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# An Informational Approach to Emergence

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**Abstract**
Emergence can be described as a relationship between entities at different levels of organization, that looks especially puzzling at the transitions between the major levels of matter, life, cognition and culture. Indeed, each major level is dependent on the lower one not just for its constituents, but in some more formal way. A passage by François Jacob suggests that all such evolutionary transitions are associated with the appearance of some form of memory–genetic, neural or linguistic respectively. This implies that they have an informational nature. Based on this idea, we propose a general model of informational systems understood as combinations of modules taken from a limited inventory. Some informational systems are "semantic" models, that is reproduce features of their environment. Among these, some are also "informed", that is have a pattern derived from a memory subsystem. The levels and components of informed systems can be listed to provide a general framework for knowledge organization, of relevance in both philosophical ontology and applied information services.

**Keywords** Emergence · General systems theory · Information theory · Knowledge organization · Levels of reality

## 1 Emergence, Material and Formal

Emergence is a widely discussed phenomenon in philosophy. It is known as an alternative to reductionism in understanding the transitions between different aspects of reality being compared, where certain properties can be observed in a "higher" level but not in the "lower" one. The identification of such emergent levels has relevance for many domains, including the arrangement of different classes of entities in knowledge organization systems, as we will briefly discuss in the last section.

Although different philosophers use the term *emergence* with different shades of meaning,

> [w]e might roughly characterize the shared meaning thus: emergent entities (properties or substances) 'arise' out of more fundamental entities and yet are 'novel'

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> or ‘irreducible’ with respect to them. (For example, it is sometimes said that consciousness is an emergent property of the brain.) (O’Connor and Wong, 2015)

This description implies that (1) the emergent entities are in some way made of elements consisting of the “more fundamental entities”, like in the reductionistic interpretation, but also that (2) the result of their union is acknowledged to be substantially new. Familiar examples include combinations of chemical elements, such as oxygen or hydrogen, which produce molecules of compound substances, such as water. Indeed, water has certain properties, like being a good solvent for salts, that cannot be predicated of oxygen atoms alone or hydrogen atoms alone. This can happen because water molecules tend to surround each salt ion by orienting their oxygen part towards negatively charged ions and their hydrogen part towards positively charged ions, thus creating a layer that separates the ions. Being a solvent is then an emergent property of water.

Emergence may be understood in a static way, as at a given time the more fundamental entities are so grouped and organized to form the emergent ones; or it can be understood in a dynamic, historical way, to mean that at some time the fundamental entities got organized in such a way to produce the emergent entity. While entities of the more basic kind have continued to exist, the emergent ones have also appeared in the world on the top of them. This interpretation has been common in the last couple of centuries, in connection with the evolutionary thought as introduced by Lamarck, Darwin, Haeckel, Spencer and others, which understands different kinds of entities as originated from each other (Gould, 1986; Maynard Smith & Szathmáry, 1995; Mayr, 1982). Emergent entities are then seen as the result of a historical process that started from more fundamental entities, as before such evolution they simply did not exist.

In general, classes of entities that result from the combination of simpler ones are said to form a different *level of reality* (sometimes described as a “level of organization”, or an “integrative level”, etc.) (Kleineberg, 2017). Philosophers have someway acknowledged the existence of different levels in all times. In the Middle Ages, a sequence of levels including stones, plants, animals, humans, angels and God was described as “the nature ladder” (*scala naturae*) (Lovejoy, 1936). Modern science has largely contributed to the understanding that living beings are made of cells, cells are made of molecules, molecules are made of atoms, and atoms are made of fermions, thus identifying a series of levels depending on each other inasmuch as material constituents. We can call the relationship between such levels a *material dependence*.

On the other hand, there are also transitions that do not appear to consist in a material dependence. The most classic example, also mentioned in the quotation above, is the emergence of consciousness out of brains. While it is true that, in most scientists’ view, consciousness requires a brain as a material basis, we cannot claim that consciousness is “made of brain” as its material constituent just in the way that molecules are made of atoms or organisms are made of cells. In this case, dependence is not material but, so to speak, formal.

A relevant modelization of this situation can be found in the ontology of Nicolai Hartmann. In his works, especially *Die Aufbau der realen Welt* (1940), Hartmann identifies a series of levels in the “real being”. According to him, there are two kinds of such levels: layers and strata. Layers are collections of emerging entities that are in a relation of “overforming” (*Ueberformung*) with the lower levels, like molecules are over atoms or organisms over cells. On the other hand, the relationship holding between some of the major strata of the real being–which include the material, the organic, the psychic and the spiritual–is one of “overbuilding” (*Uberbauung*), where the lower entities are still the basis of the higher ones, but not as their material constituents (Poli, 2001).

Hartmann’s overbuilding relationship identifies the most important, though much mysterious, transitions in reality: that from matter and life to mind and that from mind to “spirit”–which in Hartmann’s terms has no supernatural meaning, and mostly corresponds with the cultural phenomena. One can then see Hartmann’s “overbuilding” as a case of what Chalmers (2002) and others call *strong emergence*: “strong emergence is not deducible even in principle from the laws of the low-level domain, while weak emergence is only unexpected given the properties and principles of the low-level domain” (Fromm, 2005).

Both Hartmann’s ontology and science as a whole aim at understanding all real phenomena as part of one and the same interconnected reality, where even the major levels can be related through some explanation. In order to support this integrated model, we need to reach a better understanding of such mysterious relationships of dependence between major levels.

## 2 Jacob’s Law

We contend that an important clue to address the emergence of the major levels can be found in the words of Nobel-prize winner geneticist François Jacob, who has discussed the nature of life in various articles and books. In his speech on the occasion of receiving the Reymond Award, Jacob (1975) said:

> What especially characterizes the living bodies, as opposed to the inanimate bodies, is their attitude to keep track of the past experience and to transmit it. As a matter of fact, the two break points of evolution, the appearance of life first, and that of thought and language later, each correspond to the formation of a memory system, that of heredity and that of the nervous system.

Here Jacob identifies two “break points” that correspond to transitions between Hartmann’s strata: the one from material to organic and the one from organic to mental. The third transition, from mental to cultural, is lumped by Jacob in the phrase “that of thought and language”. We can observe that in fact this can be better analyzed into two different break points–the appearance of thought in sentient animals, then the appearance of language in human cultures. These, indeed, are listed as two different steps by most philosophers of levels. According to Poli (2001), following Luhmann, minds and societies/cultures would actually co-evolve; but this could be affirmed, after all, of any two levels existing at the same time.

In any case, Jacob’s main point is that the nature of such break points has to do with “the formation of a memory system”. We will call this idea the Jacob’s Law. It states that what makes the higher strata really new is that they have new ways of storing information: respectively, the genetic code, the nervous system and language. More recently, Henriques (2003) also relates the major levels with novel ways of information storage and processing. The key idea is that such novelties have an *informational* nature, rather than a material one. Here could lie the “mystery” of strong emergence as a non-material dependence.

What do memory systems keep memory of? In living organisms, genes work as a memory of structures that have proved to fit the environment where the organism has to live. Genes trasmit sequences of nucleotides that will trigger the synthesis of certain proteins, both structural and enzymatic, and the properties of the living organism will be a result of such proteins. In other words, the specific sequences that are trasmitted in genes are a memory of characters that are adapted to the environment. Jacob's Law suggests that even in the subsequent major levels–cognition and culture–some information is transmitted that makes the system adapted to its environment, although this time by different media: nervous systems and verbal symbols respectively. What is common to all these levels is the notion of stored information that makes systems adaptive.

## 3 Informational Systems

As we are investigating reality in all its levels of organization, we take *information* in its broadest sense. Indeed, in recent decades the notion of information has been generalized: from the sense of communication between animated beings, to the more abstract sense of communication between any two systems of which one affects another (Dretske, 1981; Haefner, 1992; Hofkirchner, 2010; Bawden & Robinson, 2020; Ridi, 2020). In this generalized sense, the quantum numbers that rule the orbiting of electrons in an atom, or the chemical structure that determines the shape of a crystal, are also examples of information.

In the famous phrase by Gregory Bateson (1972), information is described as "a difference that makes a difference". *Difference* is identified by Floridi (2009) as the most basic among relationships, as it is the only relationship whose meaning does not depend on the nature of the entities it connects. In his terms, any discontinuity in reality is "data", and the way data affect other entities is "information". Several authors are now considering information as a most fundamental entity, even prior to energy and matter: indeed, matter could come from information–"it from bit", in John Wheeler's words–rather than the other way around (Davies & Gregersen, 2014). This perspective suggests that we should consider real entities in a most general way as systems exchanging information.

While any interaction can be seen as an exchange of information, certain entities appear to contain information in especially interesting ways, as their discontinuities are not entirely chaotic but form patterns of specific sets of elements. We will call them *informational systems* and will attempt to draft a formal outline of their properties.

According to Bunge (1979), any system can be formalized as a set of some composition ($C$), some structure ($S$) and some environment ($E$): $\sigma = (C, S, E)$. In particular, we contend that in informational systems:

- $C$ consists in a limited set of repeatable elements, that we will call *modules*, all belonging to the same kind though existing in more than one variety: think of the 20 varieties of aminoacids that can be found in proteins, or the 26 different letters that can be found in English writing;
- $S$ consists in a set of syntactical rules controlling the possible sequences in which the modules can be arranged: think of the illegality of certain sequences of consonants in English, such as -*tkfp*-, or the mandatory occurrence of a *u* after a *q*. Notice that for the sake of simplicity we are taking examples of sequences (that is *n*-uples) in a single dimension, but sequences in two dimensions (matrices) or in more dimensions (tensors) are also possible.

In sum, any entity consisting of dispositions of modules belonging to a limited set is an informational system. In discrete mathematics, these can be treated as dispositions with repetitions, having a length $k$ and taken from a given number of modules $n \geq 2$ (the simplest case with $n = 2$ being the binary alphabet consisting of only *0* s and *1* s).

Out of the enormous number of possible dispositions, monotonous structures such as "1010101010…" are not very interesting; nor are, on the opposite extreme, completely random dispositions where the frequency of all symbols tends to be equal, like in *normal numbers* (Borel, 1909) and in most books of Borges' *Babel Library*. Only the middle way between order and chaos, that is *organization*, is what makes our world interesting: in such a sequence like "124812481248…" we can identify relevant rules and properties that are worth our attention (as a child, I used to look for such sequences in car plates).

## 4 Semantic Systems

Let us now consider a subset of informational systems that we will call *semantic systems* ($\tau$), where structure has the additional property of being affected by environment: $S \leftarrow E$. For example, gravel on a street can be described as an informational system in two dimensions whose modules are pebbles of various sizes including a free space with no pebble. At a given time, the arrangement of pebbles may be random across the road. However, the repeated passing of cars will tend to move pebbles, so that in time the middle of the street will have most free space, and bigger pebbles will be concentrated on the street sides. Bickhard and Campbell (2003) describe this as an example of selection by the environment, here represented by cars. Our point is that after some time the system structure reflects its particular environment. Such a system we call semantic in that it conveys information about its environment, that is a trace of the cars' transit.

In the sentence *green-dressed children sleep quietly*, the choice and sequence of words reflects the structure of an environment where some children indeed sleep, hence is semantic. On the other hand, the similar sentence *colourless green ideas sleep furiously*, as in Chomsky's famous example, while perfectly legal as for its syntactical structure $S$, is not semantic, as $S$ has no correspondence in the environment, that is, it is not a model of it (though having some "semantics" in strictly linguistic terms).

In common parlance, semantic systems are thought as belonging to the highest level of culture, as is the case with linguistic systems. However, our extended sense of *semantic* also applies to the lower levels, where their basic feature is still the same: having a model structure that reflects some properties of their environment. At the level of cognition, a mental representation of an actual situation is obviously semantic and adaptive, as it informs the subject about its environment. Even at the level of life, the structure of an organism is semantic in that it fits the features of its environment–think of the hydrodynamic shape of a fish or, in another example by Lorenz (1973), the flat shape of horse rooves as a model of the physical features of the steppe.

## 5 Informed Systems

In their basic forms, semantic systems can be merely patterns that are affected by features of their environment. This is the case of pebbles along a road or of U-shaped valleys produced by the erosion of glaciers. They simply are physical casts of other shapes. On the other hand, what seems to be of special interest to ontology are semantic systems that include memory components, such as genomes, neural systems and languages, as these are associated with the emergence of new major levels of organization according to Jacob's Law.

Let us then attempt to describe the key role of memories in more precise terms. The role of memories is to keep track of specific combinations that have proved to be successful through an evolutionary history. Indeed, a semantic system as such is stable only as long as its original environmental conditions persist, for example as long as traffic on the road remains the same: in case any new perturbation occurs–say a wind storm–the semantic system will be destroyed. On the other hand, the appearance of a memory subsystem can keep track of the more organized pattern and reproduce it, just as the subsystem is separate from the core semantic system itself. For example, an individual organism can be destroyed by occasional causes, like a disease or an accident, but if its genome has been kept in its descendants, it will reproduce a similar organism again through the process of protein synthesis and the subsequent ontogenetical development.

Memories thus work as specialized subsystems that keep and reproduce the structure of a semantic system. We can call such advanced systems *informed systems* ($\lambda$), as their form is the result of some "instructions". That is, in informed systems the core semantic system $\tau$ (the *model* of the environment) is informed by the *memory* subsystem ($\mu$). Additionally, more subsystems ($\varepsilon$) are often there which specialize in mediating the relationships of the model with its environment, like with peripheral devices in computers: these are *sensors* (think of sense organs in organisms, or the thermometer in a thermostat) and *effectors* (think of muscles in organisms or devices in an artifact).

To sum up, an informed system $\lambda$ is a set of three kinds of subsystems:

$$\lambda = (\mu, \tau, \varepsilon)$$

where the core model system $\tau$ (1) is informed by a memory $\mu$ and (2) interacts with environment *E* in both directions, often through sensors and effectors $\varepsilon$:

(1) $\mu \rightarrow \tau$
(2) $\tau \leftrightarrow \varepsilon$

## 6 Listing Levels of Informed Systems

Let us now consider the major levels of reality in the light of their modelization as informed systems. Each of the mentioned kinds of memories–genomes, neural systems and languages–correspond to a major level of informed systems $\lambda$ as listed in Table 1: life, cognition and culture. Genes inform cells, organisms and their populations by being translated into sequences of aminoacids that rule metabolism; experience stored in neurons inform the actions of animals; language learned from other humans informs the structure of civil

**Table 1** Major levels of informed systems

| | Memories ($\mu$) | Models ($\tau$) | Sensors and effectors ($\varepsilon$) |
|---|---|---|---|
| $\lambda_1$ | Physical laws? | Matter | Forces |
| $\lambda_2$ | Genomes | Life forms | Vital functions |
| $\lambda_3$ | Neural systems | Cognition | Senses, behaviour |
| $\lambda_4$ | Languages | Cultures | Works |

institutions by norms and customs, either oral or written. Various subsystems manage the systems' interactions with their environment in both directions.

Table 1 is only meant as a draft, leaving various questions open. For example, it is not clear whether such material systems as atoms or crystals are also informed by any hypothetical kind of memories–we have tentatively identified these as "physical laws", which should be understood here as instrinsic laws of nature, whose way of storage remains to be identified, rather than creations of human research.

Indeed, our approach also follows a law of levels identified by both Hartmann (1940, 1949) and Feibleman (1954), according to which the existence of any level $\lambda_n$ is independent from the existence of the subsequent emerging levels $\lambda_{n+1}$, $\lambda_{n+2}$… The opposite is not true: level $\lambda_n$ does require the existence of levels $\lambda_{n-1}$, $\lambda_{n-2}$ etc. in order to emerge. There cannot be life forms without a material basis, or cultures without cognitive systems.

Another research direction is the identification of minor levels that belong to the major ones. Matter manifests itself in various levels of organization, including atomic systems, molecules, aggregates, celestial bodies etc.; life manifests itself in such levels as cells, organisms, populations etc.; cultures include economies, societies, institutions, arts and scholarship… The relationships between these minor layers are not based on the appearance of any new memory system with its characteristic formal dependence, but only on more complex ways of organizing models still based on the same kind of memories: for example, organisms and their populations are still based on the same kind of genetic memories as cells are. Above we have described the relationship between such minor layers as a material dependence, or Hartmann's "overforming". On the other hand, matter itself is a level emerging from energy, and our scheme still needs to accommodate pre-material entities studied in fundamental physics, such as fields, spacetime or information itself, that could possibly lie at a basic level $\lambda_0$. Ontological enquiry is still open.

## 7 Applications in Knowledge Organization

The ontology that can be developed along these lines is of twofold interest. In first instance, it may be relevant in itself as a model of the world, to satisfy our intellectual need of understanding reality (pure ontology). In second instance, it can be the source of the schemes that are used to organize our knowledge of the world, to find and reuse such information as part of our scholarly activities (applied ontology). Such schemes are known as knowledge organizations systems (KOS) and are the core object in the expanding field of knowledge organization (Dalhberg, 1993; Hjørland, 2016; Gnoli, 2020).

While the organization of knowledge can be understood as a general philosophical problem, much of knowledge organization literature comes from the community of library and information science. This connects our study to another specialized meaning of *information*, now understood as a cultural artefact recorded in documents (Gnoli, 2019, fourth section; Bawden & Robinson, 2020, Sect. 2.2).

Among the main kinds of KOS are classification schemes used for bibliographical purposes, thesauri of controlled terms used in information retrieval, taxonomies used to model scientific or business information, and formalized ontologies developed in knowledge engineering. The connection between philosophical KOSs, educational KOSs and bibliographic KOSs was already acknowledged by Bliss (1929), also the author of a widely renowned bibliographic classification scheme.

Despite having been obfuscated by the excitement for new technologies to automatically retrieve digital texts, research in the knowledge organization field is increasingly being acknowledged as an important component of our information age. Any KOS must ultimately be based on some conceptual ordering of the world. Providing such order, and continuously refining it, is up to philosophical ontology.

We believe that our approach, taking information and memory as generalized concepts to explain the emergence of the different levels of entities, can offer a contribution in this direction.

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