BFO Classifier: aligning domain ontologies to BFO

Chiadika Emeruem[1], C. Maria Keet[1], Zubeida C. Khan[2] and Steve Wang[1]

[1]Department of Computer Science, University of Cape Town, South Africa
[2]Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa

Abstract
Foundational ontologies are known to have a steep learning curve, which hampers casual use by domain ontology developers to use them for domain ontology development. Foundational ontology developers have not provided methods or tools to lower the barriers of uptake beyond offering, at best, a computational version. We investigate an approach to bridge this gap through the development of a decision diagram for BFO, which offers the modeller a series of questions with closed answer options in order to step-wise arrive at a suitable entity to align the domain entity to. This diagram was implemented in a tool, the BFO Classifier, that keeps track of the question and answer trace and with the click of a button the alignment axiom can be added to the ontology. It was evaluated with two BFO-aligned ontologies, which showed that in at least half of the alignment axioms, a more precise BFO entity could be selected, and a minority corrected.

Keywords
Foundational Ontology, BFO, Methods and Tools

1. Introduction

A foundational ontology (FO) may assist domain ontology design, mainly to provide a main structure and to save re-inventing the wheel on core kinds of entities and relations for the ontology. It has been shown experimentally to be beneficial in domain ontology development [1] as well as in other tasks [2]. There is, however, only a limited uptake of FOs in domain ontologies, and of those, mainly BFO [3] for bio-ontologies in the OBO Foundry [4], several ontologies have been aligned to DOLCE [5], and UFO is promoted mainly for conceptual data modelling [6].

From the perspective of ontology developers, a known obstacle to using a FO is that it looks like high start-up costs, due to having to read a substantial amount of documentation and having to learn new terminology. In line with the recent term of “ontology as a service” [7], methods and tools have been developed over the years to assist with FO usage, such as selecting a suitable FO [8], developing a library and comparison that can be queried on-the-fly [9], and a decision diagram and related algorithms for alignments [10, 11]. A decision diagram for DOLCE was embedded in the FORZA method for alignment [11], but its tool is meanwhile defunct, leaving only a paper-based decision diagram. A recently proposed automatic classification [12] also focuses on DOLCE, and perdurant/endurant more broadly.

The Eighth Joint Ontology Workshops (JOWO?22), August 15-19, 2022, Jönköping University, Sweden
emrchi001@myuct.ac.za (C. Emeruem); mkeet@cs.uct.ac.za (C. M. Keet); ZDawood@csir.co.za (Z. C. Khan); WNGSHU003@myuct.ac.za (S. Wang)
0000-0002-1824-4383 (C. Emeruem); 0000-0002-8281-0853 (C. M. Keet); 0000-0002-1081-9322 (Z. C. Khan)

CEUR Workshop Proceedings (CEUR-WS.org)

Since BFO and some of the other FOs (e.g., UFO) exist in several variants, this may further deter novices exploring FO uptake. Also, there are, to the best of our knowledge, no assistive methods and tools for alignment to any of the FOs other than to DOLCE. Some of documentation contains human-readable definitions and examples, as do some of the respective computational versions, but not all, which makes the alignment process more challenging and without user feedback loops to validate candidate alignments.

The need for support for the classification of domain entities to entities in FOs is emphasised in a survey study by Stevens et. al [13]. The results of the study indicate that even for a commonsense domain such as travel, experts have conflicting opinions on the correct classification of an entity. For instance, ontologists incorrectly classify entities for the 'process' or 'process aggregate' classes.

We aim to contribute to fill this gap by designing a decision diagram for aligning one's domain entity to an entity in BFO. Ease and difficulty in question formulation of the decision points among sibling classes shed a different light on the top-level categorisation and the definitions provided. This, in turn, may be of use for refining the ontology, by BFO, or carrying out a similar process for another FO. The decision diagram for alignment was implemented in a tool, called the BFO Classifier, which also shows the trail of choices and it can write the alignment into the OWL file. The diagram was evaluated with two BFO-aligned ontologies to re-assess those alignment axioms. A majority of those alignment axioms would benefit from an update, mostly alignment to a more precise BFO entity, or one in another branch in BFO.

The remainder of the paper is structured as follows. We first touch upon the limited related work in Section 2. The design of the decision diagram for BFO is described in Section 3 and evaluated in Section 4. We conclude in Section 5.

2. Related Work

There has been some work on aligning domain ontologies to foundational ontologies. Notably regarding methods and tools, there is the decision tree, D3 [11] that aligns domain terms to the DOLCE foundational ontology [5]. D3 had been integrated with the Moki Semantic Wiki ontology development tool to automate the integration. However, Moki is currently not functional so there is no tool-based support for this. Another theory-based classification gives insight on how processes within various domains can be classified to BFO occurrents (the entity used to represent entities that unfold over time) [14]. This classification specifically demonstrates that BFO's Occurrent entities can be used to represent scientific data deriving from the measurement of processes of different types such as cardiac events and running.

Another approach to achieve domain classification to BFO ontology is indirect: obtain alignments between DOLCE and other FOs, including to BFO, and thereafter use the D3 decision tree to re-map it. This detour is possible by using the ROMULUS ontology repository [9] and an algorithm to swap the FOs, but it is insufficient as there are just 17 alignments from DOLCE to BFO, and it only considers BFO v1.0. A different step toward automation is the recently proposed deep learning approach for automatic classification into high-level FO categories [12]. It focuses on DOLCE and generic high-level categories rather than all of those in a FO, and thus cannot be used as such for aligning one's ontology to BFO or any other particular FO.

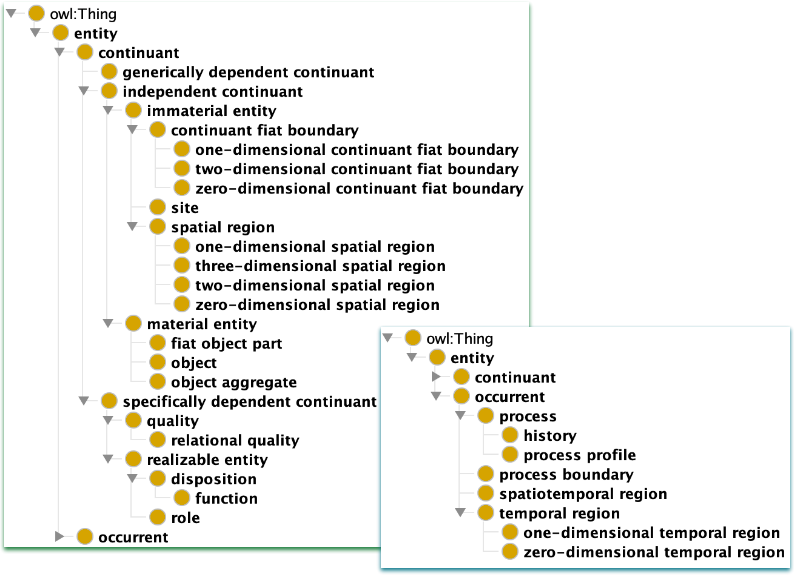

Figure 1: BFO 2.0; left: Continuant expanded; bottom-right: Occurrent expanded.

There are numerous works where ontology developers manually align domain ontologies to a FO, spanning a wide range of domains to FOs, as varied as geology [15], health [16], biology [17], cybersecurity [18] and data mining [19], and, either directly or indirectly, all the ontologies that are, or aspire to be, in the OBO Foundry [4]. There is no way to verify whether all those alignments have been done correctly, other than an 'ask the FO designers', nor is there a fast way to doing so, other than the D3 for DOLCE.

3. Decision diagram design

We describe both the process and the different considerations in devising the decision diagram. The first decision taken concerned the version of "BFO 2", since there are several variants available online. First, there are formalisations in several logics[1], there is a BFO-2020 for ISO standardisation that has a slightly different hierarchy[2] (e.g.: no process profile), and there were draft spin-offs with a BFO v2.1 and BFO that has the Relation Ontology (RO) integrated[3]. We decided to use `bfo2.0.owl`, whose hierarchy is shown in Fig 1.

We devised a procedure upfront and then systematically followed to create the decision diagram for BFO. We used the following process, starting from Entity at the top:

1. At each split of the branch, questions are formulated to determine which child node/path to continue on. The steps repeated at each split are as follows:
   a) Review the definitions provided in the BFO documentation/annotations[4] for each

[1]The wiki at https://github.com/bfo-ontology/BFO/wiki currently lists OWL, OBO, and CLIF.
[2]see the diagram at https://www.iso.org/obp/ui/#iso:std:iso-iec:21838:-2:ed-1:v1:en
[3]One of the authors (MK) has downloaded local copies, but they could not be found online anymore.
[4]https://buffalo.app.box.com/v/bfo-iso-owl-cl/folder/81126451877

child node;

b) Identify the differences between the entities, with help from [3, 20] and Smith's BFO lecture[5];

c) Formulate questions with answers that point to different sub-entities;

This process terminates once all leaf nodes have been reached.

2. Evaluate the diagram with BFO-aligned ontologies.
3. Discuss the questions on understandability with someone who has not developed the questions, and adjust if needed.

To illustrate the process, we provide a walkthrough of the generation of the question that determines whether an entity is an Occurrent or a Continuant. First, the definitions for the respective entities are examined, as provided in the ontology annotations:

Occurrent (Elucidation) An occurrent is an entity that unfolds itself in time or it is the start or end of such an entity or it is a temporal or spatiotemporal region.

Continuant (Elucidation) A continuant is an entity that persists, endures, or continues to exist through time while maintaining its identity.

The next step is to identify the difference between the two entities using these definitions. We can see that an occurrent can be seen as an event or process that occurs over time whereas a continuant is described to be an entity that does not change its identity, and remains over time. The key difference here is the behaviour or difference (in the entity) over time. Hence, the question: "does this entity persist and maintain its identity through time?" If yes, it is a continuant and otherwise an occurrent. As can be seen in this case, the descriptions do not neatly 'mirror' each other to spot key differences: there is a "while maintaining its identity" for Continuant whereas the definition for Occurrent does not say anything about the entity's identity. This suggests a distinguishing factor between the two. An expert will know that occurrents do maintain their identity as well, however, and the real key difference is the persists versus unfolds.

It was also a concern that novice ontology developers might not understand terminologies used in some of the questions such as 'persist in time'. However, it was noted that in previous foundational ontology experiments, novice ontology developers were able to successfully identify correct foundational ontologies for domains using such terminology [8]. Where feasible, we re-used some of the informal wording from the explanatory annotations used in the OWL file of BFO 2.0, such as things possibly being "copied" for Generically dependent continuant.

A different type of challenge emerges when there are multiple direct sub-entities: should that become a single question with three answer options or a two-stage process where first two of them are dealt with and then the other? In case of the subtypes of Continuant—being Independent continuant, specifically and generically dependent continuant—this is straightforward: a two-stage process, since there is an implicit 'dependent continuant' (as unnamed parent of specifically and generically) entity to balance with the Independent continuant. The definitions are clear, too, and the only question is one of terminology and what might be easier to understand for a user who is not intimately familiar with the foundational ontology. Compare,

[5] https://www.youtube.com/watch?v=p0buEjR3t8A

e.g.: “Is [this entity] a property of another entity or requires at least one bearer?” or “Is [this entity] a property of another entity or depends on at least one other entity?”. The latter is, arguably, more accessible. Either way, if the answer is ‘No’, the “[this entity]” is an independent continuant; if the answer is ‘Yes’, it first moves to the next question to help distinguishing between specifically and generically dependent continuant. Conversely, for the first stage of determining the subtype of occurrent, a question with multiple options for answer together with a two-stage process was easier to handle the differences among the four subtypes: first handle the distinctions between temporal, spatiotemporal and the ‘something with processes’ (projection vs portion vs inhabits a spatial region), and then sort out the ‘something with processes’, being process vs process boundary.

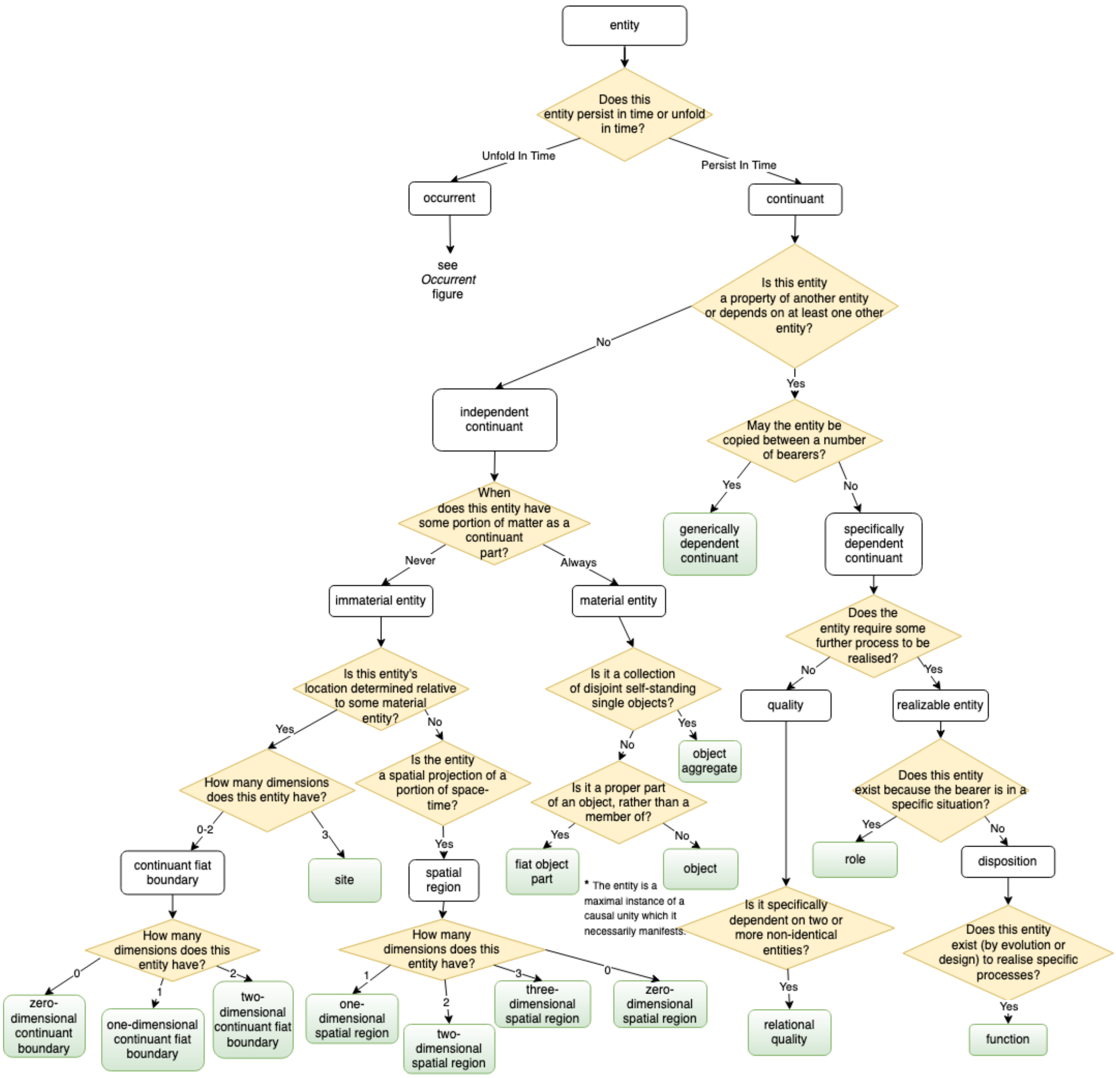

Figure 2: Final BFO 2.0 decision diagram for the Continuant branch, with the leaf entities in green (gradient grey).

The fact that there are several such two-stage steps for selection of the appropriate entity for the domain entity one wants to categorise or align, is theoretically interesting in itself. It raises questions that, perhaps, only the FO developers can answer. Does it mean that there is actually a missing, or 'ghost', entity at an implicit decision point, like the dependent vs independent (and that the predecessor, BFO v1.1, does have)? Is it an incomplete redesign? A mistake? A user of the decision diagram likely will not notice, but that does not answer the question. This issue also appeared in the design, and eventual decision diagram, of D3 for DOLCE [11].

There were design decisions to make regarding 'incomplete' answers, in the sense that an answer could take only one value, where the user would be in a dead end and would have to backtrack if that answer was not applicable. This could be because an entity has only one subtype (e.g., function is the only subtype of disposition) or a multi-stage question series had a verification question on a feature that did not quite fit in the wording of the preceding question. An example of the latter is the attempt at distinguishing between the siblings continuant fiat boundary, site, and spatial region as direct subtypes of immaterial entity. The first separation is between continuant fiat boundary or site vs spatial region, with "Is [this entity's] location determined relative to some material entity?": A 'Yes' for the former and a 'No' for the latter. To then positively choose for spatial region, there is a question on whether it is a spatial projection of a portion of space-time. But what to do on a 'No'? An earlier attempt sent it to site upon answering 'No', and therewith thus second-guessing the mistake a user would have made in the preceding question. Eventually, we decided that, once a user is stuck, they always have to backtrack to the previous question as the *modus operandi* throughout the diagram. Once taken to the previous point, they then can choose to align their domain entity to that FO entity. Only evaluation will tell whether there are common mistakes in answering, and only that will provide some indication on whether that is due to the questions or the hierarchy, and therewith how to address that.

Finally, there were entities for which it was non-trivial to formulate good questions based on the documentation and the annotations, being history and process profile, which are also among the least-annotated entities in the ontology, and to distinguish either from their parent process. Since a history process is easier to identify as one compared to process profile, we first ask the question concerning a history process. Should it not be a history process, we then use the question on disjoint part-processes as a double-checking to determine if it is a process profile (if the answer is 'No', it remains aligned to process). To possibly tighten that section of questions, if it were to be shown to be needed, it may be of use to know whether there are processes that are neither histories nor profiles and if so, why.

For presentation readability, the final diagram is split into two figures, for continuants in Fig. 2 and for occurrents in Fig. 3.

4. Evaluation of the decision diagram

The aim of this evaluation is to determine if the tool can successfully classifies an ontology to BFO. The approach taken is that of use case validation, by using two existing BFO-aligned ontologies and to validate the alignment of existing entities in the domain ontology.

Some questions in the decision diagram were formulated under the assumption that at any

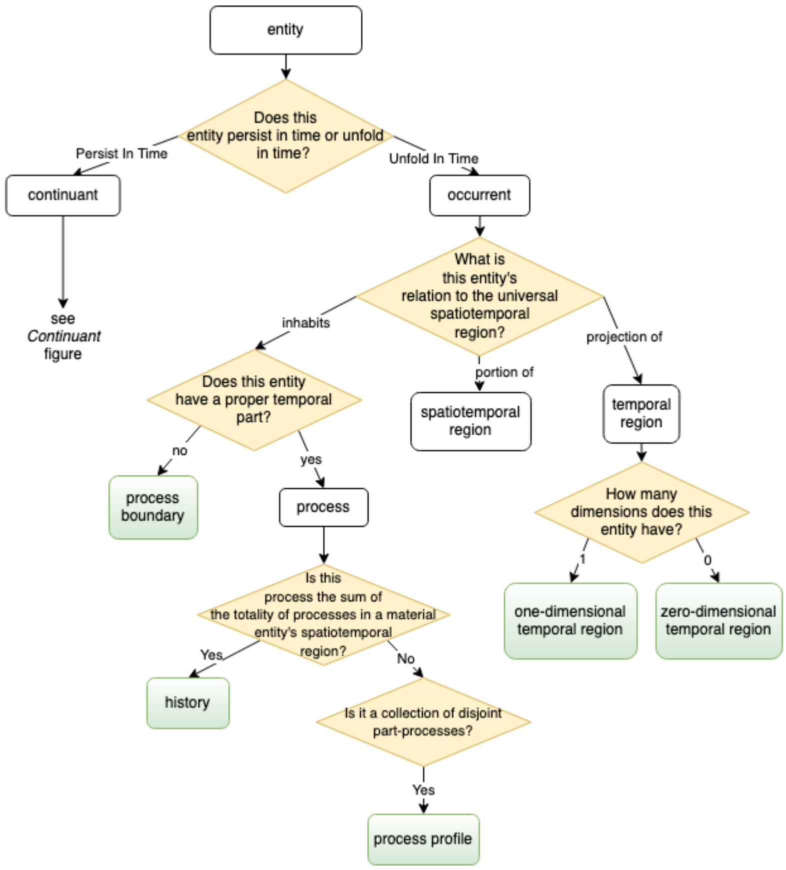

Figure 3: Final BFO 2.0 decision diagram for the Occurrent branch, withe questions coloured on yellow (light grey) and leaf entities in green (gradient grey).

non-leaf node, the only possible children are explicitly specified by the BFO foundational ontology. Since one may align an entity to a non-leaf entity of BFO, our hypothesis is that where the domain entity is classified as an entity in an existing BFO-conformant ontology, if it is not in BFO, then it remains classified as the nearest parent entity in BFO. We test this hypothesis during validation using the extant ontologies linked to BFO.

4.1. Materials and methods

For the analysis, we removed the BFO entities with their alignments, classified the 'entity trees' from the domain ontologies using BFO Classifier, i.e., a domain entity at the top of its branch with its subclasses, and saved the alignments into the OWL file. Thereafter it was compared to the original ontology. One ontologist performed these operations using two ontologies, described below, and the results analysed and discussed with another ontologist.

Ontologies Two ontologies were selected from the BioPortal repository [21] by searching for BFO entities in the pool of ontologies: the Clinical Trials Ontology (CTO) that is used to govern clinical trials [22] and the OntoFood ontology that describes the rules of nutrition for diabetic patients[6]. The test files are available online at https://thezfiles.co.za/BFOC-Experiment/

To use these ontologies to assess the tool, a manual deletion of BFO entities had to be performed, since the ontologies in question had not used BFO by the "owl:imports" feature but through the entity's IRIs.

The BFO Classifier To simplify using the decision diagram, a tool called the BFO Classifier was designed. It automates the navigation of the diagram by prompting the user with questions, and presenting the appropriate BFO 2 class based on the selected answers. There is also the option to import and alter one's domain OWL ontology document, to include the suggested subclass axiom.

The decision diagram itself is stored in an XML file, where each node is numbered and forked to other nodes if it has a question. A selection is shown for illustration in Fig. 4, where the "[ ]" in line 98 is the slot for plugging in the name of the domain entity under consideration, as provided by the user in the tool's interface. This approach makes it easy to update the tree with differently-worded questions or add a different tree for another version of BFO, recompile the tool, and have the update version available for use near-instantly.

```
97      <branch id="1.1.2">
98              <content>May [] be copied between a number of bearers?</content>
99              <fork target="1.1.2.1">Yes</fork>
100             <fork target="1.1.2.2">No</fork>
101     </branch>
102     <branch id="1.1.2.1">
103             <concept>Generically Dependent Continuant</concept>
```

Figure 4: Section of the decision diagram in the application: the XML representation of a question node (`branch`), its question (line 98) and answer options (lines 99 and 100), or the leaf entity (line 103).

The BFO Classifier interface is a simple and intuitive GUI; a screenshot is included in Fig. 5. The domain entity under consideration is always visible near the top of the screen, as is the path to the domain OWL ontology document (if one was selected). All possible answers to a given question in the diagram are provided in a single-select dropdown menu, alongside the question history for the domain entity—this allows the user to keep tabs of the path that they have followed, down the decision diagram. We also allowed for navigation back up the decision diagram, should the user want to change a previous answer. The BFO subclass axiom is dynamically updated at each question and is displayed at the bottom of the screen at all times.

The tool was implemented in Java and the source code is available on GitHub. The BFO Classifier webpage at https://bfo-classifier.github.io/ contains a how-to guide on using the tool, as well as the link to the GitHub project.

4.2. Results and Discussion

For comparing the CTO ontology's links to BFO and the ones obtained with the BFO Classifier, there were 16 entity trees that were classified; see Table 1. Four of the entity trees (25%) were

[6] https://bioportal.bioontology.org/ontologies/OF

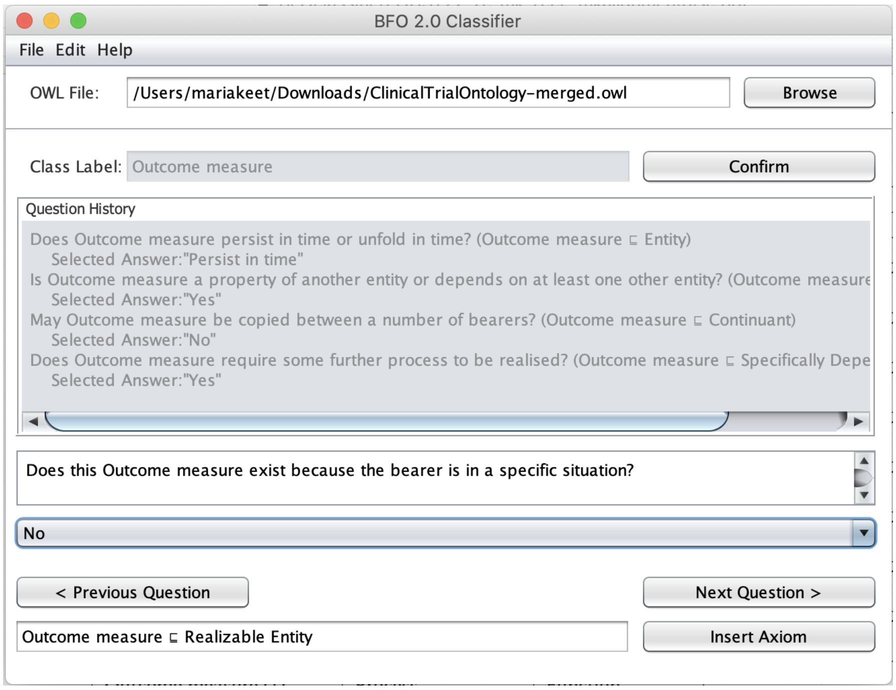

Figure 5: Screenshot of the BFO Classifier, showing a stage in the process of the alignment of CTO's Outcome measure and the question and answer trail completed so far.

classified the same way in the original ontology and in the classified one. Eight entity trees (50%) were further specialised by the BFO Classifier tool. For instance, the Medical device entity was a subclass of Material entity in the original ontology but further classified as Object using the BFO Classifier. Four entity trees were classified using different entities. Upon comparing the OntoFood ontology, there were 17 entity trees that were classified; see Table 2. Five of the entity trees (29%) were classified the same way in the original ontology and in the classified one. Eleven entity trees were further specialised using the BFO Classifier tool and one entity tree was classified differently in both ontologies.

Notwithstanding the tool's assistance, there were some difficulties in trying to align domain entities to BFO. We shall discuss a few of them that are illustrative of the sort of challenges. CTO's Status as Realisable_entity or as Function both may sound counter-intuitive: that was not really CTO, but it has an IRI import of some entities from the Ontology of Precision Medicine and Investigation (OPMI), including Status, that had it aligned to Realisable_entity. Based on the diagram's questions and Status's description, it is plausible to arrive there, largely because it is more like a stage than a status, but also the remaining two questions can be answered. The Drugproduct $\sqsubseteq$ Material_entity is imported from the Drug Ontology (DRON) ontology, and, relying on their description, easily is refined to being a subclass of object aggregate. There are more such cases where the alignment turned out to have been copied over from another ontology, such as Information content entity from the Information Artifact Ontology (IAO) and Medical Device from the eagle-i resource ontology (ERO), which makes updating 'the CTO alignment to BFO' a challenging task.

Table 1
Comparing the domain entity trees for CTO using the original ontology and the BFO-Classifier ontology. Misalignments: 'More specific': a further specialisation thanks to the BFO Classifier; 'Different': a different alignment in the sense of sibling or elsewhere in the hierachy.

Entity tree and total no. of entities in tree	Original ontology superclass	BFO Classifier superclass	Reason for misalignment
Information content entity (107)	Generically-dependent-continuant	Generically-dependent-continuant	-
Physical object quality (6)	Quality	Quality	-
Process quality (10)	Quality	Quality	-
Disease (1)	Disposition	Disposition	-
Status (4)	Realizable_entity	Function	More specific
Bodily process (3)	Process	History	More specific
Planned process (52)	Process	History	More specific
Device (1)	Material_entity	Object	More specific
Medical device (1)	Material_entity	Object	More specific
Root (6)	Material_entity	Object	More specific
Drug product (1)	Material_entity	Object aggregate	More specific
Organisation (23)	Material_entity	Object aggregate	More specific
Outcome measure (1)	Process	Function	Different
Study start date (2)	Zero-dimensional temporal region	One-dimensional temporal region	Different
Study completion date (3)	Zero-dimensional temporal region	One-dimensional temporal region	Different
Date of registration (1)	Zero-dimensional temporal region	One-dimensional temporal region	Different

CTO's Organization's IRI is actually pointing to OBI_0000245, hence, it was also imported. Again, it is the Ontology for Biomedical Investigations (OBI) that has the alignment axiom ($\mathsf{obi}:\mathsf{Organization} \sqsubseteq \mathsf{bfo}:\mathsf{Material\_entity}$). Arguably, at the question after continuant, it may also be answered with 'Yes', i.e., that it depends on another entity and can be copied among bearers and therewith be a generically dependent continuant rather than a material entity. The OBI editors also discussed this issue in an annotation in the OWL file, and pondering to align to just continuant. OBI having chosen for material entity, however, one may as well push further to a leaf node and following through with the reasons for having chosen material entity—principally all the things that make up an organisation (not the thing as legal entity)—and then it could be argued to be an object aggregate or object. Interestingly, and what surfaced in our attempts as well: the consideration to align to a higher-level entity rather than deeper in the hierarchy, because of not knowing enough of the intended meaning of the entity to be able to come to a conclusive answer. This issue was also observed and documented in other FO alignment efforts [23].

The OntoFood alignments reveal two noteworthy aspects. First, it turned out that BFO was not actually imported, neither through a file import nor through IRI, but the hierarchy was recreated and thus the entities have the IRI of that ontology rather than BFO IRIs. This means

Table 2
Comparing the domain entity trees for OntoFood using the original ontology and the BFO-Classifier ontology. Misalignments: 'More specific': a further specialisation thanks to the BFO Classifier; 'Different': a different alignment in the sense of sibling or elsewhere in the hierachy.

Entity tree and total no. of entities in tree	**Original ontology superclass**	**BFO Classifier superclass**	**Reason for misalignment**
Gender (3)	Quality	Quality	-
Measure_unit (7)	Quality	Quality	-
Quantity (1)	Quality	Quality	-
Abstract_object (26)	Immaterial entity	Immaterial entity	-
Consumable thing (6)	Material entity	Material entity	-
Afternoon (1)	Temporal region	One-dimensional temporal region	More specific
Evening (1)	Temporal region	One-dimensional temporal region	More specific
First_afternoon (1)	Temporal region	One-dimensional temporal region	More specific
First_morning (1)	Temporal region	One-dimensional temporal region	More specific
Half_morning (1)	Temporal region	One-dimensional temporal region	More specific
Material food (153)	Material entity	Object	More specific
Person (1)	Independent Continuant	Object	More specific
Evolutional_ process (2)	Process	History	More specific
Multifunction_process (2)	Process	History	More specific
Pathological_process (7)	Process	History	More specific
Physiological_process (1)	Process	History	More specific
Material_nutrient (60)	Object	Fiat object part	Different

that, unless specified otherwise with equivalence relations, any system takes them as different entities in the logical theory. The second one that resurfaced especially in this case, is the process versus its subclass history. Practically with the descriptions, explanations, and corresponding decision diagram questions, it seems many processes end up satisfying the description for history, as is the case also for several OntoFood entities (see Table 2). This may be unintended; if indeed so, further clarification in BFO or its documentation would be needed.

The results comparing domain ontologies already aligned to a domain ontology that was classified using BFO Classifier show that there is value in using the BFO Classifier tool since there were many entities that could be refined into more specific subclasses of BFO.

While some questions could be easily understood by novice ontology developers such as the ones distinguishing between continuants and occurrents, the authors note that for others, the heavy reliance on annotations from the BFO developers may not be easily understood by novice ontology developers, such as 'bearer of'. Thus, it must be noted that while the BFO Classifier does provide support for classifying entities, it still requires philosophical thinking from the user to traverse the decision diagram, and it is still a time-consuming process, albeit less so than before. It may be of use to experiment with different question formulations and decision tree structures to determine if that may reduce the alignment ease and time further and increase confidence in the alignments.

5. Conclusions

The paper presented a new decision diagram for BFO to assist a modeller to facilitate the process of aligning their domain entities to an entity in BFO. This was implemented in a tool, called the BFO Classifier, that also provides attendant services, such as adding the alignment axiom to the ontology. The results of the tool show that the BFO Classifier tool can be used to classify a domain ontology with BFO. Several improvements were found in the classification of the domain ontology when the BFO Classifier tool was used.

The tool still requires philosophical thinking by the ontology developer, however, and so future work would include improving the decision diagram questions to be even simpler. Considering the results, it may also be of use to revisit BFO with its descriptions, to at least clarify some of them not only with respect to their intended definition but also in what way each entity differs from its parent and siblings.

Acknowledgments

CE, SW, and CMK were partially supported by funding from the DOT4D project for the ontology engineering textbook of CMK. CE also received postgrad funding from the National Research Foundation (NRF) of South Africa.

References

[1] C. M. Keet, The use of foundational ontologies in ontology development: an empirical assessment, in: Proc of ESWC'11, volume 6643 of *LNCS*, Springer, 2011, pp. 321–335. Heraklion, Crete, Greece, 29 May-2 June, 2011.
[2] M. Verdonck, F. Gailly, R. Pergl, G. Guizzardi, B. Martins, O. Pastor, Comparing traditional conceptual modeling with ontology-driven conceptual modeling: An empirical study, Information Systems 81 (2019) 92–103.
[3] R. Arp, B. Smith, A. D. Spear, Building Ontologies with Basic Formal Ontology, The MIT Press, USA, 2015.
[4] B. Smith, M. Ashburner, C. Rosse, et al., The OBO Foundry: Coordinated evolution of ontologies to support biomedical data integration, Nature Biotech. 25 (2007) 1251–1255.
[5] C. Masolo, S. Borgo, A. Gangemi, N. Guarino, A. Oltramari, Ontology library, WonderWeb Deliverable D18 (ver. 1.0, 31-12-2003)., 2003. Http://wonderweb.semanticweb.org.
[6] G. Guizzardi, A. B. Benevides, C. M. Fonseca, D. Porello, J. P. A. Almeida, T. P. Sales, UFO: unified foundational ontology, Applied Ontology 17 (2022) 167–210.
[7] B. Smith, Ontology as product-service system: Lessons learned from GO, BFO and DOLCE, in: Proc of ICBO 2019, volume 2931 of *CEUR-WS*, 2019, pp. B.1–9. Buffalo, New York, USA, July 30 – August 2, 2019.

[8] Z. Khan, C. M. Keet, ONSET: Automated foundational ontology selection and explanation, in: Proc. of EKAW'12, volume 7603 of *LNAI*, Springer, 2012, pp. 237–251. Oct 8-12, Galway, Ireland.

[9] Z. C. Khan, C. M. Keet, ROMULUS: a Repository of Ontologies for MULtiple USes populated with foundational ontologies, Journal on Data Semantics 5 (2016) 19–36.

[10] C. M. Keet, F. C. Fernández-Reyes, A. Morales-González, Representing mereotopological relations in OWL ontologies with ONTOPARTS, in: Proc of ESWC'12, volume 7295 of *LNCS*, Springer, 2012, pp. 240–254. 29-31 May 2012, Heraklion, Crete, Greece.

[11] C. M. Keet, M. T. Khan, C. Ghidini, Ontology authoring with FORZA, in: Proc. of CIKM'13, ACM proceedings, 2013, pp. 569–578. Oct. 27 - Nov. 1, 2013, San Francisco, USA.

[12] A. G. L. Junior, J. L. Carbonera, D. Schimidt, M. Abel, Predicting the top-level ontological concepts of domain entities using word embeddings, informal definitions, and deep learning, Expert Systems with Applications 203 (2022) 117291.

[13] R. Stevens, P. Lord, J. Malone, N. Matentzoglu, Measuring expert performance at manually classifying domain entities under upper ontology classes, J. Web Semant. 57 (2019) 100469.

[14] B. Smith, Classifying processes: An essay in applied ontology, Ratio 25 (2012) 463–488.

[15] L. F. Garcia, M. Abel, M. Perrin, R. dos Santos Alvarenga, The GeoCore ontology: A core ontology for general use in geology, Computers & Geosciences 135 (2020) 104387.

[16] C. Pietra, R. De Lotto, R. Bahshwan, Approaching healthy city ontology: First-level classes definition using bfo, Sustainability 13 (2021).

[17] E. Beisswanger, S. Schulz, H. Stenzhorn, U. Hahn, BioTop: An upper domain ontology for the life sciences: A description of its current structure, contents and interfaces to OBO ontologies, Applied Ontologies 3 (2008) 205–212.

[18] L. Obrst, P. Chase, R. Markeloff, Developing an ontology of the cyber security domain, in: Proc. of 7th Int. Conf. Semantic Technologies for Intelligence, Defense, and Security, volume 966 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2012, pp. 49–56.

[19] C. M. Keet, A. Lawrynowicz, C. d'Amato, A. Kalousis, P. Nguyen, R. Palma, R. Stevens, M. Hilario, The data mining optimization ontology, Web Semantics: Science, Services and Agents on the World Wide Web 32 (2015) 43–53.

[20] R. Rudnicki, An overview of the common core ontologies, Online, 2019. https://www.nist.gov/system/files/documents/2021/10/14/nist-ai-rfi-cubrc_inc_004.pdf.

[21] P. L. Whetzel, N. F. Noy, N. H. Shah, P. R. Alexander, C. Nyulas, T. Tudorache, M. A. Musen, BioPortal: enhanced functionality via new web services from the National Center for Biomedical Ontology to access and use ontologies in software applications, Nucleic Acids Research 39 (2011) 541–545.

[22] A. Y. Lin, S. Gebel, Q. L. Li, S. Madan, J. Darms, E. Bolton, B. Smith, M. Hofmann-Apitius, Y. O. He, A. T. Kodamullil, CTO: A community-based clinical trial ontology and its applications in pubchemrdf and scaiview, in: Proc. of ICBO'20, volume 2807 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 1–12.

[23] C. M. Keet, Exploring the ontology of pandemic, in: Proc. of ICBO'22, volume xxx of *CEUR-WS*, 2022, p. (in print).