Models, Fictions and Artifacts

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Abstract

This paper discusses modeling from the artifactual perspective. The artifactual approach conceives models as *erotetic devices.* They are purpose-built systems of dependencies that are constrained in view of answering a pending scientific question, motivated by theoretical or empirical considerations. In treating models as artifacts, the artifactual approach is able to address the various languages of sciences that are overlooked by the traditional accounts that concentrate on the relationship of representation in an abstract and general manner. In contrast, the artifactual approach focuses on epistemic affordances of different kinds of external representational and other tools employed in model construction. In doing so, the artifactual account gives a unified treatment of different model types as it circumvents the tendency of the fictional and other representational approaches to separate model systems from their "model descriptions".

1. Models, representation and languages of science

Modeling is certainly the scientific practice that relies on the richest repertoire of diverse languages and representational vehicles: mathematical, computational, diagrammatic, and natural spoken and written languages, and concrete of objects of various kinds, spanning from material and digital 3D objects to various biological preparations. Moreover, the recent philosophical interest on representation has precisely been raised in the context of modeling. One would thus have expected the discussion of representation to address these various representational languages and other vehicles of model construction, but this has not been the case. The discussants have, instead, focused on the relationship of models to worldly target systems in a general and formal manner, the main issue being whether representation can be understood in terms of a similarity, isomorphism or some other kind of morphism (e.g. Suárez 2003, Frigg 2010, Bueno and Colyvan 2011, Chakravartty 2010). To be sure, especially the complexities of mathematical languages and their suitability for representing the world has been addressed in the discussion of representation. Yet even in these discussions the main goal has still been that of arguing for (or against) the structuralist/semantic conception that approaches representation through mappings between model and a target system (Bueno and French 2011, Pincock 2004).

In addressing the role different representational languages and tools play in modeling, I will leave the aforementioned discussion of scientific representation aside, concentrating instead on two novel approaches that aim to give a more fully-blown account of modeling. The first one of them, the DEKI account (e.g. Frigg and Nguyen 2016, 2017), still attempts to tackle the problem of model-based representation head-on, but it also recognizes the different kinds of models, aiming to treat both concrete and nonconcrete models in a unified manner. In contrast, the other approach, the artifactual account seeks to bypass the problem of accounting for the representation relationship, focusing on the epistemic uses of various representational tools.

I will argue that despite its unificatory aims the DEKI-account treats nonconcrete and concrete models non-symmetrically. It supposes that in the case concrete models – e.g. scale models and other physical models – the physical object is the model, whereas in the case of nonconcrete models – e.g. mathematical models – the model is an imagined-object rendered with a model description. The problem with this account is that in distinguishing imagined systems from the model descriptions conveying them, Frigg and Nguyen leave unexplained how scientists' imaginings are related to the enablings of different kinds of representational tools, or coordinated among different scientists, and with real-world phenomena.

I will argue for the artifactual alternative that treats models as purposefully created epistemic tools that are constructed for the study of certain scientific problems. The artifactual account puts languages of science on the center stage. It addresses the actual representational tools that are used in model construction highlighting their epistemic functioning: how they enable, shape and delimit scientific reasoning and imagination. The artifactual account is able to give a unified account of the wide variety of different kinds of models; it treats them as entities with both abstract and concrete dimensions, realized in different representational modes and media.

In what follows, I will first discuss Roman Frigg's and James Nguyen's DEKI account of representation (Section 2) and its philosophical critique (Section 3). I will then introduce the artifactual account of models (Section 4).

2. The DEKI account of model-based representation

Frigg and Nguyen's DEKI account is an elaborate construction weaving Nelson Goodman's (1976) and Catherine Elgin's (e.g. 2004) theory of pictorial representation together with Kendall Walton's theory of make-believe (1990). Frigg and Nguyen develop the DEKI-account from a case of a concrete vehicle. Following the philosophical tradition, their prototypical model is a three-dimensional object with some distinct properties. Frigg and Nguyen call this object a "base", or an "O-object", where "O" specifies what kind of a thing an object is. In line with the pragmatic view of representation, such an object becomes a representation first when an agent chooses to *use* it to represent something. Central for Frigg and Nguyen's account is the idea of *representation-as* that they derive from Goodman and Elgin. An object may be used to represent something as something else, thereby becoming a Z-representation (e.g. Elgin 2010). For instance, there is a genre of caricatures representing Winston Churchill as a bulldog. In this case, an O-object, a picture of Churchill, is interpreted as a Z-representation (a bulldog-representation) becoming thereby a vehicle of representation.

The DEKI-account of representation refers to the notions of *denotation, exemplification, imputation,* and *keying* up. In order to represent, a vehicle has to both denote a target system and exemplify some properties, *imputing* those properties or related ones to a target system. However, the properties exemplified by a model cannot usually be directly imputed to some target as the model and the target are usually very different kinds of things. A *key* is needed to translate the properties exemplified by the representational vehicle into properties of a target system. Frigg and Nguyen (2018) analyze Phillips-Newlyn hydraulic model of macroeconomy that is a concrete object consisting of pipes and reservoirs with water flowing through it. This example shows material machine can, under interpretation, exemplify some features to be imputed to actual economies, e.g. stocks and flows of commodities (Frigg and Nguyen 2018).

In the case of mathematical models there seems not to be any concrete object doing the representing, and so Frigg and Nguyen treat them as fictional constructs, imagined-objecs:

> Nonconcrete models are typically presented through descriptions, portraying things like spherical planets and immortal rabbits. We call these descriptions *model descriptions*. This gives us the essential clue: model descriptions are like the text of a novel: they are props in games of make-believe. (Frigg and Nguyen 2016, 237)

The notion of a prop and make-believe are adopted from Kendall Walton's theory of mimesis as make-believe (Walton 1990). One attractive feature of Waltons' account is its solution to the problem concerning the ontological status of fictional entities: there are no such things as fictional entities, only pretense. From this perspective, fictional stories merely *pretend* to assert something about real people and places. The fictional characters, and the literary works they inhabit, are just props in the game of make-believe. And this applies to any other kinds of make-believe. Any thing that can affect our senses and is furthermore subject to a "principle of generation" can function as a prop in a game of make-believe – like toys in children's games (Walton 1990, 38).

In scientific modeling, it is *model descriptions* that function as props that prompt scientists to imagine a model system. The model system is an imagined-object that due to the principles of generation "can have properties that have not been written into the original model description" (Frigg and Nguyen 2016, 237). Consequently, the imagined-objects inhabiting scientists' minds are, according to Frigg and Nguyen, richer than what can be read from the model descriptions alone. Such richness derives from the way the model description, combined with principles of generation, creates a an imagined-object. The imagined object can then have some pretended properties, i.e. it is fictional in the model that the imagined-object has such properties. Imagination is not free from constraints, however. The game of make-believe constrains imagination due to facts about the props and the principles of generation. Nguyen and Frigg do not say too much about how this is supposed to happen, they merely mention that principles of generation involve "background theories" (2016, 11) About model descriptions they also have little to say but they notice that "mathematics can enter models in two places: in the model description and in the rules of generation" (15). These sparse remarks are not that surprising given that Frigg and Nguyen's focus is on the imagined-object, which they consider as the vehicle of representation: "By mandating those involved in a certain game to imagine certain things, the model description generates the imagined-object that serves as the vehicle X of a representation as." (2016, 13). But the critics have been skeptical of positing such intermediate fictional entities (e.g., Toon 2012, Weisberg 2013, Levy 2015).

3. Some problems of imagined-objects

Levy (2015) and Toon (2012) argue against the fictionalist retour through unobservable imagined objects. Levy argues that such objects "by virtue of their non-actuality, […] are not the kinds of things we can observe and come into contact with" (784-785).[1] Instead of such indirect approaches Toon and

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[1] He levels the same kind of critique also against the approaches that take models to be abstract objects (Weisberg 2013, Giere 1988).

Levy prefer what they call "direct approaches to representation". Somewhat surprisingly, however, they are also making use of Walton's make-believe in order to account for the idealized and simplified nature of scientific modeling. They consider models as "imaginative descriptions of real-world phenomena" (Levy 2015, 797) that "prescribe us to imagine things about the actual system" (Toon 2011, 308). But this approach has difficulties with models that do not have real world-targets, or models with general targets (see e.g. Frigg and Nguyen 2017, 109-112). Perhaps the biggest problem of their direct make-believe construal is its inability to account for how models enable surrogative reasoning. This seems unnecessary a sacrifice as surrogative reasoning is generally considered as central for many modeling practices. But Toon's and Levy's criticism does not actually concern indirect approaches per se, but rather the way they postulate fictional (or abstract) entities that lack sensuous qualities. The question is how can imagined-objects – being mental phenomena (see Frigg 2010), and as such not intersubjectively available – act as vehicles of surrogative reasoning in such a collective endeavor as science. At least three issues seem to appear.

First, if fictions are analyzed in terms of the pretense theory, it becomes a problem how these imagined-objects are related to real-world objects and systems. Since an imagined-object is strictly speaking non-existent, its features are uninstantiated that makes any comparisons to the real world objects difficult. It is not clear why the uninstantiated properties of imagined objects should be less problematical than those objects themselves (whose ontological status the pretense account was designed to solve)?[2] It is difficult enough to explain how external representations can stand for and bring knowledge about real-world systems, and so to ask the same question about the imaginings of the scientists seems even more challenging. Moreover, this question seems to lead us from philosophy of science to the realm of cognitive science – and the thorny issues of mental representation. Frigg and Nguyen do not try to solve this problem. They simply mention that the DEKI account of representation does not "require comparative claims" and refer to Salis' (2016) proposal of how model-world comparisons could be made.

Second, the problem concerning the relationship between model descriptions and imagined-objects is no less taxing especially as Frigg and Nguyen (2016, 2017) do not explain how model descriptions combined with principles of generation generate richer imaginary worlds in the minds of scientists. Presumably, they think that this cannot be a problem philosophy of science needs to address, since it is an everyday phenomenon in how literature is being received. Yet the problem is central for philosophy of science as the changes in the mathematical representation of a model frequently alter

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[2] See Godfrey-Smith 2009 for discussion.

many of its epistemically relevant properties. Weisberg (2013) highlights this shortcoming of the fictional account. A case in point is provided by his analysis of the Lotka–Volterra model, and what difference it makes when the model is presented in individual based methods in contrast to ordinary differential equations (Weisberg and Reisman 2008). A fictionalist might want to claim that the two different mathematical representations describe the same imagined system, especially as one of the benefits of the fictional approach is that of maintaining the identity of the model system under different descriptions (e.g. Frigg 2010, 256, Frigg and Nguyen 2016, 231). Yet, if it is the fictional system that is supposed to represent, or resemble, the target system, the epistemic consequences of using different, mathematical, or computational modeling methods are left without recognition.

Finally, there is the problem of how the imaginings of different scientists are supposed to be coordinated. In his criticism of the fictional accounts, Weisberg (2013) also addresses the variation in the imaginings of individual scientists. Even if the problem of comparing the features of imaginary systems to the real-world systems were solved, how can we ascertain that we are dealing with the features of the same imagined-objects.[3] Frigg suggest that "[a]s long as the rules [of a particular game of make-believe] are respected, everybody involved in the game has the same imaginings" (2010, 264). But this solution does not recognize that what *is* intersubjectively available to scientists are the representational tools (i.e. "model descriptions") with which models are constructed and whose properties, in the modeled configuration, modelers are studying. The rules and norms concern the use and interpretation of these external representations, in particular scientific contexts, in which the background knowledge is embedded.

The question is, what is the philosophical added value of invoking additional imagined-objects? What kind of rules of generation, over and above the ones concerning the use of shared external representational means, in some specific contexts of use, are needed to understand modeling practices? Moreover, it does seem that the ascent from model descriptions to imagined-objects tends to set aside important aspects of scientific work. For instance, modelers pay a lot of attention to the particular mathematical abstractions they are using, and to the modeling choices due to approximations and tractability. Yet these choices and their justification tend to get ignored if the focus is on pretend properties of imagined-objects. And what about model systems, whose workings cannot be imagined or understood? How are we to ascribe fictional features to computational models, whose computational processes are quite opaque to human mind? It is difficult if not impossible to mentally simulate the

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[3] Weisberg also points out the variation in the imagining abilities of scientists. Individuals are likely to vary in this respect.

dynamic of interactions in non-linear complex systems, or imagine probabilistic or high-dimensional models. This is precisely one of the most important reasons for why these models are so indispensable tools for scientific practice.

The aforementioned problems are due to the way the fictional account of modeling sets apart model descriptions and imagined-objects, locating the most important epistemic role to the latter.[4] While the question of representation is already difficult one to tackle on its own, the reliance of the DEKI account on imagined-objects in the case of nonconcrete models makes the question even more complex. Moreover, making imagined-objects the locus of representation largely ignores how humans are able to creatively extend their cognitive capabilities by developing and using an ever expanding and diversifying array of representational and computational tools. The cognitive sciences have accumulated abundant evidence on how different representational tools are crucial for our cognitive accomplishments, studied within diverse approaches such as extended, distributed and enactive cognition (e.g. Clark 2008, Hutchins 1995). Zhang (1997) presented an important early experimental study on how particular representational devices facilitate reasoning. He showed that the same abstract structures conveyed by different representational devices have different enablings for human reasoning. Vorms (2011) argues essentially for the same point using scientific examples. She demonstrates how theoretical representations that are identical from the formal and empirical point of view can nevertheless expedite different kinds of inferences.

To conclude, the problem of the DEKI account when it comes to “nonconcrete models” is not due to its indirectness but rather its reliance on the supposed representational abilities of imagined-objects. To understand the contemporary modeling practice, it seems important to make room for surrogate reasoning and also for the modal nature of modeling. One of the main motivations of engaging in modeling is the exploration of various possibilities, and hypothetical or imaginary scenarios. In the following, I will present an artifactual alternative to the DEKI-account that can, as well, accommodate the surrogate reasoning, and address the modal dimension of modeling.

The artifactual approach differs from the representational accounts of modeling in not supposing that models give us knowledge in virtue of representing some actual target systems more or less accurately. However, the artifactual approach is not incompatible with the DEKI account of

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[4] Godfrey-Smith (2006, 2009) has also put forth a fictional account that relies on the distinction between model systems and model descriptions. Knuuttila (2017) and Salis (2019) have recently argued, though approaching scientific models from different perspectives that model descriptions should be considered as parts of models.

representation, apart from two important respects. First, the artifactual approach does not divide models into concrete and nonconcrete models, the latter having no objective existence of their own (apart from the imaginings of the scientists). Instead, the artifactual account treats also mathematical models as objects that are susceptible to manipulation, although the representational media used plays a different epistemic role in mathematical modeling than in scale modeling, for example. Second, in considering scientific models as concretely embedded intersubjectively available objects, the artifactual approach does not set apart "model descriptions" from the (fictional or abstract) content they convey. The representational tools used in model construction are envisaged as inseparable ingredients of a model.

4. The Artifactual Account of Models

From the artifactual perspective models are like any other artifacts in that they are human-made, or altered objects intentionally produced and used for some purposes within the sphere of particular human activities (e.g. Knuuttila 2005, 2011, 2017). They are concretely constructed things, making use of various representational tools and material media. As artifacts they are constructed for certain purposes, although they may also be repurposed to other uses. In scientific research such purposes are many: explanation, exploration, prediction, experimental design, didactic uses etc. Of these uses the philosophy of science discussion has mainly been interested in the epistemic ones, supposing that in order to give us knowledge, or explain, models need to be able to represent their actual target systems. While this assumption has often seemed too obvious to even be questioned, giving an account of representation has proved difficult and contested (e.g. French and Ladyman 1999, Suárez 2003, Frigg 2010).

The DEKI account is perhaps the most developed – and, to be sure, the most convoluted – attempt to analyze scientific representation. Apart from the problems concerning imagined-objects, it is plagued by the same problem as many other accounts of representation, except for the most deflationary ones: it assumes too much to be known. Representational relation is accomplished by imputing the properties of the model system to the target system according to a key. But where does the key come from, and how are we to articulate the target such that keying up becomes possible in the first place? I do not wish to contest the possibility of keying up per se, but simply to point out that for such a translation from the properties of the model to the features of the target system to succeed, a lot of epistemic work has already been done. The question is how this is being accomplished. It seems that modeling plays an important part in such exploration, and so a clue to the epistemic functioning of models can be found from the processes of constructing and using them. [5]

The volume *Models as Mediators* (Morgan and Morrison 1999) was crucial in shifting the philosophical interest on models towards the practice of modeling. The focal point of the analysis of Morrison and Morgan (1999) is on how scientists *learn* by building and manipulating models. This constructive and interventional side of modeling is central for the artifactual approach. It highlights how scientists gain knowledge through articulating and working with the different relationships built into the model – instead of supposing that *the* route to knowledge is through (at least) partially accurate reproduction of the actual state of affairs in the world. In contrast, models as external artifacts allow an epistemic access to many theoretical and empirical problems by enabling various inferences (Suárez 2004), providing new results, and, as a consequence, possessing considerable modal reach (Godfrey-Smith 2006). The important thing to note is that for a model to be manipulable and experimentable, and able to be communicated, it has to have an intersubjectively available concrete embodiment.

For understanding the epistemic functioning of modeling, then, the concrete embodiment of a model needs to be considered as an integral part of it, and not just a "model description". The artifactual account approaches this concrete dimension of modeling through the distinction between representational mode and media (e.g. Kress and van Leeuwen 2001). The epistemic importance of material embodiment is obvious in the case of physical models but it also applies to mathematical and other "nonconcrete" or abstract models. The point is that depending on the type of a model, its concrete implementation by available representational tools and materials plays different epistemic roles. This is what the distinction between representational mode and media aims to pinpoint.

4.1 Representational modes and media

One of the most conspicuous features of the contemporary modeling practice is the amazing variety of representational tools it makes use of. It is somewhat ironical that in its fixation on the representational relation between a model and its target system, the representational approach does not consider the actual representational devices that scientists use in model construction. To get a firmer grip on the epistemic functioning of different kinds of representational vehicles, representational mode needs to be distinguished from representational media. The *representational mode* refers to the different symbolic or semiotic devices (pictorial, linguistic, mathematical, diagrammatic etc.) with which various

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[5] For explorative modeling, see Gelfert 2016.

meanings or contents can be expressed. Such representational modes are embedded in *representational media* that encompasses the material means with which representations are produced (such as ink in paper, a digital computer, biological substrata and so forth). For instance, natural language is a representational mode that can be realized by different media, either as speech or as writing (Knuuttila 2011). In model construction and use, representational mode and media are often closely coupled, yet it is analytically useful to distinguish between them. The distinction enables a more unified treatment of different kinds of models. For example, the material embodiment of mathematical models is crucial for their manipulation, yet the concrete media plays a different, more prominent role in physical three-dimensional models than in mathematical modeling. Below, I will briefly discuss the representational modes and media in some different model types, ordered according to the degree of the importance of their concrete material dimension. It is important to note that all model types have both abstract/ "nonconcrete" and concrete dimensions, though in varying combinations.

i) Mathematical models

Highly idealized mathematical models provide the prototype for the fictional models in science. It appears less natural to speak about fiction in relation to diagrams or scale models, since they make use of the iconic, geometrical and material properties of the representational means in question. Yet on the artifactual account there is no in principle difference between these different model types, it is just that from the point of view scientific practice, representational modes and representational media, respectively, play different roles in their scientific uses (the representational mode and the representational media providing the two entangled dimensions of any representational means). In the case of mathematical modeling, the representational media is less important and the focus is on the representational mode. For instance, in mathematical modeling of genetic networks one can use different methods such as coupled ordinary differential equations (ODE), Boolean networks, and stochastic methods, all representing different mathematical representational modes. As for the representational media, it does not (usually) matter whether the media is chalkboard and chalk or whiteboard and erasable markers, for example. But the external scaffolding they provide for mathematical reasoning and imagination is nevertheless crucial for memorizing, manipulation, computing or demonstration.

ii) Computer simulations

The step from a mathematical model, e.g., ODEs, to a simulation model serves as an example of a change in representational mode. As the recent philosophical discussion of simulation has stressed, the discretized programmed equations of the simulation model stand in no straightforward relationship to the equations of the basic theoretical model. Another illustrative example of a change of representational mode is presented by Weisberg and Reisman (2008), who discuss the reconstruction of the Lotka–Volterra model (i.e., population-level ODE model) in the individual-based framework. This change of representational mode has epistemic consequences: population level models are simple and more tractable, but they do not provide the means to study local-level interactions between individual organisms.

As for the representational medium, there has been philosophical discussion of what role a material artifact, the digital computer, plays in simulation (see Parker 2009). Can simulations be considered basically immaterial or not? The majority of the discussants agree that the fact that computer simulations are implemented on a concrete device and thus involve physical processes, when run on it, provides them with a material status. But then the next question concerns the epistemic role of digital computers. Should we regard them as mere computational aids, as number-crunching devices, or does computational modeling introduce epistemic characteristics of its own? Humphreys (2009) is among those who claim it does: there are several features of simulation that distinguishes it from mathematical modeling, such as epistemic opacity and the dynamic temporal nature of computation.

iii) 3-D physical models

Consider two three-dimensional physical models both in which the flow of water plays a crucial epistemic role, the San Francisco Bay model and the Phillips–Newlyn machine. The San Francisco Bay model is a huge 1.5 acre model simulating the tidal and river action in the San Francisco Bay. The Phillips–Newlyn model is a 3-D hydraulic model of a macroeconomy in which colored water flows and accumulates in a system of tanks and channels. In the case of these two models the philosophical intuition seems not to find any problem in locating the model system: it is the concrete thing! For example, Weisberg (2013) proposes, among many others, that a mathematical model is an abstract structure, while a scale model is a concrete physical object. It then follows that in the case of mathematical models, the written equations, for instance, are so-called model descriptions, whereas in the case of San Francisco Bay model the technical drawings and pictures on it would qualify as model descriptions. From the perspective of the artifactual account this introduces an asymmetry in the way we approach mathematical models and so-called concrete models. If we consider the representational modes and media with which different models are constructed, then the written equations should be on par with various materials and artifacts that are used in *building* the 3-D scale model. The various technical drawings of the 3-D model are in turn more like a commentary accompanying a mathematical model in which the modeling decisions and assumptions made are discussed.

What then is the abstract – or nonconcrete – dimension of these 3-D physical models? Such abstract dimension is easier to pinpoint it in the case of the Phillips–Newlyn model, which embodies and renders visible economic ideas such as the principle of effective demand and the conceptualization of the economy in terms of stocks and flows (Morgan and Boumans 2004). As for the San Francisco Bay model, a lot of theoretical knowledge of various kinds was needed in its construction, yet it can more readily be seen as an imitation of the behavior of one particular target system. The model actually functioned as a concrete demonstration of the disastrous effects of the Reber dam plan that, as a result, was not undertaken (see Weisberg 2013).

iv) Biological model systems

Biological sciences use a host of models whose medium is biological, such as model organisms and laboratory populations. Among the newest inhabitants in this group are synthetic genetic networks that are engineered from genes and proteins. They are typically built by using mathematical models as kinds of blueprints. First, a mathematical model is constructed in order to study some hypothetical mechanism and its properties, and then, second, a gene regulatory network is engineered on the basis of the mathematical model and implemented in a host cell, frequently the *E. coli* bacteria. Knuuttila and Loettgers (e.g. Knuuttila and Loettgers 2013) have studied such synthetic genetic circuits from a philosophical perspective. The first and most famous of them, the repressilator, consists of a negative feedback loop of three genes that repress each others' expression. While the San Francisco Bay model partly shares the same material with its target system (e.g., water and its salinity), the repressilator is of the same materiality as naturally evolved genetic networks, functioning moreover under the same constraints as any other genetic circuits within the cell. The same materiality was crucial for its epistemic functioning: it was constructed to study whether some circuit designs from engineering, already extensively studied by mathematical modeling, could be realized also by biological organisms. Hence even though the material medium of the repressilator was biological it simultaneously embodied an abstract theoretical idea, the negative feedback loop. Here the conceptual theoretical idea merged with the material medium as the feedback loop was biologically implemented. It should also be pointed out that one goal of synthetic biology is to standardize biological parts such that they could then be combined in a multitude of ways to fulfill new functions (e.g. Endy 2005). This research program amounts to establishing a kind of biological language, for the purposes of which synthetic biologists have also been developing a Synthetic Biology Open Language. SBOL is composed of genetic vocabulary terms and graphics for the representation of possible biological designs.[6]

4.2 Constrained constitution and justification

The representational devices used in model construction provide scientist an access to the worldly systems, but for this access to be epistemically rewarding, the model has to be built in a particular way. The other side of the epistemic access that models provide is due to their constrained constitution. In order to give us knowledge, models need to be constructed in such a way that they enable scientists to study the questions they are interested in. Instead of conceiving models as representations, the artifactual account views them as *erotetic devices.* That is, they are approached as artificial systems of dependencies that are constrained in view of answering a pending scientific question, motivated by theoretical and/or empirical considerations. What this means is that models are always already embedded in our existing world knowledge, and not separate entities in need of connection to worldly systems by a relation of representation. Consequently, the epistemological puzzle of how the representational relationship between a model and the world should be analyzed becomes that of studying how the model construction facilitates the study of some pending scientific questions.

The idea of constraint is central for the philosophical discussion of idealization. It has addressed the constrained nature of models in two different ways. On the one hand, it has paid attention to how models are designed to isolate some relevant or difference making features of the target system by disregarding and/or distorting the rest (Strevens 2008, Cartwright 1999, Mäki 2011). On the other hand, it has been recognized that some idealizations are needed for tractability reasons and are entailed by the mathematical and statistical methods used (McMullin 1985, Rice 2018). In other words, the discussion of idealization has highlighted both the enabling and limiting aspects of the constrained character of models. Part of this simultaneously enabling and limiting nature of models can be directly attributed to the affordances and restraints of the representational tools used. Furthermore, representational tools

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[6] https://sbolstandard.org. Accessed 03.07.2020.

used go often hand in hand with the questions asked, or answers sought for. Modeling is typically both method-driven and outcome-oriented (Knuuttila and Loettgers 2017).

The Lotka-Volterra model provides a good example of the erotetic character of models, and its interplay with available representational tools. Volterra's version of the model is often traced back to the special characteristics of post-World War I fish populations in the Adriatic Sea, as if Volterra primarily sought to theoretically explain that particular phenomenon (e.g. Weisberg 2007). Knuuttila and Loettgers (2017) show that the model was actually a result of a longer-term research program of Volterra. Already more than decades before the publication of the model, Volterra was interested in introducing the methods of physics to biology and economics, in particular the differential calculus, and what he called "the method of hypothesis". It does seem that the fluctuations in the predator and prey populations gave him a good case to explore such oscillations by mathematical means. The question he was interested in studying was whether the interdependence of the two populations was able to produce oscillations in their sizes. The ecologists of his time often attributed such fluctuations to environmental changes. To study the dynamics between the predator-prey populations Volterra constructed a hypothetical system consisting solely of '*the intrinsic phenomena* due to the voracity and fertility of the co-existing species' (Volterra 1927, 68).

One can approach Volterra's version of the Lotka-Volterra model as a purposefully designed, and patently artificial, epistemic tool. Volterra was not even remotely interested in the realistic depiction of any particular predator and prey system. Instead, he distinguished theoretically between 'external' and 'internal' causes, and wanted to study the interplay of some causes that he considered as 'internal'. Those causes would have "[...] periods of their own which add their action to these external causes and would exist even if these were withdrawn" (Volterra 1928, 5). Volterra's version of the Lotka-Volterra model was intimately connected to representational tools and the modelling methods he used. While some of the assumptions of the model were due to the way the model was constrained in order to answer the question concerning the fluctuations in the number of the predator and prey populations, others were due to the application of differential calculus to the problem of predation. Consequently, the assumptions that species increase or decrease in a continuous way makes them describable by using differential equations. Moreover, in order to make the model tractable, Volterra assumed that the individuals of each species are homogeneous and the birth and death rates are proportional to the number of living individuals of the species.

The case of the Lotka-Volterra model shows how the strategy of formulating a simple hypothetical system to study a well-defined question goes hand in hand with the application of particular mathematical tools and methods. Indeed, one conspicuous feature of modeling that has not been addressed by the representational approach is its use of transdisciplinary computational templates or methods (Humphreys 2004, Knuuttila and Loettgers 2016). A computational template is a tractable formal device, like the Lotka-Volterra equations that can be transferred across the disciplines to model various kinds of phenomena, exhibiting similar kinds of empirically observed patterns. Computational templates may have their origin in the formal sciences, like the network models in mathematics, or in specific research fields such as the Ising-model in the study of ferromagnetism, or the Lotka-Volterra model in population biology. Focusing on the prominent role of cross-disciplinary formal templates and methods in contemporary modelling practice requires a shift of perspective towards the artifactual dimension of scientific work. The representational approaches, the fictional approach included, approach models as targeting specific wordly phenomena, while the artifactual approach pays heed to the representational tools and methods that facilitate the study of various kinds of empirical and theoretical questions.

Finally, the critical question for the artifactual approach is that of how the various inferences, new results, and learning from models, more generally, can be justified. The allure of the representational approach to models is due to its seemingly clear-cut answer to the problem of justification: the model gives us justified knowledge if it resembles the target system more or less accurately, in relevant ways. Although neat, this solution is probably all too cheap: how is the model supposed to be compared to the worldly target systems as they are in themselves, independently of our representing them? In actual scientific practices the justification of models, and interpretations and inferences based on them, is two-fold. The justification is already partly built-in due to the already established resources – theoretical, empirical, mathematical, computational, and representational – utilized in model construction (Boumans 1999). On the other hand the justification of a models is a result of the triangulation of different epistemic means: other models, experiments, observations and background theories. Such processes of triangulation are distributed in terms of epistemic labor, likely very complex and indirect, and usually inconclusive in character.

5. Conclusion

One of the paradoxes of the philosophical discussion of models and representation has been that it has largely kept away from the actual representational tools that scientists employ in model construction. In order to address the many languages of science – mathematical, diagrammatic, 3D, synthetic, and natural and written language – I have examined two recent approaches to models and representation, the DEKI-account of representation and the artifactual account. The DEKI-account recognizes different kinds of models, and groups them into concrete and nonconcrete models. I have argued that its treatment of nonconcrete models is misguided in that it separates the model system from its description. The model system is the imagined-object that is considered as the representational vehicle. The separation of the model system from its description leads to several problems concerning how the imaginings of scientists are generated and coordinated, how the enablings of various representational tools can be recognized, and how imagined-objects are supposed to represent. The artifactual account does not begin from trying to solve the problem of representation, but focuses instead on the representational tools used on modeling. These symbolic, semiotic, and material vehicles do not just provide an access to the problems scientists are interested in, but also draw together theoretical considerations, conceptual resources and empirical aspects of scientific work.

Bibliography

Boumans, M. (1999). Built-in justification. In M. S. Morgan and M. Morrison (Eds.) *Models as mediators. Perspectives on natural and social science* (pp. 66–96). Cambridge: Cambridge University Press.

Bueno, O. & Colyvan, M. (2011). An inferential conception of the application of mathematics." *Nous* 45: 345–374.

Bueno, O. & French, S. (2011). How theories represent. *The British Journal for the Philosophy of Science 62*, 857–94.

Cartwright, N. (1999). *The vanity of rigour in economics: Theoretical models and Galilean experiments*. (Centre for Philosophy of Natural and Social Science. Discussion paper series 43/99.)

Chakravartty, A. (2010). Informational versus functional theories of scientific representation." *Synthese 172,*197–213

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension.* Oxford and New York: Oxford University Press.

Elgin, C. Z. (2004). True enough. *Philosophical Issues 14*, 113–31.

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

Endy, D. (2005). Foundations for engineering biology. *Nature 438*, 449-453.

French, S. & Ladyman, J. (1999). Reinflating the semantic approach". *International Studies in the Philosophy of Science* 13(2): 103–121.

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

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

Frigg, R., & Nguyen, J. (2016). The fiction view of models reloaded. *The Monist, 99*(3), 225-242.

Frigg, R., & Nguyen, J. (2017). Models and representation. In M. Magnani, & T. Bertolotti (Eds.), *Springer Handbook of Model-Based Science* (pp. 73-126). Berlin and Heidelberg: Springer.

Gelfert, A. (2016). *How to do science with models: A philosophical primer*. Cham: Springer.

Giere, R. N. (1988). *Explaining science: A cognitive approach.* Chicago and London: The University of Chicago Press.

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

Godfrey-Smith, P. (2009). Models and fictions in science. *Philosophical Studies, 143*(1), 101-116.

Goodman, N. (1976). *Languages of art*. Indianapolis, IN and Cambridge, MA: Hackett.

Humphreys, P. (2004). *Extending ourselves. Computational Science, empiricism and scientific method*. Oxford: Oxford University Press.

Humphreys, P. (2009). The philosophical novelty of computer simulation methods. *Synthese, 169*(3), 615-626.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Knuuttila, T. (2005). Models, representation, and mediation. *Philosophy of Science 72*(5), 1260–1271.

Knuuttila, T. (2011). Modelling and representing: An artefactual approach to model-based representation. *Studies in History and Philosophy of Science Part A, 42*(2), 262-271.

Knuuttila, T. (2017). Imagination extended and embedded: Artifactual and fictional accounts of models. *Synthese,* https://doi.org/10.1007/s11229-017-1545-2

Knuuttila, T., & Loettgers A. (2013). Synthetic modeling and the mechanistic account: Material recombination and beyond. *Philosophy of Science, 80,* 874–885.

Knuuttila, T., & Loettgers, A. (2016). Model templates within and between disciplines: From magnets to gases—and socio-economic systems. *European Journal for Philosophy of Science, 6*(3), 377-400.

Knuuttila, T. & Loettgers, A. (2017). “Modelling as indirect representation? The Lotka-Volterra model revisited.” *The British Journal for the Philosophy of Science 68*(4): 1007-1036.

Kress, G., & van Leeuwen, T. (2001). *Multimodal discourse: The modes and media of contemporary communication*. London, UK: Arnold.

Levy, A. (2015). Modeling without models. *Philosophical Studies, 172*(3), 781-798.

M. S. Morgan, & Morrison, M. (Eds.), *Models as mediators. Perspectives on natural and social science*. Cambridge: Cambridge University Press.

Mäki, U. (2011). *Models and the locus* of *their truth*. *Synthese, 180,* 47–63.

McMullin, E. (1985). Galilean idealization. *Studies in History and Philosophy of Science* Part A 16, 247-273.

Morgan, M. S., & Boumans, M. J. (2004). Secrets hidden by two-dimensionality: The economy as a hydraulic machine. In S. de Chadarevian, & N. Hopwood (Eds.) *Model: The Third Dimension of Science,* (pp. 369–401). Stanford, CA: Standford University Press.

Morrison, M., & Morgan M. S. (1999). Models as mediating instruments. In M. S. Morgan, and M. Morrison (Eds.), *Models as Mediators. Perspectives on Natural and Social Science* (pp. 10–37). Cambridge: Cambridge University Press.

Parker, W. (2009). Does matter really matter? Computer simulations, experiments and materiality. *Synthese*, *169*, 483–496.

Pincock, C. (2004). A new perspective on the problem of applying mathematics. *Philosophia Mathematica* 12, 135–161.

Rice, C. (2018). Idealized models, holistic distortions, and universality. *Synthese 195*(6), 2795–2819.

Salis, F. (2016). The nature of model-world comparisons. *The Monist*, *99*(3), 243-259.

Salis, F. (2019). New fiction view of models. *British Journal for Philosophy of Science*, https://doi.org/10.1093/bjps/axz015

Strevens, M. (2008). *Depth: An account of scientific explanation.* Cambridge, MA: Harvard University Press.

Suárez, M. (2003). Scientific representation: Against similarity and isomorphism. *International Studies in the Philosophy of Science 17*, 225–244.

Suárez, M. (2004). An inferential conception of scientific representation. *Philosophy of Science 71*, 767–779.

Toon, A. (2011). Playing with molecules. *Studies in History and Philosophy of Science Part A, 42*(4), 580-589.

Toon, A. (2012). *Models as make-believe: Imagination, fiction and scientific representation*. Chippenham and Eastbourne: Palgrave Macmillan.

Volterra, V. (1927). Variations and fluctuations in the numbers of coexisting animal species. In F. M. Scudo and J. R. Ziegler (Eds.), 1978, *The Golden Age of Theoretical Ecology: 1923–1940* (pp. 65–236). Berlin: Springer-Verlag.

Volterra, V. (1928). 'Variations and fluctuations of the mumber of individuals in animal species living together', *Journal du Conseil International Pour l'Exploration de la Mer 3*, 3–51.

Vorms, M. (2011). Representing with imaginary models: Formats matter. *Studies in History and Philosophy of Science 42*, 287-295.

Walton, K. (1990). *Mimesis as make-believe: On the foundations of the representational arts*. Cambridge, MA: Harvard University Press.

Weisberg, M. (2007). Who is a modeler? *The British Journal for the Philosophy of Science, 58*(2), 207-233.

Weisberg, M. (2013). *Simulation and similarity: Using models to understand the world*. New York: Oxford University Press.

Weisberg, M., & Reisman, K. (2008). The robust Volterra principle. *Philosophy of Science, 75*(1), 106-131.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*, 179-217.