1 Levels, Robustness, Emergence, and Heterogeneous Dynamics: Finding Partial Organization in Causal Thickets

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Overview

In this chapter, I review the philosophical and scientific contexts the led me to argue for the importance of levels of organization (and other real causal structures in nature—perspectives and causal thickets) and their implications for other exploratory, manipulative, and explanatory practices. I then propose a systematic account of nineteen different characteristics of levels, divided into three groups relating to dynamics, robustness, and evolutionary elaboration of levels. From this emerge new discussions of emergence, level leakage and manipulation, and relations between levels and perspectives, and with multiscale modeling. I will briefly explore other approaches to levels to indicate how they differ. This analysis articulates particularly closely with the chapters of Batterman, DiFrisco, Griesemer, Love, and Woodward, as well as resonates with the complementary accounts of Brooks and Eronen, and Green, emphasizing the heuristic role of invoking levels in scientific activities and Baedke's discussions of temporal change in levels through development and evolution.

1.1 History and Orientation

The discussion of levels of organization that I initiated in Wimsatt (1976a) was originally intended to characterize realist claims about the organization of nature, following those made by some physicists, biologists, and social scientists, who persisted in taking upper levels of organization—their objects, regularities, processes, and phenomena—seriously in a context dominated by eliminative reductionist philosophers and "nothing-but" reductionist scientists, allied only in their suspicion of macroscopic theory and objects. For the latter scientists, talk about ontology was always a search for the bottom-most stable objects and their interactions out of which everything else was built (although they seemed unable to agree on what these were—for neurophysiologists, neurons; for geneticists, genes; for chemists, atoms; etc.). The former eliminativist philosophers were suspicious of any posited upper-level things, motivated by examples of earlier falsified theories whose posited entities turned out not to exist. Both groups assumed that a future complete and correct apocalyptic science would express all in terms of the ultimate lowest-level entities of an all-encompassing physics, one that would successfully "cash in" all of the "in principle" claims made to date. This foundationalist attitude seemed inappropriate to most of the science I knew (Wimsatt, 1976b, 2007).

In addition, philosophers, secure in the belief that we could access nature only through linguistic concepts, persisted in talking about levels of theory, predicates, and law statements as if vocabulary could substitute for natural objects, relations, and phenomena entirely. This seemed truly strange! Philosophers may talk about vocabulary, but scientists did not. I was convinced that there was a way through the veil of language using robustness. Although any single means of access might be instrument, concept, and (for cultural objects) even language dependent, *the convergence of multiple at least partially independent lines of access or detection seemed capable of penetrating gaps in the linguistic armor of our concepts with real objects simply being the consilient coincidence of multiple properties within boundaries that are stable over the appropriate time scale* (Wimsatt, 1974, 1980). Robustness, used as a criterion for what is real, also proved to be a way to reverse the rush to eliminative reductionism, to recognize higher-level objects interacting with an autonomous dynamics, and to embrace multiple realizability and a form of emergence consistent with reductionism.[1]

But levels don't capture everything. Biology[2] is also characterized by multiple complementary systematic partial perspectives on systems not ordered by level, like anatomy, physiology, and genetics (Wimsatt, 1974). These and the background and sometimes foreground anarchy of causal thickets (Wimsatt, 1976a, 1994, 2007; Griesemer, this volume) together affect our practices of explanation and other related activities in all of the compositional sciences. (Figure 2 of 1976a and 1994 depicts a kind of phylogenetic ontology exploring the articulations of these different kinds of causal structures.) These have intertwined ontological, epistemological, and heuristic import richly clarified by Griesemer's penetrating analysis in this volume.

It is hard now to remember the schizophrenic context in which "responsible reductionists" embraced a desert ontology from which everything else was *in principle* derivable, while at the same time employing their theoretical and experimental procedures on molar processes and objects. This sort of ontological "nothing-but-ism," combined so happily with a pragmatic molar realism, seemed to me to be bizarre. It clearly also concerned Herbert Simon in 1962 in his classic paper, "The Architecture of Complexity." This awareness led in 1972[3] to my paper, "Complexity and Organization" which began with Simon's puzzle of how an *in principle* reductionist should conduct themselves as a pragmatic holist.

I had strong realist sympathies (only exacerbated by my work as an engineer, fascination with technology, and the creative use of approximations), extending to a menagerie of complex forces, processes, and objects, including chromosomal mechanics, hormonal regulatory systems, groups, social organizations, institutions, and much more as units,[4] as well as biological and cultural selection and social cohesion and the like, not as "theoretical constructs" but as real molar forces. I argued for what I later called the "ontology of the tropical rainforest" against the adequacy of a "desert ontology." Quine's ontological desert, a philosophical chimera first explored by Russell, was populated by entities whose explanatory power was after all only said to be usable *in principle*[5] (a dead giveaway that they couldn't deliver anything *in practice*), and I wanted to understand the effectiveness of the tools we actually used. I wanted room for the importance of heuristic and approximate methods, and scientific processes of discovery (stimulated by Simon's work on problem solving with computers[6]) rather than the reconstruction and justification of the static formal icons of finished theory characteristic of positivism.

1.2 Levels

I also felt that composition alone did not exhaust the notion of a level, so I sought other handles to capture their riches. I found multiple others, and one was particularly forceful to me. This was Plato's observation about the desirability of "carving Nature at its Joints" (Plato, *Phaedrus* 265e). And levels seemed to me to be at least major vertebrae in the body of nature. But how to capture this intuition in modern terms and to mine and relate it to the resources of other characterizations? (Unlike Potochnik, 2017, I saw these characterizations as complementary, rather than competing, sources of confusion.) Inspired by statistical mechanics (where I had learned about the concept of a phase space[7]) and by the notion of a fitness topography from population genetics, I speculated that perhaps one could imagine levels as local maxima of regularity and predictability in a phase space of all of the alternative modes of organization of matter. (This ambitious characterization in search of grounding also seemed for its scope to be dangerously metaphorical and metaphysical.) Attempts to characterize it further led to my imprecise but suggestive diagram of levels and a diagrammatic attempt at a phylogenetic ontology of alternative states of matter in figures 1 and 2 of Wimsatt (1976a). Turning from this characterization to the many heterogeneous and productive ways of characterizing levels led to the relatively disordered form of my analysis in both 1976a and 1994, as a list of properties of levels interspersed with articulating comments. I did not expect or find an analysis in terms of necessary and sufficient conditions. Here I will attempt a more systematic account to relate them.

Many relate to the ordering relationships that Bob Batterman has addressed in his discussions of multiscale modeling. Batterman's work and that of Sara Green (Green & Batterman, 2017) and Mark Wilson (2016) provide a grounding for much of my discussion of levels of organization in physical relationships that are important and of wide applicability to systems studied in different disciplines.

I place the characterizations of levels into three groups. The first emerges from considering the energetics of interactions among elements of a system and yields a perspective I attribute to Herbert Simon. These provide suggestive connections between Batterman's account and mine. The second emerges from noting that objects are paradigmatically robust, with levels as products of clustered interactions among robust objects yielding a systematic domain in which the entities and processes at levels provide relatively economical explanations of a wide variety of phenomena. This is what makes levels primary "joints" in the body of nature. This also connects with Batterman's approach (see Batterman, 2017), through his concern with dynamical autonomy at the molar level. The third group of characterizations arises from an ampliative and speculative exploration of how levels, as characterized according to these first two sets of indicators, could over evolutionary time grow in extent (in kinds of objects at that level) and complexity, in their interactions with other entities at the same level, and increasingly, at other levels, through "level leakage" and selection-driven accretion. (See also Baedke's important characterizations of the evolution and development of levels on phylogenetic and ontogenetic time scales.)

1.3 Levels and Strength of Interaction

So what do we use to identify and to argue for the existence of levels? Composition, size, dynamics, robustness, a kind of completeness, and a kind of decomposability all figure into it. First, the energetic characterization:

1. Composition: clearly levels are compositional,[8] but this is not sufficient. Why are some collections of objects levels and other not? Why cannot we pick any contiguous set of objects and declare it a level?[9]

2. Processes at the same level commonly have comparable relaxation times.

3. Processes at the same level commonly have roughly the same size scale.

4. Processes organize by energy level of interactions, which tend to cluster by size scale.

5. From 1 to 4, we get the possibility of a hierarchical near-decomposability account,[10] yielding levels, and

6. Level-specific dynamics, each with its own range of roughly comparable relaxation times,[11] and from that,

7. A simple form of multiple realizability (of the stable higher-level weak interactions over the variable lower-level strong interactions) once they go to equilibrium.

Energy level, and the physical clustering of interactions by energy level, is apparently Herbert Simon's primary criterion (Simon, 1962), and he argues that energy level commonly corresponds roughly to relaxation times (time to equilibrium) and to size scale. Composition is presupposed, so for him, items 1 to 4 go together, and indeed, textual comments imply that he thinks that compositional ordering would be determined by relative energy levels. Since near-decomposability relates to relative strengths of interaction, when a system is nearly decomposable (often through multiple levels of strength of interaction), one also gets decomposition of a system into hierarchically characterized parts, each with a level-specific dynamics, so the first seven characteristics go together. This could even fit the mechanism-levels account in some cases, although Griesemer's account (in this volume) shows that Simon needs scaffolding as well. Bechtel and Richardson claim a strong debt to Simon in the introduction to their classic and important work (Bechtel and Richardson, 1993, 2010) in their accounts of mechanism (see also Wimsatt, 2018, on the "Chicago Mechanists"). So Simon's is an extremely powerful and rich multifaceted account of level leveraged ultimately in terms of energy levels. If I had to backslide to a more conservative position, I would favor something like this, but even it is inadequate to the richness we find in the dynamics and ontologies of biological and sociotechnological cultural systems, and its power depends too much on *in principle* promissory notes when applied to such systems. Systems also may simply fail to be nearly decomposable because their interaction strengths overlap too much and do not cluster, so no levels, and we are most probably faced with a causal thicket.[12] When the dynamical separation fails, levels are (correctly) shown to be nonuniversal. If the power of general physical principles is to be extended further, I would expect insight from the kinds of multiscale modeling emerging from condensed-matter physics (see Batterman, 2017, this volume).

1.4 Levels and Robustness

I turn now to criteria for levels relating to inferential and dynamical robustness (Wimsatt, 1981). Inferential robustness is the detectability, measurability, or derivability of an object or property by multiple independent and individually fallible means. Although individually fallible, the fact that their modes of failure are independent of each other means that their collective probability of failure declines exponentially with increasing numbers of fallible links. They are also keying into different properties of the detected object, thus getting a richer characterization of the causal network involving its properties and their detectors. The kind of cross-checking provides both knowledge about the object (it is the kind of entity that can be detected by these diverse procedures) and also about the procedures. (They commonly don't produce exactly the same results, but these differences, as reflections of the same entity, tell us more about how the procedures interact with the entity.) This yields a lovely bootstrapping of knowledge both about the object under study and about the means for studying it that circumvents the classical argument from illusion for the unreality of sensory information.

Robustness is primarily applied to objects—a criterion from the trenches, one used by scientists as a working criterion for trustworthiness, but also serves for the reality of a process or property. It is a worthy successor to the philosopher's fruitless search for certainty. (See also Eronen, 2015, for an extended defense of the connection between robustness and reality.) This is clearly related to (but not identical with) the idea of physical robustness or stability or invariance of a physical property across differences in state description (see Batterman, 2003;[13] Wagner, 2005; Wimsatt, 1981; Woodward, 2003). An object will be inferentially robust because it is central to our concept of an object that it has many properties and thus that there are multiple ways of detecting it. This is richly imbedded in scientific practice. But the multiple ways of detecting something are also multiple ways of interacting with it. Most of these will involve other objects at the same level because we would also locate at that level other things with commensurate dynamics. And this has more implications that I flesh out below.

8. The idea of cutting nature at its joints suggests that cutting it at other places will be less successful in finding ordered patterns and objects to be used to construct theory. Thus, the metaphor of different theories as having sieves of different sizes (and properties) that yielded objects and their causal relations with different degrees of predictive power and simplicity—thus levels as local maxima of regularity and predictability in a phase space of all alternative modes of organization of matter.

9. Thus, levels on this account ought to be where we can construct theories that are both powerful and simple—where we get this biggest bang for the smallest buck.[14]

10. A robust object is an indicator of a level through the richness of its connections with other objects.

11. Since levels are composed of robust objects that are rich in relations with one another, levels are themselves a peculiar sort of robust object.

12. Levels suggest a kind of order in the causal thicket: a scope of same-level causality and a kind of local explanatory and descriptive completeness—everything detectible at that size scale ought to be characterizable at that scale.

13. Given that we have multiple realizability (from 7, but also from the stability of upper-level objects and relations and compositionality with smaller parts), yielding a more robust multiple realizability, a level-specific dynamics ought to be quasi-autonomous.[15]

1.5 The Evolution of Levels

In "The Architecture of Complexity,"[16] Herbert Simon suggested a mode of evolution of complex systems through the "aggregation of stable subassemblies." He used this to argue against a view that selection processes did not have time to generate the complex systems that we see. With this mode of composition, he suggested, we could get exponential increases in complexity in linear time.[17] He also imagined that we would in effect get a new level of organization with each aggregation operation. We could imagine this process in the engineering of complex technologies, and it would fit well the Bechtel or Craver accounts of levels. It also suggests some cases of biological evolution, such as the evolution of eukaryotes (if we ignore the massive coevolution of their components), of metazoa (as "aggregates of cells"—ignoring development), or evolution of sociality (as "aggregates of people"). But these claims fail where there is a significant developmental or a scaffolding process mediating growth in complexity.[18] This includes individual ontogeny, where complexification involves morphological change and differentiation. (Thus, even the evolution of metazoa as "aggregates of cells" fails as an example, and characterizing sociality in this way leads too easily to a simplistic and incorrect methodological individualism.) But cases not simply characterizable as "aggregation of stable subassemblies" also include processes like those discussed below, which could act to facilitate the articulation of stable subsystems to form Simon's next level up.

In 1994, I went further in a speculative mode to look to the evolution of levels. These approaches, which I propose to call "Levinsian," all presuppose levels as characterized in terms of the above list of properties:

14. Richard Levins (1968) suggests that organisms evolve under selection to minimize the uncertainty in their environments. Thus, for example, an organism should evolve sufficient reserve food and water storage to reliably reach the next resource site, and changes in the size and distribution of resources should drive changes in the capabilities of organisms.

15. Because of their regularities, levels are attractors for such systems that key into and use their patterns, often at multiple levels simultaneously, so the populations of entities at a given level should evolve over time.

16. Differential selection processes should tend to expand the scope of dynamical autonomy—increasing the range of multiple realizability and of robustness—still further in cases where a macro-level property contributes positively to fitness (Wagner, 2005; Wimsatt, 1994, p. 253).

17. Thus, levels should themselves evolve over time, through accretion, elaboration, and coevolution of their component parts. This has broader consequences:

18. As the objects at a level increase in size and complexity, their increased number of degrees of freedom should lead more commonly to "level leakage," in which they interact with objects or processes at other levels.

19. For this reason, higher levels should become increasingly less well defined, and what patterning occurs might increasingly often fit perspectives or causal thickets.[19] Levels might thus be less relevant, well defined, or a thinner (more limited) cut on the phenomena for some scientists and sciences than others—for example, ecology, psychology, or social sciences, especially the intersecting varieties of cultural evolution—and suggests the need for more relevant perspectives for a fuller account.

This evolution of levels (or of the causal thickets from which they emerge) could involve the generation of new forms of regular patterns, what I call perspectives, and in some cases new higher levels. This has happened in biological evolution (for the emergence of multicellularity and at the ecosystem level), especially at the levels of human social and technological evolution with greatly expanded powers and modes of construction, manipulation, and communication (Arthur, 2009; Wimsatt, 2013b, 2019; Wimsatt & Griesemer, 2007). This requires enough complexity—sufficient degrees of freedom—to allow not only new order-finding interactions but also new levels. Nuclear physics (beginning with the discovery of X-rays) was a level detected initially by level leakage.[20] Or in new technology, consider the systematic conjoint exploitation of semiconductor devices and photolithography to produce a hierarchically expanding range of complex devices beginning with integrated circuits of different types (perhaps a perspective, within which there are levels?).[21] One could imagine in the future the emergence of a new constructional technology driven by the systematic use of CRISPR technology (CRISPR DNA sequences from procaryotic genomes allow manipulation of genomes of all kinds with heretofore unprecedented precision). These also promise the potential for more frequent intersection with causal thickets.

1.6 One Type of Emergence, or Two?

Use of robustness as a criterion for the reality of objects (Wimsatt, 2007, chap. 4) gives us not only stones, organisms, and cathedrals. These objects are related, dynamically and compositionally, to others. With assembly, some properties may show no particular qualitative changes (as a cathedral is composed of arranged quarried and shaped stones, whose total mass is nonetheless preserved), but new properties may emerge, as when stones are arranged into an arch, permitting a loadbearing opening in a wall, and changing the stability of their arrangement and how it interacts with other parts of the cathedral and with the people who use it.

One form of emergence arises when a system property depends upon the organization of the parts (Wimsatt, 2007, chap. 12). Given the open-ended multiplicity of forms of organization, characterizing it seems an impossible task, so I turned the task around and asked what was required for a system property to be *nothing more than* a sum or aggregate of parts properties, as, for example, for mass, energy, and charge. I found four conditions for aggregativity that could be met (or violated) independently, thus giving a total of $2^4 = 16$ possible combinations.[22] Aggregativity results if all conditions are met.[23] But fifteen different ways in which the combination of conditions may fail to be met yield kinds of organization-dependent emergent properties. Diverse combinations illustrate how different properties such as critical mass (for U-235 or other fissionable materials), genetic epistasis, and being an oscillator (for a series-connected resistor, capacitor, inductance, and voltage source) were emergent properties. In each case, realization of the property is dependent upon the arrangement of the parts and their modes of interaction (relative to each other and to other parts, either as possible substitutes or as external to the system but affecting its behavior). Thus, whether a chunk of U-235 is a critical mass depends upon its arrangement (in a sphere or in a long linearly extended wire), its compression (so a shaped charge surrounding it is used for detonation in some nuclear bombs), and the presence of neutron absorbers in its environment (so neutron-absorbing control rods regulate reaction rates in some power reactors). Many different examples are found in Wimsatt (2007, pp. 278–279, table 12.1).

But Bob Batterman has convinced me that I must deal with a second concept of emergence that arises not when a system property is highly dependent upon the organization of its parts but just the reverse—when it is robust, invariant, or insensitive to the arrangement of parts (but where it seems nonetheless misleading to describe it as just an aggregate of parts' properties). The difference is quite striking—are these approaches polar opposites? The concept I have elaborated as non-aggregativity is particularly appropriate to machines and mechanisms where the system property arises through the structured interaction of a number of differentiated parts. But there is obviously more in the emergence tent, so I return to robustness.

The four criteria for aggregativity lead heuristically to what I call the "Waring Blender" criterion for emergence: take the system, and disrupt it in a Waring Blender. The emergent properties are the ones that disappear.[24] In effect, just such a criterion is used by those in biology who prepare their specimens with an ultracentrifuge. You can tell the scientific specialty by the rotation speed! For biological specimens, lower speeds (lower Gs) yield whole cells, and higher speeds produce objects at lower levels, cellular fragments that allow studying cellular ultrastructure. I return to this criterion later.

But emergence is also striking for generic properties and multiple realizability. Systematicity of behavior that remains invariant or nearly so at the macro-level under widespread changes at the micro-level is what I have elsewhere called "dynamical autonomy" (Wimsatt, 1976a, 2007). Robustness can arise for multiple reasons and, in biology, is a frequent product of selection (e.g., Wagner, 2005). In fact, widespread robustness of phenotypic properties across changes in genetic constitution in sexual species is a necessary condition for heritability—and thus is a requirement for evolution even to be possible (Wimsatt, 2007, pp. 218–219).

In a more familiar classical case, we have molecular gases governed at a microscale by collisions and exchange of momentum, but also, on a macroscale, they are the continuous incompressible fluids of hydro- and aerodynamics manifesting properties like pressure, viscosity, and laminar versus turbulent flow that seem qualitatively different from anything found at the microscale. And so also with the multiple different emergent properties of solids and their crystals, alloys, and mixtures that arise from structures at meso-levels between the micro- and the macro-level.

I accept Batterman's claim that this is what is often meant by scientists who talk about emergence. Their notion applies to macroscopically homogeneous bulk matter, whose macro-properties remain robust, stable, or invariant under almost all changes at more micro-levels. But at one (or more) intermediate mesoscales, such bulk matter *has* structure reflected in the contents of a "representative volume element" or RVE on a given intermediate size scale far above that of the micro-level and far below that of the macro-level.

For a metal, this might be characterized in terms of local misalignments in the crystal structure, yielding fractures or empty volumes and also inclusions of other elements. The RVE is a statistical concept reflecting the occurrence and distribution of other structural elements on an intermediate size scale, with properties that can be related both upward and downward to explain the upper-level emergent properties. These intermediate properties are commonly invariant over changes at the microstructural level and can be characterized in terms of one or more correlation lengths for the distribution of different kinds of matter at their level. See Batterman (2002, 2017, this volume) for more exposition of these ideas.

So the concept of emergence as non-aggregativity depends upon a highly specific arrangement of the parts of the system to generate the emergent property or behavior, while Batterman's concept applies to emergent properties or behaviors that are highly robust and multiply realizable over micro-level rearrangements of its parts. But despite their enormous difference, these two notions have a deeper connection: both disappear with application of the transformation of the "Waring Blender" criterion, although in different kinds of ways. Indeed, does not the emergence of different kinds of order—of whole cells at the higher level and of cellular ultrastructure at the lower level—just in effect generate different RVEs through the application of different energy levels to disrupt biological materials? And would not the application of higher energies (in an imagined ultra-ultracentrifuge) yield macromolecules, small molecules, atoms, and ions? Are the higher energy accelerators of particle physics simply an extension of the Waring Blender criterion? So Batterman's emergence involves a statistically characterized failure of homogeneity assumptions at intermediate levels and thus seems to be a special kind of case of emergence as non-aggregativity in my sense.[25]

It is special in that in order to develop appropriate theory to characterize it, the kinds of deviation from homogeneity on all scales (the continuum) are best described in terms of correlation lengths rather than the four dimensions of aggregativity. But both appear to be covered by the Waring Blender criterion, which interestingly, has a deep connection with the energy required for disrupting the order. Perhaps neither the four dimensions of aggregativity nor the formulation in terms of correlation lengths are exclusive fundamental characterizations of emergence but formulations adapted to different specific ways of characterizing order and raises the question whether there might be other formulations particularly suited to other kinds of order, such as fractals or turbulence.[26]

1.7 Levels as Explanatory Attractors: The Level Relativity of Explanations

I start with a quote from Wimsatt (2007, pp. 214–216) that describes Brownian motion (hereafter BM) in terms of the characteristics of relevant entities at lower and upper bounding levels. It is intriguing because no ontology is reified at the same (BM) level, but explanations are done in terms of entities and processes at lower and upper levels. Levels in this case are attractors of explanations, because of the higher robustness of entities and processes there. Perspectives also show a similar feature and for similar reasons.

There is a general level-centered orientation of explanations that can be explained in terms of the greater stability and robustness of entities at levels of organization, and probably more globally, in terms of the consequent robustness of levels themselves. This is a general and important meta-principle for the organization of explanations that is usually taken for granted and seldom commented on. It facilitates explanatory clarity, but occasionally misfires.[27] The robustness of levels tends to make them stable reference points that are relatively invariant across different perspectives and therefore natural points at which to anchor explanations of other things. *Explanations of the behavior of between-level entities tend to be referred upwards or downwards in level, or both—rather than being pursued in terms of other between-level things. Even the fine tuning of the exact "altitude" of the between level entity—its size and thus the distance it is above the lower and the distance it is below the upper levels—is motivated by concerns originating at one or the other of the levels.* The robustness of levels makes the level-relativity of explanations a special case of the phenomenon referred to in the preceding section-the explanation of that which is not robust in terms of that which is robust. I will consider the case of Brownian motion as a between-level phenomenon, which, by its very nature requires very special relations to the level below and the level above. (For a more technical exposition of some of the details, see Jeans, 1940 [and Batterman 2017].)…

[A] revealing indicator that Brownian motion particles are between levels is that they are given no intrinsic characterizations—as is indicated by the fact that things as diverse as dust motes and bacteria can all be Brownian motion particles. *Between-level entities tend to be defined functionally [as we must for their mass and surface area to be detectable] rather than in terms of their intrinsic properties—it is almost as if they have no intrinsic properties to use in such a definition.* If so, this suggests the paradoxical conclusion that we may recognize the intrinsic properties of things, at least in part, due to characteristic interactions they have with other same-level things, since only levels have the intensity of different kinds of interactions among entities to fix unique sets of intrinsic properties as being causally relevant. Multiple realizability in between-level contexts washes out the causal salience of most specific [lower-level] intrinsic properties.

This discussion of Brownian motion provides a starting place for assessing the strengths and limitations of using levels as a heuristic approach to problems where it does not fit exactly. This must start with a characterization of situations where an ideal characterization of levels as complete and isolated from other levels does not apply, for the failure of this isolation is the realistic general case.

1.8 Level Leakage

We must consider how *levels can leak interactions or effects* to other levels,[28] in ways that can facilitate our understanding of their relationship (Wimsatt, 2007, chap. 10).

Many gateway phenomena or experiments, like Brownian motion, have the form of finding level leakage and exploring ways to exploit it to manipulate lower-level variables, which can give far-reaching control of processes and entities at the other level. This is endemic in the biological sciences and in technology as well. Indeed, the richness of interactions in both of these areas makes it seem likely that level leakage is far more common in such cases and pushes them in the direction of causal thickets.[29]

In the Hewlett-Packard HP-41C programmable calculator, released in 1979, an error in early software allowed manipulation and movement of the supposedly fixed boundaries (the "curtain") between registers that were supposed to be visible and under user control and those that were not. Through this error, ingenious hackers were able to reach through the operating level to the machine language level of the system. They rapidly developed a language using "synthetic instructions" that they called "synthetic programming," which allowed new and powerful ways to manipulate the calculator by doing new things in newly accessible registers giving new control functions. These sped up many operations and allowed entirely new kinds of others, such as the manipulation of individual pixels in a display that normally permitted only whole alphanumeric characters. But this came with a danger of new and dangerous kinds of system crashes. The HP-41 users club produced a custom PPC ROM and a 500-page manual that allowed use of, and systematically documented, these capabilities, as well as other applications created using it.[30] Indeed, this story seems generalizable and important to the emergence of many new technologies and scientific fields.

1.9 Other Accounts of Levels

Perhaps one should argue, as Potochnik does, that we should just recognize that there are multiple distinct concepts of level that we fail to distinguish at our peril. To some extent, this is true. Thus, "levels of abstraction" is an entirely separate concept relating to the detail of a description. And David Marr's influential notion of levels are more like my perspectives (McClamrock, 1991. Levels of functional organization are plausibly assimilated to mechanistic levels, as characterized by Bechtel and Craver, which makes their account more broadly important. For them, the parts of a system entering in causal role explanations of system behavior are lower level to the system behaviors that they explain. A graph-theoretic account of functional organization in my dissertation (Wimsatt, 1971) and published much later (Wimsatt, 2002) would add some formal structure to that account, although unlike Cummins's account of function, I consider (Wimsatt, 2013a) the role of selection to be crucial. (A powerful critique of psychology's attempts to do without selection is Chiramuuta, 2018.)

But how are parts determined? Physical forces should tend to aggregate natural objects into sizes determined by their strengths and that of aggregating forces (like gravity, electrostatic attraction, and surface tension). For engineered objects, which invariably require substantial scaffolding in their production, it seems more that we see the *limits* in their sizes as determined by physical forces. Mechanisms may use heterogeneous materials and, for metals, special alloys, with properties appropriate to their roles. In the case of machinery (with transmitted forces and velocities determined by contact), shape and anchor points for motion are of crucial import. But mechanisms would include also electrical, electronic, and chemical interactions, in an open-ended manner, and I cannot see a systematic but general way to analyze how the diverse physical forces play a role in addressing their behavior.

A major difference between engineered objects and biological ones is that for engineered objects, the parts are constructed separately, with all of the scaffolding necessary for their individual creation, and then appropriately assembled, requiring significant additional scaffolding. Biological development requires coordinated scaffolding and generation operations that are for the most part self-directed as long as appropriate resources are provided. Griesemer's (this volume) account of scaffolding in managing causal thickets is of central importance here. Batterman's discussion of the role of multiscale modeling in "inactive matter" and "active matter" is also a very promising and complementary beginning. When targeting a complex system, some aspects of that organization will fit levels well, some perspectives, and some undisciplined causal thickets. Even when there are diverse differentiated parts involved in a complex mechanism, some aspects of its behavior should yield to the kind of analysis by Needleman and Dogic (2017) for mitotic spindle formation and cytoskeletal fiber networks and described by Batterman (this volume) as an example of multiscale modeling in active materials. Newman (2013) has systematically championed the role of generic forces in formation of biological structures. Evolution is nothing if not opportunistic, so we would expect selection to use order produced by generic forces wherever possible for increased robustness. However, the heterogeneity of biological structures and processes acting on different time scales suggests that multiple different RVEs ("representative volume elements") may be required to deal even with different aspects of a complex process at the same scale. In this way, we slice perspectives out of causal thickets in order to rearticulate them in search of an explanation.

1.10 Perspectives

The idea of a perspective is introduced in Wimsatt (1974), further discussed in Wimsatt (1976a), and probably most fully in Wimsatt (1994; see 2007, pp. 227–242). A new perspective emerges when a kind or small number of kinds of descriptive terms or causal interactions allow a systematic treatment of a class of behaviors of the system in relative isolation from other aspects of the system. Thus, anatomy, physiology, genetics, and network analysis define perspectives on the system and its behavior that are capable of explaining a class of behaviors of the system. Then the tools for accessing these interactions within a perspective will constitute a methodology, and the resulting behaviors define a kind of worldview or perspective on the system or, less metaphorically, a descriptive causal and explanatory niche for or cross section on the system. Rational decision theory, but also a more realistic heuristic and biases-laden behavioral decision theory, would represent (different) theories about how an individual's *beliefs, desires, attitudes, and personality characteristics* mediate how their inputs lead to their choice among possible actions. Perspectives are by definition incomplete and usually mutually complementary in the analysis of more complex behavior of the multiperspectivally characterized system.[31] We must not assume that the articulated sum of perspectives on a system will exhaust its description or causal interactions. There may remain an unsystematized skein of causal interactions constituting a causal thicket.

A perspective may become applicable also through a physical or conceptual manipulation of a system. In 1973, Richard Levins compared the complexity of a recently killed organism with a living one. He argued that the dead organism is much more complex than the living one, because in the latter, several hundred enzymes speed up key reactions by orders of magnitude, and these rates escalating above background mean that they dominate and control the rest. It looks as if this defines a perspective on the system (perhaps primary metabolism?), and it also looks like the addition of enzymes to a system not containing them (a thought experiment only—such a system without enzymes would not be living) would at least massively increase the near-decomposability of the system, suggesting that it might define a level on Simon's account.

Could a level be a perspective that also meets certain compositional relations? This might sometimes be revealing but is likely more confusing, since I take it that the notion of a perspective is less clear and less well defined than that of a level or the things involved in characterizing it above. A perspective that is not a level would presumably require at least the following: (1) a set of causally specific interactions that affect target entities selectively that are (2) rate dominant for the class of things that they affect and (3) acting fairly broadly across the parts of the system as characterized from that perspective, (4) which include entities at more than one level. I earlier (Wimsatt, 1974) characterized perspectives as (5) corresponding to the reach of a technology or set of technologies and claimed that (6) each perspective had a class of problems that could be solved within that perspective, (7) as well as some that required going beyond it, thus recognizing its incompleteness (see Wimsatt, 2007, chap. 10). Thus, the emergence of a new communication system or information channel (as in the neural, hormonal, or immune systems) and frequently in technological evolution, with new waves generated by speech, written language, printing, telegraphy, telephone, TV, and internet communications, would each presumably constitute new perspectives (or parts of one). (For technological evolution, see Arthur, 2009; Wimsatt, 2013b; Wimsatt, in Love & Wimsatt, 2019.)

Other researchers (particularly Dan Brooks, 2017; Brooks and Eronen, 2018) wish to resist the ontological claims of levels and regard them as heuristic tools in describing and organizing phenomena. But there is no conflict here. On my view, there is a kind of entanglement of epistemology and ontology once we can speak of processes of detection or interaction (Wimsatt, 1976a, part III). Before genes were ever physically detected, classical genetics provided a rich set of tools for inferences about heredity and led some writers to adopt an operationalist stance toward genes (see Wimsatt, 2007, chap. 6). Heuristic use of entities that may also have an ontological status might be indicated for entities with different degrees of robustness or that have ambiguous or context-specific boundaries. (Is the boundary layer of air stabilized around an organism part of the organism or part of its environment? Is the organism the right evolutionary unit for biological species or is it the mating pair?) Given that objects can be regarded as sets of processes with relatively slower relaxation times while still recognizing their ultimately ephemeral character, time scale changes may also indicate transformations in how objects are regarded. They can be regarded as particularly effective "false models" in organizing explanations, but don't forget that "false models" can hide dangerous simplifications and lead to problematic characterizations if we forget about their clay feet. I think that this is correct, but even a multiplicity of heuristic uses need not rule out realist claims as well.

1.11 Prologue as Epilogue

People will debate the role of levels of organization in the ontology of biological systems and their role as heuristics in investigating them. For all of these disputes we engage in, I am perhaps most intrigued by the following conjecture—a kind of empirical transcendental argument that reaches beyond biology through all of the sciences: if we did not have regularities in the universe, and indeed, regularities like what I have called levels of organization and perspectives, not only we but also all organized forms of life could not exist. We could not have evolved, nor could we persist. Selection needs developmental processes producing heritable order to work on, and relatively well-behaved small variations in it, to generate a kind of robust adaptive topography that is not so full of holes as to make a progressive accumulation of organized dynamical structures impossible. We are not inevitable (and surely not immortal) products of nature, but at least until our sun becomes a red giant or we succeed in practicing a comparable form of self-immolation, levels of organization seem unavoidable.

Acknowledgments

In constructing this chapter, I have benefited particularly from reading the extensive historical and critical writings of Daniel Brooks, James DiFrisco, and Markus Eronen. Coediting with Dan and James has been a pleasure and a privilege. Jim Griesemer and I have practiced a form of coevolution now spanning four decades that has produced in his chapter an elaborative inspiration and extension that substantially strengthens the account offered here and does much more. Alan Love's particularly acute reading led to several important organizational changes, and his "manipulationist" account interfaces nicely with the account offered here. But no one has had greater influence through multiple drafts and discussions than Bob Batterman in my attempts to articulate my account with his. And I am delighted if my actions have played a role in his emerging status as closet philosopher of biology. My year at the Pittsburgh Center for Philosophy of Science allowed me to attend Bob's superb graduate seminar on multiscale modeling, so I owe the center a debt of thanks for this as well. The final version of this chapter was edited by James DiFrisco.

Notes

1. The need for an adequate account of emergence consistent with reductionism would not have occurred to me at first, but my assignment at the conference for which I wrote my first levels paper (Wimsatt, 1976a) was to comment on the views of Roger Sperry. My invitees regarded this as a problematic challenge: Sperry easily skirted back and forth between reductionist claims and asserting emergence. They thought I would just have to tell Sperry that he was being inconsistent: every philosopher knew that to be reducible was not to be emergent. But a working principle of mine has been to take scientists seriously, and surely so for Sperry, whose surgical experiments I already knew and admired (well before the work on commisurotomy that got him fame and the Nobel Prize in 1981). And indeed, the more I looked at his position, the more I thought he was right and I could justify it, so my account of levels was developed from my new position as an "emergent reductionist." More recently, Bob Batterman has noted that there are *two* distinct (and equally necessary) strands in my discussions of emergence and defended the other. I discuss their relations below.

2. And of course, the human sciences and technologies (such as advertising and the manipulation of human behavior in elections and decision making practiced by Cambridge Analytica) reflect the role of our diverse but causally relevant subjectivities (see also Ervin Goffman's work, the *Dramaturgical Image of Self in Everyday Life* (1956), and von Uexkull's notion of Umwelt). It is not a surprise that perspectives should be crucial in the human sciences. What made my work (Wimsatt, 1974, 2007, chap. 10) unusual was that they could be found also in "objective" biology (and in ecologies' species niches). Our deep problem here is in our reductionistic biases in favor of monadic properties and massively underestimating the role of complex relational properties.

3. The "Complexity and Organization" paper was extracted from my dissertation (Wimsatt, 1971) and given at PSA-1972 but not published until 1974. The levels material was originally devised for a conference on Consciousness and the Brain in April 1973 (the date of the illustrations) but not published until 1976.

4. The thought that realism toward objects could go as far as social (and later toward biological) groups was almost certainly bolstered by Campbell (1958), which introduced me to his notion of triangulation (i.e., robustness as developed in Wimsatt, 1981) and applied it to social groups. But I had also been introduced to and fascinated by Lewontin's models and accounts of group selection as early as 1965 in a book, *Ideas in Modern Biology*, edited by John Moore, given to me by my father. See Wimsatt (2019) for my latest account.

5. As I noted in Wimsatt (1976b), any mathematician would see this use of "in principle" as unfounded unless it could be mapped onto the natural numbers, which it could not.

6. I first encountered Simon in 1964, along with early papers by Don Campbell and John Holland in Frank Rosenblatt's remarkably broad and deep course on Brain Models and Mechanisms. Rosenblatt was the grand-

father of the connectionism or "deep learning" of the 1980s for his work (especially in the period 1958–1962) on "Perceptrons." And his idea that one should seek "genetic" properties (i.e., properties realized or realizable in virtually all randomly constructed neural networks) anticipated Kauffman's (1969) work on "generic properties" of randomly constructed gene control networks, "simulated annealing," and essentially all work on emergent multiple realizability since.

7. In graduate school, I began to think of generalized property spaces as conceptual tools in biology and the social sciences by analogy with the idea of a phase space. This was also furthered by discussions of state spaces with trajectories and search trees in chess. Particularly stimulating were Lewontin's remarks on the dimensionality of genetic state spaces, in his classic work (Lewontin, 1973, chap. 6) and Simon's classic (1973) article on ill-structured problems.

8. Batterman (this volume) disagrees that levels are necessarily compositional. His development of many of the same points using "correlation lengths" has the advantage of articulating well with developing physical theory. Woodward's discussion (this volume) of conditional independence and his argument in favor of lower- versus upper-level variables rather than parts in articulating interlevel causation are also crucial to explicating the role of compositionality. Batterman will be analyzing the relations between their views in a current book manuscript.

9. Thus, if compositionality were the only criterion, wouldn't it be more elegant, for example, to go up a level simply by doubling the number of basic objects and then chunking them? This is so obviously false as to provide a *reductio*. Nature intervenes with its own sized chunks!

10. The interacting elements here might be specified either in terms of variables or in terms of parts. The former would coordinate with Batterman's interpretation and is most plausibly Simon's (see also Woodward's important discussion, this volume). The interpretation of levels as relating to a system and to its material parts is most congenial to the mechanists' interpretation of levels.

11. This picture is suggestive of Alfred Lotka's (1924) writings on stability, in which if one focused on a set of processes with roughly commensurate relaxation times in a complex dynamical system, other processes going to equilibrium significantly faster could be treated as transients and ignored, and others with significantly slower relaxation times would define "moving equilibria" in the variables under study. Simon was influenced by Lotka, who was also read by von Neumann, Wiener, von Bertalanffy, Weiss, and others in the intersection of mathematics, physics, and biology. Lotka's formulation is essentially the same as Simon's "near-decomposability" analysis.

12. This is one path to causal thickets, but there are others. Two or more perspectives showing too much interactional complexity would degenerate into a causal thicket because it would yield too much ambiguity as to how to locate or characterize the interacting objects and would produce conceptual confusion, as well as conflicts about which methodologies are appropriate to analyzing the phenomena. These methodological conflicts could also be a sufficient cause of a causal thicket (perhaps nature has too much scar tissue!), though, by making the very nature of the operative causes unclear. Is this a mechanistically explicable characterization of how a mechanistic account could fail (Wimsatt, 1976a)?

13. Batterman distinguishes stability of two types: stability under changes in initial conditions and stability under changes in the parameters of the system that he calls structural stability. He regards the latter as most centrally connected with robustness. See Batterman (2002, pp. 58–61). Since "multiple means of detection" is intended to refer most centrally to different causal or inferential processes in detecting or measuring, this is a different approach. Still not yet analyzed is the relation between the two approaches.

14. Thus, theoretical vocabularies come in levels because that's where the phenomena are, not the reverse, as was suggested by the linguistic turn in philosophy.

15. See also the discussion of "dynamical autonomy" for levels working through this argument in greater detail in Wimsatt (2007, pp. 220–221) and earlier in Wimsatt (1976a). It is an independent (although weaker) argument for the autonomy of upper-level dynamics that complements Batterman's in 2017.

16. This article has almost everything. It is the most important essay on the analysis and application of levels and hierarchical organization and their dynamics in the second half of the twentieth century. To say merely that it is a classic is an underestimate.

17. I speculate that even when development and scaffolding are taken into account, the rate of growth in complexity is greater than linear and nonuniform. It could be qualitatively stepwise logistic, beginning exponentially and slowing down when a limiting factor appears (as has happened at least twice, for cell size and for organism size), until a mode of scaffolding allows chunking of the top-level systems as units, which then may undergo higher-level articulation processes. I think that at the scale of the differentiated group ("super-organism" or "society," which may itself have multiple strata), at least one (or more) additional levels have become possible (markets? nation-states?) through the development of our rapid electronic broadband communication.

18. As Jim Griesemer argues in a searching analysis of Simon's "watchmaker" argument concerning evolution through stable subassemblies (Griesemer, this volume), Simon ignores the crucial role of scaffolding in the aggregation process, and this is part of what goes wrong in his failure to treat development adequately in the evolution of complexity.

19. There is a countervailing force here, however, when factors such as increased means of systematic variation production (e.g., Wimsatt, 2013b) and communication speeds can generate conditions for new higher-level selection processes acting upon newly chunked units of selection. This is what has happened with the emergence of cultural selection processes and correlative cultural units. See Wimsatt in Love and Wimsatt (2019).

20. Hacking (1983) notes that a scientific experiment may lead to construction of a new entity, phenomenon, or system that did not exist before. Technological creations like chip architectures or communication networks fit Hacking's characterization unproblematically like a glove.

21. Indeed, the construction of integrated circuits, with multiple layering of different semiconductor elements to realize their functions, is the construction of an interactionally complex object (Wimsatt, 1974) whose layers are like the material embodiments of multiple partial perspectives except that none of the layers are causally active by themselves until they are integrated and produce complete circuits!

22. In fact, the classification is even richer, since these four conditions can be treated as degree properties, allowing aggregativity as an approximation.

23. Aggregativity must seem like a very uninteresting property (or meta-property), but the aggregativity of mass, energy, and charge is embodied in the great conservation laws of physics discovered in the nineteenth century and has significant implications for theories using them.

24. This criterion has an unfortunate origin that cuts to the core of aggregativity and emergence. Jack Cowan (personal conversation) tells how the president of the University of Chicago (John Wilson, a psychologist) called him in for a talk. Cowan was then chair of the department of theoretical biology. Wilson, who didn't like small departments, said, "You and biophysics both use a lot of math and physics to study organisms—you must be doing the same thing." Cowan said, "Let me explain the difference. Take a rat and drop it into a Waring Blender. The biophysicist is interested in those properties that are invariant under that transformation." Wilson didn't appreciate the joke, or the need for the distinction, and merged the two departments, to the detriment of less well-funded theoretical biology.

25. One still needs to consider whether the energy necessary to create a given kind of order is the same as the energy necessary to disrupt it. In general, it is not.

26. Fractals could plausibly yield to an account in terms of a distribution of correlation lengths.

27. See the discussion of "perceptual focus" in the last two sections of Wimsatt (1980), where I discuss the biasing effect of the tendency to refer group phenomena down to the individual level of description or to describe groups as "collections of individuals," as if they had no organizational properties of their own, in the units of selection controversy.

28. I owe this fortuitous phrase to Stuart Glennen. Other key gateway experiments in which upper-level changes could effect specific kinds of lower-level changes would include Millikan's "oil drop" experiment to discover the charge of the electron and Boveri's "dispermic fertilization" experiments to show the individuality of the chromosomes in heredity.

29. I morphed the term "gateway experiment" from Mark Bedau's "gateway technology" (Bedau, 2019) where he applies the term to patent technologies that open a whole new adaptive niche to applications of that basic idea in often quite different contexts and morphologies. His key example is the development of inkjet technology.

30. My favorite (and my own programming contribution designed for the ROM) allowed the plotting of families of curves and up to nine functions at a time with different symbols, vastly extending the power of the standard plotter, which only allowed a single curve for a single function.

31. Since my 1974 paper, the first to argue for the importance of perspective-like things, a number of others have adopted some form of perspectivalism. These would include Ronald Giere, Sandra Mitchell, Helen Longino, Kenneth Waters, and Alan Love.

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