philosophies

Article

Matching a Trope Ontology to the Basic Formal Ontology

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Received: 19 May 2019; Accepted: 15 July 2019; Published: 18 July 2019

Abstract: Applied ontology, at the foundational level, is as much philosophy as engineering and as such provides a different aspect of contemporary natural philosophy. A prominent foundational ontology in this field is the Basic Formal Ontology (BFO). It is important for lesser known ontologies, like the trope ontology of interest here, to match to BFO because BFO acts like the glue between many disparate ontologies. Moreover, such matchings provide philosophical insight into ontologies. As such, the core research question here is how we can match a trope ontology to BFO (which is based on universals) and what insights such a matching provides for foundational ontology. This article provides a logical matching, starting with BFO's top entities (continuants and occurrences) and identifies key ontological issues that arise, such as whether universals and mereological sums are equivalent. This article concludes with general observations about the matching, including that matching to universals is generally straightforward, but not so much the matching between relations. In particular, the treatment of occurrences as causal chains is different in the trope ontology, compared to BFO's use of time arguments.

Keywords: ontology; BFO; tropes; applied philosophy

1. Introduction

The field of applied ontology came to prominence in the 1990s [1,2], driven by knowledge engineering issues. In order to achieve coherent and shareable knowledge bases, engineers and scientists sought answers to questions in essence like "what is the meaning of a physical quantity?" [3] or "what exactly constitutes a gene?" [4]. The similarity to questions raised in philosophical ontology was readily apparent [5], opening up the possibility of joint engineering and philosophical ontology research.

Arguably, applied ontology is not merely the application of philosophy *to* other disciplines like engineering. Rather, the discipline also informs philosophy itself—at the very least by raising new questions about the existence of things, but hopefully also by novel approaches and answers to those questions. As such, applied ontology is one pathway in the journey of reconstituting a natural philosophy, in the sense of Dodig-Crnkovic and Schroeder's connected conceptual engineering [6].

The interaction with philosophical ontology is especially visible at the foundational ontology level. Foundational ontologies[1] deal with fundamental aspects of our world, such as "material objects", "events", "being part of" and so forth. They underpin ontologies of particular domains such as biomedicine or information systems [2,7] (pp. 115–139).

Currently, one of the most prominent foundational ontologies is the Basic Formal Ontology (BFO) [8]. BFO is a realist ontology, based on a relatively small set of universals and relations[2]. That is, BFO asserts that the (real) universe can be carved up into universals such as *objects*, *processes*,

[1] Also called "upper ontologies".
[2] BFO includes relations (as per the specification), but these are as yet not included in the bfo.owl file. The discussion here refers to the specification.

boundaries and *qualities*. By "universals", BFO means " ... what all members of a natural class or natural kind such as a *cell*, or *organism*, or *lipid*, or *heart* have in common ... not only in the realm of natural objects such as enzymes and chromosomes, but also in the realm of material artifacts such as flasks and syringes, and also in the realm of information artifacts such as currency notes and scientific publications" [9] (p. 13). BFO has been successful in supporting engineering and scientific research in areas such as genetics, information systems and defence [10].

In previous work on the ontology of competitive intelligence [11], I developed a core ontology based on particularized relations, or *tropes*, which are fundamentally different from the universals that BFO is based on (discussed in detail below). It is beyond the scope of this article to review the arguments for and against tropes (of which there are many flavors), suffice it to say that tropes are prominent in ontological theory that addresses the nature and quantity of properties (like being "a chair" or "being red") [12]. At the applied level, tropes as particularized relations provide a way to connect causes to the structural relations that define entities, providing a seamless foundation for both entities and causality [11]. From either perspective, universals vs. tropes is a core ontological commitment.

The previous work compared the trope ontology to several other ontologies, but not BFO. Given the prominence of BFO, it is important for lesser known ontologies such as the trope ontology to provide at least some comparison, but preferably a "matching" to BFO. This is important because foundational ontologies often act as the "glue" to connect disparate domain ontologies and, if a matching is possible, it would link the trope ontology to the wider world of ontologies based on BFO. Moreover, given the subject matter of foundational ontologies, discussion of such matchings informs philosophical ontology—albeit with a constructive, rather than critical emphasis.

Matching is commonly defined as "the process of finding relationships or correspondences between entities of different ontologies" [13] (p. 39). I include in this looking for points of similarity, where terms in one ontology can be coherently defined in terms of another. As such, "matching" reflects a perspectivist stance towards ontology. That is, it recognizes that different ontologies may reflect different aspects or viewpoints of reality (including perhaps some level of denial of that reality).

In summary, this article examines how the trope ontology was matched to BFO and what ontological insights we might obtain from such a matching. The next section will briefly outline the trope ontology and the remaining sections will match core terms of the trope ontology to BFO. In the conclusion, I will provide some general observations about the results of the matching and the relationship between the two ontologies.

2. The Trope Ontology

Given the relative obscurity of the trope ontology, I will provide a brief overview here. For more detail, see my previous research [11].

The trope ontology is grounded in a view that relations between entities are real and exist primarily as individual relations, rather than universal relations. For example, when John stands next to Jane, it is not just John and Jane who exist, but also the relation of John's standing next to Jane. If John is also standing next to Jake, then that "standing next to" has a distinct existence from the "standing next to" of John and Jane. Moreover, these individual "standing next to" relations cannot exist without the entities that they bind. This strong dependence of relations on their relata supports calling such entity/relation constructions "tropes", although it represents only one view of tropes [12]. Philosophically, I have defended tropes by following Armstrong's reasoning [14] towards particularized universals, but rejecting Armstrong's argument that "states of affairs" are needed to bind relations to objects [11] (pp. 29–30). In this way, particularized relations (tropes) become an alternative theory that underpins relational realism. At the applied level, this results in individually identifiable relations, which provide a very convenient way to implement change and causal relations (discussed below).

Methodologically, I try to adhere to parsimony and minimize the different kinds of relations that are admitted into the ontology, if for no other reason than the effort required to carefully examine each relation for coherence in the ontology. On the other hand, one typically tries to choose relations that are as expressive as possible—i.e., relations with which one can say or represent as much as possible. So, the key principle of parsimonious expressiveness (or "say the most with the least") guides much of the work in the trope ontology. As such, the trope ontology is based on two main kinds of relations: mereological parthood and a primitive causality relation that ranges over the parthood relations. The semantics and formal properties of these relations are as follows.

The two primitive relations are represented with a simple predicate schema:

$$p(N, part, X, Y), \tag{1}$$

$$p(M, cause, A, B), \tag{2}$$

Here, N and M represent unique identifiers for each relation, typically constructed as a list of numerals[3]. The second argument in the predicate is the kind of relation (e.g., part or cause) and the remaining arguments represent the entities that the relation binds.

A small digression is needed on the meaning of "kind of relation" in the context of trope theory. At first glance, it seems that "kind" introduces universals again. For instance, each individual parthood relation seems to instantiate a universal parthood. Might this not undermine the supposed "fundamental difference" (asserted in the introduction) between the trope ontology and a universal-based ontology like BFO? The short answer is "no", for the following reasons. Firstly, these are not the universals you are looking for. BFO distinguishes between universals (i.e., what members of certain classes of entities have in common) and relations such as "instantiates" or "has participant" [8] (p. 7). There is a sense in which universals in BFO are more complex entities (e.g., *cells*, *flasks* or *currency notes*) than the comparatively bare relations. Secondly, even if we admitted that relations have characteristics like universals, it does not oblige a trope ontologist to commit to relations *as universals*. There are two common realist options other than universals [12]. One is to posit resemblance as primitive, so that tropes are *resembling tropes* without having to distinguish "resemblance" from a relation like parthood. An alternative option is to posit a higher order resemblance relation, which avoids vicious regress by supervening on "lower level" particulars. The trope ontology is based on the former (i.e., *resembling tropes* as primitives) as it is the simpler of the two. In case "simplicity" seems like an inadequate justification, it should be noted that a choice of "primitives" needs to be accepted, at some level, in any ontology. Moreover, primitives are preferred where they reduce the number of ancillary ontological commitments needed (i.e., commitments that are needed only to maintain coherence, rather than to do the main "definitional" ontology work). Arguably, this is based on no more than a philosophical stance away from an "overpopulated universe [that] is in many ways unlovely" [15], but I shall nevertheless let it rest on that.

The specific kinds of relations and their arguments can be expanded for particular domain ontologies, but the core of the trope ontology has at least the parthood and causal relations. The parthood relation is formally defined through the axioms of General Extensional Mereology [16] (pp. 31–37). Note that I interpret general sums here as any collection of individuals under some meaningful relation, and not arbitrary collections [11] (p. 73), leaving the discussion of "meaningful" to individual cases.[4] Furthermore, it is important to understand parthood in a general sense in the trope ontology. For example, John's hand is part of him and therefore part of John's family, even though the hand is arguably part of John in a different way than John's being part of his family. However, the meaning of parthood is understood in the context of the relata of *hand* and *family*. This approach follows Eschenbach and Heydrich [17] by combining a general mereology with restricted domains.

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3 The use of lists of numerals as identifiers helps with the inference of transitive relations. For example, if we have p([1], part, a, b) and p([2], part, b, c), then we can infer p([1,2], part, a, c), where [1,2] represents the unique identifier for the a-c parthood relation.

4 This stipulation supports a matching to the universals, discussed later.

The causal relation is transitive, irreflexive, anti-symmetric and ranges over parthood relations (and possibly other relations, if such relations exist within a specific domain ontology that is based on the trope ontology) [11] (pp. 86–96). The justification of causal primitives follows the reasoning of causal singularists like Richard Taylor [18], who argue that causality like "the fire started because of the lightning" has a stronger connection than mere constant conjunction (like "the fire started and there was lightning"). Moreover, singularists would also argue that the laws or rules that are often posited as underpinning causal relations merely describe the very causal relations that exist in the world [11] (pp. 86–90). In the trope ontology, we end up with a primitive causal relation that ranges over other relations—in particular over the individual parthood relations. The causal relation in the trope ontology should be understood as a "simple" relation that merely represents a linkage between an antecedent situation and its consequential situation in terms of the primitive relations (e.g., parthood) that the causal relation ranges over. This means that, in contemporary language, relations that are not ordinarily thought of as "causes" may indeed be causes in the ontology. For example, if John intentionally moves from Sydney to Melbourne, then both his intention and his prior being in Sydney are causal antecedents to his being in Melbourne. The way that John's being in Sydney is a causal antecedent to his being in Melbourne is similar to Aristotle's material cause, whereas John's intention is more aligned with a final cause [19] (94b.3).

The causal relations are *replacement* relations, in that the consequence replaces the antecedent. For example, if "John's being part of Sydney" causes "John's being part of Melbourne" then "John's being part of Sydney" no longer exists[5] at the end of that causal chain. This also applies in cases where arguably the antecedent could persist. For example, if "John's desire to be in Melbourne" causes him to be in Melbourne, it might be that his desire persists even when he is in Melbourne. Insofar as the causal relation reflects a change between situations, we must decide that either relations persist from the antecedent by default, or that they perish by default. The physical world indicates that antecedents are replaced by their consequent, therefore relations perish by default. For example, the relation of "John being in Sydney" perishes in the causal process. However, this implies that persistent antecedents must be explicitly renewed as additional consequences. Thus, if John's desire causes him to be in Melbourne and his desire persists, then, in order to persist, his antecedent desire must also cause (i.e., renew) his further desire. There is a certain level of representational choice in this part of the ontology, because one could assert persistence as the default representation (with explicit assertion of perishing relations). For example, in the case where John's walking and his intention to walk cause him to (keep) walking, one might argue that the physical situation persists by default. However, it seems that linguistically at least, we tend to interpret physical relations as perishing under causation, and this is what the trope ontology orients on.

The trope ontology is further extended with support for multiple worlds, represented with additional structure in the identifiers. For example, p([w:1], part, john, kitchen) might represent the relation that john is in the kitchen in world w (where w stands for some identifier). These multiple worlds form the basis for a modal description of the ontology, where we can talk of "possibility" and "necessity" [11] (pp. 108–114). In this case, I use the causal relation as the *accessibility relation* between worlds [20]. For instance, if John currently is in one room of a house, then it is possible that John can be in another room by asserting that John's being in one room (in the current world) is cause for John's being in another room (in another world). The stipulation of different worlds enables us, in this case, to interpret "cause" modally as "may cause". Note that using the causal relation as the basis of accessibility means that the ontology can only support a modal logic that stops short of *normal modal logic* ("S5" in Kripke semantics [20]). Rather, the modal logic that is supported is S4 plus anti-symmetry.

Worlds also support the representation of informational states of entities. That is, the content of such an informational state—i.e., the *information*—can be represented with the same kinds of predicates

[5] "exists" in the sense of John's location in the physical world.

as used for the rest of the ontology, but isolated in their own world. For example, we might represent that John is thinking about being in Melbourne as,

p([0:1],part, thinking(1), 'John').
p([1:10], part, 'John', 'Melbourne').

The representation uses "reserved" functional terms such as thinking (1) to refer to an informational state, the *content* of which is represented by the predicates with the world indicator (1). Predicates with different world indicators are isolated from each other. It is only the informational state (in this case, "thinking") as a whole that exists as part of John, not the relations within the informational state. This isolation is necessary to avoid that whatever John thinks also automatically exists in the world outside his thoughts. So, just because John *thinks* he is in Melbourne, does not mean he *is* in Melbourne—his thinking and the physical universe are two different worlds. Assertion of informational states provides the pathway for defining core elements of the sociotechnical domain ontology that the trope ontology was first concerned with. That is, agentive "intentions" are defined as information states of some entity (i.e., the agent). Those information states (e.g., the state of neurons, or the magnetic state of electronic memory) may cause subsequent situations in the world.

The trope ontology is not only particularist in its view of relations, but also particularist in scope and intent. That is, trope ontologies will typically be limited to particular domains or investigations. The aim is not that such ontologies are complete in their own right but can be used as modules in a network of ontologies. Moreover, there is allowance for enhancements or even corrections of ontologies. As such, ontological inferences on a certain domain ontology that is based on the trope ontology will necessarily be limited to that domain ontology. To put it another way, inferences for a particular ontology do not necessarily hold when that ontology is changed, or when other ontologies are added. However, that limitation also enables us to make a simplifying[6] "closed world" assumption for inferences on the ontology. That is, any inferences are particular to a specific ontology and do not extend beyond unless explicit linking is asserted.

The trope ontology was intended as a foundation for constructive exploration of ontology, where one adds elements to the ontology based on particular cases. That is, in exploring the ontology of a domain, one starts by attempting to describe particular cases or examples of situations or states of affairs in that domain. Such attempts will highlight the kinds of entities and relations that an ontology needs to represent. The core of the trope ontology provides the scaffolding of basic relations that is suggestive of how as yet undefined terms or relations might work. For example, we might begin investigating an ontology of migration by trying to express John's intended move between cities. With parthood, causation and informational states we might attempt a simple version like, "John is part of Melbourne, because John was a part of Sydney; and John intended that John will be a part of Melbourne." So far, the example ontology is severely incomplete. That is, entities like John and the cities are captured as undifferentiated entities in the ontology. Similarly, we are using a generic relation like parthood only to capture the general idea of what is happening in this case, but we would likely need more details to capture the semantics of "existing in a city". However, it is exactly these attempts at definition with a minimal ontology that reveal where more definition is needed, and thus supporting an iterative process of construction, inferential testing, and elaboration of the ontology.

At the practical level, the trope ontology is implemented as a logic program, with utilities to convert to other formats. In particular, programs are available to convert to and from "controlled natural language" statements [21]. Sentences like the one above (John's move) can be entered as plain text and are then converted to collections of predicates that comprise the ontology.

[6] Simplifying in the sense of making one closed world assumption for the ontology, rather than asserting for example the scope of each class. An overall closed world assumption also enables efficient inference in certain logics, such as the logic programming language Prolog.

3. From Tropes to Universals

In BFO, "an entity is anything that exists. BFO assumes that entities can be divided into instances (your heart, my laptop) and universals or types (*heart*, *laptop*)" [8] (p. 6). In other words, for BFO, a type like *heart* is as real as the numerous hearts that instantiate it. The trope ontology is also realist in its stance. However, in the trope ontology your heart's relationship to your body has a distinct existence from Jane's heart's relationship with her body. In contrast, BFO views the property of your heart being a *part of* your body (at some time) as the exact same "part of" property as Jane's heart being *part of* her body[7]. Given this difference between the trope ontology and BFO, we now face the question of how to match the different accounts of reality that BFO and the trope ontology present.

There are two problems here: one is how to match tropes to general relations and, secondly, how to match certain particularized tropes to the universals of BFO. Note that we are just aiming for matching one ontology to another and not a justification of one ontology versus the other. However, a matching, if successful, will hopefully underpin a philosophy of reconciliation on these points.

Mereology, the theory of parts and wholes, provides a way to get from particular relations to general relations. That is, we could match general relations, such as *part of* used in BFO, to sums (collections) of all the particular tropes (such as your heart being part of your body and John's heart being part of his body) used in the trope ontology[8]. What matching does in this case is to acknowledge that in BFO there exists a *general* relation, but such a general relation does not exist in the trope ontology—and yet, wherever BFO's *part of* is applied, a *part of trope* can be understood to exist (from a tropist viewpoint). This is not an extensional equivalence, because for every *a being part of b*, BFO counts three things (*a*, *b* and *part of*)[9], whereas the trope ontology counts only one (*a being part of b*). However, we can match one such trope to a corresponding BFO structure of *a being part of b*, without having to compromise either ontology's philosophical principles (i.e., without having to commit to unacceptable entities in either ontology).

A similar use of mereological sums also provide a partial pathway to universals. The general extensional mereology discussed above allows for the existence of any collection of entities under some relation. For instance, in the trope ontology, objects would exist as the collection of individual objects, on the assumption that there is a particularized relation of " … is an object" for every individual object. If we assume that tropes like "x is an object" exist, then the matching to BFO's universal *object* can proceed in the same way as the matching of relations like "part of". However, many such "relations" (e.g., BFO universals such as *object*, *process*, *quality*) do not exist in our sparse trope ontology. On the other hand, we can easily assert in the trope ontology that "x is part of objects", by using the existing parthood relations. What is missing for matching purposes is the assertion that there is a relation *in virtue of which* x is part of objects. This situation can be solved by simply asserting the existence of such relations. Note that we wo not necessarily add the relations as primitives to our ontology. Rather, for certain sums, we add an additional assertion that there exists a relation under which the individuals become a sum—without necessarily defining that relation in a formal sense. In essence, these are "placemarker" assertions. We'll use the following schema to assert the existence of such covering relations, nominating the functional term "universal" as a reserved term for this purpose:

p([n], part, universal(X), universal(X)).

For example, in BFO the universal *object* is defined as a "maximal causally unified material entity". In the trope ontology, if my watch is asserted as an object, we would use the following predicates to represent this:

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[7] BFO version 2 would define such a property more precisely as continuant_part_of, but our point remains the same.
[8] We have to take care not to fall afoul of self-referential regress, but will not address that detail here.
[9] Actually, it is not entirely clear whether BFO counts "part of". The specification says such relations are not first-class citizens (i.e., entities), but does not say what that means in terms of existence.

p([1], part, 'my watch', objects).

p([2], part, universal(object), universal(object)).

The reflexive declaration of the universal *object* simply establishes the existence of the relation under which the individuals (like my watch) are part of the mereological sum of objects. As such, there is an unstated, but implied and axiomatic inference from the universal (noted as a singular term, *object*) to the corresponding mereological sum (noted as a plural term, like *objects*). The rule can be schematically stated as follows.

$$p(\_, part, universal(X'), universal(X')) \longrightarrow p(\_, part, X, \_) \text{ or } p(\_, part, \_ , X). \tag{3}$$

where X' is the singular form of X[10].

In other words, the trope ontology keeps track of the extension of the universal through the corresponding mereological sum. Thus, the transitive property of the subtype relation of the universal is inferable through the transitivity of parthood relations. For instance, a further assertion that "An object is a material entity", would add the following relations to the ontology:

p([3], part, objects, material-entities).

p([4], part, universal(material-entity), universal(material-entity)).

It can be readily seen that:

- my watch is part of objects,
- objects are part of material-entities
- and there is an (implicit) rule matching objects and material-entities to their respective universals

Therefore, it also the case that, by transitivity of the subtype relation, my watch belongs to the universal *material-entity*.

These assertions of the existence of special relations enables us to consistently match BFO's universals with mereological sums in the trope ontology. Note that BFO, at least in its OWL 2 implementation, uses *classes* in a similar way to keep track of the transitive properties of universals [22].

The account so far enables us to match (mereological) tropes to corresponding general relations and universals. Next, we need to look at the specific universals that BFO commits to.

4. Accounting for Continuants and Occurrents

BFO carves entities into *continuants*, which retain their identity over time, and *occurrents*, which have temporal parts. For example, John (a particular human) remains himself over time (i.e., John is a continuant), but John's life (an occurrent) has different parts from time to time. That does not mean that John exists all the time. John can *exist at* a particular time, but whenever John exists, then he exists entirely as John. On the other hand, John's life has different parts in each time period: he is born, he eats a meal, he has a birthday party, etc. Each of these experiences is an *occurrent part of* his life. To complete this picture, it may also be the case that John (the continuant entity) has different parts at different times. For example, he may have a beard today, but be clean shaven tomorrow—so, something may be *part of* a continuant *at a time*. Occurrents like processes or events may also have parts, but we do not need to specify "at some time", because occurrents come with time built-in, so to speak. In other words, a process stretches over time and any part of that process occupies a fragment of that time. Lastly, we make the connection between continuants and occurrents by allowing an occurrent to *have a participant*. So, John participates in John's life.

[10] Note that the distinction between plural and singular is not formally necessary, but a naming convention maintained for consistency with BFO's naming convention of universals as singular.

By contrast, the trope ontology asserts a primitive causal relation that may exist between entities, or more precisely between relations of entities[11]. So, John's life comprises the sum of causally linked stages of John, where those stages are defined by individual relations. Note that in the trope ontology, a continuant can be the mereological sum of all its parts, without the causal separation of those parts. For example, there may be a relation of "John having a natural right hand" and another of "John having an artificial right hand", with a causal link between them (where one relation replaces the other). In this case, if we *ignore* the causal link, then the mereological sum of John (i.e., the continuant) has both a natural right hand, as well as an artificial right hand—but that seemingly strange sum in the trope ontology only exists when one "sums up" without regard for the causal relations. This overly broad summing up would be tantamount to saying, "what are all the right hands that John has, regardless of time".

The existence of an occurrent without regard of time cannot match to BFO's view of an occurrent existing in its entirety through time. The reason is that parthoods that occur at particular times in BFO are always specified with the temporal designator (e.g., "John's hand is part of John at time t"). As such, one can only get a sum of *John at a certain time*, ensuring the impossibility of a sum of John with *and* without an artificial hand in BFO. Given this disparity in views of what constitutes the sum of John, the matching from the trope ontology to BFO should either exclude parts that are impermanent, or always attach a temporal property to parts.

To illustrate the preceding treatment of events as named causal sequences, consider the following sentences (to avoid noisy punctuation, we are using lowercase names for entities):

john is part of melbourne, because john was part of sydney;

and john intended that john will be part of melbourne.

The process from john was part of sydney upto john is part of melbourne is the move of john.

These sentences translate into predicate form in the ontology text as follows (where terms like "the move of john" are transformed into functions like *move*(*john*) and we assume the existence of certain universals):

p([5], part, john, sydney).

p([1], part, john, melbourne).

p([30:32], part, john, melbourne).

p([31], part, intending(30), john).

p([33], cause, [5], [1]).

p([34], cause, [31], []).1

p([35], part, 'cause*'[[5]],[[1]]), move(john)).

p([37], part, move(john), moves).

p([39], part, universal(move), universal(move)).

Predicate [35] represents the notion that the causal chain is part of an occurrence called the "move of john" (i.e., *move*(*john*) in functional form). We use a special predicate called 'cause*' to indicate that the first argument refers to a chain of relations starting with predicate [5] and ending with predicate [1]. Once the chain of events is a "named" entity, that entity can then be treated like any other entity. For example, the last two predicates reflect that the "move of john" is part of the mereological

[11] Keeping in mind that tropes are an integral complex of a relation and the entities it relates.

sum of *moves*. In other words, John's move is a *move*, where *move* is a universal that ultimately would be an *occurrent* in BFO's terms.

Note that the trope ontology does not use a time argument in its occurrences. Rather, causal chains are demarcated by the events they span. One can calculate a time metric based on the lengths of chains, but we can speak about occurrences entirely without needing explicit time parameters. This means that matching from the trope ontology causal chains to BFO occurrence membership is straightforward, but not so much for matching to participation or parthood relations that have time parameters. At the minimum, we would need to pick a time reference point, but we might also need an explicit causal relation in BFO (if that could be countenanced). Moreover, causal chains allow different time metrics along different chains (think of the mind experiment of the astronaut on a fast extra-terrestrial trip who experiences a different length of time than people on earth). In other words, while we can match to occurrence universals in a straightforward way, the matching of corresponding relations depends on the specific scope of the ontology.

On the other hand, occurrents as causal chains does provide for a straightforward way to implement process boundaries and regions. That is, the relations that demarcate the causal chain can also be used to demarcate process boundaries. The further matching of regions would mirror the matching of immaterial entities that is discussed in the next section.

5. Other Universals

BFO divides continuants into independent, specifically dependent and generically dependent continuants. Independent continuants are either material or immaterial entities, of which the former include common objects like tables, elephants and the like. The latter divides into *continuant fiat boundaries* and *sites*, which support the ontology of things like holes and geographic boundaries [8] (p. 41). Following the process discussed above, all these can be matched straightforwardly from the trope ontology to their respective universals in BFO. For example,

HMAS-Beagle is part of Sydney-harbour.

The hold of HMAS-Beagle is part of HMAS-Beagle and a hold.

A hold is a continuant-fiat-boundary.

The example would be represented by the following predicates, readily seen to be following the same matching principles for universals described above.

p([1], part, 'HMAS-Beagle', 'Sydney-harbour').

p([3], part, hold('HMAS-Beagle'), 'HMAS-Beagle').

p([4], part, hold('HMAS-Beagle'), holds).

p([2], part, universal(hold), universal(hold)).

p([5], part, holds, 'continuant-fiat-boundaries').

p([7], part, universal('continuant-fiat-boundary'), universal('continuant-fiat-boundary').

One aspect about such matchings does need clarification. Namely, the trope ontology would need extra predicates to capture the rules that are part of BFO. For example, material entities cannot be part of immaterial entities. Since the trope ontology is primarily expressed as a logic program (i.e., Prolog), it is a relatively simple matter to add extra predicates that capture such rules. One approach is to implement the rules as constraints that can be checked for an entity. For example, below is a possible constraint on any entity that if it is part of *immaterials*, then it cannot also be a part of *materials*.

constraint(X) ⟵ *part(X, immaterial), not(part(X, material))*.

Specifically, dependent continuants are either a *quality*, such as “the mass of this piece of gold” or “John’s being the biological son of Jane”, or a *realizable entity*, which are either a *role* or a *disposition*. Realizable entities are like qualities but are not always part of the entity that they adhere to. For example, “John’s ability to sleep” is a disposition, because John does sleep, but not always (assuming John is an ordinary person). One can see the same with roles, which are dependent continuants that an entity has due to circumstances and which leave the bearing entity physically unchanged if the role is removed [8] (p. 58). For example, John’s being CEO would be a role. *Generically dependent continuants* are like their specific cousins but can be copied between bearers. For example, the arrangement of chess pieces on a board can be exactly copied to another chess board.

The implementation of such dependent continuants is structurally simple through the use of functional terms. Previous examples, such as “the hold of HMAS-Beagle” already show the use of functional terms. Dependent continuants such as qualities would use functional terms as well. For example, “the temperature of 37-C is part of john” in predicate form would be p([1], part, temperature(‘37-C’), john). However, qualities such as these are only part of their bearers in the most general interpretation of parthood. That is, we can only say in the most general sense that John’s temperature is also part of the mereological sum of all humans (of which John is part). We will probably want more nuance to reflect the nature of dependency. The trope ontology already has an example of generic dependence in the case of informational states. There, we use reserved terms to indicate the special nature of the entity. That in turn enables particular treatment (i.e., logical rules) of informational states. On that foundation of informational states, the trope ontology has previously defined roles as entities in some description (i.e., information) that classify entities in the world [11] (p. 182). However, such an approach is more nominal than in BFO, because it relies on the entities with the information for the role to exist. Nonetheless, the same approach of special terms to represent qualities can be used. For example, we might preface qualities with “quality of”, as in “the quality of the temperature of 37 °C”. This would enable us to recognize qualities for what they are and assure correct inferential rules. This approach follows Eschenbach and Heydrich’s use of restricted domains, mentioned earlier.

6. Conclusions

The trope ontology is oriented towards building up an ontology from individual cases, rather than focusing on universals. Universals, in the sense of entities that form collections under some covering relation, emerge in the trope ontology as entities that need to be talked about as collections and need to be distinguished for some reason from other entities. This reflects more of a “bottom up” approach than BFO. However, it also comprises an approach of developing ontologies of bounded scope. Limiting the ontological scope is something that the trope ontology has in common with BFO.

Matching universals in BFO to corresponding entities in the trope ontology is simple, as long as we formally recognize the existence of universals in the first place (i.e., as covering relations of mereological sums). From that point onwards, being a universal in the trope ontology is essentially a property that certain mereological sums have. If a universal can be wholly defined in terms of parthood (or possibly with additional relations that also exist in a trope ontology for a specific domain), then the universal can be defined in the trope ontology directly using the corresponding covering relation of a mereological sum. Alternatively, the existence of the universal can be asserted without formal definition of its trope relation, perhaps with annotation of the informal definition, as is the case with various universals in BFO.

The matching between the primitive causal relations in the trope ontology and *occurrences* in BFO is more complicated. What is available in the trope ontology is the ability to declare causal chains as entities, where those entities match BFO’s occurrences. However, temporal measures like “time” are secondary inferences in the trope ontology. For example, a point in time would be derived from the length of a causal chain. Therefore, while causal chains can be classed as occurrences, some relations like “being part of X at time t” require specific assumptions about the measurement of time. Moreover, in the trope ontology a continuant is the mereological sum of all its parts, regardless of causal relations.

This is not the case in BFO, because some mereological relations are only specified with explicit time arguments. As such, the matching of continuants that fall under causal relations will need to exclude causally dependent parts.

In general, the trope ontology can relatively simply match to universals in the Basic Formal Ontology, because universals have an extension that can be represented by corresponding individuals in the trope ontology, and because the trope ontology allows for mereological sums under some covering relation, where that covering relation matches the universal. However, since the trope ontology has causal relations that are not part of BFO, the matching of occurrence properties and relations is not as straightforward. With regard to occurrences, the trope ontology can be seen as an ontology of different granularity that can be matched with BFO, but where the matching requires assumptions about the nature of time.

Funding: This research received no external funding.

Acknowledgments: My thanks to Tim van Gelder for helpful review comments. My thanks also to the anonymous reviewers for the many insightful comments.

Conflicts of Interest: The authors declare no conflict of interest.

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