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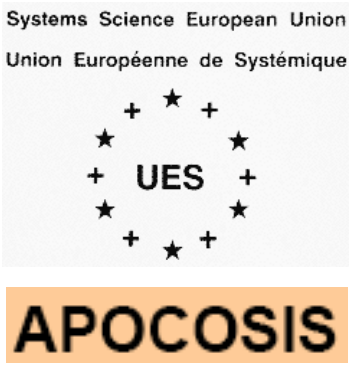

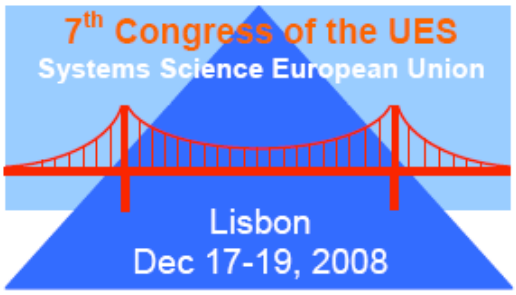

What is «self-organization»? A journey of a small child

Shelia Guberman
Digital Oil Technologies
guboil@hotmail.com

Abstract

It is trivial to say that there is no widely accepted definition of self-organization. In 1999 *Scientific American* published a long list of different definitions of self-organization. This paper will present an analysis of that notion based on two fundamental sources – H. Haken's book *"Synergetic",* published in 1977 [1], and S. Kaufmann's book *"At Home in the Universe"*, published 20 years later in 1995 [2].
Three basic examples of organization and self-organization used by H. Haken will be analyzed.

1. Consider a group of workers. We then speak of organization or, more exactly, of organized behavior, if each worker acts in a well defined way on given external orders, i.e., by the boss. We would call the same process as being self-organized if there are no external orders given but the workers work together by some kind of mutual understanding.
2. Skiers on a ski-lift pulled uphill by the lift. Here the causes are the forces acting on the skiers. The action consists in a motion of the skiers.
3. Consider a set of vessels into which different chemicals are poured continuously. This input causes a reaction, i.e., the output of new chemicals.

Two basic concepts of S. Kaufmann's book will be analyzed as well:

1. Relation between Darwinian natural selection and self-organization in development of the biosphere.
2. The notion of "self-organized criticality" as it was presented by S.Kaufmann and the author of that notion P. Bak.

Keywords: self-organization, Haken, Kaufmann, systems, analysis.

1.

A year ago Prof. G. Minati and I published a book on the Systems Theory [3]. When working on the book we critically analyzed some basic notions of that discipline. We started with very different approaches to many problems of System Theory, but we both were looking for scientifically accepted answers to our questions. At the end we succeeded in definition of a system, on necessity of the observer, on crucial role of the language of description and a number of other concepts. However, to me there are still some basic concepts of System Theory for which I was not able to find meaningful content or definition. One of such concepts is "self-organization".

It is trivial to say that there is no widely accepted definition of self-organization. I decided to analyze the notion and I started with one of the fundamental sources – H. Haken's book *"Synergetics: An introduction. Nonequilibrium Phase Transitions and Self-Organization In Physics, Chemistry and Biology."* I will represent quotes from that book related to self-organization (text in bold) and my understanding of these quotes.

Quote 1: **"The spontaneous (without influence of outside forces – S.G.) formation of well organized structures out of germs or even out of chaos is one of the most fascinating phenomena and most challenging problems scientists are confronted with. Such phenomena are an experience of our daily life when we observe the growth of plants and animals. Thinking of much larger time scales, scientists are led into the problems of evolution, and, ultimately, of the origins of living matter. When we try to explain or understand in some sense these extremely complex biological phenomena it is a natural question, whether processes of self-organization may be found in much simpler systems of the unanimated world."**

That text contains a (not explicit) definition: self-organization is a formation of well organized structures without influence of outside forces. But the expression “well organized structures” is internally contradictive. One can say “well organized system”, which means that the system has a definite structure. That structure can be simple or complicated and, consequently, we call the system a simple one or a complex one. The structure is the organization of the system. That is why there are *organized systems* but it could not be *organized structures.* Finally, the definition for me looks as follows: self-organization is a formation of structures without influence of outside forces.

From the point of view of that definition it is not a question, if there are self-organized systems simpler then living beings. Ice, diamonds, solar system, volcanoes are some of the infinite number of examples.

Quote 2: **“In recent years it has become more and more evident that there exist numerous examples in physical and chemical systems where well organized spatial, temporal or spatio-temporal structures arise out of chaotic systems. Furthermore, as in living organisms, the functioning of these systems can be maintained only by a flux of energy (and matter) through them.”**

If a diamond is a self-organized system, it is true that phase transaction from carbon to diamond demands a flux of energy, but for functioning of the “diamond system” no energy is required (in contrast to live systems).

Quote 3.**” In contrast to man-made-machines, which are devised to exhibit specia1 structures and functioning, these structures develop spontaneously – they are self-organized.”**

In my opinion it means that all non-man-made (natural) systems that are organized (i.e. have structure) are self-organized. Because any natural system has some structure (except pure chaos), that fact could not be a surprise to scientists. The surprise is that now all natural systems are called *“self-organized”*.

After these remarks in the preface of the book on self-organization it takes 6 chapters until the attention returns to that notion.

Quote 4: **“7. Self-Organization.**

In this chapter we come to our central topic, namely, organization and self-organization. Before we enter into the mathematical treatment, let us briefly discuss what we understand by these two words in ordinary life.

a)*Organization*

Consider, for example, a group of workers. We then speak of organization or, more exactly, of organized behavior, if each worker acts in a well defined way on given external orders, i.e., by the boss. It is understood that the thus-regulated behavior results in a joint action to produce some product.”

To connect that example of organization with previous definitions we will assume that the set of workers is the system. To do the work the workers are included in a structure, which determines the duty of each worker, the sequence of procedures, tariffs, and so on. Existence of that structure is the proof that the set of workers is organized. The source of the organization of workers is the boss. He does not belong to the system we are exploring.

Quote 4:**” b) *Self-Organization***

We would call the same process as being self-organized if there are no external orders given but the workers work together by some kind of mutual understanding, each one doing his job so as to produce a product.”

It seems that that basic example of self-organization is not the best choice. Such self-organization can work only if the production process is very simple, and it can happen only if in the past the workers get the instructions. The production in such system will collapse as soon as something will change (for example, some workers become sick, or there happens a shortage in electrical power). Such self-organization system reminds mostly the colony of ants where workers get their instructions genetically and forever. It is obvious that if the boss will be included in the system the system will become self-organized. Because the observer chooses what the system which he wants to investigate is, it becomes a pragmatic problem.

Quote 5: **"7.1 Organization**

The above mentioned orders of the boss are the cause for the subsequent action of the workers. Therefore we have to express causes and actions in mathematical terms. Consider to this end an example from mechanics: Skiers on a skilift pulled uphill by the lift. Here the causes are the forces acting on the skiers. The action consists in a motion of the skiers. Quite another example comes from chemistry: Consider a set of vessels into which different chemicals are poured continuously. This input causes a reaction, i.e., the output of new chemicals. At least in these examples we are able to express causes and actions quantitatively, for example by the velocity of skiers or the concentrations of the produced chemicals. "

It is strange that the basic example of organization – workers and the boss – the only one, which deals with organization in the common sense of the word, was missing in the attempt of mathematical formulation. Let us fill the gap. Let us define the cause and consequent action for that particular example. The amount of product could be the measure of consequences. But what is the cause of organized behavior? It is orders of the boss. But how to express that cause in mathematical terms (as the author invites us)? Absolutely nothing comes to mind. I suppose that that is the reason why the first and most adequate example was lost on the distance of one paragraph.

The next example: skiers on the ski lift. Forces on the skiers are the cause, motion of skiers – the consequence action. But where is the organization?

The last example: chemicals are poured in a vessel. The output is new chemicals but it is not appropriate to say that the chemicals are the cause of the reaction. Let us look on Internet and find what people think about the cause of chemical reactions (from the first page on Google search):

"Excitation of molecules by infrared radiation was an important cause of chemical reaction"

"The cause of chemical reaction lies in the physical and mechanical properties of compounds.(Mendeleev)"

"cause of chemical reaction is the interchange of energy due to molecular impact."

So, people are saying that the molecular forces are the cause of chemical reaction. But that cause can't be measured by amounts of input gradients. Could one call the concentrations of produced chemicals an action? The answer is clear – no, and that is why in the next sentence the word "action" was equate to the word "effect", which has synonyms "result", "outcome", "consequence", but not the word "action". Effect is a result of action. That example also says nothing about organization.

Then the author proceeds to the equation, which describes the relations between the cause and the effect. The model is: the effect is the quantity q, it changes proportional to small time intervals dt and the size of the cause F. (It is a bitter irony to describe self-organization with linear equations!) The author didn't explain how that model fits the three examples. So, I have to do it myself.

Example 1. It is difficult to find a production process, which is homogeneous in each small interval of time, but may be it is possible. But how to measure the cause F – the boss' orders? By the numbers? And has the amount of the final product to be proportional to the number of orders? It sounds ridiculous. I can't find any reasonable interpretation.

Example 2. As it was stated, the cause is the force applied to skiers, and the action is the motion of the skiers. The measure of the motion was defined as the velocity of skiers. But the velocity is not proportional to the time interval dt, the velocity of the lift is mainly a constant. The velocity of the skiers is also not proportional to the force F. According to Newton's law, it is not the velocity but the acceleration is proportional to the force (the idea that the velocity is proportional to the force was an idea of Aristotle's physics).

Example 3. The proposed equation is the standard description of a simple chemical production: the amount of output product is proportional to the amount of input ingredients and the time interval. It is well known for a long time and has nothing to do with workers, bosses, skiers, organization, and self-organization.

Note: As a matter of fact in the paragraph 7.1 under title “Organization” there is no definitions of that term, no explanation of the meaning of that word, and – no one will believe – not a single use of that word.

The next paragraph of the book (7.2) has the heading “Self-organization”.

Quote 6: **“7.2 Self-organization.**

A rather obvious step to describe self-organization consists in including (it seems to me it has to be “considering” – S.G.) the external forces as parts of the whole system.”

That statement is in agreement with ideas developed by Guberman and Minati in 1977 [3]: systems exist in our mind and the observer is free to combine any set of objects in a system. At the same time that statement disoriented me in my attempt to understand the concept of self-organization. If one wants to get a self-organized process one has to exclude the boss from the system, but if one wants mathematically describe the self-organized process one has to include the boss in the process. But as soon as the boss is included in the system the system is no longer a self-organized system! So, what will be mathematically analyzed?

The same contradiction appeared 15 years ealier in writings of Ross Ashby. Here are comments made by Prof. Cosma Shalizi (Carnegie Mellon University) on the article "Principles of Self-Organizing Systems" [4]: “Remarkably enough, for such a paper, it claims that there's really no such thing as self-organization. The argument runs as follows. By the "organization" of a system, Ashby means the rule which takes present states into future states. A self-organizing system, at the very minimum, must change its organization. One could try to represent this by making the evolution-rule depend on the current state, but obviously this just means you have a different, unchanging rule than you first thought. You could make the rule depend on some external input: then the organization would change with the input; but then it isn't really *self*-organizing; and if you include the input-device in the system, you're back where you started.”

As a result of addressing myself to the bible of self-organization I found myself in the end at the starting point: I still don’t understand what “self-organization” means.

2.

Then I turn to the modern interpretation of self-organization” – to the book of a prominent representative of the self-organization movement Stuart Kaufmann “At Home in the Universe. The Search for the Laws of Self-Organization and Complexity”.

Quote 1: **“As I will argue in this book, natural selection is important, but it has not labored alone to craft the fine architecture of the biosphere, from cell to organism to ecosystem. Another source – self-organization – is the root source of order”.**

Let me paraphrase the statement in my words to explain my understanding. The author believes that the organization (order) of living beings and their coexistence couldn’t appear from natural selection alone. Another source of that organization is self-organization. But if it is a correct interpretation, then I find a contradiction.

The majority of educated people know that Darwinian natural selection is responsible for diversity and harmony of life (acknowledging some difficulties in the theory). It is also recognized that forces of natural selection doesn’t come from outside the biosphere, for example, from God. That means that the life in all its manifestations – the biosphere – is self-organized. Thus, until today we know that 1) the biosphere is self organized (i.e. developed without outside forces), and 2) the mechanism of self-organization is natural selection. Now the author suggests to add another player to natural selection–, namely, self-organization. But it is already in. So, what we have to add?

Quote 2: **The order of the biological world, I have come to believe, arises naturally and spontaneously because of the principles of self-organization – laws of complexity that we are just beginning uncover and understand.”**

What a surprise! In the previous sentence from the same paragraph (see quote 1) the author claims that there are two sources of order in the biosphere: natural selection and self-organization. But in the quote 2 he dismissed natural selection as a mechanism of evolution of the biosphere

and pronounces that "the order of the biological world arises because of the principles of self-organization". The end of the sentence is absolutely amazing: the principles, which according to the author's belief define the order in biological world, are still uncovered! So, what will the book be about?

At that point of the book I was completely lost. I decided that may be the text expresses author's ideas not adequately and I continued to read the book with hope to find the development of the idea of self-organization. It is a pity to say, but I found no definition or at least an explanation of self-organization. I didn't find any description of a particular principle of self-organization. But this is what I do find in the book on self-organization.

Quote 3**: "We have seen that the origin of life itself comes because of self-organization that arises naturally"(**p. 71).

As I mentioned above, the theory of natural selection claims that the life is self-organized, so, this book doesn't add something to our world outlook. What attracts my attention is the adverb "naturally". Does it differentiate the natural self-organization from unnatural one? Or is it a tautology (because one of the meanings of "naturally" is "without outside forces")?

The book is full with many groundless ideas and imaginable consequences in biology, economy, linguistic, sociology, democracy and the universe itself, which will follow *IF* these ideas turn out to be true. There is a huge disproportion between the number of promising consequences and the number of proves of any of these ideas. Here is an example of if-epidemic on the first two pages of Chapter 4 on self-organization.

Quote 4: **"*if it proves true* that the life may be an expected emergent property of matter and energy…**

Spontaneous order, *I hope to show you,* has been as potent as natural selection in the creation of the living world.

***If* life emerged as collectively autocatalytic systems …**

Is there a way that an autocatalytic set could evolve without all the complications of a genome? My colleagues *have hinted* at how this might happen.

Richard and Doyne found a natural way that variation and evolution in such systems can occur. They *proposed* that a random, uncatalyzed reaction will occasionally occur as an autocatalytic net goes about its business.

***There is reason to believe* that autocatalytic sets can evolve without a genome** " (p. 71 – 73).

I didn't find a solid ground to set my foot.

I found in the book a reference to a work in physics on "self-organized criticality" done by Danish physicist Per Bak from Niels Bohr Institute. It was interesting to read the original paper. It seems to me that S. Kaufman and P. Bak have different things in mind when using the same expression "self-organization". P. Bak introduces self-organization this way:" We have shown that our model economy evolves to a critical state when driven by extremal dynamics. This occurs without fine-tuning of parameters, i.e., the system is self-organized." So, he says that if a system operates without fine-tuning of parameters, it is a self-organized system. To me that definition is so far from the notion that appears explicitly or implicitly in books by H. Haken and S. Kaufmann.

As a matter of fact the basic model of "self-organized criticality" is a sand pile which is supplied with sand from above. The process creates a growing conic pile. At some moment the slope angle becomes critical and after that from time to time avalanches occur, keeping the critical angle of the slopes. From Haken-Kaufmann's point of view to be a self-organized system the Earth (as a source of gravitational forces) has to be included in the system, but P.Bak does not demand it.

I also recall that in his famous book *Quark and the Jaguar* [5] M.Gell-Mann (Nobel Prize winner in physics) wrote about the same phenomena. To some extend that book touches the same problems as S. Kaufmann's book did: complexity, biological evolution, selection, and universe. But M. Gell-Mann never used the notion of self-organization. More accurately, he used it only on one occasion – describing the sand pile model of P.Bak, and he used it only in the term "self-organized criticality", used it in quotation marks showing that he treat it not as a common

scientific term but as a label of phenomena “what is called “self-organized criticality”, a concept proposed by P. Bak” ([5], p.97). A couple of paragraphs later he emphasizes that he keeps himself apart from terms like “self-organization” and “emergency”: ”These systems are said to be self-organized and their properties are said to be emergent”(p.100). That caution is expressed even though both are prominent members of Santa Fe Institute of Complexity.

The similar attitude of another outstanding physicist P. Anderson (Nobel Prize winner in Physics) can be found on the cover of S. Kaufman’s book : “Stu Kaufmann is immensely and erudite explorer of the world of ideas and concepts. As with many explorers, not everyone will wish accompany him but the description of the trip is fascinating.” It is a very cold review and I would be upset if it were about my book.

It is particularly interesting to compare that very polite and very reserved review with another one written by a representative of free art, an economist K. Errow (winner of so called Nobel Prize in Economy): “Stuart Kaufmann gives us a rich and compelling picture of new principle of self-organization and understanding the emergence of order in complex systems, whether life or society or economy.”

Conclusion

I have to summarize that after observational reading of these two books I still found no scientific meaning in the term ”self-organization”. Maybe I am not smart enough. But may be the term is naked? “Of course, all the townspeople wildly praised the magnificent clothes of the emperor, afraid to admit that they could not see them, until a small child said:*" But he has nothing on!"* (H. C. Andersen, *The Emperor's New Clothes*).

I am not insisting that I am right – I am looking for a discussion. I am optimistic on that matter – I have a very positive experience of discussing that kind of things with Prof. G. Minati (published in our book).

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