Transfer and templates in scientific modeling

Abstract

The notion of (computational) template has recently been discussed in relation to cross-disciplinary transfer of modeling efforts and in relation to the representational content of models. We further develop and disambiguate the notion of template and find that, suitably developed, it is useful in distinguishing and analyzing different types of transfer, none of which supports a non-representationalist view of models. We illustrate our main findings with the modeling of technology substitution with Lotka-Volterra Competition equations.

1. Introduction. One intriguing feature of modeling techniques is that they may be applied across scientific disciplines. Harmonic-oscillator models, for instance, are seemingly applied wherever there is scientific work to be done. Still, not all models are migratory. The Nambu-Goldstone model, for instance, is a staple of quantum field theory, but sees no application elsewhere. The evaluation of modeling efforts in different contexts of application warrants further analysis – which minimally requires a clear identification of what may be *transferred* between such contexts. On the semantic view of models, for instance, transfer could concern the mathematical structure (i.e., a system of coupled differential equations), this structure along with its interpretation (i.e., the representation of a target system as a harmonic oscillator), or anything 'in between'.

Recently, (computational) *templates* have been proposed as the subjects of transfer (Humphreys 2002, 2004; Knuuttila 2009, 2011; Knuuttila and Loettgers 2012). Templates are types of differential equations, such as Lotka-Volterra equations, or modeling techniques, such as agent-based modeling, that are primarily constructed for their computational tractability, and that can be applied across disciplines to phenomena that, in the most extreme case, "may have nothing in common 'physically'" (Humphreys 2002: S4). Remarkably, the notion of template has been used to argue for both a "selective" realist and a thoroughgoing instrumentalist view of modeling. In particular, the tractability-driven and "opportunistic" (Knuuttila 2009: 74) transfer of templates has been used to argue that models are epistemic tools, which are constructed and manipulated to contribute to a modeler's understanding, and not (primarily) valued for their representation of target systems. Thus, while it seems intuitive to claim that cross-disciplinary modeling efforts[1] involve transfer of templates, there is a tension in (applications of) the notion of template with regard to one of the central philosophical questions regarding models.

In this paper, we argue that the notion of template illuminates cross-disciplinary modeling efforts, but that it does not support non-representationalism with regard to models. We distinguish three types of cross-disciplinary applications of modeling efforts, all of which may be understood as transferring templates and not interpreted computational models. Where templates are studied independently from computational models, there is only transfer in a degenerate sense; and where templates are genuinely transferred, this is strongly motivated by applications in computational models, valued in their different disciplinary contexts. Still, a marginal, but non-negligible role in modeling efforts for studying templates free from any specific interpretation shows that templates should not be identified with computational models. We illustrate our claims with a case study of transfer: the application of Lotka-Volterra Competition (LVC) equations in modeling technology substitution.

2. Computational and non-representational templates. The notion of computational template was proposed by Paul Humphreys (2002, 2004), in the context of emphasizing the importance to science, especially with regard to the interconnections between disciplines,[2] of computational techniques rather than

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[1] Throughout, “cross-disciplinary modeling efforts” is used where we do not want to express commitment about any items (models or templates) that are transferred.

[2] We use “discipline” to indicate a – not necessarily large – branch of scientific research with characteristic subject matter and method(s) of inquiry.

theories. Mentioning several examples, including Laplace's and Lotka-Volterra equations and normal distributions, Humphreys argues that some modeling techniques see widespread use primarily because of their computational tractability. The notion of computational templates is meant to identify what is common to these applications. Humphreys distinguishes such templates from computational models: the latter come with an interpretation that relates a formalism to a specific subject or target system, whereas the former are relatively independent of any specific subject. Thus, "templates with different interpretations are not reinterpretations of the same model, but are different computational models entirely" (Humphreys 2002: S7). Thus, transfer of a modeling technique involves applying the template, not the model, to a new subject matter; there is, strictly speaking, no *model* transfer.

Humphreys warns against an instrumentalist conception of models, and claims that modelers take some parts of their models as true and others as false – in both cases expressing ontological commitment rather than the non-commitment that would indicate an instrumentalist attitude. Users of a template take a selective-realist attitude, by adding to the template (minimally) a subject-dependent *correction set*, which details the effects of relaxing its *construction assumptions* – the abstractions, idealizations, constraints and approximations that went into the construction of the template. Moreover, Humphreys maintains that construction of a template is not interpretation-free: the template is constructed in the light of its application to specific target systems, and at least one (subject-dependent) correction set is co-constructed.[3]

[3] "The correction set is also always subject-dependent and so, despite its flexibility, is the template itself. This is in part because of the inseparability of the template and its interpretation, in part because of the connection between the construction of the template and the correction set." (Humphreys 2002: S10).

Tarja Knuuttila uses the notion of template in her epistemic-tool account of models (e.g., Knuuttila 2009, 2011). On this account, models are primarily "result-oriented" instruments for increasing the modeler's understanding of the world. Models are purposefully constructed and manipulated, like tools; in particular, in evaluating a model, what matters is not its representational relation to target systems, but the contribution that its construction and manipulation makes to the realization of a given epistemic purpose (e.g., Knuuttila 2011: 263).

Knuuttila specifically mentions templates in her discussion of the "opportunistic" adoption of models constructed in other disciplines.[4] She emphasizes that the cross-disciplinary application of templates is guided first and foremost by considerations of tractability or solvability rather than any ability of the transferred item to represent accurately the (new) target system. She then uses the latter feature to argue against the view that models provide knowledge in virtue of being representational, intrinsically or as determined by modeler's intentions. The cross-disciplinary and opportunistic use of templates would show that modelers seek to "learn from the construction and manipulation of models quite apart from any determinate representational ties to specific real-world systems they might have" (Knuuttila 2011: 267). As 'epistemic tools', models may provide understanding in a variety of contexts, none of which is prevalent over others in terms of intrinsic representational content or modeler's intention. Moreover, opportunism is recommended, not restricted, in the light of the result-orientedness of modeling: new

[4] "[T]here is an element of opportunism in modelling: the template that has proven successful in producing certain features of some phenomenon will be applied to other phenomena, often studied within a totally different discipline." (Knuuttila 2009: 74; 2011: 268).

applications of a template are to be evaluated on the basis of results obtained in the new context, not prior to transfer (Knuuttila 2011: 268). Here, a strong positive analogy with tools is employed: like tools, models and/or templates may be used for a variety of purposes, not all of which are foreseen by the tool's original designer, and many of which require fine-tuning or tinkering on the user's part before proving their true value to the purpose. The only explicit negative analogy is that models serve an epistemic, tools a practical purpose.[5]

Elsewhere, Knuuttila (with Loettgers, 2012) employs the notion of template to offer another, more implicit argument for her non-representationalism: templates can be constructed without any representational relation to a specific target system in mind. To establish this, the construction of Lotka-Volterra models by Volterra and Lotka is contrasted. The mathematical biologist Volterra was motivated by empirical phenomena regarding a specific target system (marine ecosystems), and only constructed a highly idealized set of coupled differential equations to model this phenomenon after concluding that a more realistic model would be mathematically intractable. By contrast, the general systems theorist Lotka derived the same set of differential equations from an abstract theory, irrespective of any specific target system, and only then showed that these equations could be applied to model oscillations in ecosystems and in concentrations of chemical substances. Thus, the very construction of a template may be non-representational – contrary to Humphreys' (2002) claim.

[5] This effectively restricts the analogy to a subclass of tools, since measuring instruments such as rulers and cognitive artifacts such as abaci do serve an epistemic purpose.

Summing up, the notion of template seems to offer a view of transfer of modeling efforts that is both plausible and at odds with representationalism or even realism regarding models. In what follows, we shall show that the template account of, in particular, transfer is in need of further development, which retains its plausibility and resolves the apparent tension with a representationalist view of models.

3. Cross-disciplinary modeling as transfer of templates. In the previous section, we noted that there is a tension in the notion of template: for one author, it supports a selective-realist, representationalist view regarding models, for another an instrumentalist non-representationalism. One might, in response, opt for abandoning the notion. To retain it, we shall in this section develop the notion in such a way that the tension is resolved.

To see why the notion needs developing, consider the claim that cross-disciplinary applications of modeling efforts involve templates, which are primarily valued for their computational tractability. As it stands this claim is uninformative. *That* something serves as a cross-disciplinary template does not make clear *why* some modeling efforts (e.g., involving coupled-oscillator models) see cross-disciplinary application and others (e.g., involving Nambu-Goldstone models) do not. Moreover, computational tractability cannot provide the sole reason: Nambu-Goldstone equations are as computationally tractable as Lotka-Volterra equations, but only the latter feature in cross-disciplinary templates.

Now, within each context of application of modeling efforts, computational tractability is valued because it allows derivation of specific implications or simulation of specific behaviors. Still, in transferring modeling efforts, both disciplinary interests in and the interpretation of implications and behavior change. Balancing these evaluatively relevant aspects is difficult. On the one hand, emphasizing the versatility of the transferred items, and the necessary change of interpretation may underestimate the reason as to *why* tractability is still valued, viz., because of specific implications or behaviors, of new disciplinary interest – which may even be a direct counterpart of the original interests. Emphasizing similarities on the level of target systems, on the other hand, runs the risk of wrongfully equating templates and models and implying that, because representational content changes across applications, models are not primarily intended to represent target systems.

There is an ambiguity in the very notion of a template that is directly related to this balancing act. On one reading, it may refer to a purely formal object, the behavior of which can be studied independently of any context of application. On another reading, a template may be what computational models, valued in different disciplinary contexts, have in common. Although representational content is necessarily different in these contexts, this does not entail that the template is valued exclusively for its formal properties: the applicability of a template in one discipline may still be justified by reference to computational models in another discipline. Lotka's construction of the Lotka-Volterra template illustrates this ambiguity: it may be read as construction of a mathematical object, valued only for its tractability; or as a starting point for constructing multiple computational models, valued (also) for their diverse representational content.

To resolve the ambiguity and improve our understanding of the role of templates in modeling, we may distinguish three types of cross-disciplinary applications of modeling efforts. All of these may be understood as transferring templates, not computational models. Yet the motivations for these application, and consequently the justification for use of the template, are relevantly different – and bring to light the role of interpretations in the evaluation of templates.

In the first type, modelers in one disciplinary context draw on modeling efforts in another discipline, not only because these involve application of computationally tractable mathematical structures (typically: sets of differential equations), but also – and primarily – because they want to apply the same implications of the computational models to similar target systems, or behavior of target systems. In such ‘conformist transfer’, not only the computational template is transferred, but also – in Humphreys’ terms – its construction assumptions and correction set, appropriately re-interpreted, in order to transfer what is taken to be a central result. In justifications for this transfer, one would expect modelers to emphasize similarities between target systems, on the level of properties and/or behavior, at least as much as computational tractability. Possibly, but not necessarily, this emphasis on similarities takes the form of suggesting highly abstract models or encompassing theories, as is also acknowledged in cognitive theories of analogical reasoning (e.g., Holyoak and Thagard 1995).

In a second type of transfer, modelers draw on efforts in another discipline because they are interested in *different* implications of the same mathematical structure. For such ‘creative transfer’, a more general or extensive evaluation of the computational tractability of the template may be required, since the sensitivity of previously unstudied implications to construction assumptions must be assessed. This might lead to reformulation of the correction set. In justifications of creative transfer, one would not expect modelers to emphasize similarities between the properties and behavior of target systems and, by contrast, a stronger emphasis on formal analysis or general robustness of the template. However, this analysis is not independent from an interpretation of the template in its new context of application: its ability to represent behavior of a target system motivates application of the template, even if this behavior may have no counterpart, or no counterpart of any disciplinary interest, in the original context of application. In the extreme, target systems may have "nothing in common 'physically'".[6] Here, what is transferred is a template plus interpretation potential.

Extremely creative transfer must be distinguished from a third type of extension of modeling efforts, which can only be called 'transfer' in a degenerate sense. Here, modelers may study the behavior of a mathematical structure that has seen application in one disciplinary context *purely* out of an interest in its computational tractability or its formal implications. They may, for instance, relax various constructive assumptions or change parameter settings, not in order to make a computational model more realistic, but because they want to test the general robustness of a template. Here, the template is studied independently of any context of application, even the original one – these investigations strictly speaking study *template* behavior, not *model* behavior. Moreover, although these modeling efforts may not involve transfer, they may prove valuable in justifying subsequent creative transfer, and may (but need not) be motivated by the possibility of such transfer.

Templates are thus involved in a variety of modeling efforts, and only seldom independently from (the presentational content of) computational models, valued in their different disciplinary contexts. Where templates are studied in independence from computational models, there is only transfer in a degenerate sense. Thus, although templates are strictly speaking without representational content, and they are

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[6] Note just how extreme such a case is, since similarities must be absent (or remain unmentioned) on the level of entities, properties, relations and behavior. Analogical reasoning must, in short, play no role whatsoever in such transfer of modeling efforts.

what is transferred, the phenomenon of transfer can hardly be used in support of a non-representationalism regarding models. Still, that there is a role in modeling efforts for studying template behavior free from any specific context of application shows that templates should not be identified with computational models.

4. A case study: LVC models of technology substitution. In this section, we look at one case of transfer of modeling efforts: the modeling of processes of technology diffusion with Lotka-Volterra Competition (LVC) equations. We first give a necessarily brief description of these modeling efforts in their disciplinary context. Then, we analyze some features of these efforts with the notion of template, as it was developed and differentiated in the previous section. In particular, we point out a distinction between conformist and creative transfer, the importance of application of templates in computational models, and a marginal (but non-negligible) role of interpretation-free templates.

Predicting and explaining how technological innovations capture market share is of obvious commercial interest. One model of this process fits the simplest logistic curve to the growth rates of technologies (Fisher and Pry, 1971), following the observation that these rates tend to follow a sigmoid curve after capture of a small but significant market share. The (perhaps surprising) predictive success of these and other phenomenological models has led to widespread use in industry, and to an increasing focus in research on hybridization of existing models for predictive purposes,[7] as well as attempts to construct more explanatory models.

[7] Meade and Islam (1998) review twenty-nine phenomenological models and show that a combination provides a better fit to data sets than each of the individual models.

One such attempt follows a suggestion by Fisher and Pry that the diffusion of innovations can be understood as, primarily, a process of competition between an emerging and an established technology. Several researchers have therefore, for explicitly explanatory purposes, sought to apply the LVC equations to the growth rates of rival technologies. They describe the merits of these models as providing "clearly defined assumptions about the nature of technological growth" (Porter et al. 1991: 197). Often, the behavior of the LVC model is studied in relation to the various phenomenological models, for instance by arguing that, under a range of conditions, LVC models reduce to Fisher-Pry models (Bhargava 1989). Occasionally, LVC equations are directly fitted to data sets of competing technologies. Farrell (1993), for instance, applies them to the substitution of soldered cans by lead-free cans, of fountains pens by ballpoint pens; and two other substitution processes.

These modeling efforts are thus explicitly motivated by explanatory concerns, expressed in claims that LVC models should provide an understanding of the mechanisms of technology substitution. Moreover, the analytic and computational tractability of these models plays an important role, in deriving well-established phenomenological models as special cases (e.g., Bhargava 1989), in deriving general properties of systems of competing technologies (e.g., Saviotti and Mani 1995), or in applications to data sets (e.g., Farrell 1993).

Yet there are at least two strategies for seeking this understanding, reflecting the distinction between conformist and creative transfer made in the previous section.

The first strategy – explicit in, e.g., Bhargava 1989; Porter et al. 1991; Farrell 1993 – starts from noting the similarity between the logistic (Pearl-Verhulst) growth models of ecology and the Fisher-Pry model, where a 'technological' counterpart is indicated for each element of the biological model: technologies are likened to yeast cultures, growing in an environment with a maximum carrying capacity (corresponding to market saturation), etc. Then, it is noted that LVC models should comprise Fisher-Pry models as a special case, just as they comprise logistic growth models, the technological interpretation of the latter is carried over to the LVC equations, and the behavior of these equations that is familiar from biological applications (e.g., a bell-shaped growth curve for the 'defending' species/technology on emergence of a new species/technology) is found in data sets on technology substitution.

A second strategy – explicit in Saviotti and Mani (1995) – involves the same template, but strays further from its ecological context of application. It starts by constructing a model that is supposed to capture the microeconomic mechanisms behind technology substitution: a set of three equations with an elaborate, detailed interpretation in terms of obsolescence, learning-by-doing, and purchase of intellectual property rights and other factors that have no obvious counterpart in ecology – and even for those factors that do, no such counterpart is mentioned. The behavior of these equations is not studied, apart from a qualitative reconstruction of various modes of competition (perfect, monopolistic, Schumpeterian and inter- and intra-technological), mostly known from the economic literature. Only then, the LVC equations are introduced, as an "aggregate representation" of technological change, with reference to their similar status for ecological change. After some manipulations, counterparts of the microeconomic model – especially of the parameters corresponding to its distinction between inter- and intra-technological competition – are sought; and the behavior of the manipulated equations is simulated to derive a relation between technological variety and the relative strength of modes of competition, along with the conditions under which the relation holds.

Both strategies involve transfer of the same template, and in each case, its adoption is partly motivated by its tractability (analytical or computational) and partly by its interpretability in technological terms. However, the first strategy may be identified as strongly conformist, and the second as comparatively creative. This is revealed both in the interpretation of the template and in what is presented as its relevant behavior and assumptions. The first strategy attempts a term-for-term translation, and emphasizes behavior that is familiar from applications in ecology.[8] The second interprets the LVC equations in the same terms as a microeconomic model, and studies behavior that has no obvious counterpart in ecological applications.[9] This difference also shows in remarks made on the sensitivity of results: those that follow the first strategy note that applications of the LVC equations assume a stable environment, and find a counterpart in fixed-sized markets; the second strategy involves explicit analyses of conditions under which the main results obtain, formulated as relevant parameter intervals and ceteris paribus conditions. This confirms, with qualifications, Humphreys' claim that conditions on the applicability of the template equations do not feature as ceteris paribus conditions in statements of results: they do not feature as such in conformist transfer, but they do in creative use.

Another feature of templates that is revealed in LVC modeling of technology substitution is that transfer of the LVC template is strongly motivated by its application in (fully interpreted) computational models. In the first strategy,

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[8] Farrell (1993) also seeks to translate the *method* of applying LVC equations, in order to arrive at familiar results.

[9] Saviotti and Mani (1995) do note in passing that one of their intermediate results has an ecological counterpart.

technologically meaningful counterparts of virtually all ecological concepts are identified before presentation of the result – which is itself a counterpart of a central result in ecology. Thus, there is no discernable study of the behavior of the equations apart from a prior, and heavily 'bio-inspired' interpretation. The second strategy differs from the first, not in being interpretation-free, but in interpreting all concepts, as well as the central result, in micro-economic terms. Still, a tension between interpretability and tractability shows up occasionally. Most notably, Farrell (1993: 174) cautions against interpreting the interaction terms in the LVC equations in terms of comparative technological performance. Such an interpretation, while tempting, would neglect that "[t]here is no specific mechanism behind these *equations*" (emphasis added). Here, the formal character of the template is emphasized in order to prevent over-interpretation of the equations.[10]

Finally, in only one place, we find evidence for some interpretation-free manipulation of the LVC template in the literature on technology substitution. Morris and Pratt (2003) use a rather sophisticated graphical method to derive analytically that the LVC equations may "revert" to the Fisher-Pry curves, but that they can only mimic, not match, the behavior of other phenomenological models. Although the positive result is the same as in papers that exemplify the first strategy, it is here derived without any interpretation of either the LVC or the Fisher-Pry equations – and the same goes for the negative result, which is unique to this paper.

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[10] Farrell goes on to speculate about the possibility to derive a technological model from knowledge of the underlying mechanisms – which seems exactly what Saviotti and Mani (1995) claim to have done, arriving again at the LVC equations, which are now fully (micro-economically) interpreted.

There is, summing up, hardly any evidence for an interpretation-free application of templates, let alone for non-representational models; in neither of the two strategies for transferring the LVC template, the template is applied in isolation from computational models. Moreover, the representational content of these models – sometimes including a translation of this content from other contexts of application – is emphasized by practitioners in their attempts to understand the mechanism(s) of technology substitution. Still, we identified a marginal, but non-negligible role in these modeling efforts for studying the LVC template free from any specific interpretation, illustrating that templates should not be identified with highly abstract computational models.

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