The Fictional Character of Scientific Models

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1. Introduction

Many philosophers have drawn parallels between scientific models and fictions, from Vaihinger's (1911/2009) invocation of the "as-if," to Cartwright's construal of models as "work[s] of fiction" (1983) or "fables" (1999), and other theorists who have noted the role of idealization, invention, and imagination in modeling.[1] In this paper I will be concerned with a recent version of the analogy, which compares models to the imagined characters of fictional literature. Roman Frigg summarizes the approach this way:

> The core of the fiction view of model-systems is the claim that model-systems are akin to places and characters in literary fiction. When modeling the solar system as consisting of ten perfectly spherical spinning tops physicists describe (and *take themselves* to be describing) an imaginary physical system; when considering an ecosystem with only one species biologists describe an imaginary population; and when investigating an economy without money and transaction costs economists describe an imaginary economy. These imaginary scenarios are tellingly like the places and characters in works of fiction like Madame Bovary and Sherlock Holmes. These are scenarios we can talk about and make claims about, yet they don't exist. (Frigg 2010a, 101; cf. Godfrey-Smith 2006, 735)

Though versions of the position differ, the shared idea is that modeling essentially involves imagining concrete systems analogously to the way that we imagine characters and events in response to works of fiction. I will call this view the account of Models as Imagined Systems, or MIS for short.[2]

Philosophers in other domains who assimilate puzzling entities—properties, possible worlds, numbers, and so forth—to fictional or imaginary characters are usually motivated by a desire for ontological parsimony, with the appeal to fiction designed to undermine commitment to the entities in question. In the debate over scientific realism, for instance, fictionalism is a deflationary position (Fine 1993). By contrast, the goal of MIS is to capture a central feature of scientific practice. What matters to advocates of this position is the *epistemology* or methodology of modeling, not the ontology.[3] They argue that imagining concrete systems plays an ineliminable role in the practice of modeling that cannot be captured by other accounts.

The approach thus leaves open what we should say about the ontological status of scientific models, or more accurately about the status of *model-systems*, the hypothetical scenarios described by modelers. (To avoid ambiguity I will distinguish *model specifications*—

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[1] See for example the papers in Suárez (2009a) and the bibliography in Magnani (2012). These discussions invoke fiction in a wide variety of ways, but only some draw the analogy with imagined characters that is my focus.

[2] Advocates of MIS who take model-systems to be akin to fictional characters include Godfrey-Smith (2006, 2009), Frigg (2010a, 2010b), and Contessa (2010). Toon (2012) and Levy (2012, 2015) defend versions of MIS according to which model descriptions sometimes (Toon) or always (Levy) invite imaginings directed at real entities. Morgan's (2014) account of economic modeling is similar to Toon's, though her purpose is not to defend MIS.

[3] Suárez (2010) also makes this point in discussing a fictions approach to modeling. For a similar point from advocates of other approaches to modeling, see Weisberg (2013, 19-20) and French (2010).

broadly construed to include texts, equations, diagrams, and so forth—from model-systems in what follows; I use the term *model* for the combination of these elements.) The analogy with literature does not settle the matter, for the status of fictional entities is the subject of ongoing debate (Friend 2007; Kroon and Voltolini 2011). According to some fictional realists, fictional characters are the inhabitants of possible worlds; according to others they are nonexistent concrete objects; for still others they are abstracta of one sort or another. Antirealists deny that there are any fictional characters at all, understanding claims apparently about them in alternative ways. Correspondingly, some MIS advocates adopt realism about model-systems, others propose interpretations of those practices designed to avoid realism, and still others remain neutral but consider the ontological issue a challenge. In defending their positions these philosophers take for granted that the ontological debate has implications for how to construe scientific practice.

In this paper I argue that the debate over the ontological status of model-systems is misguided. If model-systems are the kinds of objects fictional realists posit, they can play no role in explaining the epistemology of modeling for an advocate of MIS.[4] So they are at best superfluous. Defenders of MIS should focus on developing an account of the epistemological role of imagining model-systems. In what follows I describe MIS and the motivations behind it in more detail (§§2-3) and outline the epistemological challenges it faces (§4). I then consider several realist accounts of fictional characters, arguing that none helps MIS meet those challenges (§5). I conclude by looking at more promising approaches to the epistemology consistent with MIS. Though I do elaborate MIS in the way I find most plausible, my goal is not to defend it against critics of the general approach. Rather, it is to move the discussion among advocates of MIS away from issues of ontology.

2. Motivating the Theory

Before looking at MIS in more detail, I note two important qualifications. First, the analogy between model-systems and fictional characters is limited; it does not imply, for example, that books or articles containing model specifications are works of fiction rather than nonfiction.[5] Second, the imagining involved need not involve images. Although many discussions of scientific modeling seem to identify imagination with imagery, the kind of imagining engaged by fiction is standardly taken to be propositional (see e.g. Walton 1990; Currie 1990).[6] On any plausible version of MIS, modeling requires imagining systems to possess concrete properties; it does not require picturing those properties.[7]

Advocates of MIS motivate their position by arguing that more traditional accounts, which construe models as set-theoretic or mathematical structures, neglect the significance of imagining concrete systems such as biological populations. Peter Godfrey-Smith is explicit about this motivation: "An imaginary population is something that, if it was real, would be a flesh-and-blood population, not a mathematical object" (2006, 735). In this respect it is similar to fictional characters and places. The issue here is not ontological. Godfrey-Smith rejects the identification of models with mathematical objects, not because of doubts about the existence of such objects, but because the identification neglects an essential aspect of modeling.

[4] This is not to deny that different realist positions would interpret the epistemological issues differently, but rather that postulating models-as-fictional-characters does not itself resolve epistemic questions.
[5] Giere (2009) raises this concern.
[6] My own view is that imagining in response to fiction involves a combination of propositional and objectual imagining in Yablo's (1993) sense, yielding the possibility of analogical representations, which may or may not involve imagery (Friend n.d.).
[7] Though imagery may play an important role in some cases (Morgan 2004).

MIS advocates thus aim to capture what Martin Thomson-Jones calls the *face value practice* of modeling, essential to which are "descriptions of missing systems" (2010, 284). Modelers may describe a pendulum as a point mass attached to a massless string and subject to no external forces such as friction, or populations of predators and prey that interact with each other but with nothing else. The model specifications that specify the simple pendulum or the Lotka-Volterra model of predator-prey interaction are satisfied by no actual pendula or populations. But if there were such populations or pendula they would be concrete rather than abstract. Of course many models can be identified with actual concrete objects: for instance, Crick and Watson's double helix model of DNA and the Phillips-Newlyn hydraulic model of the British economy. Though these *material models* exist in space and time, they share with *theoretical models*—the ones involving "missing systems"—their purposeful misrepresentation of real-world target systems. My primary focus will be on theoretical models.

There are other features of the face value practice that parallel our engagement with fiction. One is the way that both readers and scientists systematically "fill in the gaps" to elaborate scenarios on the basis of relatively little explicit information. For instance, we know that it is "true-in-the-fiction" that Anna Karenina has a liver and a heart but no wings even if this is never made explicit.[8] Although model specifications provide only a limited number of details, scientists achieve widespread agreement in inferring many other properties of model-systems. "It is, for instance, true that the Newtonian model-system representing the solar system is stable and that the model-earth moves in an elliptic orbit; but none of this is part of the explicit content of the model-system's original specification" (Frigg 2010a, 102).

A related feature of practice is that we can take an *internal* and an *external* perspective on the model-system, analogous to the duality that characterizes our engagement with fiction (Contessa 2010, 223; Levy 2012, 739). From a perspective internal to Tolstoy's novel, Anna Karenina is a flesh-and-blood human being, born to human parents; from an external perspective, Anna is a fictional character created by Tolstoy (see Friend 2007). The internal perspective generates the statements that are true-in-the-fiction, whereas external statements appear to be true *simpliciter*. The same applies to discourse about models. An internal statement such as "electrons orbit the nucleus at discrete intervals" is "true" within the Bohr model of the atom, whereas an external statement such as "the Bohr model of the atom represents the hydrogen spectrum" seems to be true *simpliciter*. This duality of perspective contrasts with our way of thinking about such abstracta as numbers or sets.

Now, one might accept that the face value practice reflects scientists' "folk ontology" of models without accepting that imagining concrete systems plays a role in the epistemology of modeling.[9] Defenders of MIS offer several reasons that such imagining plays an essential role. First, many important models appear to be entirely non-mathematical. Godfrey-Smith cites Maynard Smith and Szathmáry's models of the origin of membranes and compartmentalization and models of memory in cognitive science (2006, 736; see also Levy 2015). Another example is the standard diagram of a eukaryotic cell given in biology textbooks, which presents an idealized model of no particular kind of cell (Downes 1992, 145). Plausibly, the diagram specifies an imaginary concrete cell.[10] The thought is that if we can learn from such models, it is not by engaging with mathematical structures.

[8] For an overview of accounts of truth-in-fiction see Woodward (2011).
[9] The term is Deena Skolnick Weisberg's, cited in Godfrey-Smith (2006, 735) and Weisberg (2013, 68). The view stated in this sentence is defended by Weisberg (2013, Ch. 4).
[10] Here I disagree with Weisberg's interpretation (2013, 19).

Second, proponents of MIS argue that understanding how a model relates to reality seems to depend on grasping concrete but imaginary features of a model-system. Frigg gives the example of Fibonacci's model of the rate at which a pair of rabbits would breed in one's garden (2010a, 105-106). The model specification provides an equation that applies only to "rabbits that never die, a garden that is infinitely large and contains enough food for any number of rabbits, and rabbits that procreate at a constant rate at constant speed" (2010a, 106). To understand the implications of the model, Frigg argues, the mathematics is insufficient.[11] We must recognize that the fictional *scenario* differs from the actual situation, in which the rabbits are mortal, the garden and food supply are limited, and so on. This contrast leads us to conclude that the Fibonacci model is appropriate for only a certain length of time.

A third advantage, according to some advocates of MIS, presupposes that scientists learn from modeling by comparing model-systems to target systems. The argument is that treating model-systems as imagined concrete entities rather than abstract mathematical structures illuminates the sense in which models can resemble targets. For example, the simple pendulum is said to *swing sinusoidally*, but an abstract object cannot have this property, at least not in the same sense (Thomson-Jones 2010, 291). The difficulty applies not just to claims about isomorphism between mathematical structures and concrete targets, but also to Giere's (1988) account of models as description-fitting abstracta. Thus Giere is often criticized for leaving unexplained the similarity relations between abstract models and concrete target systems. Godfrey-Smith contrasts the situation with fiction, where "we have an *effortless* informal facility with the assessment of resemblance relations … We often assess similarities between two imagined systems (Middle Earth and Narnia), and between imagined and real-world systems (Middle Earth and Medieval Europe)" (2006, 737). If this is right, taking the analogy with fiction seriously has the potential to clarify how scientists learn from models through comparison.[12]

The idea that we learn from modeling through comparison takes for granted that models represent phenomena *indirectly*. In fact this is the standard position in the literature on modeling, and some take indirectness to define modeling as a distinctive scientific practice (Weisberg 2007). Godfrey-Smith adopts the assumption explicitly:

> Model-based science is fundamentally a strategy of indirect representation of the world. In understanding a real-world system, the modeler's first move is the specification and investigation of a hypothetical system, or structure. The second is consideration of resemblance relations between this hypothetical system and the real world "target system" that we are trying to understand. (Godfrey-Smith 2006, 730; see also Frigg 2010b, 252)

Though this approach is motivated by function rather than ontology, it is hard to see how scientists can use models to represent target systems or engage in comparisons between model-systems and relevant phenomena if model-systems do not exist. In addition, scientists seem to investigate models and thereby discover new features of model-systems, again implying a real object of investigation. And scientists make apparently true statements about model-systems that

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[11] This is not to say that opponents of MIS cannot accommodate this observation. Weisberg (2013), for example, says that models are not merely structures but *interpreted* structures.

[12] In fact it is not clear that comparisons in the fiction case are any more (or less) straightforward than comparisons in the modeling case (Giere 2009). See §§4-5 below.

seem to presuppose that there are such things. The first two aspects concern the epistemic significance of modeling, whereas the last concerns the semantics of the associated discourse.

Much of discussion about the ontological commitments of MIS, like the debate over fictional characters, focuses on semantic issues. However, in my view semantic considerations provide little motivation for realism. I have argued elsewhere that realism about fictional characters offers little advantage over antirealism concerning the semantics of fictional discourse (Friend 2007). I would say the same about the semantics of model discourse. I return to this point in §5. The far more interesting question is whether we should adopt realism about model-systems to explain the epistemology of modeling. I propose to address this question by considering deflationary forms of MIS—those that resist postulating model-systems as real entities—and asking what, if anything, these accounts leave out.

3. Deflationary MIS

A deflationary approach accords nicely with the idea behind MIS that model-systems are imagined concrete systems. Ordinarily, when we describe something as "imagined" we imply that it does not exist. Moreover, philosophers of science are typically inclined toward a naturalistic picture of the world, incompatible with treating a model-system "as a shadowy additional graspable thing, either of an abstract platonist kind or a modally-realist kind" (Godfrey-Smith 2009, 108). The concern is just that a deflationary account is insufficient to explain the epistemic value of modeling. To address this concern I will look at the deflationary versions of MIS advocated by Frigg (2010a, 2010b), Toon (2012), and Levy (2012, 2015). Though they differ in other ways, all take as their starting point Kendall Walton's (1990) account of fiction.

Walton proposes a theory of *fiction* or (equivalently) *representation*, a category that encompasses far more than works of fictional literature. Walton defines representations as objects that have the function of serving as "props in games of make-believe." The allusion to children's games, where the props may be dolls or toy trains, is intentional, for there is continuity between the two kinds of game. The basic idea is that representations prescribe imaginings about their content; for example a story invites us to imagine that certain people did certain things. Imagining what is prescribed is participating in the *official* game of make-believe *authorized* by the prop. In a game some moves are licensed and others are not. Though nothing prevents me from imagining that Clarissa Dalloway zips around town on a small drone, for example, there is a clear sense in which this would be an unauthorized response to Woolf's novel. This explains why it is *not* true-in-the-fiction or (in Walton's terminology) *fictional* that Clarissa travels by drone. Significantly, this approach rejects the traditional association between representation and denotation.[13] A work can be a representation without referring to anything, so long as it is a prop in certain kinds of games of make-believe.

Some props are *reflexive*, prescribing imaginings about themselves (Walton 1990, 117). A doll does not simply prompt Alex to imagine a baby; it prompts him to imagine, *of* the doll itself, that *it* is a baby. When Alex places the doll in the bath, he imagines himself to be placing the baby in the bath. Although some fictional texts are reflexive props—such as Swift's *Gulliver's Travels*—more typically they prescribe imaginings directed at something else. This may be a real entity, such as a historical person or actual place; when fictions refer to such individuals, they are *objects of representation* (Walton 1990, Ch. 3). Here the prescription is to engage in singular thought, that is, *de re* imagining about the object. Orwell's *Nineteen Eighty-*

[13] The importance of this point is not always appreciated by advocates of MIS. An exception is Toon (2012).

Four prescribes imagining, of London, that it is the capital of Airstrip One, and Tolstoy's *War and Peace* prescribes imagining, of Napoleon, that Pierre wants to assassinate him. Fictions also prescribe imaginings apparently about nonexistent individuals. Orwell's novel invites us to imagine such invented characters as Winston and Julia, and Tolstoy's novel not only Pierre but Natasha, Prince Andrei, and so on. For Walton, these prescriptions involve only the pretense of reference or existence; in reality they are not directed at anything, and they express no propositions (1990, Ch. 10). But this does not mean that an account of the prescriptions cannot be given. We certainly imagine something when we imagine that Clarissa Dalloway plans a party, and explicating this content is a task for a more general semantics of intentionality.[14] Whatever the explanation, it will make no appeal to a real Clarissa.

For deflationary MIS, model specifications constitute fictions or representations in Walton's sense: they function as props in games of make-believe. For instance, descriptions of the Lotka-Volterra model prescribe imagining a population of predators and a population of prey whose growth rates and death rates are specified by a set of equations. John Maynard Smith makes the invitation to imagine explicit in presenting a model of RNA replication: "Imagine a population of replicating RNA molecules. There is some unique sequence, S, that produces copies at a rate R; all other sequences produce copies at a lower rate, r" (Maynard Smith 1989, 22; quoted in Weisberg 2013, 48). Advocates of MIS do not deny that in these and many other cases mathematics plays an essential role. Instead, the equations that are part of many model specifications serve to specify the features of the model-system to be imagined, which may include instantiating certain mathematical structures. The key to modeling remains the role of models as props in games of make-believe.

From this perspective, material models are analogous to model specifications, since both are representations that function as props prescribing imaginings. A scale model of a bridge that is one meter long might prescribe imagining a bridge that is one thousand meters long—where the scale functions as a principle of generation— just as a specification of a simple pendulum prescribes imagining a pendulum whose bob is a point mass (Toon 2012, 37-40). And like children's toys, material models may be reflexive props. A ball-and-stick model of a water molecule does not just prescribe imagining that *there is* a water molecule; given the conventional understanding of such models, it prescribes imagining, of itself, that *it* is a water molecule.[15] When we manipulate the model, we imagine ourselves to be manipulating the molecule.

Theoretical models are more akin to written fictions that prescribe imaginings about something other than themselves. Toon argues that in many cases, this something is real. Instead of taking a specification of the Newtonian solar system model to represent a hypothetical system, for example, he argues that we should treat it "as prescribing us to imagine things *about the sun and earth themselves*" (Toon 2012, 56; emphasis in original). The sun and earth are thus objects of representation in Walton's sense; we are to imagine, of the actual celestial bodies, that *they* are homogeneous spheres and so on. If this is right, the Newtonian solar system model represents the solar system *directly*, rather than via a hypothetical model-system, so that the imaginings are about the real system. Toon and Levy take this kind of direct representation to be central to modeling.[16] When scientists want to understand a real-world phenomenon, they construct model specifications that invite imagining the target in ways contrary to fact. Direct representation

[14] I develop an account broadly consistent with Walton's approach in Friend (2011a).
[15] Toon (2012, Ch. 5) provides empirical evidence that this is how we treat such models.
[16] Weisberg counters that this view reduces all modeling to idealization and thus fails to recognize modeling as a distinctive practice (2013, 64). See Levy (2013) for a reply.

presents no difficulties for a deflationary approach, since the targets are ordinary real-world entities.

Like fictions, though, many model specifications seem to invite imaginings about systems that do not exist. The Bohr model of the atom is not meant to describe a particular real-world atom, and a description of the simple pendulum need not designate a particular real-world pendulum. The same may be said of mechanical models of the ether, architectural models for buildings never constructed, models of generalized phenomena such as evolution, and models of unrealized scenarios such as three-sex biology.[17] None of these models has an object in Walton's sense. For Toon, the relevant model specifications simply do not prescribe imaginings about any real thing. The puzzle of how to understand imaginings directed at what does not exist is, he points out, a general problem of intentionality rather than a problem specific to scientific modeling (Toon 2012, 82). Whatever antirealist explanation works in other cases should also work for models-systems.

Levy argues, by contrast, that apparently objectless model specifications should be reinterpreted as inviting imaginings about real-world targets: "All we have are targets, imaginatively described" (2015, 791). If Levy is right, deflationary MIS is straightforward, since the objects of imagining are always ordinary existents. However, this view is controversial. More importantly, even if Levy is correct that there are no targetless models, there is a contrast between an *object of representation* in Walton's sense—a particular referent of singular imaginings—and a target, which may be more general. This is clear in the fiction case. Works of fiction that invite imaginings about fictional characters can also represent or "target" (without referring to or inviting singular imaginings about) real-world individuals. For example, in *Oliver Twist* Dickens uses the title character to represent real orphans in Victorian England. It is by inviting readers to imagine Oliver's travails that Dickens throws light on the plight of real orphans. So if the analogy with fiction holds, we should expect model specifications that prescribe singular imaginings about real entities and model specifications that do not.

The important question in either case is how imagining as prescribed results in knowledge of target systems. I consider how deflationary MIS addresses this challenge in the next section.

4. The Epistemological Challenge

Recall that there are two epistemically significant aspects of modeling that appear to imply realism: First, scientists seem to investigate models and thereby discover new features of model-systems. Second, they seem to compare model-systems to real-world phenomena. These two elements of the practice are closely related, since the point of investigating the model is to shed light on the target system. According to deflationary MIS, there are no model-systems; there are only representations prescribing imaginings, often about what does not exist. How can engaging in such imaginings generate discoveries about model-systems and knowledge of real-world phenomena?

For deflationary MIS the starting point for answering this question is understanding how readers of fiction discover features of a "fictional world." As noted in §2, much of what a representation makes fictional is implicit, so that readers must fill in the gaps. To do this they rely on what Walton calls *principles of generation*. In some games these are stipulations: "Anyone whose feet touch the floor have landed in the sea." With complex representations such as works of literature they are the conventions of the practice, which competent participants have

[17] The first two examples come from Toon (2012) and the last from Weisberg (2013).

internalized. Although some general principles can be identified—such the Reality Principle, which authorizes reliance on real-world truths to fill in the background of a story—Walton argues that the principles of generation are too varied to subsume under a few rules (1990, Ch. 4). For example, experienced readers of whodunits immediately recognize that the obvious suspect is not guilty, and experienced viewers of screwball comedies know that cleverly insulting banter signals love. The ability to deploy such principles appropriately constitutes competence with the relevant sort of representation.

Correspondingly, for deflationary MIS *investigating the model-system* is not investigating a real system. Instead, it is making inferences from the explicit content of the model specification to conclusions about what is fictional (prescribed to be imagined) by deploying appropriate principles of generation. Like fictions, model specifications provide only a limited number of details explicitly, so that scientists must infer many other properties of model-systems. Frigg uses his example of "the solar system is stable," which is fictional according to the Newtonian model because it is implied by a combination of the model specification and "the laws and principles assumed to hold in the system (the laws of classical mechanics, the law of gravity, and some general assumptions about physical objects)" (2010a, 118). Exactly how to spell out the principles of generation that determine what is fictional in a model will be at least as complex as the corresponding task for fiction (see §6). Still, there is systematic agreement about the features of model-systems among practitioners, suggesting that scientists have internalized certain rules and conventions that enable them to make the relevant inferences.

A worry about this picture is that different scientists may fill in the gaps in different ways, and a high degree of variation is inconsistent with the epistemic role models play in science (Weisberg 2013, 57). However, Walton invokes prescriptions to imagine in explaining what is fictional—what is *to be* imagined—not what anyone actually imagines. These are distinct. First, readers rarely imagine everything that is fictional; few readers will ever consider the proposition that Anna Karenina has a liver. A prescription to imagine should not be construed as an unconditional mandate. Rather, a work prescribes imagining P if, given the choice between imagining P and imagining not-P, one should imagine the former.[18] At the same time, readers imagine a great deal that is not fictional, that is specific to their own games. For instance I may imagine Clarissa one way while you imagine her a different way, both compatibly with the text. If no specific way of imagining certain features of the character is prescribed for every authorized game, none is fictional and the matter is left indeterminate.

Applied to modeling, the upshot is that there are facts of the matter about the features of the model-system independent of particular scientists' imaginings. These are determined by the model specification in combination with appropriate principles of generation. For example, part of the specification of the Lotka-Volterra model is a set of equations. It will be fictional in any version of the model that the model-system conforms to these equations, whether anyone actually works out the mathematical conclusions or not. Note that this applies both when we construe the model as inviting imaginings directly about actual target populations—such as predator and prey species in the Adriatic, Volterra's original concern—or imaginary populations. In either case scientists, by using computers to calculate results, discover what is to be imagined. Other aspects of the model-system will be determined in other ways, just as inferences about non-mathematical models must be made deploying non-mathematical principles of generation. The important point is that what is fictional in the model is not determined by the inferences

[18] See Friend (2014b; 2016).

scientists actually make, but by the inferences that are licensed by the model specification and principles of generation.

At the same time, much will be left indeterminate. A specification of the Lotka-Volterra model may be silent as to the species of the predators and prey. Some scientists may imagine them to be sharks and fish, foxes and rabbits, or what have you. Although there is indeterminacy, it is not the case that anything goes. Given that this is a model of predator-prey interaction, scientists are not authorized to imagine that the predators are rabbits and the prey sharks. The principles of generation determined by the model constrain what is fictional.

The next question is how to explain this kind of application. On the indirect picture suggested by Godfrey-Smith and Frigg, knowledge about real phenomena is acquired by comparing model-systems to target systems; but if there are no model-systems, such comparisons are impossible. Correlatively, comparative statements such as “This population of rabbits is dying off faster than the population in the Lotka-Volterra model” cannot literally be true. Frigg offers a solution to the semantic problem that can be applied to the epistemological concern. He claims that we can “rephrase” apparent comparisons between model-systems and target systems as comparisons between properties—specifically, the features we to imagine the model-system to have, and the corresponding features possessed by the target system (2010b, 263).[19] The implication is that modeling does teach by comparison, though of properties rather than objects. Godfrey-Smith objects to Frigg’s account that many of the properties attributed to model-systems will be uninstantiated, such as perfect sphericality for planets or infinity for populations, and therefore equally mysterious (Godfrey-Smith 2009, 113).[20] Indeed some properties attributed to model-systems may be metaphysically impossible, such as being a point mass for the bob of the simple pendulum. In that case it is not clear what is being compared.

Advocates of the direct view of modeling eschew any appeal to comparisons. Levy (2015) instead invokes Yablo’s (2014) concept of “partial truth” to explain how imagining in response to model specifications produces knowledge about target systems. For example, a model that describes the motion of a body as sliding down a frictionless plane can represent truly the relationship between mass and velocity in the actual system even if it falsely represents the lack of friction (Levy 2015, 794). The Newtonian model can represent truly the relationship between the mass and motion of the planets despite falsely representing the distribution of mass. However, even if the concept of partial truth can be elaborated sufficiently to explain these examples, it does not appear suited to explain cases where the imagining seems to be directed at nonexistent model-systems. Here there are no partial truths in the relevant sense. We still want to know how, by inviting us to imagine such systems, representations manage to teach us about the world.

Godfrey-Smith casts doubt on the prospects for a deflationary explanation of the epistemology of modeling, on the grounds of the “unreasonable effectiveness” it shares with mathematics: “By means of modeling we learn a great deal about how things do and can work in the world. A description of the coordination and elaboration of imaginings cannot be a complete explanation” (Godfrey-Smith 2009, 109). In the mathematics case, epistemic success is taken as an argument for realism about mathematical objects. In the next section I consider whether the same argument can be made on behalf of fictional realism about model-systems.

[19] Frigg (2010b) appears to suggest a fictional operator account of comparisons. Presumably his proposal could be reformulated with a pretense account, which is preferable to an operator approach (see Everett 2013, esp. 46-53).
[20] The point is not that the model-system fails to instantiate the properties—which is entailed by the deflationary assumption that there are no model-systems—but rather that the properties are uninstantiated by *anything*.

5. Fictional Realism about Model-Systems

There are two reasons someone might think that deflationary MIS is inadequate to the epistemology. First, the view entails that we are not discovering genuine features of a model but only finding out what we are supposed to imagine; this does not appear sufficiently objective to do justice to the practice. Second, we require an explanation of how imagining in response to model specifications generates knowledge applicable to the real world. The standard explanation of knowledge from modeling invokes comparison, but on a deflationary approach there is nothing to compare. For these reasons treating model-systems as real may be tempting. However, we will find that no form of fictional realism illuminates the epistemology. Whether or not there are model-systems, advocates of MIS must provide a distinct account of how we learn about the real world through modeling.

Versions of fictional realism can be distinguished by the sort of entities they postulate, in particular whether they are concrete or abstract.[21] Given the emphasis of MIS on imagining concrete systems, the place to start is with a version of realism according to which fictional characters are concrete entities. Meinongians like Parsons (1980) who take this approach construe characters as nonexistent concreta, whereas modal realists like Lewis (1983) take them to be nonactual inhabitants of possible worlds. The appeal of these theories is that they postulate entities that seem to have properties in the same sense as existent or actual individuals do. If model-systems fit into one of these categories, the idea of learning through comparison would be vindicated. Comparisons between concrete objects in respect of their ordinary properties appear straightforward.

There are, however, reasons to resist concrete realism. The most obvious is the ontological commitment, either to an infinity of possible worlds or to an infinite number of nonexistent concrete objects. In fact, the commitment is stronger than this, since many model specifications, like works of fiction, describe impossible scenarios; so the commitments may include impossible objects or worlds, consistently with some accounts of fiction (e.g. Priest 2005). A second concern is that concrete realism fails to do justice to the very features of practice that motivate MIS. In particular, concrete realism has difficulty accommodating the external perspective. According to modal realism, for example, Emma Bovary is not a fictional character at all; she is a possible *person* (or set of possible persons) who possesses the properties determined in some way by the novel (Lewis 1983, 263).[22] Similarly, the Bohr model of the atom is not a model or model-system, but a possible *atom* (or set of possible atoms) that conforms in the right way to the model specification (Contessa 2010, 222). A similar challenge faces the Meinongian approach.[23]

Suppose, however, that we set aside these worries. Let us assume that we have at our disposal the full plenitude of nonexistent concreta and an infinity of possible or impossible worlds. The question before us is what role any such entities might play in the epistemology of modeling for an advocate of MIS. The answer is none.

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[21] Contessa (2010) claims that both abstract entities and concrete (possible) individuals play a role in modeling. The criticisms below apply equally (perhaps doubly) to this account.

[22] In the fiction case the determination in question is not simply a matter of satisfying the descriptions in the novel, but something more complex (see Lewis 1983 and Woodward 2011). However, for model specifications the simpler formulation is commonly assumed.

[23] Meinongians address the external perspective by distinguishing between kinds of properties or ways of having properties. I discuss this proposal below.

The first reason can be traced to an assumption common to both forms of concrete realism: that whenever authors or scientists specify a set of properties, there is an entity—whether a nonexistent concrete object or a set of (im)possible individuals—individuated by those properties. (I use the term *entity* for all of these options.) In fact according to these views, there is an entity corresponding to *every* set of properties. When authors attribute various properties to a character in writing, they merely specify one such entity among the plenitude. Had the author set down different descriptions, she would pick out a different entity. Suppose we wish to know which entity is Emma Bovary. The answer for a concrete realist is whichever nonexistent object or inhabitant of an alternative world has the properties specified in *Madame Bovary*. To discover Emma's properties—which is the same as discovering which of all the available entities is Emma—requires figuring out which properties are specified by the novel. To do this, readers must make inferences from the explicit text using relevant principles of generation. The same applies in modeling. For any model specification, there is a model-system individuated by all and only the properties specified.[24] So for concrete realists, "investigating a model-system" is just interpreting the model specification using principles of generation, thereby simultaneously determining which of the available entities counts as the model-system. With respect to discovering the features of the model-system, concrete realism has no advantage over deflationary MIS.

On the other hand, concrete realism seems to have an advantage in applying these discoveries to real-world phenomena. Because the simple pendulum is a concrete entity, it appears to swing in just the same sense as an actual pendulum, allowing for straightforward comparisons of motion. In fact, however, it is not at all clear that this is so. The following argument is from Anthony Everett (2013, 171-172).[25] Consider such properties as being colored or having a nonzero mass. If the entities postulated by concrete realists are colored they should reflect light, and if they have nonzero mass they should be detectable by their gravitational fields. Needless to say, they do not reflect light and are not so detectable. The Meinongian could reply that nonexistent objects reflect *nonexistent* light and produce *nonexistent* gravitational fields, and the modal realist that possible individuals reflect *possible* light and produce *possible* gravitational fields.[26] But these properties are not the same as those possessed by actual, existent concrete objects. An alternative is to distinguish ways of possessing properties. Some Meinongians draw a distinction between *encoding* properties and *exemplifying* them, so that nonexistent objects might encode the ordinary property of *having nonzero mass* while existent objects exemplify (have in the ordinary sense) the same property (Zalta 1983). Whatever the unexplained primitive notion of encoding turns out to be, the entities fail to possess properties in the same sense as existent, actual objects. Either way, comparisons between model-systems and target systems are not straightforward. Everett suggests a way of construing encoded properties consistent with MIS: they are the properties a fiction invites us to imagine exemplified by a character (2013, 173). But that is no different from the deflationary position. The advocate of MIS has little reason to postulate nonexistent objects or nonactual worlds.

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[24] An implication is that different specifications pick out distinct model-systems. There is not a single Lotka-Volterra model, but a different one corresponding to each specification. I set this problem aside for the sake of argument.

[25] Everett's argument is directed against Meinongianism but can be extended to modal realism.

[26] Compare the distinction between *nuclear* and *extranuclear* properties invoked by some Meinongians (Parsons 1980).

We turn next to realist accounts that take fictional characters to be existent abstract objects. Versions of this position differ in how they individuate the objects, whether by internal or by external properties—that is, the properties the character has from each perspective. From an internal perspective, Emma Bovary has such properties as *being a woman*, *being married to a doctor*, and *being an adulteress*; these are the same properties that concrete realists would attribute to her. From an external perspective, she has such properties *being created by Flaubert* and *being Flaubert's most famous character*.

For realists who individuate characters by internal properties, fictional characters are person-kinds, roles, or character-types (Wolterstorff 1980; Currie 1990; Lamarque 2010, respectively; see also Zalta 1983). Call this *type realism*. Applied to model-systems, the position is similar to Giere's (1988) proposal that models are description-fitting abstract objects. It is therefore subject to the same objection: namely, that abstract objects cannot possess internal properties in the same sense as concrete objects. Just as an abstract Emma Bovary is not a woman in the same sense as Marie Curie, an abstract pendulum does not swing in the same sense as the concrete pendulum. Paul Teller addresses this objection by distinguishing ways in which objects possess properties; whereas "concrete objects HAVE properties … properties are PARTS of models" (2001, 399). This is essentially the distinction between exemplifying and encoding, and equally mysterious. But we could say that if model-systems are construed as roles or types, the idea might be that the character-type encodes concrete properties in the sense that any concrete individual who possesses the properties thereby fills the role or instantiates the type. In reading *Madame Bovary* we imagine a concrete human being filling the role delineated by Flaubert, and in grasping the simple pendulum model we imagine a concrete pendulum satisfying the model specification.[27] Even if this solution is correct, though, it remains the case that neither the character nor the model-system, qua abstract, has the specified properties in the way that concrete objects do. More importantly, antirealists could simply accept the existence of roles or character-types while denying that these are identical to characters or model-systems. According to MIS, we treat model-systems as concrete, so they instantiate types rather than being identical to them.

A more popular version of realism maintains that fictional characters are existent abstract objects individuated by external properties, in the same ontological category as novels, plots, theories, and laws. These are real, constructed entities that are not identical to, or instantiated by, any concrete objects. According to most proponents of the view, fictional characters come into existence through the creative acts of authors; Thomasson (1999) thus describes them as *abstract artifacts*. On this view, there is no literal sense in which Emma possesses the properties attributed to her in *Madame Bovary*, such as being a woman or an adulteress. Rather, readers are invited to pretend or imagine that she does. Thomasson proposes that such imaginings are directed at the real abstract object Emma.[28] Just as *War and Peace* prescribes imagining, of the real Napoleon and Russia, that the one invades the other, *Madame Bovary* prescribes imagining, of the real Emma Bovary, that she (it?) commits adultery.

This form of fictional realism—call it *external realism*—accords with the motivations behind MIS. Take the Bohr model of the atom. For the external realist, this is an abstract object created by Nils Bohr's modifications of Rutherford's model, just as Emma Bovary is an abstract object created by Flaubert in writing *Madame Bovary*. Or the model could be construed as

[27] This interpretation was inspired by some points in Giere (2009), though I cannot attribute the view to him.
[28] Others hold that the imaginings are not directed at anything; they involve the pretense that there are such concrete individuals, with characters playing a role only from the external perspective (e.g. Kripke 2013).

socially constructed, the product of the collective effort of scientists (thus the 'Rutherford-Bohr model'), but still a created abstract entity (Giere 2009, 251). Scientists make straightforwardly true claims about the model, for instance that it is used to make successful predictions about the absorption spectrum of the hydrogen atom. From the internal perspective, though, Bohr's model specification prompts us to imagine a concrete *atom*, not an abstract object, one constituted by a nucleus surrounded by orbiting electrons. Thus when we say, "electrons follow classical trajectories," we make a claim that is merely fictional, merely true-in-the-model, but not actually true. In short, external realism captures the motivating idea of MIS, that imagining concrete systems is central to modeling, while taking the external perspective to specify what is genuinely true.

Though it captures these aspects of the face value practice, however, external realism will not help advocates of MIS to explain the epistemology of modeling. The difficulty is simple. According to external realism, model-systems possess only external properties; but the properties that are epistemically relevant are the internal ones. For instance, when scientists draw conclusions about the rate at which prey are consumed by predators within the Lotka-Volterra model, they are not discovering features of a real model-system, for these features are merely imaginary. There are no prey or predators, and thus no rate at which the former are consumed by the latter. So for external realists, "investigating the model system" cannot be construed as anything other than interpreting the model specification according to relevant principles of generation to determine what should be imagined—just as deflationary MIS maintains. External realism also has no advantage in providing an account of comparisons between model-systems and target systems. The properties that provide the respects of comparison are, once again, internal. Since according to external realism these features are merely imagined, the account is in exactly the same position as deflationary MIS.

Notice that in consequence, external realism offers little advantage over a deflationary approach when it comes to the semantics of comparative statements. "The rabbits in the Lotka-Volterra model are dying off faster than the rabbits in my garden" cannot literally be true, since the model does not contain any rabbits. The intuition that the statement is true must ultimately be explained by what the model specification prescribes imagining. It is worth pointing out that other forms of realism fare little better. On these views the statement turns out to be ambiguous. Either the rabbits in the model encode dying off whereas the rabbits in the garden exemplify it, or the model rabbits have a nonexistent or merely possible property of dying off whereas the garden rabbits have the existent or actual property. So realism does not necessarily offer a smoother semantic account than a deflationary approach (Friend 2007).

Even if it did, though, there would be no epistemological argument in favor of adopting any of these versions of fictional realism about model-systems. This is not to deny that there may be other reasons either for or against accepting possible worlds, nonexistent concreta, or various sorts of abstract objects. The claim is just that it would make no difference to the epistemology of modeling for an advocate of MIS.

6. Moving Forward

If this is right, advocates of MIS should set aside the debate over the ontology of model-systems. Even if these are real entities of one sort or another, they are epistemologically superfluous. Instead, the focus should be on the key claim of MIS, that the practice of modeling essentially involves imagining concrete systems in response to model specifications analogously to the way that we imagine characters and events in response to works of fiction. Defending MIS against other accounts of modeling requires answering the question of how this sort of imagining produces knowledge of the real world. The upshot of the previous section is that model-systems, thought of as real fictional entities, can play no role in the answer. By way of conclusion I briefly sketch the resources available to MIS in addressing the epistemological challenge.

As we have seen, for any version of MIS investigating a model-system is determining what a model specification prescribes imagining given appropriate principles of generation—whether or not the imagining is about anything real. To defend this position, advocates of MIS must provide detail about how this kind of determination works. What are the principles of generation? How do they take us from the model specification to conclusions about the model-system? What justifies scientists in deploying the principles they do? Although arguments explicitly defending MIS have not addressed these questions in detail, there is plenty of material in related work upon which they can draw.

For example, Morgan (2014), relying on her previous work in Morgan (2012), identifies two sources of principles of generation for the games of make-believe that economists play with models: "the medium or language of the model (whether it is made up of equations or diagrams or is an hydraulic model)" and "the economics subject knowledge which acts both as a constraint on, and a prompt for questions about, the kinds of things that are imagined to happen within that world in the model" (2014, 232). A specification of the Lotka-Volterra model might simply postulate a population of predators and a population of prey related by the relevant differential equations, without further explicit information. Ecologists know that the only solutions to the equations that are relevant are those that assume an integer number of members of each population, though this restriction is not explicit in the model specification (Weisberg 2013, 59).[29] Relying on something like the Reality Principle, the biologists import information about real populations—which have no fractional members—in drawing their conclusions, because their purpose is to explain precisely those populations.

Justifying the principles deployed and the inferences made in any particular instance of modeling requires detailed analysis of the specific case. For this reason Morgan defends her position by looking at how the principles operate for different economic models and why the models are successful. Notice, though, that the same is true whatever one's account of modeling. Weisberg, who takes the Lotka-Volterra model to be an interpreted mathematical structure, points out that the mathematical equations by themselves do not determine that the populations have an integer number of members. This fact must come from the interpretation, and the same question of how the interpretation is justified arises for Weisberg as for the advocate of MIS. Justification can only be given on a case-by-case basis, looking at the details of particular models and their fruitfulness.

The more difficult challenge to MIS is explaining how determining these fictional truths and imagining as prescribed generates knowledge of the real world. If the argument of §5 is correct, the explanation cannot ultimately appeal to comparisons between model-systems and target systems, or indeed any other relation that presupposes the reality of model-systems. In this respect advocates of a direct approach to modeling are right. However, if the direct approach relied only on the notion of partial truth invoked by Levy (2015), it would not be sufficiently general to account for the epistemological power of model specifications that invite imaginings about nonexistent model-systems. There is, though, a more general account of how modeling yields knowledge of the world available to advocates of MIS. Frigg (2010a), Bokulich (2012),

[29] Weisberg takes this example to be a problem for fictionalists, but I do not agree.

and Morgan (2014) each appeal to a "translation key" that takes one from information about the model to information about the world.[30] This proposal is promising but requires development.

First, the notion of a translation key must be articulated in the right way. For example, Frigg takes the translation to occur between model-systems and targets (2010a, 128), but given the argument of §5, it cannot be model-systems playing this role. Bokulich says instead that "the translation key is from statements about the fictions to statements about the underlying structures or causes of the explanandum phenomenon" (2012, 735). If we treat "statements about the fictions" to mean fictional truths, this construal is on the right track. However, I suggest that a focus on statements is too narrow.[31] As with maps, information need not be contained in sentence-like structures. We should think of the translation key as taking us from *representations* of the model-system to *representations* of the target.

The next question is *which* representations are the ones between which we translate. In an instance of learning by an individual, the answer is straightforward: mental representations. Consider a toy explanation of how we learn by reading works of fiction, for instance how we learn from *Oliver Twist* about the plight of real Victorian orphans.[32] In reading the novel we first form a mental representation of what obtains in the "fictional world." This mental representation constitutes the content we imagine in response to the fiction (Friend n.d.). The next step is selectively exporting aspects of this mental representation into our beliefs about Victorian orphans. For example, from our imagined representation of Oliver Twist as having been sent to a work farm we may form a belief that Victorian orphans were at least sometimes sent to work farms. If the belief is true and has been formed in the right way, we will have acquired knowledge (Friend 2014a). Part of what defines "the right way" is the utilization of appropriate *principles of export*, which determine how we move from the representation of the fictional world to beliefs about the real world. In the case of *Oliver Twist*, the principles derive from our knowledge of Dickens's methods and purposes and his reliability in describing the contemporary situation.

Principles of export can be compared to the translation keys discussed by philosophers of science. And I think something like the picture in the previous paragraph can be used by advocates of MIS when we focus on the individual scientist, who learns by deploying principles of generation to determine the features of the model-system to be imagined, and then infers features of the target by using principles of export. However, although learning is a psychological process, the epistemological value of modeling is not restricted to the mental states of the individual scientist. For the knowledge acquired through modeling to play a role in the social practice of science, it must be available through public representations. From this perspective a key enables translation between the content of a model specification—thought of abstractly as what is to be imagined by anyone engaged with the model—and the content of collective beliefs about the target. Making sense of this claim requires accounts of collective beliefs and of semantic content, and no such accounts will be uncontroversial.[33] But this is a general problem, not one specific to modeling.

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[30] Though he does not use the same terminology, Suárez's (2009b, 2010) proposal that scientific fictions function as rules of inference is closely related.
[31] Nothing Bokulich says commits her to disagreeing with this point.
[32] The following is the basic account given in Friend (2006). I elaborate on it in Friend (n.d.).
[33] For instance, semantic content is sometimes identified with sets of possible worlds. This view is unlikely to appeal to the advocate of MIS unless the reference to possible worlds can be given a deflationary explanation.

For either the intrapersonal or interpersonal case the question is how to justify the translation keys. As with the justification of principles of generation, the answer turns on the particularities of the model. For some models considerations similar to those in the Dickens case may be important, such as historically-oriented economic models (Morgan 2014). In many other cases, the factual reliability of the model's creator will be irrelevant and different considerations will play the justificatory role. For example, Bokulich (2009) details the experimental evidence that has convinced physicists of a semiclassical explanation of absorption spectra for certain elements, which combines the (true) assumption that electrons in highly excited atoms function as waves exhibiting interference with the (false) assumption that they travel in classical trajectories. No other explanation generates predictions as precise or as much in agreement with experimental data. Once again, the justificatory work is in the detailed analysis of particular cases.

To summarize, the advocate of MIS need not appeal to model-systems construed as real entities in order to explain the epistemological value of modeling. What is necessary instead is a detailed examination of principles of generation and translation keys across different instances of modeling, with attention to the ways in which concrete imaginings play a role in elaborating fictional truths about models and selectively exporting them to beliefs about the real world. For purposes of this project the ontology is simply irrelevant.[34]

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