The Levels of Scientific Disciplines

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Abstract

It is plausible that the sciences are leveled. Many maintain that physics is more fundamental than chemistry, for example, and that chemistry is more fundamental than biology. I use truth-maker semantics to provide an account of how this is so. In particular, I exploit the mereological structure of states of affairs (which is central to the truth-maker approach) to provide conditions for one scientific discipline to occupy a higher level than another.

Introduction

Philosophy of science is rife with discussions of level. Quite plausibly, physics occupies a lower level than chemistry, which occupies a lower level than biology, which occupies a lower level than ecology, etc. Practicing scientists are also prone to invoking disciplinary levels. It is not uncommon to encounter assertions like, 'This problem ought to be handled at the level of quantum mechanics, rather than organic chemistry.'[1] However, despite the widespread appeal to disciplinary level, there is currently no consensus on what a scientific level itself consists of. While many maintain that physics is more fundamental than chemistry is, it is hardly obvious what makes this the case; what it is in virtue of that one discipline lies at a lower level than another.

One proposal is epistemic. Perhaps we ought to account for scientific level in terms of what is needed to understand that science. The reason chemistry lies at a lower level than biology, on this interpretation, is that an adequate understanding of biology requires at least some comprehension of chemistry, while an adequate understanding of chemistry requires no knowledge of biology at all. More generally, there is a perfectly intelligible interpretation according to which discipline D_1 lies at a higher level than discipline D_2

[1]One example, chosen effectively at random, is the following: "Nowadays, both theoretical and experimental investigations have presented a conclusion that the evanescent modes of the electromagnetic field can superluminally propagate. *At the level of* quantum mechanics, via tunneling analogy the superluminal propagation of evanescent modes has been described as the quantum tunneling behavior of photons, which implies that the superluminality of evanescent modes is due to a quantum effect. In this paper *at the level of* quantum field theory, we will further show that the superluminality of evanescent modes is due to a purely quantum effect, and clarify some misunderstandings on the physical properties of evanescent modes" (Wang, Xiong and He, 2008, pg. 319—emphasis mine).

just in case an understanding of D_1 requires at least some understanding of D_2, but an understanding of D_2 does not require an understanding of D_1.[2]

But there is another conception of level—one that finds its home in metaphysics, rather than epistemology. On this conception, the reason economics lies at a higher level than physics has nothing whatsoever to do with our epistemic access to economic and physical facts. Rather, the disciplines are so-leveled because they stand in a worldly relation to one another. An interpretation of level, then, is an account of what that worldly relation is. It is my aim to provide such an account—to uncover necessary and sufficient conditions for one discipline to occur at a higher level than another.

Here, I identify scientific disciplines with sets of predicates. It may be, for example, that chemistry is associated with {'is a chemical compound,' 'is carbon,' ... } and that biology is associated with {'is an organism,' 'reproduces asexually,' ... }.[3] Of course, there is a great deal more to disciplines than predicates. Each may have its own laws, methods, questions, journals, and much more besides. This identification of disciplines is not intended to exhaust what a discipline consists of—nor is it a definition of what that discipline is. But the disciplines, as standardly understood, can be individuated by the predicates that they characteristically use. Because vocabulary relates to interests, orientations, subject matters, and methods, it can serve to demarcate the boundaries of a field of study. On the present approach, these predicates suffice to construct an account of level.

Here, I exploit the theoretical resources of truth-maker semantics.[4] Roughly, I claim that discipline D_1 lies at a higher level than discipline D_2 just in case the states of affairs which make it the case that an object falls within the purview of D_1 are composed of states of affairs which make it the case that an object falls within the purview of D_2. For example, it may be that the states of affairs which make it the case that an object is water are composed of states of affairs which make it the case that objects are hydrogen and oxygen. Relative disciplinary level thus arises from the mereological structure of states of affairs.

First, a few caveats. What I provide is not intended to be a linguistic analysis of

[2]Arguably, this interpretation of level is intransitive. It may be that ecology is at a higher level than biology, which is at a higher level than chemistry, which is at a higher level than physics. But if an understanding of physics is not needed for an understanding of ecology, then—on this interpretation—ecology does not occur at a higher level than physics.

[3]To the best of my knowledge, the first philosophers to suggest identifying disciplines with sets of predicates were Oppenheim and Putnam (1958). I leave it as an open question which discipline is associated with which set of predicates. Perhaps it is determined sociologically, so that a discipline's predicates are those used by scientists practicing that discipline. My thanks to Barry Loewer for this suggestion. Perhaps it is determined by laws, so that a discipline's predicates are those that figure in a description (perhaps in an idealized language) of that discipline's laws—see Fodor (1974) for a proposal along these lines. Or perhaps it is permissive, so that every set of predicates constitutes a discipline broadly construed, and practical factors determine which disciplines we engage with. However it is that the disciplines are identified with sets of predicates, the account I provide may proceed.

[4]See Fine (2017), deRosset (2017); Elgin (2020) for the development of this approach and its applications to puzzles in the philosophy of science.

'level' as it is used by practicing philosophers and scientists. Given the variety of contexts in which this word occurs, I very much doubt that a univocal account exists. Relatedly, I do not maintain that what I provide is the unique (or best) interpretation. It is perfectly conceivable that two (or more) distinct interpretations explicate the notion of level adequately—perhaps even equally well. Rather, I aim to demonstrate that this account satisfies the theoretical requirements that an interpretation of level ought to satisfy. To that end, I proceed not by arguing that this account is better than all available alternatives, but rather by outlining what I take the theoretical demands on an interpretation of level are, and demonstrating how this account satisfies them.

It may help, in characterizing this program, to recall the Lewis (1970) discussion of the definition of theoretical terms. Roughly, Lewis held that the meaning of a theoretical predicate was given by its expanded postulate: the claim that there is an F which theoretically functions as F is postulated to. The expanded postulate for 'level,' then, is given by the theoretical function that levels are intended to perform. The following discussion of the theoretical requirements of 'level' can thus be understood as providing its expanded postulate—and the ensuing account constitutes the relation that witnesses this existential claim.

Additionally, I am strictly agnostic about which disciplines occupy which levels—and, indeed, on whether the disciplines are leveled at all. Although I occasionally appeal to intuitions about the levels of science, and although I am personally susceptible to the view that there are levels in the actual world, it is perfectly compatible with what I have to say that there are not. In this case, I provide conditions which fail to obtain; the reason that the sciences are unleveled is that they do not stand in the relation I articulate.

Theoretical Desiderata

I maintain that the following are theoretical desiderata for an account of scientific level. An account ought to:

1. Form a strict partial ordering over the disciplines.
2. Account for the reductive component of level.
3. Allow for properties to be multiply realized.
4. Remain agnostic about what the levels of science are.
5. Permit crossover in subject-matter between levels of discipline.

Let us take these in turn.

1. Form A Strict Partial Ordering Over The Disciplines

A binary relation is a strict partial ordering just in case it is irreflexive, asymmetric and transitive. By claiming that an adequate account of level forms such an ordering, I thus maintain that the following obtains:

i) No discipline is at a higher level than itself.
ii) If discipline D_1 is at a higher level than discipline D_2, then discipline D_2 is not at a higher level than discipline D_1.
iii) If discipline D_1 is at a higher level than discipline D_2 and discipline D_2 is at a higher level than discipline D_3, then discipline D_1 is at a higher level than discipline D_3.

I have nothing substantial in support of this desideratum to offer. Its best defense is that it is overwhelmingly obvious that it is true. The intuition that sciences do not occur at higher levels than themselves (and that the other corresponding claims obtain) runs deep. In my mind this is the most indispensable criterion—one whose satisfaction is not merely desirable, but compulsory. An interpretation which fails to from a strict partial ordering over the disciplines ought to be abandoned, regardless of any theoretical benefits it might have.

2. Account For The Reductive Component Of Level

Levels seem inextricably tied to reduction.[5] If physics is the lowest-level discipline, it is no accident that the other disciplines reduce (in some notion of reduction or other) to physics. And if thermodynamics lies at a higher level than statistical mechanics, it seems no accident that thermodynamics reduces to statistical mechanics as well.[6]

Another way to frame this desideratum concerns *relevance*: the lower-level sciences are relevant to the higher-level sciences. It does not suffice, when investigating interdisciplinary level, to demonstrate that two fields of study are merely compatible. Chemistry and physics not only avoid conflict, but complement—physical goings-on are relevant to chemical reactions. And it is partially for this reason that chemistry plausibly lies at a higher level than physics. If the fields had nothing whatsoever to do with one another, it would preclude them from being relatively leveled. Interpretations of scientific level ought to explain why this is the case: to account for the respective relevance of the differing levels.

Some reject reductionism and countenance emergence. Roughly, the thought is that a higher-level property is emergent just in case its existence can be partially—but not wholly—derived from or explained by lower-level properties. For example, emergentists about the mental maintain that although minds depend on brains, mental properties have

[5]For discussions of this point, see Oppenheim and Putnam (1958); Nagel (1961); Fodor (1974). There are numerous types of reduction that might be employed. Perhaps reduction ought to be understood in terms of causation and explanation—see Kim (1998)—organization—see Churchland and Sejnowski (1992)—relative size—see Kemeny and Oppenheim (1956); Oppenheim and Putnam (1958); Wimsatt (1976)—analysis—see Sheperd (1994)—or realization—see Gillett (2002).

[6]See, e.g., Sklar (1993, 1999); Callender (1999); Albert (2000)

features over and above those that their dependence on brains can account for. For our purposes, the important point is that both reductionists and emergentists frame their dispute by appeal to levels.

There is, arguably, a deep conflict between the first two desiderata. It might even be claimed that no account of level could possibly satisfy both and, consequently, that the very notion of level ought to be abandoned. Many maintain that metaphysical reduction is closely tied to identity.[7] If one theory were to reduce to another, but facts about the former remained distinct from facts about the latter, it would seem to be reductive in name only. But if facts about two disciplines are identical, it is difficult to see how either discipline could be at a higher level than the other. That is to say, it appears that the claim that D_1 reduces to D_2 requires that $D_1 = D_2$. But if $D_1 = D_2$, then an application of Leibniz's Law ensures that every property D_1 bears is also borne by D_2.[8] By stipulation, this includes the property of *being at a higher level than* D_2, which entails that D_2 is at a higher level than itself. There is, therefore, a violation of *irreflexivity*, which I have claimed to be indispensable to a theory of level. If an account were—somehow—able to satisfy both the first and second desiderata, it would count substantially in its favor.

3. Allow For Properties To Be Multiply Realized

It is widely accepted that some properties are *multiply realizable.* A property is said to be multiply realizable just in case it can be manifested by diverse underlying configurations. Plastic shaped in the appropriate way may form a cup, but cups can be made of metal or glass as well. And it may be that *being in pain* is associated with firing C-fibers in humans, but it is perfectly conceivable for organisms with other neurological profiles to experience phenomenal pain as well.

Some interpretations of level preclude the possibility of multiply realizable properties. For example, Nagel (1961) requires that the properties of the higher-level sciences be identified with properties in the lower-level sciences. In order for the biological property *being a heart* to reduce to a chemical property, there must be some chemical property that it is identical to. But if *being a heart* is multiply realizable (perhaps hearts can be composed of carbon, silicon, etc.) there may be no one chemical property that it is identical to. We can, of course, identify properties with the disjunction of their instances—perhaps to be a heart is to either be carbon shaped thus and so, silicon shaped thus and so, etc. But, some have argued, these disjunctive identifications are explanatorily poor. One learns much more about the nature of hearts by learning the function that hearts perform, rather than a lengthy disjunction. And because these disjunctive identifications are explanatorily

[7]For recent discussions along these lines, see Dorr (2016); Correia (2017).

[8]There has been extensive recent discussion on how to revise higher-order logic in order to abandon Leibniz's Law—see, e.g., Bacon and Russell (2017); Bacon (2019); Caie, Goodman and Lederman (Forthcoming). One way to avoid the conflict between the asymmetry of reduction and the symmetry of identity is to abandon Leibniz's Law—this method was defended by Correia (2017).

inadequate, they are poor contenders for reduction.

It is challenging to make this objection stick. It assumes that the disjuncts have nothing explanatorily significant in common. If, say, two genotypes gave rise to the same phenotype, the fact that the organism had one of the two would give some explanation of its displaying the phenotypical trait. If we knew that only organisms with one of the genotypes displayed the trait, we would know rather a lot. If we further knew that these two genotypes displayed the same vulnerability, we would be in a very good position to explain the occurrence of the trait, even if the explanation took the form 'This trait can occur in one of two ways'. In any case, one need not claim that the lower-level properties explain the higher level one. The lower-level properties need only make it the case that the higher-level one obtains. Whether or not higher-level properties answer to multiple configurations at a lower level seems a question for empirical science to investigate, and is not something to be decided *a priori*. That being so, a schema for levels should leave the prospect open.

4. Remain Agnostic About What The Levels Of Science Are

An interpretation of level should remain agnostic about what the levels of scientific disciplines are. Philosophers are an ambitious lot. Some, no doubt, are keen for their theories to settle as many debates as possible. But while philosophy may reveal what a level *is*, the sciences determine what the levels *are*. It may be that physics occupies a lower level than biology, and it may be that we have evidence to that effect, but this is not an issue that can be settled by considerations about level alone.

On approaches in which the practice and interpretation of science are intertwined, the commitment to agnosticism may not be so pressing. But there is a method of analysis—a method carried out here—in which the interpretation of level is carried out in a predominantly *a priori* manner. And *a priori* considerations ought not have *a posteriori* results. There is a limit the investigative power of armchair philosophy. Although one can investigate the notion of level through introspection, it is incumbent upon scientists to provide information about the way the world actually is. It may be, as Weinberg (1992) claims, that the arrows of explanation point to the very small; that the lowest level is comprised of a discipline like quantum field or string theory. Others, however, maintain that the arrows point to the very large. Schaffer (2010), for example holds that the universe as a whole is in a state of quantum-entanglement, and that consequently there is more information regarding the whole than there is regarding its parts.[9] However that might be, it is an empirical matter. A theory of level that builds in a commitment to one side or the other of such a debate oversteps its bounds.

[9] I take it that Schaffer's argument, which concerns facts about quantum entanglement, is an argument that relies upon paradigmatically *a posteriori* considerations.

5. Permit Crossover In Subject-Matter Between Levels Of Discipline

The empirical sciences are a motley crew. There are no sharp dividing lines—such that the practitioners of one field dare not venture forth into another. Although 'is carbon dioxide' may be a paradigmatic predicate of chemistry, ecologists may investigate whether volcanic explosions that release sufficient carbon dioxide trigger mass extinctions; some psychologists study how risk-averse people typically are, while behavioral economists investigate how risk-aversion affects macroeconomic trends; and astronomers and physicists alike are concerned with the implications of general relativity. If the notion of levels of science was incompatible with interdisciplinary crossover, the prospects of scientific levels would be poor.[10] Some have advocated abandoning the very notion of level on the grounds that no account could permit such interdisciplinary crossover.[11] Because it is impossible to identify the 'real level' of a phenomenon, the very notion of level may be suspect. However, if there were an account of level which allowed objects to occur at different levels, this objection would lose its bite.

Guttman (1976) and Potochnik and McGill (2012) discuss this point at length.[12] For them, the crossover of subject-matter isn't so much a problem for the analysis of level (they largely assume that levels preclude such crossover), but rather a reason to believe that disciplinary levels do not exist. One of Guttman's examples concerns the study of ecosystems. Although many traditionally conceive of ecosystems as composed of organisms, he notes that ecosystems are actually composed of numerous kinds of things. There are water and air molecules, rivers and mountains, etc. Furthermore, the study of ecosystems does not concern itself solely with the organisms therein, but rather with how organisms interact with these other features of their environment. This observation is in tension with any conception of level incompatible with interdisciplinary crossover (which, Shapiro (Forthcoming) argues, includes Oppenheim and Putnam (1958)'s view). If a concept of level requires that the levels be entirely isolated from one another, it seems unlikely that the sciences are leveled. Numerous things are objects of study in several disciplines. However, if there were a conception of scientific level which allowed for the crossover of subject-matter, it may assuage these concerns.

The criteria I have discussed are not exhaustive; there may well be further conditions that could be added—conditions that reflect any addition theoretical work that the notion of level ought to accomplish. But they are enough to begin. I now turn to current developments in truth-maker semantics, which I rely upon in this account.

[10]This point is briefly endorsed by Oppenheim and Putnam (1958), when they allow for there to be crossover of language between scientific disciplines at different levels (pg. 5). However, they deny that an object at one level has parts at a higher level (pg. 9).

[11]See Wimsatt (2006).

[12]For another such discussion, see Craver (2007, 2015), who argues on these grounds that the scientific disciplines, as actually practiced, do not correspond to levels within nature.

An Overview of the Truth-Maker Approach

The underlying thought behind truth-maker semantics is that there exists something within the world—a state of affairs, perhaps, or a way that the world is—which verifies, or renders true, a representational entity such as a proposition or sentence. Moreover, it is held that the meanings of the representational entities can be identified with that which makes them true.[13]

When stated so generally, this may seem uncontroversial. After all, a great many philosophers—tracing back at least to Tarski (1944), and possibly as far back as Frege (1892)—have identified the meanings of sentences with their truth-conditions. What differentiates truth-maker semantics from more traditional approaches is its commitment to *exact* truth-makers. If a state of affairs verifies a proposition it does not merely necessitate its truth, nor is it merely partially relevant to its truth; rather it is *entirely* relevant to its truth. So, while the state of affairs of grass being green and the sky being blue arguably verifies 'Grass is green and the sky is blue,' it does not verify '$2 + 2 = 4$' despite necessitating the equation's truth, nor does it verify 'Grass is green' because a part of that state—the part concerning the sky being blue—is irrelevant to 'Grass is green.'

On this approach, states of affairs are structured: some are proper parts of others. It may be that the state of roses being red is a proper part of the state of roses being red and violets being blue, and it may be that the state of Jane being a fox is a proper part of the state of Jane being a vixen. Given that states are capable of mereological composition, it is desirable to describe this structure within our formalism. This is accomplished with a state-space: an ordered pair $< S, \sqsubseteq >$ where S is a set of states of affairs, and $\sqsubseteq$ is a binary relation on S, with the intended interpretation of parthood, such that '$s \sqsubseteq s'$' asserts that state s is a part of state s'. Here, I make the standard assumption that parthood is a partial ordering—i.e., that $\sqsubseteq$ satisfies the following criteria:

REFLEXIVITY:	$s \sqsubseteq s$
ANTISYMMETRY:	$(s \sqsubseteq s' \wedge s' \sqsubseteq s) \rightarrow s = s'$
TRANSITIVITY:	$(s \sqsubseteq s' \wedge s' \sqsubseteq s'') \rightarrow s \sqsubseteq s''$

The only additional restriction is that state-spaces are *complete*—that is to say, they allow for arbitrary fusion.[14]

[13] The development of truth-maker semantics is largely due to Fine (2013, 2016, 2017). I rely heavily on these developments within this paper.

[14] For states spaces of finite size, this can be accomplished simply by assuming that every two states within S have a fusion within S. However, this approach fails for infinitely large state-spaces. For these state-spaces, it may be that every finite collection of states within S has a fusion within S, but that there are infinitely large collections of states within S that lack a fusion within S.

Accommodating infinitely large state-spaces requires a few more definitions. First, we may let an *upper bound* of $T \subseteq S$ be a state which contains every state within T as a part: i.e., t is an upper bound of T iff $\forall s \in T, s \sqsubseteq t$. We then say that a state t is a *least-upper-bound* of $T \subseteq S$ iff it is an upper bound of T and

The development of a semantics requires a language which meaning is attributed to. I restrict my attention to a simple, first-order language. This language contains infinitely many predicates $F_1, F_2, ...$, of fixed adicity, infinitely many names $a_1, a_2, ...$ such that there is a unique name for every object, and the logical operators $\neg, \wedge, \vee$—each of which is defined in the standard way. Additionally, this language is equipped with infinitely many variables $x_1, x_2, ...$ and the quantifiers $\exists, \forall$, which serve both to bind the variables and to express generality.

Let a model $\boldsymbol{M}$ be an ordered quadruple $< S, \sqsubseteq, I, |\cdot| >$ such that $< S, \sqsubseteq >$ is a complete state-space, I is the set of individuals, and $|\cdot|$ is a valuation function which takes, as its input, an atomic sentence (i.e., the application of a predicate to names of objects—something like 'John is human'), and has, as its output, an ordered pair $< V, F >$ where both V and F are subsets of S—intuitively those states of affairs which verify and falsify the input respectively. So, for example, if the valuation function were to take 'Mary is tall' as its input, its output may be the ordered pair $< \{\textit{Mary being tall}\}, \{\textit{Mary being not tall}\} >$—i.e., the ordered pair whose first element is the singleton set containing the state of Mary being tall, and the second element is the singleton set containing the state of Mary being not tall. With the definition of a model in place, we may then define our semantics inductively:

$i.^+$ $\quad s \Vdash Fa$ iff $s \in |Fa|^V$

$i.^-$ $\quad s \dashV Fa$ iff $s \in |Fa|^F$

$ii.^+$ $\quad s \Vdash \neg A$ iff $s \dashV A$

$ii.^-$ $\quad s \dashV \neg A$ iff $s \Vdash A$

$iii.^+$ $\quad s \Vdash A \wedge B$ iff there exist t, u such that $t \Vdash A$ and $u \Vdash B$ and $s = t \sqcup u$.

$iii.^-$ $\quad s \dashV A \wedge B$ iff either $s \dashV A$ or $s \dashV B$

$iv.^+$ $\quad s \Vdash A \vee B$ iff either $s \Vdash A$ or $s \Vdash B$

$iv.^-$ $\quad s \dashV A \vee B$ iff there exist t, u such that $t \dashV A$ and $u \Vdash B$ and $s = t \sqcup u$

It is my hope that this semantics is extraordinarily intuitive. Negation swaps a sentence's verifiers for its falsifiers; if the state of it being windy verifies 'It is windy' then it falsifies 'It is not windy.' Verifiers of conjunctions are fusions of verifiers of their conjuncts; if the state of the ball being red verifies 'The ball is red,' and if the state of the ball being round verifies 'The ball is round,' then the fusion of these states—the state of the ball being red and being round—verifies 'The ball is red and round.' Verifiers of disjunctions are verifiers of a disjunct; if the state of water being wet verifies 'Water is wet,' then it also

is a part of all upper bounds of T: i.e., just in case if s is a least upper bound of T, then $t \sqsubseteq s$. Provably, if a set has a least upper bound, then it has a unique least upper bound. Suppose, for reductio, that a set T had two least upper bounds t and t'. Because they are both least upper bounds, they are both upper bounds. And because each least upper bound contains every upper bound as a part, it follows that $t \sqsubseteq t'$ and $t' \sqsubseteq t$. Given antisymmetry, this then entails $t = t'$. We denote the least upper bound of T as $\bigsqcup T$. A complete state-space is one in which every subset of S contains a least upper bound within S. For the purposes of this paper, I restrict my attention to complete state-spaces.

verifies 'Water is wet or sand is wet.'

There are several ways to expand this semantics to clauses with quantifiers. We might, for example, countenance generic objects—so that a verifier of 'Everything is F' is a verifier of a generic object being F. The approach I adopt, instead, is instantial. Verifiers of universal statements are fusions of verifiers of their instances. So a verifier of '$\forall xFx$' is the fusion of a verifier of 'Fa' with a verifier of 'Fb,' etc. Verifiers of existential statements are verifiers of their witnessing instances. The state of affairs which verifies '$\exists xFx$' is a state of affairs which makes it the case that a particular object is F. More formally, we have:

$v.^{+}$ $s \Vdash \forall xFx$ iff there is a function $f : I \to S$ such that $f(i) \Vdash F(i)$ for all $i \in I$ and $s = \bigsqcup\{f(i) : i \in I\}$
$v.^{-}$ $s \dashV \forall xFx$ iff there is some a such that $s \dashV Fa$
$vi.^{+}$ $s \Vdash \exists xFx$ iff there is some a such that $s \Vdash Fa$
$vi.^{-}$ $s \dashV \exists xFx$ iff there is a function $f : I \to S$ such that $f(i) \dashV F(i)$ for all $i \in I$ and $s = \bigsqcup\{f(i) : i \in I\}$

There is a wide variety of philosophical uses for this semantics. Some have argued that it underlies the logic of analytic content (see Fine (2013, 2016)), deontic logic (see Fine (2018*a*,*b*)), counterfactual conditionals (see Fine (2012)), natural language semantics Moltmann (2020), epistemic closure Elgin (Forthcoming*a*), and philosophical analysis (see Correia and Skiles (2017); Elgin (Forthcoming*b*)). But its closest application, to our present concern, occurs in Elgin (2020) who defends an interpretation of identity theory in terms of truth-maker semantics. In particular, he claims that the distinction between type-identity theory (the claim that every type is identical to a physical type) and token-identity theory (the claim that every token is identical to a physical token) is dissolved, and that this dissolution resolves canonical problems with both interpretations. The present aim, however, is not with the reflexive and symmetric relation of identity, but with an irreflexive and asymmetric relation of relative level.

An Account of the Levels of Science

I seek conditions for one scientific discipline to lie at a higher level than another: for what it is that completes the biconditional *Higher Level* (D_1, D_2) *iff ...* , where both D_1 and D_2 are scientific disciplines. Recall that, for the present purpose, I identify scientific disciplines with sets of predicates—where the number of predicates within each discipline may or may not be finite. Let us identify D_1 and D_2 with the following:

$D_1 = \{F_1, F_2, ...\}$
$D_2 = \{G_1, G_2, ...\}$

The motivation behind this account is that the relation between D_1 and D_2 arises from the mereological structure of states of affairs. It may be that 'a is a water molecule' has verifiers, and that these verifiers have proper parts. Arguably, the state which verifies that a is water is itself composed of states of affairs concerning hydrogen and oxygen—i.e., perhaps that which makes it the case that a is a water molecule is something which can be decomposed into states which make it the case that the parts of a are hydrogen and oxygen composed in a particular configuration. If this is correct, we might account for the difference in level between chemistry and physics, for example, by appealing to the fact that the verifiers of chemical statements (i.e., statements which predicate a chemical predicate of an object or some objects) are composed of verifiers of physical statements (i.e., statements which predicate a physical predicate of an object or some objects). So, at an *extremely* rough first pass, we might claim:

Higher Level(D_1, D_2) iff
$s \Vdash Fa \rightarrow (((t) \sqsubseteq s) \rightarrow (t) \Vdash Ga)$

For the moment, let (t) remain a free variable ranging over states of affairs. This proposal claims that discipline D_1 is at a higher level than discipline D_2 just in case, if state s verifies Fa, then if (t) is a part of s, then t verifies Ga. Obviously, refinements are required at the outset—minimally, s, F, a and G must be replaced by terms bound by various quantifiers. After all, it is not enough for there to be a particular state of affairs, predicate and object for which this condition holds; rather, it applies generally. Interestingly, the choice and placement of these quantifiers impacts the satisfaction of the theoretical desiderata.[15] Replacing the terms with variables bound by the appropriate quantifiers results in the following:

Higher Level(D_1, D_2) iff
$\forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow ((t) \sqsubseteq s \rightarrow \exists G_m((t) \Vdash G_m x)))$

As before, (t) remains a free variable. This claims that D_1 is at a higher level than D_2 just in case for all states of affairs, for all predicates within D_1, and for all objects, if a state verifies that an object falls under the scope of a higher-level predicate, then if (t) is a part of that state, then (t) verifies that the object falls under the scope of some lower-level predicate.

Yet another refinement is in order. It need not be the very same object which satisfies the higher-level predicate be the object which satisfies the lower-level predicate. If an object is a water molecule, different objects satisfy the predicate 'is a water molecule' and 'is hydrogen.' So, instead of requiring that a state which verifies that an object is F is composed of states which verify that *the very same object* is G, I allow for these states to verify that some object or other is G, i.e.:

[15] This point is discussed in greater depth when below in reference to the desideratum concerning multiple realizability.

Higher Level(D_1, D_2) iff
$\forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow ((t) \sqsubseteq s \rightarrow \exists G_m \exists y((t) \Vdash G_m y)))$

Perhaps some suspect that further restrictions are needed After all, if an object is a water molecule, it is not merely the case that some-objects-or-other are hydrogen and oxygen; rather, the parts of that very water molecule are hydrogen and oxygen. So, perhaps we ought to impose the further requirement that the objects which satisfy the predicates of the lower-level discipline compose the objects which satisfy the predicate of the higher-level discipline.

This is not an approach I take. I note that, as the formalism currently stands, the relation of mereological composition is not defined upon the set of objects; it is a relation that holds between states of affairs. In order to describe mereological relations between objects, the semantics would need to be revamped—to reintroduce a notion of composition which holds between objects. Of course, nothing would stop us from modifying the semantics in this way, but it is incapable of this modification without further refinement.

So far so good, but we now face the elephant in the room: the free variable (t). As I suspect those with a rudimentary understanding of logic have considered by now, an obvious approach is to bind this variable with a universal quantifier. On that proposal, if a state verifies that an object is F (for some higher-level predicate F), it must be the case that every part of that state verifies that an object is G (for some lower-level predicate G). We would then have:

Higher Level(D_1, D_2) iff
$\forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow \forall t(t \sqsubseteq s \rightarrow \exists G_m \exists y(t \Vdash G_m y)))$

This proposal has the advantage of being truth-evaluable: it has the disadvantage of being false. The problem is perhaps easiest to appreciate by shifting back to the (arguably more conventional) way of understanding mereology as a relation between objects. If a water molecule is composed of hydrogen and oxygen, it isn't the case that every part of that water molecule is either hydrogen or oxygen. After all, these atomic parts can themselves be decomposed into their subatomic constituents. A proton which partially composes the oxygen atom is itself a part of the water molecule, but the proton is neither hydrogen nor oxygen. This problem resurfaces when mereology is taken to be a relation between states. Suppose that state s is the state of a's being a water molecule, and further that this state verifies 'a is a water molecule.' It may be that this state can be decomposed into states concerning atomic physics—i.e., states concerning hydrogen and oxygen. These states may themselves be decomposed into states which verify that objects are electrons, protons, quarks, and the like. If this is so, then state s has parts which do not verify that an object satisfies the predicates of atomic physics. Some of its parts concern *subatomic* physics, rather than atomic physics. And so, on the present proposal, this would insure that chemistry is not at a higher level than atomic physics. But, surely, this is not the kind of thing which ought to prevent one discipline from occupying a higher level than another. So the universal quantifier doesn't work: it's just too strong.

Exchanging the universal for an existential quantifier is hardly an improvement. In particular, such a proposal could not hope to accommodate the reductive component of levels. Suppose, for example, that there were a discipline which involved the interactions of atomic physics and disembodied minds. A state verifies 'Fa' in this discipline, just in case a part of it verifies that there is a disembodied mind and another part verifies that a is a hydrogen atom. In this case, a part of a verifier of 'Fa' concerns atomic physics, so this discipline would occupy a higher level than atomic physics (assuming that other verifiers acted appropriately as well). But it would be absurd to take this to lend support to the claim that this discipline reduces to atomic physics. After all, a part of its subject-matter is disembodied minds; something which has nothing to do with atomic physics at all. And so, while the universal quantifier is far too strong, the existential quantifier is far too weak. Some intermediate position is required in their place.[16]

For the sake of clarity, let us once again revert to a notion of mereology as a relation between objects. What does it mean to claim that two hydrogen and one oxygen atoms compose a water molecule? It is not the claim that every part of the water molecule are the hydrogen and oxygen atoms; after all, the parts of these atoms are themselves parts of that molecule. Rather, it is the claim is that the hydrogen and oxygen atoms so-configured leave nothing out. The object which is composed of the hydrogen and oxygen atoms misses no part of the water molecule; it is identical to it. A similar move can be made with regard to the mereology of states of affairs. The claim that the parts of state s verify that something is G does not amount to the claim that *all* parts of s verify that something is G. Rather, it is the claim that we can fully describe state s—we can leave nothing out—when describing it in terms of its parts that verify that something is G. That is to say, there are parts of s—each of which verifies that something is G—whose fusion is identical to s.

There are (at least) two ways could represent this formally, one of which employs plural quantification and the other of which quantifies over sets. I will primarily address the formulation in terms of set-quantification, but I mean nothing metaphysically robust by that choice. As before, allowing S to be the set of states of affairs, results in the following condition:

Higher Level(D_1, D_2) iff
$$\forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow \exists T \subseteq S(\bigsqcup T = s \wedge \forall t \in T, \exists G_m, \exists y(t \Vdash G_m y)))$$

The notation is becoming more cumbersome, but the underlying thought (hopefully) remains intuitive. If a state of affairs verifies that an object is F (where F is a predicate

[16] It might also be suggested that we require a notion of normality or typicality: perhaps a typical part of a verifier of the higher-level discipline involves a verifier of the lower level discipline. I myself am skeptical that this strategy will succeed. It seems eminently plausible to me that a typical verifier of 'a is a hydrogen atom' involves subatomic, rather than atomic particles—after all, every helium atom is composed of subatomic particles.

of the higher-level discipline), then there exists some set of states of affairs, the fusion of which is identical to s, such that each element of that set verifies that an object is G (where G is a predicate of the lower-level discipline). This is perfectly compatible with the claim that s has parts which don't verify that something is G; all that is required is that s is identical to some fusion or other of states which *do* verify that something is G. If these states themselves have parts which are unrelated to G, that need not undermine the claim that one discipline is at a higher level than the other. This also resolves the problem which plagued the existential quantifier—of a discipline concerning atomic physics and disembodied minds. If a state s cannot be decomposed into states within the scope of atomic physics (because, perhaps, one part of s verifies that an object is a disembodied mind), then it does not satisfy the present condition.

At long last, we have arrived at a putative account of what it takes for a discipline to be at a higher level than another. It is now possible to examine its theoretical virtues—to determine whether it satisfies the desiderata for a theory of level. The first, and arguably most indispensable, criterion was that an account ought to form a strict-partial ordering over the disciplines—that it ought to be irreflexive, transitive and asymmetric. So, how does the present account fare?

Not well, unfortunately. The relation is transitive, all right, but it's also reflexive. That is to say, not only is this account *compatible* with the claim that a discipline is at a higher than itself, but rather it *entails* that every discipline is at a higher level than itself.[17]

Something has gone wrong, and rather catastrophically so. In comparison to accounts with a free variable, this at least has the virtue of being truth-evaluable—but it has the vice of being false. It cannot be correct as it stands, for it fails to satisfy a central requirement for a theory of level.

What is it that went wrong? It seems to me that the account has narrowly missed its mark. The relation it defines is not that of *being at a higher level than*, but rather *being at the same or a higher level than.* I had attempted to define $>$, but ultimately defined $\geqslant$ instead. But once we have a definition of $\geqslant$, it is straightforward to define $>$. To be greater than is to be greater than or equal to and not equal to. In the present context:

Higher Level(D_1, D_2) iff
$\forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow \exists T \subseteq S(\bigsqcup T = s \wedge \forall t \in T, \exists G_m, \exists y(t \Vdash G_m y))) \wedge D_1 \neq D_2$.

This simply results from appending the requirement that the disciplines not be identical to the previous account. What does it mean to claim that $D_1 \neq D_2$? On the present approach, disciplines are identified with sets of predicates, so to say that two disciplines are distinct is to say that their respective predicates are distinct.

[17]To see why this is the case, select an arbitrary discipline D, which may be identified with the predicates $F_1, F_2, \ldots$. Select an arbitrary s, F_n and o such that $s \Vdash F_n o$—i.e., an arbitrary state of affairs that an arbitrary object is F for an arbitrary F. In this case, there is a $T \subseteq S$ (in particular, $\{s\}$) such that $\bigsqcup T = s$ (i.e., $\bigsqcup\{s\} = s$) and every element of T verifies that some object or other is F_n (i.e., $\exists x(s \Vdash F_n x)$).

There are two ways this requirement might be met—one more demanding than the other. On the more demanding conception, we might require that the discipline's predicates be *entirely* distinct—that no predicate employed within one discipline be employed by the other. On the less demanding conception, all that is required is that the disciplines have *at least some* predicates that are distinct. Perhaps they have no predicates in common at all, but there may be some overlap. All that is required is that one discipline have a predicate which the other lacks.

The demanding conception is far too restrictive for practical purposes. Of course, from a logical perspective, the conditions are perfectly well defined. But I think it unlikely that any scientific discipline is at a higher level than another with this restriction in place. Minimally, it seems inevitable that numerous disciplines will employ mathematical predicates. If this precluded one from being at a higher level than another, it is extraordinarily unlikely that the disciplines would be leveled. However, even if we jettison the restrictive conception, the moderate one remains. All that is required, on this conception, is that there be some difference in predicates between different disciplines. But whichever approach we adopt, the first theoretical desideratum is satisfied: this account forms a strict partial ordering.

The second requirement was that an account of level ought to explain the sense in which higher level sciences reduce to lower level sciences. If chemistry is at a higher level than physics, there ought to be a way in which chemical truths can be reduced to physical truths.

This is a requirement the present account easily accommodates. If chemistry occupies a higher level than physics, then states of affairs which verify that an object is F (for a chemical predicate F) are composed of states of affairs which verify that an object is G (for a physical predicate G). The reason this account is reductive is precisely the same reason that mereology is reductive: the fusion of parts is identical to a whole.

A few points at this stage: recall that it seemed unclear how any account could be both irreflexive and reductive—and yet this is a criterion that the present account easily accommodates. It is irreflexive in that it forms a strict partial ordering, and yet reductive in its use of mereological structure. I take it that this is a strong mark in favor of this theory. However, it is worth emphasizing the respects in which this account is *not* reductive. It does not, for example, entail that the laws of the higher level disciplines reduce to laws of lower-level disciplines. Those who doubt that the laws reduce may nevertheless maintain that the disciplines are leveled if they adopt this interpretation. In contrast, those who seek a reduction of law must adopt some other notion of reduction for their demand to be met.

The third criterion is that an account of scientific level ought to allow for predicates to be multiply realized. It may be that 'heart' is a biological predicate, but that hearts may be composed of many types of things. Perhaps carbon shaped thus-and-so constitutes a heart in many cases, but an artificial heart composed of plastic counts as well. Minimally, an account of level ought not preclude the possibility that some predicates may be multiply realized.

It is here that the power of the truth-maker account comes to the fore. There is no requirement, on this approach, that the truth-makers of predicates resemble one another in any way. The claim 'John has a heart' may have a truth-maker which is vastly dissimilar from truth-makers of 'Jane has a heart.' For a higher-level predicate F, all that is required is that, for an arbitrary name a, 'Fa' be verified by states that are decomposable into states concerning lower level predicates G. There is no requirement that these be the same lower level predicates which verifiers of 'Fb' are decomposable into. It may be that a verifier of 'Fa' concerns predicates $G_1 - G_m$, while a verifier of 'Fb' concerns predicates $G_n - G_o$. That is, what makes it the case that a is F may concern some lower-level predicates, and what makes it the case that b is F may concern *different* lower-level predicates. So long as each instance may be decomposed into states concerning some lower-level predicates or other, the present conditions are satisfied.

It was important, when developing this account, to place the quantifiers as they are placed. Consider the following alternative, which simply shifts the placement of an existential quantifier:

> *Higher Level*(D_1, D_2) iff
> $\forall s, \forall F_n, \forall x, \exists G_m(s \Vdash F_n x \rightarrow \exists T \subseteq S(\bigsqcup T = s \wedge \forall t \in T, \exists y(t \Vdash G_m y))) \wedge D_1 \neq D_2$.

This account is poorly equipped to accommodate multiple realizability. It requires that, for every predicate of the higher-level science, there be a *unique* lower-level predicate such that states which verify statements with the higher-level predicate are decomposable into states which verify statements with the lower-level predicate. If a state which verifies 'John has a heart' may be decomposed into states concerning 'Carbon,' then 'Jane has a heart' must be decomposable into states concerning 'Carbon' as well (on the assumption that biology is at a higher level than chemistry).

Shifting the existential quantifier further results in an account which is more restrictive still:

> *Higher Level*(D_1, D_2) iff
> $\exists G_m, \forall s, \forall F_n, \forall x(s \Vdash F_n x \rightarrow \exists T \subseteq S(\bigsqcup T = s \wedge \forall t \in T, \exists y(t \Vdash G_m y))) \wedge D_1 \neq D_2$.

This not only requires that each higher-level predicate be associated with the same lower-level predicate. Rather, it maintains that there is a unique lower-level predicate that every higher-level predicate is associated with. For each statement involving any higher-level predicate, its verifiers must be decomposable into states which verify statements involving the same lower-level predicate. Suppose, for the sake of argument that 'has a heart' and 'has a kidney' are both biological predicates, while 'is made of carbon' is a chemical predicate. On this approach, if 'John has a heart' is verified by a state which can be decomposed into states concerning 'is made of carbon,' then in order for biology to lie at a higher level than chemistry, ‘Jane has a kidney’ must be verified by states that can be decomposed into states concerning ‘is made of carbon’ as well.[18] Both of these alternatives are far more restrictive than the original account which, in contrast, has no difficulty in accounting for predicates which are multiply realized.

The fourth requirement was that an account ought not to take a stand on what the levels of the empirical sciences actually are. One cannot, simply by reflecting upon the concept of level, come to realize that ecology is at a higher level than physics.

This is an area where the shift to discussions of mereology in terms of states of affairs, rather than objects, proves beneficial. It is natural to think of the mereology of states as mirroring, perhaps imperfectly, the mereology of objects. So if hydrogen and oxygen atoms compose a water molecule, one might suspect that states of affairs concerning hydrogen and oxygen compose states of affairs concerning water. And, indeed, many examples I have used throughout this paper take that precise form. However there is nothing in the truth-maker approach which requires this alignment. It may be that the mereology of states of affairs comes entirely apart from the mereology of objects. Perhaps oxygen and hydrogen atoms compose a water molecule, but states of affairs about water compose states of affairs about oxygen and hydrogen. This possibility is unintuitive, but there is nothing from a semantic perspective which precludes it from being the case. And so, this account does *not* assume that sciences concerning smaller objects are the only candidates for lower-level sciences. Of course, it may turn out that these types of objects lie at the more fundamental level, but this is not something which follows from the analysis of level alone.

The final criterion is that there should be some crossover between the subject matter of disciplines at different levels. Coming to recognize that two fields are compatible may increase our general understanding, but compatibility is not itself enough to guarantee that the sciences operate at different levels from one another.

In the first place, this is achieved by allowing the same predicates to occur within disciplines at different levels. If both ecology and chemistry employ the predicate ‘hydrogen,’ then they may be disciplines which concern hydrogen. And the more predicates that disciplines have in common, the greater the overlap in their subject matter will be.

As it turns out, there already exists an account of subject-matter in terms of truth-maker semantics. Fine (2017) outlines one such account, partially in response to Yablo (2014). Fine is primarily concerned with the subject-matter of sentences, rather than disciplines. He identifies the subject-matter of sentences with the fusions of their verifiers. Let us suppose that ‘Roses are red or violets are blue’ has two verifiers—the state of roses being red and the state of violets being blue. In this case, the subject-matter of the sentence—what the sentence is about—is the state of affairs of roses being red and violets being blue. Any other sentence whose fusion of verifiers is the same (e.g., the sentence ‘Roses are red and violets are blue’) is about precisely the same thing. Some sentences

[18] Of course, for this particular example the result is not entirely implausible. But it should be clear that this generalizes to the point where it is doubtful that accounts are leveled.

have a subject matter which is a part of others. If the only verifier of 'Roses are red' is the state of roses being red, then the subject-matter of 'roses are red' is a part of the subject matter of 'Roses are red or violets are blue.' The subject-matter of the atomic sentence is a literal part of the subject-matter of the disjunctive sentence.

It is readily possible to expand this account of subject-matter to disciplines. Once we identify disciplines with sets of predicates, we might identify the subject matter of a discipline with the fusion of the verifiers of all sentences within that language. So, for example, if chemistry consists partially in 'is Nitrogen' and 'is Helium,' then the subject-matter of chemistry will be the fusion of states of affairs which verify that a is hydrogen with those that verify that b is Helium, etc.

The contention that leveled disciplines are about the same thing can be interpreted almost literally on the present approach. The states of affairs which make it the case that higher-level predicates obtain are all composed of states which make lower-level predicates obtain. So the subject matter of a higher-level discipline is literally a part of the subject-matter of the lower-level discipline. And so this accounts for leveled disciplines to share the same subject-matter.

It has been my aim to explicate an account of scientific level on the truth-maker approach. This account, I maintain, satisfies numerous plausible criteria for scientific level. As such, it is a worthy candidate.

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