# Fundamental challenges in systems modelling[1]

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**Abstract:** In the context of information systems, and digital ecosystems at large, many different forms of *systems modelling* are used. This includes: enterprise (architecture) modelling, business process modelling, ontology modelling and information modelling. The resulting models have come to play an important role during all stages of the life-cycle of digital (eco)systems, where we see such systems as being socio-technical systems involving a hybrid of human and digital actors, supported by (other) technologies.

In our view, the key role of models also fuels the need for a more fundamental reflection on core aspects of modelling itself. In line with this, the goal of this paper is to explore some of the underlying fundamental challenges of modelling, and in doing so create awareness for, and initiate discussions on, the need for more foundational research into these challenges.

The discussion of these challenges has been structured in terms of three clusters: the *semiotic foundations*, the *essence of modelling*, and the role of *normative frames* (such as modelling languages).

## 1 Introduction

Over the past forty years, EMISA's domain of interest has shifted, or rather enlarged, from *information systems* to *digital ecosystems*[4] at large, where we see such systems as being socio-technical systems involving a hybrid of human and digital actors, supported by (other) technologies. In the context of digital ecosystems, many different forms of (socio-technical) *systems modelling* are in use. This includes: enterprise (architecture) modelling, business process modelling, ontology modelling, soft systems methodology, organisational modelling, and information modelling. The resulting models have come to play an important role during all stages of the life-cycle of digital (eco)systems. This now includes their development, improvement, maintenance, operation (e.g. models at "run time"), and regulation.

As a result, the produced models carry (potentially) valuable knowledge regarding digital (eco)systems and their environment(s), which puts even more stress on the role of systems

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modelling. It is, therefore, no surprise that modelling has always been a central topic in the domain of EMISA.[5] In line with this, it is also interesting to observe that, for their own institutional information systems, the European Union relies heavily on a model based approach, even resulting in the creation of a dedicated *competence centre for modelling*.[6]

In our view, the key role of models across the life-cycle of digital (eco)systems, fuels the need for more fundamental reflection on modelling itself. This includes e.g. topics such as *the act of modelling*, *the essence of what a model is*, and *the role of (modelling) languages*.

Such fundamental topics have certainly been studied by different scholars (see e.g. [69, 64, 18, 39, 73, 20, 22, 74, 89, 65]), including ourselves (e.g. [33, 60, 34, 12, 11, 10, 88]). In our view, many challenges remain, however.

The amount of research effort that has been put into such fundamental topics, also seems limited in comparison to the quantity of research conducted in specific "applied" domains of modelling, such as information modelling, enterprise (architecture) modelling, (business) rules modelling, and business process modelling. We are certainly not arguing against the importance of research conducted in these "applied" domains of modelling. We do, however, argue that there is a need to find answers to some of the more generic underlying challenges that will lead to generic insights, and results, that can / may be applied across the more specific areas of modelling.

The goal of this discussion paper is therefore to explore some of the fundamental challenges we see. In doing so, we do not claim to be complete, nor do we claim to provide an exhaustive overview of all relevant work related to these challenges. The goal is rather to create awareness for, and initiate discussions on, the need for more foundational research into modelling in the context of digital ecosystems.

We have grouped the challenges, as discussed in this paper, into three main clusters that build on each other:

1. *Semiotic foundations* concerned with the challenges that originate from viewing models as linguistic artefacts.
2. *Essence of modelling* pertaining to challenges related to the role of a model as being a representation of a purposeful abstraction of some domain of modelling.
3. *The role of normative frames* pertaining to the role of different normative frames (including modelling languages in particular) when modelling, and the impact (positively or negatively) these may have.

The remainder of the paper is structured accordingly.

[5] Entwicklungsmethoden für Informationssysteme und deren Anwendung, see `http://emisa.org/index.php/fachgruppe/historie/gruendung-und-entstehung`

[6] `https://ec.europa.eu/jrc/sites/jrcsh/files/ccmod_leaflet.pdf`

## 2 Semiotic foundations

The semiotic triangle by Ogden and Richard's [51], depicted in Figure 1, is quite often used as a base to theorise about meaning in the context of language [49, 78, 68, 16], and is essentially a continuation[7] of the work by Peirce [54].

The semiotic triangle expresses how a person attributes meaning (*thought or reference*) to the *combination* of a *symbol* and a *referent*, where the former is some language utterance, and the latter is something that the person can refer to. The *referent* can be anything, e.g. something in the physical world (tree, car, bike, atom, document, picture, etc) or something in the social world (marriage, mortgage, trust, value, etc). In addition, it can be something in an existing world, or in a desired / imagined world.

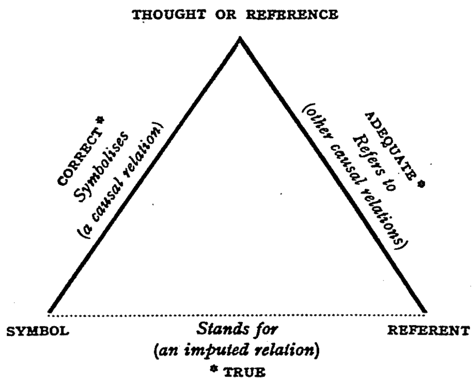


Fig. 1: Ogden and Richard's semiotic triangle [51]

The semiotic triangle is also used directly or indirectly (in terms of the use of semiotics) by several authors to reason about the foundations of (information) systems modelling [70, 39, 37, 42, 22, 73, 75, 9]. In the nineties of the last century, the IFIP 8.1 working group on the *Framework of Information System Concepts* (FRISCO), developed a variation of the triangle in terms of the so-called semiotic tetrahedron [18]. The role of the semiotic triangle in modelling has also been reflected upon explicitly in e.g. [25, 53].

When using the semantic triangle in the context of systems modelling, we essentially end up with the variation as depicted in Figure 2, where a model (as an artefact) is positioned in the role of symbol and the domain that is being modelled in the role of the referent.

Searle [68] added to the above by observing that a language utterance has both a *writer* and a *reader*, which both have their own thoughts about the symbol / utterance, in the context of (possibly) the same referent. If the referent is an existing thing in the physical

[7] We prefer not to simply state *based on*, as there are certainly nuances in the views presented by the involved scholars

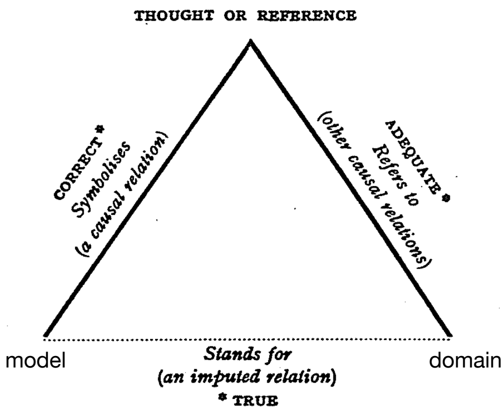


Fig. 2: Ogden and Richard's semiotic triangle applied to modelling

world, humans can apply their senses to "observe" the referent, and as such, have a chance of agreeing that they are indeed looking at the same "thing". When the referent is part of the social world, it becomes more problematic to validate if the reader and writer are relating their respective thoughts to the same referent, leading to the need for e.g. "semantic reassurance" of a shared understanding by means of, for instance, paraphrasing [32]. When the referent is (in addition) a desired / imagined world this becomes even more problematic.

In our modelling context, we see these issues re-appearing, leading to a first two fundamental challenges (stated in the terms used in Figure 2):

**Challenge 1**: *How to ensure that different creators / readers of a model relate it to the same domain / referent?*

**Challenge 2**: *How to ensure that different creators / readers of a model have the same understanding (thought) of the model, assuming they relate it to the same domain / referent?*

The first of these two challenges is an important topic in the context of collaborative modelling, where groups of people are expected to e.g. jointly create an enterprise model [72, 66, 5].

The second challenge relates directly to the question of model understanding. For instance, empirical studies have shown that diagrams can easily be misunderstood [26, 27, 50, 62, 47, 14], which is likely to lead to problems in practical use.

In general, these challenges have also fuelled the work on e.g. the quality of models and modelling. See e.g. [40, 39, 13, 48, 80] to mention but a few. These challenges can also be seen as the major driver on the work towards the use of animation [58], gamification, and natural language verbalisation [63, 23, 30, 45], to increase model understandability, and increase the chances of achieving a shared understanding. Strategies to measure the latter have e.g. been explored in [44, 35].

On a more fundamental level, these challenges are also related to the concept of *boundary object* [71] from the social sciences: "*They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds.*" The applicability of this concept in the context of systems modelling has been explored in e.g. [1, 2].

## 3 The essence of modelling

Several scholars within the field (in the broadest sense) of systems modelling have provided definitions of the concept of model [69, 64, 19, 18, 33, 6, 42, 46, 73, 11]. Most of these definitions, indeed, take the considerations of the semiotic triangle as discussed in the previous Section on board.

One of the key sources on the notion of model itself is the work by Stachowiak [69]. Stachowiak makes a distinction between three key features ("*Merkmale*") of a model. The *representation feature* ("*Abbildungsmerkmal*") referring to the fact that a model is a representation of some original. The *abstraction feature* ("*Verkürzungsmerkmal*") concerned with the fact that a model only captures a limited number of properties, with a limited precision, of the properties that are present in the original. The *pragmatic feature* ("*Pragmatisches Merkmal*") dealing with the fact that the relation between a model, and its original, is related to its usage. In our understanding, in defining the concept of model, Stachowiak also takes the views of e.g. Peirce [54] and Ogden & Richards [51] on board.

In a practical context, such as systems modelling, the *pragmatic feature* of a model will impact the other two features in the sense that a specific usage context of a model, will put requirements on the representation feature (i.e. what should be represented) and the abstraction feature (i.e. what level of detail / specificity / precision is needed). As such the *pragmatic feature* also corresponds directly to the notion of *purpose* of models [36].

One possible way to summarise the above notion of model is to state that a model is [11]: "*an artefact that is acknowledged by an observer as representing some domain for a particular purpose*", where *observer* refers to the (group of) actor(s) involved in the creation and use of the model, and *domain* can be any "part" or "aspect" of the past / existing / desired / imagined world. As such, the word *domain* as used here, is used in a general sense. This should not be confused with a *specific* use of the concept of domain when e.g. referring to the automotive domain or the genomics domain.

This allows us to highlight some additional fundamental challenges in modelling:

**Challenge 3**: *How to make the (intended) purpose of a model explicit?*

**Challenge 4**: *How to tune a model's representation and abstraction features to its (intended) purpose?*

Work into better understanding the usage context has indeed been conducted. The *purpose* of a model is often considered as the main discriminant of the added value of a model [69, 64, 73], while also being a central consideration in e.g. *agile modelling* [3] and the notion of *Return on Modelling Effort* (RoME) [52, Chapter 4].

When discussing the purpose of models in a systems modelling context, it is important to realise that in engineering, software engineering in particular, one has developed the implicit assumption that models are artefacts with a highly controlled structure (syntax) and mathematically defined semantics [24]. There are, however, more, many more, forms of models in use, including informal sketches, textual descriptions, regulatory / legal texts, strategy documents, etc. [55]. One can even go as far as saying that modelling [69, 64, 33, 65] occurs naturally, when people use explicit artefacts (texts, diagrams, sketches, formal descriptions, etc.) that *stand model for* some observed / normative / desired aspect of a part of reality of a (service) system and its environment.

We consider *purpose* as aggregating three (interrelated) key ingredients: (1) the *domain* (of interest) that the model should represent, (2) the intended *usage* of the model by its *audience*, and (3) the *competences* of the (human) actors involved in the creation and use of the model. In our view, the latter is an important, yet sometimes forgotten, aspect of the usage and creation of models [21, 83, 80].

The purpose of a model thus provides the basis for identifying required qualities of the specific model [13, 12] (whereby the qualities may be defined in terms of e.g. the Sequal framework [39]).

When considering the challenges on semiotics, as raised in the previous Section, in the context of collaborative modelling, we are immediately confronted with an additional challenge:

**Challenge 5**: *How to ensure that all actors involved in the creation and / or use of a model have the same understanding about, and agree to, its purpose?*

As the work reported in [21, 83, 80] illustrates, understanding the competences needed in the creation and use of models are not trivial. So, in this vein, another fundamental challenge we see is:

**Challenge 6**: *What are the competences that are needed by the creators and users of models?*

In line with the considerations behind the concept of *natural modelling* [11, 88], as also echoed more recently in the ideas on *grassroots* modelling [65], the final challenge we mention in this section concerns:

**Challenge 7**: *How to support the processes involved in modelling?*

Such support may, for instance, be in terms of explicit strategies for modelling [34, 31], support for step-by-step refinement / specialisation of models [61, 56], more natural notational styles [11, 88], as well as explicitly structured modelling dialogues [31, 15].

## 4 The role of normative frames

In this final Section, before concluding, we aim to consider some "normative frames" that are likely to influence modelling activities. Again, we do not aim to be complete, but primarily attempt to create awareness for the existence of these frames, and potential influences.

The normative frames as discussed below, leads to four main challenges in modelling:

**Challenge 8**: *Which normative frames exist?*

**Challenge 9**: *How to ensure that all actors involved are aware of the role of the normative frame(s)?*

**Challenge 10**: *What are the positive and / or negative impacts of the normative frame(s) on the resulting models (in relation to its purpose)?*

**Challenge 11**: *How to manage (mitigate / optimise) these impacts?*

The first main normative frame involves the *philosophical stance* of the actors involved in a modelling process. Even though not all actors involved in modelling may be explicitly aware of their metaphysical position, it will have a clear influence on the model and modelling process if a modeller is essentially an *objectivist*, a *subjectivist*, or a *constructivist*. The role of the philosophical stance of actors involved in (systems) modelling, and its impact on the modelling process, has e.g. been discussed in [18, 53].

Additionally, the differences between these philosophical stances is likely to also influence the orientation of researchers in the field of systems modelling, and as such also influences the appreciation of the challenges presented in this paper so far and the role of normative frames as discussed below.

A second class of normative frames are the *cognitive biases* which the actors involved in modelling may have developed during their professional, educational, and private lifes. The work by Lakoff [41] in terms of the *categories* in terms of which we classify the world around us, certainly illustrates this point. Experiments in the context of conceptual modelling also indicate that this potentially plays a role during modelling as well [79, 81].

A third class of normative frames are concerned with the *self interests* which the actors may have regarding the domain being modelled. Depending on an actor's personal goals /

concerns with a domain being modelled, they will take a specific perspective on the domain, highlighting (or hiding) aspects that impact their interests.

The *design frameworks* we use in the context of system engineering, are a fourth class of normative frames. Different methods [87, 67, 38, 17, 76, 84] for the engineering of information systems, enterprises, etc, each feature their own framework of aspects / abstraction layers to consider when engineering a system representing the "design philosophy" which the respective method is based upon. In doing so, each of these frameworks defines a structure (essentially a mega-model [7]) of different aspects / perspectives to consider, and as such *normatively* defining the scopes of what can / should be modelled about a system. This is clearly a potential benefit in the sense of ensuring all relevant (from the perspective of the respective "design philosophy") aspects are covered, and a clear line of reasoning is followed [59]. At the same time, however, these frameworks do bring about the risk of essentially creating a "tunnel vision".

In creating system models, we use different modelling languages, possibly in combination with the above mentioned design frameworks. These languages provide the fifth class of normative frames. The *linguistic structure* of a chosen modelling language, i.e. its meta-model, may not only limit the freedom of what can be expressed in a model. It may even limit, or at least influence, the way in which modellers observe the domain. This may lead to situations where a modelling language may "feel unnatural", in the sense that the linguistic structure puts to much restriction on a modeller's "freedom of expression". At an anecdotical level, this corresponds to the *hammer* and *nail* paradigm. At a more fundamental level, it corresponds to the notion of linguistic relativity [77],[8] which states that the structure of a language determines, or greatly influences, the modes of thought and behaviour characteristic of the culture / context in which it is spoken. The impact of linguistic relativity in the context of modelling has been explored in e.g. [10, 4].

The potential advantage of creating a model in a well-defined modelling language, is that the transferability of the resulting models over time, and between actors, is likely to increase. Even more, when, for instance, foundational ontologies [22] are applied in the creation of these models, or is even used in shaping the *linguistic structure* of the modelling language itself, the improvement of the transferability is likely to increase even further.

Furthermore, using a modelling language with a formally defined syntax and semantics [29, 28, 24] also enables computer-based manipulation of the models in terms of checking of correctness, possibly animation and simulation, or even execution (depending on the precision at which the semantics has been defined).

This clearly surmounts a trade-off, which has to be made in line with the *purpose* for modelling in a situation at hand [8] as well as the expected *Return on Modelling Effort* (RoME) [52, Chapter 4].

[8]More colloquially also known as the Sapir-Whorf hypothesis.

The role of modelling languages as a normative frame, has certainly sparked a lot of debate in literature as well. For example, Wyssusek's [85] critique on the Bunge-Wand-Weber ontology [82] providing a normative frame on the linguistic structure of a modelling language, resulted in a lively debate (summarised in [86]).

## 5 Conclusion

The goal of this paper was to explore some of the underlying fundamental challenges of modelling. In line with this, the paper presented 11 challenges, taking us from the *semiotic foundations*, the *essence of modelling*, to the role of *normative frames*. In doing so, we hope to have created more awareness for the need for more foundational research into these challenges.

In the future, we aim to further elaborate these challenges in terms of their underlying understanding and generic solutions / strategies that can be used across different more applied modelling domains, such as such as information modelling, enterprise (architecture) modelling, (business) rules modelling, and business process modelling.

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