Foundationless Ontologies

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Abstract. One of the purported benefits of foundational ontologies is that they facilitate the design of sharable and reusable domain ontologies. Nevertheless, there has been little formal analysis of the relationship between foundational and domain ontologies. In this paper we explore the role of foundational ontologies in axiomatizing the intended semantics of the signature of a domain ontology. In particular, we propose a way of designing domain ontologies such that different foundational ontologies can be used for the axiomatization. In this sense, the resulting domain ontologies may be considered to be agnostic of any given foundational ontology.

This work was motivated by the development of the Industrial Ontologies Foundry, but may also be applied to existing domain ontologies such as the Semantic Sensor Network Ontology.

Keywords. ontology design, upper ontologies, foundational ontologies

1. Introduction

The use of a foundational ontology undoubtedly provides guidance for ontology developers in the design of their ontologies, particularly if the new ontologies are conceived as extensions of the foundational ontology. The use of foundational ontologies for ontology design should naturally be encouraged, but the choice of a foundational ontology raises issues of premature ontological commitment; we must also be careful to avoid pigeon-holing a domain ontology before its requirements are fully known or understood. Furthermore, the choice of a particular foundational ontology might impede sharability and reusability with other domain ontologies that use a different foundational ontology, since navigating between foundational ontologies can be prohibitively difficult.

To address this challenge, we consider whether it might be possible to "swap out" one foundational ontology for another for the same domain ontology. By extracting the domain signature-specific module from the domain ontology, it should be possible to replace the original foundational ontology with some alternative and by definition, all of the consequences of the module will remain unchanged, regardless of the foundational axioms used. The *foundationless* ontology that results from this exercise serves to effectively capture the intended semantics of the domain while allowing for alternate foundational ontologies to be used interchangeably. This avoids the challenge of studying and choosing between foundational ontologies in the initial stages of ontology design. In existing ontologies, it allows for the reversal of a commitment to a foundational ontology, thus improving the potential for integration with other ontologies. The ontology that results from this approach is "foundation-agnostic" – it does not require a commitment to a particular foundational ontology, while at the same time allowing people to use whatever foundational ontology they like without the need for merging or prior harmonization of any foundational ontologies.

Following this approach, the choice of foundational ontology only makes a difference in the case that the required reasoning and scope of concepts extends to include the foundational concepts, for example, where the competency questions include foundational concepts as well as domain-specific ones. The distinguishing factors for selecting a foundational ontology are then "soft" characteristics like usability and possibly implementation-specific characteristics like the size of the resulting representation. Any adequate foundational ontology may be used to capture, via some extension, the intended semantics of a given domain.

Another way of looking at the foundationless ontology approach is that it serves to clarify the relationship between a particular domain ontology and a set of foundational ontologies. It is often unclear whether or to what extent foundational ontologies contribute to the required semantics of a given domain ontology. At the root of this is the question of what role the foundational ontology is intended to play for the domain ontology. While answers to this question may vary, regardless of the role of the foundational ontology, the challenge of choosing between foundational ontologies should be addressed. The foundationless ontology illustrates precisely what semantics, if any, from the foundational ontology contributes to the domain-specific ontology. We conjecture that it may often be the case that most of the foundational ontology's axioms serve to support the high-level design and understanding of the domain ontology but do not contribute to the axiomatization of its required semantics. The extraction of foundationless ontologies is also a useful task to better understand the intended semantics of a domain, and more flexibly apply an ontology with various foundational theories.

The key research challenge addressed in this paper is the role of foundational ontologies in the axiomatization of sharable and reusable domain ontologies – given a class of intended structures for a domain ontology, how can we provide an axiomatization of this class such that the resulting domain ontology can be reused with other foundational ontologies? We tackle this problem by considering in turn a series of five question:

- What are the intended structures of an ontology?
- Under what conditions can a foundational ontology be used to axiomatize the class of intended structures $\mathfrak{M}^{domain}$?
- Are foundational ontologies necessary for axiomatizing the class of intended structures $\mathfrak{M}^{domain}$ or can they be axiomatized using only a theory in the signature σ^{domain}?
- Can $\mathfrak{M}^{domain}$ be axiomatized using different foundational ontologies?
- Is the adoption of a single foundational ontology for the axiomatization of T^{domain} necessary to for semantic integration?

All of these questions arose within the development of the Industrial Ontologies Foundry (IOF), whose mission is the creation of a set of core ontologies that spans the entire domain of digital manufacturing. This set of ontologies will be non-proprietary and are expected to serve as the foundation from which other domain-dependent and/or application ontologies can be derived in modular fashion across all industrial domains and manufacturing specializations. Different foundational ontologies were advocated for use in the design of the IOF Ontologies which led to the proposal that one foundational ontology be selected to the exclusion of others. The foundationless approach outlined in the current paper is a response against this proposal and a demonstration of the viability of designing domain ontologies that can be used with multiple foundational ontologies.

2. Intended Semantics of the Domain Ontology

In any ontology design activity, the goal is the specification of a domain ontology T^{domain}, that is equivalent to the axiomatization of the class of intended structures $\mathfrak{M}^{domain}$ for the signature σ^{domain}. A key question is how foundational ontologies can be used to design such domain ontologies.

Question 1. *What are the intended structures of an ontology?*

When developing or selecting an axiomatization of an ontology for an application domain, the knowledge engineer typically has some requirements in mind. These requirements for the ontology are specified with respect to the intended semantics of the terminology; from a mathematical perspective the requirements may be characterized by the class of structures which capture the intended semantics, and such structures can be referred to as the required, or intended, structures for the ontology. We therefore need the class of intended structures if we are to evaluate T^{domain} ([1] [2]).

Foundational ontologies are used to axiomatize the intended semantics of the domain signature, not to specify their intended semantics. The specification of intended semantics must be prior to the axiomatization, and the intended structures for a domain ontology must be specified in the signature σ^{domain} of the domain ontology.

Definition 1. $\mathfrak{M}^{onto}$ *is an elementary class of structures iff there exists a first-order theory* T *such that* $\mathscr{M} \in \mathfrak{M}^{onto}$ *iff* $\mathscr{M} \in Mod(T)$.

Definition 2. *Let* L *be a first-order language,and let* $\mathfrak{M}^{onto}$ *be a class of* L*-structures.*

$\mathfrak{M}^{onto}$ *is a pseudoelementary class of structures iff there is a first-order theory* T *with signature* L' *such that* $L \subseteq L'$ *and* $\mathscr{M} \in Mod(T)$ *iff* $\mathscr{M}\,|_L \in \mathfrak{M}^{onto}$.

Loosely speaking, a class of structures is pseudoelementary if it is axiomatizable by a theory with an expanded signature. For example, in the signature $\{\mathbf{adj}\}$, the class of connected graphs (in which **adj** is the adjacency relation) is not elementary, but this class is pseudoelementary – connected graphs are reducts of models of a first-order theory using the expanded signature $\{\mathbf{adj}, \mathbf{R}\}$, where **R** is an irreflexive and transitive relation with a minimal element[3].

In the following sections, $\mathfrak{M}^{domain}$ will denote the class of intended structures for the domain ontology, and we will assume that the class is elementary or pseudoelementary.

3. Using Foundational Ontologies for Domain Ontology Design

In this paper we explore the role of foundational ontologies in the design of sharable and reusable domain ontologies. In this context, the problem of ontology design becomes: given a class of structures that captures the intended semantics of the signature of the domain ontology, provide an axiomatization of this class of structures such that the resulting domain ontology can be used with multiple existing foundational ontologies.

Question 2. *Under what conditions can a foundational ontology be used to axiomatize the class of intended structures $\mathfrak{M}^{domain}$?*

To address this question, we need to consider the relationship between foundational ontologies and domain ontologies, in particular, the relationship between the models of foundational ontologies and the intended structures of the domain ontology.

Definition 3. *A class of structures $\mathfrak{M}^{domain}$ is definable by the foundational ontology $T^{foundation}$ iff there is a mapping $\varphi : \mathfrak{M}^{domain} \to Mod(T^{foundation})$ and a structure $\mathscr{N} \in \mathfrak{M}^{domain}$ with signature $\sigma(T^{foundation}) \cup \sigma^{domain}$ such that $\mathscr{M} \in Mod(T^{foundation})$ is isomorphic to the reduct of $\mathscr{N}$ to the signature σ^{domain} (denoted as $\mathscr{M} \cong \mathscr{N} |_{\sigma^{domain}}$) and $\varphi(\mathscr{M})$ is elementary equivalent to the reduct of $\mathscr{N}$ to the signature $\sigma(T^{foundation})$ (denoted as)$\mathscr{N} |_{\sigma(T^{foundation})}$.*

Thus, $\mathfrak{M}^{domain}$ is definable by the foundational ontology $T^{foundation}$ iff each structure in $\mathfrak{M}^{domain}$ is definable in an expansion of a model of $T^{foundation}$.

For example, consider the Simple Event Model [4] as the domain ontology and PSL [5] as the foundational ontology. The work in [6] introduced the technique of ontology grafting, in which the domain ontology is a theory that is faithfully interpreted by another ontology.

The following Theorem generalizes this approach:

Theorem 1. *$\mathfrak{M}^{domain}$ is definable by the foundational ontology $T^{foundation}$ iff there is a set of sentences $R^{foundation}$ with signature $\sigma(T^{foundation}) \cup \sigma(T^{domain})$ such that $Th(\mathfrak{M}^{domain})$ and $T^{foundation}$ are conservatively extended by $T^{foundation} \cup R^{foundation}$.*

Proof. $\Rightarrow$:) Suppose $\mathfrak{M}^{domain}$ is definable by the foundational ontology $T^{foundation}$.

By Definition 3 and Theorem 4 of [7], there exists a theory T that is a conservative extension of both $Th(\mathfrak{M}^{domain})$ and $T^{foundation}$. By Definition 3, the models of T are structures $\mathscr{N}$ with signature $\sigma(T^{foundation}) \cup \sigma^{domain}$ such that $\mathscr{M} \cong \mathscr{N} |_{\sigma^{domain}}$ and $\varphi(\mathscr{M})$ is elementary equivalent to $\mathscr{N} |_{\sigma(T^{foundation})}$. Thus, T has signature $\sigma(T^{foundation}) \cup \sigma^{domain}$.

$\Leftarrow$:)

Suppose $Th(\mathfrak{M}^{domain})$ and $T^{foundation}$ are conservatively extended by $T^{foundation} \cup R^{foundation}$. By Theorem 4 of [7], $T^{foundation} \cup R^{foundation}$ is a conservative extension of $Th(\mathfrak{M}^{domain})$ iff every structure $\mathscr{M}_1$ in $\mathfrak{M}^{domain}$ is elementarily equivalent to a structure $\mathscr{N}$ that can be expanded to a model $\mathscr{M}_2$ of $T^{foundation} \cup R^{foundation}$. By Definition 3, $\mathfrak{M}^{domain}$ is definable by $T^{foundation} \cup R^{foundation}$.

Because $T^{foundation}$ itself is conservatively extended by $T^{foundation} \cup R^{foundation}$, every model of $T^{foundation}$ is elementarily equivalent to a structure $\mathscr{N}$ that can be expanded to a model $\mathscr{M}_2$ of $T^{foundation} \cup R^{foundation}$. Thus, By Definition 3, $\mathfrak{M}^{domain}$ is definable by $T^{foundation}$. □

The sentences in $R^{foundation}$ correspond to the domain-specific axioms by which the foundational ontology is extended to axiomatize $\mathfrak{M}^{domain}$. Using the terminology of [8], $R^{foundation}$ is the residue of $T^{foundation} \cup R^{foundation}$.

Theorem 1 shows the conditions under which foundational ontologies are sufficient to axiomatize a domain ontology. We next consider whether domain ontologies can be axiomatized without the foundational ontologies.

Question 3. *Are foundational ontologies necessary for axiomatizing the class of intended structures $\mathfrak{M}^{domain}$ or can they be axiomatized using only a theory in the signature σ^{domain}?*

The next Theorem shows that the answer to this question is based on the distinction between elementary and pseudoelementary classes of structures.

Theorem 2. *Suppose that the foundational ontology $T^{foundation}$ axiomatizes $\mathfrak{M}^{domain}$.*

If $\mathfrak{M}^{domain}$ is an elementary class, then there exists a theory T^{domain} in the signature σ^{domain} that is elementarily equivalent to $Th(\mathfrak{M}^{domain})$.

Proof. Suppose that $T^{foundation} \cup R^{foundation} \cup T^{domain}$ axiomatizes $\mathfrak{M}^{domain}$, but without the axioms of the foundational ontology, T^{domain} will have unintended models (in the signature σ^{domain}). We will show that this claim is false.

Suppose $\mathscr{N} \in Mod(T^{domain})$ but $\mathscr{N} \notin \mathfrak{M}^{domain}$, that is, $\mathscr{N}$ is an unintended model of T^{domain}. There is a sentence φ in signature σ^{domain} such that for all $\mathscr{M} \in \mathfrak{M}^{domain}$

$$\mathscr{M} \models \Phi$$

$$T^{domain} \not\models \Phi$$

However, since $T^{foundation} \cup R^{foundation} \cup T^{domain}$ axiomatizes $\mathfrak{M}^{domain}$, we have

$$T^{foundation} \cup R^{foundation} \cup T^{domain} \models \Phi$$

and $T^{foundation}$ is not a module of $T^{foundation} \cup R^{foundation} \cup T^{domain}$,
contradicting Theorem 1. □

This Theorem shows us that a domain ontology with an elementary class of intended models is standalone insofar as it is sufficient for axiomatizing its class of intended models. In the context of a foundational ontology, there might be unintended models, that is, there might exist unintended models of $T^{foundation} \cup R^{foundation} \cup T^{domain}$. Such models can be eliminated only by extending the residue $R^{foundation}$, since both $T^{foundation}$ and T^{domain} are modules.

On the other hand, if the class of intended models for the domain ontology are not elementary but rather form a pseudoelementary class, then any axiomatization of the intended models requires a theory with an expanded signature, and the foundational ontology is needed.

4. Modularity of Domain Ontologies

If a foundational ontology is used to axiomatize a domain ontology, a question arises on whether or not this impedes the sharability and reusability of the domain ontology.

Question 4. *Can $\mathfrak{M}^{domain}$ be axiomatized using different foundational ontologies?*

Although it is common to align existing domain ontologies with different foundational ontologies, this is typically thought of as an ontology mapping exercise rather than ontology design. However, the results of the preceding section tell us that we should instead think of this as a problem of ontology modularization.

4.1. Modularizing an Existing Domain Ontology

It is easy to see from Theorem 1 that $\mathfrak{M}^{domain}$ is axiomatized by distinct foundational ontologies $T_1^{foundation}$, $T_2^{foundation}$ iff there exist theories T_1,T_2 such that

- $T_1^{foundation}$ and $Th(\mathfrak{M}^{domain})$ are modules of T_1,
- $T_2^{foundation}$ and $Th(\mathfrak{M}^{domain})$ are modules of T_2.

that is, $Th(\mathfrak{M}^{domain})$ is a module of both theories T_1 and T_2.

We can treat the domain ontologies as modules in a larger ontology that imports the foundational ontology of one's choice. For example, let $T_1^{foundation}$ and $T_2^{foundation}$ be two foundational ontologies, and let T^{domain} be the axiomatization of the domain ontology using only the signature σ^{domain} (i.e. this axiomatization contains no classes or relations from any external ontologies, including any foundational ones). For each combination of T^{domain} and a foundational ontology, there will be a residue, that is, a set of sentences in the combined signature that are used to "bridge"/"align" T^{domain} with the foundational ontology.

Let R_1 be the set of such sentences with respect to $T_1^{foundation}$ and let R_2 be the set of such sentences with respect to $T_2^{foundation}$. Since T^{domain} is a module of both $T^{domain} \cup R_1 \cup T_1^{foundation}$ and $T^{domain} \cup R_2 \cup T_2^{foundation}$, both axiomatizations agree on the set of sentences in the signature σ^{domain}.

We can illustrate this with the Semantic Sensor Network (SSN) Ontology [9]. The axiomatization of the SSN Ontology is included what the designers considered to be an alignment with DOLCE-Ultralite as a way to make their ontological commitments explicit. The signature of the SSN Ontology is comprised of 41 unary relations (classes) and 39 binary relations (object properties). The SSN Ontology can be decomposed into a module T^{ssn} corresponding to the SSN signature (which is equivalent to the ontology depicted in Figure 1 of [9]), a module consisting of DOLCE-Ultralite, and a residue R_{dolce}^{ssn} consisting of sentences in the combined signature.

The case of Event-Model F [10] illustrates the importance of understanding the intended models. This ontology is axiomatized as an extension of DOLCE-Ultralite+DnS, rather than the full first-order theory of the DOLCE Ontology. The only nontrivial module with the signature of the domain ontology is the axiomatization of the taxonomy, and there are few additional axioms. However, the ontological commitments of this ontology are debatable, as it treats events as social objects, which is quite different from other foundational ontologies.

4.2. Implicit Specification of Intended Models

In some cases, there is no explicit specification of the intended models $\mathfrak{M}^{domain}$; instead, a foundational ontology is used to write axioms that are implicitly satisfied by the intended models. How does such an approach work if multiple foundational ontologies are used?

We begin by taking a closer look at the relationship between the foundational ontology and domain ontology.

Theorem 3. *Let $T^{foundation}$ be a foundational ontology and let R be a set of sentences in the signature $\sigma(T^{foundation}) \cup \sigma^{domain}$.*

If $T^{foundation} \cup R$ is consistent, then there exists a unique (up to logical equivalence) theory T^{domain} in the signature σ^{domain} such that $Mod(T^{domain})$ is definable by $T^{foundation}$.

Proof. Suppose $T^{foundation} \cup R$ is consistent.

There exists a unique (up to logical equivalence) theory T^{domain} in the signature σ^{domain} which is the strongest theory such that

$$T^{foundation} \cup R \models T^{domain}$$

It is easy to see that T^{domain} is conservatively extended by $T^{foundation} \cup R$.

By Theorem 1, $Mod(T^{domain})$ is definable by $T^{foundation}$. □

Since $T^{foundation} \cup R \cup T^{domain}$ is a conservative extension of T^{domain}, we will refer to T^{domain} as the domain module for $T^{foundation}$. By Theorem 3, we can assign a domain ontology with signature σ^{domain} to each foundational ontology.

Theorem 4. *Let $T^{foundation}$ be a foundational ontology and let R be a set of sentences in the signature $\sigma(T^{foundation}) \cup \sigma^{domain}$.*

If T^{domain} is the domain module of $T^{foundation}$ and $T_i^{domain} \leq T^*$, then $T^{foundation} \cup R_i \cup T^*$ is a conservative extension of T^*.

Proof. By Theorem 3, T^{domain} is the maximal module of $T^{foundation} \cup R$ with signature σ^{domain}, so that $T^{foundation} \cup R \not\models T^*$ and for any sentence Φ in signature σ^{domain}, $T^{foundation} \cup R \models \Phi$ iff $T^* \models \Phi$, and $T^{foundation} \cup R \cup T^*$ is a conservative extension of T^*. □

We can therefore extend the domain module for $T^{foundation}$ with sentences in the signature σ^{domain} to create a new ontology that is also a module of the ontology that extends $T^{foundation}$.

Now suppose that we have a set of different foundational ontologies $T_1, ..., T_n$. Remember that we are evaluating the use of foundational ontologies $T_1, ..., T_n$ for proposing the axioms in T^{domain} – we are not comparing the foundational ontologies themselves. Furthermore, the challenge is with the axiomatization of the intended models of T^{domain}, not the intended models of $T_i \cup R_i \cup T_i^{domain}$ for some foundational ontology T_i. This problem is not solved by selecting a particular foundational ontology, but rather by determining the intended models of T^{domain}. The question is therefore – how are these these ontologies related to the unique theory T^{domain} that axiomatizes the intended semantics of the signature of the domain?

For each foundational ontology T_i, there will axioms R_i that are used to either provide conservative definitions for domain terms or to extend T_i with axioms that constrain the interpretation of domain terms. Let T_i^{domain} be the strongest theory in the signature of T^{domain} such that

$$T_i \cup R_i \models T_i^{domain}$$

Given a set of foundational ontologies T_i, how are the ontologies T_i^{domain} related to each other? From Theorem 3, it is straightforward to observe that for two foundational ontologies T_1, T_2, exactly one of the following cases must hold:

1. T_1^{domain} and T_2^{domain} are logically equivalent.
2. T_1^{domain} and T_2^{domain} are mutually inconsistent, and there exists a similarity T_0^{domain}.
3. T_1^{domain} and T_2^{domain} are independent of each other, and there exists an ontology T_0^{domain} that is a consistent extension of T_1^{domain} and T_2^{domain}.

The problem is that in general the T_i^{domain} will all be different from each other, so that it appears that there is no agreement on a common ontology T^{domain}. However, this problem is not solved by selecting a particular foundational ontology, but rather by determining the intended models of T^{domain}. The question is therefore – how are these these ontologies related to the unique theory T^{domain} that axiomatizes the intended semantics of the domain terminology? Considering the task of evaluating the relationship between T_i^{domain} and T^{domain}, there are four cases:

1. If T_i^{domain} is weaker than T^{domain}, then there exist unintended models of T_i^{domain}. We can extend T_i^{domain} as appropriate with sentences in the signature of T^{domain} to eliminate these unintended models. Furthermore, it follows that this extension is consistent with the foundational ontology T_i.
2. If T_i^{domain} is stronger than T^{domain}, then there exist omitted models of T^{domain}. This is a problem, unless $T_i \cup R_i$ can somehow be weakened to allow these models, and hence be equivalent to T^{domain}.
3. If $T_i^{domain} \cup T^{domain}$ is inconsistent, then we have a big problem – the foundational ontology $T_i^{foundation}$ cannot be used with the domain ontology T^{domain}.
4. If T_i^{domain} and T^{domain} are independent of each other, then their combination will be too strong (and omit models of T^{domain}) but their similarity will be too weak (and have unintended models). This is a problem similar to the second case – since omitted models exist, we cannot simply extend the foundational ontology, but rather must find a subtheory (which will lead to the introduction of unintended models of the foundational ontology).

These four cases are objective ways of determining the adequacy of an foundational ontology T_i for axiomatizing the intended semantics of the domain signature. Note that in only one of these cases is T_i adequate (i.e. the case in which T_i^{domain} is weaker than T^{domain}); all of the other cases have problems. Furthermore, the relationships between the T_i^{domain} (and the foundational ontologies T_i in general) are irrelevant. A foundational ontology is adequate if and only if T_i^{domain} can be extended to T^{domain}.

5. Reusability

One of the purported benefits of a foundational ontology is that domain ontologies axiomatized by the same foundational ontology are sharable and reusable. Since we have already seen that a domain ontology can be axiomatized by different foundational ontologies, we need to determine whether reusability is still supported.

Question 5. *Is the adoption of a single foundational ontology for the axiomatization of T^{domain} necessary to for semantic integration?*

An adequate answer to this question requires a formal definition of semantic integration.

Definition 4. *Two ontologies T_1, T_2 are semantically integrated iff there exists a faithful interpretation of T_1 in T_2 and a faithful interpretation of T_2 in T_1.*

For domain ontologies that are axiomatized by different foundational ontologies, we cannot satisfy this definition of semantic integration unless the foundational ontologies themselves are mutually faithful interpretable. For foundationless ontologies, we have the following more restricted notion of integration as a straightforward consequence of Theorem 1:

Theorem 5. *Suppose $\mathfrak{M}^{domain}$ is axiomatized by both an extension T_1 of the foundational ontology $T_1^{foundation}$ and by an extension T_2 of the foundational ontology $T_2^{foundation}$.*

For any sentence $\Phi \in \sigma^{domain}$,

$$T_1 \models \Phi \Leftrightarrow T_2 \models \Phi$$

In other words, both ontologies agree on sentences with the signature of the domain ontology, so that we have a form of partial semantic integration that is restricted to the domain ontology but which does not carry over to the foundational ontologies themselves.

6. Conclusions

In this paper we have proposed an approach to designing domain ontologies in a manner that does not require a commitment to a particular foundational ontology, while at the same time allowing people to use whatever foundational ontology they like without the need for merging or prior harmonization of any foundational ontologies. Although this has the benefit of improving the sharability and reusability of domain ontologies, we conclude this paper by addressing some of the limitations of the approach.

One problem is the specification of the intended semantics of the domain ontology without using a prior set of ontological commitments. Users often employ a foundational ontology with which they are familiar when articulating the intended semantics of their terminology. Even the competency questions that they pose can be contain an implicit bias to one foundational ontology or another. This was evident with Event Model F, in which there seems to be no specification of the intended semantics of events that is independent of DOLCE Ultralite+DnS.

Another question is the scope of the foundational ontologies – which concepts belong to a foundational ontology and which belong to a domain ontology? For example, do any axioms about the ordering of timepoints and the relationship to time intervals form a module of the foundational ontology? If they do not, can be they be considered to be part of the domain ontology? This related to the question of whether or not foundational ontologies can be partially reused – can modules from different foundational ontologies be combined together to form a new foundational ontology? Such radical modularity would allow more flexibility in applications where independently designed ontologies need to be used together (e.g. OWL-Time together with DOLCE, SUMO, or BFO).

Is the foundationless approach best applied to existing ontologies for analysis and to facilitate integration with other ontologies or is it best used to design new domain ontologies to ensure that they are sharable and reusable with multiple foundational ontologies? Our claim is that we can use the foundationless approach at design time to ensure that the domain ontology is sharable and reusable with multiple foundational ontologies. If a domain ontology has been designed without the use of a foundational ontology, it might be the case that the foundationless approach arrives at the same solution as those efforts that align the ontology with existing foundational ontologies.

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