Levels

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The levels metaphor is commonly used to describe science, its theories, and the world. Yet the metaphor means different things in different contexts, inviting equivocation. These distinct applications of the metaphor can be distinguished by the relata they relate, the relation between levels that they assert, and the rule by which they locate items at a level. I discuss these many applications of the levels metaphor with an eye to developing a descriptively adequate account of one particular application: levels of mechanisms. I argue that this application of the metaphor is central to the explanatory practices of the special sciences and defensible as a metaphysical picture of how phenomena studied in the special sciences are constituted.

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1 Introduction

The levels metaphor is ubiquitous in our descriptions of science and the world. So simple and elegant, the metaphor takes an apparently heterogeneous collection of objects and arranges them in space from bottom to top. The metaphor works in so many contexts because it leaves open just what kinds of object are to be arranged, what distinguishes top from bottom, and what it means to say that an object is at some levels and not others. This flexibility explains the metaphor's fecundity, but it also helps to obscure the fact that it is used in many different ways in many different contexts.

A survey of kinds of levels drawn from science and philosophy would have to include levels of abstraction (Floridi 2008), aggregation (Wimsatt 1997), analysis (Shepherd 1994; Churchland & Sejnowski 1992), causation and explanation (Kim 1998), implementation (Marr 1982), organization (Churchland & Sejnowski 1992), processing (Craik & Lockhart 1972), realization (Gillett 2002), sizes (Wimsatt 1976), sciences, theories, and explanations (Oppenheim & Putnam 1958). Many of these familiar applications of the levels metaphor are distinct from but also clearly related to one another. And when they are related, they often have rather indirect and reticulate connections. The level metaphors thus takes subtly different forms when applied in neighboring contexts, and this obscures the extent to which features of one application of the metaphor do and do not transfer from one context to the next. My first thesis, then, is that our ways of describing sci-

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ence and the world contain many distinct, legitimate applications of the levels metaphor that are either unrelated or that have only indirect relations with one another.[1]

This *descriptive pluralism* about the levels metaphor is directly opposed to eliminativism about levels (Fehr 2004; Machamer & Sullivan 2001; Thalos 2013). The suggestion that we might be better off abandoning the levels metaphor is about as likely to win converts as the suggestion that we should abandon metaphors involving weight or spatial inclusion. These metaphors are too basic to how we organize the world to seriously recommend that they could or should be stricken from thought and expression. Yet, descriptive pluralism about the levels metaphor is consistent with the thought that some applications of the metaphor distort the structure of the world or represent it as having conceptually incoherent structures. I discuss some examples below. The central message of this paper is that there can be no single verdict concerning the utility or conceptual soundness of the levels metaphor *simpliciter*. The metaphor must be evaluated and used with caution, especially when it is called on to settle disputes about the character of science and the metaphysical structure of the world.

As some motivation for adopting this proposal, and as a step toward a more positive thesis, I show that we can avoid some simple confusion by separating the different applications of the metaphor. To make this case, I build slowly toward a particular application of the metaphor that, as I have argued elsewhere (Craver 2001, 2007), is central to explanatory practices in neuroscience and across the special sciences: levels of mechanisms. This application of the levels metaphor is metaphysically plausible and, so far as I can tell, more or less innocuous; that is part of its virtue. Yet this simple and useful application of the metaphor can begin to appear problematic when it is inappropriately assimilated to other applications that serve altogether different purposes in our thinking about science and the world.

My point is not to defend levels of mechanisms as the one true application of the levels metaphor (that would be as pointless as eliminativism). Rather, my first positive goal is to provide a reasonably clear account of levels of mechanisms and to show that this application is metaphysically benign yet exceptionally important for doing science. Levels of mechanisms are, as would be expected, richly but indirectly connected with many other applications of the metaphor. My second goal is to highlight and disentangle some of the confusions that arise from failing to keep levels of mechanisms distinct from other senses of levels. In particular, I show that commitment to the existence of levels of mechanisms entails no commitment to: a) monolithic levels in nature, b) the stratification of sciences by levels, or c) a tidy hierarchy of theories among the sciences. I will also show why levels of mechanisms are d) distinct from Marr's views about levels of abstraction and e) distinct from levels of realization more generally. I argue that f) the idea of interlevel causation is conceptually awkward within levels of mechanisms (but not to levels of size, for example). Furthermore, g) the idea of levels of mechanisms nicely expresses the idea of emergence as a kind of non-aggregativity while providing no support to those who seek evidence in biology for a more robust kind of emergence. The failure to disambiguate altogether separate applications of the levels metaphor creates a conceptual malaise for which levels of mechanisms are at least a partial cure.

2 Refining the levels metaphor: Three defining questions

In its barest of forms, the levels metaphor demands little of its object; it requires only a set of items and some criterion for ranking them as higher or lower than one another in some respect. Seniors are at a higher level in the American high school system than juniors, poetry is at a higher level than pushpin, lust is at a higher (and lower) level than like, and cells are at a higher level than molecules. In these ex-

1 Standard etymologies trace the term "level" to the balance and from there to the idea of a flat, horizontal landing, as in the stories of a building. From there, it is easy to see how the metaphor might be extended to the kinds of hierarchy discussed in this paper.

amples, it is obvious that different kinds of thing are related by entirely distinct kinds of relation. In subtler cases, the equivocation is less noticeable, and for that, all the more misleading.

Three defining questions can be used to explicate how the levels metaphor is applied in a given context:

The Relata Question: What kinds of item are being sorted into levels?

The Relations Question: In virtue of what are two items at different levels?

The Placement Question: In virtue of what are two items at the same level?

The Relata Question provides an important clue about the intended sense of levels. The flexibility of the metaphor allows it to be applied to *abstracta*, such as branches of mathematics and ethical principles, or to *concreta*, such as astronomical objects and stereo equipment. The metaphor can be applied to types, such as sergeants and corporals, or to tokens, such as the relationship between Colonel Blake and Corporal O'Reilly. It can be applied to objects such as cats and mountains, to activities such as releasing neurotransmitters and making decisions, and to properties such as excitability or charge. Within the neurosciences, the levels metaphor is applied fluidly to causes, descriptions, developmental stages, events, explanations, scientific fields, objects, properties, techniques, and theories. Confusion arises when we assume that each application is the same.

The Relations Question concerns the ordering relationship by which items are said to be at a higher or a lower level than one another. A theory, for example, might be said to be at a higher level than a second if the first is derivable from the second (and not vice versa); the lowest-level theories are in this sense "fundamental." Poetry might be said to be higher than pushpin in the sense that it requires greater intellectual skill and training to take pleasure in the former than to take pleasure in the latter. A technique might be said to be at a lower level than another because it detects phenomena at a smaller size scale. Some applications of the levels metaphor are discrete in the sense that there is a gap between things at lower and high levels; other applications are continuous, as when one uses the metaphor to describe size. We are unlikely to confuse such wildly different kinds of relationship. However, as we will see, the metaphor is used in other contexts where it is beguilingly difficult to keep them distinct, even for those who know better.

The Placement Question asks for the principle by which different items are located on the same level. Many uses of the levels metaphor rely at heart on an answer to the placement question. When the metaphor is used to describe size scales, for example, puffins and porcupines are at roughly the same level, vasopressin and oxytocin are at roughly the same level, and hydrogen and oxygen atoms are together at a lower level still. Juniors are all juniors because they are in their third year of American high school. For Marr, computational level questions are directed at what is computed and why it is computed that way (Shagrir 2010; Bechtel & Shagrir 2013).[2] Not every account of levels requires an answer to the placement question affirmatively. Indeed, it is of central importance that the idea of levels of mechanisms articulated here entails no positive story about what it means to be at a level, only a negative story about when things are not at different levels.

3 From gesture to prototype

Perhaps the most common application of the levels metaphor is to gesture loosely at the relationship between different fields of scientific research, *levels of science*.[3] In neuroscience, for example, some researchers work at "the molecular level," doing things such as sequencing channel proteins, studying enzyme kinetics, or manipulating genes. Others work at the cellular level, doing things such as staining cells, recording action potentials, or studying neural migration. Others study brain regions, characterizing

2 One consequence of the following discussion is that not every account of levels must offer a unique answer to the placement question. Levels of mechanisms are defined by their distinctive relata and relations; these constraints, by themselves, offer no unique answer to the placement question. This is why levels of mechanisms are, as I will argue, local rather than monolithic.

3 For the relevant sense of a scientific "field", see Darden & Maul (1977) and Darden (1992).

their anatomical features or, studying the propagation of neural signals within them. Still others work at the level of systems, using functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), and cognitive tasks to find large-scale cognitive systems in the mind-brain. One could perhaps insinuate other levels between these, and one could certainly extend the hierarchy further down or higher up. But the central idea is that the *scientific fields* can be ordered as higher or lower than one another.

Scientific fields are individuated in part by their theories (Darden 1992). The gestural sense of levels, then, can seem to carry the implication that scientific *theories* are or will someday be ordered more or less clearly into levels. Oppenheim & Putnam's (1958) influential view of the unity of science is based on a rough correspondence between levels of science, levels of theory, and levels of parts and wholes (see Table 1). They divide the world into six ontological strata (societies, organisms, cells, molecules, atoms, and elementary particles). These strata are defined by mereological relationships among types: elementary particles are the parts of atoms, atoms are the parts of molecules, molecules are parts of cells, and so on. Each of these strata is assigned a distinct science: economics and the social sciences at the top, particle physics at the bottom. Each science develops its theory more or less autonomously from the others, so the theories developed by these sciences can themselves be ordered, like the layers of a cake, from top to bottom. The unity of science, for Oppenheim and Putnam, is to be achieved by explaining phenomena in the domain of a higher-level science, as described in the theory of that science, in terms of the items in the domain of the more fundamental science, as described in the theories of that science. (Levels of mechanisms, as defined below, involve a kind of part-whole relation as well but without any commitment to the idea that such type-level part-whole relationships correspond in even a rough way to the structure of the sciences or to the structures of their theories.)

Wimsatt's detailed and influential exploration of the levels metaphor confronts Oppenheim and Putnam with the complexity of the levels found in many areas of contemporary science (Wimsatt 1976). Against Oppenheim and Putnam's six-layer model, Wimsatt's "Reductionist Illustrative" (Figure 1) represents multiple branches of levels fanning out from the lowest level in subatomic particles to cosmological objects, the sociocultural world (e.g., economic and political phenomena), and the socioecological world (e.g., evolution).

Wimsatt's tree diagram, however, represents only one aspect of his *prototype account* of levels that encompasses many more features than Oppenheim and Putnam's layer-cake mapping in Table 1. The core features in Wimsatt's prototype are:

- **Size.** Higher-level items are larger than lower-level items.
- **Composition.** Higher-level items are made up of lower-level objects and processes.
- **Laws.** Laws of nature hold only or mostly between items at the same level.
- **Forces.** Distinct forces operate at different levels.
- **Predictability**. Levels are local maxima of regularity and predictability that appear at different size scales.
- **Detection.** Items at a given level tend to be detected or detectable primarily by other items at that level.
- **Causes.** Causal relationships hold only or mostly between items at the same level.
- **Theories.** Scientific theories describe phenomena exclusively or mostly at a single level.
- **Techniques.** Different techniques and instruments detect items at different levels.
- **Disciplines.** Different disciplines of science direct their attention at different levels.

Wimsatt's view is a prototype view in the sense that it characterizes the levels metaphor in terms of a core set of features, not all of which must be present in order for the metaphor to apply. Insofar as Wimsatt embraces a prototype model, he can be seen as embracing descriptive pluralism while, at the same time, holding that there is a sufficiently strong family resemblance

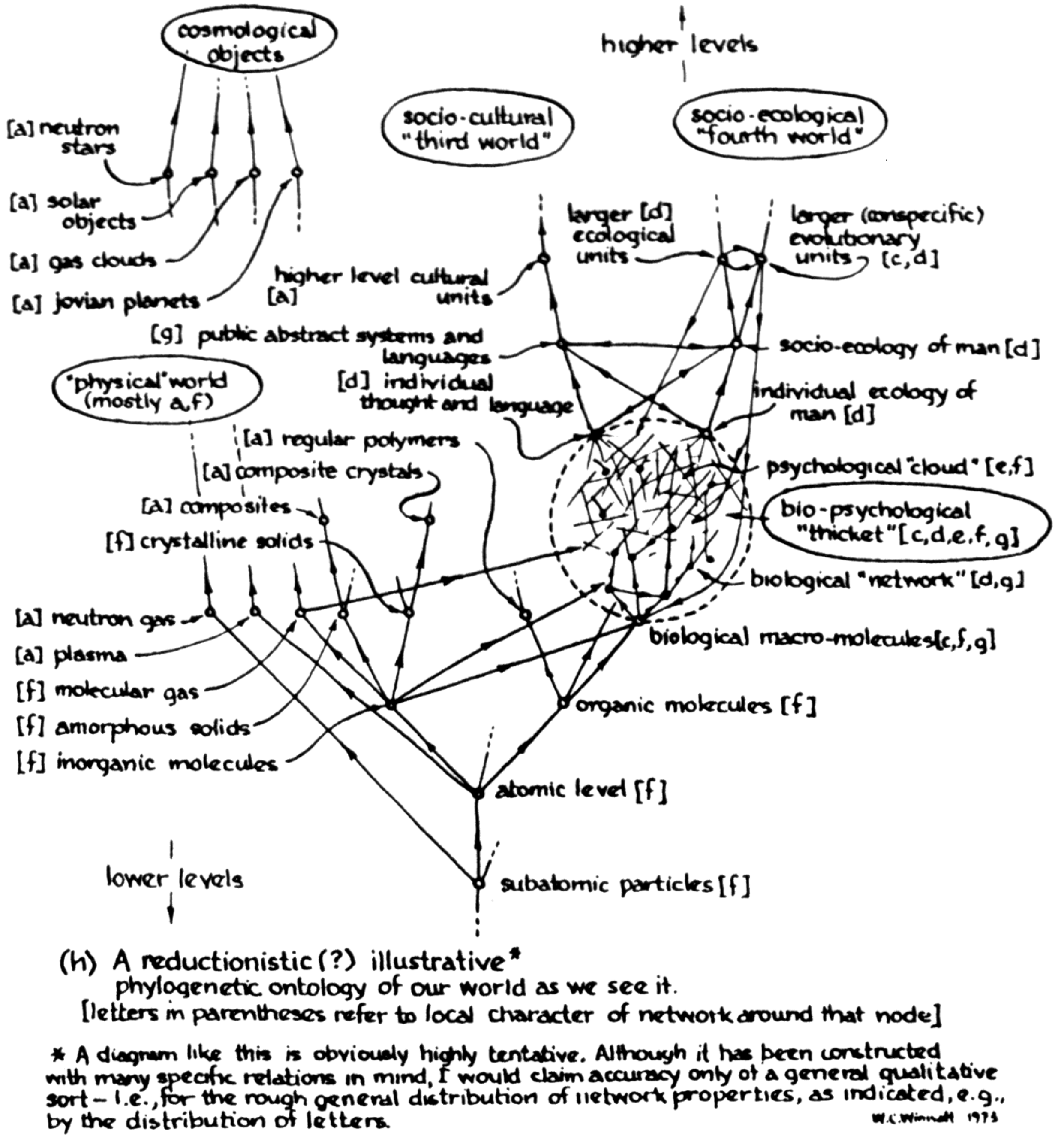

Figure 1: Wimsatt's tree of levels branches to preserve compositional relationships among levels (1976).

among the plurality of applications of the levels metaphor to warrant their inclusion in a single prototype.

Is the levels metaphor sufficiently unified across these different applications to warrant a single prototype? My remarks on the relata, relation, and placement questions should already indicate that it is not—that different features in Wimsatt's list are at best indirectly related and so fail to map to one another in any tidy way. While the prototype approach usefully highlights the complexity of the levels metaphor, it also obscures the extent to which the different features in the prototype are features of different applications of that metaphor.[4]

4 Wimsatt's diagram in Figure 1 reflects this. The branching tree structure is ordered by compositional relations. Wimsatt's view of levels as dissipating waves (see Figure 3 below) flouts that relation.

Table 1: Oppenheim and Putnam's layer-cake sketch of the levels of mereology (left), sciences (middle), and theories (right).

Mereological level	Sciences	Theories
Societies	Economics	Classical Economics
Organisms	Psychology	Law of Effect
Cells	Cytology	The Neuron Doctrine
Molecules	Chemistry	The Central Dogma
Atoms	Physics	The Bohr Model
Sub-Atomic Particles	Quantum Mechanics	Schrödinger Equation

4 Levels of sciences and theories

Wimsatt, Oppenheim, and Putnam all include within their analysis of levels the gestural idea that different fields or disciplines of science are arranged by the sizes of the objects they study. Wimsatt's branching hierarchies depict a more ornate structure. Within that structure, it seems inappropriate to say that astrophysics is at a higher level than biology or economics, though astrophysicists typically deal with things that are orders of magnitude larger than the things biologists and economists study. The gestural sense of levels doesn't seem to branch that way.

When we apply the levels metaphor to *sciences*, the relata are units of scientific organization (such as fields, research programs, or disciplines). Answers to the relations and placement questions are more difficult to discern and are likely impossible to express both accurately and concisely for this application. Size seems to be relevant, but we have just seen that it cannot be the whole story. The branches in Wimsatt's diagram follow, in addition to size relationships, relationships of composition. The things studied by economists (groups) are composed of things studied by psychologists (organisms), which are composed of things studied by physiologists (physiological systems), and so on. The things studied by Darwin are composed of the things studied by zoologists, which are composed of the things studied by cytologists. The point of these examples is not to get the branches in Wimsatt's hierarchy exactly right; any proposed hierarchy of the sciences and the items in their domains is bound to be historically contingent and provisional at best.

In fact, many sciences appear to resist tidy compartmentalization within levels. Neuroscience, especially cognitive neuroscience, is a paradigm of multilevel science, encompassing the study of ions, ion channels, cells, populations of cells, brain regions, and behaviors of whole organisms. No competent evolutionary biologist can avoid knowing something about genes, physiological systems, organisms, populations, and environments. Many sciences, in short, contain items within their domain that stand in compositional relations to one another. Such sciences often construct multilevel theories that integrate findings across multiple levels of organization. This is one reason why the relationship between levels of science and part-whole levels is indirect.

Another reason is that, in many cases, more than one science is dedicated to studying items at the same mereological or size level. Cytologists, anatomists, and electrophysiologists all study aspects of cells with different tools. The ethologist and the experimental psychologist study animal behavior, but they approach that behavior with different assumptions, methods, and theories. Economists, ecologists, epidemiologists, and organizational psychologists study populations of organisms. The relationship between levels of science and the ontological levels that Oppenheim and Putnam presume is many to many.

For this reason, it is unlikely that any precise answer to the placement question will correctly express the application of the levels metaphor to sciences. One might say that two sciences are on the same level when they pertain to items at the same compositional level. Perhaps it makes sense to say that Camillo Golgi was investigating the same level when he stained Purkinje cells with silver nitrate that Alan Hodgkin was investigating when he used his voltage clamp to study the action potential of the squid giant axon. They were both studying cells, but they studied different phenomena and used different techniques. If we focus now on the parts of these wholes, we see that these different scientists are not even on the same branches of a Wimsatt diagram, and the levels metaphor begins to break down. Ask Golgi about the relevant parts of the cell, and he will tell you about its gross morphological features and its organs. Ask Hodgkin and Huxley about the relevant parts of the squid giant axon, and they will tell you about membranes, axon hillocks, ionic conductances, and voltage gradients. An epidemiologist might talk about nodes and networks and hubs in a model of contagion. Economists will talk about producers and consumers. Differences in scientific interests often entail differences in the relevant ontology for the science; and the same thing can be carved into parts in many ways depending on what one is interested in describing or explaining (Kauffman 1971; Wimsatt 1972).

The take-home lesson: the application of the levels metaphor to fields of science yields a notion of levels only indirectly related to ontological levels (as understood in a roughly compositional, part-whole sense). The idealized, Oppenheim-Putnam correspondence between levels of science, levels of theory, and levels of mereology breaks down in the face of this many-many mapping. And the compositional aspect in Wimsatt's prototype appears to be only loosely related to the application of the levels metaphor to fields of science. These are, in short, distinct applications of the metaphor, offering different answers to the relata, relations, and placement questions. As a result, an understanding of how sciences can be organized loosely into levels provides no direct insight into ontological levels. This will come as no surprise to those who study intellectual history, or to those who have witnessed for themselves how fields of science change their boundaries over time. Our age, perhaps more than any other, has witnessed an explosion of hybrid fields (neuroeconomics, behavioral genetics, cognitive ethology) that cross levels, combine approaches, and attempt to feed off insights shared between distant scientific neighbors. The historical relativity of disciplinary boundaries makes them unreliable guides to ontology.

The same considerations suggest that *levels of scientific theory* will also have a many-many relationship with ontological levels. In this application of the metaphor, the relata are theories or models. And the relationship is typically construed as a kind of subsumption, e.g., deductive subsumption (Hempel 1965; Schaffner 1993; Kitcher 1989), or some kind of similarity or inclusion (Bickle 1998). The disciplinary hodgepodge of the special sciences fails to match this philosophical reconstruction. Single theories, such as the theory explaining spatial memory in terms of memory systems, grid cell organization, synaptic plasticity, and changes in ionic conductances through a membrane (see Moser 2008), often reach across many different part-whole levels (Darden & Maul 1977; Bechtel 1988; Craver 2002, 2008). One and the same mereological unit (e.g., cells) can appear in many distinct theories (e.g., neurons play some role in most theories in neuroscience).

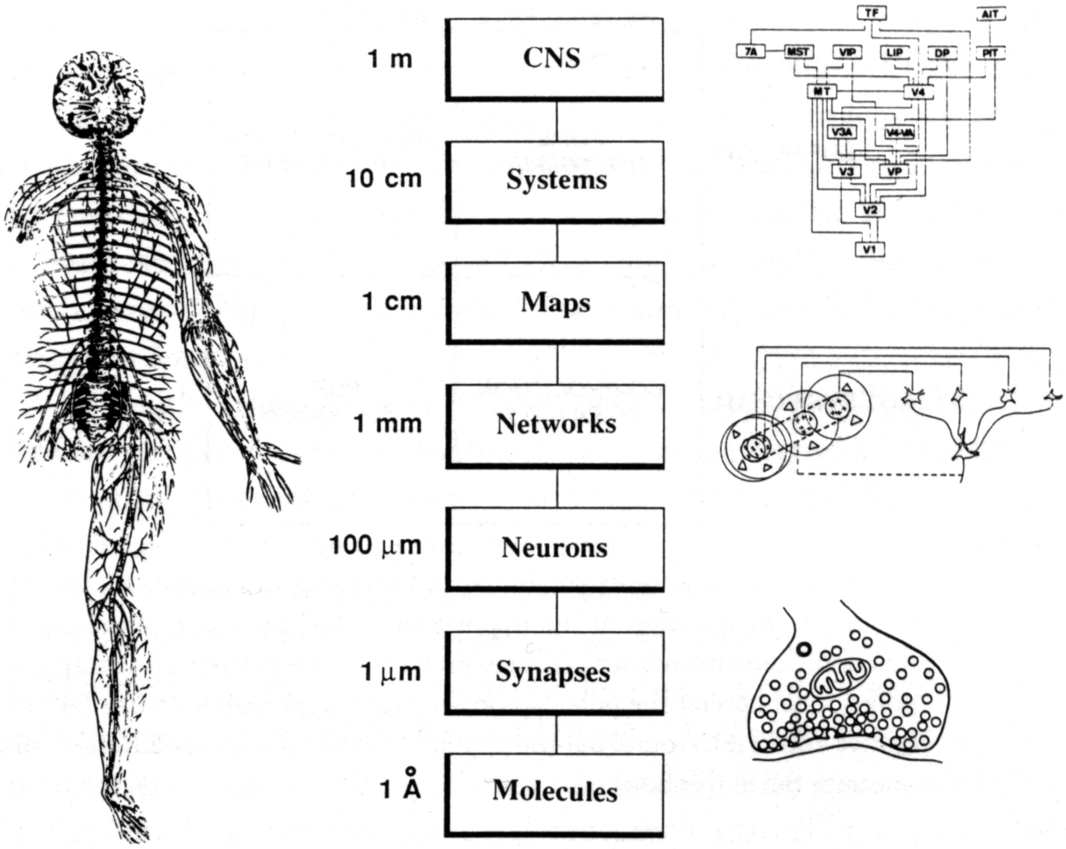

Figure 2: Churchland & Sejnowski's (1992) diagram of levels of organization in the central nervous system.

The multilevel structure of contemporary science emphasized in nearly every corner of the special sciences is not best understood as a hierarchy of theories. Nor is it a hierarchy of fields. Instead, there is an ontological hierarchy working behind the scenes. This background ontological assumption guides the development of theories, informs the criteria for evaluating explanations, and underlies the roughly hewn idea that sciences and theories are organized into levels. It is the expression of an ideal of explanation to understand how things work in terms of their component parts and to understand how those parts work in terms of still lower-level components. It is precisely because the world is presumed to have this kind of multilevel structure, of mechanisms within mechanisms, that the sciences investigating that world and the theories describing it are so reticulate that they can look like the "bio-psychological thicket" on the right side of Wimsatt's tree. In the thicket, the orderly relationship among levels breaks down and is replaced by a jumble. The image makes it hard to see any meaningful sense in which distinct items are at different levels. Perhaps this thought fuels eliminativism about levels.

The biological sciences are undeniably thicket-like. But this sociological fact is only indirectly related to the ontic structures presumed to lie behind and scaffold the development of these theories. From now on, then, I focus on applications of the levels metaphor to the world, not to sciences or theories.

5 Size levels

One ontological application of the levels metaphor emphasizes the relative sizes of objects at different levels. The relata in size levels are objects or kinds of object, and the interlevel relationship is relative size (larger, smaller). Things in the same size range are at the same level. Churchland and Sejnowski's classic diagram of

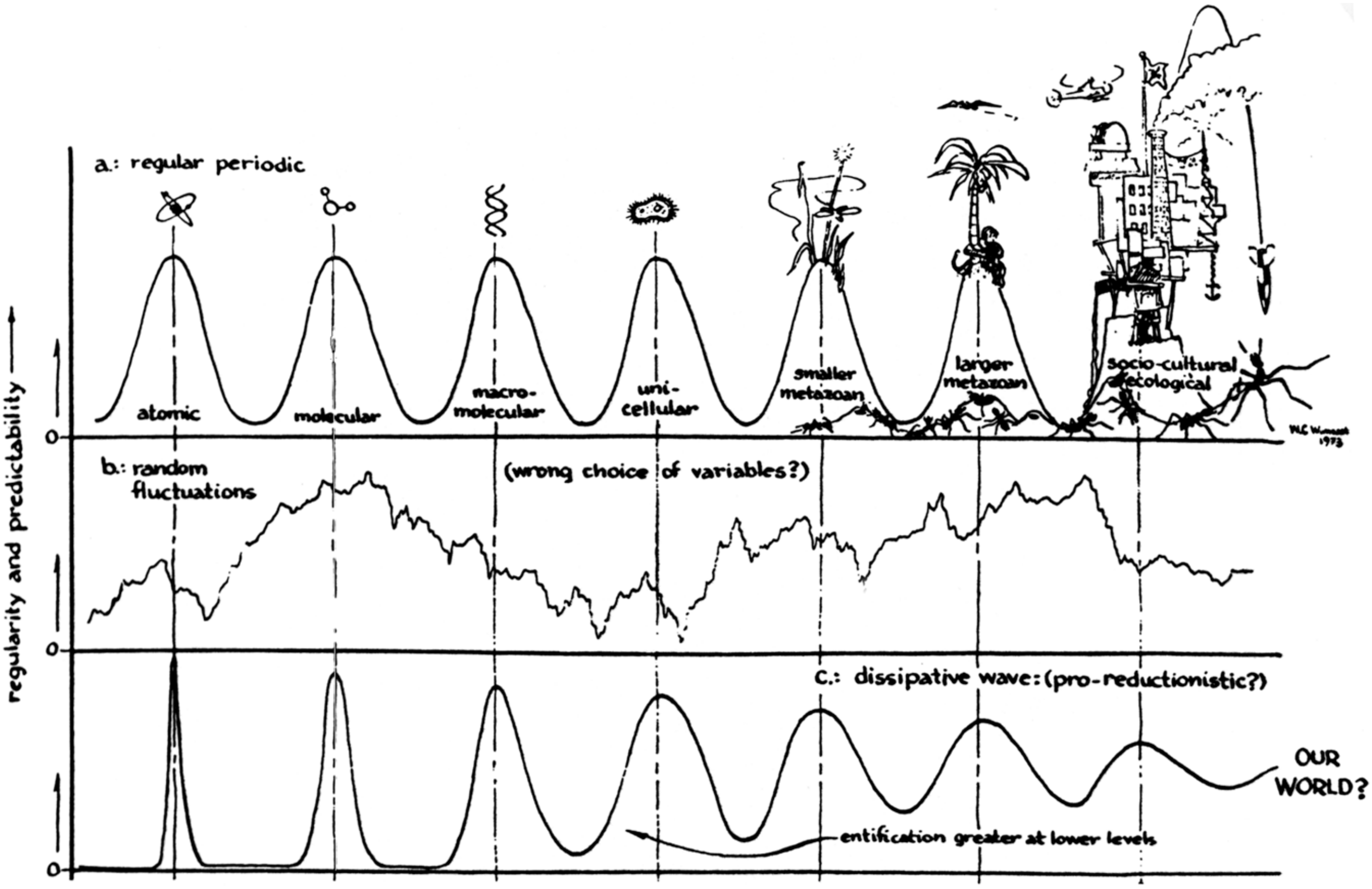

Figure 3: Levels as local maxima of regularity and at different size scales (Wimsatt 1976).

levels in the neurosciences (Figure 2) is accompanied by size scales for each level, ranging from Angstrom units to meters.[5]

As noted above, Wimsatt's tree diagram branches precisely because it is tracking something stronger than size: some kind of compositional relation. In a second diagram (Figure 3), Wimsatt emphasizes size and abandons the compositional relationship implicit in Figure 1. The abscissa in Figure 3 represents a roughly logarithmic size scale, and yet the figure is not compositional. Large metazoan organisms are not generally composed of smaller metazoan organisms, and it would surely be a stretch to claim that these two are generally composed of unicellular organisms (though there might be some truth in that claim). The ordinate in this diagram is a measure of regularity and predictability. The figure is repeated three times, each illustrating a different way the world might be organized with respect to size. At the top is an orderly world (despite impending doom on the right). Objects become more regular and predictable in their behavior, and to the same degree, at certain size scales. Beneath this is a world with no sharp peaks of regularity and predictability. As Wimsatt notes, scientists confronted by such a world might question whether they have chosen the right variables for their models. On the bottom is Wimsatt's conjecture for our world, where regularity is very high for single atoms but falls off at larger or smaller scales. This wave dissipates over time, peaking lower and spreading out over larger and larger size ranges as scale increases. Wimsatt's diagram thus represents an *empirical hypothesis* about how levels, as peaks of regularity and predictability, are in fact distributed across different size scales in our world. If his empirical hypothesis is correct, it calls out for explanation that our world is more like the first and third graphs than it is like the second.

5 One might, analogously, arrange a hierarchy of activities, with different activities occurring on different temporal scales. The idea of levels of mechanisms combines these two ideas; it is a hierarchy of doings framed by a relevance relationship between those at lower levels and those at higher levels.

Why does Wimsatt represent size as the determining factor in regularity and predictability? The answer turns on other features in his prototype account. For example, things of different sizes effect and are affected by different forces, and objects of different sizes act and interact with one another more than they interact with objects at other levels. Market forces run economies, cosmic objects move under gravitational forces, and hydrogen bonds hold molecules together. Regularity and predictability peak at different size scales because the forces act and the causal relationships occur mostly at those size scales.

Wimsatt's empirical hypothesis has not been tested.[6] Despite its intuitive appeal, one can readily produce examples of causes, forces, and laws that operate promiscuously across a very wide range of size scales. Big things (even very big things) and little things (even very little things) routinely interact, as when planets attract molecules into atmospheres or when a five-millimeter louse attaches itself to a thirteen-meter gray whale. Forces also act at many scales. Gravitation affects the human species on an evolutionary scale just as much as it influences individual human actions and the otoliths in our vestibular system. The very existence of interlevel theories, bridging molecules to behaviors (for example), provides ample evidence that regularity and predictability often span size scales: facts about gasses can be predicted from facts about molecules, and facts about learning can be inferred from facts about molecules.

If we could find a way to test Wimsatt's hypothesis, it might turn out that causes, forces, and laws do tend to cluster around certain size scales. This would be a striking empirical fact about the world and would, again, call out for some kind of explanation. In contrast, Wimsatt raises no *principled* objections to interlevel causes, forces, or regularities; he offers an *empirical* hypothesis that interlevel causes, forces, and regularities tend to be less prevalent than those operating at a single level.

6 It is hard to say how it would be tested and, in particular, how predictability is to be measured. Surely items in the valleys of this diagram are not unpredictable, full stop. Rather, they are more difficult to predict for creatures *like us*, unaided by machines and programs. It is not clear why human cognitive abilities should have any further ontological significance.

There are, however, apparent principled, *conceptual* difficulties faced by the effort to describe *levels of realization* in terms of a causal relation. There are many notions of realization, often tailored to altogether distinct philosophical disputes (Craver & Wilson 2007). On most accounts, however, one and the same object or event has both the realized and the realizing property, and the object cannot differ with respect to the realized property without the realizing property being different in some way (supervenience). The relata here are properties. The interlevel relationship is or includes supervenience.[7]

Marr's levels, as I understand them, are levels of realization. The hardware realizes the algorithm, which, in the right context, realizes the computation. It is awkward at best to say that the algorithm causes the computation; rather, the algorithm implements the computation in context. Changing context can change the computation. For example, a subtraction algorithm can implement division; the log of a division is a difference of logs. Likewise, the function represented in the algorithm is not caused by the hardware; the hardware instantiates or implements the algorithm. Computation-, algorithm-, and hardware-level theories are all different ways of describing one and the same thing—different predicates applied to one and the same system as a whole in its working context.

The same holds for what we might call micro-realization: when some property of a whole is realized by the organized and interacting collection of parts that constitute the property of the whole. An early edition of the *Betty Crocker Cookbook* apparently contains an explanation of how the microwave heats the soup (Churchland 1995). According to this explanation, the molecules excited by the microwave rub against one another and heat the soup by friction. As Churchland points out, Betty misrepresents the relationship between the heat of a liquid and the kinetic energy of its constituent molecules. Temperature is not produced by the

7 Supplemental conditions might be added to make realization more demanding (e.g., Melnyk 2003; Haug forthcoming). The point I wish to make doesn't turn on this matter.

mean kinetic energy of component molecules in such cases; rather, temperature in such situations is constituted or realized by (Churchland would say identical to) the mean kinetic energy of the components. In the same way, one might think that the behavior of a mechanism as a whole is realized by, rather than caused by, the organized collection of its components. The beating of the heart is realized, not caused, by the choreographed movements of the auricles and ventricles. It is awkward and unnatural to assert otherwise.

The apparent awkwardness and unnaturalness of such ways of talking follows from many core principles that many (rightly or wrongly) embrace about the nature of causation. If one thinks that causes must precede their effects, and one understands the realization relationship as a synchronic relation, then levels of realization cannot be causally related. If one thinks of causation in terms of the intersection of processes and the exchange of marks or conserved quantities, then the relata in levels of realization do not *come to* intersect in space-time (they always and everywhere intersect), they do not carry their marks beyond the locus of the intersection (because they always and everywhere intersect), and they do not pass anything from one to the other. In short, the *intimacy* among levels of realization seemingly precludes any standard metaphor of production, or "oomph," or expression of a disposition, or the exertion of a power. This intimacy stands in the way of anyone who believes that causes and effects must be altogether distinct from one another.[8] So indistinct are levels of realization that many philosophers, Churchland included, prefer to speak of identity in such contexts (see Polger 2006). Finally, if one thinks of causation in terms of the ability to manipulate effects by intervening on causes, one will note that there is no way to intervene to change the properties of wholes without, at the same time, intervening to change the supervenience base of those properties.[9]

I raise these issues not to cement a case against the possibility of understanding realization and causation so as to leave conceptual space for causation between levels of realization. (For a fuller discussion, see Kim 2000; Craver & Bechtel 2006). I mention them only to point out that relations of size and realization have very different implications for the intelligibility of interlevel causation. No theory or principle of causation that I know places any metaphysical restrictions on causal relations among objects of different sizes. Many theories or principles of causation appear to rule out the possibility of causal relationships between levels of realization. The point is that Wimsatt's empirical hypothesis that causes, laws, and regularities tend to be sequestered within size scales is altogether distinct from the claim that there is no conceptual room for causation between levels of realization. Interlevel causation is mysterious or not depending on which views of levels and causation one adopts.[10]

6 Parts and wholes

A distinct and indirectly related application of the levels metaphor in the neighborhood of

8 I discuss a representative quote from Lewis below when considering causal relations between levels of mechanisms.

9 One can, in cases of multiple realization, intervene into the parts and their organization without intervening to change the property of the whole, and this affords some measure of independence. Perhaps one can find room in this view for the idea of understanding bottom-up relations in a hierarchy of realization as causal (though, again, realization or token identity seem to be better ways of talking). But there is no room in the view (no conceptual room) for causation to work from the top down in such levels. For a penetrating discussion of this matter and its implications for causation in a multilevel world, see Baumgartner 2010, 2013; Romero (forthcoming).

10 Levels of control and levels of processing, in contrast, are defined in terms of causal relations. In *levels of control*, the relata are agencies and the relation is dominance. Items at higher levels direct or regulate the activities of their underlings. Majors and corporals, queen bees and drones, bosses and workers occupy different levels of a control hierarchy. Analogous relations are sometimes found among physiological systems. When one speaks of "executive function" in cognition, one is describing levels of control.
The idea of control or dominance is a causal notion, and it is independent of matters of size (witness the sauropod brain). Contra Fehr (2004), the idea that the world is organized in levels of realization or organization (as defined below) is not an expression of patriarchy; it is an equivocation to characterize realization and organization as relations of dominance. In levels of control, the relata are logically independent and spatiotemporally distinct interactors. It is not at all implausible for one to control the other causally (more on this below).
In ***levels of processing***, the relata are processing units of some sort (such as brain regions or computational modules), and they are related as "upstream" or "downstream" in the flow of information or the order of production. In the early visual system (neglecting feedback for the moment), one can describe visual information as passing from lowest- (shallowest-, earliest-) level processing in the retina to higher- (deeper-, later-) level processing in the Lateral geniculate nucleus (LGN) and the primary visual cortex. Levels of realization and organization are not earlier or later than one another. Craik and Lockhart define levels of processing in terms of depth of semantic or cognitive processing, not in terms of decomposition.

levels of realization invites a different kind of equivocation, this time concerning the existence of higher-level powers. This application involves not a whole-whole relationship but rather the relationship between the behavior or property of a whole and the behaviors or properties of one of its parts. The behavior of the whole does not (except in special cases) supervene on the operation of the individual parts. The grain of sand contributes to the mass of the sand pile. The kidney contributes to the capacity of creatures to maintain plasma osmolality. In each case, the property of the whole (the mass of the pile, the regulation of plasma osmolality) might differ even when the contribution of these singular parts remains the same. In *part-whole* levels, as opposed to levels of realization, the relationship is between parts and wholes, not between wholes and the corresponding organized collections of entities, properties, and activities. In this case, eliminativism about levels is a non-starter (whatever its metaphysical credentials); it is impossible to imagine neuroscience, biology generally, or indeed most special sciences without the idea that things have parts.

In applying the levels metaphor to this part-whole relation, one emphasizes the relations question over the placement question.[11] In levels of size, things are at a given level because they are similar in size. Levels, thus conceived, are *monolithic*: they reach across all of nature, embracing everything within a given size range. Oppenheim and Putnam's layered model of the world might be read as similarly monolithic. Wimsatt's tree diagram breaks with this monolithic view precisely because it emphasizes compositional relationships: different branching levels are required because different kinds of whole (cosmological objects, human societies) are composed in different ways. If one centers part-whole thinking in one's application of the levels metaphor, then the metaphor carries no particularly useful answer to the placement question. One can offer only a necessary condition: two things are at the same level only if they are not related as part to whole. Given that most things are not related to one another as part to whole, the resulting idea of being "at" a part-whole level has little or no conceptual significance.

Levels of parts and wholes lack many of the features in Wimsatt's prototype of levels. Many of the features in that prototype appear to derive from the monolithic conception shown in Figure 3: causes, forces, and laws are most plausibly thought to cluster together on the assumption that size is relevant to which forces can act, that causal relations are expressions of forces acting, and that laws govern these interactions. But if one places the part-whole relation in the center of one's metaphor, then there is no reason to embrace an empirical association between being at a given level and having a proprietary set of causal interactions for that level. Levels of parts and wholes must also be correlated with size differences because parts can be no larger than the wholes they compose. But the size differences between levels of parts and wholes are an accidental consequence of the part-whole relationship itself, not part of defining what it is for things to be at different part-whole levels.

In the following subsections, my goal is to sketch some contours of the relevant notion of part and whole. I start with classical mereology only to make the point that this apparatus was not constructed with an eye to developing a descriptively adequate account of the levels described by science. The more we learn about the limits of these classical models for our present purposes, the more we place constraints on the relevant notion of levels that, as I and others have argued, is central to the explanatory structure of neuroscience and the special sciences generally: *levels of mechanisms* (Bechtel 1988; Bechtel & Richardson 1993; Craver 2001; Machamer et al. 2000).

6.1 Types and tokens of parts and wholes

The Gibson SG has two humbucker pickups. My Gibson SG has two humbucker pickups. Not all

11 I am here using the terms "part" and "whole" in an intuitive and inclusive way. Much of the literature on the metaphysics of parthood is simply unrelated to the many senses of part and whole used in the theories of the special sciences. I am not thinking only of objects or sets, but also about events and temporal units. I sketch a more restrictive kind of part-whole relation below, but this remains an open question (see Sanford 1993).

Gibson SG's have two humbucker pickups. But that's the factory model, the central exemplar or prototype against which variations are evaluated as more or less "typical." Likewise, when we talk about *the* human brain or *the* frog kidney, we are talking about types: the human type of brain, the frog type of kidney. And we talk also about the parts these types of things typically have.

The monolithic, layer-cake image in the Oppenheim-Putnam hierarchy is a mereology of types: societies are formed of organisms, organisms of cells, cells of molecules, and so on. Wimsatt's tree also represents relationships between types. Crystals are made of crystalline solids, which are made of inorganic molecules, which are made of atoms. It is true, of course, that all cells are made of molecules and that all organs are made of cells. But is not true that all cells are at a higher level than molecules generally.

It seems natural and harmless enough to treat the part-whole relations among types as generalizations over relations between particular wholes and particular parts. When one says, "The human brain has two hemispheres and a corpus callosum," one asserts that having these parts is typical of human brains. One is warranted on the basis of such a claim (though not always correct) in asserting of a particular human brain that it has two hemispheres. That is, the relation among part and whole *types* derives from a more primitive, token relationship between particular parts and wholes. Type-level claims about part-whole relations assert that such part-whole relations regularly or typically hold in the individuals in the relevant reference class.

One of the many useful insights contained implicitly in the branching structure of Wimsatt's tree diagram (Figure 1) is that different types of wholes are made up of different types of parts and are naturally decomposed into different levels. Both the human brain and the frog kidney are organs, and both are made of cells, but the cells in each are different, and these cells are organized differently into higher-level components. If we look within the human brain, we find that different brain regions are composed of altogether different components and exhibit more or less proprietary organization. Broadman mapped the brain by studying these differences in cytoarchitecture from one brain region to the next. The receptive field organization of the visual cortex has, to my knowledge, no companion in the organization of the amygdala or of the mammillary bodies. Different types of brain regions/systems are made up of different types of components: they have different part-whole levels.[12]

When we say that objects or processes of one type are parts of objects or processes of another type, we are asserting that *ceteris paribus* token objects of the one type are composed of token objects of the second type. Indeed, standard attempts to define the part-whole relationship with logical rigor are expressed in terms of relationships among token individuals (Varzi 2014).[13]

6.2 Mereology

Although Oppenheim and Putnam describe the layer-cake structure of science in terms of different types of objects, the mereological structure they use to support this picture is expressed in terms of tokens. Classical mereology provides a very general and content-neutral account of the part relation. It can be used equally well to express the sense in which

12 Elephant hearts are parts of elephants, and puffin hearts are parts of puffins, and hearts are parts of organisms. Yet puffin hearts are not at a lower part-whole level than elephants, and elephant hearts are not at a lower part-whole level than puffins.

13 I shall not enter here into the difficult question of how token properties, processes, and objects are individuated in the biological sciences. Consider the spatial memory system in a rat. If we take this to be one thing over the life of the organism, then it will be composed of many different sets of parts over the course of its existence, like the ship of Theseus. If we take it instead to be the spatial memory system involved in learning the layout of one particular maze, which learning might be constituted by multiple trials and extended investigation, then again we will have a single higher-level system composed differently at different time slices. If we focus on a given instant in time, then no learning can occur; learning is a kind of change. For now, I simply note (along with Bechtel & Mundale 1999) that the appropriate mapping between such parts and wholes presupposes a criterion of individuation for the whole, and what counts or does not count as a part will be determined by whether it contributes to that whole, however specified. This is related to Marcus' (2006) thought that any token identity between levels presupposes a (non-dummy) sortal that fixes the individuation conditions of the relata in the same way. Carl Gillett (2013) has called attention to the need for different accounts of compositional relations for properties, processes, and objects. Here, I am glossing over these differences to keep the discussion simple.

the word apple has the letter "a" as a part, in which courage has judgment as a part, and in which apple pie has cinnamon as a part. Common axioms associated with classical mereology, including the mereology adopted by Oppenheim and Putnam (Rescher & Oppenheim 1955), include:

> **1) Reflexivity:** Every object is a part of itself.
>
> **2) Transitivity:** Every part of a part of an object is part of the object.
>
> **3) Extensionality:** An object is completely determined by the set of its parts; i.e., for objects to be identical, it suffices that they have all and only the same parts.
>
> **4) Summation**: Any pair of objects (x, y), is itself an object, z, which is their sum.

I list these constraints only to illustrate that classical mereology will take us only so far in the effort to characterize part-whole levels. This is a formal theory, abstracted entirely from the concerns of practicing scientists. This means that there are constraints in the scientific conception of parts and wholes that classical mereology need not honor. First, the levels that Churchland and Wimsatt describe are space-, structure-, and time-involving in ways that classical mereology need not be. The set of integers is part of the set of real numbers, and "Consider the Lobster*"* is part of Wallace's corpus, but not in the same way that the glutamate receptor is part of the chemical synapse. The glutamate receptor takes up part of the space occupied by the synapse as a whole. Its opening is part of the extended process by which neurons communicate. None of this is expressed or intended to be expressed in the generic part-whole relation of classical mereology.[14]

Second, although reflexivity is involved in certain theoretical applications of mereology, it has no application in thinking about such space-involving levels. It does no justice to the biological concept to assert that every hippocampus is a part of itself. If levels are defined as a relationship between a part and a whole, and everything is a part of itself, then everything is at both higher and lower levels than itself. The parts surely must be proper parts.[15]

Third, it has been noted that the transitivity axiom often fails to apply to functional parts of the sort that populate physiological and biological theories (Varzi 2014). Eric is part of the championship pool team, and Eric's locks are part of Eric, but his locks are not part of the team. However, if one requires of a part (entity, property, or activity) that it must be *relevant* to the property or behavior of the whole, then one can retain the transitivity of this relation, at least in many contexts. *If we ask not about Eric, but about the motion of his arm as he wields his cue*, then his locks are clearly not relevant while the muscles gliding his arm steadily forward *are* relevant. So too are, in some sense, the molecules transmitted across the neuromuscular junction during his backstroke. When what counts as a part is filtered in each iteration by explanatory relevance relations (they are not mere spatial or temporal parts but working parts—parts that are involved in, contribute to, or make a difference to the property or activity of the whole), then the relationship is, in fact, transitive. The appearance of a failure of transitivity in functional systems trades, it seems, on failing to relativize the decomposition into parts by a highest-level target (explanandum) phenomenon; not all the spatiotemporal parts of an object or process are relevant to everything it does. It is only relative to a highest-level activity or property of the hierarchy under consideration that the lower level parts are visible as components—as working parts in the mechanism. *If we think not about the team, Eric, and his locks, but rather*

14 Marr's levels are not space-involving in this way. The algorithm is not located within the computation, it is not a substage of the computation, and it is not organized together with other parts in the service of the computation.

15 This is not a big departure from classical mereology; one could simply restrict one's attention to proper parts. But the point underscores the fact that classical mereology was not developed with an eye toward understanding the sense in which pyramidal cells are parts of the hippocampus.

about the victory, the shot, and the muscular contraction, matters seem different.[16] The contraction contributes to the shot, which contributes to the victory. The locks will not appear in this hierarchy, but the relevant parts will.[17]

The extensionality theorem holds that no two distinct objects share all and only their proper parts. A hippocampus and a bust of the Dalai Lama formed out of the same pyramidal cells, granule cells, etc. that compose the hippocampus are, according to classical mereology, one and the same object. But in biological systems, the organization of components is often (perhaps always) relevant to the properties and activities of the whole. Again, parts appear as parts only relative to a decomposition framed by reference to some highest-level property or activity. This is Kauffman's point, enshrined in Glennan's law: a mechanism is always a mechanism of a given phenomenon (Kauffman 1971; Glennan 1996). Thus Kauffman:

> A view of what the system is doing sets the explanandum and also supplies criteria by which to decide whether or not a proposed portion of the system with some of its causal consequences is to count as a part and process of the system. Specifically, a proposed part will count as a part of the system if it, together with some of its causal consequences, will fit together with the other proposed parts and processes to cause the system to behave as described. (1971, p. 260)

The more general point is that there is an application of the levels metaphor that is not merely a part-whole relationship as specified in classical mereology, but one in which the parts are relevant (explanatorily and constitutively) to some property or activity of the whole.

One can make a similar point with respect to the summation axiom. This theorem allows one to form arbitrarily many gerrymandered wholes out of disparate and unconnected parts with no spatial, temporal, causal, or functional unity. Lewis (1991) calls this "unrestricted composition": whenever there are some things, there is also a fusion of those things. The Yankees's starting rotation and the now disparate parts of my mother's old Chevy Vega together form a whole. This way of thinking about parts and wholes has little or no application in biology because such gerrymandered wholes don't do anything interesting (though such wholes will have aggregate properties of the sort discussed below). The whole in such gerrymandered collections typically doesn't play any explanatory role. And what goes for wholes goes for parts as well. According to this classical picture, it is perfectly legitimate to claim that my dog, Spike, has four parts: a front quarter, a hindquarter, and two midsections of approximately equal length. There is nothing to prevent this way of talking; but the parts revealed in this decomposition do not cut Spike at his joints. The biological decomposition finds joints at causal interfaces, and identifies parts with more or less isolable (nearly decomposable) subsystems (Simon 1962) that contribute to the behavior of the whole.

In short, many of the ideas central to classical mereology must be amended or restricted if they are to apply to the part-whole levels distinctive of biology, neuroscience, and the special sciences generally. At least some of the work can be done by restricting the part-whole relation by a *relevance condition* on biological parthood: all the lower-level properties, activities, and organizational features of the parts are relevant to—contribute to— the property or activity of the whole.

6.3 Levels of organization: Aggregates and mechanisms

So let us focus on an application of the levels metaphor that is a part-whole relation and a (constitutive) relevance relation. I will not dwell here on the appropriate notion of relevance (see Craver 2007, see also Harinen 2014). For now, we can work with the idea that each part in

16 Clearly Eric's muscles are not part of the team, but this reflects only the fact that teams can have only certain kinds of part as members. If we look rather at an activity of the whole and ask what contributes to that, a different picture emerges.

17 Specific details about lower-level parts might be screened off in cases of multiple realization. Specific details about the parts might not be relevant. In that case, it would appear one must appeal to more abstract properties of the parts.

such a hierarchy (in addition to being spatially and/or temporally contained within the whole) plays a necessary but insufficient role within a collection of parts that are jointly sufficient (but possibly redundant) for a given explanandum phenomenon (Couch 2011). That is, relevant parts might usefully be thought of as constitutive insufficient, but necessary part of an unnecessary but sufficient condition (I) for the behavior of the mechanism as a whole (Mackie 1973).[18]

Again following Wimsatt (1997), we can distinguish two ways that spatiotemporal parts contribute to a property or activity of a whole: *aggregation* and *organization*. An aggregate property is literally a sum of the properties or activities of the parts. The current flowing through an ion channel, for example, is a sum of the charges carried by individual ions. The concentration of a volume of a fluid is a sum of the number of particles in that unit volume. Aggregative properties change linearly with the addition and removal of parts. And aggregative properties do not change as the parts are intersubstituted with one another. Some properties of the hippocampus, such as its mass, remain the same when the cellular constituents of the hippocampus are reorganized to represent His Holiness. Other properties of the hippocampus, such as its information processing capacities, are destroyed. For truly aggregative properties, spatial, temporal, and causal organization among the components is irrelevant.

Aggregates are rare. The masses of the individual grains in a sand pile do, in fact, depend on the spatial distribution of the other grains (if one takes relativity seriously). What is presumed to be a homogeneous concentration of a liquid can in fact have local concentration differences depending on how the ions are organized in different parts of the fluid. In the case of non-aggregates, the activity or property of the whole is not a simple sum of the properties of the individuals. Adding or removing parts (e.g., the human heart) can lead to dramatic changes in how the system (e.g., the body) works. And rearranging the parts and their activities in space and time can eliminate the explanandum phenomenon entirely (as would happen if one randomly swapped parts of the circulatory system for one another). This is all true because spatial, temporal, and causal organization are relevant to (make a difference to, partly constitute) the property of the whole.

I use the term "mechanism" permissively to describe non-aggregative compositional systems in which the parts interact and collectively realize the behavior or property of the whole. Mechanisms are by definition more than the sums of their parts: they have properties their parts do not have, and they engage in activities that their parts cannot accomplish on their own.

Most mechanisms with which I am familiar involve myriad part-whole relations, some of which are more aggregative in nature, and some of which are less so. Many things brains do, for example, involve the flux of ions across a membrane, which flux is closer to the aggregative than the mechanistic end of the organizational spectrum. Other things brains do (such as the developing grid cells in the entorhinal cortex) require precisely organized relations among the activities of cells in and around the entorhinal cortex. This organizational spectrum from aggregate to mechanism covers all the relations that go into levels of organization, the superordinate class.[19]

In levels of mechanisms, the relata are some activity or property of a mechanism as a

18 Once we have made this adjustment, the relata in this relevance-mereology are no longer objects but rather properties, activities/processes, or (as is more common in philosophical parlance) events. One does not explain the elephant; one explains why the elephant has large ears or how the elephant circulates its blood. One does not explain gasses; one explains their temperature and pressure. This point marks a significant departure from the mereological views of levels discussed above. Each of those applications of the levels metaphor focuses on objects or types of objects (societies, organisms, cells, and so on) as the relata, not on their properties, activities, and aspects of their organization. In many cases, the components picked out in a mechanistic decomposition fail to correspond to paradigmatic objects with clear spatial boundaries. The synapse, for instance, is composed of part of a presynapatic cell (the axon terminal), part of a postsynaptic cell (the dendrite or bouton), and a gap between them. What unifies these items into an object is their organized behavior: the pre-synaptic cell releases transmitters that traverse the cleft and act on the postsynaptic cell. Synapses are not cells or parts of cells, nor are they composed of cells. Rather, they are objects unified by their relevance to a given actvity of the whole, such as chemical transmission.

19 Levy (2013) calls attention to the fact that biological systems typically involve both aggregation and organization.

whole,[20] and the activities, properties, or organizational features of its components (its relevant parts and organization). Some component, X's φ-ing, is at a lower mechanistic level than S's ψ-ing if and only if X's φ-ing is a component in S's ψ-ing, that is, if and only if X's φ-ing is a relevant spatiotemporal part of S's ψ-ing. In levels of mechanisms (as opposed to aggregates) lower-level components are organized together to make up some behavior or property of the whole; in aggregates, the properties of the parts are summed.

Levels of mechanisms are represented in Figure 4. At the top is the activity of some mechanism as a whole (S's ψ-ing). S's ψ-ing is a behaving mechanism. Although one can speak of the mechanism and its activity separately (as when a mechanism stands inactive but ready to act), such separation in thought is artificial. Even the static mechanism is defined and sub-divided by reference to what it does. ψ is the topping-off activity of the mechanism for which all lower-level components are relevant. It can be idealized as an input-ouput relation, though this is an impoverished way of understanding phenomena (see Craver 2007). One level down are the activities and components, the X's φ-ing, which compose and are organized together to constitute S's ψ-ing.[21] Below that is another iteration of levels: the ρ-ings of Ps organized such that one of the Xs φs as it does. By organization, I mean that the parts have spatial (e.g., location, size, shape, and motion), temporal (e.g., order, rate, and duration), and active (e.g., feedback or other motifs of organization; see Levy & Bechtel 2014) relations with one another by which they work together to do something they cannot do on their own. As noted above, the relationship between levels is a part-whole relationship filtered further by constitutive relevance (Craver 2005; Harinen forthcoming). In levels of mechanisms, parts are made into higher-level components by being organized spatially, temporally, and actively into something. In more aggregate compositional relationships, they are summed into higher levels.

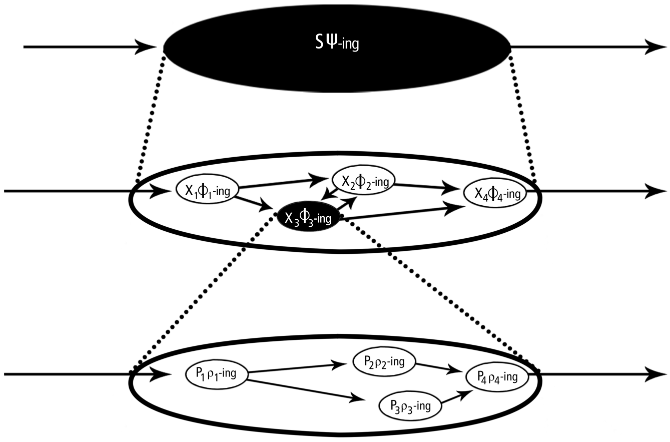

Figure 4: An abstract diagram of levels of mechanisms.

Contemporary theories of learning and memory provide a compelling example of levels of mechanisms (see Craver & Darden 2001; Craver 2002). The top level is a mechanism as a whole engaged in a spatial memory task, such as learning to run efficiently through a maze. One component in that mechanism, and so one level down in this description, is the hippocampus, a region of the brain thought to form a "map" of locations and orientations within the maze. The capacity of the hippocampus to acquire such an internal map of local spaces is thought to be explained, in part, by changes in synapses between pyramidal cells, specifically by a process known as Long-Term Potentiation (LTP). And it is now known that n-methyl d-aspartate (NMDA) receptors (n-methyl d-aspartate is a pharmacological agonist that binds these receptors preferentially), contribute to LTP. This story could continue downward, looking

20 These might be understood as the obtaining of a property or the unfolding of a process over time. What counts as a static property often depends on one's temporal resolution.

21 I have not always chosen my language in a way that comports with common usage among metaphysicians, preferring to follow Salmon (1984). In this paper, I have tried to make it clear that I am interested in components. Components, as the name suggests, compose behavior of the higher-level mechanism when organized together. All of the component entities and activities organized together, it now seems appropriate to say, jointly constitute the behavior of the whole. That is, I am now using componency to talk about relationships between wholes and parts, and I am using "constitution" to talk about levels of micro-realization. I am not especially interested in the relationship between statues and lumps of clay. I am interested in how parts are organized and interact so that together they exhibit higher-level behaviors. I know of no metaphysician who has developed an adequate notion to express this, so perhaps I will be forgiven for appropriating these words for new uses.

into aspects of protein chemistry and the structural changes thought to underlie channel functioning.

6.3.1 Levels of mechanisms are local

Levels of mechanisms are of entirely local significance. The levels in our example are defined by reference to a topping-off point, spatial memory, contribution to which determines whether or not a spatiotemporal part of the system is in fact relevant—whether it is a component in the mechanism *for S's* ψ*-ing*. The hierarchy in Figure 4 and the levels of spatial memory as I have described them follow only a single (local) strand of embedding: from the behavior of the mechanism as a whole, to the behaviors of its components, on to the behaviors of *one* of these components, and so on.

Levels of mechanisms, like part-whole levels generally, are not monolithic divisions in the furniture of the world. Levels of mechanisms are defined only within a given part-whole hierarchy. There are different levels of mechanisms in the spatial memory system, in the circulatory system, in the osmoregulatory system, and in the visual system; the levels in each need not map onto one another. How many levels there are, and which levels are included, must be determined on a case-by-case basis by discovering which sorts of components are explanatorily relevant for a given phenomenon. Levels of mechanisms cannot be read off a menu of levels in advance.

If we apply the levels metaphor only locally, then it makes no sense to ask whether the hippocampus is at a higher or lower level than the nephra in the kidney. The nephra are not part of the hippocampus, and they are not relevant to the functioning of the hippocampus. Neither similarities of size nor similarities in kinds of part are definitive of levels of mechanisms. Rather, levels of mechanisms are defined relative to one another within a hierarchically organized mechanism.

The idea that levels of mechanisms retain some hint of the layer-cake model can sneak its way back into one's application of the metaphor if one slides unknowingly between tokens and types of parts and wholes. Compare the following three sentences:

a) This pyramidal cell is at a lower level of mechanisms than this hippocampus.
b) Pyramidal cells are at a lower level of mechanisms than hippocampi.
c) Cells are at a lower level of mechanisms than organs.

Statement (a) expresses a mechanistic notion of levels: a particular pyramidal cell is a component of a particular hippocampal mechanism. This statement is true if the cell is a component in a mechanism for a given activity in which the hippocampus is engaged. It might be, for example, that a given pyramidal cell is a component in some hippocampal mechanisms but not others; if so, it is at a lower level to some hippocampal activities and not others.

Wimsatt describes the compositional relationship between levels as a relationship between types. He writes: “Intuitively, one thing is at a higher level than something else if things of the first type are composed of things of the second type” (Wimsatt 1976, p. 215). This is a departure from the idea of levels of mechanisms and one that threatens to reinstate something like the Oppenheim and Putnam hierarchy. Pyramidal cells are found outside the hippocampus, and those pyramidal cells are not parts in hippocampal mechanisms; they are not at a lower level of mechansitic organization. Likewise, both the hippocampus and the kidney are composed of cells; organs tend to be composed of cells. But the cells in the hippocampus are not at a lower mechanistic level than kidneys because they do not contribute to kidney function. The slide from sentences such as (a) to sentences such as (b) and (c) is a slide back toward the layer-cake model. Of course, scientists typically deal with types. But as I suggest above, this is a generalization over a relationship between tokens. The correct generalization is that the cells that compose hippocampuses are at a lower level than the hippocampuses they compose.

This is significant for two reasons. First, it helps to show that many objections to thinking about neuroscience and other special sciences in terms of levels simply do not apply to this restricted application of the metaphor. If one thinks, with Wimsatt, me, and probably Oppenheim and Putnam, that the Oppenheim and Putnam layer cake is an overly simplistic representation of the diverse ontological structures one finds in the special sciences—that things like occular dominance columns and synapses don't readily fit that picture—one can nonetheless retain the idea that mechanisms are susceptible to multiple nested decompositions. These are different applications of the levels metaphor. Secondly, and perhaps more importantly, the idea that levels are local significantly shifts the reductionist world-view for which Oppenheim and Putnam developed their ontology of levels. If one thinks of levels as levels of organization (as levels of mechanism and levels of aggregation), then it is inaccurate to think of reduction as involving relationships among theories developed to describe the items at a particular monolithic level. If reduction is simply a matter of explaining a higher-level phenomenon in terms of the organized activities of components, then reduction is still possible within a mechanistic world-picture, but it will be achieved not through grand reductions of overarching theories, but rather through piecemeal explanatory achievements for specific phenomena. Visions of the unity of science through interlevel reduction have to be revisioned not as grand unifications across the whole of science but rather as local explanatory successes. Such local explanations will, in fact, integrate findings from different sciences and bring different theoretical vocabularies into conversation with one another (see Craver 2005; Craver & Darden 2001), but it only deceptively resembles the layer cake that Oppenheim and Putnam sketched as a working hypothesis.[22]

22 Nothing in this picture is meant to deny token identity between the behavior of a mechanism as a whole and the organized behavior of its parts. Because there are some conceptual difficulties that stand in the way of speaking meaningfully about token identities between levels, I have written with fewer commitments about constitution.

6.3.2 Placement is weak and derivative in levels of mechanisms

One consequence of the mechanistic application of the levels metaphor is that there is no unique answer to the question of when two items are at the same mechanistic level. Only a partial answer is avialable: X's φ-ing and S's ψ-ing are at the same level of mechanisms only if X's φ-ing and S's ψ-ing are components in the same mechanism, X's φ-ing is not a component in S's ψ-ing, and S's ψ-ing is not a component in X's φ-ing.[23] Unlike size levels or levels defined in terms of the types of objects found at a given level, levels of mechanisms are defined fundamentally by the relations question: by the componency relationship between things at higher and lower levels. If two things are not related as part to whole, they are not at different levels, and so, if they are in the same mechanism, they are, in this very weak sense, at the same level. But this is just to say that sameness of level has no significance within this application of the metaphor.[24]

If one thinks of levels of organization as levels of aggregates and levels of mechanisms, then spatial containment and size relations between levels follow as an accidental consequence of the componency relation. The pyramidal cells are contained within the hippocampus, which is contained within the spatial memory system. The activities of these entities are also related as temporal part to whole: the binding of glutamate is a

23 This has struck some readers as circular because it appears to state that X and S are at the same level if they are not at different levels. Appearances to the contrary, this is not circular. I have defined "same level" in terms of the notion of "different level" and the latter is defined in terms of componency relations. The appearance of circularity, I believe, results from the fact that most people assume that the notion of "same level" must be primitive relative to the notion of "different level," and I have reversed that assumed order.

24 Another way to see that levels of mechanisms do not answer the placement question is to recognize an apparent failure of transitivity. Suppose X1 and X2 are components in the same mechanism, that neither is a component in the other, and that the behavior of X2 can be decomposed into a set of interacting components, including P1. X1 would, according to this account, be "at the same level" as both X2 and P1 even though X2 and P1 are at different levels from one another. This problem, first raised by Lindley Darden (personal communication), is only a problem if one demands that there must be a unique answer to the placement question for an account of mechanistic levels. My argument against the notion of monolithic levels turns on the absence of any good principle for stretching the ideal of levels beyond its local context.

temporal component in the activity of the NMDA receptor. The objects at lower levels are smaller than (or at least no larger than) the whole, giving the hierarchy a derivative size ordering. Relations of size, rather than defining what it is for an item to be at a level (the placement question), are derivative from the more fundamental relationship between levels (the relations question): namely, the relationship between a mechanism and a component.

6.3.3 Emergence and levels of mechanisms

Mechanisms do things that their components taken individually cannot. This marks a sharp distinction between levels of mechanisms and levels of realization. Kim says this point is "obvious but important":

> This table has a mass of ten kilograms, and this property, that of having a mass of ten kilograms, represents a well-defined set of causal powers. But no micro-constituent of this table, none of its proper parts, has this property or the causal powers it represents. H2O molecules have causal powers that no oxygen and hydrogen atoms have. A neural assembly consisting of many thousands of neurons will have properties whose causal powers go beyond the causal powers of the properties of its constituent neurons, or subassemblies, and human beings have causal powers that none of our individual organs have. Clearly then macroproperties can, and in general do, have their own causal powers, powers that go beyond the causal powers of their micro-constituents. (Kim 1998, p. 85)

Through aggregation or organization, wholes have causal powers that their parts individually do not have. An activity at a higher level of mechanistic organization is quite literally more than the sum of its parts. It is not an aggregate. The addition and removal of parts leads to nonlinear changes in the behavior of the mechanism as a whole. It matters how the parts are organized; it is in virtue of their organization that they have properties that go beyond the properties of the individual parts (Wimsatt 1996). This feature of levels of mechanisms is so obvious, so prosaic, and so banal as to be hardly worth mentioning. No fancy complexity is required: two toothpicks stacked perpendicular to one another have the mechanistically emergent capacity to act as a lever or catapult; neither toothpick can do so on its own.

Of course, most mechanisms in biology are substantially more complicated than that. They have many more parts. Those parts interact with one another with bewildering complexity. Often they contain feedback relations that introduce nonlinear interactions into the operation of the mechanism itself. The mechanisms of LTP, for example, have yet to yield their secrets completely despite the dedicated attention of thousands of researchers over forty-odd years. A glance at any recent textbook is enough to convince one that LTP involves myriad intracellular reactions, protein synthesis, structural features of dendritic spines, changes to vesicular release, and retrograde transmission with nitric oxide. The mechanism involves so many parts and interactions that it would be useless, if not impossible, to represent them all in a visual diagram. Keeping track of how they all work together would require a very complicated computational model of some sort that has yet to be developed. As mechanisms get this complicated, we reach the limits of our ability to predict how the behavior of the whole will change as the parts change. Any change introduced to a part has so many ramifications that it is difficult or impossible for creatures like us to keep track of them all. This is an interesting fact about us and the limits of our cognitive and modeling prowess. But, ontologically, it is the same old banal fact about the importance of organization in mechanisms. We have added only that we have difficulty keeping track of it all.

Likewise, a common scientific complaint against reductionistic research programs in biology and neuroscience is that one can make only limited progress by studying the parts of mechanisms in isolation from one another.[25]

25 This idea of reduction is not the standard notion of theory reduction but something closer to what Eric Kandel means

We can study LTP in cells grown in a culture, and we can study hippocampal computations in a razor-thin hippocampal slice, and we can study spatial learning in highly contrived environmental settings such as a large pool filled with milky water (the Morris water maze). Such reductionist practices are absolutely essential to progress in the sciences. Nonetheless, one engaged in such practices must (and typically does) bear in mind that the behavior of the part when it is isolated for experimental purposes might be very different from the behavior the part exhibits when it is working in the context of a mechanism. Causal interactions with other parts of the mechanism and background conditions "in the wild" might lead to behaviors that would never be discovered in such simplified preparations. This is an extremely important point about reductionist research programs (Bechtel & Richardson 1993), and one might choose to describe this well-known difficulty with the language of emergence. But this is just to say that one cannot truly understand how a mechanism works until one understands how all its parts are organized together and working in the relevant conditions, and this we have already said repeatedly.

I emphasize the banality of these observations to stress that many of the things one wants to say about organization in biological systems can be said within the mechanistic application of the levels metaphor without introducing anything that is metaphysically novel or suspect. As the complexity of a mechanism increases, the epistemic challenges we face in discovering and modeling it increase as well, but this is of no significance for the ontic structures—the entities, activities, and organizational features that exist in the world.

Not so for *spooky emergence*. Spooky emergence is spooky precisely because it is commited to the existence of higher-level properties that have no explanation in terms of the parts, activities, and organizational features of the system in the relevant conditions. Levels of mechanisms are levels of ontic mechanistic explanation (Craver 2014): they are defined in terms of componency and constitutive explanatory relevance. If that explanatory relationship is severed, then the sense in which emergent properties are at a "higher level" must be altogether different than the compositional notion of levels in levels of mechanisms. If one imagines that atoms compose molecules, which are organized into cells, which are linked into networks from which mental properties spookily emerge, the first three steps are upward steps in a hierarchy of levels of mechanisms, but the last is not. The ability of organization to elicit novel causal powers (that is, nonaggregative behaviors and properties) is unmysterious both in scientific common sense and common sense proper (Van Gulick 1993; Kim 1998). Appeal to strong or spooky emergence, on the other hand, justifiably arouses suspicion. Indeed, it is unclear why properties that emerge in a spooky fashion should be thought of as higher-level at all. Perhaps the very idea of spooky emergence is incoherent.

by the term: choosing to study complex phenomena in extremely simple systems. We might call this experimental reductionism.

6.3.4 Mechanistic levels are not causally related to one another

As with levels of realization, many common assumptions about the nature of causation would appear to make causal relations between mechanistic parts and the properties or behaviors of wholes suspect. Items at different levels of aggregation and at different levels of mechanisms are intimate with one another in much the same way that items at different levels of realization are intimate. Lewis is explicit. If C causes E:

> C and E must be distinct events [if they are to be causally related]—and distinct not only in the sense of nonidentity but also in the sense of nonoverlap and nonimplication. It won't do to say that my speaking this sentence causes my speaking this sentence; or that my speaking the whole of it causes my speaking the first half of it; or that my speaking causes my speaking it loudly, or vice versa. (Lewis 2000, p. 78)

The relevant kind of intimacy for levels of mechanisms is overlap between token events or processes. The relationship between LTP and the opening of NMDA receptors during LTP induction is directly analogous to the relationship between speaking the whole of a sentence and speaking its first half. The induction of LTP is partly constituted by the opening of the NMDA receptor. The would-be cause in this top-down causal claim already contains the would-be effect within it. There is nothing additional to be produced in the effect; the occurrence of the effect includes the occurrence of the cause.

What about the bottom-up case? We might say that the spark plugs cause the engine to run, all the while acknowledging that the sparking of spark plugs is part of the operation of the engine. The naturalness of this locution is at least partly due to an ambiguity in the way we commonly describe the behavior of a mechanism as a whole. Sometimes we describe it as an activity or process that starts with the mechanism's setup conditions and ends with its termination conditions (Machamer et al. 2000). Thus we might describe Long-Term Potentiation as a *process*[26] or activity beginning with a rapid and repeated stimulus (called a tetanus) to the presynaptic neuron and ending with enhanced transmission across the synapse. Other times we describe the behavior of the mechanism as a whole, the phenomenon, as the *product* of that process (or one of its termination conditions). Thus we might say that the mechanism of Long-Term Potentiation produces *a potentiated synapse*. This way of speaking leads us to think in terms of the antecedent causes of potentiation: the tetanus is a distal cause, and the subsequent changes in the NMDA receptor are more proximal. If we think about the behavior of the mechanism in the second way, as a product, it is natural to think of the opening of the NMDA receptor as a cause of the synapses being potentiated (and indeed it is). But if we think about the behavior of the mechanism in the first way, as an input-output relation starting with the tetanus and ending with a potentiated synapse, then it is wrong to think of the tetanus or the opening of the NMDA receptor as a cause of *that*. The NMDA receptor is a part of that causal process. These are two equally acceptable ways of describing the relationship between a mechanism and a phenomenon; they are easily translated into one another. However, if one is careless, these ways of speaking and writing invite equivocation of precisely the sort that we are struggling here to avoid.

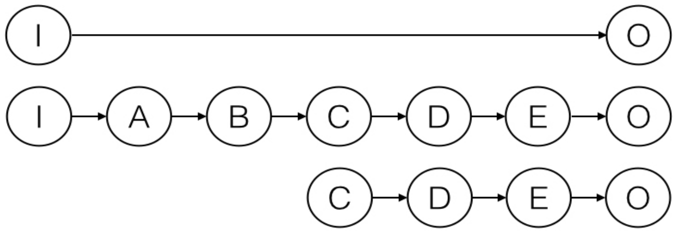

Figure 5: Why bottom-up causation is conceptually problematic.

Suppose we represent the input-output relationship constituting LTP as in the top of Figure 5, where I is a tetanus and O is a stable, potentiated synapse. Beneath this abstract I-O relation is a more detailed description of the intermediate stages in this mechanism: the tetanus excites the postsynaptic cell (A) which depolarizes it (B), causes NMDA receptors to open (C), and so on. (Nothing turns on the fact that I've idealized this mechanism as a single, step-wise causal chain.) Now, suppose we intervene to open the NMDA receptors directly and thereby potentiate the synapse (as shown in the third line). We might say that this intervention induced LTP; but when we say this, we mean that it produces the end product of the mechanism (it potentiates the synapse). We cannot coherently assert that it causes the process as depicted in the first two lines. This is for the simple reason that the process in the first two lines includes stages I, A, and B, and these are absent in the causal sequence represented in the third line. At most we can say the intervention caused the last half of the process. The NMDA receptor is not a cause of the process of LTP; it is a component of that process.[27]

26 Not in the Salmon (1984) sense, but in the colloquial sense of an unfolding sequence of states and activities.

27 This case is easiest to make for interventions that start the process midway. If an intervention, instead, were to augment C and thereby produce a more potentiated synapse than one would otherwise have had, then causal language would appear to be appropriate. The intervention changes, makes a difference to, the input-output relationship. These considerations generalize naturally to claims about types of

6.4 Levels of mechanisms in relation to other kinds of levels

This application of the levels metaphor, according to which levels of organization are understood in terms of levels of aggregation and levels of mechanisms, thus offers a no-nonsense, ontological picture that comports well with the kinds of explanatory structure one finds in neuroscience and throughout the special sciences generally.

This view eschews the idea that levels are monolithic strata in the structure of the universe, with proprietary causal laws and forces (contra the view in Wimsatt, Oppenheim, and Putnam). Likewise, it allows that items at higher levels have causal powers that things at lower levels do not, in contrast to levels of realization. Single sciences and theories might investigate phenomena at many levels of organization, and an item located at one level in such a compositional hierarchy might be studied by many sciences and described in many theories. Things at different levels of organization (aggregation and mechanism) do not causally interact with one another, though we might find more complicated ways of describing how these items depend upon one another (see Craver & Bechtel 2007). As a result, if we think about the world in terms of levels of organization, we should not be tempted into thinking that things at higher levels control or dominate things at lower levels. Levels of organization are, in a sense, levels of explanation, given that explanations for different topping off phenomena will often decompose the system into altogether different parts within parts. It might be difficult to discern such levels in scientific practice, and the organization of components might be very complex, but nothing emerges from levels of mechanisms except in the banal sense that parts organized together do things that the parts alone cannot. Levels of organization, in other words, seem to capture many of the intuitions that accompany the idea that the world is organized into levels but without many of the objectionable elements of other applications of the levels metaphor. The fact that the levels metaphor is often used carelessly and deployed in ways that violate common sense and metaphysical ideas about the structure of the world should not lead one to abandon the metaphor entirely. As we've seen, it can be given a relatively precise and metaphysically unobjectionable formulation that, in addition, fits the multilevel structures that the most advanced special sciences seem to be discovering.

mechanistic parts and wholes. Separately: When we describe this relation as a kind of production, levels show up as intermediate causes. Perhaps the temptation to speak of levels at all is lessened if one maintains that perspective. But this is not a change in what is being said so much as a change in how it is being said.

7 Conclusion

Despite the ubiquity of levels talk in contemporary science and philosophy, very little has been done to clarify the notion. Here I defend a kind of descriptive pluralism about the levels metaphor: it is applied usefully in many contexts to describe different relata, different relations, and different senses in which items might be located at a given level. Because the levels metaphor is so ubiquitous and so promiscuously applied, some vigilance is required to keep the applications distinct from one another. I have discussed only a few applications: levels of science, theory, realization, size, mereology, aggregation, and mechanism. Even in these few key examples, we have found good reason to remain vigilant. The implications of the levels metaphor in one application only occasionally transfer when the metaphor is applied differently.

I have also suggested that levels of mechanisms (or, more generally, levels of organization) are especially important to the explanatory structure of neuroscience and the special sciences generally. If one thinks of levels in this way, one can easily see why interlevel causation should seem so problematic (indeed, it is problematic), one is free to jettison Oppenheim and Putnam's idea of monolithic levels of nature, and one can see room in the causal structure of the world for the existence and legitimacy of higher-level causes and explanations. Whether the idea of levels of mechanisms truly pays off in such useful ways remains to be seen. I merely hope to have preserved the metaphor, and its application to mechanisms, in the face of problems it inherits only through equivocation.

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