21 Scientific Modelling and Make-Believe

Roman Frigg

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I. The Fiction View of Models

Models are crucial to the scientific endeavour because many investigations are carried out on models rather than on reality itself: we can learn about the motion of planets, the dynamics of populations, and the growth of an economy by studying their respective models. Some models are material objects. The aerodynamic properties of a car are investigated by putting a scale model in a wind tunnel; the spatial structure of a molecule can be understood by looking at a ball-and-stick model of it; features of cell division are explored through model organisms like the worm Caenorhabditis elegans; and the reaction of an economy to tax increases can be studied by observing how water flows through a tailor-made system of pipes and reservoirs.

But not all models are material objects. Many models are, in Hacking's words, something that one holds in one's head rather than one's hands (1983, p. 216). Such models are given to us through descriptions, which I call "model descriptions". When studying the motion of planets, Newton studied a model system consisting of two perfect spheres with homogenous mass distributions, one much larger than the other, that attract each other with a $1/r^2$ force law in otherwise empty space. And to develop his equations of the electromagnetic field, Maxwell investigated in detail the dynamical properties of a model with imaginary flows of water.

Neither Newton nor Maxwell took themselves to be describing real physical situations and they highlighted the "non-material" character of their models by describing them as the result of an act of the imagination. This raises the question: if these models are not physical objects, then what are they? The leading idea of what has become known as the "fiction view of models" is that scientific models are akin to the objects, characters, or places of literary fiction. Peter Godfrey-Smith offers the following programmatic statement of the view:[1]

> I take at face value the fact that modelers often *take* themselves to be describing imaginary biological populations, imaginary neural

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> 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. . . . the model systems of science often work similarly to these familiar fictions.
> (2006, p. 735)

However, the places and characters in literary fiction are beset with as many philosophical puzzles as models themselves, and so one might wonder whether the fiction view of models isn't just explaining *obscurum per obscurius*. This is a serious challenge, and proponents of the fiction view have to make it plausible that likening models to fiction has philosophical value. This is the project for this chapter.[2]

Before spelling out what philosophical work exactly the fiction view is expected to do, and before explaining how it gets this work done, it is worth articulating the motivations for the fiction view in some detail. Why would drawing a parallel between models and fiction seem to be a good idea to begin with? I can see four reasons for this.

The first reason is that fiction is a genre that gives the author creative freedom. Fictions can contain characters and places that do not exist, and there is often nothing in the world of which the text of a novel is a true description. To come back to Godfrey-Smith's examples, Sherlock Holmes is not a real person and Middle Earth is not a real place. Readers are of course fully aware of this and don't mistake the sentences of a novel for a direct description of something in the actual world. The same happens in scientific modelling. When reasoning with perfect spheres and imaginary fluids, scientists did not talk about, or describe, real physical systems. The objects of enquiry are imaginary in the same way in which the objects of literary fiction are.

The second reason to ponder the parallel between models and fiction emerges from guarding against a frequent misconception. To say that fictions can contain characters and places that do not exist is not tantamount to saying that models, or indeed literary fictions, are plain falsities. The fiction view neither says nor implies that scientific models are nothing but untrue fabrications that contain no factually correct information about their targets. Fiction, either scientific or literary, is not defined through falsity. Historical fictions like Tolstoy's *War and Peace* contain many true elements, and the fact that a government report is at variance with fact in a number of places does not make it fiction. What makes a text fictional is not its falsity (or a particular ratio of false to true claims), but the attitude that the reader is expected to adopt towards it.[3] Readers of a novel are invited to imagine the events and characters described. They are expressly not meant to take the sentences they read as reports of fact, let alone as false reports of fact. Imagination is, as it were, neutral with respect to truth. Nevertheless, literature often provides insight into something. When reading we may engage in comparisons between the situations in the fiction and situations we have encountered in real life and thereby learn about the world by reading fiction. Again, this has parallels in the context of modelling, where we learn from models about the world. Once we think about models as fictions this parallel becomes salient and urges us to think about how the "knowledge transfer" from a fictional scenario to the real world takes place. At least in the context of science, this transfer involves taking the fiction to be a representation of the target system. I will say what this involves in Section IV. The point that matters for now is that the fiction view is not committed to the nihilist position scientific models are falsities without connection to reality.[4]

The third reason is that fiction comes equipped with a notion of "internal truth" that is of interest also in the case of models. It is true in Hemingway's *The Old Man and the Sea* that Santiago is a Cuban fisherman and that he went fishing by himself. It is also true in the story that Santiago has a heart and a liver, and that he does not have a degree in Japanese literature. Only the first two claims are explicitly stated in the story; the others are inferred indirectly. That something is not stated explicitly does not make it arbitrary. Whether or not claims about a story's content are correct is determined by the text without being part of its explicit content. The same happens in models, where model-descriptions usually only specify a handful of essential properties, but it is understood that the model has properties other than the ones mentioned in the model-description. In fact, models are interesting exactly because more is true in them than what the model-description specifies. This is what makes them interesting as objects of study. It is, for instance, true in the Newtonian model that the model-planets move in stable elliptical orbits, but this is not part of the explicit content of the model's original specification. Philosophers of science have to understand what it means for a claim to be true in a model, and keeping an eye on how "truth in fiction" is explicated can be heuristically useful when tackling this problem.

The fourth reason follows on from the third and concerns the epistemology of claims about what is true in a story. A story not only has content that goes beyond what is explicitly stated; we also have the means to find out what this "extra content" is. Indeed, it is an integral part of our response to fiction that we supplement the explicit content and "fill the gaps" in the plot where the text remains silent. The same goes for models. Finding out what is true in a model beyond what is explicitly specified in the relevant description is a crucial aspect of scientists' engagement with the model, and the bulk of the research that goes into exploring a model usually goes into finding out whether or not certain claims about the model hold true. For this reason, an articulation of an epistemology of models may well benefit from insights gained into how we learn about fiction.

This list of communalities between scientific modelling and literary fiction is neither complete, nor should it be understood as suggesting that there are no differences between the two. The purpose of this list is just to make it plausible that thinking about models as fictions is at least a plausible point of departure.

II. Quests and Questions

You may now ask: a point of departure for what? I submit that an account of scientific models has to come to terms with at least five questions. The first two questions on my list follow relatively directly from the parallels discussed in the last section; the other three are additional concerns.

The first question is: what is truth in a model? There is right and wrong in a discourse about a model. It is true that model-planets move in perfectly elliptical orbits and it is false that their trajectories are unstable. But what makes claims about a model-system true or false, in particular if the claims concern issues about which the description of the system remains silent? What we need is an account of truth in models that explains what it means for a claim about a model-system to be true or false and that draws the line between true and false statements at the right place.

Investigating model systems to find out about them is a crucial part of any scientific endeavour that involves models. In fact, we engage with model precisely because we want to explore their properties. So, the second question is: how do we find out which claims are true and which claims are false in a model, and how do we justify our findings? In other words, what is the epistemology of models?

The third question is: when are two models identical? Having identity conditions for models is crucial because unlike in the context of literature, where we can point to a history of production, scientific models are often presented by different authors (in different papers or textbooks) in different ways. Nevertheless, many of the different descriptions are actually meant to describe the same model. So, we need to know when two model-descriptions describe the same model.

The fourth question concerns the attribution of properties. We say that the spheres in Newton's model attract each other gravitationally and that the water in Maxwell's pipes flows uniformly. What exactly do we assert when we say such things? At least on the surface, such statements look like ordinary property attributions. The conundrum is that the model objects in question don't exist, at least not as ordinary physical objects, and so there is a question how to make sense of attributing properties to something that does not exist, in particular if the properties attributed are ordinary physical properties like attracting each other or flowing uniformly. It has been claimed that such statements are outright contradictory because abstract objects like the ideal pendulum cannot have the same properties as concrete physical systems (Hughes, 1997, p. 330;

Thomson-Jones, 2010, pp. 292–294). So, our fourth question is: how is it possible to attribute physical properties to a model if models do not exist as physical objects?

A related problem concerns comparative statements. Comparing models with targets, and in some cases even different models with each other, is part and parcel of the practice of model-based science. We customarily say things like "real agents do not behave like the agents in the rational choice model" and "the agents in the first model don't behave like the agents in the second model". These statements are problematic for the same reason as property attributions: if models don't exist, how can we compare them with targets, or even with each other? Our fifth and last question therefore is: how is it possible to compare models with target systems and with other models if models do not exist as physical objects?

Answers to these questions should satisfy two requirements. The first is that they must be able to account for how models are employed in scientific practice. A philosophical theory of models that makes a mystery of how scientists use models in the practice of their work is useless, and hence answers to the aforementioned questions have to be compatible with, and indeed account for, how scientists work with models. The second requirement belongs to the realm of philosophy and is that we have to have a clear notion of the ontological commitments that we incur in our answers and that we have to be able to justify them, if necessary.

III. Models and Make-Believe

The contention of this chapter is that Kendall Walton's (1990) pretence theory (PT) offers convincing answers to all our questions.[5] PT's point of departure is the capacity of humans to imagine things. Sometimes we imagine something without a particular reason. But there are cases in which our imagining something is prompted by the presence of a particular object. If so, this object is referred to as a *prop*. An object becomes a prop due to the imposition of a rule or *principle of generation* prescribing what is to be imagined in response to the presence of the object. If someone imagines something due to the presence of a prop they are engaged in a *game of make-believe*. Someone who is involved such a game is *pretending*. So "pretence" is just a shorthand way of describing participation in such a game and has nothing to do with deception.

PT considers a variety of different props ranging from novels to movies, from paintings to plays, and from music to children's games. In the present context I discuss only the case of literature. Works of literary fiction are, on the current account, regarded as props as they prompt the reader to imagine certain things. By doing so a fiction generates its own game of make-believe. This game can be played by a single player when reading the work or by a group when someone tells the story to the others.

Some rules of generation are *ad hoc*, for instance when a group of children spontaneously imposes the rule that stumps are bears and play the game "catch the bear". Other rules are publicly agreed on and hence (at least relatively) stable. Games based on public rules are "authorized"; games involving *ad hoc* rules are "unauthorized".

By definition, a prop is a *representation* if it is a prop in an authorised game. On this view, then, stumps are not representations of bears because the rule to regard stumps as bears is an *ad hoc* rule. By contrast, *The Old Man and the Sea* is a representation because everybody who understands English is invited to imagine its content, and this has been so since the work came into existence. "Representation" is used as a technical term in PT. Representations are not, as is customary, explained in terms of their relation (e.g., resemblance or denotation) to something beyond themselves; representations are things that possess the social function of serving as props in authorised games of make-believe (I will come back to this point in Section IV).

Props generate fictional truths by virtue of their features and principles of generation. Fictional truths can be generated directly or indirectly; directly generated truths are *primary* and indirectly generated truths are *implied*. The intuitive idea is that primary truths follow immediately from the prop, while implied truths result from the application of some rules of inference. One can then call the principles of generation that generate primary truths *principles of direct generation* and those that generate implied truths *principles of indirect generation*.

This distinction can be seen in action in literary fiction. As we have seen in Section I, the reader of Hemingway's *The Old Man and the Sea* reads that Santiago is a Cuban fisherman who has gone 84 days without catching a fish. These are primary truths that the reader is mandated to imagine because they are explicitly stated in the text. The reader should also imagine that Santiago was involved in an epic struggle, that he was determined and relentless, and that he has a heart and a liver. None of this is explicitly stated in the story. These are inferred truths, which readers deduce from the text given their background knowledge about human psychology and anatomy.[6]

PT has the resources to flesh out the idea that models are like the characters and places of literary fiction and to answer our five questions about models. Models are usually presented to us by way of descriptions, which we earlier called "model descriptions". These descriptions should be understood as props in games of make-believe. This squares with the practice of modelling where model-descriptions often begin with "consider", "assume", or "imagine", which make it explicit that the descriptions to follow are not intended to be descriptions of real-world objects but should be understood as a prescription to imagine a particular situation. Although it is often understood that the situation is such that it does not occur anywhere in reality, this is *not* a prerequisite in PT. We will come back to this point later.

Let us begin by discussing truth in fiction, which will provide an answer to our first question in Section II. I here focus on so-called intra-fictional statements, that is, statements like "Santiago is Cuban fisherman" that are made within the fiction.[7] Such statements are not meant to be believed; they are meant to be imagined. Although some statements are true in the fiction as well as true *tout court* ("Cuba is in the Caribbean" is true and true in Hemingway's story), we often qualify false statements as true in the fiction ("Santiago is a fisherman" is true in the fiction but false because there is no Santiago) and true statements as false in the fiction ("Cuba is governed by a communist regime" is true but false in the story, whose plot takes place before the revolution).[8] So truth and truth in fiction are not only distinct notions; they are also not coextensive. Walton goes as far as saying that truth in fiction is not a species of truth at all (1990, p. 41). While I see no harm in using the moniker "truth in fiction", I here follow Walton and replace locutions like "true in the fiction" or "true in a fictional world" by the term of art "being fictional", and I use the shorthand "$F_w(p)$" for "it is fictional in work w that p", where p is a placeholder for an intra-fictional statement.

We can now define $F_w(p)$. Let the w-game of make-believe be the game of make-believe based on work w and similarly for "w-prop" and "w-principles of generation". Then, p is fictional in w iff p is to be imagined in the w-game of make-believe (1990, p. 39), or, in more detail: $F_w(p)$ iff the w-prop together with the w-principles of generation prescribes p to be imagined. Nothing in this definition depends on w being a work of literature, and so this definition equally applies to scientific contexts. We can take w to be Newton's work on planetary motion. The description of the Newtonian model (which we have seen in Section I) is the w-prop and the general principles taken to be in operation in this context, including Newton's law of motion, are the w-principles of generation. The statement "model-planets move in elliptical orbits" is then fictional in the Netwonian game of make-believe because the w-prop together with the w-principles of generation prescribes participants to imagine model-planets as moving in elliptical orbits.

The definition alleviates two worries. The first worry concerns the alleged subjectivity of imaginings. Imagination, one might argue, is a private activity and everybody's imagination is different. Therefore, an understanding of models as imaginings makes them subjective because every person imagines something different. This is not so. PT regards imaginings in an authorised game of make-believe as sanctioned by the prop itself and the rules of generation, both of which are publicly shared by the relevant community. If someone plays a game of make-believe, their imaginings are governed by intersubjective rules and these rules force everybody involved in the game to have the same imaginings.[9] Furthermore, for a proposition to be fictional in work w it is not necessary that it is actually imagined by anyone: fictional propositions are ones for which there is a prescription to the effect that they *have to be imagined*, and whether a proposition is to be imagined is determined by the prop and the rules of generation. Hence, props, via the rules of generation, make propositions fictional independently of people's *actual* imaginings, and for this reason there can be fictional truths that no one knows of.

The other worry concerns the point mentioned in the second motivation in Section I, namely that the fiction view regards models as falsities. As we have just seen, being true and being fictional are different concepts, which, crucially, are not mutually exclusive. A statement can be fictional while at the same time also being true ("Cuba is in the Caribbean"). Therefore, an understanding of models as fiction does *not* force the absurd view on us that all models must be regarded as false. The view simply leaves the question of truth open, and this is how it should be. Models are often proposed as a suggestion worth considering, and their exact relation to reality is worked out once the model is understood. This is particularly palpable in elementary particle physics, where a particular scenario is often proposed simply as a suggestion worth exploring and only later, when all the details of the model are worked out, the question is asked whether the particles in the model actually exist. We are neither committed to regarding these particles as non-existent simply because they appear in a model; nor should we accept them as real because of some foot-stomping insistence that "science deals with reality!". The question whether the particles exist is answered experimentally, usually at large research facility like CERN, and this is how it should be.

This take on truth in fiction – or fictionality – also provides us with an answer to the question about the epistemology of models: we investigate a model by finding out what follows from the primary truths of the model and the rules of indirect generation, where these rules will include general principles and laws of nature that are taken to be in operation in the context in which the model is used. For instance, we derive that the planets move in elliptical orbits from the basic assumptions of the Newtonian model and the laws of classical mechanics. This is explained naturally in terms of pretence theory. What is explicitly stated in a model-description are the primary truths of the model, and what follows from them via laws or general principles are the implied truths.

To formulate identity conditions, we first introduce the notion of a "fictional world" or "world of a fiction": the world of work *w* is the set of all propositions that are fictional in *w*.[10] It is then natural to say that two models are identical iff the worlds of the two models are identical. Note that this condition does not say that models are identical if the model-descriptions have the same content. In fact, two models with the same model-descriptions (the same prop) *can* be different because different rules of generation are assumed to be in operation. This is the case, for instance, when what might look like "the same model" is treated first classically and then quantum mechanically. A common model-description of a model of a hydrogen atom is to say that the model consists of an electron and a proton that attract each other with a Coulomb force. If we assume that the laws of classical mechanics serve as the principles of generation in the model, we get the Bohr model and it is true in the Bohr model that electrons move in precisely defined trajectories. If we assume that the laws of quantum mechanics serve as the principles of generation in the model, we get the Schrödinger model of the atom and it is false in the model that electrons move in precisely defined trajectories. Regarding these as different models despite being based on the same model-description is the right verdict.

The attribution of a property *P* to a model is explained as it being fictional in the world of the model that the model has *P*. To say that the model-planet moves in an elliptical orbit is like saying that Santiago is a fisherman. Both claims follow from a prop together with rules of generation. In other words, saying that a hypothetical entity possesses certain properties involves nothing over and above saying that within a certain game of make-believe we are mandated to imagine the entity as having these properties. For this reason, there is nothing mysterious about ascribing concrete properties (like flowing regularly) to non-existent things, nor is it a category mistake to do so.

Comparisons are more involved. The problem is that comparing a model either with another model or with a real-world object involves elements that are not part of the authorised game of make-believe and hence are not covered by it. How to best overcome this problem is a matter of some controversy, and different suggestions have been made. Walton's suggestion is that we devise an unauthorised game of make-believe to make such comparisons, one that contains the constituents of both models, or the model and the real object, and then carry out comparisons within that extended game of make-believe. I recommend that we run with this suggestion.

We have now seen how PT answers the five problems concerning models that we formulated in Section II. But some readers be left wondering: where is the model? The proposed account has a large number of moving parts, and it is not obvious which of them, if any, should be called "the model". Different versions of the fiction view give different answers, which also leads to different ontological commitments. In my original formulation of the view (Frigg, 2010c), I took models to be the imaginings that scientists have when they are involved in the game of make-believe. This is a firmly antirealist view according to which models don't exist: they are figments of the imagination. Salis (2019) argues that this is too minimal a notion of models and submits that a model should be regarded as a complex object composed of a model-description together with the model-description's content (generated by both the rules of direct and indirect generation). On this view models exist, at least in as far as texts and their content exist.

If our aim is to understand the internal workings of models not much depends on how this issue is resolved. It becomes relevant mostly when the fiction view is combined with a theory of representation (which is the project for the next section). Many accounts of representation involve the notion that models denote their target systems. Denotation is a dyadic relation between certain symbols and certain objects. But relations can obtain only between two things that exist. Hence an antirealist view of models undercuts the possibility of models denoting targets and antirealists will have to resort to the notion that models have pretend denotation rather than "real" denotation. If one insists on real denotation, then the model has to exist and Salis's version of the fiction view makes this possible.[11]

How does the PT version of the fiction view of models fare as regards our two requirements? I submit that it scores high for being able to account for how models are employed in scientific practice. Specifying basic assumptions and studying their consequences when combined with general principles like laws of nature seems to be exactly what scientists do when they investigate a model. So, the fiction view is in line with scientific practice.

What ontological commitments are incurred depends on which version of the fiction view is adopted. As we have just seen, the original version of the view incurs no commitments while Salis's version is committed to the existence of texts and their content. What matters is that at no point in the argument is the account forced to introduce fictional or abstract entities into its ontology. An expedition into Meinong's jungle can be avoided. This does of course not mean that the expedition must be avoided. Those who see virtue in the introduction of such entities into the fiction view are free to do so; the observation at this point is only that introducing such entities is not forced on us by the internal requirements of the view, and that's a good thing.[12]

IV. How Models Represent: The DEKI Account

As mentioned in the previous section, pretence theory *defines* a representation as a prop in an authorised game of make-believe. On this view, the text of a novel and a model-description are representations. While this is not an implausible use of the term "representation", the term usually has a different meaning in both science and philosophy of science where it designates the relation between a model and its target. But far from being in conflict with each other, these two notions of representation are actually complementary. However, we have to be careful not to get them mixed up, and for this reason I call the former "p-representation" ("p" for 'prop') and the latter "t-representation" ("t" for target).[13] Using this idiom, PT provides an analysis of p-representation. This leaves the task of articulating an account of t-representation. This is the project for this section.

In principle the fiction view can be combined with any account of representation, and there is a whole array of options on the market. My own preferred option is the DEKI account, and so I will spell out briefly how this account works in conjunction with the fiction view of models as developed in the previous section.[14] The name of the account derives from its four core features: denotation, exemplification, keying up, and imputation. We will now go through these and explicate how they work in tandem with the fiction view.

Models are representations of something. Newton's model is a representation of (parts of) the solar system; Bohr's model is representation of the hydrogen atom; and so on. For a model to be a *representation of* a target, it has to denote the target. This is Goodman's point when he notes that denotation is "the core of representation" (1976, p. 5). To distinguish something being a representation of something from other forms of representation we introduce the locution "representation-of".

Not every representation is a representation-of. A picture showing a dragon is not a representation-of a dragon because things that don't exist can't be denoted (and I take it that there no dragons). Yet, there is a sense in which such a picture is a representation – after all it *shows* a dragon. Goodman and Elgin's solution to this conundrum is to distinguish between being a representation-of something and being a something-representation (Goodman, 1976, pp. 21–26; Elgin, 2010, pp. 1–2). A picture showing a dragon is a dragon-representation, but it is *not* a representation-of a dragon. Generally, something is a *Z*-representation if it portrays a *Z*. Crucially, a symbol being a *Z*-representation does not imply it also being representation-of *Z*, and vice versa. The word "Spetses" denotes an island (and hence is a representation-of Spetses), but it is not an island-representation. Vice versa, a seventeenth-century drawing may be an Atlantis-representation, but it cannot be a representation-of Atlantis because Atlantis does not exist. This does not preclude the notions to go hand in hand in some cases: a portrait of Beethoven is both a man-representation and representation of a man. The point here is that there is no necessary connection between being a *Z*-representation and being a representation of a *Z*, nor are the two notions coextensive for some other reason.

This raises the question of what turns something into a *Z*-representation. What, for instance, turns a canvas covered with pigments into a dragon-representation? In the context of pictures this is a much-discussed question. Perceptual accounts argue that a picture is a *Z*-representation if, under normal conditions, an observer sees a *Z* in the picture (Lopes, 2004). Goodman and Elgin analyse *Z*-representation in terms of a picture belonging to a certain genre (Elgin, 2010, pp. 2–3; Goodman, 1976, p. 23). Whatever the merits of these accounts in the context of visual representation, neither of them is helpful when dealing with scientific models. The DEKI account submits that what turns a model into a Z-representation is an act of interpretation by a model user: we *interpret* the objects that constitute the model in terms of Z. Newton's model consists of two perfect spheres with a homogenous mass distribution that attract each other with a $1/r^2$ force law. What turns this assemblage into a solar-system-representation is that scientists working with the model interpret the large sphere as the sun, the small sphere as the earth, and the $1/r^2$ force law as gravity. Likewise, Boltzmann's imaginary collection of billiard balls becomes a gas-representation when we interpret billiard balls as gas molecules; Schelling's imagined checkerboard becomes as social-segregation-representation when we interpret the squares as locations in a city; and so on.

The "E" in "DEKI" stands for exemplification. Something exemplifies a property if it at once instantiates the property and refers to it. As Goodman puts it: "Exemplification is possession plus reference. To have without symbolising is merely to possess, while to symbolise without having is to refer in some other way than by exemplifying" (Goodman, 1976, p. 53). Samples are straightforward examples of items that represent by exemplification. The chip of paint on a manufacturer's sample card instantiates a certain colour and at the same time refers to that colour (Elgin, 1983, p. 71).

But what does it mean to say that a model has a property if the model is not a physical object? Recall that in the last section we said that property attribution in models was analysed within PT: a non-material model instantiates a property P iff it is fictional in the world of the model that the model has P. To say, for instance, that model-planets attract each other is like saying that Santiago navigates a boat. Exemplification does not require a metaphysically "thick" notion of instantiation and pretend instantiation is all that is needed for exemplification.

Exemplification is selective in that not every property that is instantiated by an object is exemplified by it. The chip of paint, for example, does not exemplify its shape. In order to exemplify a property, an object must both instantiate the property and the property itself must be made salient. How saliency is established will be determined on a case-by-case basis, depending on context and epistemic interest of the users of a representation.

We can now introduce the notion of representation-as. We encounter this mode of representation in caricatures, where we see, for instance, Margaret Thatcher represented as boxer or Winston Churchill as a bulldog. The grammar of the concept is that an object X represents a subject T as being a Z. With the tools developed so far we can define representation-as in the following way: X represents T as Z if, and only if, (i) X denotes T (i.e., X is a representation-of T), (ii) X is a Z-representation exemplifying certain properties associated with Z, and (iii) X imputes these properties, or related ones, to T (Elgin, 2010, p. 10).

Scientific representation is representation as, and the "I" in "DEKI" stands for "imputation". But to make the basic idea tick in the context of scientific representation, a fourth element needs to be added. Condition (iii) of the definition of representation-as says that *X* imputes certain properties, *or related* ones, to *T*. The reason for adding this qualification is that the properties exemplified by a scientific model and the properties imputed to its target system need not be identical. In fact, few models portray their targets as exhibiting *exactly* the same features as the model itself. Newton's model, for instance, does not impute to the solar system that planets are perfect spheres and that they move in exact ellipses. It imputes the related properties that planets are roughly spherical and that their trajectories are elliptical to a certain degree of approximation. Invoking the notion of a "related" property is not wrong, but it lacks specificity. Any property can be related to any other property in some way or other, and as long as no particular relation is specified it remains unclear which properties are imputed onto the system.

Precision can be added to the account by building a specification of the relationship between model properties and target properties directly into an account of t-representation. Such a specification is given by a *key*, which is the "K" in "DEKI". A key in effect translates one set of properties (the ones exemplified by the model) into another set of properties (the ones imputed to the target). This key can, but need not, be identity; any rule that associates a unique set of properties ready to be imputed to the target with the properties exemplified by the model can in principle do the job. The relevant clause in the definition of representation-as then becomes: *X* exemplifies one set of properties and imputes another set of properties to *T* where the two sets of properties are connected to each other by a key.

Maps provide an intuitive example. The exemplified "model property" is the measured distance on the map between the point labelled "Rome" and the point labelled "London"; the imputation property is the distance between Rome and London; and the key is the scale of the map. The key allows us to translate the property of the map (the distance between the two dots being 18cm) into a property of the world (the distance between Rome and London being 1800km). The keys used in scientific models are often more complicated than the scale of a map and involve idealisations, approximations, and analogies, but they perform the same function.

Pulling together the different elements we have introduced so far furnishes the sought-after analysis of t-representation. Consider an Agent *A*. The agent chooses an object and turns it into a *Z*-representation by adopting an interpretation. The model *M* is the package of the object together with the interpretation that turns it into a *Z*-representation. Model *M* then t-represents target *T* iff (i) *M* denotes *T* (and, possibly, parts of *M* denote parts of *T*); (ii) *M* is a *Z*-representation exemplifying certain *Z*-properties; (iii) *M* comes with a key *K* specifying how the

Z-properties exemplified in the model translate into other properties, and (iv) *M* imputes at least one of these other properties to *T*. This is the DEKI account of representation.

The formulation of the account speaks of an "object". If the model is a material model, this is to be taken literally because it is a physical object that figures in the account. If the model is non-material, the "object" is an imagined "object" of the kind introduced in PT. The relevant "objects" in the Newtonian model are the two perfect spheres. They have no physical existence; they are imagined. But that's enough. We can interpret them as the sun and the earth in our imagination, and they can have all kinds of properties in the sense explicated in the last sections, as well as exemplify them. And neither the key nor the act of imputation depends on whether the model is material or imagined.

V. Conclusion

We have seen how the DEKI account of representation and the fiction view of models converge: the DEKI account explains how the features of a model figure in scientific representation, and the fiction view – fleshed out in terms of games of make-believe – furnishes a notion of fiction that explains how models can be said to have the properties that provide the input to the DEKI machinery. Together the DEKI account and the fiction view provide a complete account of what models are and of how they represent.

Notes

1. The fiction view can also be given a linguistic formulation: if the passages that describe models do not describe ordinary physical situations even though they appear to do so, then what, if anything, do these passages describe? Thomson-Jones (2010, p. 284) refers to model-descriptions of the kind we have just seen as "descriptions of a missing system". These descriptions are embedded in what he calls the "face value practice": the practice of talking and thinking about these systems as if they were real systems. The fiction view of models then is the proposition that model-descriptions function like the text of a work of literature.
2. I here discuss my own response to the challenge as originally articulated in my (2010a, 2010b, 2010c) and later developed in Salis and Frigg's (2020), Frigg and Nguyen's (2016, 2020, chs. 6 and 9), and Salis et al. (2020). I concentrate on the development of a positive view and by and large set aside criticisms of the view. For an extensive discussion of, and a response to, criticisms of the fiction view, see Frigg and Nguyen's (2021). Alternative ways of articulating the analogy between models and fiction can be found in Barberousse and Ludwig's (2009), Contessa's (2010), Godfrey-Smith's (2009), Levy's (2012, 2015), and Toon's (2010a, 2010b, 2012), as well as in a number of the contributions to Levy and Godfrey-Smith's (2020).
3. This is one of the important points in Walton's (1990), and we will come back to it in Section III.

4. For an extensive discussion of this point, see Frigg and Nguyen's (2020, ch. 6, 2021).
5. Strictly speaking, Walton (1990) restricts the use of "pretence" to verbal (or more generally behavioural) participation, which does not include the activity of someone reading on her own. However, it has become customary to use "pretence" as synonymous with "make-believe" and I stick to this wider use in what follows.
6. The distinction between primary and inferred truths is not always easy to draw, in particular when dealing with complex literary fiction. Walton also guards against simply associating primary truth with what is explicitly stated in the text and inferred ones with what follows from them (1990, ch. 4). For the purpose of the current discussion, which focusses on scientific models, these worries can be set aside.
7. Intra-fictional statements contrast with transficational statements, which involve a comparison between characters in the fiction and something outside that fiction ("Santiago is more determined that any real fisherman"), and metafictional statements, which comment on the content of the fiction ("In Hemingways story, Santiago is determined").
8. I deviate from Walton at this point because Walton himself would say that sentences like "Santiago is a fisherman" express no proposition because since "Santiago" fails to refer (Walton, 1990, ch. 10). Friend (2011) and Salis (2013) criticise this position as being unable to distinguish between acts of pretence that seem to be about different fictional objects. I bypass this discussion and assume that sentences like "Santiago is a fisherman" have truth evaluable content, no matter how this content is eventually explicated.
9. As far as their participation in the game is concerned. Individual actors can also have further imaginings outside the game.
10. Fictional worlds thus defined are different from the possible worlds of modal logic, the most significant difference being that the former are incomplete while the latter are not.
11. For an extensive discussion of the issue of denotation see Salis et al. (2020).
12. For a discussion of recent versions of the fiction view that are hospitable to fictional entities see, for instance, Thomasson's (2020) and Thomson-Jones (2020).
13. A more intuitive choice of terminology would be to reserve the term "representation" for what I call t-representation and refer to p-representation as "presentation".
14. For a discussion of the different options see Frigg and Nguyen's (2020). The discussion of how the DEKI account is put to use in the context of the fiction view broadly follows Frigg and Nguyen's (2016). For a general statement of the DEKI account see Frigg and Nguyen's (2018), and for a discussion of how the account develops out of Goodman and Elgin's account of representation-as see Frigg and Nguyen's (2017). For a discussion of how mathematics is used in models see Nguyen and Frigg's (2017).

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