berkley Initiative in Soft Computing) lists 12 definitions of anticipation. However, the following definition, listed as the first one is the essence of anticipatory systems: “An anticipatory system is a system whose current state is determined by a future state. The cause lies in the future.” (Rosen, 1985) (BISC-SIG-AS).

An anticipatory system may be difficult to model, since the value of its current state would be determined by the value of a future state. However, by defining a behaviorally anticipatory system, one can circumvent this problem as follows: a behaviorally anticipatory system can have, at time t, one or more predicted model(s) of itself and/or of its environment at time $t+n$. Hence, at time t, its next state can depend on the current image of the predicted model (at $t+n$) of its state and/or its environment. Since, current image, at time t, of the predicted model of itself and/or of it environment is well specified, next state can be calculated without any contradiction with causality.

Ören and Yilmaz (2004):

1. give a systematic and comprehensive classification of input and point out the relevance of perception as an important type of input in intelligent systems;
2. give a categorization of perception and present anticipation as a type of perception;
3. clarify the inclusion of anticipation in simulation studies and elaborate on other aspects of perceptions in simulation studies especially in conflict situations.

5. MULTISTAGE MODELS AND MULTISIMULATION

The sequence of models with emergent states and/or transitions can be conceived as a set of multistage models which can then be simulated by multisimulation. The concepts of multistage models and multisimulation were introduced in 2001 (Ören, 2001) as a methodology to allow simulation of several aspects of a system simultaneously, especially for conflict management studies. Elaborations on multisimulation are made by Yilmaz and Ören (2004), Yilmaz et al. (2006); Yilmaz et al. (2007), Lim (2007) and Yilmaz and Tolk (2007).

In some aspects of social system dynamics, completely new conditions may emerge and accordingly, a simulation study would need to be interrupted, model needs to be replaced by a new one and then the simulation study would resume. In some cases, at the update instant of the simulation study, one may want to continue with two or more models under same or different experimental conditions.

This concept would lead us to multistage modeling and multisimulation since after the interrupt, more than one simulation study (successor simulation study) would occur. If the successor simulations are realized under the same experimental conditions, they may be coupled or not. Coupled successor simulations can have common resources.

Figure 1, taken from Ören (2001), depicts an example multistage model.

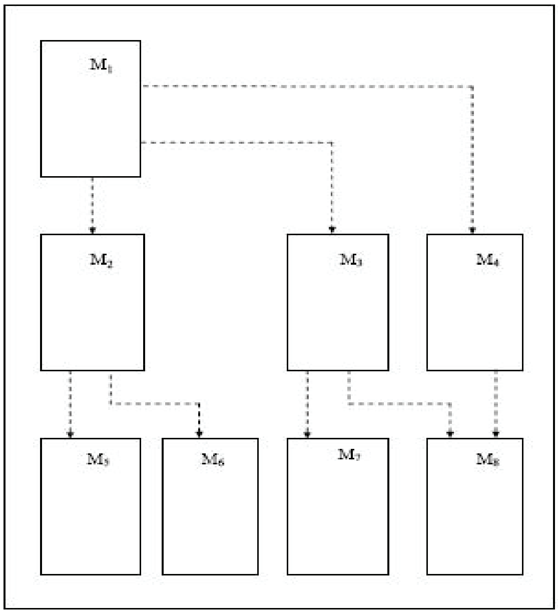

Figure 1: An Example Multistage Model

In the example, the following multistage models are identified: M1, M1M2, M1M2M5, M1M2M6, M1M3, M1M3M7, M1M3M8, M1M4 and M1M4M8. A model, which can be used after another one in a multistage model, is a successor model. Normally all the multistage models may not be known a priori. Only the initial model M1 may be known. In this case, one can attempt to model alternative models to get ready for contingencies. Supposing that M2 and M3 are also modeled, one can have two multistage models: M1M2 and M1M3. One can perform a simulation study with each multistage model to find out for example, the outcomes of having M2 or M3. Accordingly, one can try to control the conditions to facilitate transition to a specific model module and/or to make it difficult the transition to another one. If the status of a module of a multistage model is not acceptable or desirable, one has to generate successor model(s) and facilitate transition to that module model,(Ören, 2001).

6. BASES FOR A MODELING METHODOLOGY: EMERGENCE OF TRANSITIONS AND STATES

Figure 2 depicts emerged states (g) and (h) and emerged transitions a-c, d-g, and g-f, h-f, and g-h. In Figure 2, a dynamic system is represented as a state machine. To make the point of two types emergences, let's consider that initially, the system consists of the states (a) through (f), the initial state is (a), and that only transitions represented by solid arrows exist. The two types of emergences that we would like to elaborate on are:

1. *Emergent transitions*: Under certain conditions of the control parameters (or control variables) and their critical values (or threshold values), a transition may emerge, for example from state (a) to state (c) as represented in Figure 2. Similarly, under certain conditions of control variables and their threshold values, some transitions may *disappear* or may be *deactivated*. In the case of disappearance, the change is long-term (it can also be irreversible). In the case of deactivated transitions, the transition is reversible and depends on the occurrence of favorable conditions.
2. *Emergent states*: Under certain conditions of the control variables and their threshold values, a new state may emerge. In the example, state (g) emerges under favorable conditions. Emergence of a state, (h) for example, may start by emergence of a state, (g) in the example, and be realized by a series of emergent states. In evolutionary systems, this may correspond to the evolution of the system. Under other favorable conditions a state may disappear or may be deactivated. Once a state emerges, still under some favorable conditions transition to and transition from it may emerge.

Emergence of transitions and states may not be dichotomic; i.e., they can best be represented as fuzzy entities having a presence of 0% to 100%.

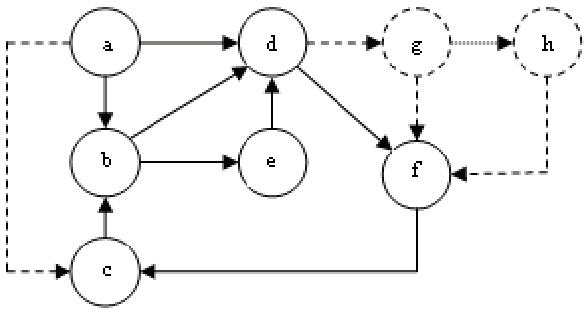

Figure 2. Emerged states and emerged transitions in a state machine

7. CONCLUSIONS

Both types of simulation are important in conflict studies to either provide experience under controlled conditions, hence for training decision makers; or for performing goal-directed experiments to analyze conflict situations to test hypotheses or to understand the mechanisms. In such studies being reactive is not sufficient; the needed proactivity can be modeled and simulated as a behaviorally anticipatory system. Furthermore, social systems, being highly non-linear complex systems can exhibit several types of emergence. Development of proper modeling formalisms for representing emergence and using multisimulation may be useful in the study of conflict problems. Representation of several types of emergence of states and transitions discussed in this article as well as multisimulation may be useful in simulation and management of conflicts.

APPENDIX A – TYPES OF EMERGENCE

- **Behavior emergence**;
- **Bottom-up emergence**: A perturbation causes the system parts to interact synergetically in such a way that at least one new feature on a higher level emerges (Arshinov and Fuchs, pp. 7- 8);
- **De-emergence**;
- **Emergence**: the appearance of a new property of a system which cannot be deduced or previously observed as a functional characteristic of the system. … Generally, higher level properties are regarded as emergent. For example, water has emergent properties different from its interconnected parts (molecules of H and O). These properties disappear if the molecules are separated again (Fenzl, pp. 252). The notion of emergence means that a system is more than the sum of its parts and that a developing system has new qualities that can't be reduced to old states or prior existing systems (Brunner and Klauninger, pp. 23).
- **Emergence of coherency between two open systems**;
- **Emergence of order**: in all self-organizing (physical, biological, and social) systems the emergence of order is triggered by fluctuations that cause synergies between the elements of the systems (Fuchs, pp. 219);
- **Epistemological emergence**;
- **Horizontal merger**;
- **Immersion**;
- **Innovative emergence**: the representation of attaining a new model class that improves the modelling process in the first place (Zimmerman, pp. 38).
- **Macro emergence**;
- **Merger**;
- **Micro emergence**;
- **Non-reflexive emergence**;
- **Ontological emergence**;
- **Re-emergence**;
- **Reflexive emergence**;
- **Second-order emergence**;
- **Semantic emergence**;
- **State emergence**;
- **Strong emergence**;
- **Structural emergence**;
- **Submersion**;
- **Top-down emergence**: downward causation can be described as top-down-emergence if

new qualities of certain parts (seen as wholes or systems themselves) show up (Arshinov and Fuchs, pp. 7).

- **Transition emergence**;
- **Vertical merger**;
- **Weak emergence**.

APPENDIX B – BASIC CONCEPTS RELATED WITH EMERGENCE

- **Cohesion**: cohesion means the closure of the causal relations among the dynamical parts of a dynamical particular that determine its resistance to external and internal fluctuations that might disrupt its integrity (Arshinov and Fuchs, pp. 7-8).
- **Complex**;
- **Complicated**;
- **Downward causation**: once new features of a system have emerged they along with the other structural macro-aspects of the system influence, i.e. enable and constrain, the behavior of the system parts. Downward causation means the localization of more global qualities (Arshinov & Fuchs, pp. 7-8);
- **Emerged**;
- **Emerged feature**;
- **Emergence condition**: necessary and sufficient condition to trigger an emergence;
- **Emergent**;
- **Emergent behavior**;
- **Emergent condition**;
- **Emergent dynamics**;
- **Emergent feature**;
- **Emergent function**;
- **Emergent functionality**;
- **Emergent input**;
- **Emergent output**;
- **Emergent output function**;
- **Emergent property**: there is the important assertion that some properties of the whole cannot be explained by, or deduced from, the properties of the parts. Such properties are emergent, as opposed to resultant properties;
- **Emergent state**;
- **Emergent structure**;
- **Emergent transition**;
- **Emergent transition function**;
- **Emergentism**;
- **Emergentist**;
- **Emerging feature**;
- **Emerging paradigm**;
- **Emerging phenomenon**;
- **Globalization and Localization**: bottom-up emergence means the globalizing sublation of local entities, downward causation the localization of more global qualities.
- **Hierarchy**: the *s*elf-organization of complex systems occurs in a hierarchical systems. Upper levels are more complex and have additional emergent features (Arshinov and Fuchs, pp. 6-7).
- **Macroscopic emergent behavior**;
- **Non-emergent**;
- **Non-emergent property**;
- **Non-linear causality**: causes and effects can´t be mapped linearly. Similar causes can have different effects and different causes similar effects; small changes of causes can have large effects whereas large changes can also only result in small effects but nonetheless it can also be the case that small causes have small effects and large causes large effects. Emergence is based on non-linear causality (Arshinov and Fuchs, pp. 7).
- **Ontology of emergence**;
- **Self organization**: self-organization means *appearance of new system structures* without explicit pressure from outside the system, or involvement from the environment. In other words, the constraints on the organization of the system are internal phenomena, resulting from the interactions among the components and usually independent of their physical nature. Self-organization can produce structural changes maintaining a stable mesoscopic form of the system, or show transient phenomena (Fenzl, pp. 252).
- **Self-organizing systems**: self-organising systems are complex systems. Emergence is a fundamental quality of self-organising systems. Self-organisation of complex systems produces a hierarchy in two distinctive senses: the level of emergence is a hierarchically higher level, i.e. it has additional, new emergent qualities that can´t be found on the lower level which is comprised by the components. The upper level is a sublation of the lower level; self-organisation results in an evolutionary hierarchy of different system types, these types are hierarchically ordered in the sense that upper levels are more complex and have additional emergent qualities (Arshinov and Fuchs, p. 6-7);
- **Semantic emergent behavior**;
- **Spatially emergent behavior**;
- **Syntactic emergent behavior**;
- **Systemness**: self-organisation takes place in a system, i.e. in coherent whole that has parts, interactions, structural relationships, behavior, state, and a border that delimits it from its environment (Arshinov and Fuchs, pp. 6-7).

APPENDIX C – PRINCIPLES OF PHYSICAL SELF-ORGANIZATION

(from Fuchs, pp. 206-207)

- *control parameters*: a set a parameters influences the state and behavior of the system;
- *critical values*: if certain critical values of the control parameters are reached, structural change takes place, the system enters a phase of instability /criticality;
- *fluctuation and intensification*: small disturbances from inside the system intensify themselves and initiate the formation of order;
- *feedback loops*: there are feedback loops within a self-organizing system;
- *non-linearity*: in a critical phase of a self-organizing systems, causes and effects can´t be mapped linearly: similar causes can have different effects and different causes similar effects; small changes of causes can have large effects whereas large changes can also only result in small effects (but nonetheless it can also be the case that small causes have small effects and large causes large effects);
- *bifurcation points*: once a fluctuation intensifies itself, the system enters a critical phase where its development is relatively open, certain possible paths of development emerge and the system has to make a choice. Bifurcation means a phase transition from stability to instability;
- *selection*: in a critical phase which can also be called point of bifurcation, a selection is made between one of several alternative paths of development;
- *emergence of order*: in a critical phase, new qualities of a self-organizing system emerge; this principle is also called order from chaos or order through fluctuation. A self-organizing system is more than the sum of its parts. The qualities that result from temporal and spatial differentiation of a system are not reduceable to the properties of the components of the systems, interactions between the components result in new properties of the system that can´t be fully predicted and can´t be found in the qualities of the components. Microscopic interactions result in new qualities on the macroscopic level of the system;
- *information production*: new features (in the original text the term "quality" is used. Instead we used the term "feature" to be neutral; since all features are not necessarily "qualities") of a self-organizing system emerge and have certain effects, i.e. a complex reflective relationships is established between the trigger of self-organization (the reflected), the emergent features (the result of reflection) and the function the new features fulfill for the system in its adaptation to its environment. We have defined this relationship as information, self-organizing systems are information-producing systems, information is not a pre-existing, stabile property of a complex system;
- *fault tolerance*: outside a critical phase, the structure of the system is relatively stable concerning local disturbances and a change of boundary conditions;
- *openness*: self-organization can only take place if the system imports entropy which is transformed, as a result energy is exported or as Prigogine says dissipated;
- *symmetry breaking*: the emerging structures have less symmetry than the foundational laws of the system;
- *inner conditionality*: self-organizing systems are influenced by their inner conditions and the boundary conditions from their environment;
- *relative chance*: there is a dialectic of chance and necessity in self-organizing systems; certain aspects are determined, whereas others are relatively open and according to chance;
- *complexity*: the complexity of a system depends on the number of its elements and connections between the elements (the system´s structure). There are three levels of complexity: 1. there is self-organisation and emergence in complex systems, 2. complex systems are not organized centrally, but in a distributed manner; there are many connections between the system´s parts, 3. it is difficult to model complex systems and to predict their behavior even if one knows to a large extent the parts of such systems and the connections between the parts.

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