THE SEMANTIC (MIS)CONCEPTION OF THEORIES

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Abstract

On the traditional, “syntactic” conception, a scientific theory is a (preferably axiomatized) collection of statements. On the version of the opposing “semantic” conception advanced by Beatty and Giere, a theory is a definition plus a hypothesis that the definition has application. On the version advanced by Giere and van Fraasen, a theory is a non-linguistic model specified by a definition plus a hypothesis that the model applies to some empirical system. On the version advanced by van Fraassen, Suppes, and Suppe, a theory is a collection of mathematical models. The advantages claimed for these versions of the “semantic” conception are either spurious or can be obtained under a suitable version of the “syntactic” conception. This conclusion will be argued here for the first two conceptions.

THE SEMANTIC (MIS)CONCEPTION OF SCIENTIFIC THEORIES

The Statement Conception

On the traditional conception, a scientific theory, T, is a collection of statements, interpreted sentences, or propositions. The most effective (but not the only) way of specifying the collection is to provide a list of basic statements (axioms) of the theory and then stipulate that the theory is the collection of logical consequences (theorems) of the basic statements. The oldest and most famous example of a scientific theory that conforms to this conception is the geometry of Euclid’s *Elements*. It has five geometrical postulates, including a first postulating a unique straight line lying on any two points, and the famous fifth postulating a unique parallel line through any point not on a given line. It also has five common notions that state the logical properties of equality (symmetry, transitivity, etc.), and twenty-three definitions. From a logical point of view, all thirty three of these statements are axioms of the theory. Some of Euclid’s alleged theorems are not logical consequences of his axioms, and in his *Foundations of Geometry* Hilbert (1971 [1902]) offered a new set of axioms to repair the defect.

Hilbert's work illustrates the utility of logic for scientific theories. It is often difficult to determine whether the theorems of a scientific theory are logical consequences of its axioms. Logic can assist by translating sentences of the theory into a formal language designed to reveal their syntax, recursively defining truth under an interpretation, defining logical consequence as preservation of truth under every interpretation, and providing effective methods for determining whether a sentence is a logical consequence or theorem of others. However, this use of logic does not imply that (i) geometry and other scientific theories are collections of uninterpreted formal sentences recognizable only by their syntax, or that (ii) a scientific theory is a collection of partly interpreted formal sentences with interpretations of some or all terms provided. For that use of logic is entirely compatible with the traditional, realist view that (iii) a scientific theory is a collection of statements or propositions, i.e., completely interpreted, meaningful sentences.

Conception (i) is entirely syntactic; but it implies that scientific theories are meaningless and has had no (sane) adherents. Conception (ii) is partly syntactic and partly semantic, but it has been held only by a few logical positivists who maintained that only the logical and observational terms of scientific theories are interpreted and that their theoretical terms are contextually defined in terms of their logical relationships to observational terms. Conception (iii) is entirely semantic, since it maintains that scientific theories are collections of completely interpreted, completely meaningful sentences, sentences with a complete semantics. Conception (ii) is often vilified as "syntactic" and used as a target or stalking horse by adherents of the "semantic" conception; however, it is partly semantic and most of its opponents—Giere, Beatty, and van Fraassen among them—also oppose conception (iii), which is entirely semantic! Clearly some new, less misleading labels for the contending positions are needed. The first misconception of the "semantic" conception is that its name is appropriate.

Opposed to the mislabelled "semantic" conception is the view that scientific theories are collections of statements or interpreted sentences written in a language adjudged suitable (by scientists) for the science in question. Usually the language adjudged suitable is a mixture of ordinary language and a technical language devised by the scientists who propose the theories. Often the technical language includes mathematical language whose terms are interpreted as numerical measures of empirical quantities and other mathematical objects. The sentences need not be and normally are not written in a formal language, such as the language of first-order or second-order logic. It may sometimes prove useful to rewrite the sentences in "logicalese", a mixture of logical and ordinary symbols, in an attempt to understand their structure. However, such clarification does not alter their status as interpreted sentences, as statements written in scientific language. It may also prove useful to translate the axioms of a scientific theory into sentences of a formal first or second order logical language in order to determine what the theorems are. However, such translation does not alter the status of the theory as a collection of statements written in the language of the scientists that construct and use it.

We will therefore refer to the conception above as the *statement conception* of scientific theories and to the views in opposition to it as nonstatement conceptions. This terminology is not completely satisfactory in two respects. First, although nonstatement conceptions maintain that theories are not statements, they concede that the presentation and application of theories involves statements. Second, one version of the Giere/Beatty conception identifies a theory with a definition, which of course is a statement, albeit a statement of a special kind. Informative yet completely satisfactory labels for the positions at issue are unavailable, and the one chosen here seems less misleading than most others. To add to the confusion caused by misleading labels and classifications, there are at least three versions of the nonstatement conception, which are rarely distinguished from one another. The first two will be distinguished and criticized in what follows, and it will be shown for each version that some of its alleged advantages are spurious and the rest are available in suitable versions of the statement conception. Unfounded claims for their advantages and disadvantages constitute the substantive misconceptions of the "semantic", or as we shall henceforth call them, *nonstatement conceptions* of scientific theories.

The Beatty/Giere Conception

On this conception a scientific theory consists of (a) a theoretical definition of a kind of system and/or (b) a theoretical claim or hypothesis that some system fits a definition of type (a). One version of the conception (Beatty 1981)) identifies a theory with (a) alone; other versions (Giere 1979) identify a theory with (b) alone or with (a) and (b). For Newton's theory of gravitation the theoretical definition is the following.

A Newtonian gravitational system is, by definition, a system of objects such that for any two objects, x and y, of the system (1) if $F(x) = 0$ then $v(x) = c$, (2) $F(x) = m(x)\ a(x)$, (3) $F(x,y) = -F(y,x)$, and (4) $F(x,y) = G\ m(x)\ m(y)$ _ $d(x,y)^2$), where F is force, m is mass, d is distance, and G is the constant of universal gravitation.

The hypothesis that our solar system is a Newtonian gravitational system is an example of a theoretical hypothesis often used by Giere. The hypothesis that the system of molecules of gas in a closed container is a Newtonian gravitational system is an example used by Beatty. On Beatty's version a scientific theory is identified only with the theoretical definition in (a). Giere sometimes identifies a scientific theory only with the theoretical hypothesis of (b), sometimes with both the theoretical hypothesis and the theoretical definition of (a). On all versions both definition and hypothesis are held to be essential to the process of making and using theories.

The fundamental critical question is whether there is any important difference between the statement and the nonstatement conceptions. On the statement conception, Newton's theory of gravitation is the conjunction of his four laws (and their logical consequences), each of which is an assertion about all physical objects ("ponderable bodies"). Whether the *theory* should identified with the theoretical definition, the theoretical hypothesis, or both seems to be a terminological question. The best answer is the second, because the definition by itself is neither true nor false and the hypothesis employs and therefore includes the definition, thus reducing to the third answer. Newton's theory is then the hypothesis that the system of all physical objects fits the definition of a Newtonian gravitational system. Now, to say that the system of physical objects fits that definition is merely a cumbersome way of saying that the four statements in the definition are true of all physical objects. Hence Newton's theory is simply the hypothesis that the four laws are true of all physical object. Why prefer the more cumbersome way of describing his theory?

Beatty's Argument

Beatty's (1980) answer is that, although Newton's theory of gravitation can be "reconstructed" on either the statement conception or the nonstatement conception, other theories fit only the latter. The example he offers is the synthetic theory of biological evolution (synthetic because it is a synthesis). He takes the "central premise" of this theory to be a law deducible from Mendel's law of gamete (sperm and eggs) formation, namely the Hardy-Weinberg law, which he states approximately as follows:

Within a breeding group, if gametes combine randomly during mating and no forces (such as

> selection, mutation, or migration) affect gene frequencies from the time of fertilization to the time of gamete formation in the next generation, gene frequencies will remain constant from one generation to the next.

If we were to construct the synthetic theory of evolution according to the statement conception, the sole axiom of the theory would be the Hardy-Weinberg law above. But we cannot so construct it, Beatty argues, for the following reason. The statement conception requires the axioms of a theory to be *laws of nature*, that is, universal generalizations that have no actual or physically possible exceptions. Although the statement "All bodies consisting of pure gold have a mass of less than 100,000 kilograms" has no actual exceptions, exceptions are possible, larger masses of gold in a physically possible but nonactual universe; consequently, the statement is not a law of nature according to Beatty. Similarly, even if there are no actual exceptions to the Hardy-Weinberg law, exceptions are physically possible. For it is physically possible for the biological process of meiosis—the process in which gametes are formed—to change through biological evolution, so that the Hardy-Weinberg law is no longer true of the process (p. 407). Furthermore, "there are clear-cut exceptions to...the Hardy-Weinberg law", that is, to the process of normal meiosis described by the law, and so the law is not true as an unrestricted generalization. One exception is nondisjunction, the possession by a gamete of either both or neither of two homologous chromosomes; another is meiotic drive, which results in a lower survival rate of one the two homologous chromosomes.

To summarize Beatty's argument, the statement conception of scientific theories requires that they consist of laws of nature, generalizations that are (a) necessary and (b) universal. However, the theory of biological evolution contains no laws of nature in this sense, and yet it is clearly a scientific theory. Consequently, the statement conception is inadequate and must be replaced by the nonstatement conception. On the latter, the synthetic theory of evolution is contained in the following definition:

> A Hardy-Weinberg (or Mendelian) breeding group = def a breeding group whose genetic frequencies obey the Hardy-Weinberg law (p. 410).

Having formulated this definition, the evolutionary biologist then makes the empirical claim that it applies to the class of breeding groups, which is simply to claim is that all breeding groups are Hardy-Weinberg breeding groups. Since definitions are neither true nor false, and empirical claims about the applicability of the definition are not required to be (and normally are not) either necessary or universal, the theory of evolution qualifies as a scientific theory on the nonstatement conception, although it makes no necessary or universal claims.

The reply to this argument is that there are versions of the statement conception that accommodate the synthetic theory of evolution as well (or badly) as Beatty's conception. Beatty selects as his target a version of the statement conception he seems attributes to Hempel, on which the axioms of a theory are required to be (a) necessary and (b) universal. If this is the interpretation, it is incorrect. For although Hempel requires universality of the covering law of an *explanation*, he does not explicitly require it of the axioms of a scientific *theory;* and he does not require necessity of either an explanation or a theory. However Hempel is interpreted, there is a version of the statement conception on which neither necessity nor universality is required of the axioms of a scientific theory; and it is that version which should be placed in competition with his Beatty's conception. Beatty has given no good reason to prefer his conception to the appropriate competing version of the statement conception.

Oddly, Beatty seems to concede the point, at least in regard to the requirement of universality, when he acknowledges that the problem of exceptions can be avoided by modifying the traditional view to require only that theoretical statements be generalizations whose range of application is restricted and does not include the exceptions (p. 409). Furthermore, he implies—citing Ruse and Scriven—that this "looser" version of the traditional view must be adopted if it is to accommodate even physics, most of whose laws also have exceptions and therefore fail to have unrestricted application. Giere, by contrast, is not conciliatory, and an examination of his argument will take us deeper into the issue of exceptions to and restrictions on laws.

Giere's Argument

The problem of exceptions to laws is identical with the problem of provisos, which Giere (1988) offers as a conclusive reason for abandoning the statement conception. His argument, to which we will add some detail, constitutes a second answer to our question of why the Beatty/Giere conception is preferable to the statement conception. Giere illustrates the problem of provisos with the law of the pendulum, which gives the period of oscillation, T, as a function of pendulum length, l, and the strength, g, of the gravitational field affecting the bob, as follows:

$$T(x) = 2\pi\ (l(x)/g(x))^{1/2},$$

where x is intended to refer to a pendulum. To make the referential intention explicit, the law must be written as:

$$\text{If } P(x) \text{ then } Tx = 2\pi\,(l(x)/g(x))^{1/2},$$

where P(x) means “x is a pendulum”. (Of course, physicists almost never write laws in such explicit form.) According to the statement conception, to qualify as an axiom of the theory of the pendulum the sentence above must be universally quantified, as follows:

$$(x)(\text{if } P(x) \text{ then } T(x) = 2\pi\,(l(x)/g(x))^{1/2})$$

The problem of provisos is that universal generalizations are not true unless adequately qualified, and completely adequate qualified is impossible. If the bob of the pendulum is made of metal and a magnet is located near it, then the bob will not oscillate according the law above. So the law must be qualified to say that its consequent holds only if such conditions do not obtain. That is, the qualification -Q(x), where Q(x) is the conjunction of conditions under which the consequent does not obtain, must be conjoined with P(x) in the antecedent. The problem is that any such list of such conditions is incomplete, either because it is infinite or because it is finite and too large to be known. For these reasons Q(x) can never be completely constructed; but for any partially constructed Q(x) the law is false.

On Giere’s conception the theory of the pendulum is presented in the following definition:

A classical pendulum system (CPS) = def a system, x, such that $T(x) = 2\pi(l(x)/g(x))^{1/2}$.

The theory is applied by hypothesizing of empirical systems that they are classical pendulums. The hypothesis may apply the theory to one, several, or infinitely many systems; and it may do so by listing the systems or by defining a class of systems. However the theory is applied, the qualification -Q(x) is no longer necessary: it does not appear in either the theoretical definition or the theoretical hypothesis that applies the definition to empirical systems. Thus, the problem of provisos is eliminated, so Giere alleges.

That the problem is entirely eliminated is, however, an illusion. Furthermore, an equally good solution can be achieved by a version of the statement conception. The problem is eliminated only for *particular* theoretical hypotheses, hypotheses that apply the theoretical definition to particular empirical systems $a_{1,}\ a_{2,}\ldots a_n$. In this case the hypothesis asserts that each of the a_i is a CPS, which is equivalent to the statement that the sentences obtained by substituting names of the a_i for “x “ in the open sentence $T(x) = 2\pi\,(l(x)/g(x))^{1/2}$ are true. But suppose the physicist wishes to a assert a *general* theoretical hypothesis, for example, the hypothesis that all pendulums are CPS. In that case the assertion is equivalent to the statement (x)(if P(x) then $T(x) = 2\pi\ (l(x)/g(x))^{1/2}$) and is no more true without the qualification -Q(x) than is the original. Consequently, provisos are as much (or as little) a problem for general theoretical hypotheses on the nonstatement conception as they are on the statement conception. The problem is completely eliminated only by restricting theoretical hypotheses to the particular case, which is as easily achieved on the statement conception as on the nonstatement. But scientists have not required its elimination: they formulate, or least imply, general hypotheses and are satisfied if these are even approximately true. This practical solution to the problem is available on either of the competing conceptions.

The Giere/ van Fraassen Conception

On this version of the statement conception, a scientific theory consists of (a) a theoretical definition, and/or (b) a theoretical model or collection of theoretical models specified by the definition, and/or (c) a theoretical hypothesis claiming either that some real, empirical system is similar to one of the theoretical models. Giere is the main architect of this version. However, because van Fraassen (1970, 1972, 1980) inspired the inclusion of component (b) and he endorses Giere's "elegant capsule formulation" (1987, p. 110), he is appropriately listed as co-architect. At first Giere identifies the theory with a generalization of component (c) (1984, p. 84), but later he identifies it with the "cluster" of all three components (1985, p. 345). Van Fraassen, on the other hand, tends to identify the theory with component (b) and to regard the other components, or perhaps the entire cluster, as the *presentation* of the theory. He undoubtedly means to endorse Giere's formulation as a conception, not of a theory, but of a theory's presentation. The Giere/van Fraassen version of the nonstatement theory differs from the previous version in its addition of *models* to the list of components and its reformulation of the final component as the hypothesis that some empirical system is *similar* to one of the models. Our focus will therefore be on these additional notions.

One of Giere's illustrations of this conception of a scientific theory is Newton's theory of universal gravitation applied to the solor system (1984, pp. 81ff). Another is Galileo's theory of the pendulum. In the former example component (a)—the theoretical definition—is the definition of a Newtonian particle system by means of Newton's three laws of motion and his law of universal gravitation (for which see the previous section). Component (b)—the theoretical model—is a system of ten spherical bodies whose masses, positions, and accelerations are those our sun and its planets are estimated to have at the present time. Component (c)—the theoretical hypothesis—is the statement that our solar system is similar to, approximately like the model. Giere identifies scientific theories with theoretical hypotheses, not a particular hypothesis, but rather a general theoretical hypothesis to the effect that many systems resemble theoretical models of a single theoretical definition (p. 84). Thus, Newton's theory of mechanics is the general hypothesis that solar systems, gases, and all systems composed of massive particles are Newtonian particle systems.

What is the advantage of the above conception of a scientific theory over the statement conception? And what is its advantage over the two-component Beatty/Giere conception criticized in the previous section? Given our conclusion that the Beatty/Giere conception is virtually indistinguishable from one version of the statement conception, the first question reduces to the second. Now, the distinguishing feature of the Giere/van Fraassen conception is its requirement that a scientific theory involve a theoretical model hypothesized to be similar to some empirical system. So our question is: What is the advantage of this additional requirement?

Giere's Argument

Giere's answer is that a conception with the additional requirement best reflects the practice of scientists and others when they "talk about [and consider] scientific theories" (1984, p. 84). Although the laws in theoretical definitions never hold exactly of real empirical systems, scientists talk about and consider systems that exactly satisfy the laws they propose. For example (p. 84):

> Galileo frequently asks his readers to consider such things as a ball moving on a perfectly smooth, perfectly flat surface, infinite in all directions. ...But there are no such surfaces as Galileo asks us to imagine....Such things are to be understood, I suggest, not as hypotheses about the real world, but as descriptions of a theoretical model. The hypotheses come later.

The systems that scientists imagine to satisfy exactly the laws of a theoretical definition are the theoretical models of component (b), and they must be included in the conception of a scientific theory if it is to reflect the practice of scientists. So Giere argues.

On one interpretation, the argument above is the following. (1) In their theorizing scientists imagine and talk about systems that do not exist in a real, physical sense; (2) one cannot imagine and talk about that which does not exist in any sense; therefore, (3) when scientists imagine and talk about systems that do not exist, they are imagining and talking about models, systems that exist, but not in a real, physical sense. On this interpretation, Giere has advanced a controversial, metaphysical argument of ancient provenance. It is a variant of one presented by the Stranger in Plato's *Sophist* (para. 237 ff) who claimed that since one cannot think or speak of something that does not exist, the thing thought or or spoken of must in some sense exist, on pain of contradiction. Variants have been more recently employed by Meinong, Heidegger, and Wittgenstein of the *Tractatus.* One does not expect to find the argument used by a contemporary, empirically minded, naturalistic philosopher of science such as Giere.

Further evidence that he does use the argument is his apparent concern with the burning question it raises If the systems that physicists imagine and describe are not real, concrete, physical systems, then what are they? One possible answer is that they are ideal, abstract systems; but it seems embarrassingly metaphysical. A less embarrassing answer is that they are psychological systems, systems of thought. Another is that they are linguistic systems. We find Giere wrestling with the question and considering all the answers listed in his attempt to characterize theoretical models.

At first he merely contrasts theoretical models with the "real" systems which are hypothesized to be similar to them (1984, p. 83, diagram), thereby implying that they are ideal systems without saying so. Soon after he says explicitly that models are "abstract, idealized system[s]" (1985a, p. 345). They are, however, apparently not of the Platonic sort, since they "are humanly constructed abstract entities" (p. 347). Still later he concedes that a model is a "creature of language" (presumably of the linguistic definition that describes it), but insists that it is not a linguistic entity (1988, pp. 80, 84). By this he means that models are unlike sentences, where sentences are to be contrasted with statements or propositions, the latter being abstract entities introduced by philosophers to be the meaning of sentences (1988, p. 84). (If this passage contains a suggestion that models might be statements or propositions, Giere must reject it if his conception is not to collapse into the statement conception he means to oppose.) In another passage he says models "function as 'representations' in one of the more general senses now current in cognitive psychology" (1988, p. 80), and some passages suggest that he has visual images in mind. Occasionally he seems to consider pictures, sketches, or diagrams as models. (The suggestion that such concrete, empirical objects can be theoretical models must be rejected if Giere is to retain his earlier, well-motivated distinction between scale models and theoretical models (1984, pp. 79-81).)

The passages above reveal an empirically minded philosopher of science wrestling with the classical ontological problem of universals. To use a classical example, what is a perfect right triangle, given that no such real, concrete entity exists? The Platonist says it is a Form, an ideal, abstract entity (perhaps existing in some nontemporal realm); the constructivist says it is a human construct; the conceptualist says it is a concept in the minds of those who think about a perfect right triangle; the nominalist says it is the term “perfect right triangle”. The passages cited above reveal that Giere considers each of these four ontological positions for his models, exhibits a preference for those later in the list (as a good empiricist should), but never decides definitely between them. Each position seems objectionable: the first because it posits strange, transempirical entities; the second because it is unintelligible or indistinguishable from the third; the third and fourth because they imply that to think of a perfect right triangle is to think of a concept or a term, when plainly it is to think of a triangle.

What a good empiricist should say is that perfect triangles, ideal particle systems, and other theoretical models are intentional objects of thought and language, the meanings of statements and the contents of thoughts; and as such they do not exist in any sense That a word means triangle or that a person thinks of a triangle does not entail that any triangle exists. That a statement describes an n-particle system or that that a person thinks of such a system does not entail that any such system exists. Models are not ideal abstract entities, either linguistic or nonlinguistic; nor are they real concrete entities, either physical, mental, or linguistic. Even to try to assign them to any of these ontological categories is a mistake, the mistake of reification; for it is to try to decide in what sense they exist, when in truth they do not exist in any sense.

That models should not be reified is buttressed by examining component (c) in the Giere/van Fraassen conception of a theory. This component is the hypothesis that some real, concrete system is similar to the model or ideal system in component (b), which is described by the definition in (a). Continuing with our classical example, let the model be the perfect right triangle and let the hypothesis be that the paper cutout on my desk is similar to that model.. If the model is a term or a concept then the hypothesis is necessarily false, because terms and concepts are not even approximately triangular. Since the hypothesis is supposed to be a scientific, it must be either directly confirmable through observations or indirectly confirmable by inference from observational data. But if the model is an ideal triangle and thus transempirical, then the hypothesis cannot be directly confirmed, because a transempirical, ideal triangle cannot be observationally compared with the paper cutout on my desk. Consequently, the similarity of the ideal triangle to the real one on my desk must be confirmed indirectly, by inference from observational data. Now what would such an inference be? Only one reasonable answer coms to mind. The observational data are that (1) the paper triangle has three angles (determined by looking and counting), one of which is approximately right (determined by using calipers, or by making a duplicate triangle and fitting the two right angles together to make a straight angle), which logically entails that (2) the paper cutout approximately satisfies the definition of a (perfect) right triangle as a plane figure with three angles, one of which is right. From From (2) it is inferred that (3) the paper cutout is similar to the perfect right triangle.

The above considerations show that a real, empirical entity cannot literally be similar to a model in any of the senses suggested by Giere, and that the hypothesis of their similarity is a metaphor. The explanation for its metaphorical character is, as argued above, that models in Giere's sense do not exist. What then is the literal truth underlying the metaphor? To say that a real, empirical entity is similar to a theoretical model means that the entity approximately satisfies the definition or thought whose object is the model. In virtue of this equivalence, the three-component Giere/van Fraassen conception almost reduces to the two-component conception of Beatty/Giere.

But not quite. Theoretical models are fictions, i.e., they do not exist. Nonetheless, thoughts about the fiction do exist and they sometimes play a role in the thought processes of scientists. Perhaps some scientists even believe the fictions exist, and perhaps it is useful for them to believe it. It is permissible for scientists to believe in fictions if doing so improves their practice; but philosophers describing the practice of scientists are not permitted to make the same mistake. Hence, the Giere/van Fraassen conception should be

formulated as follows: a scientific theory consists of (a) a theoretical definition, (b´) a fictitious system or collection of such systems so conceived as to satisfy the definition, and (c´) a theoretical hypothesis claiming either that some real, empirical system satisfies the definition. The new second component is obtained by replacing "model" in the original with "fictitious system". The new third component replaces the similarity metaphor of the original with its literal equivalent. Since the fictitious system does not exist in itself, it must be the object either of a description or of a thought. In the first case component (b´) reduces to (a), and the conception reduces to Beatty/Giere and inherits the objections to that conception. In the second case (b´) must be altered to read (b´´): thoughts of some scientist(s) about a fictitious system or systems. There are two objections to the revised conception. First, some scientists do not think about ideal, fictitious systems. Second, because a thought must be the thought of some person, the existence of a scientific theory will not exist unless the owner of the thought in (b'') exists.

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