Scientific Polysemy, Semantic Detoxification, and Sophisticated Operationalism*

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February 16, 2022

Abstract

Two commonplace phenomena of scientific practice have been taken to challenge operationalism. I provide a version of operationalism that, in fact, explains these phenomena: scientific polysemy and semantic detoxification. Scientific polysemy is generated by cases of semantic extension: the extension of the usage of old terminology in new theoretical or experimental regimes. The changes in the usage of that terminology result in polysemy. Semantic detoxification follows semantic extension's resultant polysemy; it is a reconciliation of novel and past usages. The new usage takes priority over older uses in the novel context, correcting and circumscribing old usages in their native contexts. Focusing on the case of quantity terms, I present a holist operationalism that explains both phenomena: Multiple meanings arise because of differences in the relation of some quantity to other quantities; Multiple meanings are unified into one term because the functional roles determined by these meanings all share analogous positions in the different contexts, specified by the quantity dimension.

*I'd like to thank Alexis Wellwood and Porter Williams for discussion of various drafts and ancestors of this paper. I'd also like to give thanks to the audience at the 2021 Young Scholars Pragmatism Conference in Cambridge generally. And I especially want to give thanks to the organizers: Céline Henne, Oscar Westerblad, Bobby Vos, Miguel Ohnesorge, and Sarah Hijmans. I'd also like to thank Cristian Larroulet Philippi for some helpful and stimulating discussion regarding these matters. This work was supported by a Ralph and Francine Flewelling Graduate Fellowship.

Contents

1 Introduction

This paper establishes and describes two commonplace phenomena of scientific practice which have been taken to challenge forms of operationalism, and provides a version of operationalism that, in fact, explains these phenomena. The first of the two phenomena is scientific polysemy, which is generated by cases of theoretical change as well as "semantic extension" which occurs in the usage of old terminology in new contexts (Chang, 2004). Of particular concern are cases in which quantitative terms develop polysemy due to differences in measurement standards—this tends to involve both theoretical and experimental changes. A term (or concept)[1] is polysemous if it has a plurality of meanings or senses that are related in a systematic way, e.g. book as object and book as information. The second phenomena, semantic detoxification, coined by Wilson (2006), follows semantic extension in a scientific context. Semantic detoxification is a reconciliation of novel and past usages of a term. The new usage comes to not only take priority over older uses in the novel context but also to correct and circumscribe old uses of the term, validating the old usage in its native contexts. This is commonly seen in cases where the value of the quantity associated with some term comes to be equivalent to the value of the old definition of the term as some limit is approached, e.g. relativistic velocity reducing to classical velocity when $v << c$.

The concurrent use of different—and inconsistent—theoretical and experimental conceptions of quantity terms has been taken to undermine the operationalism developed by Bridgman (1927)). Operationalism involves a semantic thesis:

> (Bridgman's Semantic Thesis)[2] The meaning of some quantity term is just the set of quantities measurable by some set of operations.[3]

[1]As will be made clear, my preferred understanding of polysemy is that a term is polysemous in virtue of being associated with multiple concepts. Many in the literature talk of distinct meanings or content associated with one concept. This difference in terminology is innocent if we understand concepts to be in some sense mere "pointers" to real semantic content (see e.g. Pietroski, 2018; Glanzberg, 2014, 2011). For a discussion of possible uninnocent uses see 3.2.3.

[2](Chang, 2019, 2004, 148) calls this "Bridgman's reductive theory of meaning". We both argue that this is not the best statement of operationalism.

[3]Compare: "What do we mean by the length of an object? We evidently know what we mean by length if we can tell what the length of any and every object is and for the physicist nothing more is required. To find the length of an object, we have to perform certain physical operations. The concept length is therefore fixed when the operations by which length is measured is fixed: that is, the concept of length involves as much as and nothing more than the set of operations by which length is determined. In general we mean by any concept nothing more than the set of operations; *the concept is synonymous with the corresponding set of operations.*" (Bridgman, 1927,

Here the set of operations refers to the set of operations by which the property indicated by the concept is *measured*. There are two problems for this semantic thesis with respect to polysemy:

> (Overgeneration) New measurement operations proliferate concepts associated with a term, undermining comparisons of the new and old usages of the term, e.g. of relative precision. The proliferation of *distinct* meanings generates *ambiguous* rather than *polysemous* quantity terms.
>
> (Underspecification) Operations for measurement underspecify meaning?in particular, the reduction of the theoretical terms to measurement operations fails to provide the explanatory power that theories have over lists of facts.[4]

Building on several reappraisals of operationalism,[5] I develop a liberalized version of operationalism that allows multiple sets of operations, including inconsistent sets, to comprise the meaning of polysemous quantity terms. This account explains both faces of scientific polysemy. Different meanings of a term arise because of differences in the relation of some quantity to other quantities. These different meanings are unified into one term because they all share an analogous position in the different theoretical and experimental contexts, as specified by the quantity's *dimensionality*.

2 Scientific Polysemy

The aim of this section is to present the linguistic phenomenon of polysemy, distinguishing it from other forms of semantic underdetermination, and to convince the reader that polysemy as such is endemic to the sciences in both experimental and theoretical contexts.

5, his emphasis) Just add the adjective "actual" to "meaning" or "concept" to make the thesis intensional—an extensional conception of meaning is sufficient to get the problematic going.

[4]My focus is primarily on the overgeneration objection, though I take my discussion of the reality criterion to provide a partial response to the underspecification objection: no single measurement procedure exhausts meaning, but they all do so conjointly (and temporarily). I cannot say if this theory of meaning answers the explanatory version of the underspecification objection. For a discussion of these sorts of objections in the context of verificationism, see Uebel (2019).

[5]Including Hempel (1965), Chang (2004, 2017, 2019), and Vessonen (2021).

2.1 Polysemy as Linguistic Phenomenon

The presentation of polysemy given here is primarily contrastive. A positive semantic account of polysemy is not intended, and there is as of yet no consensus in linguistics or linguisitic philosophy. By the end of this paper a semantic account of *scientific* polysemy will be given; however, how this fits into a broader theory of semantics is left undetermined. Polysemy is a phenomenon of semantic underdetermination and is to be understood as distinct from other forms of semantic underdetermination such as structural ambiguity and lexical ambiguity.

A simple understanding of polysemy is that it is a phenomenon in which some word has multiple meanings which are distinct but related. One class of paradigm examples is content-container words:

(1) Joe can drink ten bottles of beer in one sitting.

(2) Joe likes to smash beer bottles against the wall once they're empty.

In (1) "bottle" is used as a unit of measurement of the content of the container;[6] here it refers to beer. In (2) "bottle" refers to the glass container itself. These meanings are clearly related but are distinct; we cannot drink glass bottles nor can we smash (liquid) beer. Another class of paradigm examples is object-information polysemy:

(3) The schoolboy's bag was full of heavy books.

(4) The schoolgirl could not remember the plot of the book she read for class.

In (3) "book" refers to a physical object made of paper, ink, and glue, with some magnitude of mass. In (4) "book" refers to the informational content in a book, e.g. a preface, characters, poems. The distinctness of the two meanings makes itself starkly apparent, as in the other case, when you consider that you can have a "book" in one sense but not the other.[7]

[6] Though I've stated that I will not pretend to an account of polysemy in general, such cases of unit polysemy seems the most apt for a treatment similar to that below. There is an intimate link between units and the dimensionality of what is measured by them.

[7] See Dölling (2020) for a more complete listing of the classes of polysemous words and a catalogue of approaches to polysemy in the semantics literature.

We can further develop an intuitive understanding of polysemy through the consideration of some examples of distinct forms of semantic underdetermination:[8]

> (Structural Ambiguity) “The boy saw the man with a telescope.” (Chomsky, 1965)
>
> (Lexical Ambiguity) “Joe likes to go to the bank on Wednesday afternoons.”
>
> (Polysemy) “He had no more room for books in his luggage but luckily he had many books in his laptop.”

In the case of structural ambiguity, the string has two meanings: one in which the boy *uses* the telescope to see the man and one in which the man *has* the telescope. These two meanings are distinguished by the scope of the “with a telescope” prepositional phrase. Lexical ambiguity has its source of underdetermination in just one word, in this case ”bank”, which can refer either to a financial institution or the side of a river. What distinguishes this lexical ambiguity from genuine polysemy is that the two senses of ’bank’ are *completely unrelated*; they are mere homophones, while the two sense of ”books” have deeply related container-content meanings.

Generally, polysemy is distinguished from by homonymy by the felt similarity of the two uses of the term. If we assume such a similarity metric exists, we can follow Apresjan (1974) in providing a semi-formal criterion for polysemy: A term is polysemous iff for any two of its meanings, m_i and m_j there exists a chain of meanings meeting a certain similarity threshold such that $m_i \approx m_1 \approx \cdots \approx m_j$. The empirical marker of polysemy, as opposed to homonymy, is that two incommensurable predicates can be applied to the term simultaneously. Compare:

[8] Gillon (2004) provides a litany of amphiboly tests to distinguish polysemy (which he calls “lexical ambiguity”) from other forms of what I am calling semantic underdetermination: homophony, deixis, generality, and vagueness. I cannot discuss these here, especially due to the risk of muddling things a bit. Gillon’s tests are syntactic in that they use (formal) lexical ambiguity as a guide for (semantic) polysemy. I focus on multiplicity of *meanings* rather than multiplicity of label bracketings (formal structure), though the latter is taken as evidence for the former. It is not clear to me exactly what the status of the label bracketings in Gillon’s discussion take, they seem to mix both features: “On the one hand, linguistically minded semanticists. . . , hold ambiguity to be a relation between any semantic representations and an expression corresponding to them in natural language. On the other hand, logically minded semanticists. . . , hold ambiguity to be a relation between many syntactically unambiguous formulae of an intensional logic and an expression corresponding to them in natural language. . . [T]he entities are neither semantic representations nor formulae in a canonical logic, but labeled bracketings.” (Gillon, 2004, 165)

? The bank is in the desert and is near a rare species of fish.

Joe enjoys drinking bottles of beer and throwing the bottles against the wall.

I am concerned here with a particular sort of regular polysemy that appears in a class of terms: quantity term polysemy.

2.2 Case Studies in Science: Velocity and Pressure

In scientific contexts quantity term polysemy is generated by the extension of predefined quantity terms into novel theoretical and experimental contexts. Scenarios include:

The explication of ordinary terms into technical terms, e.g. the mathematical definition of common geometrical terms like "dimension" (Menger, 1979).

The carrying over of a term into a new theory, e.g. the change of the meaning of velocity and related terms in the transition from classical to relativistic physics.

New measurement standards (by experimental method or degree of precision) applied to the same quantity, resulting in different measurement outcomes, e.g. hardness (Wilson, 2006), length (Bridgman, 1927), pressure Bridgman (1949).

Below I briefly examine two cases of quantity term polysemy that motivated operationalism.

2.2.1 Velocity

Next let me consider an even more standard example brought on by the development of the special theory of relativity: velocity. Generally, velocity is defined as the time derivative of position, equivalent to (the infinitesimal limit of) the amount of distance traveled by some object divided by the duration of the travel.[9] In special relativity,

[9]There is some question as to whether these two understandings of velocity are equivalent or if one is to be more fundamental than the other (see Easwaran, 2014), I am setting aside any such complications here.

measures of distances and times are effected by the relative motion of the observer. This presents in relativistic velocity as a factor which encodes the relativistic effect of velocity on space and time: $v_{classical} = \frac{dx}{dt} \rightarrow v_{relativistic} = \gamma\frac{dx}{dt}$ where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$. At low velocities, meaning γ approaches unity, $v_{relativistic}$ "reduces to" or approximates $v_{classical}$, explaining the pragmatic utility of the classical velocity in physics prior to the development of relativity theory. This relation and the general form of the equation for the $v_{relativistic}$ makes it implausible to deny that it is really a "velocity" or that these two velocities only have a homophonic relation—the meaning of the two terms are related in a well defined manner.

2.2.2 Pressure

This case study and the one before it are particularly significant from a historio-genealogical perspective as the advent of special relativity spurred Bridgman to develop his operationalist philosophy and his work on high pressure physics guided his treatment of scientific concepts. The final example, then, is pressure. The measurement of pressure was an issue which vexed the experimental investigations of Percy Bridgman, who won the 1946 Nobel prize in physics "for the invention of an apparatus to produce extremely high pressures, and for the discoveries he made therewith in the field of high pressure physics."[10]

In his 1949, Bridgman summarizes both his own work and the development of high pressure physics as an experimental field of investigation. Many different measurement procedures and techniques are described and criticized in great detail. Bridgman separates his discussion of truly high pressure physics from his more general discussions of pressure measuring techniques and their historical development. It is in this focused discussion that he makes clear a fundamental distinction between primary pressure gauges and secondary pressure gauges. This is something like the distinction between direct and indirect measurement made in the philosophical literature (e.g. Kyburg, 1984)—though even primary measurement of pressure is not direct.[11]

Of the primary pressure gauges, Bridgman singles out an open column of mercury as the most basic and earliest in use. Recall that pressure is the quotient of force

[10] ?? (Nob).

[11] Bridgman recognizes that there is no primary gauge of pressure "in the strict sense"—here we are dealing with *degrees* of mediation.

divided by some area of application. As such, the height of mercury in an open column will correlate to the source pressure according to the equation:

$$P = h\rho g,$$

where h is the height of the mercury in the tube, P is the pressure, ρ is the density of mercury (or whatever pressure gauge fluid is used), and g is the gravitational acceleration. As the pressures of interest get higher—above 1000 kgcm^2—a free piston gauge is required as a primary gauge. Various designs are made to minimize leak and the number of buckle points. Again due to practical reasons, like the necessary scale of the gauges, free pistons are not useful for high pressure investigations. Bridgman's own gauge design, involving a manganin coil and syrup, was calibrated to be linearly correlated with pressures up to 13,000 kg/cm^2 and he used it with linear extrapolation to 21,000 kg/mc^2. He recognizes this extrapolation as "not completely safe", but argues that the minimal error already demonstrated makes it a safe bet. It was surely this necessity for extrapolation that concerned Bridgman methodologically—guiding the development his operationalist philosophy in the wake of relativity.

3 Semantic Detoxification

This section presents a phenomenon that results from the generation of polysemy in the sciences, semantic detoxification. Semantic detoxification, first dubbed by Wilson (2006), is presented in two phases. First, the generation of polysemy, the semantic extension of terms, is analyzed by way of Chang's 2004 case study, temperature. Then, Wilson's account of semantic detoxification, the conciliation of multiple conceptions of a scientific concept or multiple uses of a scientific term is presented and compared with the general semantic model of Carnapian explication. The conclusion of this section is that semantic detoxification, Carnapian explication, and conceptual engineering effectively all come to be the same thing, and as such comprise the primary tool for developing a sophisticated operationalism that *explains* scientific polysemy and is in no way threatened by it.

3.1 Chang's Semantic Extension: Temperature

In multiple places Chang (2004, 2019) refers to Bridgman's operationalism as a philosophy of extension. It is a progressive methodological prescription: we ought to recognize when our use of a term has changed, and we ought to provide operational meaning when our old measurement schemes no longer apply. While I cannot go into a thorough discussion of the development of measures of temperature in the classic Chang (2004), it will be useful to have the concrete cases in mind.

Much like in Bridgman's case with pressure, the pioneers of thermometry had to reckon with temperatures that exceeded those measurable by their current tools. One case is the case of temperatures below the freezing point of mercury, which—due to the relative shrinking of solidified mercury—undermined the accuracy of the mercury thermometer. The lack of a more reliable measurement instrument made this a serious issue: there was no operation to (accurately and reliably) measure temperatures below the freezing point of mercury, nor any to determine this critical temperature.[12]

Another case is the attempts of the potter Josiah Wedgwood to measure temperatures above the boiling point of mercury. Estimates of such high temperatures based on the thermal expansion of metals according to Newton's law of cooling were problematic as the law lacked independent validation (e.g. by a thermometer) at those temperatures. Wedgwood improved on such estimates by creating more reliable high-degree thermometers (pyrometers)—correlating the shrinkage of clay in a kiln to the hottest temperature reached by the kiln. However, in order to calibrate his *sui generis* temperature scale to the ordinary Fahrenheit scale, Wedgwood made recourse to the thermal expansion of metal method as a bridge. With this came consistency problems, and, perhaps more seriously, the issue of one of his primary auxiliary assumptions: that the degree of contraction of clay was linear with the temperature.

With both phenomena we find a common problem, what Chang has dubbed "the problem of nomic measurement": the proposed novel measurement standards depend on theoretical assumptions, be they full fledged laws or merely true generalizations, which lack any validation independent of the phenomena that the measurement standard exploits. This leaves the novel measurement standard untethered from prior

[12]Luckily, clever workarounds for determining the freezing point of mercury were forthcoming, though with mixed success for about a century. See Chang (2004, 107-118).

standards. Being so untethered, it is not clear that the novel usage standard measures the same quantity—the commonality between the old and novel measurement standards is postulated. This postulate yields the distinctness and unity that characterizes semantic extension and scientific polysemy.[13] Here I quote Chang at length:

> "These cases illustrate that concepts can and do get extended to fresh new domains in which experiences are scant and observations imprecise, even if no definite measurement operations have been worked out. I will use the phrase semantic extension to indicate any situation in which a concept takes on any sort of meaning in a new domain. We start with a concept with a secure net of uses giving it stable meaning in a restricted domain of circumstances. The extension of such a concept consists in giving it a secure net of uses credibly linked to the earlier net, in an adjacent domain. Semantic extension can happen in various ways: operationally, metaphysically, theoretically, or most likely in some combination of all those ways in any given case. One point we must note clearly, which Bridgman did not tend to emphasize in his philosophical discourses, is that not all concrete physical operations are measurement operations (we may know how to make iron melt without thereby obtaining any precise idea of the temperature at which that happens). Therefore even operational meaning in its broader sense is not exhausted by operations that are designed to yield quantitative measurement results. What I would call metrological extension, in which the measurement method for a concept is extended into a new domain, is only one particular type of operational extension, which in itself is only one aspect of semantic extension."(Chang, 2004, 150)

This section only uses Chang's notion of semantic extension to provide a model for the problematic. It should be noted, however, that Chang preempts the solution to the problem of scientific polysemy that supplied by semantic detoxification and explication. He puts forward two standards for the *validity* of a semantic extension:

> (Conformity) If the concept possesses any pre-existing meaning in the new domain, the new standard should conform to that meaning.

[13] This "common quantity assumption" (Tal, 2019), the problem of nomic measurement, and the coherentist epistemology developed in response to these facts of scientific practice will be more fully addressed in 4.3.

> (Overlap) If the original standard and the new standard have an overlapping domain of application, they should yield measurement results that are consistent with each other. (Chang, 2004, 152)

As we move from semantic extension to semantic detoxification, these two conditions will be examined in detail.

3.2 Wilson's Semantic Detoxification as Explication

This section has two aims: to introduce Wilson's 2006 notion of "semantic detoxification" and to show that it fits in the model of Carnapian explication.[14] This will be to show that his "linguistic engineering" is a form of what is more popularly called "conceptual engineering" (modulo 3.2.3). I take semantic detoxification to be a model of how explication works in conceptual engineering (Brun, 2016); A model which aims to avoid the "discontinuity objection," i.e. the changing-the-subject objection (Prinzing, 2018), that accuses the engineer of the plague of Kuhnian incommensurability. Given some recent developments in the literature, it will be simple, then to assimilate the process of operationalization to this unified account of meaning change.

3.2.1 Wilson's Critique of Classical Semantics

Wilson targets what he calls "classical thinking" with respect to semantics, as exemplified in the work of Russell and Frege. The aspects of classical thinking that Wilson challenges are shared by operationalism (as characterized by Bridgman's semantic thesis):

> (Semantic finality): Competent speakers of a language acquire a complete conceptual grasp of their language's conceptual contents at an early age.
>
> (Semantic rigidity): Predicates pick out conceptual content that is invariant to any pragmatic concerns.[15]

[14] I retain the reference to Carnap here for the sake of familiarity. Carnapian explication bears great similarity to the views of Carnap's fellow Vienna Circle member, Karl Menger (see Gillies (1981); Carnap (1950, 7) and Menger (1928, 1943, 1979, chapter 2)). Though Carnap has become a standard reference in the conceptual engineering literature (beside my other references see also Dutilh Novaes (2020b,a), there are much deeper roots in German Idealism (Neo-Kantianism, Hegelianism), and American Pragmatism.)

[15] Semantic finality and semantic rigidity are Wilson's terms. The latter is used in (Wilson, 2017, 417). Wilson rejects both theses and the inference from finality to rigidity, which is broadly

Both of these claims are grounded in what Wilson calls classical gluing, that is, the one-to-one correspondence of ideas (in the head) and attributes (in the world) which is reified in *concepts* and expressed by rigid predicates. This one-to-one correspondence is embodied in contemporary semantics by the interpretation function, which maps lexical items to meanings. The operationalist interpretation function maps quantity terms to sets of measurement operations. Wilson's litany of examples of semantic extension and scientific polysemy are intended to show that no such interpretation *function*[16] exists—the linkage of terms to meanings is far more complicated and varies according to practical considerations.

Wilson describes his successor concept to "conceptual content" or "intension" as "strands of practical advantage", which he calls directivities. These directivities can be thought of as recipes, routines, or guides for use (of words) that inherit "distributive correctness" (2006, 228) from their roles in practically successful sentences. A useful extended metaphor Wilson introduces is the comparison of parts of language to map projections, of which many may project the relations of the same domain many times over, thereby forming atlases of distinct projection maps. Wilson's discussion of global map projections, which serve as a model ("prototype") for distributions of directivities:

> "As is well known, it is impossible to map terrestrial topography onto a sheet of paper without introducing considerable distortion in the result. At best, we can select a few features that we would like to register in our maps accurately and conveniently... How do we correct for these representational pitfalls in our maps? The most effective scheme is to supply a rich atlas of maps that cover the earth several times over, each of which is

accepted due to a misunderstanding of the results of linguistics. "The chief mischief that an exaggerated faith in semantic finality brings to our understanding of linguistic process is the belief that all these quiet mature adjustments of context and usage don't matter to conceptual content proper; that, mutatis mutandis the latter must remain essentially mummified from age 8 to 85. But this presumption of invariant continuation, I claim, is not correct at all and often proves the source of grievous misunderstanding. After all, when we typically wonder about the 'proper content' of our concepts within the intrigues of ordinary life (or when we become scientifically confused), we are rarely interested exclusively in the invariants required to recognize grammaticality, but instead worry about matters of larger cope. Can we trust this concept to behave acceptably when we try to bring it into an *untested domain* of application? Will we be *led astray* if we trust old inference patterns in this new arena?"(Wilson, 2006, 22)

[16] Wilson models his theory of content on the generalized 'functions' of complex analysis and physics, see e.g. (2006, 380-90). For a proposal for a finer-grained model of semantic interpretation in linguistics see Wellwood (2020).

> dedicated to answering questions best suited to its personality... we shuttle between its member representations according to a suitable strategy of usage." (Wilson, 2006, 290-2)

Through the different semantical pictures of a domain of fact run fibers connecting counterparts in different mapping systems, these common threads are the unity of linguistic terms. This produces a manifold of lexical items connected by directivities and rules of usage, transformation, etc.[17] A cluster of directivities comprises one of these semantic maps, applying to the domain names, predicates, and rules of reasoning between them. However in other maps some of these rules may dropped, e.g. the condition of one-to-one correspondence being dropped in the transition from mathematical functions to generalized functions. In such shifts the "conceptual content" attached to the predicate "function" changes, allowing us to associate multiple values with one argument. This change then has knock on effects in terms of what operations on functions are available and the meaning of terms we give to these operations, like "function composition".

These maps, or "patches", may be distinguished by scale length, whether some idealization condition is close to being met (e.g. temperature), by method of measurement (e.g. hardness), theoretical change, etc. Important for Wilson, these shifts do not amount to changes of a language and may be entirely intra-theoretic.[18] These shifts in semantic pictures are driven by practical advantage and occur on a linguistic meso-scale. Wilson is never quite specific but this scale is larger than a word or a

[17] One could idealize this model a bit to produce a coherent higher dimensional space in which lexical items take positions according to their various properties (e.g. grammatical roles) and relations (e.g. rules of usage, contextual constraints), which is not without precedence. A developed formal theory of conceptual spaces is provided by Gärdenfors (2000). While I must leave a full investigation of this model of cognition for future work, it is noteworthy that one of the benefits of such a model, according to Gärdenfors, is that it properly accounts for concept acquisition, a chief concern for Wilson. Do not forget also that a theory of acquisition is a condition for an explanatory rather than merely descriptive semantics (see Chomsky, 1965).

[18] Two reasons for this: (1) we have great facility with switching between these patches and often do so within a single line of reasoning; (2) we do not know a priori when such shifts are needed or even when they have occurred, so this cannot always be modeled as a shift of interpretation models based on context or choice. On this latter point Wilson seems to waver and often speaks of patch shifts or changes of directivities as contextually driven. However he does make the explicit argument late in the book that this is not mere context sensitivity because "we have no way of knowing what significance 'cause' presently carries. That is, we often learn useful ways for dealing with the events around us that we describe in causal argot and which we initially picture in a 'causal process" manner, yet later turn out, through no fault of our own, to constitute unexpected mimics." (2006, 581)

single sentence, but smaller than a language, he tends to use “a set of sentences” within which meaning is determined by a “distributive normativity”.

Wilson describes distributive normativity as a “salient notion of ‘correctness’... derived from the *global purpose* the device addresses” which is determined by an “*internal evaluation* of the ‘correctness’ of the devices’s component parts” and their performance (2006, 171-2). This distributed normativity is contrasted with the direct normativity that determines the proper usage of terms in classical semantics. This direct normativity is in the simplest case a standard of reference: the usage of a name picks out its referent, usage of a predicate ascribes a property to some entity which in facts exemplifies that property, and so on through truth-conditional semantic specifications of meaning. Distributed normativity is not entirely divorced from truth, but its target is more varied: Whether a term is properly used depends on the purpose of the patch of language it is being used in.[19]

Through the different semantical pictures of a domain of fact run fibers connecting counterparts in different mapping systems as determined by transformation rules between patches of language. Wilson gives the “canonical” process of semantic extension and semantic detofixication a number of glosses, here is a semi-formal one with minimal jargon:

> “If we review the patterns in which our canonical developments unfold, we will witness our two detoxifying policies for eliminating unwanted heritages in seasonal action. Thus, a stereotypical history runs: (1) the predicate ‘P’ gets up and running under the nurturing shelter of picture **P** →(2) strands of practical advantage **R** are developed under **P**’s aegis, usually regarded as somewhat fallible by its lights→(3)other directivities suggest that **R** should be expanded and corrected to $\mathbf{R}^*$ in a manner that **P** no longer accommodates ably, initiating an agnostic interval where the indications of $\mathbf{R}^*$ are trusted more than those supplied by **P** →(4) a replacement picture $\mathbf{P}^*$ for ’P’ is articulated that once again dominates and corrects the indications supplied within rules $\mathbf{R}^*$... And sometimes oscillations between (3) and (4) occur a number of times over an unfolding career.”(Wilson, 2006, 555)[20]

I take step (4) of the above iterative procedure to be semantic detoxification, in a

[19]See Wilson (2006, chapter 10) for discussions of truth and truth conditions.
[20]See also the model presented in Wilson (2006, 377-9).

narrow sense. This "correction" bears clarification. Such correction is ubiquitous in science and takes on different modes. The scheme for any such reflection is to take a set of directivities (or operations) that specify the conceptual meaning or intensional character of some term and modify them in light of a novel, but overlapping set of directivities or operations that specify the conceptual content that term in a different context of use. We can provide an incomplete list of some types that fit this scheme:

- A measurement operation is circumscribed to a particular range of values, and another standard takes its place for values outside of this range. The two operations are calibrated to one another and a rule for adjudicating inconsistencies is established.

- A novel measurement operation is found to yield more accurate or more precise measurements than the former standard. When such exactness is needed or economical, the new operation takes precedence over the old one.

- A theoretical equation is found to be valid only for certain ranges of values for certain parameters. A new theoretical equation takes its place outside those ranges and can be used to generate correction terms within the old equations range, if such precision is required or economical.

- A model may be given a novel representation in cases in which the information needed for the former representation is more difficult to attain than that of the novel representation, modulo differences in precision and accuracy.

All of these sorts of detoxifications would change the conceptual content attached to the terms whose referent we are attempting to target (e.g. some quantity), yet they provide ties of continuity. This list could be extended quite a bit and many case studies beyond those discussed here could be categorized. Here is a consolidation and restatement of the detoxification process:

(1) A term gets 'dragged' into a novel context; the conceptual contents of the predicate changes and moves beyond the boundary of its native patch.

(2) In the new patch practical usage of the term and its limits are developed and consolidated.

(3) These new conceptual contents are used to correct (detoxify) the role of the term in the old patch of usage producing a replacement "semantic picture".

3.2.2 Explication and Conceptual Change

I have already indicated that semantic detoxification is to be understood as a method of explication. I will not here attempt to give a thoroughgoing analysis (or explication) of explication, nor will I give a summary of its development. I here only want to give an outline sufficient to support my thesis. I start in the customary place, with Carnap:

> "The task of *explication* consists in transforming a more or less inexact concept into an exact one or, rather, in replacing the first by the second. We call the given concept (or the term used for it) the *explicandum*, and the exact concept proposed to take the place of the first (or the term proposed for it) the *explicatum*. The explicandum may belong to everyday language or to a previous stage in the development of scientific language. The explicatum must be given by explicit rules for its use, for example, by a definition which incorporates it into a well-constructed system of scientific either logicomathematical or empirical concepts." (Carnap, 1950, 3)

Explications can be understood generally as an ampliative (as opposed to analytical) definitions; they provide an account of the conceptual content associated with some term which is fit to purpose (more precise, better cohering, more useful, etc.). Explications are *ampliative* in the sense that they provide contents that go beyond the antecedent contents of the term. This amplification may take many forms: explication may well restrict or expand the terms extension, or its domain of applicability, or its usefulness in traditional contexts. That the prior meaning coexists with the novel meaning, adds to the contents possibly associated with the term. Generally, Carnap's focus was explication in service of science, as is mine, so I will set aside issues regarding the more (explicitly) morally and politically oriented models of explication like ameliorative analysis (see Haslanger, 2012; Dutilh Novaes, 2020b).

Carnap requires of a satisfactory explicatum that it meets certain standards of similarity, exactness, fruitfulness and simplicity. Similarity may be broken up into the two standards given by Chang: the explicatum conforms to the explicandum in its native context (in which we find no need for the explicatum); overlap in a shared domain of applicability must be approximately congruent. These are both essential aspects of the semantic detoxification process: Old usages are modified so as to not overstep their domain of usefulness (consider the weakening of laws with *ceteris* *paribus* clauses), and within that domain the novel usage of a term is close enough to be apt to provide that modification—there must be some shared aspect that the novel usage improves upon. A particular standard for the continuity of quantities under the process of explication or semantic detoxification will be proposed in 4.3.

It is important to note that Carnap's standards for *satisfaction* are not anything like truth-conditions or requirements for joint carving, they are relative to the purpose at hand and determined in the context of some embedded patch of language—Carnap gives a less general gloss on Wilson's "distributive normativity".[21] We can cluster the standards exactness, fruitfulness, and simplicity along with many others under this general heading. All of these standards for satisfaction are determined and ranked by the purpose to which the explicatum is to be put to use.

3.2.3 A Confession of Confusion

In order not to do undue violence to Wilson's own views, I here confess that at least one of us is confused regarding the nature of the phenomena in question—ideally this is only a confusion of tongues. The matter of confusion is where and whether Wilson and I come apart on just what the challenge to classical semantics is. Wilson explicitly rejects the characterization of the cases of semantic extension above as cases of *polysemy*. This, he claims, is a classical response. In his listing of characteristic of theses of classical semantics entry 27 includes:

> "Likewise, in language use, the meanings of various words often drift or multiply into secret polysemy without our noticing the alterations, but such meanderings could have been prevented by a more vigilant program of *conceptual hygiene*." (Wilson, 2006, 143)

Later, considering Wilson's example shift of "foe" in the terminology of Japanese swordsmithing from "human being that is used to cool a red hot sword" to "some suitable body that is used to cool a red hot sword". Wilson claims that the classical

[21] "In a problem of explication the datum, viz., the explicandum, is not given in exact terms; if it were, no explication would be necessary. Since the datum is inexact, the problem itself is not stated in exact terms; and yet we are asked to give an exact solution. . . It follows that, if a solution for a problem is proposed, we cannot decide in an exact way whether it is right or wrong. Strictly speaking, the question whether the solution is right or wrong makes no good sense because there is no clear-cut answer. The question should rather be whether the proposed solution is satisfactory, whether it is more satisfactory than another one, and the like."(Carnap, 1950, 4)

semanticist will understand such episodes as minor episode in the development of language. He characterizes explanations by way of (possibly unwitting) polysemy as appeals to "changes in attached concept" which avoids "granting any special prominence in language to the strong classificatory directivities that often arise in connection with specific strands of practical advantage."(Wilson, 2006, 230-1) However, the position that this passage suggests is Wilson's doesn't so much deny polysemy as much as it claims that the phenomena that polysemy is intended to describe is *central* to the development of language (rather than "mere eccentricity") and is better described as an extension of the use of "foe" according to classificatory directivities like "a foe is whatever one can plunge a red hot sword into to quickly cool it while swordsmithing". The contrast being that there are no "conceptual contents" that are so well attached to the term foe that this extension of use counts as a change in concept, rather the domain of use has extended though the "foe" role in swordsmithing recipes has not changed.

The issue with Wilson's apparent dismissal of polysemy is that it misrepresents proper polysemy as more akin to lexical ambiguity (i.e. mere homophony). It may very well be the case that classical semantics must assimilate polysemy to lexical ambiguity, but this is not my purpose here. This apparent confusion or perhaps purposeful undermining of the distinction between polysemy and ambiguity is belied by Wilson's repeated references to different *predicates* in a patchwork, e.g. "is hard"$_{\text{PLASTICS}}$ and "is hard" $_{\text{METALS}}$ and his resistance to describing what he calls property dragging as "shifts in meaning", which comes out in his discussion of causation and his assimilation of causation polysemy to the bank-bank paradigm of lexical ambiguity:

> "I have spent some time on this example, because it beautifully illustrates a rather common linguistic process: a linguistic methodology R (Euler's method) well suited to phenomena A described by predicate 'P' ('cause') gets borrowed as a subroutine within some methodology R* (shooting method) natural to a distinct variety of physical situation B. In the process, 'P' is dragged in the borrowing as well, pulling 'cause' away from a patch where it genuinely conveys the significance of *bringing about as a subsequent causal effect* into an adjoining sheet where it merely signifies *being the next thing to consider in a steady state computation.* The ensuing ur-philosophical confusion then inspires our authors' wild claims the qualitative calculus captures the 'general meaning of "cause"'found in ev-

> eryday thinking, which physics fails to represent (such boastful claims are structurally equivalent to contending that the Securities Exchange hasn't been monitoring banks correctly because it has failed to attend to the shores of rivers)." (2006, 588)

The focus throughout the book on predicates and their usage rather than properties or concepts *qua* content[22] is ambiguous as to the semantic model in mind. The difference between the semantic model for polysemy and that for ambiguity is the difference between there being two or more values (e.g. $[\![\mathrm{HARD}]\!]_{\textsc{plastics}}$ and $[\![\mathrm{HARD}]\!]_{\textsc{metals}}$) for a single predicate "is hard" and there being multiple hard predicates "is hard"$_{plastics}$ and "is hard"$_{metals}$, as Wilson seems to suggest.[23] Given that mere lexical ambiguity is no threat to the classical semantic picture, let's assume that either Wilson is really talking about polysemy or, more contentiously, he denies, rather than ignores, the ambiguity–polysemy distinction. This may be reflected in his shiftiness between predicates, properties, and concepts.

One reason to reject the distinction comes from early Wittgenstein and his distinction between a sign and a symbol. A symbol is a picture of some facts and a sign is the sensible part of that picture.[24] So if a proposition is a representational picture of the facts, then its embodiment in a sentence is its sign; however, the sentence is only a sign if it is used as part of a symbol. This is not to say that Wilson subscribes to any Tractarian picture theory, however the common presupposition is this: for something to count as a bit of language it must be *used* as such. Lexical items, in this case predicates and quantity terms, only count as such if they figure in some meaningful locutions, otherwise they are merely sounds or scribbles. This is the relatively uncontroversial aspect of the "meaning is use" orientation that Wilson himself aligns with. When he's careful he talks about not shifts in meaning but changes in the uses of predicates. So then, he might think there is no distinction to be drawn between a

[22] "In stressing predicative use, I am mainly trying to bring forth the *skills we manifest* when we possess a concept, as opposed to the *contents we happen to grasp*, for one of our chief tasks is to understand better how skills and contents interrelate. In this way, my emphasis on predicate usage is really intended as emblematic of a more general range of skills." (Wilson, 2006, 15)

[23] Note that in the paragraph following his discussion of "cause" quoted above he discusses the "multiplex character" of the *concept* cause, and then just two sentences later, discusses predicates again.

[24] "A sign is what can be perceived of a symbol" (Wittgenstein, 1974, §3.32). Note also the following proposition: "So one and the same sign (written or spoken, etc.) can be common to two different symbols—in which case they will signify in different ways" (§3.321).

multiplicity of uses of some scribbles or sounds and a multiplicity of meanings, which the polysemy-ambiguity distinction relies on.

Ultimately the exegetical question of whether Wilson takes the multiplicity of intensional character or directivities to be reduplicated on the lexical level is of only minor importance here. What does matter is that an apparently singular lexical item directly, or indirectly via disambiguation, comes to hold different such contents in different situations, though something besides the mere lexical sign remains unchanged. Wilson and I agree that this phenomenon threatens the functional character of the classical interpretation function (one argument, one value)—*this I will continue to refer to as polysemy.*

4 Sophisticated Operationalism

In this section I describe Bridgman's influential account of scientific concepts, operationalism[25], and the nature of the challenge to it posed by scientific polysemy. I then go on to describe Hempel's corrective account of operationalism that attempts to avoid some of the objections posed to Bridgman. I use this account as a starting point to a sophisticated operationalism that meets the challenge of scientific polysemy and explains semantic detoxifixation. In a (simple) twist of faith, this liberalized operationalism is in fact evident in Bridgman's own writing[26]—here his general point that the physical reality of some posited object or property depends on its being "uniquely connected with other physical phenomena, *independent of those which entered its definition* (Bridgman, 1927, 56, his emphasis) is made more determinate. This reality criterion requires a fixed point for all these independent connections to join at—as does a theory of measurement. In the context of physics, the fixed point which allows this holist identification of some physical quantity is its dimensionality, which encodes its possibilities of measurement.

4.1 A Naive Interpretation of Bridgman's Operationalism

In response to the shocks to our basic physical concepts caused by the theories of relativity and quantum mechanics, Bridgman sought an establishment of the foundations

[25]Sometimes called "operationism", most often in psychology.

[26]This point is made also by Chang (2017), consider this work here an elaboration of this undervalued aspect of Bridgman's thought.

of physics such that "another change in our attitude, such as that due to Einstein, shall be forever impossible." (Bridgman, 1927, 2)[27] As Bridgman's account of scientific concepts was born in the wake of great scientific change, it is appropriate that some version of that account can be adapted to the problems of scientific polysemy and semantic detoxification as I've described them.

Naive interpretations of Bridgman's operationalism center on what I've called his semantic thesis, here I restate it:

> (Bridgman's Semantic Thesis) The meaning of some quantity term is just the set of quantities measurable by some set of operations.

The application of this semantic thesis is evident in Bridgman's distinction between tactual and optical concepts of length. Einstein's light signal convention for synchronizing clocks grounds judgments of distance in operations involving light signaling—in the context of cosmology, measurements by such optical operations are all that is available, so calibration of the optical standards with tactual standards is not even possible. Therefore, strictly speaking, Bridgman concludes that the two concepts are distinct.[28]

There are two major lines of criticism of Bridgman's semantic thesis.[29] The first criticism being that the operations associated with a concept are insufficient to specify its meaning. We believe there is more to temperature than its measurement by thermometers, e.g. that it is equivalent to mean kinetic energy. We also may think,

[27] Of this attitude Bridgman later said "To me now it seems incomprehensible that I should ever have thought it within my powers, or within the powers of the human race for that matter, to analyze so thoroughly the functioning of our thinking apparatus that I could confidently expect to exhaust the subject and eliminate the possibility of a bright new idea against which I would be defenseless. Of course, my point of view did have the justification that the fundamental physical material is with us now, being contained within our skulls, and is not subject to the sort of expansion that has occurred, for example, in the stellar universe, as modified in the light of information obtained with larger and larger telescopes or by radio-astronomy." (Bridgman, 1959, 520) Note the transcendentalist or subjectivist aspect of this reconsideration, see Walter (1990).

[28] "We are still worse off when we make the extension to solar and stellar distances. Here space is entirely optical in character, and we never have an opportunity of even partially comparing tactual with optical space. No direct measures of length have ever been made, nor can we even measure the three angles of a triangle and so check our assumption that the use of Euclidean geometry in extending the concept of space is justified."(Bridgman, 1927, 16) Interestingly, Bridgman cites this and the inaccuracy of astronomical length measurements (though angular measurements are highly accurate) in his dismissal of the debate regarding whether space is Euclidean or not as "merely academic".

[29] For some interesting discussion of other matters in Bridgman's operationalism, like his rejection of mechanistic explanation, see Stebbing (1928).

that there is more to intelligence than what is measured by IQ tests. Generally, the meaning of quantity terms *must* go beyond our measurement operations, insofar as it is possible that our measurement operations are not perfectly accurate. Bridgman's semantic thesis makes our measurement operations infallible by fiat. Criticisms like those lobbied at varied forms of verificationism seem to apply. For example, Harré (1985) argues that since operationalism reduces theory to operations, scientific theories lose their explanatory power.[30]

Another issue is the overgeneration of concepts by this principle. Bridgman makes clear that each concept is to have a unique set of operations:

> "In *principle* the operations by which length is measured should be *uniquely* specified. If we have more than one set of operations, we have more than one concept, and strictly there should be a separate name to correspond to each different set of operations." (1927, 10)[31]

This would entail that distinct and contradicting sets of operations used to define the tactual and optical length would in fact specify two distinct length concepts. This makes operationalism vulnerable to the old problem of conceptual change: how can we say some set of operations are better (more accurate, more precise, etc.) than another if they simply specify distinct quantities? Compare: how can we claim some theory is better than another if they posit completely distinct ontologies, with corresponding interpretations of the phenomena?[32]

[30]Interestingly Harré (1985, 72-3, 76-8) cites the chemist Benjamin Brodie as a precursor to Bridgman's operationalism. Harre's discussion was raised to my attention by a very interesting discussion of Aldous Huxley's operationalist sympathies in Deery (1996).

[31]Being not so strict, Bridgman accepts that we equate concepts whose values approach each other as the condition approaches a limit, e.g. proper time and observer time as relative velocities approach zero. Still considering an optical standard of length: "The practical justification for retaining the same name is that within our present experimental limits a numerical difference between the results of the two sorts of operations [rod based and optical] has not been detected." (Bridgman, 1927, 16). This semantic equivalence is only a matter of practical equivalence, a case of "loose talk".

[32]Both sorts of objections, from conceptual extension and conceptual evaluation are instructively discussed by Gillies (1972). Gillies in fact anticipates Chang's problem of nomic measurement and suggests an alternative to operationalism very similar to accounts given by Chang, Tal, and myself. However Gillies makes the mistake of thinking that he himself is not lapsing into some sort of operationalism by way of giving a novel concept empirical content by detailing consequences that are independent of it and using non-quantititative assumptions. For one, these resources are available to Bridgman (though maybe not to Mach), see the discussion of his reality criterion in 4.3. Secondly, the qualitative assumptions he allows suffice to define quantitative scales and he still relies on the "common quantity assumption" (Tal, 2019), again see 4.3. Gillies' view and a sophisticated operationalism converge.

An operationalist point of view is not beholden to such a standard of semantic disambiguation. Two desiderata for an operationalism that does not fall victim to these objections:

(1) Single operations do not purport to exhaust the meanings of the concepts they explicate, it is only a necessary condition that there is some (direct or indirect) possible operation for each meaningful concept;[33]

(2) Operative "definitions" are only partial and so the overall meanings of terms are mutable as additional operations are introduced and old ones are excluded.

Bridgman uses "set of operations" to refer to a particular procedure for measurement. An amended operationalism will exploit an available liberalization of this standard to a *set of procedures*, i.e. sets of operations. Under a sophisticated operationalism any particular measurement procedure provides only a partial specification of a physical concept and Bridgman's "concepts" would be subsets of the these sets. Such a liberalization will allow for the fallibility of measurements as some procedure may come to be preferred to another as more accurate, due to theoretical or experimental factors, but will not eliminate, but rather detoxify the antecedent procedure which remains in the set of procedures which define the concept. This is to say that these operational definitions are paired with a blurring of the analytic-synthetic distinction. Some definitions of a term will enjoy greater coherence with the rest of the semantic web and will so will enjoy greater "analyticity"—the semantic account given here is *dynamic*.

[33]This is to pull back from operationalism as a theory of meaning but to hold it as a thesis as a criterion of empirical significance (see Uebel, 2019). I hold that there is an inbetween view wherein some operation is a minimal condition for meaningfulness, but additional operations contribute more and more meaningfulness to a term (see **?**).

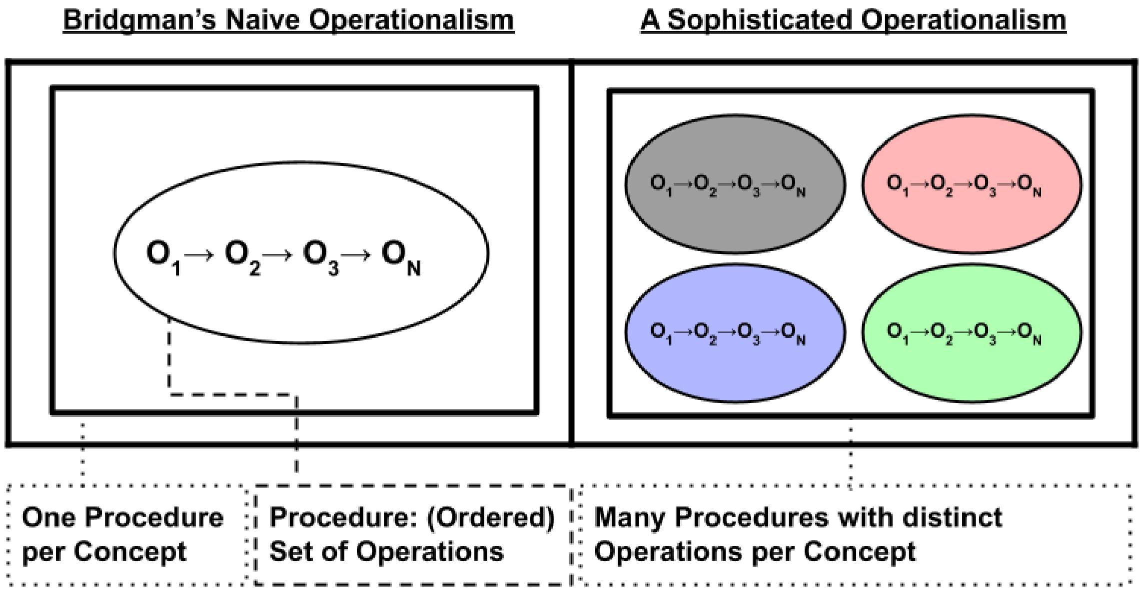

Figure 1: A comparison of the naive and the sophisticated semantic models.

4.2 Hempel's Appraisal and a New Operationalist Model

A sophisticated approach has been developed by Hempel (1965), building off of the work of Carnap (1936, 1937, 1952), replacing Bridgman's strict definitional scheme with partial "reduction sentences" and "meaning postulates". The general form of such a reduction sentence is $Sx \rightarrow (Cx \equiv Rx)$, where S are some test conditions, C is the defined property and R is the response condition. Consider a partial definition of being one kilogram in mass: S comprises conditions of temperature, lack of electromagnetic forces, a non accelerating frame, etc.; R is equalizing with the standard kilogram on an scale; C is being one kilogram in mass. Hempel goes further and generalizes reduction sentences to interpretative systems (of which explicit definitions and reduction sentences are special cases). The more general interpretative system gives quantity terms their meanings holistically,[34] In the fashion of Hilbertian axiomatics and its implicit definitions, Hempel sets up an a-metaphysical[35] structuralism that

[34] "If the introduction of nonobservational terms is conceived in this broader fashion, which appears to accord with the needs of a formal reconstruction of the language of empirical science, then it becomes pointless to ask for the operational definition or experiential import of any one theoretical term. Explicit definition by means of observables is no longer generally available, and experiential—or operational—meaning can be attributed only to the set of all the nonobservational terms functioning in a given theory." (Hempel, 1965, 131)

[35] This view is neutral regarding the question of realism insofar as "meaning" can be understood independently of assuming realism—I am here silent regarding the question of semantic internalism

parallels mathematical structuralism:

> "The interpretative sentences used in a given theory may be viewed simply as postulates of that theory, with all the observation terms, as well as the terms introduced by the interpretative system, being treated as primitives. Thus construed, the specification of the meanings of nonobservational terms in science resembles what has sometimes been called the implicit definition of the primitives of an axiomatized theory by its postulates... The use of interpretative system as here envisaged has this distinctive peculiarity, however: the primitives include a set of terms—the observation terms—which are antecedently understood and thus not in need of any interpretation, and by reference to which the postulates effect a partial specification of meaning for the remaining, nonobservational, primitives." (Hempel, 1965, 131)

We ought to understand such a system dynamically in which we take at some time a measurement procedure, say balancing some multiple of standard kilograms to partially define having some mass, but as convention or theory changes we may hold some other procedure as primitive, or as has recently been done we can specify some quantities, the constants of nature as primitive and define other quantities out of them.[36] The observational-nonobservational distinction need not be understood as a distinction that cuts nature at the joints. Indeed, Hempel makes the case that this distinction becomes a matter of degree as does the analytic-synthetic distinction.[37]

Hempel's adaptation of operationalism meets the two desiderata. A quantity term is not completely defined by one operation but by its position in a network of theoretical and observational operations—every operational specification of a quantity term is partial. As such, some parts of the network of theoretical and observational operations change so does the full concept of some quantity term, but still some operations remain intact or useful within some contexts. Hempel's interpretative system provides a model for a sophisticated operationalism. However, its extreme holism

or externalism.

[36]The new Système international d'unités has definined the basic units using only the fixed values of the constants of nature. See BIPM (2019); Quinn (2017). This means the current operative definition of mass involves more theory laden "paper-and-pencil" operations in its defining procedures.

[37]Here we have a rapprochement of Carnap's empiricism and Quine's empiricism (Hempel makes reference to Duhem).

is both unnecessary and possibly problematic, my full account will circumscribe the holism to multiple smaller interpretative systems.

4.3 How Sophisticated Operationalism Accounts for Scientific Polysemy

We can recover an operationalist principle that does not lead to the absurdities generated from Bridgman's semantic thesis. We can state the amended semantic thesis so:

> (Sophisticated Operationalist Semantic Thesis) The meaning of a quantity term is the set of quantities which are measured[38] by any member of a non-empty set of procedures, both theoretical and empirical, which are themselves (non-empty) sets of operations.[39]

Due to my focus, I have restricted this thesis to apply to quantity terms, which in a scientific context correspond to the theoretically significant predicates. If we understand an operation as some set of actions which yield an indicator value which, under some interpretation, is said to measure a quantity, then we understand procedures

[38] Properly speaking I want to broadly include theoretical determinations of quantity magnitudes in "measurement". This corresponds to Bridgman's 1927 "paper-and-pencil" operations and can be conformed to the primary phenomena by treating them as standards or conventions for "indirect" measurement. I will largely be preoccupied with measurement or at least phenomenological theories. Theoretical and empirical procedures taken together roughly correspond to Wilson's directivities.

[39] This "cluster concept" model may raise Kripkean hackles. I cannot dismantle the edifice of *Naming and Necessity* 1980 but I can make two points, one defensive, one offensive: (1) This is a dynamic cluster concept theory (as practically all are), issues regarding circularity of ascriptions to names synonymous with them only arises when the analysis of term is taken to be all at once. *Which* descriptions, here operations, figure in a definition and which are accidental or to be tested is a function of the interests of inquiry. The same applies for counterfactuals. Analyticity is *contextual.* (2) Kripke's notion of names as (perfectly) rigid designators is fallacious. He ignores the fact that rigidity and designation trade off. He takes an idealization, perfect rigidity and non-descriptive designation, which only applies to *logical names* and so logical simples, and applies it to *proper names* sneaking in designative descriptions through "metaphysical" intuitions of essential properties. If these "essential" properties are constitutive of the name ("Nixon" is a name for a man) names are descriptive. If not, there are no essential properties associated with the rigid designator and his particulars are indeed bare. Appeals to indexicals only make the point clearer. When I point at a rabbit shaped thing or a statue made of clay, etc., what am I pointing *at.* Disambiguation requires description, there is no "pure" manner of designation and the designation does not carry over, even by stipulation, to other situations without background assumptions regarding essential natures, which are descriptions.

to be generalizations of such operations allowing for different interpretations (e.g. units) and coarse-graining the operations in such a ways as to make "comparing to the marks on a meter stick" a single procedure.

There is a question of how modally fragile quantities and procedures are. We can simply stipulate that the copula is intensional, that is at any world, w_i, quantity Q_i is identical to Q_j at w_2 iff the set of procedures which measure the two quantities have a nonsignificant overlap such that $m_i \approx m_j$. This last condition is not to make this trivial as whether $m_i \approx m_i$ can be evaluated in one world as we do during semantic extension. Generally certain procedures, i.e. definitions, will be seen as more fundamental than others, so the overlap comparison will be weighted and can't have a threshold set in the manner of a majoritarian counterpart relation. In practice, the determination of meaning similarity will be a pragmatic and conventional matter.

Procedures can be similarly "intensionalised". As the quantity term refers to the targets of the procedures rather than simply the procedures themselves, discrepancies in measurement result do not raise the threat of inconsistency to the set. Whether by due to errors or wholesale failures of auxiliary hypotheses (weights being measured on the moon), the procedure sets will be tolerant—less consistent procedures will be in many cases pushed out of the meaning set. They then will be corrected or "detoxified" by various explanations for error.

The resource upon which the sophisticated operationalist semantic thesis is founded is what I will call Bridgman's reality criterion:

> (Bridgman's Reality Criterion)The physical reality of some posited object or property requires on its being "uniquely connected with other physical phenomena, *independent of those which entered its definition.* (Bridgman, 1927, 56, his emphasis)

Let me be careful to state that we are reading this semantically. This is not (directly) about diversity in the ways of being, rather: the reality (semantic significance or robustness) of a quantity *term* is a function of the number of operations associated with a the term (or concept) that meet an independence condition. The independence condition can be glossed as: each of the operational senses of a term are independent if they could each serve as independent (partial) operational definitions. That there are many available operational bases for the meaning of a term is important because the operations which are taken to be definitional (grounding analytic truths) and those whose connection to the term is established empirically is a contextual matter. What at one time is a experimental result, like the numerical value of some constant, may at another time be set as analytic truth.[40]

With this reality criterion, Bridgman anticipated the sophistication of operationalism.[41] Its primary use is as a razor which distinguishes the real from the unreal:

> (The Unreal and the Real) "The essential point is that our constructs fall into two classes: those to which no physical operations correspond other than those which enter the definition of the construct and those which admit of other operations, or which could be defined in several alternative ways in terms of physically distinct operations" (Bridgman, 1959, 59-60).

His example of a physical quantity which cannot be directly measured, but nevertheless is real according to this principle is stress. Stress is caused by the application of forces on multiple parts of a body. In all its forms (tensile, shear, bulk), stress is defined as the ratio of some force to some surface area, giving it dimensions of pressure:

$$S = \frac{F}{A} \qquad \text{(Stress Equation)}$$

If the equation above serves to *define* the quantity stress, then Bridgman's reality criterion requires that it either have some independent method of observation or that it bears some meaningful relation to some other quantities, independent of the definition. This requirement is met by the strain, a measure of the deformation of the object under stress, which is related to the stress (in the case of tensile stress) by Young's modulus, which is a material dependent measure of elasticity:

$$Y = \frac{S}{T}$$

Y represents the Young's modulus, S represents the stress, and T represents the strain. Different moduli take the place of Young's modulus depending on the sort of stress under consideration. The important thing is, the strain, which has an independent source of meaning in its empirical measurement, links the stress to empirical measurement procedures.

Bridgman's example of an unreal construct is the electric field. The electric field

[40] A vivid example is given by the recent changes at the Système Internationalé, see **?**.

[41] This is also noted in Chang (2017).

is not directly accessible by empirical procedures, but is measured indirectly via its force on probe particles. There is no other route to the electric field besides through its action on some charge, which constitutes its definition. Therefore the existence of the electric field cannot be countenanced from an operationalist point of view, though it may have some pragmatic use.[42]

Bridgman's reality criterion also has a methodological aspect—it prescribes increasing the operational significance of scientific terms whenever possible. In this way, the criterion cohere's nicely with Carnap's specification of the criterion of fruitfulness for a satisfactory explication:

> "The explicatum is to be a *fruitful* concept, that is, useful for the formulation of many universal statements (empirical laws in the case of a nonlogical concept, logical theorems in the case of a logical concept)."(Carnap, 1950, 7)

A scientific term proves the reality of its referent and its usefulness by being used in as many laws or generalizations as possible, i.e. being connected to as many *other* terms and therefore operations as possible. Chang (2019) presents Bridgman's operationalism as a "tool of self-diagnosis and self-improvement" and states that an operationalist dictum would read: "maintain and increase the empirical content of theories by the use of operationally well-defined concepts". This methodological reading is very important for understanding the scientific usefulness of operationalism. At its introduction, the reality criterion would deem dark matter unreal; This is not, however, a prescription to abandon the construct altogether. It is rather a challenge to investigate and perhaps adapt the concept so dark matter can gain empirical significance other than the ad-hoc explanatory role it was defined to fill.

Now we can return to the problem of polysemy. Thus far it has been left vague what it is, other than the word or lexical entry, that units different meanings of a term so as to distinguish polysemy from mere bank-bank style ambiguity. We've seen similarity conditions placed on semantic extensions and explications. Wilson's model suggests that either some directivities must be privileged or core meanings of some term or else some sort of plurality rule is at work.

With Brun (2016, 1221), I hold that the similarity of the meanings associated with a term may not be determined extensionally, as Carnap (1967) originally thought, but

[42] The lesson here can be learned regardless of whether the electric field actually should be regarded as unreal. For a good argument for field realism see Lange (2002).

rather functionally. I disagree with Brun, however, that Goodman's 1966 replacement of extensional equivalence—clearly inadequate for the notion of explication we are here concerned with—with isomorphism is inapplicable due to targeting systems of concepts rather than individual concepts. First, Goodman's holism was already capable of being restricted, as it was meant to apply to incomplete systems:

> The function of a constructional system is not to recreate experience but rather to map it. Though a map is derived from observations of a territory, the map lacks the contours, colors, sounds, smells and life of the territory... A map is schematic, selective, conventional condensed, and uniform. And these characteristics are virtues rather than defects... There is no such thing as a completely unabridged map; for abridgment is intrinsic to mapmaking. (Goodman, 1963, 551-2)

Though Goodman (and Carnap) talk in terms of languages and translations, we need not hold the psychologically untenable position that by this they mean complete language systems which describe everything in the world and are to be translated *in toto*—the map projections and their translations can be done piecemeal. Second, it is already evident that the explication of a singular term in isolation is only an idealization. In the case of semantically extending pressure, as was necessary in Bridgman's experiments, there are ripples into related quantities, e.g. temperature. This does not require that this is a translation between distinct languages, but only a recognition that terms exist in interrelated patches of uses, a web of meaning.[43]

I will not follow Goodman's weakening of the extensional identity criterion for similarity to *extensional* isomorphism, but will invoke a notion of *functional* isomorphism in line with the pragmatist bent of Wilson's directivities. (Extensional isomorphism is a special case for terms which only have classificatory uses.) This move also provides protection from Newman's objection: isomorphism is cheap. So then, what is the restriction that functionalism is supposed to apply to the isomorphism criterion? In order to answer this question, it must be made clearer what the issue is that I propose functionalism can solve. In other word, why exactly do we want similarity?

[43]This is more fully discussed in "Commensurability, Comparability, Communicability" in Kuhn (2000, 33-57), where Kuhn moderates an earlier position attributed to him. He dubs this web of meaning as "local holism". Wilson would reject any comparison with Kuhn, as he rejects comparisons to Neo-Kantians, see Ryckman (2021); Wilson (2021). There is no room here for full account of the explanation of the similarities between paradigms (in the narrow sense) and directivities.

The unity of quantity terms is necessary for the semantic detoxification process: both for recognizing conditions of polysemy and for the novel meaning to detoxify the old meaning—this is what Tal (2019) refers to as the *common quantity assumption*. Tal raises the necessity of this assumption in the context of a particular form of semantic detoxification, developing standards for determining error. The problem that faces the metrologist is calibrating multiple forms of measurement such that some more precise and more accurate method may show the range of error in some other method. In order for this relationship to hold, it must be the case that these two measurement procedures *target* the same true quantity. Agreement under particular conditions is intuitively thought to justify the common quantity assumption. However, this is the source of paradox:

> [P]rior to the evaluation of error and uncertainty there can be no test of agreement. In other words, any claims about agreement and disagreement are conditional on the common quantity assumption, and therefore cannot be viewed as independent evidence for or against it. Testing the common quantity assumption independently of the results of the calibration would require yet another calibration, leading to an infinite regress. (Tal, 2019, 863)

This regress undermines hope for a foundationalist epistemology for measurement—though the practical methods of determining error in the face of these issues provide a guide to a coherentist epistemology.

The essentially holistic elements of a sophisticated operationalism have already been exposed by Chang under the title of the "Problem of Nomic Measurement", of which Tal's puzzle is a variant. The problem being: In setting up some quantity Y as a measure of some not directly observable quantity X, we posit that there is a law that defines some function from Y to X, but we cannot know the form of this function empirically as that would require correlating the values of both X and Y. In other words: "Whenever we have a method of measurement that rests on an empirical law, we have. . . [a] problem in testing and justifying that law." (Chang, 2004, 59) In cases of error determination, the "law" is identity and the would-be criterion of accurate correlation would be consistency. With an assumption of the single-valuedness of a physical quantity, the quantity and measurements of it, under a number of measurement procedures, must be mutually consistent. This requirement works in a condition of reliability in measurement, insofar as Y can be taken as an indirect observation of X. Chang calls conditions like single-valuedness “ontological principles”. I prefer the Kantian language of “constitutive principles”, but the meaning is the same: these principles are conditions of objective reality (Chang, 2004, 86, 90-1).[44] As a constitutive principle, the common quantity assumption serves as a idealized posit upon which some domain of theory, models, or experiment depend; its assumption is necessary to begin the work of determining error in cases of “hard problems of coordination” (Ohnesorge, shed) wherein sources of error are undetermined.

This provides an alternative, non-foundationalist, epistemic ground for measurement practices, removing a naive empiricism from operationalism. Our check for the suitability our our varying procedures and theoretical roles which partially define quantities is their mutual consistency. Both the discussion of the problem of nomic measurement Chang and the model-based epistemology of measurement developed by (Tal, 2011, 2016, 2017, 2019) lead to a coherentist, iterative model of measurement. This is perfectly consistent with Bridgman’s reality principle considered as a *regulative ideal*: the operationalist method is to connect posited quantities with more and more independent theoretical and empirical operations, yielding more and more evidence that the quantity is real and its variation has particular, though perhaps quite indirect, empirical effects.

Still then the question is, what does the assumed unity of some quantity across measurement operations consist of if not numerical value? As Tal has it, the measurement models all hold the quantity in question to be of the same *kind* such that the quantity can be measured by some procedure definable by the model.[45] What are quantity kinds? Dimensions.

Dimensions just are that which determines that some parameter “enters into ap-

[44] Chang (2004, 91) notes the similarity to Kant’s synthetic a priori. I use constitutive principles following (Friedman, 2001, 65-66)—note that Friedman rejects operationalism 2001, 76-77, fn 6.It is my opinion that these are also the same as Wittgenstein’s 1969 “hinge” propositions. See also the remarks on grammar around §371, “Essence is expressed by grammar”, in Wittgenstein (1953). A full articulation and defense of this syncretic view regarding the constitution of (the meaning of) objects remains for further work.

[45] “The model-based view provides a straightforward account of quantity individuation that is not exposed to the underdetermination problem discussed above. In order to individuate quantities across measuring procedures, one has to determine whether the procedures can be coherently and consistently modeled in terms of the same type of quantity in the background theory. If the answer is “yes”, then these procedures measure the same type of quantity relative to those models and the background theory. A few clarifications are in order. First, by ?type of quantity? I mean either a general or a specific quantity type.”(Tal, 2019, 872)

proximately the same nomic relations with other theoretical parameters."(Tal, 2019, 873). One of the primary uses of the logic of dimensions, dimensional analysis, is to distinguish the grammatical and ungrammatical nomic relations between quantities in advance (or in lieu) of detailed and complicated investigation, both theoretical and experimental (see Sterrett, 2021). One simple gloss of this idea is that in order to determine the mutual consistency of quantity measurements, one much assume or establish that the are commensurable on *the same scale*—this property of direct commensurability is just to be to be of a quantity kind, to be of the same dimension.

This commensurability condition can be given precision by appeal to the principle of dimensional homogeneity. Dimensional homogeneity is a principle that holds that a necessary condition on the identity of quantities is that they have the same dimension. This is often put as a principle restricting the manipulation of quantity equations (following Fourier, 1878):

> (Dimensional Homogeneity) A representationally adequate physical equation must have terms of equal dimension, i.e. equal exponents in each basic dimension.

With this principle in hand, my proposal is this: The dimension of a quantity is what is invariant across polysemous usages of a quantity. A necessary condition on the common quantity assumption is that different measurements target a common quantity *dimension*.

Let's consider again the case of pressure, which we take to be defined as a measure of force on some surface:

$$P_{Def} = \frac{F_{\perp}}{A}.$$

The dimensions of pressure are also given by this equation:

$$[P_{Def}] = \frac{[F]}{[A]} = \frac{\mathrm{M}}{\mathrm{LT}^{-2}}.$$

If we are given a manometer for the first time, how is it that we know that the displacement of the mercury column is an indicator of the pressure acting on the mercury? Setting aside the derivation, we can check that P_{Def} and the P as calculated from the manometer equation are commensurate by inspection. Recall the equation for the "pressure" described in 2.2.2:

$$P = h\rho g.$$

The dimensions of the constituent quantities are: $[h] = \mathrm{L}$; $[\rho] = \dfrac{\mathrm{M}}{\mathrm{L}^3}$; $[g] = \dfrac{\mathrm{L}}{\mathrm{T}^2}$. So then, $[P] = \dfrac{\mathrm{M}}{\mathrm{LT}^{-2}}$ and $[P] = [P_{Def}]$. Now the equivalence of dimension alone does not guarantee the equivalence of the target pressure and the pressure as determined by the manometer, no more than it guarantees the equivalence of the length of an ant and the distance from Mars to Jupiter. Physical reasoning is necessary to relate the variables in the equation to their physical quantity counterparts and so will be the same for extended uses of pressure in domains were normal manometers break down. Dimensional homogeneity is a necessary, but not sufficient, condition for quantity identity. I will not here defend this metaphysical thesis. Note, however that this does not require a strong constructionist thesis: that each kind of quantity has one dimensionality or that derived quantities are "built up" out of basic quantities. The dimensionality of a quantity kind may be system dependent (i.e. conventional) and my thesis holds so long as the dimensionalities change in the same fashion, e.g. that pressure remains in a positive correlation to mass.[46]

This condition also applies also to different measurement standards. The dimension of some quantity is the aspect of that quantity which is invariant under unit changes; I propose that this invariance further generalizes over *measurement procedures*—which in fact define units. A quantity is represented by a family of number unit pair, $\langle N, U\rangle$, such that any two pairs are related by a unit transformation variable, X, such that $N' = XN$ and $U' = X^{-1}U$. Each unit serves as a map from the quantity to a numerical representative; the group of all unit maps of a kind, those that have the unit transformation relations just described, have identical dimension. With this established, consider the fact that each unit is itself a quantity (defined to be represented by 1) that is defined with reference to some measurement procedure. There are of course the classic procedures of comparison to some reference object, like the French kilogram. Even with the recent move to make the physical constants fundamental to defining SI units (see Quinn, 2017; BIPM, 2019), it is not the case that

[46]See Tolman (1917) for a strong metaphysical conception of quantity dimensions. See Skow (2017) for a distinction between definitional and constructionist accounts of derived quantity dimensions and for an argument for the relative weakness of the former. I take my commitment here to be the minimal one: quantities are identical only if they can be swapped in all equations *salva congruitate*.

these definitions are free of reference to any operations: there is still the exception of the definition of the second in terms of the "microwave transition of caesium" which remains "for the time being, the basis of the definition" (BIPM, 2019, 203). While the BIPM suggests that this aberration will eventually be eliminable, it is significant to note that this "choice of an atomic parameter" which "does not disconnect definition and realization in the same way that h, c, e, or k do" (BIPM, 2019, 120) shows up in the definitions of almost all the other base units. So even the changes which have been made do not fully eliminate reference to some measurement procedure or operation. As units are tools for comparison, it is not even clear that it would be coherent to eliminate all references to measurement procedures from their definition. Comparison and therefore an assumption of dimensional homogeneity—commensurability—is embedded in the conceptual structure of unit systems and science in general. That quantities of like dimension are to be found in a number of systems and across theoretical developments is a source of their explanatory usefulness.

5 Conclusion

This paper has had two main aims and one subsidiary aim. First, the phenomenon of scientific polysemy has been established and examples of it have been furnished. Particularly, I have been concerned here of the regular polysemy of quantity terms; one and the same quantity may be measured by standards with varying results. Second, phenomenon of semantic detoxification has been analyzed and modeled on explication—a sophisticated operationalist version of semantic detoxification is shown to explain scientific polysemy. Further, this sophisticated operationalism, founded on Bridgman's reality criterion—that real constructs are related to operations other than those that define them—leads to a proposal: that in cases of quantities, dimensional homogeneity is a necessary condition for polysemy as opposed to ambiguity. That the same *kind* of quantity can be accessed by multiple theoretical and empirical measurement procedures provides a target upon which a program of investigation can aim.

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