Constraining structures and the emergence of macro-levels of organization

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1. *Levels*

The world in which we live appears to be an integrated whole, and the elaboration of an equally integrated knowledge about it has been a permanent goal in philosophy and science (Oppenheim & Putnam, 1958; Cat 2017). Despite unity, however, reality exhibits diversity as well, so a view of the world including various kinds of entities naturally emerged during the history of knowledge. This view, however, gives rise to further questions, such as how these different kinds of object are related, and how they influence each other. To answer these questions, a hierarchical view of entities organised into different levels of "being" has been formulated and with it a hierarchical view of theories and sciences as well.

As stated by Jaegwon Kim,

> […] the shared imagery evoked by levels talk is a picture, somewhat fuzzy and unarticulated, of the physical world neatly stratified into a structure of discrete levels, with a bottom level of basic particles – perhaps leptons and quarks, or whatever our best physics tells us are the fundamental constituents of matter – and the rest as forming a vertically ordered system of levels each resting on the one below and all ultimately resting on the base level of microparticles (2010, p. 43).

This hierarchical view of reality implies that entities can be described from the bottom to the top, from the simplest, most basic, and fundamental ones to the most complex, structured, and derivative ones, but although *prima facie* intuitive, conceptually neat, and elegant, this picture is hardly understandable from a more fine-grained metaphysical and epistemological point of view because many details remain unclear.

On the one hand, it seems intuitive to state that particles are simpler than atoms, atoms than molecules, molecules than cells, and so on. This classical list traces back to the reductive levels enumerated by Oppenheim's and Putnam's "layer-cake" account:

6……………………. Social groups
5……………………. (Multicellular) living things
4……………………. Cells
3……………………. Molecules
2……………………. Atoms
1……………………. Elementary particles (Oppenheim & Putnam, 1958, p. 9).

On the other hand, however, a huge number of questions arises when this view is considered in detail. Paraphrasing Kim (2002) and Carl Craver (2015), adopting the levels picture requires to clarify (i) how levels can be clearly distinguished and identified; (ii) what makes a given level higher (or lower) than another one; (iii) how a phenomenon should be placed in a particular level rather than in another one; (iv) whether there is a bottom level; (v) which kind of relation orders the different levels; (vi) whether there is a fixed system of levels; and so on. In Craver's words, "[...] there can be no single verdict concerning the utility or conceptual soundness of the levels metaphor *simpliciter*" (Craver, 2015, p. 2).

When discussing about levels, therefore, many things should be clarified, starting from the kind of level at issue. In this paper, I will focus on levels of organization, and I will define them not just in terms of compositional and functional relationships, as it is usually done (Oppenheim & Putnam, 1958; Craver, 2015; Eronen & Brooks, 2018) but also in terms of constraining capacities. So, let's see what levels of organisation are.

2. *Levels of organisation*

Levels of organization are usually defined as structures composed of other (lower-level) structures forming a nested natural hierarchy that exhibits a "tendency […] towards increasing complexity" (Eronen & Brooks, 2018, §1). Despite the relevance of this hierarchical thinking, especially in the biological field, few philosophers have tried to provide a comprehensive and clear account of these levels, and those who did it offer models that are questionable in different ways (see Eronen & Brooks, 2018, §2).

The most common feature of levels of organisation is their ordering according to compositional, part-whole relationships. Oppenheim and Putnam, for instance, highlighted that "Any thing of any level except the lowest must possess a *decomposition* into things belonging to the next lower level" (1953, p. 9). William Wimsatt says that "By level of organization, I will mean here *compositional* levels – hierarchial divisions of stuff (paradigmatically but not necessarily material stuff) organized by part-whole relations, in which wholes at one level function as parts at the next (and at all higher) levels" (1994/2007, p. 201). Markus I. Eronen declares that he understands levels of organization as "*compositional* levels, such that things at a higher level are composed of things at the next lower level. In other words, there are wholes at higher levels and their parts at lower levels" (2015, p. 39). Eronen shares a deflationary view about levels (2015), and he even assumes that levels can be eliminated in favour of "more fundamental and well-defined notions such as scale and composition" (*ibidem*).

However, just focusing on compositional, part-whole relationships, might not be enough to provide an exhaustive description of levels of *organization*, for levels of organization involve organised entities and not just aggregates. In this respect, William Bechtel's and Carl Craver's models may be an example of how the ordering relation can be further specified to become more complete (Bechtel 2008; Craver, 2001 and 2015).

Craver, for instance, formulating his theory about levels of mechanism, states that the relation ordering the levels of organisation has a twofold dimension: it corresponds to a part-whole relation, but also to a "(constitutive) relevance relation" (2015, p. 15), and this "constitutive relevance" is able to specify when a part of a mechanism is relevant to it – being one of its *genuine* components – and when it is not. In any mechanism, in other words, there are relevant as well as irrelevant components and interactions, and good models and explanations should include the former and ignore the latter because the latter, despite being material parts of the mechanism, are not functional, active components (2007, p. 144) of it.

The constitutive relevance relation is therefore a *functional* relation: to be a genuine component of a mechanism, a part has to play a relevant role in it, and this means that it must be able to causally contribute to the function, behaviour and/or activity of the whole[1].

Craver calls his mereology about levels of mechanism a "relevance-mereology" (2015, p- 16), and highlights the differences between this mereology and other classical mereologies just based on composition or size (Churchland & Sejnovsky, 1992).

It should be noticed that Craver's distinction – classical mereologies *vs*. relevance-mereology – reflects the one between aggregation and organization (Craver, 2015; see also Wimsatt 1997). In aggregative systems, the whole is just the sum of the parts, so their spatial, temporal, and causal organisation is irrelevant and can be ignored. In these cases, a classical, compositional mereology can do the job. Differently, in organized systems, the parts are spatially, temporally, and causally organised to collectively realize the whole, so functional organisation should be taken in consideration as well. Craver's relevance-mereology aims at doing this. Relevance-mereology integrates classical mereology with principles of constitutive relevance able to distinguish between material parts and active components of a mechanism. In Craver's frame, therefore, to recognise a property or a process as being embedded into some level of mechanism, that property or process must be (i) a spatio-temporal part of the mechanism, but also (ii) an active constituent or realizer of the activities and behaviours of the mechanism. In his words, "the relationship between levels is a part-whole relationship filtered further by constitutive relevance" (Craver, 2015, p. 17). Differently from levels of aggregation, in levels of organisation, functional principles are as important as compositional ones, so I think that Craver's view of levels is better than a mere compositional view, because it focuses on both compositional levels and functional levels of mechanism.

This model, however, might be further enhanced, for in certain domains (e.g., in many biological systems) organisation implies composition and bottom-up realisation – the composing and constitutive functional relationship recognised by Craver (2015, p. 17) –, but also some sort of top-down constraining determination. Constraining principles should therefore enter the picture, defining levels of organisation *together with* compositional and functional ones. If in Craver levels of organisation were compositional levels and levels of mechanism, I am suggesting that in many cases levels of organisation are compositional levels, levels of mechanism, *and* levels of constrain.

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[1] Bechtel treatment of these topics is analogous: "Within a mechanism, the relevant parts are […] working parts – the parts that perform the operations that enable the mechanism to realize the phenomenon of interest. […] they are distinguished by the fact that they figure in the functioning of the mechanism. It is the set of working parts that are organized and whose operations are coordinated to realize the phenomenon of interest that constitute a level" (2008, p. 146).

When a constraining relationship takes place, eventually, a new level of organisation emerges and can be recognised. Let me now offer a brief detour about this latter concept of constrain.

3. *Mechanical and biological constraints*

In general terms, a constraint is something that limits, forces, coerces, disables or, more generally, affects what it constrains. However, the notion of constraint, as understood by scientists, is not univocal, since constraints exhibit different features depending on the contexts in which they are observed. In classical mechanics, for instance, a constraint is a parameter that limits the possibility of movement of a body. A standard example involves a sphere rolling along a plane: the sphere is not free to move in any direction (e.g., it cannot pass through the plane) but must move along the plane, which constrains it. Its motion, therefore, is bound to the shape of the external surface on which it rolls.

A second example is that of a trolley that cannot deviate from the trajectory of the rail on which it runs. Similarly to the first case, if the trolley were subject only to fundamental physical forces, the body would have more possibilities of movement, but being bound by the rail it is forced – i.e. constrained – to move in a certain manner. Alternative ways to express this concept is by saying that the degrees of freedom of the constrained objects decrease because of the constraints, or that the constraints limit the access to certain dynamical states or trajectories of the system (Hooker, 2013).

An important issue should be noted, however. Mechanical constraints like these ones are *external*, for the constrained entity is constrained to certain movements because of other entities that limit its possibilities *from the outside*. The same cannot be said, however, for all types of constraints.

Biological constraints, for instance, are often *internal* to the system and are produced by the same dynamics that they constrain (Bich & Mossio, 2011). This notion of constraint was developed between the 1960s and 1970s by Michael Polanyi (1968) and Howard Hunt Pattee (1970) to solve some difficulties related to the fact that several complex systems cannot be exhaustively described in purely physical or physico-chemical terms, given the various constraints to which they are subject.

According to Polanyi:

> [...] the organism is shown to be, like a machine, a system which works according to two different principles: its structure serves as a boundary condition harnessing the physical-chemical processes by which its organs perform their functions. Thus, this system may be called a system under double control (Polanyi, 1968, p. 1308).

So, on the one hand, there are the laws of physics and chemistry that regulate the parts of the organisms – e.g., its organs, tissues, or cells; on the other hand, there are higher-order laws that regulate the higher-order structure (Polanyi, 1968). The higher-level principles, however, are not neutral about the lower-level ones: they are *binding*. The structure, in other words, acts as a *boundary condition* able to "harness" the physical-chemical processes of the parts on which the higher-level functions depend. For this reason, this kind of systems are defined by

Polanyi as 'system[s] under double control' (1968, p. 1310). Polanyi talked about machines, like sewing or printing machines, and organisms, but I think that another intuitive and revealing example of this twofold dynamics can be represented by social insect colonies.

This is a video recorded in June, in Italy. You can see a small group of ants taking care of aphids (the pale-yellow little critters nested in the leaf rib are aphids). Now, ants *farm* aphids: they protect them from predators and keep them together; and they *milk* them, because aphids produce a honeydew which is rich in sugar and ants eat it and bring it to the queen in their nests. Ants do incredible things, as well as all other social insects such as wasps, bees, and termites, but I will just focus on ants because I know them better.

Now, in general, ant colonies are composed by many ants performing different tasks (Gordon Gordon, 2010). All these ants are subject to their individual biology but, at the same time, they are subject to principles of collective behaviours as well. Ants are therefore constrained by the higher-level structure in which they live, namely the colony. You can notice this fact by examining the behaviour of these animals, that when isolated have a randomic behaviour which is impossible to predict, while when living in a colony show an ordered, goal-directed behaviour which is easier (not easy, but easier) to predict, and this is because this behaviour must be consistent with the goals of the whole system.

4. *Conclusions*

It seems natural to state that individual ants are the low-level components of a higher-level organised structure which is the colony. This is something that can be further specified by adding what follows:

1. Individual ants are *material parts* of the colony. Nothing remains if you remove the ants from the colony. The colony is materially composed by the ants. If you remove the ants it remains the architecture of the nest, but this is really nothing, it is something like a merely ghost village.
2. Individual ants are *functional, active components* of the colony. The colony exists and performs its functions because of the specialized labour of the individual ants. We have the ants that take care of the aphids, as we saw, but also those who take care of the nest, the larvae, and the queen, those who defend the colony, those who search for foods and so on and so forth. Ants surely play relevant roles in the colony.
   BUT we would miss the nature of this superorganism ignoring the fact that the individual ants are determined by the colony as well as the colony is determined by the individual ants. So, third:
3. Individual ants are *constrained* by the colony. The colony limits the causal contributions of the components (i.e., the possible behaviours of the ants) to what is functional to the system.

We can therefore conclude that in the case of systems such as ant colonies, there are at least three kinds of principles that can describe levels of organisation:

1. Compositional principles
2. Functional/relevance principles
3. Determinative/constraining principles

The arising question, now, is what is the added-value of this third feature. I think that it corresponds to the fact that considering constraining principles in addition to compositional and functional ones offers a description of these organised systems which is more detailed. It offers, in short, a better explanation. No myrmecologist would ignore the influence of the colony on the ants describing an ant colony and its components, so in the abstract modelling of this kind of structures, the top-down vector of determination should be duly considered as well.

While compositional and functional principles are focused on the parts, moreover, constraining principles are focused on the whole: compositional and functional criteria focus on the low-level side of a multilevel system, while the criterion about constraints focuses on the high-level side of the system.

If we ask the question: *what are the roles that define levels of organisation* in these systems, we might state what follows. On the one hand, at the lower level there are entities that are *compositional parts* or *realizers* of the whole and perform roles that are functional to the whole; on the other hand, at the higher level there is an entity that exerts a constraining determination on the parts in order to select the most useful causal contributions that those parts can exert. The higher-level system acts by "shaping" (Gillett, 2016) or "pruning" the low-level contributions admitting those that let the system exist, function, and persist.

Eventually, a last remark. I focused on ant colonies, and I think that in this case, talking about the emergence of a macro-level of organisation in coincidence with the appearance of a macro-constraining structure is particularly appropriate. Obviously, to consider this theory about levels of organisation as a more general theory about levels, a deeper analysis considering in detail other organised systems is required. So, even if I find this model promising, I'd like to conclude leaving provisionally open the issue about its *scope*, for it requires further examination.

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