Models and Denotation

Fiora Salis, Roman Frigg, James Nguyen

Published in: Falguera José L. and Martínez-Vidal, Concha (eds.): *Abstract Objects: For and Against*, Synthese Library, Cham: Springer, 2020, 197-219.

Many models function representationally. Considerable differences notwithstanding, most accounts of representation involve the notion that models denote their targets. Denotation is a dyadic relation that obtains between certain symbols and certain objects. This does not sit well with the fact that many models are not concrete objects. If a model does not exist, how can it denote? We present an antirealist theory of models that reconciles the notion that models don't exist with the claim that there is real denotation between models and their targets.

1. Introduction

Denotation is a dyadic relation that obtains between certain symbols and certain objects. Symbols can be of many different types, including linguistic, pictorial, and mental. Proper names are paradigmatic examples of denoting symbols. For example, we can use a token of the name "Diogenes" to denote a particular individual, namely Diogenes the Cynic.

This raises two questions. The first concerns the nature of the symbols themselves: what objects are they and how do we identify them? We call this the *identification problem*. The second concerns the relation between the symbol and the object the symbol stands for: in virtue of what does it hold? We call this the *relation problem*. Philosophers of language spent a great deal of time investigating the nature of linguistic denotation,[1] with a particular focus on proper

[1] Or reference – in the philosophy of language the terms "denotation" and "reference" are often used as synonyms.

names. The focus in this endeavour was on the relation problem because philosophers of language – rightly – took the nature of linguistic symbols to be clear enough not to worry greatly about it.[2]

In recent years the issue of scientific representation has attracted considerable attention and a range of different accounts of scientific representation have been proposed (for a review see (Frigg and Nguyen 2017)). Considerable differences notwithstanding, many of these accounts rely on denotation. The structuralist conception requires that there is a correspondence between objects in the model and objects in the target, as well as between properties and relations of the model and of the target (see, for instance, French and Ladyman 1999), and Contessa (2007) explicitly construes these correspondences in terms of denotation. Advanced versions of the similarity view require hypotheses that denote the target system (Giere 2010). Accounts based on Goodman and Elgin's notion of representation-as (Elgin 2010, 2017) see denotation as the core of representation (Frigg and Nguyen 2018).

A further point of convergence is that many accounts recognise models as the units that are doing the representing: it's models that represent target systems. Hence, in the case of scientific representation models take the place of proper names in linguistic representation. This adds an additional layer of complexity to the problem. While philosophers of language can rest reasonably content that the ontology of proper names (and linguistic symbols more generally) is sufficiently unproblematic to set the identification problem aside, there are no such assurances concerning scientific models and a great deal of ink has been spilled on the problem of the ontology of scientific models in recent years.

The so-called fiction view of models submits that scientific models are, from an ontological point of view, akin to characters and places in literary fiction. As Godfrey-Smith puts it "modelers often take themselves to be describing imaginary biological populations, imaginary neural networks, or imaginary economies. [...] Although these imagined entities are puzzling, I suggest that at least much of the time they might be treated as similar to something that we are all familiar with, the imagined objects of literary fiction. Here I have in mind entities like Sherlock Holmes' London, and Tolkien's Middle Earth" (Godfrey-

[2] Kaplan's (1990) investigation into the nature of words (and proper names in particular) as the media of denotation is a noteworthy exception.

Smith 2006, 735). Combining the views that models are the vehicles of scientific representation, that denotation lies at the heart of representation, and that models are like fictions gives the position that fictions denote target systems in the world.[3]

Previously we have said that denotation is a relation between a symbol and an object. At least *prima facie*, only existing objects can enter into relations and so one may wonder how a fictional model can possibly denote a target system. Indeed, one might take this to be a *reductio* of the position: fictions don't exist and hence can't denote anything. A position that combines the fiction view of models with an account of representation that involves denotation must therefore be incoherent.[4]

In what way exactly a fiction account of models faces this challenge depends on one's metaphysics of fiction and on the exact analysis of models. Realists about fictional entities might reply that fictions do exist and that denotation therefore poses no problem. Whether realism actually offers a quick fix to the denotation problem is an interesting question, but for want of space we cannot pursue it here. Our focus is on antirealism (with respect to fictions and models), and we discuss how antirealists can respond to the incoherence charge. As such our argument in this paper addresses the conditional question: if antirealism about models is correct, then how do they denote? We will briefly return to the other options available to someone who subscribes to the position that models are fictions (and therefore not concrete objects) that nevertheless denote their targets in the conclusion.

Throughout the paper we are concerned with the identification problem. The identification problem is conceptually prior to the relation problem because one can ask *how* something denotes only once it is clear that the "something" in question is the kind of thing that could at least in principle enter into a denotation relation. As we have just seen, in the context of the

---

[3] Fiction accounts of models have also been advocated by Barberousse and Ludwig (2009)
Frigg (2010a), Frigg and Nguyen (2016), Giere (2010, 278) (although he stresses that this is restricted to ontology, functionally models and fictions might come apart), Salis (2019) and Salis and Frigg(forthcoming). Levy(2015) and Toon (2012) present accounts that appeal to fiction, but are designed in way that does not require the a model denote a target. For a discussion of their account see Frigg and Ngueyn (2017, 86-88).

[4] The objection actually applies more generally: anyone who thinks that models are not concrete objects but denote their targets will have to meet this challenge.

fiction view this cannot be taken for granted. The aim of this paper is to show how the fiction view can give a positive answer to the identification problem even in the context of an antirealist view of fiction, thereby paving the ground for a future discussion of the relation problem.

We discuss the identification problem in the context of modelling in the natural sciences. The kind of models we have in mind are the billiard ball model of gas, the Newtonian model of the solar system and the Lotka-Volterra model of predator-prey interaction. The term "model" is some time used with a different meaning in normative contexts to describe fictional characters as representatives of vice and virtues or right and wrong. This is also relevant in the context of using (at least some) models from the social sciences, e.g. models of decision-making, which have normative rather than descriptive content (i.e. the model doesn't represent what an agent does, it represents what an agent *should* do). Such normative use of models, and representations more generally, is an underexplored topic in the literature on scientific representation. However, this is not the place to fill that lacuna: irrespective of the particular issues that arise from their normative content, presumably they still need to be identified, and still denote their targets. Thus, any account of them will also require a resolution to the issues that we are addressing here. As such, we set aside the thorny issue of how to analyse such normative contexts here.

The structure of the paper is as follows. In Section 2 we introduce an antirealist position about scientific models that builds on Walton's (1990) account of fiction. In Section 3 we draw on the literature in philosophy of mind and psychology to provide an answer to the question of how we can imagine things about non-existent objects. In Section 4 we apply this to scientific models and argue that by identifying models with their descriptions and the fictional truths we are prescribed to imagine when engaging with them, we can accommodate the idea that models can denote their targets. Section 5 discusses some ramifications of this position, and Section 6 integrates it with the DEKI account of scientific representation (Frigg and Nguyen 2016, 2018). Section 7 concludes.

2. Antirealism about Models

Antirealists claim that there are no fictional objects. Walton (1990) developed a paradigmatic antirealist theory of fiction as a game of make-believe that has been influential among contemporary developments of the fiction view of models.[5] Construing models as akin to works of fiction and games of make-believe does not amount to portraying modelling as something unserious or even frivolous. Walton emphasises that one of the reasons why children engage in games of make-believe is to cope with their environment. He mentions an extreme case of a game played in Auschwitz called "going to the gas chamber"[6] and argues that the children playing the game were "facing the reality of genocide with the utmost seriousness" (1990, 12). The ability to engage in games of make-believe continues in our adult life when we interact with works of art. We imaginatively engage with literary fictions, dramas and other works of art that can in no way be dismissed as unserious (think of *Anna Karenina* or *Othello*). Scientists imaginatively engage with models for many serious purposes, including learning about reality.

Walton argues that works of fiction are akin to games of make-believe, which he characterises as imaginative activities involving props. Props are objects like toy trucks or texts of works of fiction. Props make propositions fictionally true in virtue of certain prescriptions to imagine that are stipulated, or implicitly understood, to be in force within a game. Fictional truth is a property of imagined propositions: fictionally true propositions are those that *ought to* be imagined in the relevant game. Fictional truths divide into two kinds, primary fictional truths and implied fictional truths. The former are generated directly from the text of a fictional story, while the latter are generated indirectly from the primary fictional truths via principles of generation. These principles might vary from case to case, depending, for example, on the genre of the fiction. Walton discusses the reality principle, which keeps the world of the fiction as close as possible to the real world, and the mutual-belief principle, which is directed toward the mutual beliefs of the members of the community in which the story originated. Games of make-believe are of two main kinds, authorised and unofficial. They are authorised when they are constrained by the author's prescriptions to imagine. They are unofficial when the principles of generation constraining them are *ad hoc*. Finally, games of make-believe can involve imaginings that are about real objects (we can imagine that Churchill was a member of

[5] See, for instance, Frigg (2010a), Levy (2015), and Toon (2012).

[6] See Opie and Opie (1969) for a description of this game.

the communist party) as well as about fictional objects (we imagine that Sherlock Holmes plays the violin). But either way imaginings do not have any ontological import and do not commit us to postulate fictional entities.

Applying these ideas to scientific models gives us the following picture. Models involve model descriptions that function as props. They are descriptions of models we find in scientific papers and textbooks. They prescribe imagining certain fictional truths. The model content includes the explicit fictional truths prescribed by the model description and the implied fictional truths generated by certain principles of generation that are in operation in the context in which the model is used (these can be, for instance, assumed laws of nature or other general principles of the scientific field in which the modelling practice is embedded). Typically, model descriptions express general propositions about properties and relations in virtue of having those properties and relations among their constituents. For example, the proposition "all humans are mortal" is about the properties of being human and being mortal. Model descriptions can, but often do not, describe objects in the world. Indeed, there need be no objects that satisfy the descriptive conditions stipulated by scientists.[7]

Nevertheless, model descriptions *seem* to prescribe imaginings about some particular fictional systems. Thomson-Jones (2010) emphasises this aspect of the phenomenology of the modelling practice – what he calls the *face value practice* – when he says that a model description "has the surface appearance of an accurate description of an actual, concrete system (or kind of system) from the domain of inquiry" (2010, 284). Fibonacci's model of population growth, for instance, seems to prescribe imaginings about a particular fictional population of rabbits. Furthermore, this model system is identified with the vehicle of the representation

[7] Walton assumes referentialism, the position that utterances of sentences containing proper names express singular propositions. For instance, the proposition "Saint Paul's Cathedral is Northern Europe's biggest church" is directly about St Paul's in virtue of having St Paul's among its constituents. This view entails that utterances of sentences containing fictional names (names without referents) express either no proposition or a gappy proposition. Walton (1990, Ch. 10) assumes the former and argues that utterances of sentences containing fictional names are to be analysed in terms of *kinds of pretence*. Friend (2011) and Salis (2013) emphasise that this is insufficient to distinguish different kinds of pretence that seem to be about different fictional objects. They offer alternative analyses in terms of gappy propositions and participation in different networks of information (Friend 2011) and different name-using practices (Salis 2013).

relation between the model and the world, and so this model system *seems* to denote the target of the model.[8]

Hence, antirealists actually face two problems. The first is to make sense of the face value practice that takes model descriptions to be about a particular model system even though there are no such systems. We call this the *problem of model systems*. The second is the problem concerning denotation that we have already mentioned: how can models be the vehicles of denotation if they don't exist? It turns out that a reflection on the first problem also offers a solution to the second problem, and so we start with a discussion of the face value practice.

3. Object-Directed Thoughts and Mental Files

To address the face value practice, it pays to note that the problem of model systems is an instance of the more general problem of the object-directedness – or *intentionality* – of mental states. To get a grip on this problem we now introduce a cognitive account of the intentionality of thoughts that are directed to particular objects, and then show how the account offers an answer to the problem.

The account is best introduced with an example. The philosophy department has to move to a new building. The head of department receives a dossier about the building, containing a detailed description of the layout of the rooms along with architectural plans. But she can't inspect the building because it is undergoing extensive refurbishment and the administration considers it unsafe for her to visit the building site. So she forms a view of the building and starts planning the move of the department solely based on the content of the dossier.

Let us have a closer look at what happens in this process. The *dossier D* is a conglomerate of sentences in English, drawings, plans, etc. The dossier has *content C*. The content is objective and publicly accessible to everybody who is able to read *D*. The content of the dossier is *about* the building *B*. When the head of department reads the dossier she forms a *mental file F* of the

[8] In fact, Weisberg (2007) identifies the existence of a secondary object that does the representing as a defining feature of modelling.

building.[9] Mental files are modes of presentation of individual objects. They involve information about properties that one takes the object to have. So, the head of department's mental file contains information, which she takes to be about the building. *F* is informed by *C* (recall that the only source of information about *B* is *D*), but it need not be identical with it. In fact, *F* is how the object is given to the head of department: *F* contains her personal construal of the building, which can, but need not (and usually does not), line up with *C*; and, indeed, different people can (and usually will) have different mental files about the same object. The head of department may not have realised that there is a storage room in the basement; she may have paid no attention to the roof structure; and she may have miscounted the number of offices on the first floor. Her mental file differs from *C* in all these respects.

[9] In the late sixties philosophers of mind and language introduced the notion of a mental file as a cognitive representation of concrete objects as individuals rather than as the possessors of properties. Originally, Grice (1969, 141-142) introduced this notion under the label "dossier" in his discussion of vacuous names and referentially used descriptions. The idea is that our thoughts latch onto reality in a direct way, i.e. through a perceptual relation with individual objects rather than through the mediation of a descriptive condition that looks for the object as the satisfier of a certain set of qualitative features. In line with this idea, Perry (1980) introduced the term "mental file" to account for the phenomenon of continued belief and he appealed to the same notion to account for the phenomenon of co-reference in his (2001, 128-146). Bach (1987, Ch. 3, spec. 34-39, 44) deployed mental files in his discussion of *de re* thought. More recently, Jeshion (2010) presented a new theory of singular thought as thought from mental files. Friend (2011, 2014) appeals to mental files to explain the phenomenon of intersubjective identification of fictional characters within fictional antirealism. Intersubjective identification of the same object, or co-identification, is further explained in terms of participation in the same information network (Friend 2011, 2014) or the same name-using practice (Salis 2013) supporting the mental files. Linguists have used the notion of a mental file as discourse referents (Heim 1982; Kamp and Reyle 1993; Karttunen 1976). Cognitive psychologists have introduced the analogous notions of *object files* to study visual representations in adults' object-directed attention (Pylyshyn 2001, 2007, 2000; Fodor and Pylyshyn 2014) and *object concepts* to theorise about object representations in infancy (Spelke 1990; Baillargeon 1995; Carey 2009). Pylyshyn (2001, 129) draws an explicit connection between the philosophical literature on mental files and the notion of object files to emphasize the purely causal relation between object files and their referents. Philosophers Murez and Recanati (2016) make some important distinctions between Pylyshyn's notion of object files and mental files by underlying the conceptual nature of the latter. They emphasise that mental files can store qualitative information about their objects (and in this sense they can be construed as conceptual representations of individual objects). However, this qualitative information is not used to fix the referent of the mental file. Information can be updated, retrieved and deleted without changing the referent of the file. It is in this sense that we say that mental files represent concrete objects as individuals rather than as the possessors of properties. Perner et al. (2015) explicitly appeal to mental files to develop a cognitive theory of belief representation in infancy.

Information contained in F can be construed as a list of predicates that one takes as satisfied by the object (Recanati 2012, 37). Predicates can be relational, and importantly, may involve other mental files. As a consequence, two files could appear in each other's list.[10] To avoid a regress, one cannot construe mental files as constituted and identified by their predicates and corresponding properties. The properties are merely associated with the file, and information can be added to and deleted from the file without changing the file itself. And, as noted previously, information can be subjective and idiosyncratic to the extent that different individuals can associate different information with their mental files for the same object independently of whether this exists or not.

Mental files are also modes of presentation of particular objects, and so they play cognitive roles akin to Fregean senses. This solves both the problem of cognitive significance and the problem of object-directed but objectless thoughts. The former is the problem of explaining how one can have different thoughts about the same object, possibly even without realizing that one is thinking about one and the same object. The solution in terms of mental files is that one can associate two distinct mental files involving different information with the same object, analogous to the way in which Frege's introduction of senses accounts for the classical example with the morning star and the evening star. With "Phosphorus" and "Hesperus" associated with "the morning star" and "the evening star" respectively, we can explain their different cognitive significance by claiming that the belief that Phosphorus will rise and the belief that Hesperus will rise are associated with different mental files involving different information.[11]

The account we have introduced is summarised in Figure 1.

---

[10] This happens, for instance, when a file involves an expression that *appears* to be a proper name. The head of department says "room 425 is too small to host the admin office". A singular term like "Room 425" has its own individual mental file, and so does each item described in the dossier. In fact, there can be a hierarchy of files. But the files contain only information (predicates) about the objects. They don't contain singular terms. They are cognitive representations in the mind that stand for objects in reality, if there are any. They are associated with singular terms without including them.

[11] Fregean senses are usually interpreted as descriptive modes of presentation of objects, i.e. descriptive conditions such as "the morning star", that are parts of the propositional content of thoughts. For example, the content of the thought that "Phosphorus will rise in the morning" will be that *the morning star* will rise in the morning. Mental files, however, are not necessarily interpreted as descriptive modes of presentation that enter into the propositional content of thoughts. See, e.g., Recanati (2012) for a critical discussion of the relation between mental files and descriptivism.

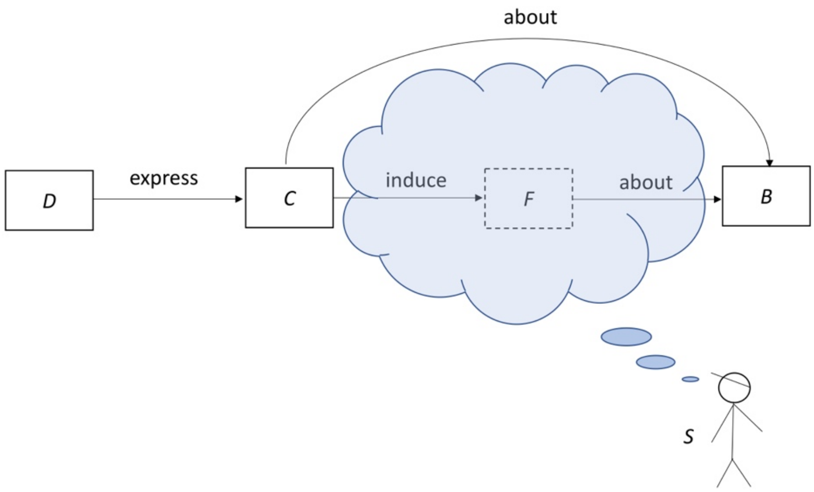

Figure 1: Mental file of an existing object

Now let us change the story slightly. Rather than moving into a pre-existing building the university decides to commission a new building for the philosophy department. In this case the dossier that the head of department sees does not contain information about an existing building. It contains information about something that does not exist at all: if the building has not yet been built there is no *B* and on pain of incoherence neither the *C* nor *F* can be about *B* (at least if we take it that *B* must exist to be the subject of an intentional thought). So, strictly speaking, *C* and *F* are not about anything. Nevertheless, we habitually engage into a practice of reflecting and talking "about" the inexistent "building" as if it was real. The head of department may object that the "building" does not have enough offices and that the seminar room is too small. How can one make sense of this practice if there is no building?

Realists about intentionality argue that every mental state needs an object of some kind and therefore argue that there exists a fictional or abstract object – the future building – that the discourse is about. Antirealists about intentionality disagree and submit that not every mental state needs an object. Our focus here is on imagination. Imagining a pink dragon (which is a kind of mental state) does not require us to postulate that there is a pink dragon that we are thinking about, and, likewise, imagining the future philosophy building does not require the postulation of a fictional or abstract object that we are thinking about.[12] Regardless of what antirealists say about other mental states, imaginings at least are not necessarily directed at anything in the world.

But now we're faced with a generalised version of Thomson-Jones' face value practice: we habitually talk about pink dragons and future buildings as if they were ordinary objects and yet there are no such objects. But how can it seem to us that we are thinking about an object when there is no object to think about? At this point mental files come to rescue because they explain the seemingly oxymoronic phenomenon of object-directed yet objectless thoughts.

When thinking about pink dragons or inexistent buildings we deploy a mental file. As we have seen, a mental file is akin to a concept or a mental representation that stands in for an individual object. Yet, as a cognitive structure for the storage of information mental files incur no ontological commitments, and a subject can (and usually does) have mental files both for real objects and figments of the imagination. Someone may have a mental file for "hotel" as well as for "griffin", where the file simply is a list of properties that the subject takes the object to have. Since mental files are standardly associated with something that exists, it *seems* to us that we are thinking about an object *whenever* we deploy a mental file – even if there actually is no object. This is because thoughts that seem to be about an object without there being one effectively engage the same types of cognitive resources as thoughts about existing things. From a cognitive point of view, internally, there is no genuine difference between the two cases.

For this reason, when we deploy a mental file that is not about an object, it is natural to think and talk as if we were thinking and talking about an object even if we know full well that there isn't one. This cognitive illusion is practically impossible to escape. It is an effect of the deployment of the same cognitive structures that originally enable our thoughts and discourse about real objects. This is why we think and talk *as if* there were an object. One can then say that these thoughts seem to be about an imaginary object toward which the mental file is directed. But actually, this is only pretend-aboutness rather than genuine aboutness. What this

[12] In this section we use "pretend" and "imagine" in their non-technical sense, which is broader than the technical sense introduced in Section 2.

means is that there seems to be an imaginary object, one that (fictionally) exists in our minds. Effectively, this seeming object is a construct of the imagination. But, as we said before, imagining that something is so and so does not commit us to postulating that there really is something. In pretence, we can manipulate, explore and transform this imaginary object just like we would manipulate, explore and transform a concrete object. What this actually means, however, is that we can only pretend to manipulate, explore and transform the imaginary object. What we really do is updating, adding or deleting information from the mental file for the imaginary object.

When the head of department talks about the new philosophy building, her mental file is not about a building (it's yet to be built!), but she, as well as her interlocutors, pretend that the information they have (the one that is stored in the mental file) is about the same particular object. They do so by engaging in a way of thinking and talking that seems to involve reference to an object, and the content of their mental files is about this imaginary object. Ultimately, what they are really doing is not thinking and talking about a real object (indeed, they are even aware of this). Rather, they manipulate, explore, and (possibly) transform the information they have to better plan for the future building. The head of department might add comments to the dossier and ask for clarifications, further information, and even changes to the plan. Her interlocutors will understand these comments as being about the future building (the imaginary object), and they will clarify, explain, and amend the dossier by changing its content. Once the content has been changed, the mental files that the head of department and her interlocutors have will also change in a way that reflects the agreed content of the new dossier. They will update, add or delete information that they take to be, in the imagination, about the same object. And as a consequence, the imaginary object itself will be thought about and described (in the imagination) as being different from the way it originally was thought about and described.

The account we introduced is summarised in Figure 2.

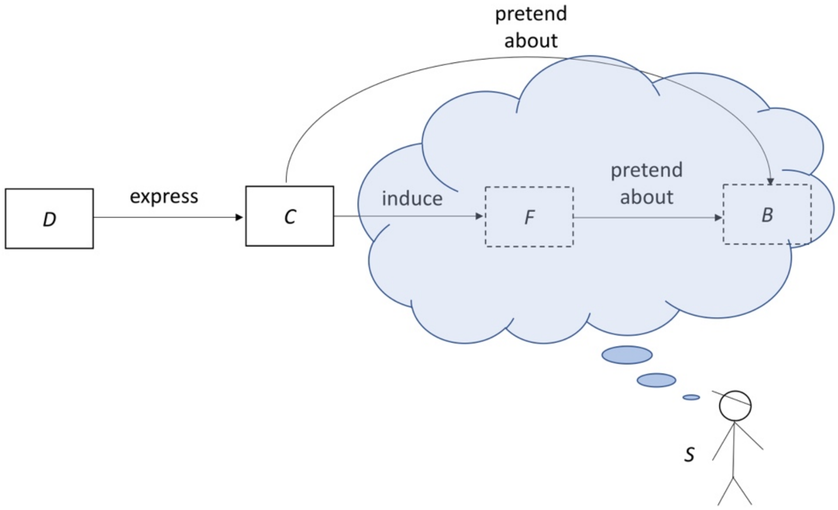

Figure 2: Mental file of non-existing object

4. Revisiting Models

The account of object-directed thought that we introduced in the last section equally applies to models if we associate *D* with the model description (which, like the architectural dossier, can contain a mix of verbal descriptions, drawings, graphs, etc.); *C* with the "content" of the model (which, in the Waltonian framework we're working in, includes the primary fictional truths from *D* and also the secondary fictional truths that result when applying the principles of generation in operation); *F* with the mental file the agent forms based on *C*; and *B* with the model system. To make symbols intuitive we use "*MS*" rather than "*B*" in the context of modelling. If the model system is a material object, then we're in the situation of Figure 1. The use of model organisms in biology, water-based "dumb holes" in cosmology, and the Phillips-Newlyn machine in economics are of this kind. If the model system is fictional, then we're in the situation of Figure 2. Newton's model of planetary motion or Fibonacci's model of population growth belong to this group.

When engaging in the face value practice, we talk about Newton's planets or Fibonacci's rabbits as if they were actual concrete systems in the domain of inquiry. As we have seen at the end of the previous section, we can do this because we deploy a mental file. Let us illustrate this with the example of a Newtonian two-particle model system, which prescribes imagining that two homogeneous perfect spheres gravitationally interact with each other and nothing else. The model description expresses what seem to be particularised propositions, propositions that involve the properties specified by the model description and that seem to be about some particular system. But there is no system that the relevant propositions are about. The modeller's impression that she is dealing with a system is explained in terms of her deploying a particular mental file to store descriptive information that she takes to be associated with a particular system without there being any object this information is about. In this way the use of a mental file explains why it seems to us that our thoughts are about a particular system even though there is no such system.

An analysis of the face value practice requires us to introduce mental files, so that the practice now has three elements: the model description (the set of linguistic and mathematical symbols presented in papers and books), the description's propositional content, and the mental file that a scientist associates with them (which contains information that the scientist, internally, takes to be about some object independently of whether it exists or not).

Let us now turn to the second problem we identified at the end of Section 2. Often scientists think and talk as if models were the vehicles of denotation of real-world targets. They say things like "the two-particle system represents the Sun and Earth system", or "the infinite rabbit population represents the real rabbit population". Since, as noted in the Introduction, representation involves denotation, this claim implies that models denote their targets. How can an antirealist about models make sense of this?

A first option is to bite the bullet and say that, appearances notwithstanding, there is no denotation. When using a model to seemingly denote a target, the scientist actually claims *in pretence* that the model system denotes the target. So, models have *pretend denotation* but no "real" denotation. This does not mean that no true claims about models and their relations to targets can be made. Claims like "the Newtonian two-body system denotes the Sun-Earth system" can be analysed as being implicitly prefixed with a fictional operator, so that a full version of the claim would be something like "in the game of make-believe for Newton's model, a scientist uses the two-particle model system to denote the sun-earth system". This statement can be assessed for genuine truth if there is a rule according to which, in the game of make-believe for Newton's model, a scientist can use the two-particle model system to denote the Sun-Earth system. But even if true, models have no real denotation.

However, one may think that pretend denotation is insufficient to accommodate the role the relation is supposed to play in scientific representation and that we need real denotation between models and their targets. But if models don't exist, how could that be? It is not clear that this objection cannot be met, and we want to leave the option of building an account of scientific representation on the notion of pretend-denotation a live option. But we do not have the space to do that here. Instead we will investigate whether a solution can be offered which accommodates proper denotation.

The key to such a solution is to reconceptualise what a model is. Rather than focusing on the model system we can turn to the model descriptions and provide a new and different antirealist proposal. We can identify a model with a complex object composed of a model description *D* together with the model content *C*: $M = [D, C]$. *D* is the description of a model one finds in a paper or textbook. The content *C* is the set of both the primary fictional truths specified by the prescriptions to imagine specified by *D* and the implied truths derived from the principles of generation in force in the relevant context. A scientist *S* then uses *D* and *C* to generate, in the imagination, the model-system *MS*, but without there ever being any model system that is the object of *S*'s imaginings.

S constructs and develops the model through an act of pretence wherein certain linguistic and formulaic symbols (contained in *D*) are used to prescribe certain imaginings that *S* assumes to be about some particular system, the model system, without there being any such system. These imaginings specify descriptive information (propositions) that *S*, internally, takes to be about one and the same system and therefore stores in the same mental file. Of course, the mental file is not part of the model *M*. The mental file is a cognitive structure for the storage of descriptive information that *S* draws upon when constructing and developing the model. From a cognitive point of view, at the level of thought, this is akin to the way in which *S* would store information that she takes to be about any real individual object. And this is fundamental for the explanation of the phenomenology of the modelling practice, as we have previously seen.

In this way antirealists about model systems can preserve the indirect view without committing to exotic entities. *S* plays a game of pretence wherein certain information that is relevant for deriving the model's outcomes are stored in a mental file for an imagined system without any ontological commitment to the existence of any such system.

The upshot as regards denotation is as follows. As we have seen, the model *M* is the complex entity that is composed of the model description *D* together with the content *C*. The model *thus defined* exists and hence can enter into a denotation relation. The problem with the original version of fictionalism is avoided. This new version of antirealist fictionalism identifies the vehicle of denotation with objects that are akin to fictional stories rather than fictional characters. The model involves props that are analogous to the texts of literary fictions to the extent that they express certain propositional contents and that they prescribe imaginings that certain objects are so and so without any ontological commitment to the existence of such objects. Antirealism recognises that scientists construct and develop models in pretence, but it also allows them to genuinely use models to denote their targets by recognising that they are bona fide vehicles of denotation, and these are the model descriptions together with their descriptive contents. Model descriptions themselves do not denote any real targets just like fictional texts do not denote any real objects. Furthermore, they do not prescribe imaginings about any real systems, but rather prescribe imaginings about fictional systems without there being any such systems. In this sense, this antirealist interpretation remains an *indirect* version of fictionalism about scientific models. Model descriptions together with their contents can be construed as denotating vehicles that, under certain uses, can stand in genuine (rather than pretend) denotation relations with real world targets. This view is summed up in Figure 3.

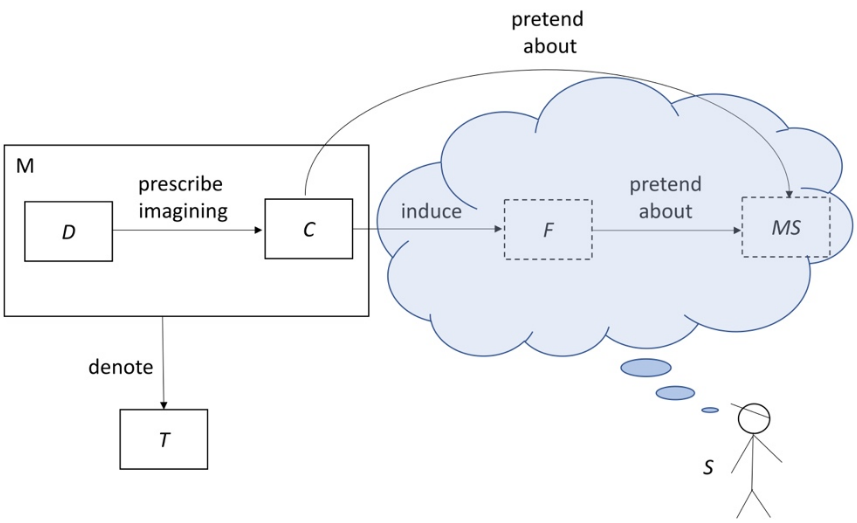

Figure 3: Models

On this interpretation, models exist. They are constituted by model descriptions (linguistic and mathematical symbols) and propositional content. Both model descriptions and propositional content exist, and so the *whole* model exists. Model systems, however, don't exist (just like the fictional characters specified in fictional stories don't exist). Indeed, they are not part of the model at all. The intuition that model descriptions prescribe imagining propositions that seem to be about some particular model systems can be explained in terms of the deployment of mental files for the storage of information that they take to be about some particular object independently of whether the object exists or not. Mental files, however, are associated to the model without being part of it. They are the psychological components that explain the phenomenology of the modelling practice without being part of the intersubjective, objective and public objects that are the models.

In sum, our brand of antirealism identifies models with model descriptions and their propositional content. Since both model descriptions and their content exist, there can be genuine reference to real target systems on this version of antirealism about model systems.

5. Reverberations

The proposal in the last section regards descriptions as a part of a model. Isn't it thereby repeating well-known mistakes? The so-called syntactic view of theories takes theories to be sets of sentences. Opponents of this view have long argued that it has the absurd consequence that every small change in the description (for instance replacing one symbol by another) results in a new theory (Suppe 2000). Does one not run into the same problem for models if descriptions are a definitional part of models?

If this was a real problem, then one would. But it isn't. In fact, a number of writers have pointed out the syntactic view of theories is not committed to an identity criterion based on description. The root of the problem is that this criterion conflates a theory and a theory formulation. A *theory formulation* is given in a particular language. It is what we encounter when we read a textbook or a scientific paper. The theory is *expressed* by a set of sentences that constitutes a formulation, and for two theories to be equivalent it isn't necessary for the theory formulations to be syntactically identical. Of course, this invites the question under what conditions theory formulations express the same theory. This question is beyond our scope here, but it is worth pointing out that there are options available. For example, Hendry and Psillos (2007) argue that two theory formulations are equivalent iff they have identical truth conditions, and Thomson-Jones (2012) makes a similar suggestion in the context of models. Quine (1975) suggests that two formulations express the same theory iff they are empirically equivalent and if the two formulations can be rendered logically equivalent by switching predicates in one of them. Relatedly, Glymour (1971) proposes that two formulations are equivalent iff they are definitionally equivalent (see also Worrall (1984), and for a recent discussion of Quine and Glymour's proposals (Barrett and Halvorson 2016)). More recent suggestions have emerged following Halvorson's (2012) discussion of theoretical equivalence in the context of the syntatic and semantic view of theories. How each of these criteria could be utilised to account for syntatically different but nevertheless equivalent model descriptions is a question worthy of further research. Our point here is only that this is a live option, and that considering model descriptions to be part of models does not *ipso facto* imply a commitment to absurd identity conditions.

An important part of the face value practice is that we attribute properties to model systems, deem claims about model systems true or false, and investigate a model to find out about its properties (Frigg 2010a). What sense can we make of this aspect of the practice if there are no model systems? Content is the key to the explanation of these aspects of the modelling practice. The attribution of properties to model systems can be explained in terms of the fictional predication of properties as expressed in the relevant propositions. Attributing the properties having-limitless-food-supplies and immortality to the imaginary rabbit population in Fibonacci's model simply amounts to imagining that the imaginary rabbits have limitless supplies of food and that they (the same imaginary rabbits) never die. We assume, in the imagination, that these properties are satisfied by the rabbit population and store the predicates in a mental file without thereby committing to the existence of any such population. These propositions will be true in the model – or *f*-true – if (as we stated in Section 2) they are among the prescriptions to imagine in force in the game, and they will be false otherwise. According to Fibonacci's model, the rabbits have limitless supplies of food and they never die. We can imagine that they do die, but this is false in the model and therefore it is not part of its content. In these cases, *S*'s mental file contains predicates contradicting the predicates contained in *C*, just as the head of department's mental file contradicted information contained in the dossier when she miscounted the number of offices.

Moreover, we construct and develop models for the purpose of eliciting new information about the model system. This aboutness, as we explained previously, is merely pretend aboutness. What we really do is construct and develop the model description to explore its content and reveal what is implicit in it and/or increase the content by generating further claims through the principles of generation. Fibonacci's model increases its content through the implementation of some simple mathematical calculations according to which the number of rabbit pairs (one male and one female) at some time *t* is the sum of the numbers of pairs at the previous two times, namely $N(t_i) = N(t_{i-1}) + N(t_{i-2})$. Thus, when we imaginatively engage with a model it seems that we construct and develop a model system. But what we really do is construct and develop model descriptions that prescribe imagining certain propositions and, through the principles of generation, we further explore and expand this content. Since the model content is normatively and objectively constrained by the model descriptions and the principles of generation we can talk about right and wrong in the predication of properties of the model and in the generation of the model's outcome.

Finally, the conjunction of the views that a model contains a description and that a model denotes could be understood as implying a descriptivist theory of denotation. This is not so. The view here is that the model is a complex entity consisting of a description and its content, and it is this entity *as a whole* that denotes. In the case of the Newtonian model of the solar system, it is the entire description and its content that denotes the solar system. In some cases, a model's denotation indeed derives from the denotation of some of the terms in the description. This is what happens in the case of the Newtonian model when the use of the terms "sun" and "earth" in the model description fixes the model's denotation. However, this does not commit the view to a descriptive theory of denotation. First, the view is silent about where terms like "sun" get their denotation from and it is a matter of indifference to the fiction view of models whether descriptivism or the direct reference theory is favoured. Second, some models' denotation does not derive from the model description and comes from outside the model, as it were. As an example, consider epidemiological models as used by the crime fighters.[13] The

[13] See Slutkin's (2016). Thanks to David Kinney for telling us about this case.

models are about how diseases like tuberculosis spread, and accordingly the model descriptions contain terms like "disease", "infectious", etc. These models have been studied for many years by epidemiologists who investigate the dynamics of the spreading of infectious diseases. The same models are now used by the police in Chicago to predict the spreading of violent crime. So, a disease model is taken to refer to violence, but nothing in the model description is responsible for that. So, what we have said here does not entail a descriptivist answer to the relation question raised in the introduction above.

6. DEKI

We now want to integrate the above insights into the DEKI account of scientific representation, which is named after its four crucial aspects: models *denote* their targets, *exemplify* certain properties, which are translated via a *key*, into properties to be *imputed* to their target. The account was originally introduced in terms of concrete models (Frigg and Nguyen 2018), and previous discussion about how it works in the context of fictional models remained silent on how denotation worked (Frigg and Nguyen 2016, 239-240). If the account is based on the notion of a model system as an imaginary object (as, for instance, in (Frigg 2010a)), then, as we have seen in Section 4, the relation between model and target is pretend-denotation. In order to accommodate the conjunction of an antirealist ontology about model systems and the view that a model ought to have "real" denotation, we had to identify a model with a description and its content. It's now time to address the ramifications this has on the rest of the account.

Having already addressed how models denote, it's important to establish how they can exemplify certain properties. Frigg and Nguyen, drawing on the work of Nelson Goodman and Catherine Z. Elgin, define exemplification as follows: *X* exemplifies *P* in a certain context iff *X* instantiates *P* and the research context highlights *P*, where a property is highlighted if it is identified in the context as relevant and epistemically accessible to users of *X* (Frigg and Nguyen 2016, 227). An object that exemplifies a property is an *exemplar*. A simple example is a sample card which instantiates a certain shade of red. The card both instantiates *red*, and *red* is highlighted as relevant and epistemically accessible in the context of using it in a paint shop.

Now the problem that arises is that models, identified with descriptions and their content, don't instantiate the sorts of properties that we take them to exemplify. A description of a population of rabbits doesn't instantiate *growing according to a Fibonacci sequence*, simply because it is the wrong kind of object to instantiate such a property – it consists of marks on a page and the content thus expressed. The solution to this worry is to appeal to the Waltonian apparatus: although the model doesn't, strictly speaking, instantiate the property, it is the case that "the population grows according to a Fibonacci sequence" is a secondary truth in the relevant game of make-believe. So, whilst models don't instantiate the relevant properties in the way in which a paint sample instantiates a certain colour, these properties are part of the model content C_M. C_M provides a suite of properties, and the context specifies which of these properties are highlighted as relevant. This suffices to play the role that exemplification was introduced to play. This provides us with two ways of speaking. We can talk about the model-system *MS* as pretend exemplifying certain properties. Or we can talk about the content of the model C_M containing and highlighting those properties. In the former case we are working within the scope of the pretence operator: *MS* exemplifies P_1, … P_n in the game of make believe. In the latter, outside it: the content of the model contains and highlights (together with the research context) P_1, … P_n. These are related because the latter is true precisely because the game of make-believe prescribes us to imagine P_1, … P_n, and the context highlights those properties as relevant.

With this qualification at hand, we can now have a closer look at the model description and its content. We said that a model *M* is a pair consisting of a description and its content. Previously *D* was understood to be the *entire* model description and the content of *D* was the entire model content. In the context of DEKI it is helpful to break the model description up in several parts to make transparent the various elements in modelling. We now take *D* to be the model description narrowly construed; i.e. a description of the model system itself. This is separate from a statement of the rules of generation *G* which we take to be in operation in the model. *G* contains the statements, laws of nature or other general rules, that are at work in the model and generates secondary truths from the model's primary truths. The primary truths are expressed in *D*. As noted elsewhere (Frigg and Nguyen 2016, 238), *D* can be further subdivided into D_X and D_I. D_X is the part of the description that – in pretence – generates the "model object" (for instance two perfect spheres attracting each other with a $1/r^2$ force). D_I specifies how this "object" should be interpreted (for instance by instructing us to imagine the larger sphere as the sun, the smaller sphere as the earth, and the force as gravity). Each part of the description contributes to the model's content. The total content of the model C_M is therefore generated by D and G together: it contains all primary truths generated by D and all secondary truths can be derived from them using G.

In the original formulation of DEKI, a Z-representation is defined as an object under an interpretation, and model is said to be a Z-representation where the object is used as base of the representation in a certain situation (Frigg and Nguyen 2018, 213). In the fictional case D_X generates the content that plays the role of the model object; D_I provides the interpretation of this "object"; and G generates the claims that are true of the object. Taken together D_X, D_I, and G therefore generate the content of the Z-representation. But, as we have previously seen, they also generate the model content. It follows that the model content C_M simply is the content of the Z-representation. If we let C_{ZR} denote the content of a Z-representation, then we can write: $C_M = C_{ZR}$. This equation is the "fiction equivalent" of the association of a Z-representation with an object under an interpretation in the case of a material model. C_M (or C_{ZR}) contains all the properties that the Z-representation has. Some of these are highlighted by the context. The set of the properties so highlighted corresponds to the exemplified properties P_1, … P_n.

In DEKI, the exemplified properties are then "keyed up" with properties to be imputed to the model's target. What we have said so far about identifying models with their description and content is orthogonal to how both the key and imputation steps work. All that keying up requires is a collection of exemplified properties and relations (which are given by the content in combination with the context), and then the key can be introduced to translate these properties to those to be imputed to the target. For example, a model consisting of Fibonacci's equations, combined with their content in a given game of make believe (using mathematical derivations to generate secondary truths and so on), provides us with some content C. In a given context this provides us with the property of *growing according to a Fibonacci sequence* as highlighted, and this property can be translated into a property like *growing in a non-linear way* to be imputed onto the target system. The introduction of the key into the account is to accommodate the mismatches between model properties and what scientists in practise take the models to tell us about their targets, and once we have those properties the rest of the DEKI account carries over without further alterations.[14]

An actual model user has a mental file *F,* which is supposed to match C_M, but allows for mistakes to accommodate cases where the model user fails to investigate the model appropriately. Whilst there is no system which C_M (or *F*) is about, in the game of make-believe we imagine a model system *MS* which is their object. *MS* contains the elements of an "object" (two perfect spheres) and an interpretation (the large sphere is the sun), and so the mental file corresponding to the model is in fact also the mental file of a *Z*-representation. Then, depending on how one wants to speak, we can either say that *MS* exemplifies properties P_1, … P_n (the properties that are highlighted in a given context of investigation), or we can say that C_M highlights the properties P_1, …, P_n. These properties can then be keyed up with properties Q_1, …, Q_m to be imputed onto the target system.

The elements of this account are summarised in Figure 4.

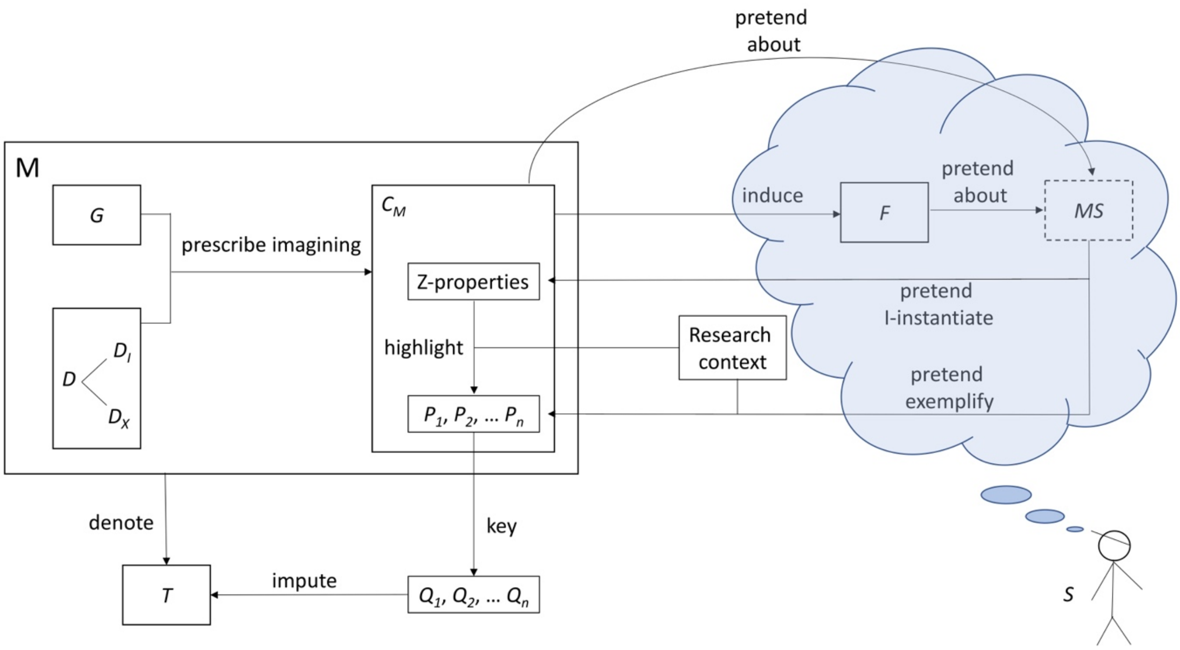

Figure 4: DEKI

[14] It's worth noting here that we take the model's *representational* content to be the result of imputing the Q_1, …, Q_m to *T*. this representational content is distinct from the model-content itself in so far as the latter concerns claims about target systems whereas the former concern claims about, or pretend about, the model systems themselves.

7. Conclusions

We argued that anyone who subscribes to the idea that at least some models are non-concrete objects which nevertheless denote their targets faces the problem that denotation is a two-place relation that holds between existing objects. The identity problem was to specify *what it is* that denotes the target system in cases of model-based representation. There are various options available here: one could adopt a realist account of what models are, and then attempt to accommodate those objects as the sorts of things which can denote. Alternatively, as we have done, one could adopt an antirealist position towards models. There are two options here. One could attempt to deflate the notion of denotation in operation in scientific representation and adopt the view that scientific representation involves pretend-denotation (rather than denotation), or, alternatively, one could identify the objects of denotation elsewhere. The focus in this paper was on the latter approach. We have argued that we can identify models with their descriptions and their content generated in a Waltonian game of make belief. Our approach demonstrates that there is a coherent way of meeting the identification problem, by invoking model descriptions and their content, which captures much of what is valuable about indirect accounts of scientific representation like DEKI, and we hope to have at least indicated how other coherent answers could be developed.

There is a final thing to note. By identifying models with their descriptions plus the description's content it might seem like we have introduced an asymmetry into DEKI, and indeed many accounts of representation, with respect to how concrete and fictional models represent. In the case of concrete models, the concrete objects are themselves the objects of denotation: the wooden model-ship represents the real ship and the Phillips-Newlyn machine represents the economy (Frigg and Nguyen 2018). If we were to carry over the account presented in Sections 4 and 6 to the context of concrete models (developing the picture displayed in Figure 1), then symmetry with respect to how concrete and fictional models represent would seem to imply that it should be the descriptions of the concrete object which denote the target system, rather than the concrete object itself. This doesn't seem right. It would seem that it's the concrete object that is the model in those cases, not the descriptions thereof. If one were to insist on this, then DEKI (and with it other accounts of representation) would be asymmetric across the fictional/concrete model divide. If one were to accept it is model descriptions rather than objects that denote then one would have to reconsider how one thinks about concrete models.

One way of addressing this issue is to say that in the concrete case the model is a triple consisting of *D*, *C* and the material object *O*. So, the model constructed by Philips and Newlyn was actually the machine plus a description of the machine along with the description's content. This suggestion is more natural than it might appear at first blush. In fact, it has been implicit in DEKI all along. DEKI says that a model is a model object under a certain interpretation (Frigg and Nguyen 2018, 213). Phillips and Newlyn's pipe system becomes a model when the flow of water is interpreted as the flow of money. This involves two steps. First one has to identify certain properties of the material object as relevant: the Phillips-Newlyn machine has to be construed as water-pipe-system rather than, say, as a plastic-and-metal system or a post-war-production system to become an economy-representation. In a second step the so-identified properties have to be connected to other properties to form an interpretation (in DEKI's sense), for instance by connecting the amount of water to the amount of money. None of this is in the material object *itself*. The scientists using the machine use a description to describe the machine as a water-pipe-system and then another description to interpret water properties in terms of economy properties. So, descriptions (and their content) really are part of the model, and including them in a material model is not just an ad hoc move to remove a tension between different parts of our account. So concrete models work like fictional models, just with a material object added to the unit we call "model".[15]

Finally, and possibly most importantly, whilst the identification problem has been solved, it remains to answer the relation problem. That models, identified with their descriptions and content, *can* denote target systems does not tell us *how* they do so. We have argued that our approach does not commit us to a descriptivist answer to this problem, but the answer itself remains to be explored.

[15] A difference is that *G* becomes obsolete in concrete models because the material object itself generates the model truths. When using the Phillips-Newlyn machine, we don't use principles of generation to find out how the economy behaves; we let the machine run!

References

Bach, K. (1987). *Thought and Reference*. Oxford: Clarendon Press.

Baillargeon, R. (1995). Physical reasoning in infancy. In M. Gazzaniga (Ed.), *The cognitive neurosciences*. Cambridge, Mass.: MIT Press.

Barberousse, A., & Ludwig, P. (2009). Models as Fictions. In M. Suárez (Ed.), *Fictions in Science: philosophical essays on modeling and idealization* (pp. 56-73). New York: Routledge.

Barrett, T. W., & Halvorson, H. (2016). Glymour and Quine on Theoretical Equivalence *Journal of Philosophical Logic, 45*(5), 467-483.

Carey, S. (2009). *The Origion of Concepts*. New York: Oxford University Press.

Contessa, G. (2007). Scientific representation, interpretation, and surrogative reasoning. *Philosophy of Science, 74*(1), 48–68.

Elgin, C. Z. (2010). Telling instances. In R. Frigg, & M. C. Hunter (Eds.), *Beyond Mimesis and Convention: Representation in Art and Science* (pp. 1-18). Berlin and New York: Springer

Elgin, C. Z. (2017). *True Enough*. Cambridge, Mass: MIT Press.

Fodor, J., & Pylyshyn, Z. (2014). *Minds without meanings: An essay on the content of concepts*. Cambridge, Mass.: MIT Press.

French, S., & Ladyman, J. (1999). Reinflating the semantic approach. *International Studies in the Philosophy of Science, 13*, 103-121.

Friend, S. (2011). The great beetle debate. *Philosophical Studies, 153*(183-211).

Friend, S. (2014). Notions of Nothing. In M. G.-C. a. G. Martí (Ed.), *Empty Representations: Reference and Non-Existence* (pp. 307-332). Oxford: Oxford University Press.

Frigg, R. (2010a). Models and fiction. *Synthese, 172* (2), 251-268.

Frigg, R., & Nguyen, J. (2016). The Fiction View of Models Reloaded. *The Monist, 99*, 225-242.

Frigg, R., & Nguyen, J. (2017). Models and representation. In L. Magnani, & T. Bertolotti (Eds.), *Springer Handbook of Model-Based Science* (pp. 49-102). Cham: Springer.

Frigg, R., & Nguyen, J. (2018). The turn of the valve: representing with material models. *European Journal for Philosophy of Science, 8*(2), 205-224.

Giere, R. N. (2010). An agent-based conception of models and scientific representation. *Synthese, 172*(1), 269 - 281.

Glymour, C. (1971). Theoretical Realism and Theoretical Equivalence. In R. C. B. a. R. Cohen (Ed.), *Proceeding of the 1970 Biennial Meeting Philosophy of Science Association* (pp. 275-288). Dordrecht: Reidel.

Godfrey-Smith, P. (2006). The strategy of model-based science. *Biology and Philosophy, 21*(5), 725-740.

Grice, P. (1969). Vacuous Names. In D. D. a. J. Hintikka (Ed.), *Words and Objections* (pp. 118-145). Dordrecht: Reidel.

Halvorson, H. (2012). What scientific theories could not be. *Philosophy of Science, 79*(2), 183-206.

Heim, I. (1982). *The semantics of definite and indefinite noun phrases*. University of Massachusetts, Amherst.

Hendry, R. F., & Psillos, S. (2007). How to do things with theories: an interactive view of language and models in science. In J. Brzeziński, A. Klawiter, T. A. F. Kuipers, K. Łastowski, K. Paprzycka, & P. Przybysz (Eds.), *The Courage of Doing Philosophy: Essays Dedicated to Leszek Nowak* (pp. 123-157). New York: Rodopi.

Jeshion, R. (2010). Singular Thought: Acquaintance, Semantic Instrumentalism and Cognitivism. In R. Jeshion (Ed.), *New Essays on Singular Thought* (pp. 105-140). Oxford: Calarendon Press.

Kamp, H., & Reyle, U. (1993). *From Discourse to Logic: Introduction to Modeltheoretic Semantics of Natural Language, Formal Logic and Discourse Representation Theory* (Vol. 42, Studies in Linguistics and Philosophy). Dordrecht: Springer.

Kaplan, D. (1990). Words. *Proceedings of the Aristotelian Society, Supplementary Volumes, 1*(64), 93-119.

Karttunen, L. (1976). Discourse referents. In J. McCawley (Ed.), *Notes from the linguistic underground (syntax and semantics, vol. 7)* (pp. 363-385).

Levy, A. (2015). Modeling without models. *Philosophical Studies, 152*(3), 781-798.

Murez, M., & Recanati, F. (2016). Mental Files: An Introduction. *Review of Philosophy and Psychology, 7*(265-281).

Opie, I., & Opie, P. (1969). *Children's Games in Street and Playground*. Oxford: Clarendon Press.

Perner, J., Huemer, M., & Leahy, B. (2015). Mental files and belief: A cognitive theory of how children represent belief and its intensionality. *Cognition, 145*, 77-88.

Perry, J. (1980). A Problem About Continued Belief. *Pacific Philosophical Quarterly, 61*, 317-332.

Perry, J. (2001). *Reference and Reflexivity*. Stanford: CSLI Publications.

Pylyshyn, Z. (2000). Situating vision in the world. *Trends in Cognitive Science, 4*, 197-207.

Pylyshyn, Z. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition, 80*, 127-158.

Pylyshyn, Z. (2007). *Things and places: How the mind connects with the world*. Cambridge, Mass.: MIT Press/Bradford Books.

Quine, W. V. O. (1975). On Empirically Equivalent Systems of the World. *Erkenntnis, 9*, 313-328.

Recanati, F. (2012). *Mental Files*. Oxford: Oxford University Press.

Salis, F. (2013). Fictional names and the problem of intersubjective identification. *Dialectica, 67*(3), 283-301.

Salis, F. (2019). The new fiction view of models. *The British Journal for the Philosophy of Science*.

Salis, F., & Frigg, R. (forthcoming). Capturing the Scientific Imagination. In P. Godfrey-Smith, & A. Levy (Eds.), *The Scientific Imagination*. New York: Oxford University Press.

Slutkin, G. (2016). Is Violence 'Senseless'? Not According to Science. Let's Make Sense of It and Treat It Like a Disease. *Health progress, 97*(4), 5-8.

Spelke, E. (1990). Principles of object perception. *Cognitive Science, 14*, 29-56.

Suppe, F. (2000). Theory Identity. In W. H. Newton-Smith (Ed.), *A Companion to the Philosophy of Science* (pp. 525-527). Oxford: Wiley-Blackwell.

Thomson-Jones, M. (2010). Missing systems and face value practise. *Synthese, 172*(2), 283 - 299.

Thomson-Jones, M. (2012). Modeling without mathematics. *Philosophy of Science, 79*(5), 761-772.

Toon, A. (2012). *Models as Make-Believe. Imagination, Fiction and Scientific Representation*. Basingstoke: Palgrave Macmillan.

Walton, K. L. (1990). *Mimesis as Make-Believe: On the Foundations of the Representational Arts*. Cambridge MA.: Harvard University Press.

Weisberg, M. (2007). Who is a modeler? *The British Journal for the Philosophy of Science, 58*, 207-233.

Worrall, J. (1984). An Unreal Image. *British Journal for the Philosophy of Science, 34*(1), 65-80.