Chapter 11
Theories, Models and Reality

Structure is what matters to a theory, not the choice of objects.

W. V. O. Quine

11.1 Introduction

We use the concept of a theory essentially in two distinct ways. In certain situations, we make a distinction between theoretical and empirical propositions, where we use the concept of theory to mark a contrast with observations and things inferred from these. In other situations, the point of the concept of a theory is primarily to contrast theory with reality, observed or otherwise. It is in this second sense that we say of a hypothesis that it is 'just a theory' where we are allowing that the world may be such that the hypothesis is false. If one could claim that the content of observations are 'pure reality', then there would be no difference between these two ways of using the concept of a theory; but unfortunately, as we saw in Chap. 4, observation sentences are often theoretically loaded. One can say that when we use the concept of a theory in the first way we want to stress the abstract nature of a theory, whereas in the second usage we want to stress the provisional nature of a theory as a picture of reality.

In many cases, the concept of model is used as a synonym for theory, where 'theory' is interpreted in the second sense. In this chapter, we shall dig a little deeper into the meaning of theories as models of reality.

That a model and what it models resemble one another is easily understood in the case of a concrete object such as a toy car, but what does it mean for a theoretical model to resemble the part of reality it models? An example is helpful.

Example: Maps and Reality
The figure below shows a map of Stockholm's commuter train network. The map exhibits an essential property of the commuter train network, namely, the topology of its various connections between stations. From the map one can, for example, see that one can travel directly from Jakobsberg to Stockholm Central Station and that on the way one will pass four stations (Barkaby, Spånga, Sundbyberg and Karlberg) (Fig. 11.1).

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Fig. 11.1 A map of Stockholm's commuter train network

However, one cannot see how long the distance is, how windy the track is, or how long it will take to travel; the metrical properties of the commuter train network are not displayed, only the topology.

Two interesting questions immediately arise: (1) is it, in principle, possible to construct a model that gives a complete picture of a part of reality, and (2) if we had such a model, and if we knew that it was complete, should we then call it a model of reality? We shall return to these questions later on. First, we must more precisely understand what is meant by a model *resembling* reality.

I propose that resemblance must be some kind of *structural similarity* between the model and reality. Structural similarity can, in turn, be understood in two ways. In certain cases are we interested in special relations between parts of reality (things, properties, measurement results, etc.), while in other cases we are interested in certain kinds of operations or actions that can be performed on the various elements of reality. In both cases our task is to find a representation of these aspects using a model. The first type of structural similarity is the simpler of the two, so we shall begin with it. We shall then discuss the second type, which may be understood with help of the mathematical concept of *isomorphism*.

11.2 Structural Similarity as a Mapping of Relations

In some scientific disciplines theories are not mathematically formulated for various reasons. Nevertheless, one often uses models for describing reality. A common example is the use of causal models. These often take the form of diagrams where one indicates causal relations between different factors using a series of arrows. The following diagram is such a causal model, displaying the causal network behind myocardial infarction (Note that this is only an illustration and is not meant to be a correct model of the causal network!).

The fundamental structural relation in this diagram is an arrow starting at one box and ending at another. This arrow represents a causal relation; the factor in the box where the arrow starts is a cause of the factor in the box at the arrow's point.

One important feature of causal relations that is visible in this model is transitivity: if A is a cause of B, and B a cause of C, then A is an (indirect) cause of C. Following the arrows in the above diagram yields precisely this. However, what is not shown is the relative strength of the different causal factors. This is a general characteristic of all models; they display *certain aspects* of reality while leaving out others (Fig. 11.2).

An interesting question with regards to the present example is whether the model is complete in the sense that it contains all the causal factors. Generally, this is not the case as typically such models only include those causes that are known/suspected and significant. Naturally, this question is not one that can be ascertained from the model alone; rather, one must compare the model with reality.

11.3 Mathematical Models

The two models above display non-quantitative relationships between parts of reality. In contrast, some sciences make extensive use of mathematical models that give information about quantitative relationships between observed properties of objects. One example that is often discussed is the ideal gas law: the product of the pressure (p) of a gas and its volume (V) is equal to the product of the amount of matter (n), the gas constant R, and the temperature (T); $pV = nRT$. What is essential is that the model is structurally similar to (observed) reality in the form of *measurements on portions of gases*. The mathematical formula expresses relations

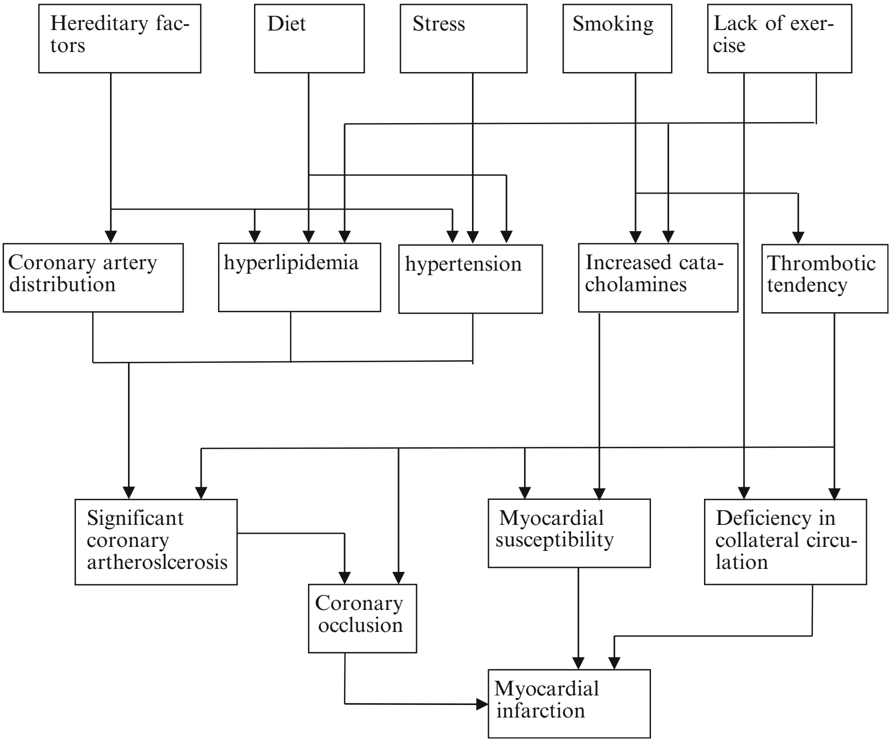

Fig. 11.2 Model of the causal network behind myocardial infarct (Adapted from Friedman, M & Rosenman, R. H. (1974))

between certain properties of any specific quantity of gas. However, it is not stated that this description of gases is complete, or even exactly correct.

The concept of structural similarity is usually specified within mathematics as an *isomorphism*, which is the idea of two sets having the same structure regardless of the nature of the elements in those sets. It is tempting to say that the observed measurements are isomorphic to the ideal gas law, but it requires a rather detailed discussion about set theory, groups, and measurements to show that. Suppes (2002) contains a detailed analysis of the notion of an isomorphism and results of measurements.

Normally, an equation functions as a model only under certain conditions. In the case of the ideal gas law, it is derived from the assumption that gas particles have no inner structure, that there are no forces active between them and that all collisions between them are elastic. However, from our background knowledge about molecules it is easy to understand that if the pressure or temperature is sufficiently high, then the gas particles will spend more time near one another. But if the gas particles spend more of their time in close proximity, the forces between them that we previously discounted will be stronger. In effect, what we have is no longer an ideal gas. Could the model be improved by removing one or more of the restrictions? Yes, in this case, taking into account interactions between gas particles gives us a more complicated law called van der Waal's law, which is valid in more cases.

Is this process of successive improvement by adding structure always possible? Most scientists seem to assume this to be the case. In fact, this assumption has been confirmed on a number of occasions, such as the addition of quantum and relativistic effects in the case of the ideal gas law. But is there a limit beyond which no more improvement of a model is possible? An obvious limit is the case where one can construct a complete model in which all observed and unobserved phenomena are captured by the model. Naturally, one can never be certain that such is the case, but if we were to have such a model, we would have reached the limit of improvement.

However, if it is not the case that our model is complete, is it then always possible to make such a model better? James Brown has presented an interesting argument for this possibility:

> We already have set theory in our possession. In some important and relevant sense we can grasp it. When we do science we in effect assert that some part of the physical world (or even the whole universe) has the same structure as some mathematical object. Since the realm of sets provides all possible mathematical structures, any way that the world could be is exactly isomorphic to some set-theoretic object. Since all of these mathematical structures are graspable in some relevant sense by the human mind, any way that the physical world could be is also graspable by the human mind. Of course, any alleged isomorphism between the physical world and some set-theoretical structure is a conjecture, which may be false; science after all, is very difficult and very fallible. But there is no way of thinking about physical reality which is ruled out by our genetically cognitive capacity, since (standard) set theory can provide the representation of any possible way reality might be. The mere fact the we possess set theory shows that there can be no (non-logical) constraints on our thinking. Brown (1994, p. 76)

The crucial point is that set theory is so flexible and general that any thing whatsoever can be represented by a mathematical object constructed using set theory. This is not the place to scrutinize the argument for this statement, let me simply state that I agree with Brown on this point. A thorough analysis of these matters are found in Chaps. 2 and 3 in Suppes (2002).

Another thing to notice is that Brown clearly hold that the world is in some definite way independent of our ideas, concepts or theories. This is the basic idea in realism. Some philosophers deny that such realist theses are meaningful or comprehendible, thus expressing a form of anti-realism. Anti-realists have further claimed that wave-particle dualism in atomic physics supports this view.

11.4 Wave-Particle Dualism

The well known phenomenon that reality's smallest pieces, neutrons, protons, electrons, photons, neutrinos, etc., show both particle and wave behaviour raises a central question; is it in principle possible to find only one model for a certain part of reality? All observable features of the micro world are captured, as far as we know, by quantum mechanics, but we need two models for thinking about the micro objects, viz., the particle model and the wave model. Thus quantum mechanics represents, in a certain sense, the dualistic character of elementary particles. This provides a strong reason to doubt the idea that theories, conceived as models, can be improved until they give a complete description of the external world. This in turn raises the following question regarding a theory's relation to reality: Are theories merely models that describe observable phenomena as the anti-realists claim, or do (the best) theories describe *reality*, not only observable traits, as the realists claim? This conflict does not concern what we know, but how the world actually is and what is meaningful to say of it.

A realist might formulate wave-particle dualism as: reality, as it were, show two faces in our experiments, the wave face and the particle face. This does not mean that the two models do not concern reality. One could still claim that we have yet to construct a more complete model, which encapsulate both wave and particle behaviour in one model.

However, according to Bohr, this is not possible; nature has *complementary* properties, which makes the completion of either model so as to cover all phenomena, impossible. That two properties are complementary means that the *conditions* for observing these two properties in the same system are mutually exclusive. It is important to note that the properties themselves are not contradictory, but the *conditions for ascribing these two properties to a system* are. Concretely, this means that in certain situations, when we arrange for observing positions of particles, which are decided by how we arrange our experiments, the conditions for observing wave behaviour are not fulfilled and cannot be fulfilled. In other situations, where the conditions for observing particle behaviour are not fulfilled but the conditions for wave behaviour are, we observe only wave behaviour. It is not possible to conceive of situations arranged such that both types of properties are observable, according to Bohr. The conditions for observing particle behaviour and wave behaviour are logically incompatible.

One is now prone to ask whether the objects under observation do not simultaneously *have* both wave and particle properties (which would explain why we cannot observe them at the same time), or whether it is only a principal limit of our ability to measure and observe the micro cosmos that hinders us from simultaneously observing particle and wave behaviour. This is a controversial question in the philosophy of physics. I believe that the first alternative is the correct one. In short, in motion from one place to another all electrons, protons, photons, etc., have wave properties (wavelength, frequency, extension in space), while during interactions (collisions) they have particle properties (definite position, energy, momentum). This makes it possible to construct a model that fulfils the requirement of structural similarity to the reality that presents itself in all of our observations. And this has been done! That is what we have in quantum mechanics. This theory is a *mathematical model*, which, as far as we know, represents all observable phenomena in the micro domain. Antirealists have always claimed that this purely mathematical structure cannot be given one unified visualizable interpretation in terms of things moving around in space, hence, we should accept that realism is disproved. This is a highly controversial issue. I do think quantum mechanics, as we now know it, can be given a visualizable interpretation, but this issue is far beyond the scope of this chapter.[1]

11.5 Can One Measure Structural Similarity?

In some areas of research and technology, such as image reproduction, one is interested in measuring how good a copy is or how structurally similar two different objects are. Could it be measured? In the case of similarity between images we have the SSIM index, which measures the structural similarity between two images. It is valued between -1 and 1. When two images are nearly identical, their SSIM is close to 1, see Wang et al. (2004). The function *ssimval = ssim(A, ref)* in Mathlab computes the SSIM value for a picture A, with 'ref' as reference picture.

Another measure of structural similarity, to be applied to graphs displaying business processes, is presented in Dijkman et al. (2009).

11.6 Ontology and Structural Similarity

Suppose that we have succeeded in constructing a mathematical model of reality that is perfect in the sense that all observable phenomena fit in with this model. How do we know that the model is not reality itself? The answer may seem obvious. Models and reality are entirely different types of things. In many cases, a model consists of mathematical objects that *represent* real things and their properties. This is the fundamental relation, and it is obvious that we could not talk about something representing something else if we could not distinguish the two relata. The fundamental difference is that the elements of the model are mathematical objects, whereas the elements of reality are physical objects, things that can be found in space and time.

Is this difference between model and reality actually important for how we think about models and theories? Quine has claimed that 'structure is what matters to science and not the choice of its objects' (*Theories and Things*, p. 20.). What he means is that from a scientific perspective it does not matter whether we suppose that physical reality is built of particles, fields or even some type of mathematical object (n-tuples of numbers) so long as the sets of these objects have the same structure. This stance also implies that one can assert the existence of abstract things like numbers, functions, social institutions, etc., without dwelling in speculative metaphysics. The essential step in constructing theories about, e.g., social

[1] I have given my view on quantum mechanics in my (2007).

institutions is that we clearly state how these postulated entities relate to each other and to statements about observable phenomena. However, science cannot answer the ontological question of what there is in the world, *independently of which theories we use*; we can only say things like, 'according to theory T, there exists objects of kind K, and since we have very good evidence for T and it is presently the best theory available, it is reasonable to assume that there exists K-things.' Now assume that we make progress and construct a better theory T′, which assumes not objects of kind K but other kinds of objects. So we have changed our ontology, but what we have not changed is some structural features, in one of the senses here described. So structure is what really matters. This is not an uncontroversial stance, quite the contrary, but the arguments in its favour are stronger than one might think at first glance.

Further Reading

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