The Significance of Levels of Organization for Scientific Research: A Heuristic Approach

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Abstract: The concept of 'levels of organization' has come under fire recently as being useless for scientific and philosophical purposes. In this paper, we show that 'levels' is actually a remarkably resilient and constructive conceptual tool that can be, and in fact is, used for a variety of purposes. To this effect, we articulate an account of the importance of the levels concept seen in light of its status as a major organizing concept of biology. We argue that the usefulness of ‘levels’ is best seen in the heuristic contributions the concept makes to treating and structuring scientific problems. We illustrate this with two examples from biological research.

1. Introduction.

'Levels of organization' is a cosmopolitan term found throughout the natural (and particularly biological) sciences and in philosophy, and is used to express a wide number of ideas and theses concerning the hierarchical structure of the world or the phenomena populating the world. The basic idea of ‘levels of organization’ can be understood as a loose conjunction of the following elements: (a) (Part of) the world, or our representation of it, is structured into strata, where (b) each stratum comprises classes of structures or processes of relevant similarity, and (c) relationships within and between strata are based on some biologically relevant criteria (such as composition or scale).

Until recently, only sporadic attention has been paid to the precise character and significance of 'levels' as it is used in scientific contexts. Though a number of philosophical accounts have

1 Many thanks to Beate Krickel, Eva-Maria Jung, Lena Kästner, and two anonymous reviewers for their important feedback.

2 We refer to ‘levels of organization’ rather than other iterations of the ‘levels’ moniker (such as David Marr’s “levels of analysis”). Though we will not argue for this point here, we feel that a number of ‘levels of x’ labels fall under the “of organization” qualifier as cognates or closely related derivatives; in particular levels “of explanation” and “description” often presume an underlying scaffolding afforded by ‘levels of
already been offered concerning what levels are (Oppenheim and Putnam 1958; Wimsatt 1976; 1994/2007; Craver 2007, ch.5; 2015; Findlay and Thagard 2012), much less has been said about the significance of the levels concept for scientific purposes. This paper will pursue this latter question. We offer here a descriptive account for understanding the usefulness of the levels concept in scientific usage. We propose that the concept of levels is used heuristically by scientists not so much to describe ontological matters as to specify some aspect(s) of the phenomenon in question as useful for a scientific question at hand. We contextualize this with a brief discussion of bounded rationality, and how the many meanings of ‘levels’ can be harnessed in different contexts to do various types of work.

We will begin by offering an orienting approach that shifts the focal point of analyzing levels away from their ‘nature’ to the significance it exhibits in scientific usage (section 2). This approach posits the levels concept as a heuristic, rather than principled, notion motivated towards structuring scientific problems. This approach is well positioned to deal with a nascent levels skepticism that seeks a wholesale dismissal of the concept in science and philosophy (Brooks 2017). We then characterize two major ways that ‘levels of organization’ are heuristically applied in scientific work for problem-structuring purposes (section 3). The first pertains to its use as a descriptive term that captures the relevant details of interest in a system. The second pertains to the usage of levels as a key term within an embedding heuristic strategy for analyzing a biological phenomenon. ‘Levels’ works in both cases to impose structural assumptions on the system being investigated, to generate hypotheses regarding that system, or to mark interest or relevance of an aspect of the system that could or should be investigated to make progress on a research problem. These various applications, we continue, vindicate the usefulness of the levels concept by emphasizing more localized criteria of assessment, which do not rely on the idea first capturing ‘deep’ ontological content of the system it treats (section 4).

2. From the Nature to the Significance of ‘Levels’

Despite its prevalence, the concept of 'levels' has been getting a lot of negative attention recently (see, e.g., Potochnik and McGill 2012; Thalos 2013; Eronen 2013; Levy 2016). The crux of this organization'.
skepticism is that 'levels' apparently comprises an inherently flawed concept whose significance for scientific practice has been highly exaggerated by philosophical partisans. This “levels skepticism” has multiple threads to it, roughly corresponding to which account of ‘levels’ one is entertaining (see Brooks 2017 for more details). One thread, which focuses on comprehensive notions of the term like those similar to Oppenheim and Putnam’s (1958) “layer-cake” account, points out that the way that levels conceptualizes natural phenomena or interdisciplinary relations are simplistic or false. These and other problems are well-documented by Potochnik and McGill (2012). The more recent “mechanistic” account of ‘levels’ eschews the comprehensive spirit of the layer-cake model and opts for a contextualized understanding of the levels concept as designative of compositional relations within mechanisms. This account has been criticized as too narrow for a general understanding, because levels and interlevel relations do not easily generalize from given instances (Eronen 2013; 2015; Franklin-Hall forthcoming; DiFrisco 2017).

Regardless of the line pursued, 'levels' is consequently judged to be a flawed, and hence useless, concept that should be de-emphasized or eliminated from the scientific lexicon. This dismissal rests on the premise that ‘levels’ fails to capture deep ontological content of the world. For instance, as generally construed, the levels concept is taken to posit a comprehensive ordering of the world into uniform, and wildly unrealistic, part-whole compositional relations, which in turn reduce the nuanced complexities of the world to mere caricature (see also Craver 2007, 173). This, as Potochnik and McGill explain, identifies the problem with “the very notion” of levels itself, because “the uniformity of composition needed for stratified levels simply does not exist.” (2012, 126). Correspondingly, Eronen (2013) lays out a “deflationary” approach to the more contextualized mechanistic account to the effect that other, more well-defined notions (such as composition and scale) can seamlessly replace mentions of mechanistic levels: “One outcome of analyzing levels in terms of scale and composition is that we no longer need any distinct notion of level, at least not in any sense resembling levels of mechanisms. If scale and composition are sufficient for analyzing explanations in neuroscience, the notion of ‘level’ [in the mechanistic sense] does not add anything to our conceptual tool kit” (2013, 1049).

In contrast to this skepticism, we offer an approach that turns this assessment on its head, and embraces the ambiguity of ‘levels’ as vital to the flexibility the concept exhibits in expressing many distinct ideas. With a few caveats, we find the skeptical charges to be inconsistent with
the way that the concept is used in scientific literature. We also deny particularly the implication that a flawed or misleading concept must therefore be useless, regardless of other conclusions to the status of ‘levels’ in capturing realistic features of the systems it represents (Guttman 1976; Potochnik and McGill 2012). We believe that 'levels of organization' can be shown to be a useful resource that benefits scientific thinking.

Our motivation for focusing on the role and significance of levels instead of trying to define their nature is based on prudence rather than principle, and relates to the state of the discussion surrounding the levels concept. For one thing, there is a lack of coordinated and enduring community attention to systematically analyzing the levels concept (Wimsatt 1994/2007, 203; cf. Kim 2002, 3-4). This has resulted in a proliferation of many possible things for the term to express, a feature long observed of ‘levels’ (Bunge 1960, 396; Grene 1969; Craver 2015, 2). We do not intend to depreciate individual efforts at analyzing the levels concept, but rather to note that despite such efforts there has been little remedial effect on the rampant ambiguity that leads to confusion, misconstruals, and frustration in the way the concept is applied in philosophy. Additionally, most analyses of ‘levels’ tend to privilege only one, often framework-embedded, conception to evaluate the term’s contributions to the scientific purposes (Brooks 2017). Focusing on the ‘nature’ of levels would hence impose the assumption that any scientific value of the concept must be anchored or derivative upon first capturing deep ontological content of the things it represents (e.g., Zylstra 1992, 116).

3. A Heuristic Approach to Levels

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3. The natural continuation of this argument would be to deny that 'levels' delivers false or misleading descriptions of nature and science. The basis for this would be to build off the usefulness of the levels concept, seen heuristically, and then to motivate the inference that the levels concept in some cases delivers depictions of nature and science that are accurate enough to support the uses for which levels are applied as reliable in the first place.

4. This does not eschew the importance of the ontological nature of levels, but rather should help give more definite orientation to such approaches to understanding the concept. For now, we will argue there is ample motivation for our approach in that the levels concept has been already attributed many different functions by philosophers and scientists. That is, regardless of how one countenances ‘levels’, the term is already doing much work for scientists and philosophers in articulating and introducing their ideas.
‘Levels of organization’ appears throughout the literature as a kind of ‘fragmentary’ conceptual tool that exhibits stark variation in its conceptual content across different instances of usage, while simultaneously exhibiting some stability in the way that it is used. By “fragmentary” we mean simply a kind of structured polysemy whereby the semantic variation can be captured by distinct elements of semantic content. To illustrate this, consider for instance Carl Craver’s “3 defining questions” of levels (2015, 3), which include content detailing (i) the relata designated by each level, (ii) the interlevel relation holding between levels, and (iii) the intralevel relation holding within a given level. Each of these elements constitute distinct semantic content contributive toward the levels concept as expressed in a given instance. That is, most if not all instances of ‘levels’ will require fleshing out specifically what each of these elements means, and the particular content of these elements of meaning can vary between instances: The interlevel relation may refer to composition or scale, while the intralevel relation may refer to different projectible properties held by a class of similar constituents. This polysemy is balanced, firstly, in that the levels concept is usually capable of clarity and precision in given instances, perhaps after some reflective reconstruction. Another factor balancing this ambiguity is the overarching epistemic goal of applying the levels concept. As we have argued elsewhere, the most important unifying epistemic goal motivating the usage of levels is to structure scientific problems, roughly meaning that the usage of levels is geared toward making scientific problems amenable to investigation (Brooks unpublished manuscript). This approach emphasizes the contextual aspects of how different components of meaning comprising ‘levels’ are locally determined in usage (see also section 4). In a nutshell: scientists construct an operational definition of ‘levels’ based on localized, interest-relative criteria, and then apply this definition heuristically for the purpose of providing relevant structure to scientific problems. The uses we detail below can be seen as specific ways that ‘levels’ fulfill the particular tasks set for the concept by this contextually-determined epistemic goal.

Nancy Cartwright (2016) and Sophia Efstathiou (2016) offer a complementary approach to our notion of ‘fragmentary’ concepts.\(^5\) Referring to Neurathian Ballungen, or roughly cluster concepts, it is imperative of such concepts that they be made precise in a given scientific context, so that the claims and inferences being derived from such concepts are effective.

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\(^5\) Thanks to an anonymous reviewer for pointing out this parallel.
Cartwright refers to this as “precisification”, while Efstathiou calls this “founding” a concept. The basic idea is that in order to become a useful scientific concept, a term must undergo “transfigurative” changes (Efstathiou 2016, 53) by, e.g., “[a]rticulating the concept isolating, emphasizing, or developing aspects taken to be relevant and interesting in this scientific domain, while ignoring or dropping elements deemed irrelevant” (ibid). This often means, as Cartwright points out, that the significance of a polysemic term (such as “cause”) is tightly grounded in the methods used to illustrate and inform what that term means in a given instance. To the degree that this is case, the statements, generalizations, and inferences made with the term in question will capture robust scientific content, i.e. will be testable according to concrete standards of success (Cartwright 2016).

More importantly, when tacked onto concrete methods, the term in question will be afforded a characterization that we can then evaluate as effective or ineffective. For instance, Cartwright discusses the term “cause” as availing to multiple different methods and aims, each of which correspond to different notions of the term. These different iterations of “cause” are not equivalent, but rather only make sense in the context of the specific methods and aims that specify what the term means in each instance, and hence what it is supposed to be doing. When these notions become conflated, then the empirical support for the concrete claims we wish to derive from the individual instances of “cause” is lost. In a similar manner, we see the levels concept becoming founded in a given context (where methods and aims governing its usage are specified) as necessary for its effective application. For this reason, the usage of ‘levels’ in the examples we describe below in section 3 should be understood as founded in the attendant investigative context in which they are described.

By entertaining the levels concept as a ‘heuristic’ notion in this context, we then mean two things (see especially Wimsatt 2007, 19). Both concern the usage of the levels concept. First,  

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6 There are a number of differences between our treatment here and Efstathiou’s account of founding. For instance, founding a concept, according to Efstathiou, often comprises the process of transforming an ordinary, folk concept into a scientific one. This can be a sprawling process, involving social, political, and even economic transformative processes in addition to the epistemic and scientific activities. We cannot here accommodate such a narrative for the levels concept, but rather wish to focus specifically on the “transfigurative” (Efstathiou 2016, 53) efforts required to make a concept scientifically viable in a given instance.
we are calling attention to the locus in scientific practice where we see the usage of 'levels' having its most enduring impact: Namely the reasoning strategies involved in the recognition (or construction) of scientific problems, and in the efforts involved in providing their solutions. Secondly, we are emphasizing the tentative character of the products constructed by scientists using the levels concept. Depictions of natural systems produced using ‘levels’ are quite often highly idealized, and consciously omit empirical details of the target system, sometimes to the point of caricature. ‘Levels’ offers approximative measures for doing what they do, and is intended to provide de facto, rather than principled, insight into structuring the problem at hand where it is used. Thus, ‘levels’ is heuristic in the sense of being a conceptual tool that is imperfect and fallible, but works well enough most of the time, and contributes positively to scientific research (we will return to this point in section 4.1).

These orienting observations reflect an important underlying premise of our analysis. We see the usage of ‘levels’ as inspired by a view of human reasoning, i.e. the idea of bounded rationality (BR). BR seeks to accommodate realistic constraints placed on our depictions of human decision makers, here scientists, as agents dealing with real problems in real world scenarios, and how scientific problems and the efforts towards providing their solutions are depicted in these conditions (Gigerenzer 2001; Bechtel and Richardson 2010, 12). These constraints reflect limitations in both cognitive and material resources for providing solutions to problems that scientists wish to solve. In this way, BR represents a potent cornerstone viewpoint to construct increasingly realistic snapshots into how scientific investigation is actually conducted (Callebaut 2007, 82).7 ‘Levels’ on our view fits seamlessly into this milieu, and represents specifically a means of creating, or supplementing, productive units of effort towards scientific tasks within these constraints to transform intractable problems into tractable ones.

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7 Citing BR as a motivating cornerstone does not come without its costs, and some dismiss this view of human rationality in favor of approaches more congenial to optimal and idealized decision-making scenarios (Gigerenzer, 2001, 38; Callebaut 2007, 78). Needless to say, we find exactly the types of tenets that advocates of BR criticize in such “Olympian” views of human rationality (Bechtel and Richardson 2010, xii) to be in line with the view of ‘levels’ we are advocating here. Much more attractive, we claim, is the potential for insight into actual scientific practice for philosophical analyses of science offered by BR, which is summarized by Werner Callebaut’s characterization of Herbert Simon’s idea of BR as a “silent revolution” (Callebaut 2007).
Here, three constraints are particularly relevant for contextualizing the place of ‘levels’ in scientific thinking. First, researchers do not, and cannot, conduct exhaustive searches for problems whose 'optimal' solutions (or indeed even their characterizations) sprawl into realms that far outstrip what we know of the world at a given time (see also Richardson 1998, 566-7). What is responsibly conceivable at a given time is partially set by our current methods and the investigative scope that current states of research or technological means dispose us towards practically executing. In this way, ‘levels’ provides impetus for engaging poorly understood or highly complex systems.

Second, science is a fundamentally open process of trial and error where researchers rarely know beforehand what the finished product of their efforts will look like. Instead, both the solution and the empirical and conceptual resources brought to bear on a scientific problem themselves need to be gathered and articulated by scientists. Often the conceptual and empirical resources necessary for understanding new phenomena have not formed consensus or even been hypothesized in the early stages of investigation. Relatedly, the relevant metric for marking progress on the problems scientists engage are not agreed upon, but require exploratory work for establishing schema for progress. This means that virtually every aspect of a line of research is open to revision in the face of new evidence or new perspectives on the problem being handled. The validity of these resources, proposed solutions to the problem, and even of the problem itself, are open to negotiation within the research community or communities that investigate that problem over a period of time (Brooks unpublished manuscript). ‘Levels’, due to its conceptual openness, is an excellent tool for exploratory hypothesizing.

Third, human investigators are prone to error (Wimsatt 2007, 22). This goes in hand with the foregoing point in acknowledging the open-endedness of scientific investigation. Not only individual scientists, but also scientific communities may find themselves wed to biasing resources they bring to bear on a problem, which can be flawed, piecemeal, or downright wrong for their purposes of gaining insight into natural phenomena. These biases may be attached to scientific instruments or methods, expectations for how explanations will or should pan out, or the concepts used to pose questions in their field. Accordingly, the conceptual tools that we sketch within scientists’ usage should be prepared to tolerate and help explain the source of errors while providing the means for guiding scientific efforts (see also section 4 below).
Instances of ‘levels’ are better seen as guided by graded success criteria set by the aims of its immediate users and communities, instead of polarizing success and error into an either-or matter (cf. Knuuttila 2011).

3.1. ‘Levels’ as descriptive abstraction

One prominent way of using 'levels' in science is to provide an approximative means of characterizing a system. This usage is widely found in science and in philosophy, appearing not only in depicting particular systems and phenomena, but also in contexts applying to the whole of nature, like in general biology textbooks. One key epistemic activity involving descriptive products using levels is abstraction. Trivially, no description of a system can capture everything about that system in its entirety; we all must abstract in varying degrees away from a total depiction of nature and particular phenomena. By abstracting from the full details of a system we hope to approximately capture the relevant details of a system that productively serve one’s scientific purposes (Salmon 1977/1998, 96; see also Norton 2012 on approximation; cf. Woody 2014, 123, 125). We will not attempt an exhaustive cataloging of instances of this kind of levels usage, as this would require several distinct papers. Rather, we will emphasize here how descriptions produced by using ‘levels’ work to deliver useful contributions to problem solving practices.

The usage of ‘levels’ incorporates abstraction by providing partial descriptions against which productive scientific work takes place (such as making inferences and generalizations, designing experiments; cf. Griesemer 2005, 60). This abstraction can be understood against the background of the noncommittal characterization of the concept of levels of organization that we briefly mentioned in the introduction: (a) (Part of) the world, or our representation of it, is structured into strata, where (b) each stratum comprises classes of structures or processes of relevant similarity, and (c) relationships within and between strata are based on some biologically relevant criteria (such as composition or scale). Each of these ideas represents the basis for generalizing a claim in which the levels concept is applied. Thus, eukaryotic cells generally possess nuclei (b), but also oftentimes compose tissues (a, c), and so on. Obviously, these kinds of generalizations are not meant to hold without qualification, but according to the purposes for which they are expressed. For example, grouping cells together as a class of similarly constituted things that generally compose tissues is a useful pedagogical rule of thumb.
for introducing students to the basic themes of studying biology. The grain of difference or similarity is often finer in more research-oriented instances of levels usage (see below for an example).

More importantly, abstraction using ‘levels’ allows for specifying common features while ignoring or passing over critical differences between constituents that are grouped together in the generalization in question (e.g. non-neuronal cells typically do not possess axons; different tissues are composed of different cell types). Though these may be material to the inferences that are constructed by using the concept in the first place, such critical differences may also be exhibitive of exceptions or even limitations of the levels concept. This is to be expected of a heuristic concept, which can often reveal systematic exceptions or limitations (see also section 4.1). For example, when defined in terms of scale, there will be many exceptions to what is definable as a level in a given instance: Multicellular organisms range over a great variety of sizes, some of which overlap with contrasting scalar demarcations of other levels (e.g. most insects are smaller than most human organs). Similarly, unicellular organisms fundamentally differ from multicellular life under both scalar and compositional renderings.

In the context of abstraction, the role of choice in dealing with scientific problems becomes especially clear. Abstraction necessitates choosing which details to include and omit from our descriptions of systems. One important way of spelling this out is expressed in the idea of tradeoffs by Richard Levins (1966; 2006; see also Weisberg 2006). In depicting natural systems of immense complexity, we are practically speaking incapable of capturing all possible details in our scientific models that we may find desirable. Levins’ classical discussion focuses on the perennial aims of generality, precision, and realism, which cannot all be achieved

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8 The active choice between inclusion and omission of detail falls under many distinct possible choices that researchers can make. For instance, this often pertains only to what is chosen to be included, and omission of details ‘falls out’ from what is actively chosen to be represented in a given description. There are exceptions to this, where the omission of a particular detail is announced by the authors in order to emphasize what they are attempting to ‘get at’ by omitting that thing rather than what they wish to emphasize in their description. In such cases, omission also constitutes an active decision. Equally important, these considerations arguably capture an important aspect of research in several contexts of scientific activity outside of the lab, i.e. the way that debates between papers in scientific journals often play out: One common form of discourse in scientific literature concerns the accusations of one party that another has “irresponsibly” or perhaps only “neglectfully” forgotten to take this or detail of a system into account.
simultaneously. The best we can hope for, Levins argues, is to serve a combination of two of these aims, while excluding the third one, i.e. trading it off (1966, 422). The lesson Levins pushes is that in practical settings, the descriptive content of an abstraction is inseparable from the questions of its usefulness. To construct useful representations of nature, we must sacrifice some of these aims so that others become attainable; for example, trading precision for more generality (ibid., Weisberg 2006, 437). This leads directly to the relevance of heuristic thinking, which emphasizes, rather than conceals, active trade-offs that occur in constructing such abstracting descriptions.  

Consider one example of this heuristic usage of levels, which we choose with an eye to the generality of our point throughout biological science: modeling single neuron dynamics to apply these to other neural levels of organization. In their review of models for single-cell neuronal dynamics, Herz et al. (2006) summarize and assess modeling efforts applied to capture the behavioral dynamics of single neurons. Tellingly, their discussion is framed around issues related to moving across levels in numerous descriptive activities serving overall research goals of modeling neurons. Here they directly address the importance of tradeoffs of desirable properties for analyzing the system as requiring, and indicated in the title of their paper, “a balance of detail and abstraction”. That is, coming up with adequate descriptions of neural phenomena (here the combined products of numerous kinds of models) faces a basic dilemma of capturing biologically realistic details and retaining the tractability of modeling the system precisely by omitting these kind of details (Herz et al. 2006, 84).

An underlying aim of Herz et al.’s discussion is characterizing the challenges in constructing...

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9 Ignoring the role of aims here can trigger the danger of perniciously reifying different depictions of levels, or even whole conceptions of what levels are. In philosophy of science, for instance, the endurance of the layer-cake account of ‘levels’ developed originally by Oppenheim and Putnam (1958) continued in philosophical usage well after the abandonment of their microreductive framework. The defining features of this highly problematic conception were characterized into ‘levels’ in general, where it (falsely) motivated indicting the levels concept in general. This is discussed at length in (Brooks 2017). In science, similar situations may occur when a vague, uncritical, or simply wrong instance of ‘levels’ may come to skew scientists’ thinking. Some discussions of so-called “levels of analysis” seem to exhibit this (Sherman 1988), though we can only gesture towards this for now.

10 We chose this paper because of its discussion by Woodward (2008), to which we seek offer complementary continuity to the discussion.
useful descriptions of neural systems with the aid of the levels concept. Here ‘levels of organization’ drive their discussion in two significant ways. First, and most importantly, they explicitly identify five levels important for modeling single cells, and describing the problems and the research that revolve around these activities. The models discussed are chosen because they (to varying degrees) accurately capture different features manifested at organizational (sub-neuronal) levels relevant for understanding a single neuron.

For instance, different types of compartmental models (CMs) each specialize in capturing specific kinds of dynamics in neuronal behavior that are associated with increasingly complicated organized clusters of sub-neuronal components (ibid.). At the lowest level we find “detailed CMs”, which excel at capturing detail at immensely small scales like individual synapses (Fusi et al. 2005). “Single CMs” are used to capture larger grains of detail, as exhibited by the Hodgkin-Huxley model (cell membranes) and newer iterations of the Reichardt motion detector (whole retinal cells; Borst 2011). Cascade models and black box models, in contrast, capture even coarser grained aspects of neuronal behaviors representing larger physiological units, e.g. multiple (10^2-10^8) synapses (Fusi et al. 2005, 599) and the entire brain respectively. These make up a cluster of descriptive activities that together characterize behavior of single neurons at multiple levels. Interestingly, these levels are not defined just in terms of (size or temporal) scale, but rather (roughly) in terms of the paradigmatic or stereotypical models applied at each level. Moreover, these levels are put forward as discrete layers, which differentiates them from scales or degrees. Thus, in this case ‘levels’ clearly means something more than just scale or “degrees of abstraction”.

The second role that levels play in the discussion of Herz et al. is that understanding single neurons potentially results in uncovering phenomena at both higher (networks of neurons and the entire brain) and lower (membrane dynamics) levels of organization. In this way, levels are not only postulated beforehand to structure the problem, but progress in research can call attention to new levels, and determining what levels are needed can itself be a question that research has to answer.

11 It should be noted that the text of Herz et al.’s paper contains several uses of the naked term “level”, not all of which correspond to levels of organization. For instance, we would articulate their expressions “level of abstraction” as closer to “degree of abstraction”. 
These uses of ‘levels’ clearly co-occur with an array of active choices for scientists to make in deciding what and how to represent the phenomena they are interested in explaining, and what tradeoffs to make. These choices, furthermore, are cast in the context of a well-defined explanatory goal: i.e. “[u]nderstanding the dynamics and computations of single neurons and their role within larger neural networks” (Herz et al. 2006, 80). This is where the “delicate balance” of choice enters:

“All these tasks require a delicate balance between incorporating sufficient details to account for complex single-cell dynamics and reducing this complexity to the essential characteristics to make a model tractable. The appropriate level of description depends on the particular goal of the model. Indeed, finding the best abstraction level is often the key to success.” (ibid)

Importantly, Herz et al. emphasize that the challenges encountered in these tasks have no clear answers (ibid. 84). Rather, they designate open problems that need to be addressed (and are being addressed) by current neuroscience (Almog and Korngreen 2016, 2202). However, the motivation behind using the levels concept in this manner is to give more definite structure to these problems, so that their investigation may more constructively continue. This ability is native to the levels concept itself: The levels in the example above are partly defined through types of models that pick up different features of neurons, and therefore do not reduce to dimensions such as scale or composition. Entertaining ‘levels’ in this context involves a sort of package deal of assumptions and definitional components. Considerations of this kind insulate the levels concept from strongly deflationary approaches which would see ‘levels’ dissolved into, e.g., scale or composition (cf. Eronen 2013).

3.2 ‘Levels’ as a Guide for Scientific Research

Levels are also heuristically used within problem-solving strategies, where ‘problem-solving strategy’ refers to the rules or guidelines most often associated with the term “heuristic” in the
BR literature. Such strategies proceed either under the assumption that a levels-mediated description of the phenomenon (or nature in a general sense) is already in place, or at least with the assumption that one is possible. The key epistemic activity of levels in this kind of usage is the role the term plays in *guiding scientific research* by making suggestions about how a phenomenon can or should be studied. This in turn complements the descriptive usage discussed above.

One well-documented family of heuristic strategies in philosophy of science are those that separate a system into its component parts and relate them back to the whole phenomenon to which they belong (Simon 1962; Bechtel and Richardson 2010, Ch. 2; see also Winther 2011, 420). While not always explicitly present at the outset, a hierarchical description involving levels is either itself one of the products following this kind of strategy, or whose creation is material to implementing the strategy. Prominently discussed strategies include near-decomposability, decomposition, and localization (Bechtel and Richardson 2010, Ch. 2; Silberstein and Chemero 2013). These kinds of strategies are exceedingly common in the philosophical and scientific literature, and so we will refer the reader to these more specific treatments for considerations of space.

A second family of heuristic strategies involving levels comprises those in which a hierarchical description invoking levels is presumed as given or easily imposable. ‘Hypothetical’ or ‘exploratory’ strategies of this kind invoke calls to “move to another level” in order to gain insight into a problem, or generate hypotheses for solving that problem (see Darden 1991, who discusses this family of heuristic strategies in detail). Here, depictions of levels are especially variational in their expressed content across different instances, a point Darden attributes to the

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12 This sense of heuristic strategies corresponds to what Spencer Hey has recently called “meta-heuristic strategies”, which contrast to more specific “heuristic actions”. The two are closely related: the former comprise “rough-and-ready strategies that specify the conditions under which these [latter] activities ought to be used” (Hey 2014, 8). We find this distinction useful, and will adopt it in substance if not in language.

13 See, for instance, Craver’s classical treatment of spatial memory mechanism (2001), though we are cautious not to attribute to him the parts of our account that fall outside his own mechanistic account of levels (2015), and also point out that this usage of ‘levels’ is strongly committed to the extra notion of a “mechanism” and “mechanistic explanation” (Brooks 2017). Arguably, strategies like decomposition and localization are what make up much of the levels-thinking behind the New Mechanist paradigm.
difficulty of offering a general meaning of ‘levels of organization’ (ibid, 253). This is precisely
where our approach to understanding levels discussed above becomes so important, because
these strategies often openly portray ‘levels’ in straightforwardly ontological and epistemic
ways, even simultaneously so. That is, levels are depicted sometimes as discrete physical
structures or processes and the relations between these, or as sources of epistemic insight; e.g.
knowledge produced by methods, descriptions, and theories that investigate things taken to be
at the putative levels posited in that instance. Applying levels here hence fluctuates between
these different modes of usage. For this reason, “moving to a new level” can encompass looking
to new things (i.e. natural objects) or looking to new epistemic resources (descriptions, methods,
models) for gaining insight into a problem (or constructing hypotheses for solving those
problems).

One prominent usage of ‘levels’ in this respect can be found in the publications announcing or
advertising the creation of a new discipline or research area. In such cases, ‘levels’ is explicitly
used to address the need to structure problems of these new fields and to provide suggestions
for guiding research. Systems biology, to take one example,14 exemplifies this in making the
reconstruction of the dynamic arrangement of a system’s parts a central explanatory task, rather
than looking in these parts in isolation from the whole (Kitano 2002, 1662). In this way, ‘levels’
is also used here to emphasize breaking with the reductionistic tradition of molecular biology
in the latter 20th century (O’Malley and Dupré 2006, 1270; 1272; Reece et al. 2008, 3). This is
clearly stated in the seminal articles launching the fields of systems biology:

- Ideker’s (2001) landmark paper establishing systems biology states: “The central task
  of systems biology is (a) to comprehensively gather information from each of these
distinct levels for individual biological systems and (b) to integrate these data to
generate predictive mathematical models of the system” (2001, 345). Ideker then
immediately specifies “information” as occurring “on multiple hierarchical levels of
organization” (ibid.; see also 354).
- Likewise, Kitano (2002) explications the need for a “systems-level understanding” of

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14 Here, as in our other examples, other instances of ‘levels’ usage could easily have been cited. For example,
similar observations hold for the nascence of synthetic biology (Endy 2005) and the extended evolutionary
synthesis in evo-devo literature (Müller 2007).
biological phenomena engendered in this task “as the approach advocated in systems biology, [which] requires [i.e.] a shift in our notion of ‘what to look for’ in biology” (1662). This is easily captured as the necessity to look at multiple levels of organization, rather than lower levels such as the genetic and molecular (ibid; 1663).

- O’Malley and Dupré’s (2006) position paper echoes this in singling out ‘levels’ as unavoidably germane to the “primary task” of systems biology: “The primary task for…systems biology [is]: ‘how are individual biological units and their behaviours altered, controlled or constrained by becoming components of the system?’…Understanding this downward causation (or how causality operates at different levels of organisation) and the differences between units acting in aggregation and systematic organisation is the true and distinctive purpose of systems biology” (1273; emphasis added).

Though its content is somewhat ephemeral in these cases, ‘levels’ is clearly present at least as a significant organizing concept, where hierarchical depictions of nature, or parts thereof, are presumed as an organizing structure around which to guide further scientific work. In the context of systems biology, this work is clearly focused on coordinating the different components of a target system, or even disciplinary approaches, together in a way that increases our understanding complex biological systems. The primary role of ‘levels’ here is to inform how problems in biology can be posed in a new light, with the particular details to be filled in by researchers who take up this new levels-mediated perspective. This is nicely summarized in the following passage from an introductory textbook of biology: “The goal of systems biology is to construct models for the dynamic behavior of whole biological systems…Thus, the systems approach enables us to pose new kinds of questions” (Reece et al. 2008, 6, emphasis added).

Obviously, the different ways of heuristically applying ‘levels’ we’ve discussed are not mutually exclusive. Indeed, one point of Herz et al.’s review was, after characterizing the task to be pursued using levels, to provide a guideline for how to proceed in modeling neuronal dynamics. That ‘levels’ would persist in framing how research on this task proceeded should not be surprising. In a subsequent review, Almog and Korngreen (2016) mirror the spirit of Hertz et al. in continuing to orient neuronal modelling towards the task of producing more realistic representations of neurons, but are highly critical of “mastodonic” computational models, and particularly CMs (Almog and Korngreen 2016, 2199). Yet, despite this difference
in methodological orientation, they retain a role for ‘levels’ in both characterizing neurons and their situatedness in the nervous system (using ‘levels’ as descriptive abstraction), but also as the basis for suggesting where research should look. Interestingly, ‘levels’ and problem-solving considerations figure decisively as the reasons for constructing increasingly realistically modelled depictions of nervous systems as a useful (background) descriptive schema:

“Consider the multilevel structure of biological systems. We all agree that a neuron is a cell having many common features with other cells in our body. Like other cells, it contains a genetic code compacted in its nucleus…One level above this we find the complex biochemical network controlling the response of the neuron to neuromodulators and second messengers...Thus [constructing] a bridge between the biochemical functionality of the neuron and its electrical activity is, in our eyes, a primary goal for compartmental modeling.” (ibid, 2202; emphasis added).

It should be noticed that the levels concept and the aim of capturing realistic content of natural systems designate exclusive components in Almog and Korngreen’s call to action. To wit: The levels concept is cited as a background assumption against which increasingly realistic compartmental models should be constructed. Thus, though the aim the authors identify is one of producing more ontologically robust models, the impetus for this search is the background assumption that the systems of interest are heuristically structured by ‘levels’. Specifically, Almog and Korngreen’s citation of the “multilevel structure of biological systems” operates in both of the heuristic uses we’ve outlined in this section. First, it provides an approximative basis for abstraction. This is visible in the quote where the constitution of qualitatively similarly constituents (i.e. neurons and other cells in the body; biochemical networks) serves as a descriptive tool for generalizing common features between those constituents. Second, the multilevel structure serves as a means around which the “primary goal” of the problem, i.e. “bridging”, or coordinating, different regions of the system comes into the focus of productive effort. This fits well with our heuristic treatment of the levels concept in that both of these serve to provide structure to the problem they engage, i.e. modeling neuronal behavior.

Now that we have shown some ways in which ‘levels’ are used science, we turn to reconsidering the usefulness of the concept in the face of the significance of the term in scientific practice.
4. Reconsidering the Usefulness of Levels.

Our analysis allows us to frame the question of the significance of the levels concept into a set of contextualized concerns regarding how to assess the term in scientific usage. Drawing on the two classes of heuristic usage we developed here, a number of more general and case-specific classes of evaluative criteria can be explored according to the task for which levels are applied.\textsuperscript{15} The question now is no longer whether ‘levels’ is significant, but rather in how many ways is it useful. A novel contribution of our account is that it effectively allows us to compartmentalize the assessment of ‘levels’ to criteria derived from the concept’s use by specific scientific actors or groups.

4.1 Evaluative Dimensions of the Levels Concept

Seen as a fragmentary concept, the commitments resulting from any particular usage of levels will consequently be localized to the particular content of the term in that instance, and specifically relative to the task for which that instance of the term is applied. In our heuristic approach, ‘levels’ are not reified into a comprehensive delineation of all things natural and scientific (cf. Oppenheim and Putnam 1958), since (1) levels are not (necessarily) ontological “levels of nature” (cf. Craver 2007, 170), but can also be primarily epistemic (see Wimsatt’s comments on using levels to get the “biggest bang for your buck”; 2007, 211, 357), and (2) levels are not rigid, universal, or exhaustive, but rather context-dependent and conceptually flexible (Findlay and Thagard 2012; Craver 2015, 1; see also Darden 1991, 19). This marks a decisive retreat from overly restrictive conceptions of levels such as Oppenheim and Putnam’s layer-cake model (Brooks 2017; Potochnik and McGill 2012).

In this framework, several general dimensions of evaluation for ‘levels’ can be identified (see also Ylikoski & Kuorikoski 2010 for a similar discussion on evaluating explanatory power). For instance, one may first ask whether levels-mediated descriptions obscure the details of the system in question being treated (given the particular scientific task at hand), or whether they

\textsuperscript{15} The criteria we discuss are generally applicable to wide ranges of problems, regardless of the domain specificity of those problems. These do not preclude more fine-grained aims encompassing the usage of ‘levels’ in specific research communities, which will result in more specific criteria to reflect the particular, perhaps idiosyncratic, aims of applying ‘levels’ in alignment with its epistemic goal.
adequately capture, or prepare to capture, aspects that contribute to the completion of that task. Another dimension pertains to Levin’s (2006) discussion of the *accuracy* in capturing faithfully the descriptive details of the system in question for the epistemic purposes at hand. For instance, in neuronal modeling, the fact that observed neuronal behavior was omitted from computational model predictions served as an impetus for further studies by neuroscientists (Almog and Korngreen 2016, 2202). Subsequent work on characterizing neuronal behavior shifted towards experimental data produced by work at supra- and sub-neuronal organizational levels, as these were seen to be corrective of computational model predictions precisely because they were thought to more accurately reflect what was happening in the brain (e.g. Almog and Korngreen 2016). Moreover, the level concept’s usefulness can be evaluated according to whether the descriptions it enables capture the *relevant* details of a system under investigation. Nervous systems are by all accounts multileveled structures (Craver 2007, 1; Almog and Korngreen 2016, ibid). Whenever one methodological orientation misses some of the details considered relevant for a common task, levels-mediated descriptions may aid to adjudicate between discrepant characterizations. Likewise, whether ‘levels’ in fact contributes to guiding scientific research is yet another general evaluative dimension one can consider. The take-home message here is that each of these dimensions possess independent, piecemeal validity for determining whether the concept is considered “useful”.

‘Levels’ is also assessable by localized criteria of evaluation. Consider the term when used within a heuristic strategy (section 3.2). Firstly, one interesting feature exhibited by this usage of levels is its explicitly normative component, which follows not from the levels concept itself, but rather from the heuristic strategy in which it is embedded. ‘Levels’ here, though descriptive of nature or science, is directly instrumental in proposing a certain action or set of actions toward accomplishing a problem-structuring tasks. The products of these actions can be evaluated in terms of their usefulness for the local problem situation. Another interesting feature of this usage of ‘levels’ is that it can contribute to the limitations of the embedding strategies, particularly in the possibly limiting biases these heuristics introduce into the performance for the tasks they are expected to fulfill (see, e.g., Tversky and Kahneman 1974). This, importantly, is not an admission of the weakness or insignificance of such strategies, but rather a sign of the contextualization of ‘levels’ usage to specifiable, concrete tasks; i.e. its heuristic character. Unlike descriptive abstractions, the evaluative criteria for using ‘levels’ embedded in heuristic strategies should be understood relative to the goals of these strategies. For example, if after
“looking to another level” one makes no progress in attacking the problem at hand, then it might just turn out that ‘levels of organization’ will not be a useful concept for that specific problem.

Our sense of heuristic significance hence also captures instances where ‘levels’ is used as a background or auxiliary thesis or hypothesis informing another idea or claim (like reductionism or emergence; Brooks 2017). References to levels as a primitive, doctrinal term can be interpreted as tentatively assuming the term’s reliability as a source of description. Under our account, it is perfectly fine to accept the descriptions given by levels as working hypotheses or as a placeholder for more specific information. Though the specific evaluative criteria spelling out how or whether this occurs will be heavily case-dependent, the general point of salvaging the levels concept against accusations of uselessness should now be well-established.

4.2 Limitations and the Usefulness of ‘Levels’

Importantly, using ‘levels’ can fare better or worse in these evaluative dimensions, and thereby be judged as useful or useless depending on the case at hand. If our aims are not served by the use of levels, the concept is at best misleading, at worst useless. This being said, the usage of ‘levels’ may be evaluated by attending to aims for one group of users that contradict the aims of another group. Since, for instance, abstractions come cheaply and are unavoidable, the question of their usefulness (intended and actual) becomes central. If an abstraction obscures or misses what we wish to capture of the system or phenomenon in question, or otherwise fails to accurately represent the system’s features in a way that enhances or aids the description of a system, then it may be warranted to question the concept’s usefulness in that instance. Likewise, if an abstraction “leads nowhere” (Levins 2006, 743), i.e. fails to guide or inspire directions for research in any interesting way, then it can also fail to be useful. The crucial point is that any judgment of being useless does not immediately generalize to the concept of levels as a whole. Rather, ‘levels’ simply fails to be useful, or perhaps better: is inapplicable, for a given task by a given group of users. Instead of throwing away the concept, we simply search for another tool that better fulfills the task we would have it do. This allows us to account for the direct significance of ‘levels of organization’ in science, but we can also readily acknowledge or even emphasize cases where levels are admittedly problematic. That is, when claims involving levels turn out to be wrong, irrelevant, or otherwise deficient for the task at hand, our account allows these instances to be contextualized into different types of errors.
Take for instance James Griesemer’s discussion of the problematic role of ‘levels’ within strategies for generalizing Darwinian evolution (Griesemer 2005). Griesemer identifies the ambiguity of ‘levels’ as ultimately a hindrance to the merit of generalizations it is used to generate. These ambiguities, he continues, contain commitments made by imposing structural assumptions carried in the idea of ‘levels’ (2005, 110). However, these commitments remain unarticulated concerning what is generalized in the first place. Since structural details of a system comprise the basis of interest one wishes to extrapolate, the degree to which this is abstracted away makes such generalizations from unarticulated assumptions increasingly vacuous (ibid).

The levels concept also exhibits more systematic exceptions or limitations, which can be diagnosed in the (equally systematic) biases in the way that we treat natural systems or the problems we pose of them. Consider how coarse-grained applications of ‘levels’ (particularly those in textbooks) seem to assume that all the constituents of the world can be ordered into a neatly organized hierarchical layout or (see especially Potochnik and McGill 2012 and Brooks 2017 for a discussion of this bias). Underlying this bias is a systematic limitation to the levels concept, in that many natural constituents do not comfortably fit at any level. Morphogenetic fields in developmental biology, for instance, comprise gradients of signaling molecules (morphogens) that spread over different loci of the developing organism in different degrees of concentration, affecting multiple organizational levels simultaneously (Levin 2012, 245; see also Wimsatt 1994/2007, who discusses Brownian motion as an important exception to the levels concept).

Though problematic, these kinds of cases are completely consistent with our account in that levels-mediated descriptions can fail to accurately capture the details of the system in question or that the concept is simply not warranted for a particular problem task (see also Hey 2014, 7). Griesemer’s problem with ‘levels’ is easily resolved, as he himself points out, when one possesses the means and attention to fill in the details of what one is assuming with the levels concept in the first place: “The ambiguity [introduced by ‘levels’] is resolved by making explicit the assumptions in the background theories [of ‘levels’], which specify certain aspects of the causal structure of the biological processes required for the operation of selection and
evolution” (Griesemer 2005, 71). Griesemer also points out that the “contamination” of such ambiguities by ‘levels’ can be “useful and instructive” as they can specify where exactly our attempts to provide generalized evolutionary principles require explicative attention (ibid, 61).

‘Levels’, in other words, provides “the key to abstraction” for cases such as this “in adopting a background theory that identifies relevant kinds of explanatory factors” (Griesemer 2005, 110). This suggests a heuristic role for the usage of ‘levels’ guided by the evaluative criterion of explanatory relevance, all the while exhibiting limitations to its overall usefulness.

Likewise, outright failures of ‘levels’ can be useful (Wimsatt 1981/2007, 68-9). The systematic limitation of ‘levels’ in failing to capture and order all natural constituents (like morphogenetic fields) can actually aid in avoiding biases. Specifically, knowing this limitation of the levels concept will result in the expectation that unconditional uses of the levels concept will always be false (see especially Potochnik and McGill 2012; Brooks 2017). The bias of assuming that the world will be neat and tidily ordered into levels can thereby be avoided if we are careful to only draw conclusions that are warranted from uses of levels conditionalized (or founded) on specific methods and aims.

Erring by itself does not imply uselessness, neither for the levels concept specifically nor for scientific reasoning in general (Wimsatt 2007, 22-3). Systematic error is endemic to heuristic notions, and is even expected of them as a constituent part of their usage. This, as Wimsatt points out, is not something to be vilified, but rather embraced, as mundane to scientific concepts in general: “Now we have come to the crux of the issue [of error in science]: we can't idealize deviations and errors out of existence in our normative theories because they are central to our methodology ... Errors are often sources of creative elaboration” (Wimsatt 2007, 23). Failure in science can also lead to insightful work on the progression of science, as notions such as

\[16\] Griesemer’s understanding of ‘levels’ is quite close to ours. First, he notes that ‘levels’ operates as a major background assumption that justifies generalizing specific cases of evolution to general evolutionary principles. This corresponds to referring to ‘levels’ as an organizing concept, i.e. the “basic idea” of ‘levels’. Griesemer, secondly, also cites the role of ‘levels’ in a manner similar to our second sense of heuristic usage, saying: “The background theory of hierarchy ought to guide us through applications of the generalized evolutionary theory to problematic cases” (2005, 60; cf. section 3.2 above). This roughly corresponds to the fragmentary conception of ‘levels’ we entertain, insofar as the term comprises a componential set of content that is contextually specifiable.
phlogiston and the chemical intermediate of oxidative phosphorylation (Allchin 1997), and modeling (Knuuttila 2011) strongly attest to. We find it extremely doubtful that ‘levels’ can justifiably be described *wholesale* as a ‘phlogistonal’ notion though, considering its flexibility and usefulness.

5. Conclusion
In this article, we have argued for the heuristic significance of the concept of ‘levels of organization’. This descriptive account characterized ‘levels’ as a fragmentary concept whose meaning is founded in local methods and aims, and which is applied heuristically in at least two major ways: As a descriptive abstraction when describing a system, and as a guide for scientific research when delving into new areas of investigation. Far from being a useless or hopelessly misleading notion, ‘levels of organization’ performs important work in and for science.

6. References


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