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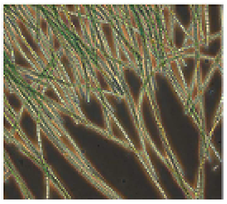

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Emergence or self-organization? Look to the soil population

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Emergence or self-organization?

Look to the soil population

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Emergence is not well defined, but all emergent systems have the following characteristics: the whole is more than the sum of the parts, they show bottom-up rather top-down organization and, if biological, they involve chemical signaling. Self-organization can be understood in terms of the second and third stages of thermodynamics enabling these stages used as analogs of ecosystem functioning. The second stage system was suggested earlier to provide a useful analog of the behavior of natural and agricultural ecosystems subjected to perturbations, but for this it needs the capacity for self-organization. Considering the hierarchy of the ecosystem suggests that this self-organization is provided by the third stage, whose entropy maximization acts as an analog of that of the soil population when it releases small molecules from much larger molecules in dead plant matter. This it does as vigorously as conditions allow. Through this activity, the soil population confers self-organization at both the ecosystem and the global level. The soil population has been seen as both emergent and self-organizing, supporting the suggestion that the two concepts are are so closely linked as to be virtually interchangeable. If this idea is correct one of the characteristics of a biological emergent system seems to be the ability to confer self-organization on an ecosystem or other entity which may be larger than itself. The beehive and the termite colony are emergent systems which share this ability.

This article considers the suggestion[1] that the concepts of emergence and self-organization are so closely linked that the appearance of emergence implies that the system also exhibits self-organization. It does so with reference to the soil population which has been seen as both self-organizing[2] and emergent.[3]

One difficulty in evaluating the concepts is that, whereas self-organization is reasonably well understood, both in general terms and in a thermodynamic context,[4] emergence is not even well defined. For example, a book[5] entitled *Emergence* does not seem to offer a definition of the term "emergence." This could just be because emergence does not readily admit of a precise definition.[6] Indeed, one quotation[7] gives little hope of a definition. "Despite its ubiquity and importance, emergence is an enigmatic and recondite topic, more to be wondered at than analyzed…"

Fortunately emergent systems have certain characteristics that can be used to identify them:

- The whole is more than the sum of the parts.[1]
- The organization is always of a bottom-up rather a top-down nature.
- Biological emergent systems often involve chemical signaling.

Emergence can also be approached through chaos and complexity, and examples, such as those in **Table 1**, may be helpful.

One of these examples, the slime mold (*Dictyostelium discoideum*) is the reddish-orange substance found in cool damp conditions on rotting wood or vegetation on the ground, and it has some remarkable characteristics.[8] It can move around, albeit very slowly, and it even seems to be able to

Table 1. Examples of emergence

• The human brain
• A city
• A beehive
• An ant or termite colony
• A slime mold
• Computer games and other software
• Artificial intelligence

vanish, but what actually happens is that the slime mold simply disaggregates from an apparently coherent mass to a collection of independent cells which are not visible individually. It re-aggregates at a chemical signal (cyclic Adenosine Monophosphate). The slime mold is the ultimate example of emergent behavior in a biological system. The whole, the slime mold, is much more than the sum of its parts, the cells, and its re-aggregation, stimulated by a chemical signal, is the best possible example of bottom-up behavior. But as well as being an exemplary emergent system, the slime mold has also been described in reference 9, as "an excellent example of self-organization." Several other examples of emergence in **Table 1** can also be seen as self-organizing. What, in brief, is the evidence that the soil population is both self-organizing and emergent?

The self-organization of the soil population and its capacity to confer it on the whole ecosystem were suggested[2] on the basis of an analog involving the second and third stages of thermodynamics, also known as linear and non-linear non-equilibrium thermodynamics.[10]

The second stage describes a system in which the flow is linearly related to the force.[11] Such a system tends towards a steady state in which entropy production is minimized, but it depends on the capacity of the system for self-organization. In a third stage system, flow is non-linearly related to force, and the system can move far from equilibrium. This system maximizes entropy production but in so doing facilitates self-organization.[12]

The second stage system was suggested earlier[13] to provide a useful analog of the behavior of natural and agricultural ecosystems subjected to perturbations, but it needs the capacity for self-organization. Considering the structure of the ecosystem suggests that this self-organization is provided by the soil population[2] when it maximizes entropy production by releasing small molecules from much larger molecules in dead plant matter as vigorously as conditions allow.

The small molecules released include plant nutrients such as nitrate, phosphate and cations locked up in dead matter, but needed for growth of new plants and the renewal and reorganization of the whole ecosystem. They also include carbon dioxide that was trapped during photosynthesis but which needs to be released before new photosynthesis can occur. Were this release of carbon dioxide to cease, the supply in the atmosphere would last about a decade.[14] Thus the soil population confers self-organization at the scale of both the ecosystem and the globe.

The soil population was suggested[3] to be an emergent system because it shows many of the characteristics of recognized in the emergent systems listed above. In particular, the whole is more than the sum of the parts, and the system shows clear evidence of bottom-up organization. Furthermore, the "quorum sensing" recently discovered[15] in soil and other bacteria strongly suggests that chemical signaling plays a part among the soil population, as it does in other biological emergent systems.

If we are correct in inferring that the soil population is both self-organizing and emergent, what are the implications? We saw that the self-organising soil population was able to confer self-organization on the whole ecosystem. It is also an emergent soil population, suggesting that emergent systems can confer self-organization on ecosystems and similar entities.

Can we find other examples of this conferment? Of the items in **Table 1**, the human brain and the city are clearly able to confer self-organization. The beehive can also do so though the pollinating activities of the worker bees in the surrounding area and the inhabitants of a tropical termite mound fulfil many of the roles of the self-organizing population of a non-tropical soil.[16]

It seems that the authors of reference 1 were correct that that the concepts of emergence and self-organization are so closely linked that the appearance of emergence implies that the system also exhibits self-organization. We can add that one of the characteristics of a biological emergent system seems to be the ability to confer self-organization on an ecosystem or other entity which may be larger than itself. This may imply that emergent systems are vital to sustainability.[13]

Whether an emergent system can confer emergence as such cannot be entirely clear while emergence remains an "enigmatic and recondite topic, more to be wondered at than analysed…"

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