FINAL DRAFT

ONTOLOGY, EPISTEMOLOGY, AND TELEOLOGY OF MODELING AND SIMULATION:

PHILOSOPHICAL FOUNDATIONS FOR INTELLIGENT M&S APPLICATIONS

GUIDELINES FOR DEVELOPING ONTOLOGICAL ARCHITECTURES IN MODELLING AND SIMULATION

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Introduction

This book is motivated by the belief that "a better understanding of ontology, epistemology, and teleology" is essential for enabling Modelling and Simulation (M&S) systems to reach the next level of 'intelligence'. This chapter focuses on one broad category of M&S systems where the connection is more concrete; ones where building an ontology – and, we shall suggest, an epistemology – as an integrated part of their design will enable them to reach the next level of 'intelligence'.

Within the M&S community, this use of ontology is at an early stage; so there is not yet a clear picture of what this will look like. In particular, there is little or no guidance on the kind of ontological architecture that is needed to bring the expected benefits.

This chapter aims to provide guidance by outlining some major concerns that shape the ontology and the options for resolving them. The hope is that paying attention to these concerns during design will lead to a better quality architecture, and so enable more ‘intelligent’ systems. It is also hoped that understanding these concerns will lead to a better understanding of the role of ontology in M&S.

Chapter Structure

The chapter starts with some background and then reviews the selected concerns and associated choices that characterise the meta-ontological landscape. Some concerns relate to the process of producing the ontology-based models; others are more metaphysical and focus on the nature of what is produced. The main sections address these topics:

- The basis for assessing these choices
- The major meta-ontological choice: what kind of ontology to adopt
- Some key methodological and metaphysical choices
- How to approach epistemology

Background

The starting point for the analysis in this chapter is the use of ontologies in M&S systems; the first section below clarifies which systems these are.

Much of the discussion in this chapter is of necessity highly abstract and theoretical. However it is also informed by the authors’ experience with developing and implementing ontological architectures, particularly the BORO ontology. The second section below introduces this.

Which kind of M&S system benefits from using an ontology?

M&S is a broad church with a variety of types of member. It is used in both science and engineering. Well known examples in science are the billiard ball model of a gas and the Bohr model of the atom; in engineering the scale model of a bridge or an airplane wing. Within this broad church, there is one kind of M&S system – large-scale, engineering, computing systems - that has been identified as likely to benefit from ontology-driven design.

What characterises this kind of system? One key underlying factor is the mode of representation. Models have different ways of representing. This is clearly evidenced by examples of the same subject represented in different ways; for example, a scale model of the wing of an airplane represents the wing in a way that is different from how a mathematical model of its shape does.

One of the ways of classifying the different ways of representing is by the nature of the representation. The scale model of the wing is a straightforward physical object ('a material model'), so are analogue models like electric circuit models of neural systems. Other models are conceptual; for example, Bohr's model of the atom. These are located in the minds of scientists or engineers rather than in the laboratory or workshop and they do not have to be physically realised and experimented upon to perform their representational function.

The development of computing led to a new kind of representational mechanism, where descriptions or data can be given behaviour and so simulate. Morgan [1, p. 231] comments on the "degree of materiality" of computer data, though as [2, p. 495] points out the computer system is a "material/physical system". This has been incredibly successful in both engineering and science. Humphrey [3, p. 64] suggests that this computational technique 'constitutes a significant and permanent addition to the methods of science'.

Building large scale computing M&S systems requires careful design. Balci et al. [4, p. 158] identified 'conceptual models' as useful tools and lists four main types and seventeen sub-types of engineering simulation systems where they can be deployed in the design of large scale complex applications. They note "… a simulation conceptual model (CM) as a repository of high-level conceptual constructs and knowledge … intended to assist in the design of any type of large-scale complex M&S application. … M&S application designers can be assisted by a CM in the design of large-scale complex M&S applications for solving problems …" [4, p. 158].

Hofmann et al. [5] are more specific about the possible nature of these conceptual models and states that "… ontologies have been proposed for modelling and simulation (M&S) as well" listing [6] [7] [8] [9] [10] [11] [12] [13] [14] as support. These papers use the term 'ontology' in a variety of related senses; one of the themes of this chapter is that these senses need to be clarified and their use made explicit. Hofmann et al. note "Among other advantages, ontology-based simulation is said to support consistent semantic model interchange, which leads to higher quality models, lower costs and a faster development process … indeed a promising solution for interoperability and composability" referring to [15]. These identify the design of large-scale, complex, engineering, computing M&S systems as an area that can benefit from an ontological approach.

Experience of developing and implementing ontological architectures

The ultimate requirement here is practical – more intelligent M&S systems. One sensible concern is whether the abstract issues raised here actually have a practical import. The authors have developed an appreciation of what features are important for ontological architecture through the development and implementation of systems. In this process, they have contributed to the development of BORO, an approach to building ontological or semantic models for large complex applications. This includes a top ontology and a process for constructing the domain ontology. A top ontology is the upper general layer of the ontology; it is this layer that is shaped by the meta-ontological decisions. The top layer then provides a structure for the lower layer, called the domain ontology. In BORO's case, the top ontology is broken out into a separate component so that it can be shared across the domain ontologies of individual systems. As well as economies of scale, this facilitates re-use and simplifies interoperability.

Partridge [16] [17] describes in detail an early version of BORO. It was originally developed to mine a single coherent ontology from multiple legacy systems – as the first stage in an architectural transformation [18] or software modernization, but has since been used for a variety of purposes. An early version was the basis for much of ISO 15926. It is used in the U.S. Department of Defense Architecture Framework Meta Model and is currently being used to develop a metamodel for the UK Ministry of Defence's Architecture Framework. A core use is enhancing the semantic interoperability of federated systems [19-22].

The authors' practical experience has guided them in their identification of the issues in this chapter. In a later section, how BORO addressed these issues is discussed.

Making good meta-ontological choices

The meta-ontological choices highlighted in this chapter can seem esoteric; certainly some of them will seem highly abstract and maybe obscure to many people. In these situations it is helpful to have some explicit criteria for assessing the choices. One helpful resource is Kuhn [23]. He took an empirical approach and studied the characteristics of successful improvements in scientific theories, uncovering this list of six features:

- Generality: where the scope of the improved theory increased.

- Simplicity: where the improved theory is less complicated (it is typically more 'deeply simple' in the complexity theory sense).
- Explanatory power: the ability of the improved theory to give increased meaning.
- Fruitfulness: the ability of the improved theory to meet currently unspecified requirements or to be easily extendable to do so.
- Objectivity: the ability of the improved theory to provide a more objective (shared) understanding of the world.
- Precision: the ability of the improved theory to give a more precise picture of the world.

Making the ontological choices explicit provides an opportunity to take a position that improves on a number of features; explanatory power and objectivity are obvious candidates.

These assessment criteria should be used as a tool to assess the choices made for the issues identified in this chapter. As the focus here is on the architectural choices in M&S system design, these criteria operate at one remove; the goal is to make design choices that lead to artefacts that score well against these criteria.

The right basis for assessment: science or engineering?

Kuhn was considering scientific theories and not engineering theories; and science and engineering have different bases for assessment. While scientific M&S is motivated by a pure search for scientific knowledge, engineering M&S is motivated by more practical, pragmatic engineering concerns. While it is important to ask whether a scientific model is true (this does not mean it has to be 'true' as [24] point out, there are cases where it is false, and known to be false, but still explanatory), an engineering model may be false yet extremely useful. There are many examples of this difference of approach in the wider world; civil engineers will knowingly elect to use Newtonian physics because is significantly more efficient for them than Einsteinian physics, despite physicists regarding it as 'false'. This distinction is recognised in the M&S community: "The development of ontologies in computer science is motivated not so much by the pure search for knowledge (in contrast to the philosophical endeavour of finding the appropriate universal 'ontology', and also in contrast to enquiries of natural science), but by the urgent need to design, engineer and manage 'knowledge', and, more tangible, complex software systems effectively." [5].

The task of designing engineering M&S systems is an engineering task. Building ontologies for engineering, computing M&S systems is ontological engineering rather than pure ontology. What should concern M&S is the usefulness and effectiveness of the approach, not its truth per se. Hence our discussion is framed by a pragmatic engineering context. It is particularly important to bear this in mind as much of the philosophical ontological content discussed here was developed in the philosophy community where truth is, if anything, a more important concern than in science – and certainly a bigger concern than in engineering.

Kuhn's criteria are sufficiently grounded to be useful for both science and engineering. However, the main sections of this chapter focus on engineering, computing M&S (hence we shall use 'M&S' to mean 'engineering, computing M&S' for the rest of the chapter unless stated otherwise). For these it makes sense to prefix Kuhn's list with some engineering specific criteria, pragmatic criteria such as 'Usefulness' and 'Effectiveness'.

What kind of ontology to adopt

One of the challenges holding back the successful deployment of ontology in the M&S community is the use of the term 'ontology' with a number of quite different (though related) senses. There are two intertwined factors at play here. One is the use of the same term to refer to different things (the real world and the model); another, and more important factor, is a different view on what ontology is (realism or idealism).

This section aims to tease apart the two factors and particularly to make clear the choice one has between the different views. We crystallise the views into two broad alternatives; the realist (real world) stance and the idealist (conceptual) stance. It will become clear as we discuss these below how different they are and how important it is that an informed choice between them is made when designing the top ontology. One of the key reasons is that the alternatives have different benefits. Unfortunately the lack of a clear distinction has led to situations where the benefits that accrue to one alternative are claimed for the other. So this chapter aims to clarify what benefits accrue to which alternatives.

A good way to understand the current situation is by putting the term into its historical context, showing how we got to where we are today; we do this below.

History of the term

The different senses have emerged in different communities, but they have a common root in philosophy where the term originated and has been significantly researched. Typically the communities into which the term has crossed-over, like M&S, have had little overlap with the philosophy community. One of the interesting questions, relevant to M&S, is how established ideas in one community (ontology within philosophy, in this case) can be fruitfully transplanted into another distant community. In particular, how the ideas should be adapted to the needs of the new community.

Origin in philosophy

The original sense comes from philosophy, where ontology is the study of existence. Though the etymology is Greek, the word has its origins in the 17th century (the oldest extant record of the word itself is the Latin form ontologia, which appeared in 1661, in the work Ogdoas Scholastica by Jacob Lorhard and in 1631 in the Lexicon Philosophicum by Rudolph Göckel), where the subject was regarded as one of the major branches of metaphysics. However, the practice is much older and can be traced back to the Ancient Greeks. For example, Aristotle, Metaphysics, IV; "all the species of being *qua* being and the attributes which belong to it *qua* being".

It has over the millennia developed into a significant practice; part of which is an understanding of what is required to produce a general characterisation of reality, known as an ontology. This has led to the modern 'objectification' derivative sense of ontology as "the set of things whose existence is acknowledged by a particular theory or system of thought: it is this sense that one speaks of 'the' ontology of a theory, or of a metaphysical system"(Jonathon Lowe in [25, p. 670]). This sense is the one most relevant to information systems, such as M&S systems. Their information element can be seen as a 'theory' that represents in various ways (explicitly and implicitly, directly and indirectly) the M&S domain [26]; so an M&S system's ontology is "the set of things in the domain whose existence is represented in some way by the information in the M&S system" or more simply, the domain.

Grounding ontology in reality

Philosophical ontology's focus is on reality – the 'real' world – and for it to get off the ground one needs to accept that we can know this reality. We do not have to accept this; this is illustrated by a key episode in ontological history, which is briefly outlined below.

In the late 18th century, Kant undermined this acceptance, claiming the idea that we can know reality as a "transcendental illusion (transzendentale Illusion)", a propensity to "take a subjective necessity of a connection of our concepts … for an objective necessity in the determination of things in themselves" [27, A297/B354] (and in the Analytic "…the proud name of ontology … must give way to the more modest title of a transcendental analytic" [27, A247/B304]). Kant's position is epistemic – it is not that the world (noumena) does not exist, it is rather than we cannot know it; and if we cannot know it, we cannot ontologise about it.

Kant's claim was largely accepted by the philosophical community and as a result ontology was neglected until the 20th century. In the late 19th century, interest in ontology was rekindled by Frege [28] [29] who argued the Kantian outlook led to a kind of psychological logic that conflated 'true' and 'being-taken-to-be-true', that we need to distinguish between psychological 'ideas' (Vorstellungen) and their objects. One outcome of this was the emergence of a clear recognition within the community that there is a choice between adopting a Kantian or an ontological position; where adopting the Kantian position typically means rejecting ontology in the philosophical sense. Another outcome was the development of a large body of analytic tools for detecting which position was being adopted and how it was being deployed.

Emergence of the realist stance in the information systems community

With the development of computing in the second half of the 20th century, a number of related communities emerged. In the information systems community, the need for ontology in the philosophical sense was clearly recognised from the start; Mealy [30, p. 525] quite clearly says "The issue is ontology, or the question of what exists". And what exists was clearly recognised as a 'real world' outside the mind, often reflected in the phrase "real world models" [31]. Within philosophical ontology, this position is known as realism, hence we call it here the 'realist stance'. Hirschheim et al.'s research [32] found that this position was mainstream among practitioners; however, as their book illustrates, academics often adopted a quite different stance, which is described in the next section.

Emergence of the idealist stance in the informatics community

In the broader informatics community a different stance emerged. There was a shift from the assumption that we cannot know what objective reality (the Kantian 'noumena') is like to the view that there is no such thing as an objective reality, that all that exists is our ideas and concepts. This leads to the ironic conclusion that we can know 'reality' as it is nothing more than a construction built out of our concepts; where everyone's concept-system constitutes a reality that has in principle an equal claim (indeed, the only claim) to constituting one of the multiplicity of ‘realities’ - Kusnierczyk [33] and Smith [34] describe this development in more detail. This is taken to imply that the information in systems must reflect our ideas or concepts (though quite a few steps are required to reach this conclusion: for example, while I may see the information in systems reflecting my ideas, how can I be sure that other people see it as reflecting *my* ideas).

Viewing reality as mentally constructed is known in philosophical ontology as idealism, so here we call this conceptual idealism in the informatics community the ‘idealist stance’. It contrasts with the realist stance; which accepts that both the ‘real’ world exists and we can know it. Clearly if one adopts this kind of idealist stance the study of ontology becomes the study of concepts rather than a mind-independent real world.

Smith at al. [35] review the adoption of the idealist stance and note “Sadly, elements … are found mixed up together in almost all terminology-focused work in informatics today.” Smith [34] argues that the idealist stance is flawed and notes that this situation “is a matter of considerable astonishment to ontology-minded philosophers”.

In our view, what is damaging from an engineering perspective is that there is often a reluctance in the informatics community to face up to the implications of this situation with the result that many of those developing ontologies have no real awareness that they have, in effect, made the choice to adopt the idealist stance and live with its implications. There are many exceptions both at the individual and sub-community levels. Tolk [36] is one example. He makes a distinction between positivism and interpretivism that appears in behavioural research in Information Systems. Though this is not exactly the same as the distinction made here, it has the same broad thrust. Tolk states that “positivism is rooted in the belief that truth exists on its own, it is independent of the observer and reality is separated from the individual who observes it” and “The alternative viewpoint is interpretivism that holds the belief that truth is a construct of the observer. Reality is relative and cannot be separated from the individual who observes it.” One difference is that unlike the discussion here, this brings ‘truth’ into the distinction. This is a live issue, as there seems to be some equivocation; where the idealist stance is adopted, but the benefits of the realist stance are claimed.

Explaining concepts and modelling methodologies

One way of understanding the different implications of the stances is looking at the fundamentally different ways they need to regard models. Models are central to M&S systems and one of the most basic requirements for a model to be of any use, is that people need to be able to agree on what the icons in a model represent.

In the realist stance, this is straightforward. People agree on what an icon represents by agreeing on the thing in the domain it represents. In the idealist stance, things are not so clear-cut. Here concepts have a central role and icons need to reflect (maybe represent) them. The usual explanation is that two people agree on what an icon represents, if they agree it represents the same concept. The problem is that to do this they need to share the same concept and it is not clear that this is even, in principle, possible.

Given the importance that the idealist stance places on concepts, one would expect there to be a reasonably clear picture of what they are in the community. This seems to be missing in the informatics literature, which seems to rely on a naïve folk notion of concept. Looking outside the community, there is one discipline that has researched the topic, philosophy of mind, developing a couple of mainstream possible views. Both of these illustrate the problem of sharing concepts.

One mainstream view is that concepts are psychological entities that are part of an internal system of representation; internal in that they are only visible to the owning mind [37], [38], [39], [40], [41], [42], [43], [44] and [45]. From one perspective, this has a strong immediate attraction to modellers adopting an idealist stance, as then modelling can be regarded as a process of transcribing one's private representations into a public model. Though if one developed this line of thought, one would need to explain how we get conscious access to the private representations.

This view has well-known problems with explaining how people share concepts. If we take it seriously, then the common claim that two people have the same concept, cannot mean that both of them have the identical concept (the usual meaning of 'same') as they cannot literally share their private internal concepts. Without a 'real world' to coordinate their concepts, they have no way to build a shared model.

Another common view is that concepts are Fregean senses (roughly speaking, meanings) [46] [47]. Typically, proponents of this view are realists who see concepts as abstract rather than mental objects that make the connection between thought and (real world) referents. If one adopts an idealist stance, then the problem with shared concepts reappears. How can a concept created by my mind, whether abstract or mental, be the same as a concept created by your mind?

Hopefully the preceding discussion has given some idea of how fundamentally different the implications of the two stances are. And also an appreciation of the need for the idealist stance to clarify what it means by 'concept' and of the hurdles it needs to negotiate to develop a useful approach to modelling.

Intentional construction: An argument for the idealist stance?
One common misconceived argument for the idealist stance is that the existence of intentionally constructed objects implies it is correct. Clearly these do exist, money and marriage are examples; they depend upon human beings to construct them. But this does not imply all objects are intentionally constructed in this way. There are also natural objects, examples are mountains and rivers; these exist whether we do or not.

Furthermore, this does not mean that intentionally constructed objects must exist as concepts in our minds; that, for example, when I look at a £5 note in my wallet, I perceive a concept in my mind. Searle [48] has explained how a realist stance towards these kinds of objects can work. He notes firstly that intentionally constructed objects are, and need to be, ultimately rooted in natural objects – without the natural objects they could not exist. And secondly that while the intentionally constructed objects are ontically subjective - that is, they depend upon human minds, they are also epistemically objective – so they can be known objectively unlike concepts.

Emergence in computer science

More recently, in the computer science community (particularly the AI community) a new sense for the term 'ontology' has emerged. The earliest documented expression is Gruber's [49]; "a formal explicit specification of a shared conceptualization". It claims that "The term [i.e. ontology] is borrowed from philosophy, where an ontology is a systematic account of Existence" but does not make clear that it is being used in a very different sense.

Guarino [50] [51] clarifies the terminology. In [51] he clarifies the shift in sense by describing the ontology (in the AI sense) as "an engineering artefact" and suggests using "the word *conceptualization* to refer to the philosophical reading" and attempts to relate these. As the earlier discussion should make clear, for people with a philosophical background, it is perverse to call a philosophical ontology a 'conceptualisation'. However, it may also be revealing as the AI community seems to be leaning towards an idealist stance and so a rejection of "the philosophical reading". For example, Guarino's [50] Figure 1 lists the "Possible interpretations of the term ontology"; this contains no mention of the strict philosophical reading and three of the seven entries contain the term ‘conceptual’.

There seem to be disagreements on the specifics of what a conceptualization is. Gruber [49], referring to Genesereth et al. [52], says that it is: “the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold [between] them”. Though he muddies the water with the odd claim that “For knowledge-based systems, what “exists” is exactly that which can be represented”. Whereas Guarino [50] says it is “an intensional semantic structure which encodes the implicit rules constraining the structure of a piece of reality” having earlier claimed that this is “the philosophical reading”. Neither of these are exactly what a philosopher would recognise as an ontology, though the Genesereth/Gruber description seems closer, the reluctance or inability to recognise the philosophical sense noted earlier seems to have been there from the start.

Implications of the different choice of sense

Within AI, one of things that happened was a shift of the sense from the represented to the representation. This is a natural progression given that the focus of work is on producing the “engineering artefact”. However, the utility of the engineering artefact depends upon it characterising the so-called ‘conceptualization’ – so this is important as well. Giving priority to one or other of these two foci can and has led to different flavours of ontology; Hofmann et al. [5] give examples of “two classes of ontologies in M&S: ontologies defining modelling methods and simulation techniques … and ontologies representing real world systems to be simulated”; they name the former ‘methodological ontologies’ and the latter ‘referential ontologies’.

Clearly Hofmann et al.’s [5] ‘methodological ontologies’ are only loosely related to philosophical ontologies. However, it appears that despite the name ‘referential ontologies’ – where ‘referential’ might be taken to imply the model refers to ‘real’ things - Hoffman et al. assume these adopt the idealist stance. For example, the paper states that “Models are conceptualizations of (real world) referents and computer simulations are executable expressions of these conceptualizations.” Firstly, this identifies the models, that is the representations, as the conceptualisations – unlike Gruber [49] and Guarino [50] [51]. Secondly it sees the relationship between the representation/model and the represented/referents as one of conceptualisation rather than one of representation or reference. This is made clear in the next sentence “Conceptualization, however, is a cognitive, purpose-driven act that varies from individual to individual and from task to task.” Clearly the authors have at least partly adopted the idealist rather than the realist stance.

This is not an isolated example in M&S. Tolk et al. [53] say “The goal of conceptual modeling in Modeling and Simulation (M&S) is not focusing on describing an abstract view of the implementation, but to capture a model of the referent, which is the thing that is modeled, representing a sufficient simplification for the purpose of a given study serving as a *common conceptualization of the referent and its context* within the study.” This again identifies the models (the representation) with the conceptualisation unlike Gruber and Guarino. It also suggests both that the model has a referent and that the relation between the model and the referent is conceptualisation – in other words, not reference or representation. This is further confirmed in Figure 14.1 ‘The semiotic triangle for M&S’ where Ogden et al.’s [54] semiotic triangle shows this relation diagrammatically, implying the idealist stance has been adopted.

In part this ‘confusion’ between the senses is understandable given the lack of an agreed definition for the term ‘conceptualization’ that would resolve which stance had been adopted.

Meeting the requirement for semantic interoperability

In information systems in general, and M&S systems in particular, there is also a growing requirement for systems integration which drives a requirement for semantic interoperability (often called composability at the model level). Within this, there is a growing recognition that semantic interoperability is a challenge and that ontology may be the answer [5].

At the heart of this claim is a view of how the semantic mapping between information systems (and models) works. If one has adopted the realist stance, then the method for identifying the correct mapping is simple. Take the simplest case; if given node *a* in Model A and node *b* in Model B, then *a* should map to *b* if and only if *a* and *b* represent the same thing [51]. All one needs to do is identify the ‘thing’ which will be in both domains; from a realist stance, their ontologies.

However, if one adopts the idealist stance, then there is not an obvious methodologically robust approach. Furthermore, one cannot discount the possibility when faced with exactly the same domain that two systems may have radically different conceptualisations – implying there is no straightforward semantic mapping.

One could argue that it is just the case that there are not always (or indeed often) straightforward semantic mappings; and the challenges people face when trying to map between systems would seem to back this up. On the other hand, this natural result of the idealist stance is at odds with our everyday experience. One can easily imagine a military engagement where one side launches a missile against the other. We might expect that (from an idealist stance) the land and air divisions of the targeted combatants would have very different conceptualisations of the missile, given their different interests. But from a practical perspective, we would resist the idea that these conceptualizations, however different, imply that there are two real missiles. For example, we would have grave doubts about a missile defence system that reported two missiles – presumably in the same portion of airspace – and we cannot conceive how one of these might be shot down without this affecting the other.

There is another explanation for these mapping difficulties, one that is compatible with the realist stance; that difficulties in identification arise when the intuition is inadequate to the task. In most current projects, the identification of the objects in the domain is left to the mappers' untutored naïve (albeit experienced) intuition. Most mappers are unaware of the analytic tools developed in philosophical ontology. If one built an M&S engineering discipline for identifying the objects in the domain based upon these 'industrial strength' tools, then the mapping difficulties might disappear.

The key point here is that the realist stance provides a robust solution to semantic interoperability – as there is a 'real' world to underwrite the semantic mapping. Whereas the idealist stance cannot provide the same simple explanation for the semantic mapping, and indeed may suggest such mappings are difficult if not impossible.

Given this, there is a good case for projects that aim to improve semantic interoperability by using ontology to be clearer about which stance they are adopting. If they adopt the idealist stance, they will need to explain how they see the benefits accruing. If they adopt the realist stance, they have an explanation (given above) for how the benefits should accrue. The real engineering test is whether these benefits can be harvested in practice. We believe they do and have documented some of our experiences [55] [56-58] [22].

From the more general perspective of the nature of M&S's ontology there is probably more useful work to be done exploring how the idealist stance can, at least in principle, support semantic interoperability.

Generalising to a requirement for a canonical representation

The problem with semantic interoperability arises because currently modellers seem to have an uncanny knack for producing quite different models for the same domain. Though common in practice, if one takes the realist stance it seems slightly counter-intuitive, as the models are representing the same objects in the domain. This suggests a solution to a wider requirement – one for a canonical representation.

If a system already exists one can reconstruct its ontology and use this to drive the semantic mapping. However, if one is starting to build the model, it makes sense to start with the ontology and use this to produce the model. All models of the domain produced this way would have the same structure, as they would be representing the same objects. In this sense the model would be a canonical representation of the domain, though the form of the representation may be different: for example, one model may be textual and another graphical. However, as they have the same structure, there will be an isomorphism between them. The business benefits of this are clear; as well as supporting semantic interoperability from the start, it greatly simplifies re-use.

Canonical representation is also a good way of distinguishing the realist and the idealist stance. The realist stance implies that there is a canonical representation of a domain, whereas the idealist stance suggests there probably is not. Though this is broadly right, there are some further considerations. There are some meta-ontological (metaphysical choices) that shape the ontological architecture and the representation will be canonical within an agreed set of choices; different choices will lead to different representations. This is a good reason to be clear about which choices have been made.

Key methodological and metaphysical choices

There are a number of meta-ontological choices that need to be considered when developing a top ontology for M&S systems. Some concerns relate to the process of producing the ontology-based models. Others are more metaphysical and focus on the nature of what is produced [59-62]. Some of the choices are more general, leading to guiding architectural principles for the design. Others are more specific, leading to specific architectural features.

Developing a better understanding of the issues will help to ensure a coherent approach to them. It will (hopefully) lead to a more coherent ontological architecture where the meta-ontological choices are made explicit and so bring engineering benefits. A lack of understanding typically leads to a much less coherent architecture where different choices are made ad hoc across the architecture. This puts at risk the benefits ontology brings, particularly the goal of more intelligent support.

The choices are closely related and some choices naturally fit together. In the sections below, we start by looking at the individual choices and assess how they meet M&S engineering goals. The individual choices are:

- Setting clear expert governance
- Avoiding abstract objects
- Providing ontological completeness
- Providing criteria of identity
- Explaining parallel worlds
- Explaining simulations and time
- Separating the concerns

In a final section, we look at how these individual choices depend upon one another.

Expert governance: what should they be responsible for

The design of a top ontology raises some specific governance issues. Typically, when building an M&S system, there will be experts in its domain. It is currently common practice to give these experts responsibility for assessing whether the M&S model is a true picture of the domain. Introducing a top ontology brings out a governance issue; who should be responsible for the way the top ontology shapes the domain ontology. The domain experts are usually not experts in top ontologies; similarly the ontology experts are not usually experts in the domain.

One could take the view that the top ontology deals with general basic things that are common currency for everyone including the domain expert, and that the ontologist's job is restricted to identifying these so that the domain expert can specialise them in her domain. Or one could think that the ontologist needs to be given the freedom and the responsibility to devise the best top ontology possible. This could be either because one believes that there is no real common view or that the common view can and should be improved, maybe substantially. If one takes the latter view, then it is likely that the resultant top ontology will encourage (even enforce) a domain model quite different in structure from that assumed by the experts. However, one of its benefits would be that it could form the basis for a deep common understanding of the domain.

This choice is clearly recognised in philosophical ontology; Strawson [63] coined the terms 'descriptive' and 'revisionary' to distinguish between the two approaches. Strawson says descriptive metaphysics seeks to "lay bare the most general features of our conceptual scheme... a massive central core of human thinking which has no history... the commonplaces of the least refined thinking... the indispensable core of the conceptual equipment of the most sophisticated human being" [63, p. 10]. Whereas, he says, revisionary metaphysics is "concerned to produce a better structure" [63, p. 9]. Strawson gave Aristotle and Kant as examples of descriptive metaphysics and Descartes, Leibniz and Berkeley as examples of revisionary metaphysics. In the descriptive approach (Strawson's preferred approach) the ontologist aims to find a top ontology that preserves as far as possible the accepted picture of the world. In the revisionary approach the ontologist has the responsibility for devising the best top ontology even if this transforms the accepted picture.

The descriptive assumption of a common underlying general picture may be optimistic. A point often made by metaphysicians is that most people unfamiliar with philosophy tend not to be consistent in the way they apply philosophical principles across their picture of a domain (as someone unfamiliar with general accounting theory may not be aware that they are applying different, maybe inconsistent, accounting rules in different situations). If one person is unlikely to have a consistent general picture, then a whole community is even less likely to. Multiple domains are another source of inconsistency – even the most conservative descriptive common picture possible may have significant differences from the individual domain pictures. Cartwright [64,65] strongly argues the case that this situation is commonplace in science, that it has different incompatible theories to model different situations in the world. If it is common in science, which places a high premium on consistency, then it is likely to be common in M&S domains. The requirement for consistency in the top ontology will almost inevitably enforce a degree of change on the domain model. However the conservative descriptive approach aims to minimise these. In so far as this is successful, it has the benefit of producing models that are more likely to be immediately recognised by the domain's community.

Lewis [66, p. 134] points out that when one adopts the revisionary approach typically one is trying to improve the theory, not replace it, and the degree of revision is "a matter of balance and judgement": noting that when "trying to improve the unity and economy of our total theory" … "I am trying to *improve* that theory, that is to change it. But I am also trying to improve *that* theory, that is to leave it recognisably the same theory we had before." Following Lewis one can make an argument that in an engineering approach one should look to improve the model but take account of any benefits of preserving the domain experts' picture of the domain.

M&S projects that make use of a top ontology will inevitably come across this issue. As with many of these meta-ontological concerns, implementing a consistent approach may be practically impossible once the development project is well underway. So it is more effective to make a clear informed decision on this aspect of governance from the start.

Tacit knowledge and the 'Transparent Vision' fallacy

A lack of understanding of two inter-related topics often leads to uninformed decisions; these are the transparent vision fallacy and tacit knowledge. Both of these deal with the nature of the domain experts' knowledge. The following sections provide an outline of the issues.

'Transparent Vision' fallacy

When a domain expert builds a model of the domain, a common assumption is that she has a transparent vision of the domain; in other words, she sees the domain's structure intuitively and that her expertise guarantees this vision's correctness. This needs to be distinguished from the weaker 'Transparency of Experience' [67] which is more concerned with our immediate experiences than the way in which we classify the world. Clearly, if one accepts 'transparent vision' as a background assumption, one would be more comfortable with a conservative/descriptive approach.

For an idealist, as introspection is transparent, domain vision is transparent. As we mentally construct the objects in the domain, and we have a transparent vision of these through introspection, we have a transparent vision of the domain.

For a realist, it is difficult to see how this assumption can be maintained with clear evidence that different domain experts build different models. A useful perspective on this assumption is given by the critics of the 'transparent vision' fallacy [68]. This criticism has a long history, going back to Hume [38]. In Hume's time this position was justified using 'The Insight Ideal' [69]; which argues that a good God would give man the ability to see the world he created clearly ("God in his goodness endowed human beings with faculties that enable them, in principle, to gain knowledge of the world he created for them. It is totally taken for granted that 'the universe was in principle intellectually transparent …" [69, p. 38]). While this religious argument would have little traction in modern times, something similar to transparent vision is commonly assumed by modellers and their managers.

Tacit knowledge

Tacit knowledge is knowledge that is difficult to write down or verbalise – a standard example being the ability to ride a bicycle. This can be regarded as non-conceptual mental content [70-73]. Obviously this causes immediate problems for the idealist stance. It also raises issues for the realist stance.

One might think that experts have their vision trained so it becomes more transparent; that while they might disagree between themselves, they have a more accurate conceptual picture than ordinary people. Tacit knowledge raises doubts that this is true for traditional expertise (know-how). The issue can be illustrated by a common problem that occurs when subject matter experts are asked to produce models. It is often assumed that their expertise is a form of mental conceptual representation and that modeling is simply a matter of recreating this in a public model. So it seems odd that, in practice, experts often have great difficulty in articulating their tacit knowledge in a form that can be directly represented. And they have similar difficulties comprehending or agreeing on the representations produced by others. This is a critical issue as the design of a computer system relies on the knowledge it needs being represented in the kind of excruciating level of detail that will enable it to carry out the task.

There has been a reasonable amount of research on the distinction between having expertise as an ability to do something and being able to represent this ability as knowledge. Ryle [74, Chapter 2] and Habermas [75] ("… we can distinguish between know-how, the ability of a competent subject who understands how to produce or accomplish something, and know-that, the explicit knowledge of how it is that he is able to do so") make a clear distinction between know-how and know-that (or know-what): though there have been defences of the position, e.g. [76]. Polanyi [77] provides a description of know-how as tacit knowledge. John Searle [78,48] makes the case for gaining expertise being a move from conscious control to unconscious action or ability, where the more expertise one has, the less one has an internal representation of that expertise (or conscious access to that representation). Collins et al. [79] and Collins [80] provide a detailed analysis of this situation.

If no conceptual picture exists in the expert's mind (or it is not accessible), then a different kind of approach is required. There is a reasonable literature describing candidates for these; for example Carnap's [81] 'rational reconstruction' ("… [in rational reconstruction] the distinction between drawing on a-priori knowledge and drawing on a-posteriori knowledge becomes blurred. On the one hand, the rule consciousness [i.e. intuitive know-how] of competent subjects is for them an a-priori knowledge; on the other hand, the reconstruction of this calls for inquiries undertaken with empirical [methods]".) and Lipton's [82] 'inference to the best explanation'. Earlier Peirce [83] called this abduction – saying that "Long before I first classed abduction as an inference it was recognized by logicians that the operation of adopting an explanatory hypothesis - which is just what abduction is - was subject to certain conditions. Namely, the hypothesis cannot be admitted, even as a hypothesis, unless it be supposed that it would account for the facts or some of them." He also more light-heartedly said "Abduction is no more nor less than guessing".

A further problem arises because experts often feel an obligation to be able to provide a representation. In these cases, they, post hoc, rationalize one, which only needs to be plausible not correct, as it is not involved in the deployment of the expertise. Shaffer et al. [84] provide a good example: in which expert baseball players provide a plausible, but completely false, (post hoc) rationalization of how they catch a fly ball. (There are many examples of this blindness in the literature; see also [85], where chess players falsely claim to be following a new strategy.) However, when this plausible representation is included in an M&S system, it is deployed. In this case, using an expert's representation (or judgment about one) is likely to be misleading.

Clearly, if one regards traditional expertise (know-how) as largely tacit and inaccessible then one would be reluctant to adopt a conservative/descriptive approach which is aimed to preserve the experts' non-existent conceptual picture of the domain. One would be more likely to adopt a revisionary approach provided this offered a way to ensure a better representation.

Ontological expertise should complement tacit expert knowledge. Ontologists (philosophical ontologists, at least) are trained to make and organize an explicit (i.e. not tacit) representation of the ontology so that it can be publically examined. Historically this was done with text, including mathematical logic; now it is being done with computer models.

Are there abstract objects?

When asking about an element of an M&S model, it is reasonably common to get the answer that it is abstract. A common example is 'roles' such as the President of the USA – an example we return to later. This can have implications for the ontology; if the object is accepted as-is into the ontology, then the top ontology needs to accommodate abstract objects. However, philosophers have spent some time clarifying the cost of doing so.

In modern ontology there is a fundamental distinction made between concrete and abstract objects; where abstract objects are defined as those that are not spatial (or spatiotemporal) and have no causal powers. Lewis [66] calls this the Way of Negation, as abstract objects are defined as those which lack certain features possessed by typical concrete objects.

There are several well-known issues with accepting abstract objects into one's ontology, and an extensive literature arguing for (e.g. [86-88]) and against (e.g. [89-92]) – where these arguments are tied into related arguments about realism, materialism and physicalism.

The main challenge supporters of abstract objects face is explaining how we can know anything about them, even know that they exist. These challenges are particularly acute for mathematical objects and were raised in relation to them in [93]. More specifically, how we explain that we know about the existence of things that are not spatial and have no causal powers. As Field [91, pp. 232–3] says "we should view with suspicion any claim to know facts about a certain domain if we believe it impossible to explain the reliability of our beliefs about that domain".

This translates into a serious issue for M&S modellers [94]. If they need to model an abstract object and its characteristics then, as they cannot explain how anyone could know anything about it and why their beliefs about it are reliable, then their resources are severely limited. It is difficult to see what analytic process could be used to determine the characteristics. When some kind of intuition is developed, how do two (or more) modellers reconcile their conflicting intuitions, when they cannot explain their own intuitions? There seems, in principle, no analytic way of resolving this.

For M&S modellers the pragmatic option is to avoid any commitment to abstract objects. This option can be built into the top ontology helping to ensure conformance in the domain ontologies. Note however, that if the domain experts' picture makes use of abstract objects, this may imply the adoption of a revisionary stance.

Why sets are not abstract

There is a misconception about sets that sometimes clouds the discussion of abstract objects. Sets are sometimes talked about as abstract, but they are not abstract in the sense outlined above. Consider a set of located objects, this has the location of its members; so, for example, the set of objects located on my desk is also located on my desk [66, p. 83]. If the location is dispersed, it may not be interesting; the set of atoms is dispersed around the whole universe, its location is of no real use. But having an uninteresting location is quite different from not having one at all.

Finding an ontologically complete framework

When modellers add a new element to the model, they expect that it will fit into the existing framework. One does not want to discover when building a domain ontology for an M&S system something that does not fit. One would then need to revise the framework to accommodate it and rollout this change across all the other systems that use the framework. So, when one is devising a top ontology for M&S systems, it is essential that it provides a framework that covers all the things that might be in a domain.

This boils down to a requirement to list, at some general level, all the types of things that might be in the range of domains that the top ontology is likely to be used for. This is closely related to categories in traditional philosophy, which are a complete list of the highest, most general kinds. In philosophy one considers everything that could exist, within M&S engineering one may wish to tailor a top ontology restricted to a specific range of domains. Interest in categories can be traced back to Aristotle [95, 1b25] who divides the world into the ten most general kinds of entities.

There are a variety of different ways to derive categories, but a common way is ontological; dividing things by how they exist. Lowe [96, p. 5] takes categories to be categories of "what kinds of things can exist and coexist". Such categories, he argues, are to be individuated according to the existence and/or identity criteria for their instances. Johansson [97, p. 1] aims to "develop a coherent system of all the most abstract categories needed to give a true description of the world". There is also the question as to whether there is a single or multiple classifications (e.g. [98, §10] [99, Chapter 2] [100]). And also the question of whether a particular classification provides mutually exclusive categories.

From an M&S perspective, what is required is completeness; so providing a single exhaustive list of categories is sufficient, it does not have to be the only possible list.

Categories based upon criteria of identity

When modelling there are many times where it would be useful to know whether two modellers are talking about two different things or the same thing (whether two elements in different models represent the same thing); this is often colloquially expressed as knowing whether the two things are the same. If one had a criterion of identity, a way in principle (though maybe not always in practice) of deciding whether two things are the same or different, then one would have a principled basis for doing this. Without this (or something similar) the goal of a canonical representation would be difficult to achieve.

One might think that devising a criterion is simple, but several puzzles have been devised to illustrate this is not so. The Ship of Theseus and Locke's socks are historically well-known examples of one kind. In these, small parts of an object are replaced until eventually none of the original parts remain. It seems intuitively clear that the thing is the same after each small part is replaced, but it is much less intuitively clear whether it remains the same or not after all the parts are replaced. The challenge is to devise a criterion that sensibly resolves the issue.

There is a link between this criterion and categories. Dummett [101, pp. 73-75], Lowe [102] and Wiggins [103] suggest building a classification based upon criteria of identity – where each category in the classification has its own criterion of identity. This relies on the 'in principle' nature of the criteria; a rough rule of thumb would not provide clear classifications. The attraction of a criterion of identity based set of categories from an M&S perspective is a simple coherent structure.

One mainstream example is the group of extensional criteria of identity. This divides objects into three broad types, each with its own criterion of identity; elements, types and tuples. The criterion of identity for elements is spatiotemporal extension; two things are identical if they have the same spatiotemporal extension. For types the criterion is extension, their members; two types with the same members are identical. For tuples, the criterion is their places; two tuples are the same if they have the same objects in the same places. There is a literature explaining the details of this classification [66,16,62,55,17]. The attraction of this classification is that it is general and simple (almost minimalistic); and that it cleanly resolves a number of identity problems as well as issues on how to deal with representing the past and future. As well as the identity over time problems such as 'The Ship of Theseus' it also addresses problems where there are two things occupying the same space at the same time – see [17, Figure 8.18]. However, adopting this classification in a top ontology is likely to be revisionary, as experts' pictures of their domain are likely to need some kind of transformation to conform to it.

Representing parallel worlds

A standard explanation of the way M&S in general functions is that it creates parallel or imaginary worlds. Weirich [104] says that following Robert Sugden [105], "I assume that a model is an imaginary world. I allow it to be a small world, including only the features under investigation. To underscore this point, I say that a model is an imaginary system, a component of an imaginary complete world." In a review of the current work, Frigg et al. [106, p. 597] find many people making the same point: "Several philosophers, historians and scientists claim that simulations create 'parallel' (or 'virtual' or 'artificial') worlds" and refer to [107-109]. Frigg at al. continue "The most plausible interpretation of this idea, we think, is that the simulant investigates proximate systems that differ more or less radically from the systems she is ultimately interested in. This usually means that inferences about those latter systems, the 'target systems', are made in two analytically separable (though in practice not always thus separated) steps: first, a conclusion is established about the proximate system; second, the claim is exported from the proximate system to the target system."

There are various ways to interpret this. Material models, such as a scale model of an airplane wing, are straightforward physical objects. Because of the way these represent, one could think of the parallel world being physically similar to the model – or even the model being the parallel world. However, for computing models this interpretation is less feasible as the data running in the computer has no physical similarity with what it represents in the parallel world. A more obvious explanation here is semantic, that the M&S system represents a parallel world. In either case, there is a need to explain why we think that what happens in the parallel world tells us something about the actual world where the simulation is carried out. This in turn raises interesting epistemic questions about how we can know anything about the parallel world that is being represented.

From an M&S model development perspective these translate into questions about how this is to be modelled. How do we know how to model the parallel (possibly imaginary) world? Does it have the same kind of top ontology as this actual world? Does it have the same categories and criteria of identity?

Interestingly, the characterisation of what is being simulated as a 'parallel' world is not quite right. It is possible to simulate an event in the past to gain an understanding. Similarly, we may simulate a possible future event and then find that one of the simulations actually happened. Both these cases suggest that in some cases the parallel world is this actual world. One can argue here that the future and, to some extent, the past and future of the actual world is inaccessible in a weaker but similar way to the parallel worlds.

Similar issues to these arise in the study of possibility (also known as alethic modality) and a number of approaches have been developed. These can be regarded as ways for M&S to explain how simulation works.

One approach that has had an influence in computing is ‘possible worlds’ [51,16,17] where statements about possible objects are taken to refer to objects that exist in possible worlds. This approach was first suggested by Leibnitz; it was developed in modern times by a number of people starting with Kripke (in a series of papers beginning with [110]) and then later Lewis [111,66] – and is known as Kripke semantics or possible world semantics. Lewis took a particularly strong stance with respect to possible worlds, saying that they were real; a position called ‘modal realism’. A weaker option is called ersatzism (or actualism, or abstractionism), which does not commit to their reality.

This approach provides a neat semantic consistency for talk about objects in parallel worlds; it can refer to these in the same way as we talk about actual objects. It also avoids complicating the overall ontological framework; the top ontology’s categories and criteria of identity span the actual and possible worlds, applying equally to both. This simplification is a benefit from an M&S top ontology development perspective.

If an M&S system is representing a ‘parallel’ world, it makes sense to have a clear understanding of what this world is. There are clear attractions to adopting a possible world approach in the development of the top ontology. However as has been noted with other options, for most domains this is likely to have a revisionary effect on the domain models and so needs to be undertaken within a revisionary governance.

There are several well-known issues with the possible world approach, but these do not seem relevant here. For example, if one is a modal realist, then for every choice a person makes in this world, there is some possible world where their counterpart makes a different choice; this is thought to raise ethical problems. Engineers tend to ignore these issues. For example, a civil engineer is unlikely to regard the implications of Newton’s mechanistic theories on free will to be relevant to using them in the construction of bridges. From an M&S engineering perspective, the relevant issue is whether this makes the development of better M&S systems easier; the choice of approach is methodological.

Simulations and time

Simulations can be regarded as dynamic models; that is models that change over time. The changes over time in the simulation are designed to represent the changes over time in the system it is representing; that a simulation imitates a process by another process [112,3].

This suggests two models of representation are in play; one where a static sign is representing an object and the other where a process working on the signs represents a process happening to the objects. This division is familiar in computing, which has a clear delineation between data and process, though there has been much confusion about whether the data-process distinction reflects a similar distinction in the real world [16, Ch. 2.4.1]. This is also a different picture from that given in much early computing system literature (e.g. [113]) – see Figure 1. This assumed that only the data represented, and the processing was manipulating the represented data. Simulation implies that it is the same distinction at work in data and process in the representation and what it represents.

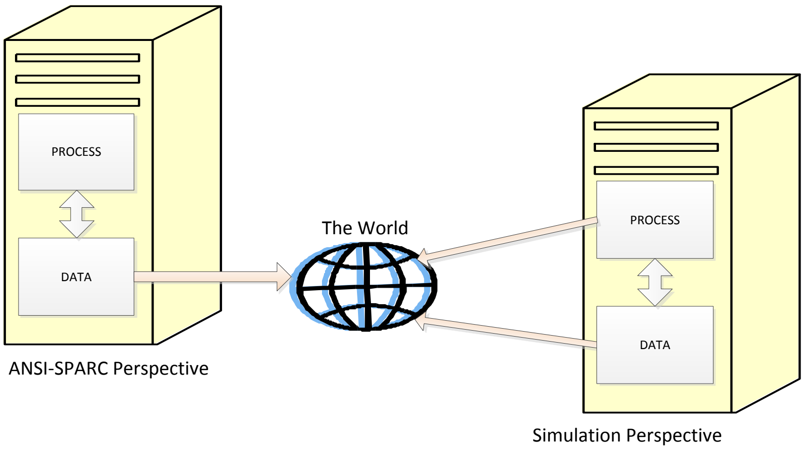

Figure 1 - Data-process to world mapping

This raises the question of how ontologically fundamental this distinction is. As is common in philosophy opinion is divided. In modern philosophy, the debate was started by McTaggart [114], though the issues go back to Heraclitus. Simplifying slightly, one approach favours a fundamental ontological division into continuants and occurrents, where occurrents are changes that happen to continuants. Another approach regards these distinctions as a matter of perspective. For example, a glacier may seem like an object in human time, but a process in geological time –

it is not intrinsically one or the other. This approach regards all objects as extended in time and change as just different timeslices of the object having different properties (this is sometimes known as a process ontology, as it can be regarded as treating all objects as processes). For example, if someone grows an inch, then this is seen as two timeslices of the extended object which differ in height by an inch. At the heart of these differences is a choice about the reality of change; as the height example illustrates in the second approach there is no object corresponding directly to the change. These two approaches are sometimes known as 3D and 4D, though this can be misleading as the issue is change rather than a number of dimensions.

From an M&S perspective, a choice between these approaches needs to be made as it will significantly impact the top ontology. A 4D approach is usually simpler (it has less distinctions) but is likely to be revisionary, with all that entails. As the glacier example illustrates, it also downgrades the static-process distinction at the heart of simulation distinction to one of perspective and context rather than ontology.

Ontology, semantics and separation of concerns

The successful delivery of ontology-based M&S systems depends not just on building a good ontology but also on fitting this into an appropriate development process. The ontological approach makes explicit an endemic development issue and so this requires particular attention. All computing information models, including M&S models, suffer from a semantic schizophrenia. On the one hand, the model represents the domain; on the other hand, it represents the implemented system, which then represents the domain. These different representation requirements place different demands upon its structure. With an ontological approach, one has a far more structured and effective way of representing the domain, making the need to manage the different demands more acute.

One of the common ways to manage this is a separation of concerns, described in many current textbooks; Pressman [115, p. 313] describes a model that is constructed by asking the customers what are "…the "things" that the application or business process addresses", and that "These "things" evolve into a list of input and output data objects as well as external entities that produce or consume data". A more structured example is the Object Management Group's Model Driven Architecture (MDA) where a model is built for each concern and this is transformed into a different model for a different concern.

With the introduction of ontology, particularly a top ontology, the process of building a domain model becomes an engineering task, much more than “asking the customers”. The ontological demands on the structure will be much clearer. Hence its separation also needs to be clearer, probably much clearer than in most M&S projects undertaken at the moment. The benefits of semantic interoperability and those arising from canonical representation rely on this; that the ontology is developed independently of the particular system’s implementation requirements.

Managing dependencies across the framework - between the choices

There is also a close link between the different choices we have been exploring [116]. For example, if one wishes to adopt an extensional approach to the criterion of identity for physical objects, then one is obliged to go 4D. 3D is not sufficiently fine grained to distinguish between objects that are in the same location at the same time. Barack Obama and the President of the USA are a common example, as is shown in the 4D space-time map below.

Possible worlds are also attractive to an extensionalist, as then the extension of types across possible worlds is able to capture nuances of meaning it could not do otherwise.

BORO meta-ontological choices

The BORO top ontology is an example of an ontology that has explicitly addressed these choices in its ontological architecture. It has adopted a realist stance towards ontology (it takes for granted a mind-independent real world). It has adopted a revisionary stance – accepting that if we want better models, we need to change the ways we look at the world. It has explicitly adopted completeness categories based upon extensional criteria of identity.

It chooses a 4D and possible worlds approach as these fit best with its commitment to extensionalism. Figure 2 shows how it approaches the Obama – President of the USA issue. The individuals, ‘President of the USA’ and ‘Mr Obama’, are both extended in space and time. At some points in time they overlap – where they are ‘in the same place at the same time’.

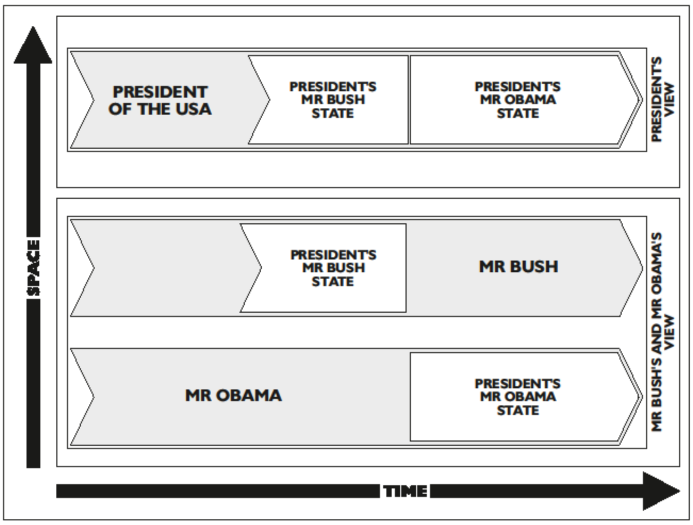

Figure 2 - 4D space-time map

Note that this explains away the same place, same time concerns – ticking the 'increase explanatory power' box in the six assessment features identified at the beginning of the chapter.

One can see further kinds of revisionary transformations in the various BORO models [16,55-58,17,22]. In each case, the transformation is justified by Lewisian arguments that it "improves the unity and economy" of the M&S system.

How to approach epistemology

The literature contains a reasonable amount of discussion of how ontologies can, in the concrete way described in this chapter, be integrated into the design of computer systems. As we mentioned earlier, there developed within philosophy an objectification of ontology, where as well as the sense of ontology as a practice or discipline there emerged the sense of ontology as the set of objects being studied – "the set of things …".

Epistemology is the study of knowledge and justified belief, and is given the same high ranking as ontology in the philosophical literature. However, there has not been the same objectification of it; a shift to a sense of epistemology as the sets of objects that are known. From an M&S modelling perspective, this would be useful, recognising an epistemology as "the set of things whose existence is *known* by a particular system" [117,55,118,58]. This is particularly useful when allied with ontology; "the set of things in its ontology that are *known* by a particular system".

To understand why this is useful, one first needs to recognise that systems have an epistemology and that this diverges from its ontology [119]. Ironically, it turns out that many system models are for good practical reasons epistemologies, models of what it can know rather than what is. Here is a simple example. An insurance system may wish to represent whether a person is married and, in cases where it has the information, represent the 'spouse of' relation. The system's model will represent what it can know (its epistemology), that married persons optionally have a spouse – whereas ontologically, being married is the same thing as having a spouse; ontologically if one is married the spouse relation is mandatory.

This suggests a need for a finer separation of concerns, one which recognises the distinction between an ontology and an epistemology. It also reveals an interesting relation between the two – that the epistemology can be regarded as a view of the ontology. This has positive implications for semantic interoperability between systems with different epistemologies but the same underlying ontology.

Summary

This chapter has concerned itself with the category of M&S systems that can make concrete use of ontology in their design; large-scale engineering computing M&S systems. Currently the community is exploring how to do this and a clear understanding has yet to emerge. One area where it is useful to develop a clearer understanding is the meta-ontological concerns that shape the ontology and the options for resolving them; the ontological architecture. These have been outlined in this chapter.

The major meta-ontological concern that needs to be addressed is what kind of ontology will be adopted, or in the terminology of this chapter, whether to adopt the idealist or the realist stance. This is an engineering decision and needs to be justified in this context, particularly in terms of the engineering benefits. Where semantic interoperability is a major requirement, it needs to be recognised that the realist stance has major advantages.

Another meta-ontological concern is top ontology governance; whether this is descriptive or revisionary. This again needs to be driven by engineering concerns; choosing the approach that delivers better overall results. The benefits of having a familiar looking model need to be balanced with the benefits arising from potential improvements in the model.

There are other detailed meta-ontological concerns, such as alethic modality and the reality of change, which need to be considered and a way of handling them decided upon. It makes sense to apply the decision consistently across the ontology, and the top ontology can be used to manage this.

Addressing these concerns directly is likely to lead to a significant improvement in the design of ontologies and the intelligence of the implemented M&S system.

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