

Modelling Nature

An Opinionated Introduction to Scientific Representation

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The full manuscript is available from the publisher's website:

<https://link.springer.com/book/10.1007/978-3-030-45153-0>

Below are the table of contents, the preface, the introduction, and the bibliography by way of preview.

Contents

Preface

Introduction

1. Problems Concerning Scientific Representation

2. General Griceanism and Stipulative Fiat

3. The Similarity View

4. The Structuralist View

5. The Inferential View

6. The Fiction View of Models

7. Representation-As

8. The DEKI Account

9. DEKI Goes Forth

Preface

Models matter. Scientists spend much effort on constructing, improving, and testing models, and countless pages in scientific journals are filled with descriptions of models and their behaviours. Models owe much of their importance in the scientific process to the fact that many of them are representations, which allows scientists to study a model to discover features of reality. And the importance of representation is not limited to science. We look at photographs, contemplate paintings, study diagrams, read novels, watch movies, appreciate statues, are perplexed by kinematic installations, and watch the lights when crossing the road. There is hardly an aspect of our lives that is not permeated by representations. But what does it mean for something to represent something else? This is the question we discuss in this book. We focus on scientific representation, but, as we shall see, the boundaries between scientific representation and other kinds of representation are porous, if not spurious, and attempts to separate scientific representation and analyse it in blissful isolation are doomed to failure.

The problem of scientific representation has by now generated a sizable literature, which has been growing particularly fast over the last decade. However, even a cursory look at this literature will leave the reader with the impression that the discussion about scientific representation is still in its infancy: there is no stable terminology, no shared understanding of what the central problems are, and no agreement on what might count as an acceptable solution. The aim of this book is threefold. Our first task is to get clear on what the problems are that we ought to come to grips with, how these problems should be formulated, and what criteria an acceptable solution has to satisfy. We then review the extant literature on the topic and assess the strengths and weaknesses of different proposals in the light of our conceptualisation of the problems and our criteria for adequate solutions. Finally, we offer our own answers to the quandaries of scientific representation and formulate what we call the DEKI account of representation.

Parts of the book build on previous publications. Chaps. 1, 2, 3, 4, and 5, and Sects. 7.1 and 7.2 are improved and expanded versions of our (2017a). We included new material in many places and updated the arguments in the light of criticisms and comments we received. Sect. 4.5 includes parts of our (2017); Sects. 7.3, 7.4, 7.5, and 7.6 are based on material from our (2017b); Chap. 8 includes material from our (2018); and Sects. 9.4 and 9.5 include material from our (2019a).

The book is intended to be intelligible to advanced undergraduate students, and it should also be useful for graduate seminars. We hope, however, that it will be of equal interest to professional philosophers and researchers in science studies, as well as to scientists and policy-makers who care about how, and what, models tell them about the world.

Introduction

Imagine you want to determine the orbit of a planet moving around the sun. You know that gravity pulls the planet and the sun toward each other, and that their motion is governed by Newton's equation. To put this knowledge to use you first have to construct a model of the system. So you make the idealising assumption that the gravitational interaction between the sun and the planet is the only force relevant to the planet's motion and you neglect all other forces, most notably the gravitational interaction between the planet and other objects in the universe. You furthermore assume that both the sun and the planet are perfect spheres with a homogenous mass distribution (meaning that the mass is evenly distributed within the sphere). This allows you to pretend that the gravitational interaction between the planet and the sun behaves as if the entire mass of each object was concentrated in its centre. Since the sun's mass is vastly larger than the mass of the planet, you assume that the sun is at rest and the planet orbits around it. With this model in place, you now turn to mechanics. Newton's equation of motion is $\vec{F} = m\vec{a}$, where \vec{a} is the acceleration of a particle, m its mass, and \vec{F} the force acting on it, and the law of gravity says that the magnitude of the force acting between the planet and the sun is $F_g = Gm_p m_s / r^2$, where m_p and m_s are the masses of the planet and the sun respectively, r the distance between the two, and G the constant of gravitation. Placing the sun at the origin of the coordinate system and plugging F_g into the equation you obtain $\ddot{\vec{x}} = -Gm_s \vec{x} / |\vec{x}|^3$, where the double dots indicate the second derivative with respect to time. This is the differential equation describing the planet's trajectory, where you have, of course, used $\vec{a} = \ddot{\vec{x}}$, i.e. you utilised that acceleration is equal to the second derivative of position.

Constructing a model of the system has been crucial to deriving the desired result. In fact, without a model of the planet and the sun you would not have been able to determine the planet's orbit. This example is not an exception. Models play a central role in science. Scientists construct models of atoms, elementary particles, polymers, populations, genetic trees, economies, rational decisions, aeroplanes, earthquakes, forest fires, irrigation systems, and the world's climate – there is hardly a domain of inquiry without models. Models are essential for the acquisition and organisation of scientific knowledge. So how do models work? How can it be the case that by studying a model we can come to discover features of the thing that the model stands for? In this book we explore the idea that they do so by *representing* the selected parts or aspects of the world that we investigate. If we want to understand how models allow us to learn about the world, we have to come to understand how they represent.

Why is this important? Given the centrality of models in the scientific endeavour, the question of how models provide us with insight into the way the world is should concern anybody who is interested in understanding how science works. And given how central science is for understanding how we are situated in the world as epistemic agents – as agents who know things, who understand things, who categorise things, and so on – it should concern anybody who is interested in human cognitive endeavours. Furthermore, the question of how models represent is also conceptually prior to other debates concerning metaphysical, epistemological, and methodological questions in connection with science, and appropriate framings of these questions presuppose an understanding of how models represent.

The realism debate is a case in point. What does it mean to be a *scientific realist* about a model-based science? The usual way of characterising scientific is that mature scientific theories must be taken literally and be regarded as (approximately) true, both in what they say about observables and in what they say about unobservables (Psillos 1999). Despite many of the participants in this discussion rejecting a linguistic understanding of theories (associated with the so-called syntactic view of theories), the scientific realism debate is framed mostly in linguistic terms, focussing on the reference of theoretical terms and the (approximate) truth of theoretical statements. There is, at least on the face of it, a mismatch between an understanding of scientific theorising as an essentially model-based activity and the framing of the realism debate in linguistic terms (Chakravartty 2001). A reflection on how models represent can help resolve this tension because it can help us understand what it means for models, or parts of models, to refer and to make truth-evaluable claims.¹

The realism problem is often seen as particularly pressing in the context of model-based science because many models involve idealisations and approximations, or they are analogies of their targets. This has got enshrined in the categorisation of models, where it is common to classify models as idealised models, approximate models or analogue models. This is salient in the current context because these classifications do not pertain to intrinsic features of model, but to the way in which models relate to their target systems. As such idealisation, approximation and analogy can be seen as being specific modes of representation and a discussion of these modes might benefit from being situated in the wider context of a general theory of representation.²

Relatedly, how are we to understand scientific *pluralism*, or *perspectivism*, the idea that scientific practice provides us with multiple models of the same target system, either diachronically or synchronically? Are we to understand these multiple models as conflicting or complementary?³ Again, this turns on how we understand their representational content.

Or consider the question of what it means for a model to *explain*. One popular way of analysing model-based explanation is to appeal to the idea that a model accurately captures the counterfactual profile of the target system because it either accurately represents how the target system would behave under various different conditions, or the it captures the difference makers of the phenomenon in question.⁴ But this approach relies on us understanding how models can represent counterfactual behaviour, which requires an account of scientific representation. Further consider the notion that science provides us with

¹ For recent discussions of scientific realism with focus on models see Reiss' (2012b) and Saatsi's (2016). For a general overview of models in science see Bailer-Jones' (2002a) and Frigg and Hartmann's (2020). For historical discussion of models in philosophy of science see Bailer-Jones' (1999), and for a discussion of how physicists view their models see her (2002b).

² Recent discussions of idealisation and approximation with an angle on models can be found in Batterman's (2009), Jebeile, and Kennedy's (2015), Nguyen's (2019), Norton's (2012), Portides' (2007), Potochnik's (2017), Saatsi's (2011a) and Vickers' (2016). For a recent discussion of analogue models see Dardashti, Thébault, and Winsberg's (2017) and Dardashti, Hartmann, Thébault, and Winsberg's (2019).

³ There is a fast-growing literature on pluralism and perspectivism. For useful discussions see Chakravartty's (2010), Chang's (2012), Giere's (2006), Massimi's (2017, 2018), Mitchell's (2002), Morrison's (2011), Rueger's (2005), Teller's (2018) and Taylor and Vickers' (2017), as well as the contributions to Massimi and McCoy's (2019).

⁴ See, for instance, Bokulich's (2011) and Strevens' (2008). Again, the relationship between models and explanation is a significant issue in its own right. For more on the relationship between representation and explanation see Lawler and Sullivan's (2020), Reiss' (2012a), and Woody's (2004).

understanding of features of the world.⁵ This understanding is, at least in part, delivered by scientific models. But in order to know what it means for a model to provide understanding of a feature of the world, we have to have some grasp of the relationship between the model and the feature. And again, this relationship should be understood as a representational one.

So the question of scientific representation is foundational for various questions in the philosophy of science. This book is intended to provide those working on these questions, as well as those who are simply interested in the relationship between models and the world, with an introduction to the problem of scientific representation. Moreover, we hope that our discussion will be useful to scientists who are concerned with the relationship between their models and the aspects of the world that they are ultimately interested in. Beyond that, we hope that the book will be relevant for researchers in science studies interested in conceptual issues concerning model-based science, philosophers working on topics related to representation, and policy makers taking decisions based on model outputs.

Before delving into the details, two caveats are in order. Approaching scientific modelling by investigating representation is not an imperialist endeavour: neither is our discussion premised on the claim that *all* models are representational, nor does it assume that representation is the *only* (or even primary) function of models. It has been emphasised variously that models perform a number of functions other than representation. Knuuttila (2005, 2011) submits that the epistemic value of models is not limited to their representational function and develops an account that views models as epistemic artifacts which allow us to gather knowledge in diverse ways; Morgan and Morrison (1999) emphasise the role models play in the mediation between theories and the world; Hartmann (1995) and Leplin (1980) discuss models as tools for theory construction; Luczak (2017) talks about the non-representational roles played by toy models; Peschard (2011) investigates the way in which models may be used to construct other models and generate new target systems; Bokulich (2009) and Kennedy (2012) present non-representational accounts of model explanation⁶; and Isaac (2013) discusses non-explanatory uses of models which do not rely on their representational capacities. Not only do we not see projects like these as being in conflict with a view that sees some models as representational; we think that the approaches are in fact complementary. Our point of departure is that *some* models represent, and that therefore representation is *one of* the functions that these models perform. We believe that this is an important function, and that it is therefore a worthy endeavour to enquire into how models manage to represent something beyond themselves.

The second caveat is that we are not presupposing that models are the *sole* unit of scientific representation, or that all scientific representation is model-based. Various types of images have their place in science, and so do graphs, diagrams, and drawings.⁷ In some contexts,

⁵ The question of scientific understanding, and the role models play in scientists' quest for understanding, has received increasing discussion in recent years. See, for instance, De Regt's (2017), Doyle, Egan, Graham, and Khalifa's (2019), Elgin's (2004, 2017), Illari's (2019), Khalifa's (2017), Kostić's (2019), Le Bihan (2019), Reutlinger, Hangleiter, and Hartmann's (2018), Sullivan and Khalifa's (2019), and Verreault-Julien's (2019), as well as the papers collected in Grimm, Baumberger and Ammon's (2017).

⁶ The issue of non-representational model explanations has also received attention phrased in terms of what Batterman and Rice (2014) call "minimal models". It is worth noting, however, that the term is used in various ways in the literature. See, for instance, Fumagalli's (2015, 2016), Grüne-Yanoff's (2009, 2013), Jhun, Palacios, and Weatherall's (2018), and Weisberg's (2007).

⁷ Downes (2012), Elkins (1999), and Perini (2005a, 2005b, 2010) provide discussions of visual representation in the sciences.

scientists use what Warmbröd (1992) calls “natural forms of representation”, and what Peirce would have classified as indices, namely signs that have a “direct physical connection” to what they signify (Hartshorne and Weiss 1931-1935, CP 1.372, cf. CP 2.92): tree rings, fingerprints, disease symptoms. These are related to thermometer readings and litmus paper indications, which are commonly classified as measurements. Measurements also provide representations of processes in nature, sometimes together with the subsequent condensation of measurement results in the form of charts, curves, tables and the like.⁸ And, last but not least, many would hold that theories represent too. At this point the vexing problem of the nature of theories and the relation between theories and models rears its head again, and we refer the reader to Portides’ (2017) for a discussion of this issue. There is no question that these forms of “non model representation” exist – they do and they play important roles in various branches of science. The question is whether these other kinds of representation function in a way that is fundamentally different from the way in which models function. Do, say, graphs represent in the same way that models do? The answer to this question will depend on what one has to say about models and hence depends on one’s account of representation. What all accounts of scientific representation have in common is that they must address the issue. An account of scientific representation remains incomplete as long as it does not specify how it deals with alternative forms of representation.

The book is organised as follows. In Chapter 1 we reflect on the tasks ahead and present a list with five problems that every account of representation must answer, along with five conditions of adequacy that every viable answer must meet. These questions and conditions provide the analytical lens through which we look at the different accounts of representation in subsequent chapters.⁹ In Chapter 2 we discuss Griceanism and Stipulative Fiat: the claim that models represent their targets because we intend them to, and that’s all there is to say about the matter. In Chapter 3 we look at the time-honoured similarity approach, and in Chapter 4 we examine its modern-day cousin, the structuralist approach. Both, in relevantly different ways, take similarities, structural or otherwise, between models and their targets to be constitutive of scientific representation. In Chapter 5 we turn to inferentialism, a more recent family of conceptions which emphasise the role that models play in generating hypotheses about their targets. In Chapter 6 we discuss the fiction view of models and distinguish between different versions of the view. In Chapter 7 we consider the conception of representation-as, largely derived from the work of Nelson Goodman and Catherine Elgin. Whilst this book is an introduction to the literature, and whilst we have endeavoured to provide a balanced treatment of the positions we discuss, the book is also, as indicated in its title, an *opinionated* introduction. The conclusion we reach at the end of Chapter 7 is that all currently available positions are beset with problems and that a novel approach is required. This is our project in the final two chapters of the book. In Chapter 8 we develop what we call the DEKI account of representation and explain how it works in the context of material models. In Chapter 9 we generalise the account to non-material models and reflect on the relation between representation art and science.

⁸ Díez (1997a, 1997b) and Tal (2017) offer discussions of measurement. For a discussion of measurement in physics, in particular temperature, see Chang’s (2004), and for discussion of measurement in economics see Reiss’ (2001).

⁹ A historical introduction to the issue of scientific representation can be found in Boniolo’s (2007).

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