# Review of: Ontologies relevant to behaviour change interventions: a method for their development [version 3; peer review: 2 approved with reservations, 1 not approved]

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## 1. Introduction

In our review of Version 1 of Wright et al.'s "Ontologies Relevant to Behaviour Change Interventions: A Method for their Development," we raised a number of concerns (Kelly et al., 2020). In particular, we focused on the issue of non-conformity with both the upper-level ontology Basic Formal Ontology (BFO) and the realist methodology and principles of best practice underlying BFO (Arp et al., 2015) and adopted by the Open Biological and Biomedical (OBO) Foundry (The OBO Foundry, 2020). Conformity with BFO, the realist methodology, and the associated principles of best practice is critical for building a maximally successful ontology, and Wright and colleagues agree in this new version of their paper. Ultimately, the authors have addressed many of the most fundamental issues we raised in our original review. As the authors note in Version 2 of their paper, many of these were the result of a bug in the OWL code of their ontology that shifted the positions of entities in an input table. The resultant errors have been corrected.

In the present review of Version 3, we focus on what we take to be some remaining issues with the Behaviour Change Intervention Ontology (BCIO). We are in full agreement with the authors' endorsement of the principles of best practice identified in Table 3 of their article. In particular, we agree that an ontology should be "logically consistent and having a clear structures [sic], preferably a well-organised hierarchical structure," and that "Maximising the new ontology's interoperability with existing ontologies by reusing entities from existing ontologies where appropriate" is critically important (Wright et al., 2020, p. 17). Our remaining concerns with BCIO relate directly to these two principles. First, we identify a number of issues with some of the classifications and definitions in BCIO that seem to be in tension with the just-mentioned principle concerning a well-organized hierarchical structure. Second, we note some reservations about the reuse of certain classes in BCIO, namely from the Gazetteer (GAZ), the Ontology of Medically Related Social Entities (OMRSE), and the Information Artifact Ontology (IAO). While the latter principle of "reuse" is important, it is also important not to let the reuse of existing classes (or their corresponding definitions) compromise the logical integrity or the realist nature of one's ontology.

It is worth reiterating that we believe the authors have successfully addressed the most fundamental of the concerns that were raised in the initial reviews. Hence, relatively minor issues notwithstanding, it remains our view that the methods outlined in Wright, et al. (such as the RODM/SELAR3 method) are a valuable contribution to the field, especially the use of formal mechanisms for literature annotation and expert stakeholder review. Moreover, we maintain our

belief that the Behavior Change Intervention Ontology (BCIO) should and undoubtedly will play an important role in the extension of OBO Foundry ontologies into the behavioral domain.

## 2. Classification and Definitional Concerns

As mentioned above, our focus here is with the classes and structure of the BCIO itself, which we accessed with Protégé by using the provided OWL file (at https://github.com/HumanBehaviourChangeProject/ontologies).

### 2.1 Site is Multiply Inherited

According to BFO, a *site* is a "three-dimensional immaterial entity that is (partially or wholly) bounded by a material entity or it is a three-dimensional immaterial part thereof" (Buffalo Developers Group, 2020). Examples include the hull of a ship, a rabbit hole, the inside of your left nostril, and, as the authors plausibly utilize in BCIO, an *environmental zone* or an *outdoor environment*. The issue we want to bring to the authors' attention is that *site*, as they use it, is multiply inherited, meaning that within their ontology it has more than one parent class (see Figure 1). Avoiding multiple inheritance to the maximal possible degree is one of the core principles of best practice documented in (Arp et al., 2015, pp. 78–82).

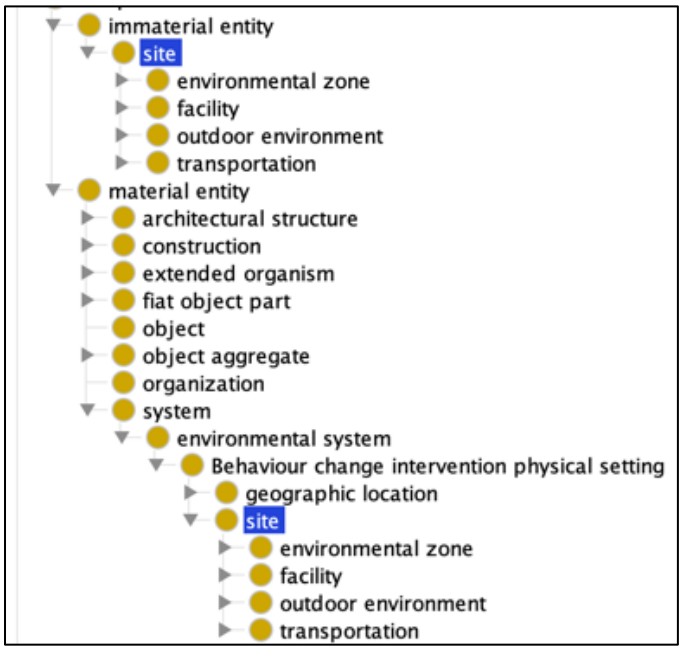

Figure 1: Multiple Inheritance of "Site" in BCIO

Because *site* is multiply inherited, each of the child classes subsumed underneath it is also multiply inherited, as well as any children of those subclasses (such as the eleven subtypes of *facility*), and so on. However, a more pressing issue raised by this error pertains to the two parent classes that *site* is subsumed under. As Figure 1 shows, *site* is a child of both *immaterial entity* and *material entity* in BCIO. The former correctly corresponds to BFO, which defines 'site' as a certain type of immaterial entity – it is in every case something like a hole or opening in which an organism might

dwell. However, since *site* is also classified as a subtype of *material entity* in BCIO (via the intermediate classes *behaviour change intervention physical setting*, *environmental system*, and *system*), we end up with contradictory classifications for *site* in BCIO. Immaterial entities cannot be subtypes of material entities. Moreover, since *site* is already a class in BFO, what is worse is that this instance of multiple inheritance introduces a contradiction into BFO.

Perhaps Wright et al. intended *site* to be understood in a different way when it is a subclass of *behaviour change intervention physical setting*. However, if this is the case, then this should be made explicit to avoid confusion or, worse, the above-mentioned contradictions.

### 2.2 Transportation as a Site

As Figure 1 above shows, BCIO classifies *transportation* as a subtype of BFO *site*. 'Transportation' is defined in BCIO as "methods of traveling from one place to another."[1] Examples of subtypes of *transportation* in BCIO are *ambulance* and *public transportation*. One issue we see with making *transportation* a subtype of *site* is that, intuitively, transportation does not seem to be a type of bounded immaterial entity akin to a rabbit hole or ship's hull. For instance, an ambulance, *qua* method of transportation, is not a site even if *the interior of the ambulance* is a site. The *method* of traveling from one place to another seems to more plausibly refer to the actual means one took in traveling, such as taking an ambulance or a public bus. In other words, the method of travel seems to be about which types of material entities were participants in a traveling process. Consider that it is hard to imagine how *walking* (or perhaps *by foot*, a plausible form of transportation on the BCIO definition) could reasonably be a child of BFO *site*.

A second and somewhat more pressing issue with this classification stems from the preceding issue of *site* being multiply inherited. *Material entity* does seem like a more fitting parent for such entities as ambulances and public buses. However, it is unclear why *transportation* counts as a *system* or *environmental system*. A system is roughly understood to be a material entity with causally interacting elements. An ambulance and a public bus do seem to be material objects with causally interacting parts.[2] However, this use of 'transportation' now seems to refer to the material object that is the ambulance itself, as opposed to the interior of the ambulance that constitutes a *site*.

### 2.3 Facility as a Site

We have similar concerns about *facility* – a class that BCIO reuses from the Ontology of Medically Related Social Entities (OMRSE) – being classified as a subtype of *site* (as seen in Figure 1 above). 'Facility' is defined as "an architectural structure that bears some function," and examples of subtypes in BCIO include *health care facility*, *research facility*, *school facility*, and *middle school*. Like an ambulance or public bus, a middle school (*qua* building or aggregate of buildings) seems to be a material entity rather than an immaterial (space-like) *site*, while *the inside of a middle school classroom* would be a site. BCIO does include the class *construction*, which is a particular

[1] Unless otherwise noted, definitions for the BCIO classes were taken from the OWL file located here: https://github.com/HumanBehaviourChangeProject/ontologies.

[2] Are there material entities with parts that do not causally interact? If not, then it is hard to see how this understanding of *system* would be distinguished from any other subtype of its parent *material entity*. We set this issue aside.

kind of intentionally made material entity and perhaps a better candidate for the parent class of *facility*. In fact, BCIO classifies *research facility* as a child of *human construction*. This seems more accurate to us, though it has the result in BCIO of making *research facility* multiply inherited as well (since it also appears under *facility*), and hence, a subtype of both *material entity* (*construction*) and *immaterial entity* (*site*).[3] This is seen in Figure 2 below.

It should be noted that military ontologies such as those included in the Common Core (CUBRC, Inc, 2019) also make use of the class *facility*, which the Common Core's Artifact Ontology defines as "an artifact that is designed as a building or campus dedicated to some specific purpose."[4] An *artifact* is an object (material entity) designed by an agent to realize some specific function. Moreover, a quick review of the Common Core OWL file did *not* indicate that *facility* is multiply inherited there. Thus, the use of 'facility' in military ontologies seems to avoid the above issues of multiple inheritance and classifying facilities as immaterial entities, while still capturing the OMRSE and BCIO developers' idea that a facility "bears some function." A fuller discussion of the implications of substituting OMRSE *facility* for the Artifact Ontology *facility* is beyond the scope of this review. We just note the possible alternative in case Wright et al. find it useful.

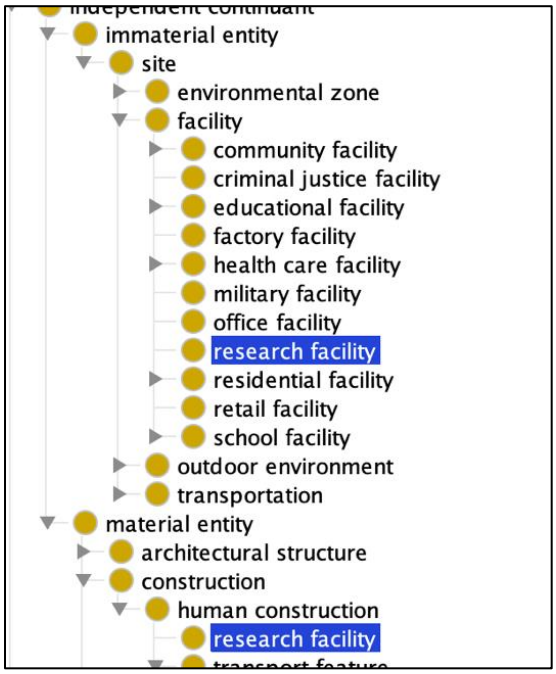

Figure 2: Multiple Inheritance of "Research Facility" in BCIO

Lastly, we acknowledge that this problem of the ambiguity of 'site' and '[aggregate of] buildings' is well-documented in the BFO literature. For instance, it applies to terms like 'Manhattan' (*the place you live in* as opposed to *the aggregate of concrete, buildings, asphalt, etc.*). However, the important point is that, whether or not an ontology includes two distinct classes to capture each side of this ambiguity, the *definitions* for each distinct type of entity cannot be the same since we must avoid classifying and defining types in ways that entail contradictory properties.

[3] BCIO class *school facility* is also multiply inherited (as a direct child of *facility* and *educational facility*).
[4] For the Common Core ontologies, see here: https://github.com/CommonCoreOntology/CommonCoreOntologies.

## 2.4 Human, Individual, and Population Behavior

BCIO also includes a number of important subtypes of the BFO class *process* that are related to human behavior change interventions. However, the classifications and definitions of some of these classes raised three concerns for us. The problematic classes are *human behaviour* and its subclass *outcome behaviour*, *individual human activity* and its subclass *individual human behaviour*, *intervention outcome*, and *population behaviour* (see Figure 3).

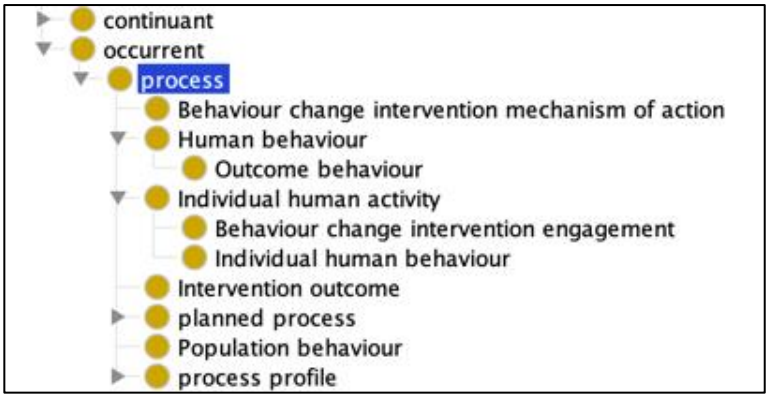

Figure 3: Classification of Behavior-Related Processes in BCIO

Definitions of these entities are as follows:[5]

1. **human behaviour** =def. *individual human behaviour or population behaviour.*
2. **outcome behaviour** =def. *human behaviour that is an intervention outcome.*
3. **individual human activity** =def. *a process that is produced by a person.*
4. **individual human behaviour** =def. *individual human activity that involves coordinated contraction of striated muscles controlled by the brain.*
5. **intervention outcome** =def. *a process that is influenced by an intervention.*
6. **population behaviour** =def. *an aggregate of individual human behaviours of members of a population.*

The first concern we have is that the definition of 'human behaviour' is potentially in violation of the "sparse ontology" principle underlying BFO, which states that we should avoid using logical combination to introduce universals (Arp et al., 2015, p. 74). In other words, if *disease* and *disorder* are both genuine entities, then we should not include the class *disease or disorder* in our ontology. The class *human behaviour* in BCIO seems to represent the introduction of a disjunctive class in just this kind of way. There is *individual human behaviour* and there is *population behaviour* (as indicated by the corresponding BCIO classes), and *human behaviour* simply captures the union of the extension of these two classes.

A second, more important concern is that *individual human behaviour* and *population behaviour* are not classified as subtypes of *human behaviour*, despite the definition of the latter implying that they would straightforwardly count as subtypes – if *x* is an A, then *x* is an A or a B. Since these classes are not subtypes of *human behaviour*, this will potentially facilitate multiple inheritance of

[5] Solely for the purposes of this list, we will use bolded font for the term being defined and italics for the definition.

further subclasses. Moreover, it may also pose problems for individuals tagging data with these terms, as well as for those searching the data tagged with these terms.

For instance, suppose a dataset contains data on both individual human behavior and population behavior. Now suppose all data about the former is tagged as BCIO *individual human behaviour* and all data about the latter is tagged as BCIO *population behaviour*. It seems to us that a reasonable query of the BCIO-tagged dataset is to search for data related to *both* individual and population behaviors by using 'human behaviour' as the search term (given its definition). However, this would not return any results since the data were not tagged with the more general BCIO class *human behavior*. One might think that the data could simply have been tagged with both the corresponding individual class (such as *population behaviour*) and the disjunctive class (*human behaviour*). The problem, though, is that this would result in the data being linked with inconsistent properties because individual and population behaviors are distinct types of entities (even if they shared a parent class). By analogy, consider the results of tagging data about dogs as relating to instances of two classes, *dog* and *dog or human*. A computer cannot consistently reason over such data since the latter tag makes it such that inconsistent properties and relations are linked to individual pieces of data. This is because *dog* and *human* are each distinct types of entity, each with its own distinct essential properties and relations.

A third related concern is that, given the current definitions in BCIO, it is hard to see why *outcome behaviour* is not classified as a subtype of *intervention outcome*. After all, a behavior that is the outcome of an intervention does seem to be a process that is influenced by an intervention. Additionally, this has the potential to create similar problems of multiple inheritance and inconsistent properties being associated with data tagged with both terms.

In our estimation, the purpose for introducing defined classes like those above is that it is likely important to know, for instance, that some process is influenced by a particular intervention (*intervention outcome*) or that someone's behavior (*individual human behavior*) was the outcome of a particular intervention (*outcome behaviour*). If this is right, then a possible remedy for this particular issue might be to eliminate some of these defined classes and simply make use of relations instead. For instance, the Relations Ontology includes subtypes of the *participates_in* and *causally_related_to* relations that could be of use, such as *is_output_of* and *causally_influenced_by*.[6] In this way, the BCIO could avoid introducing a defined class that might pose downstream issues and simply rely on tagging the relevant data with a corresponding relational link. Thus, someone's behavior that was an outcome of an intervention could be tagged as standing either in the *output_of* or *causally_influenced_by* relations to that particular intervention. This would still capture the fact that the behavior was an intervention outcome, outcome behavior, or both, as intended by the current BCIO definitions.

### 2.5 Process Attributes and Modes of Delivery

A final classification and definitions issue concerns the class *process attribute* and its subclass *behaviour change intervention mode of delivery*. BCIO makes use of the BFO class *process profile*, which BFO 2.0 defines as follows:

[6] See https://bioportal.bioontology.org/ontologies/OBOREL/?p=properties to access all the relations in the Relations Ontology.

> b *process_profile_of* c holds when b *proper_occurrent_part_of* c and there is some *proper_occurrent_part* d of c, which has no parts in common with b and is mutually dependent on b, and is such that b, c and d occupy the same temporal region (Buffalo Developers Group, 2020).

This means, roughly, that a process profile is a part of some larger process (and so is itself a process) on which some other non-overlapping part of that process "mutually depends." Typically, this will mean those parts of processes which are captured when we perform measurements or observations to pick out specific features of interest. Examples of process profiles are (i) the temperature that changes during a *process of temperature increase*; (ii) the rate (or speed) at which a vehicle moves from one point to another; and (iii) the cyclical beating of a person's heart (a *cyclical process profile* being a subtype of a *rate process profile*) (Smith, 2012, Sect. 4). It is BFO's *process profile* that serves as the parent class for BCIO's *process attribute* and its subclasses, as is seen in Figure 4 below.

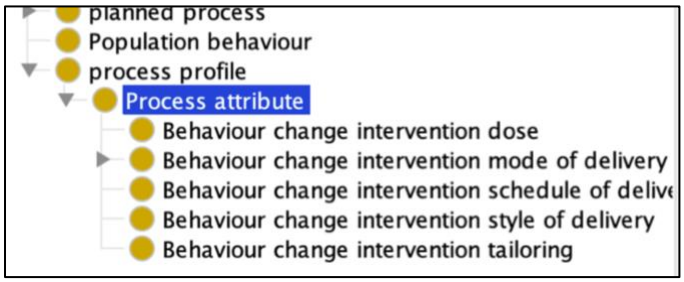


Figure 4: "Process Attribute" in BCIO

The first concern we have is with the definition of 'process attribute', which in BCIO is "an attribute of a process." While it is intuitive that processes have attributes – roughly, *ways* in which they unfold – process profiles themselves are still somewhat difficult to grasp. According to BFO, these so-called 'profiles' of processes are *not* the same as BFO *qualities* or *dispositions* since the latter must inhere in independent continuants rather than processes. Thus, we can think of a *process profile* as a property or attribute of a process only metaphorically. Hence, we are unsure how to understand the introduction of the subtype *process attribute* independently of the current BFO definition of 'process profile'. A natural way to understand 'attribute' is to think of it as a property or quality that something has. Though, as just noted, this can only be metaphorical, and so is insufficient on its own to provide a meaningful definition of 'process attribute'. Perhaps it is better to understand *dose*, *mode of delivery*, and so forth, as corresponding to measurable or observable parts of a process, and to rephrase as necessary.

A second concern we have relates to the *process attribute* subtype *behaviour change intervention mode of delivery*. BCIO defines this class as "an attribute of a BCI [behaviour change intervention] delivery that is the physical or informational medium through which a BCI is provided." The problem stems from the fact that, being a subtype of *process profile*, any *process attribute* must also be a process. However, a "physical or informational medium" through which some process is delivered seems to be distinct from that process itself (and its parts). For instance, copper is a physical medium through which processes of transmitting electrical currents can occur. An informational medium would also seem to be a physical medium, such as light rays or sound waves, through which processes of transmitting *information* occur. In short, we are inclined to read

the definition of 'behaviour change intervention mode of delivery' as referring to some type of material entity serving as the medium through which a process occurs. If this is right, it should not be a subtype of *process*. If it is not right, the definition could be clearer to avoid confusion.

A final concern relates to the subtypes of *behaviour change intervention mode of delivery*. As shown in Figure 5 below, this class has several subtypes in BCIO, including *somatic mode of delivery*.

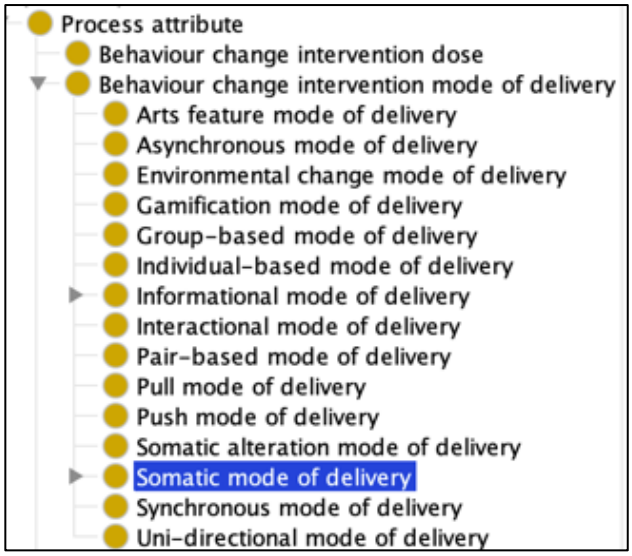

Figure 5: "Behaviour Change Intervention Mode of Delivery" and Subtypes in BCIO

Our concern here is that, when their definitions are examined, many of these subtypes would be better classified as subtypes of *behavior change intervention delivery*.[7] BCIO defines 'behaviour change intervention delivery' as that "part of a BCI that is the process by which BCI content is delivered." Thus, it is a subtype of *process* rather than *process attribute*.

For instance, consider *somatic mode of delivery*, which is defined as the "mode of delivery that involves devices or substances that alter bodily processes or structure." We acknowledge that the authors are trying to capture the fact that delivering content in a behavior change intervention (a process) might occur in this particular *way*, namely, with the use of certain devices or substances. However, our thought is that what this class really captures is a particular subtype of "the process by which BCI content is delivered" (that is, a particular subtype of *behaviour change intervention delivery*). More specifically, it refers to the delivery of BCI content when that process has certain kinds of devices or substances as participants.

By analogy, consider the process of eating dinner. This might occur through the use of a fork or a spoon, depending on what is being eaten. Thus, we might distinguish two subtypes of the *eating dinner process* on the basis of the instrument used. Importantly, though, if we were to define these subtypes, the *differentiae* – those essential features that make each subtype what it is – would amount only to *certain types of instruments*, namely, a fork or a spoon, being participants in the

[7] This is not to be confused with *behavior change intervention* ***mode of*** *delivery*. We note this in case it is easy to confuse the numerous BCIO classes that have the 'behaviour change intervention' prefix.

respective process subtype. But demarcating subtypes of *eating dinner process* by the type of instrument used is not necessarily the same as identifying a *process profile*. We simply have processes distinguished on the basis of their participants (an ordinary defined class). However, we might be interested in the part of the dinner eating process by which food is delivered into one's mouth. The upshot is that process profiles must be kept distinct from those processes which are simply different subtypes of a given process type, distinguished on the basis of their respective human or instrument participants.

The same issue arises with some of the other subtypes in Figure 5. Another example is *pair-based mode of delivery*, which is defined as a "mode of delivery that involves two recipients in the location where the intervention is delivered who have an interpersonal relationship." Again, in our view, this more likely refers to a BCI delivery that has as participants two individuals that are (i) recipients of the BCI content, and (ii) stand in a particular relation to one another. Let us now turn to two final minor issues involving reused terms.

## 3. Concerns Related to the Application of the Principle of Reuse

Reuse occurs when an ontology takes on classes from other extant ontologies. We agree with the use of this principle. Thus, our concerns here only indicate that we must still be careful in reusing existing terms and definitions so as to not inherit any pre-existing issues those terms or definitions may have already had.

### 3.1 GAZ's Geographical Location

The BCIO utilizes the Gazetteer (GAZ) class *geographical location*, which is defined as "a reference to a place on the Earth, by its name or by its geographical location." (Note the circularity in this definition.) Figure 6 below shows this class as it is in BCIO—a subtype of *behaviour change intervention physical setting*.

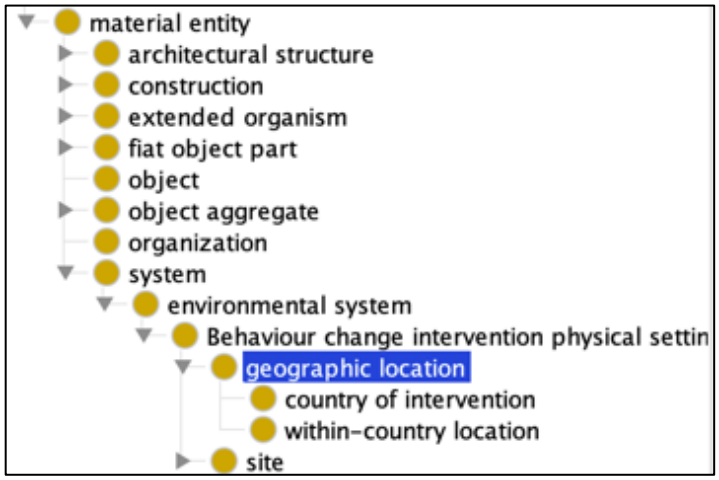

Figure 6: "Geographical Location" as Classified in BCIO

Our present concern is, first, with the use of the original definition from GAZ. One problem is that this definition seems to potentially violate the realist methodology underlying BFO and BCIO. A

geographical location, such as a country where an intervention might take place, does not seem to be a *reference* to a location (in the way the *name* of that country would be). However, perhaps the class is meant to pick out something like the longitudinal and latitudinal coordinates of a given geographical location, such as a country. If so, then we come to a second problem.

Coordinates are not material entities. To conform with BFO, geographical location as used in this second sense would be a subtype of *immaterial entity*, akin to BFO's *site* or *spatial region*. For instance, the coordinates constituting the two-dimensional surface area of the Earth wherein some specific country is located would be a kind of *two-dimensional spatial region* in BFO, which is a subtype of *immaterial entity*.[8] Hence, if BCIO retains the original GAZ definition of 'geographical region', this class should not be classified as a child of *material entity*.

Lastly, a related problem is that the GAZ definition suggests that a geographical location (in the sense just used above) could also be a name. However, names are still another type of entity altogether. They are *information content entities*, which are BFO *generically dependent continuants* and so cannot be *independent continuants* (whether material or immaterial). This can be seen in the Information Artifact Ontology (https://bioportal.bioontology.org/ontologies/IAO), the Semanticscience Integrated Ontology (https://bioportal.bioontology.org/ontologies/SIO), and the Common Core's Information Entity Ontology (CUBRC, Inc, 2019).

### 3.2 Information Entities in IAO

A final concern we have is about BCIO's use of certain entities from the Information Artifact Ontology (IAO). In particular, we focus on its use of *plan specification* (a subtype of *information content entity*), as well as its use of *plan* (a subtype of *realizable entity*). First, it should be noted that the IAO is a useful ontology that aspires to be BFO-conformant. Second, while our concern is somewhat technical and information can be very complicated, we believe it still raises important questions that need to be worked out. The problem is as follows.

The IAO defines 'plan specification' like this:

> A directive information entity with action specifications and objective specifications as parts that, ***when concretized, is realized in a process*** in which the bearer tries to achieve the objectives by taking the actions specified. (emphasis added)

This definition implies that either 'plan specification' suffers from the problem of multiple inheritance or the term 'realizable' in the definition is not meant to be understood in the BFO sense. To see why this is so, consider an analogy first to help elucidate the relevant background concepts.

Consider a physical book copy of the novel *Moby Dick*. Neither the book itself nor the ink printed on it is the *story* that we call 'Moby Dick'. The story, *Moby Dick*, is the descriptive informational content that *generically depends* on the book (and its parts and qualities), and it is *generically* dependent because it only needs *some entity or other* (for example, the book) to carry it in order

[8] If a country were located at some specific point of intersecting longitude and latitude, which seems implausible, then it would be a *one-dimensional spatial region* in BFO, which is still a type of *spatial region* and *immaterial entity*.

to exist. The book itself is a material object, and it is what *carries* the information that is the story *Moby Dick* (the same story that every copy of *Moby Dick* carries). Finally, in addition to the book itself carrying the information that is the story, according to BFO, it is the book's *specifically dependent continuants* (SDCs), such as its *qualities* and *dispositions*, that *concretize* that information. In other words, it is in virtue of (at least in part) *the way the book is*, such as the totality of ink patterns on its pages, that the story *Moby Dick* is concretized, and hence, objects like books *carry* information only because some or all of their SDCs *concretize* that information. Figure 7 below, taken from (Limbaugh et al., 2020, p. 11), illustrates part of what they call "the anatomy of information."

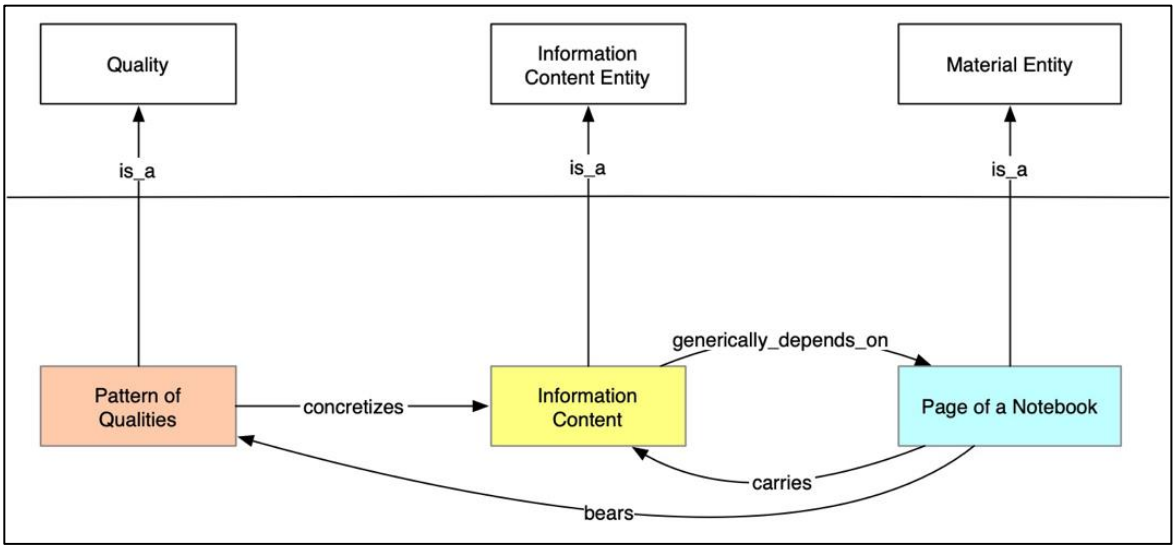


Figure 7: Diagram of the Relation between Information, Material Entities, and Qualities in BFO

Now, let us see why this matters for the BCIO use of *plan* and *plan specification*. Plan specifications, being *directive information content entities*, prescribe certain processes. For instance, a set of Ikea instructions prescribes the processes one must bring about in order to achieve the end state of a completely assembled piece of furniture: "Take piece A and insert it into piece B," "Attach piece C to piece D using screws of type E," and so on. In BFO, a *realizable entity* like a *disposition* (such as fragility) *inheres_in* – a type of *specific dependence* – an *independent continuant* (such as a vase) and is *realized_in* a *process* (such as breaking). IAO includes a type of realizable entity called a 'plan', which is distinct from the information entity *plan specification*, and which is meant to be realized in processes prescribed by *plan specifications*. The thought seems to be that, since directive information entities like plan specifications prescribe certain processes, it makes sense to introduce a kind of realizable entity that is realized when those processes unfold (as a result of intentionally trying to execute the plan). Importantly, the introduction of *plan* is also grounded in the fact that processes cannot realize information, because *information is not a realizable entity*. As we saw above, information entities such as plan specifications are not *realized* (only realizable entities are); they are instead *carried by* objects (such as books or pieces of paper) whose SDCs *concretize* the information.

The upshot, then, is the following. According to IAO (and BCIO, since it uses the relevant IAO terms and definitions), the directive information entity *plan specification* is not simply concretized *by* an object's SDCs but is instead said to be concretized *as* the object's SDCs—in particular, *as*

the realizable entity *plan* inhering in that object. Since only realizable entities can be realized in processes, this is the only way for an IAO *plan specification* to be realized, as is required by its definition above ("…that, when concretized, is realized in a process in which…").

It is for these reasons that the IAO definition of 'plan specification' appears to be flawed, an issue that we are bringing to the attention of its developer Alan Ruttenberg. There are at least three possible interpretations of the definition as it is written, each problematic in its own way.

First, the definition could imply that a *plan specification* (which is a *directive information content entity*) can change its ontological kind – become some other kind of entity – once it is concretized by the SDCs of an object that carries it.[9] This is because it would have to become a disposition-like realizable entity in order for the processes it prescribes to realize it.

Alternatively, a second possible implication of the definition is that IAO *plan specification* is multiply inherited. That is, *plan specification* is a subtype of both *information content entity* (which is a *generically dependent continuant*) as well as *realizable entity* (which is a *specifically dependent continuant*). The former stems from the fact that plan specifications are *concretized* by the SDCs of material entities that *carry* those plan specifications. These are relations that only information entities stand in to the respective material entities and their SDCs. The latter stems from the fact that, according to IAO, plan specifications are *realized by* processes that they (on the information understanding) prescribe. This is only possible for realizable entities, which are SDCs. Hence, even if the first problematic implication were avoided, IAO and BCIO can still run into another issue of multiple inheritance. This, as above, leads to downstream problems with data tagging and searching due to inconsistent properties being associated with the same term or, worse still, the same entity.

Lastly, a third possible implication of the definition is much less problematic than the first two, though still in need of attention. Perhaps the IAO developers meant that, when a plan specification is concretized by the SDCs of some information carrying entity, then it is concretized as a plan *of* that entity, such as a person (or perhaps the brain of a person). That is, the person acquires a new disposition (a *plan*), which inheres in the person in virtue of their SDCs (such as certain of their mental qualities) concretizing the plan specification, and that disposition is what is realized in the prescribed processes. In this way, the implication of the definition would be that 'realized' is not being used in the technical BFO sense. However, unless the definition is appropriately modified or annotated, including specifying in what sense 'realized' is being used there, then it will likely result in confusions or, worse, contradictory uses.

Before turning to our conclusion, it is worth noting that the Common Core's Information Entity Ontology (CUBRC, Inc, 2019) contains several information-relevant entities whose definitions do not have these problematic implications.[10] Of course, there may be other issues that utilization of

[9] We acknowledge that it is hard to understand what this actually means. If x is essentially an *A*, then x would seem to go out of existence when it stops being an *A*. Thus, x cannot "turn into" a *B*. Instead, x would cease to exist and something else, y, would come into existence that is essentially a *B*. The point here is that, according to the present implication under discussion, the definition seems to allow that something impossible can happen.

[10] Again, the Common Core ontologies can be found here: https://github.com/CommonCoreOntology/CommonCoreOntologies.

the Common Core ontology may introduce, but a full comparison of using each ontology is beyond the scope of this review. The point we want to make is just that there is an alternative that, at the very least, avoids committing the ontology to directive information entities like plan specifications being kind-changing (when concretized), multiply inherited (classified as both information and realizable entities), or defined with non-technical, non-specified uses of BFO terms like 'realize'.

## 4. Conclusion

In our view, Wright, et al.'s work developing the BCIO, as well as their RODM/SELAR3 method, constitutes a valuable and timely contribution to the field. As noted in the introduction, the authors have successfully addressed most of the fundamental issues raised in reviews of previous versions of their article. Moreover, as the authors point out, changing behaviors (whether at the individual, group, or organizational level) is required to improve public health and well-being, and to facilitate environmental sustainability (Wright et al., 2020, p. 3). Insofar as these things are valuable, so is the need to study BCIs, their efficacy, and how various factors like environment or technique influence their implementation or outcomes. Hence, given the complexity of the phenomena surrounding BCIs, the volume of research and data on BCIs, and the heterogeneity of this data, we agree with Wright, et al. that development of the BCIO is an extremely important project to undertake. We also admire the rigor and detail that is evident in their proposed method for developing and extending the BCIO.

Importantly, it is also still clear that the authors are committed to developing an ontology that is compliant with BFO and follows the principles of good ontology building used by the OBO Foundry. Indeed, Wright et al.'s RODM method outlined in the paper is strikingly analogous to the basic steps of building an ontology outlined by Barry Smith and colleagues (Arp et al., 2015). What's more, their revision even more fully emphasizes the importance of the realist methodology and the key principles of best practice.

Here we focused on what we took to be a few remaining issues with the BCIO. Our concerns with the BCIO related directly to two principles highlighted in their Table 3: that an ontology should be "logically consistent and having a clear structures [sic], preferably a well-organised hierarchical structure," and that "Maximising the new ontology's interoperability with existing ontologies by reusing entities from existing ontologies where appropriate" is critically important (Wright et al., 2020, p. 17). First, we noted some classification and definitional issues with BCIO that seem to be in tension with the former principle concerning a well-organized hierarchical structure. Second, we expressed some reservations about the BCIO's reuse of certain classes from the Gazetteer (GAZ), the Ontology of Medically Related Social Entities (OMRSE), and the Information Artifact Ontology (IAO). Our intention is to assist the BCIO developers in not letting the reuse of existing classes (or their corresponding definitions) compromise the logical integrity nor the realist nature of what we see as an important ontology.

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