Basic Formal Ontology: Case Studies

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Abstract. Basic Formal Ontology (BFO) is a top-level ontology consisting of thirty-eight classes, designed to support information integration, retrieval, and analysis across all domains of scientific investigation, presently employed in over 350 ontology projects around the world. BFO is a genuine top-level ontology, containing no terms particular to material domains, such as physics, medicine, or psychology. In this paper, we demonstrate how a series of cases illustrating common types of change may be represented by universals, defined classes, and relations employing the BFO framework. We provide discussion of these cases to provide a template for other ontologists using BFO, as well as to facilitate comparison with the strategies proposed by ontologists using different top-level ontologies.
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1. Introduction[1]

In this paper, we demonstrate how Basic Formal Ontology (BFO) may be used to represent seven cases involving change. These cases, their goals, and their accompanying focus statements are discussed in order to provide a template for other ontologists using BFO, as well as to facilitate comparison with the strategies proposed by ontologists using different top-level ontologies.

Basic Formal Ontology[2] is a top-level ontology designed to support information integration, retrieval, and analysis across all domains of scientific investigation. Containing only general terms common across disciplines, BFO serves as the top-level ontology of the Open Biomedical and Bioinformatic Ontology (OBO) Foundry [1] and the Industrial Ontology Foundry (IOF) [2].

[1]All authors contributed equally to this work.

[2] International Organization for Standardization. (2016). Information technology — Top-level ontologies (TLO) — Part 2: Basic Formal Ontology (BFO)(ISO Standard No. 21838-2:2020). Retrieved from https://www.iso.org/standard/74572.html

Moreover, BFO provides a starting point for over 350 known ontology extensions[3] covering more specific domains, such as infectious disease [3], plant development [4], and processed materials [5]. BFO has been designated an ISO standard [6] and BFO's ISO 21838-2 specification has been axiomatized in First-Order Logic, OWL 2, and CLIF.[4]

BFO is committed to the following principles [7], which distinguish it from other top-level ontologies [8]:

- *Ontological Realism* – The goal of an ontology is to describe reality. Scientific investigation is concerned with general features of reality and relations among them. Consequently, BFO consists fundamentally of representations of reality rather than merely language, concepts, or mental representations about reality [9].

- *Fallibilism* – Whereas universals themselves do not change, our understanding of them must in light of new discoveries. While present scientific theories are assumed to be our best sources of accurate statements about reality, BFO recognizes, of course, that present scientific theories may be incorrect. Consequently, BFO is committed to tracking scientific developments over time, and updating ontologies in accordance with scientific developments [2].

- *Adequatism* – Entities in a domain should not be assumed to be reducible to other kinds of entities. All scientific disciplines are worthy of representation in their own terms, and it is not necessary to paraphrase talk of these entities in terms of a privileged set of entities (e.g. those described by physics). This commitment contrasts with *reductionism*, which seeks to reduce entities described by some domain of science to another deemed more fundamental [9].

2. Principles and Structure of BFO

BFO adopts the following fundamental categories [6, 8]:

- universal and particular – Particulars are individual denizens of reality restricted to specific times and places, which instantiate universals, but which cannot be instantiated. Universals are repeatable across time and space and may have an indefinite number of instantiated particulars [13, 14].

- continuant and occurrent – BFO is largely bifurcated into disjoint universals[5], distinguished by how particulars relate to time. Continuants endure through time maintaining identity, have no temporal parts, and are fully-present at any time they exist. Examples include house cats, the

[3] Users of BFO. Accessed December 25, 2020 at http://basic-formal-ontology.org/users.html

[4] BFO-2020. Accessed December 25, 2020 at https://github.com/BFO-ontology/BFO-2020/tree/21838-2/21838-2

[5] The exceptions to disjointedness are BFO's classes fiat object part, object, and object aggregate. Some instances may belong to more than one of these classes.

color of an apple, the function of mitochondria. By contrast, occurrent entities unfold over time or have temporal parts. Examples include: the history of Japan, drinking a cup of coffee, the temporal interval on which a mitotic division occurs [15].

- relations – BFO adopts three basic relation types: universal-universal, universal-particular, and particular-particular, the latter two of which may be time indexed. Universal-universal relations in BFO relate subtypes to parent types, whereas the sole universal-particular relation is the *instance of* relation, which holds between particulars and the universals under which they fall [16].

We discuss here only those classes necessary for the comprehension of the cases.[6] In what follows, definitions are indicated with the use of "=def", and those entries regarding classes that lack this symbol are elucidations. First, subclasses of continuant:

- a is an independent continuant $=_{def}$ a is a continuant which is such that there is no b such that a specifically depends on b and no b such that a generically depends on b.
  - material entity – an independent continuant that at all times at which it exists has some portion of matter as continuant part.
    - object – a material entity that manifests causal unity and is of a type instances of which are maximal relative to the sort of causal unity manifested.
    - object aggregate – a material entity consisting exactly of ($\geq$1) object(s) as member(s).
- a is an immaterial entity $=_{def}$ a is an independent continuant which is such that there is no time t when it has a material entity as continuant part.
  - site – a three-dimensional immaterial entity whose boundaries either (partially or wholly) coincide with the boundaries of one or more material entities or have locations determined in relation to some material entity.

An independent continuant may bear dependent continuants, including:

- generically dependent continuant – an entity that exists in virtue of the fact that there is at least one of what may be multiple copies; it is the content or the pattern that the multiple copies share.

[6] We leave aside discussion of fiat object part, spatial region and its subclasses, process boundary, spatiotemporal region, relational quality, history, and continuant fiat boundary and its subclasses, as these classes were not necessary to represent the cases under discussion.

- b is a specifically dependent continuant $=_{def}$ b is a continuant and there is some independent continuant c which is not a spatial region and which is such that b specifically depends on c.
  - quality – a specifically dependent continuant that, in contrast to roles and dispositions, does not require any further process in order to be realized.
  - realizable entity – a specifically dependent continuant that inheres in some independent continuant which is not a spatial region and is of a type some instances of which are realized in processes of a correlated type.
    - role – a realizable entity that exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be and which is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed.
    - disposition – a realizable entity such that if it ceases to exist, then its bearer is physically changed, and whose realization occurs when and because its bearer is in some special physical circumstances, and this realization occurs in virtue of the bearer's physical make-up.
      - function – a disposition that exists in virtue of the bearer's physical make-up and this physical make-up is something the bearer possesses because it came into being either through evolution (in the case of natural biological entities) or through intentional design (in the case of artifacts), in order to realize processes of a certain sort.

From the occurrent portion of the hierarchy, we include the following:

- p is a process $=_{def}$ p is an occurrent that has some temporal proper part and for some time has some material entity as participant.
- temporal region – an occurrent over which processes can unfold.
  - temporal instant – a zero-dimensional temporal region that has no proper temporal part.
  - temporal interval – a one-dimensional temporal region that is continuous, thus without gaps or breaks.

There is often a practical need to accommodate terms in scientific discourse that do not correspond to universals. Examples of such terms include 'medical doctor' and disjunctions such as 'dog or cat'. Such classes are called 'defined classes', and are represented as equivalent to any member satisfying a set of assertions whose non-logical symbols are satisfied by models consisting only of relations, universals, or instances of universals. In this way, we hold that

'medical doctor' is only a short-hand way of referring to instances of persons who bear a medical doctor role, and to be a 'dog or cat' is nothing over and above being an instance of dog or an instance of cat. As with the familiar notion of 'defined class' in the OWL2 specification, every defined class is represented with an equivalency axiom however, the ontological interpretation of the notion of asserted class as corresponding to a universal and 'defined class' as picking out a mere term is unique to BFO.

3. Formalization of BFO in First-Order Logic

We describe a fragment of the BFO ISO 21838-2 First-Order Logic (FOL) axiomatization [6]. The domain is comprised of particulars that stand in the primitive **instances of** relation to universals at times. BFO's hierarchy of universals can be represented by defining the relation:[7]

$$\forall x,t \textbf{ is a}(A, B) =_{def} \textbf{instance of}(x, A, t) \rightarrow \textbf{instance of}(x, B, t)$$

For example, material entity **is a** independent continuant. Visual representation of BFO's hierarchy can be found in *Figure 1* and *Figure 2*.

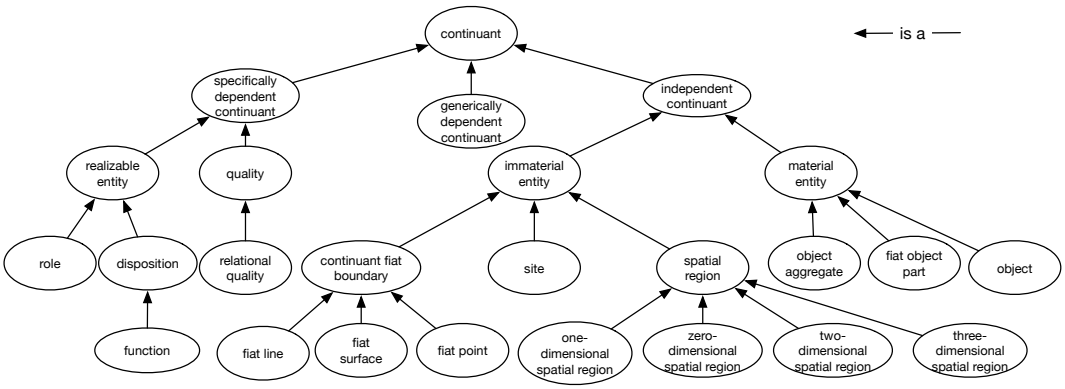

Figure 1: BFO Continuant Hierarchy

By rigid universal Ur, we mean any entity that is instantiated by Ur, instantiates Ur for the whole of its existence. All classes in BFO are rigid other than the three subclasses of material entity: fiat object part, object, and object aggregate. For example, an **instance of** object aggregate at some time may later instantiate object.

BFO's theory of parts is modeled after Minimal Extension Mereology (MEM) [7]. MEM is described in terms of binary part relations, but is extended to handle the time-indexed relations. The MEM axioms state that a part relation is reflexive, antisymmetric, transitive, weakly supplemented, and exhibits the

[7]This relation is not included in the BFO-ISO specification, but is defined here to simplify discussion.

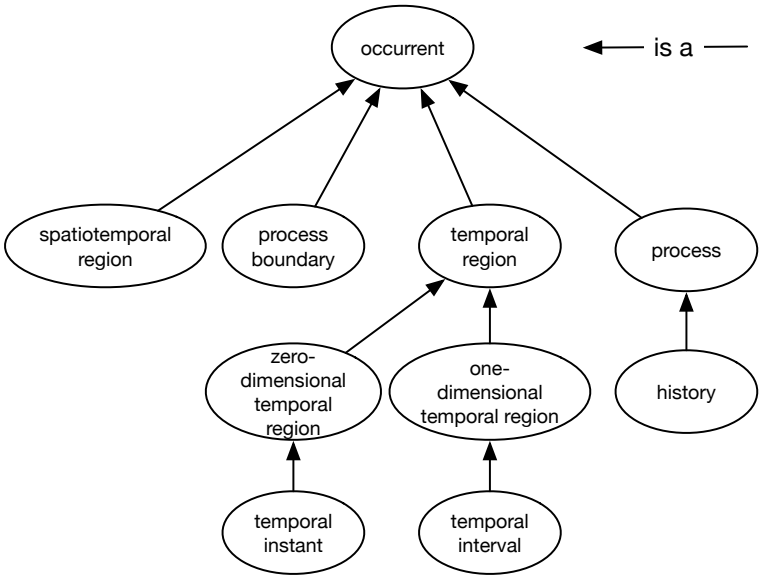

Figure 2: BFO Occurrent Hierarchy

unique product property. Any time-indexed relation implies that the first two relata exist, and holds at any time the relata exist. For instance, when a time-indexed relation is reflexive we mean that the self-relationship refers to the first two relata and it must hold at any time the relata exist.

BFO has two part of relations, one for continuants, called **continuant part of** and one for occurrents called **occurrent part of. Continuant part of** is time indexed, whereas **occurrent part of** is not. Worth noting is the treatment of the anti-symmetry of **continuant part of** applied to object aggregates. If a **continuant part of** b at *some* t and b **continuant part of** a at the same time t, we do not conclude that a=b.

Using these relations we can define irreflexive, asymmetric, transitive **proper occurrent part of** and **proper continuant part of** relations in the usual way.

Starting at the continuant side of the BFO hierarchy in *Figure 1*, an independent continuant is distinguished from other continuants in that they neither generically nor specifically depend on other entities. In contrast, a specifically dependent continuant **specifically depends on** an independent continuant[8] rigidly. If x **specifically depends on** y, then as long as x exists, the relation holds. If y ceases to exist, then x does as well.

A specifically dependent continuant is said to **inhere in** – a relation defined in terms of **specifically depends on** – an **instance of** independent continuant. The inverse of **inheres in** is **bearer of**. A generically dependent continuant

[8]In a number of relations involving independent continuants the relation is actually valid only if the entity is a spatial region. In order to keep the discussion simpler, we do not mention it in the body.

is **concretized by** a process or specifically dependent continuant. When the concretization is a specifically dependent continuant the generically dependent continuant **generically depends on** the specifically dependent continuant's bearer.

All independent continuants other than spatial regions occupy a spatial region, and so are extended in space and time. Some may be **located in** others at some time, as the food you ingest is at some point located in the lumen of your stomach after you have eaten. **Located in** is transitive.

A material entity can be **continuant part of** another material entity at some time. Material entities can have material and immaterial parts. An object can be **member part of** an object aggregate. **Member part of** is not transitive but implies **continuant part of**. An object aggregate always has at least one member, and must, at some time, have more than one.

Any independent continuant, specifically dependent continuant, or generically dependent continuant can **participate in** a process. In the latter two cases, it is implied that their bearer also **participates in** the process. When a process **realizes** a realizable entity, the realizable entity's bearer also **participates in** the process. When a generically dependent continuant **participates in** a process p, some concretization of the generically dependent continuant **participates in** p. If that concretization is a process, it is **temporal part of** p.

A process **occupies temporal region** some temporal region. Processes have at least one process boundary as part. The temporal region that a process occupies must have as part a temporal interval. A process boundary can only occupy a temporal instant.

An occurrent can be a **temporal part of** some other. Occurrent parts can differ from what they are part of both spatially and temporally (e.g. the process which occurs in the left half of a soccer field during the first period of a game). By contrast, temporal part of an occurrent differs in that there is no difference in the spatial extent of the part and the whole.

Temporal regions provide the indices for all the time-indexed ternary relations in BFO. A temporal region **has first instant** and **has last instant** a temporal instant marking its extrema. A first or last instant can be **temporal part of** the region or not. A temporal instant that **precedes** the last instant of a temporal interval and are **preceded by** the interval's first instant are necessarily part of the interval. Using these relations, the familiar and widely used Allen's interval algebra may be formulated [17].

4. Analysis and Formalization in BFO: Examples

In this section, we examine several cases reflecting composition, roles, property and event change, and scientific progress. As BFO is a small top-level ontology comprised of domain-neutral terms, the examples use either terms we define in this paper, or wherever possible, existing terms from BFO-aligned ontologies within the OBO Foundry library [18] and The Common Core Ontologies (CCO) [19].

Since the cases reflect changes over time, temporal intervals will be used throughout. We introduce some formalization here to avoid repetitions. In

each case, we will use "i" to represent the interval during which the case unfolds. We will use subscripts on "i" to represent proper[9] interval parts of i ordered by precedence. Formally:

1. **instance of**(*i*, temporal interval, *i)*
2. $\bigwedge_{1 \leq k \leq n}$ **instance of** (i_k, temporal interval, i_k)
3. $\bigwedge_{1 \leq k \leq n}$ **proper temporal part** (i_k, i)
4. $\bigwedge_{1 \leq k \leq n}$ **precedes** (i_k, i_{k+1})

Many of the cases involve information. An information content entity is a generically dependent continuant that **is about** some entity. The term originates in the Information Artifact Ontology (IAO), an ontology that extends BFO. Because information content entity is a direct subclass of generically dependent continuant, an information content entity may **generically depend on** one or more material entities. One example is the content of a novel may be **concretized by** patterns of ink in multiple physical books or may be **concretized by** the digital patterns in different network servers; when this occurs, the novel (an information content entity) then **generically depends on** the physical books and network servers.

Although it is possible to define a subclass of information content entity as always having a unique serialization (e.g. as in the case of an International Standard Book Number ISBN, which would have a unique serialization such as "978-0-393-28857-5"), it is preferable in many cases to track information that can be common across serializations or translations, much as a proposition may be expressed by different sentences. One way to enable this is to treat the serialization as a property of the **bearer of** the information content entity, rather than the information content entity itself. To illustrate, *Figure 3*[10] depicts a measurement information content entity, its subject (an **instance of** process of walking), a material entity, and the measurement unit and string associated with that material entity. If the measurement information content entity was converted to kilometers, the **instance of** information content entity would remain the same, but would now also **generically depend on** a distinct **instance of** information bearing entity that would have text value "3.22 kilometers per hour". Preliminaries in hand, we turn to the formalization of cases.

4.1 Composition/Constitution

CASE 1: *There is a four-legged table made of wood. Sometime later, a leg of the table is replaced. Even later, the table is demolished so it ceases to exist although the wood is still there after the demolition.*

[9] Any "proper" relation R(x,y) used here should be understood as R(x,y) $\wedge$ x$\neq$y.

[10] In figures throughout, we use circular nodes to represent both universals and defined classes, and diamonds to represent particulars.

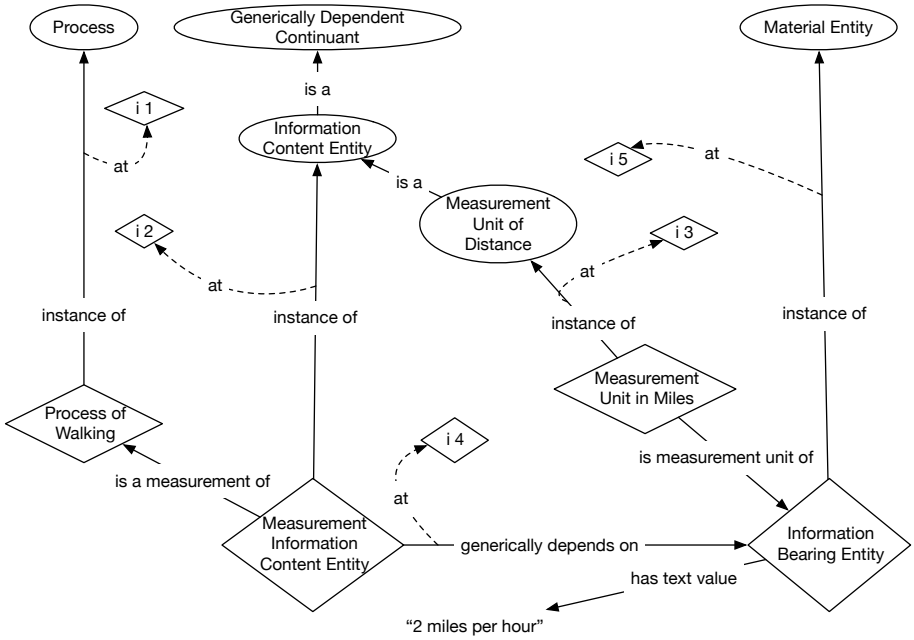

Figure 3: Relationships among Information Content Entities and Bearers

GOAL: *The example aims to show if and how the ontology models materials, objects, and components and the relationships among them.*
FOCUS: *The relationship between the wood and the table and the table's parts over time. (Artefacts and functions are not the focus.)*

BFO does not have a constitution relation such as "made of", typically related to an entity described as a mass noun. Instead, our example directly represents the particular portion of wood and its parts which are, when the table exists, part of the table. In *Table 1*, we describe the classes, particulars, and relations we will use in our discussion. The portion of wood exists throughout the interval but changes. At the beginning of the interval, the portion of wood bears a table function and has parts that bear leg functions. The portion of wood **participates in** a leg replacement process, during which one of its proper parts that bears a leg function is replaced by a material entity bearing a leg function. After the replacement, the original leg is no longer part of the portion of wood, and the replacement leg is now part of it. Afterward, the portion of wood **participates in** a destruction process, during which it loses its table function, and so no longer instantiates table.

Class	**Definition or Elucidation**

portion of wood	a material entity that was formerly part of one or more tree trunks or branches
table function	a function that **inheres in** a material entity with a flat surface that **has realization** a process during which a material entity is placed on the bearer without it falling off
leg function	a function that **inheres in** a stiff object and which **has realization** a process of support and elevation of other objects
table destruction process	a process during which a material entity **bearer of** a table function loses that table function

Particular	**Description**
wood	the portion of wood that **has continuant part** *leg 1* at *i2* and *leg 2* at *i5*
leg 1	the object that is **bearer of** *leg function 1*. *leg 1* is replaced in the example.
leg 2	the object that is **bearer of** *leg function 2*. *leg 2* replaces *leg 1* in the example.
table function	the table function that **inheres in** *wood*
leg function 1	the leg function that **inheres in** *leg 1*
leg function 2	the leg function that **inheres in** *leg 2*
leg replacement process	a process during which *leg 1* is replaced by *leg 2*
table destruction process	a process resulting in *wood* losing *table function 1*
i1	the temporal interval during which *wood* is **bearer of** *table function*
i2	the temporal interval during which *leg 1* is **bearer of** *leg function 1*
i3	the temporal interval during which *leg 1* is **proper continuant part of** *wood*
i4	the temporal interval **occupied by** *leg replacement process*, which *leg 1*, *leg 2*, and *wood* **participate in**
i5	the temporal interval during which *leg 2* is **proper continuant part of** *wood*
i6	the temporal interval at which *leg 2* **exists at**
i7	the temporal interval **occupied by** *table destruction process* in which *wood* loses *table function*

Relation	**Usage**

bearer of	holding between a portion of wood and a function it bears. **bearer of** is the inverse of **inheres in**
exists at	holding between an entity and the temporal interval when it exists
occupies temporal region	holding a process and just those temporal intervals over which the process unfolds.
has participant	holding between a process, a material entity involved in that process, and the temporal region at which the process occurs
proper continuant part of	holding between a proper mereological part of *wood* and *wood* itself, at the temporal region during which they are parts.

Table 1: Classes, Particulars, and Relations used to Formalize Case 1

wood is an **instance of** portion of wood throughout interval i and its seven sub-intervals:

1. **is a**(portion of wood, material entity)
2. **instance of**(*wood*, portion of wood, *i)*

wood bears a table function and **has proper continuant part** several legs. We focus on *leg 1*. We relate respective functions and material bearers:

3. **instance of**(*leg function 1*, leg function, *i2)*
4. **instance of**(*table function*, table function, *i1)*
5. **instance of**(*leg 1*, object, *i3*)
6. **instance of**(*wood*, object, *i2*)
7. **bearer of**(*wood*, *table function*)
8. **bearer of**(*leg 1*, *leg function 1*)
9. **proper continuant part of**(*leg 1*, *wood*, *i2*)

wood, *leg 1*, and *leg 2* **participate in** *leg replacement process*:

10. **instance of**(*leg function 2*, leg function, *i)*
11. **instance of**(*leg 2*, object, *i6)*
12. **bearer of**(*leg 2*, *leg function 2*)
13. ¬**continuant part of**(*leg 2*, *wood*, *i3*)[11]
14. **instance of**(*leg replacement process*, leg replacement process, *i4*)

[11]Strictly speaking, *leg 2* is also not a **continuant part of** *wood* at earlier times. Corresponding axioms are assumed but not displayed here.

15. **occupies temporal region**(*leg replacement process*, *i4*)
16. **participates in**(*leg 1*, *leg replacement process*, *i4*)
17. ¬**continuant part of**(*leg 1*, *wood*, *i5*)[12]
18. **participates in**(*leg 2*, *leg replacement process*, *i4*)
19. **proper continuant part of**(*leg 2*, *wood*, *i5*)

Afterwards, *wood* and its parts **participate in** an **instance of** table destruction process:

20. **instance of**(*table destruction process*, table destruction process, *i7*)
21. **occupies temporal region**(*table destruction process*, *i7*)
22. **participates in**(*wood*, *table destruction process*, *i7*)
23. ∃*t***occurrent part of**(*t*, *i7*) ∧¬**exists at**(*table function*, *t*)

We leave open whether proper parts of *wood* maintain their respective functions. That is compatible with the case that most proper parts of *wood* parts maintain their functions but are arranged such that *wood* loses *table function*. In any event, *wood* **exists at** *i7* though *table function* does not and thus *wood* no longer instantiates table. *Figure 4* provide an illustration of the change described in this case.

4.2 Roles

CASE 2: *Mr. Potter is the teacher of class 2C at Shapism School and resigns at the beginning of the spring break. After the spring break, Mrs. Bumblebee replaces Mr. Potter as the teacher of 2C. Also, student Mary left the class at the beginning of the break and a new student, John, joins in when the break ends.*
GOAL: *The example aims to show if and how the ontology models the relationships between roles, players and organizations.*
FOCUS: *The change of roles/players; the vacancy of the teaching position; persistence of the class while students come and go.*

Mr. Potter is – we assume – the only teacher of class 2C prior to Spring Break and participates in an act of resignation prior to this break. Classes at Shapism School are not in session during the break, but during this time Mrs. Bumblebee and Shapism School agree that Mrs. Bumblebee will bear a 2C teacher role at the end of Spring Break. We focus on only Mr. Potter and Mrs. Bumblebee in our formalization, as the loss of student Mary and gain of student John during this interval does not differ greatly from the loss of teacher Mr. Potter and gain of teacher Mrs. Bumblebee. We use the following assignment in our formalization:

[12]Strictly speaking, *leg 1* is also not a **continuant part of** *wood* at earlier times. Corresponding axioms are assumed but not displayed here.

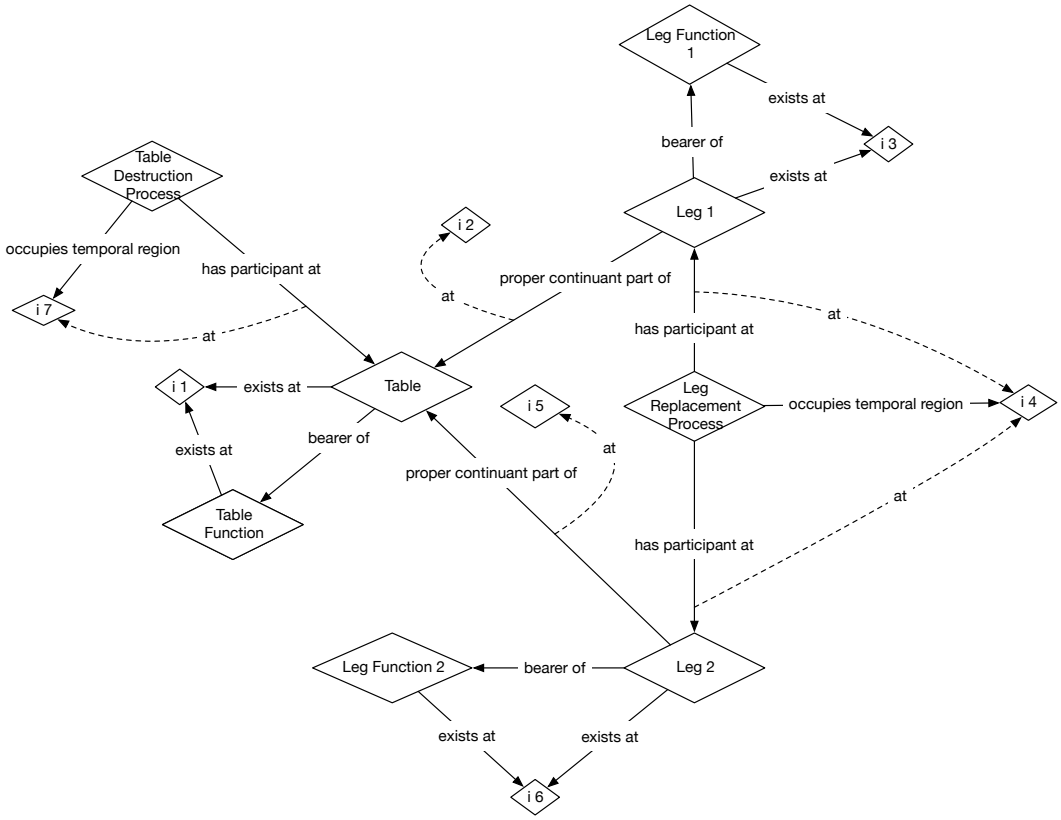

Figure 4: Table Undergoing Change in Case 1

Class	**Definition or Elucidation**
person	an object belonging to the species primate and distinguished by a high level of intelligence.
organization	an independent continuant that can play roles, has members, and has a set of organization rules.

Particulars	**Descriptions**
Mr. Potter	an **instance of** person
Mrs. Bumblebee	an **instance of** person
Shapism School	an **instance of** organization, the academic employer of *Mr. Potter* and *Mrs. Bumblebee*
2C	a **member part of** *Shapism School*, in which *Mr. Potter* and *Mrs. Bumblebee* teach
2C teacher role 1	the role borne by *Mr. Potter* as the teacher of class *2C*
2C teacher role 2	the role borne by *Mrs. Bumblebee* as the teacher of class *2C*
act of resignation	the process during which *Mr. Potter* resigns from his role as teacher of class *2C*
act of teaching assignment	the process during which *Shapism School* and *Mrs. Bumblebee* coordinate resulting in *Mrs. Bumblebee*

Relations	Descriptions
bearer of	holds between **instances of** person and the teacher roles which **inhere in** that person
proper temporal part of	holds between temporal intervals and the larger interval of which they are **occurent part**
occupies temporal region	holds between processes and just those temporal intervals over which they unfold
participates in	holds between material entities and the processes in which they are involved
member part of	holds holding between object aggregates and their members
has specified output	holds between *act of teaching assignment* and *Mrs. Bumblebee*'s *2C* teacher role

Table 2: Particulars and Relations Used to Formalize Case 2

Mr. Potter and *Mrs. Bumblebee* are **instances of** person [19]. *Shapism School* is an **instance of** organization [20,21]. Organizations may have other organizations as member parts, allowing for class *2C* to be **member part of** *Shapism School*:

1. **is a**(person, object)
2. **is a**(organization, object aggregate)
3. **instance of**(*Mr. Potter*, person, *i*)
4. **instance of**(*Mrs. Bumblebee*, person, *i*)
5. **instance of**(*Shapism School*, organization, *i*)
6. **member part of**(*2C*, *Shapism School*, *i*)

Mr. Potter was a **member part of** *2C* prior to the start of *spring break*. *Mrs. Bumblebee* was not a **member of** *2C* during this time. Before *spring break* begins, *Mr. Potter* **participates in** an *act of resignation* so that during and after *spring break* *Mr. Potter* is no longer a **member part of** *2C*. We leave open whether *Mr. Potter* remains a **member of** *Shapism School* during and after *spring break*:

7. **member part of**(*Mr. Potter*, *2C*, *i1*)
8. ¬**member part of**(*Mrs. Bumblebee*, *2C*, *i1*)
9. **instance of**(*spring break*, process, *i*)
10. **instance of**(*act of resignation*, process, *i3*)
11. **participates in**(*Mr. Potter*, *act of resignation*, *i3*)

12. ¬**member part of**(*Mr. Potter*, *2C*, *i4*)[13]

Shapism School and *Mrs. Bumblebee* **participate in** *act of teaching assignment* resulting in *Mrs. Bumblebee* being a **member part of** *2C* after *spring break*.

13. **occupies temporal region**(*act of teaching assignment*, *i5*)
14. **proper temporal part of**(*i4*, *i5*)
15. **proper temporal part of**(*i6*, *i5*)
16. **participates in**(*Shapism School*, *act of teaching assignment*, *i6*)
17. **participates in**(*Mrs. Bumblebee*, *act of teaching assignment*, *i4*)
18. **member part of**(*Mrs. Bumblebee*, *2C*, *i7*)

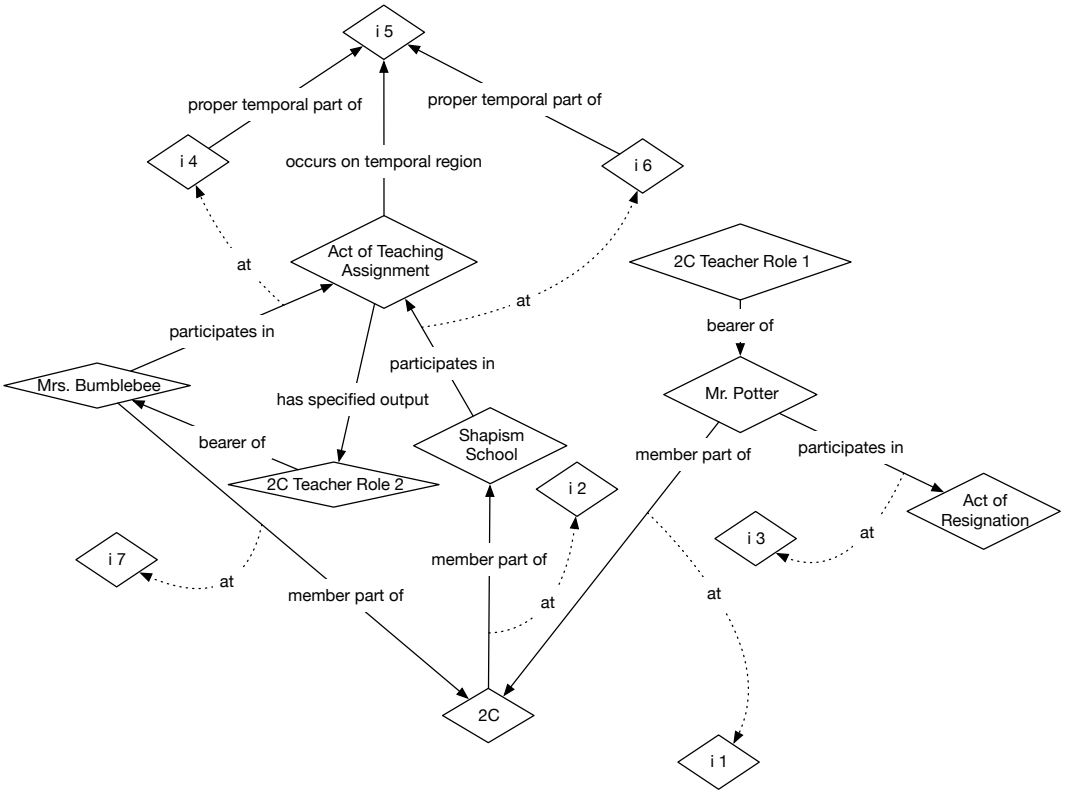

Figure 5: Resignation and Assignment of 2C Teacher Roles in Case 2

With respect to relevant roles, *Mr. Potter* bears *2C teacher role 1* – a role borne by a unique person who is a **member part of** *2C* at a given time. Following the

[13] *Mr. Potter* is, additionally, not a **member part of** *2C* during subsequent intervals.

act of teaching assignment in which *Shapism School* and *Mrs. Bumblebee* participate, *Mrs. Bumblebee* is the unique bearer of *2C teacher role 2*. There is, to date, no well developed treatment of titles, organizational positions, and offices as such, where these are understood to be independent of the particular role that persons bear when holding such offices. This may arise in cases, for instance, where one wishes to refer to advertise an open teaching position at the school. However, generically dependent continuants may serve as the parent class for such entities.

19. **bearer of**(*Mr. Potter*, *2C teacher role 1*)
20. ¬**exists at**(*2C teacher role 1*, *i4*)[14]
21. **has specified output**(*act of teaching assignment*, *2C teacher role 2*)[15]
22. **bearer of**(*Mr. Bumblebee*, *2C teacher role 2*)

4.3 Property Change

CASE 3: *A flower is red in the summer. As time passes, the color changes. In autumn the flower is brown.*
GOAL: *The example aims to show if and how the ontology models change in qualities/properties.*
FOCUS: *The change of the color of a flower.*

Color is a messy phenomenon. Color ascriptions can be described at different levels of granularity, for example, the whole flower, flower petals, or proper surface parts of petals. Distributions of colors at one level of granularity often determine color at higher levels of granularity. For example, classification of a petal as "red" depends on the distribution of red on proper parts of the petal's surface. Additionally, color may be understood as qualities, or dispositions to cause color experiences, or the color experiences themselves. We will thus need to simplify our formalization. We focus on a specific petal of the flower for simplicity, noting our formalization can be applied to lower or higher levels of granularity. Moreover, we focus on colors as qualities of entities, rather than dispositions to cause experiences or as experiences. Broadly speaking then, the petal bears a red color quality during summer that becomes brown during fall. During this time, the flower participates in an act of withering. We use the following assignments in our formalization:

Class	**Definition or Elucidation**
petal	a material entity leaf that often surrounds reproductive parts of some flower

[14] 2C teacher role does not exist during subsequent intervals.
[15] 2C teacher role does not exist before interval i5.

flower	a material entity that generates seeds during a reproductive cycle
color	a quality borne by a material entity that underwrites the reflection of light
red	a color with wavelength between 625 and 740 nanometers
brown	a color with wavelength of approximately 600 nanometers, with low saturation and luminance

Particular	**Description**
petal	the petal that bears a color quality that changes from red to brown
flower	the flower whose *petal* **continuant part** changes color through the season change
color	the color borne by the *petal* that changes from red to brown
summer	the process during which the *petal* begins as red and gradually becomes closer in color to brown
fall	the process during which the *petal* begins as reddish brown, but gradually becomes brown
process of withering	the process during which the *flower* loses elasticity and vibrancy
i1	the interval **occupied** by *summer*
i2	the interval **occupied** by *fall*
i3	the interval during which *color* is an **instance of** red, which is an **occurrent part** of both *i1* and *i6*
i4	the interval **occupied** by *process of withering*, which is an **occurrent part** of *i2*
i5	the interval during which *color* is an **instance of** brown, which is an **occurrent part** of both *i4* and *i6*
i6	the interval during which *color* is an **instance of** color

Relation	**Usage**
participates in	holds between *flower* and *process of withering*
occupies temporal region	holds between *summer*, *fall*, *process of withering*, and the respective *temporal region*s they each occupy

occurrent part of	holds between *temporal interval*s and larger *interval*s of which they are **parts**
proper continuant part of	holds between *petal* and the *flower* of which it is a part
bearer of	holds between *petal* and the *color* that it bears

Table 3: Classes, Particulars, and Relations Used to Formalize Case 3

We use the classes flower and petal [4,22] and assert the instance *flower* of the former has **continuant part** *petal*, which is an **instance of** the latter:

1. **instance of**(*flower*, flower, *i)*
2. **instance of**(*petal*, petal, *i)*
3. **proper continuant part of**(*petal*, *flower*, *i)*

Color is a specifically dependent continuant in BFO [23]. We assert two subclasses of color: red and brown, and we furthermore assert that *petal* bears an **instance of** color:

4. **is a**(color, quality)
5. **is a**(red, color)
6. **is a**(brown, color)
7. **instance of**(*color*, color, *i6*)
8. **bearer of**(*petal*, *color*)

The **color** borne by *petal* is an **instance of** red during *summer*, and an **instance of** brown during *fall*:

9. **instance of**(*summer*, process, *i1*)
10. **instance of**(*fall*, process, *i2*)
11. **occupies temporal region**(*summer*, *i1*)
12. **occupies temporal region**(*fall*, *i2*)
13. **instance of**(*color*, red, *i3*)
14. **instance of**(*color*, brown, *i5*)
15. **occurrent part of**(*i3*, *i1*)
16. **occurrent part of**(*i3*, *i6*)
17. **occurrent part of**(*i5*, *i4*)
18. **occurrent part of**(*i5*, *i6*)

The *flower* **participates in** a *process of withering* that occurs during *fall*:

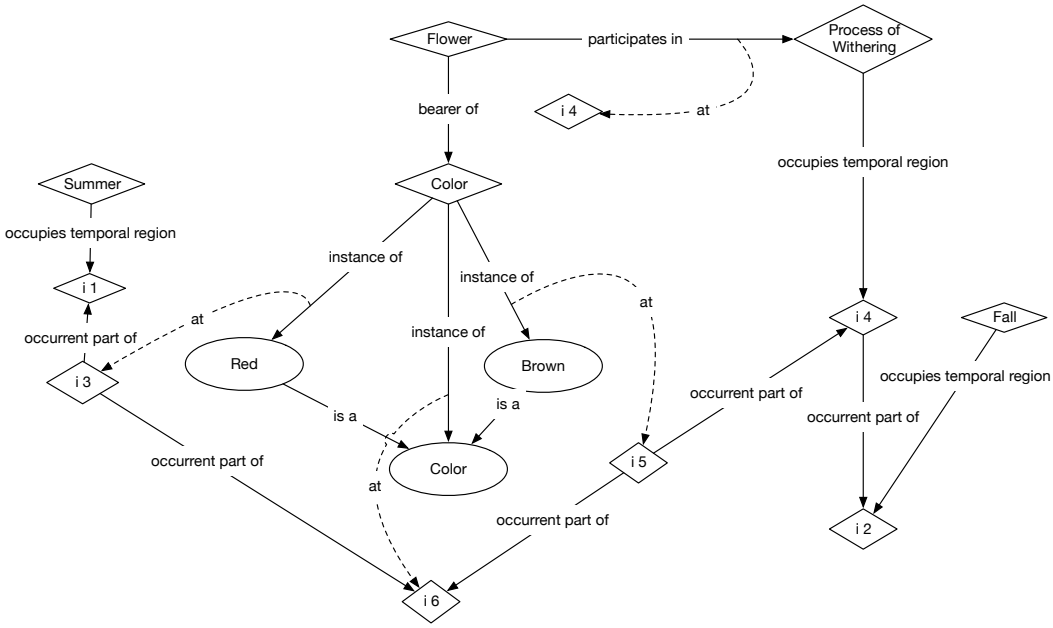

Figure 6: Petal Changing Color in Case 3

19. **instance of**(*process of withering*, process, *i4*)
20. **occupies temporal region**(*process of withering*, *i4*)
21. **occurrent part of**(*i4*, *i2*)

CASE 4: *A man is walking when suddenly he starts walking faster and then breaks into a run.*
GOAL: *The example aims to show if and how the ontology models change during an event.*
FOCUS: *The change in the speed and mode of locomotion.*

Processes do not change; they are changes. Participating in an act of locomotion, however, may have proper process walking, accelerating, and running parts. Intuitively, walking and running consist of sequences involving an agent who makes patterned contact with the ground using their feet, over some duration. For a given agent and given duration, walking is distinguished from running based on the number of moments of contact between the agent's feet and the ground. If this number is above some threshold, which may vary given the agent's size and shape, then it will count as running. An individual is accelerating when the there is a patterned decrease in the duration between contacts with the ground and an increase in the spatial distance traversed by the agent.

In this case, a man is participating in an act of locomotion having proper process parts an act of walking, act of running, and act of accelerating. Our

formalization uses the following assignments:

Particulars	**Descriptions**
man	an **instance of** *person* who bears some male gender
act of locomotion	an **instance of** process in which the *man* changes spatial position
act of walking	an **instance of** process in which the *man* changes spatial position exerting little effort, at a low speed
act of accelerating	an **instance of** process in which the *man* increases speed at which he changes spatial position
act of running	an **instance of** process in which the *man* changes spatial position, while exerting significant effort, at a high speed
i1	the interval during which the *man* **participates in** an *act of walking*
i2	the interval during which the *man* **participates in** an *act of accelerating*
i3	the interval during which the *man* **participates in** an *act of running*

Relations	**Usage**
proper occurrent part of	holds between acts of accelerating, walking, and the larger act of locomotion of which they are parts
participates in	holds between the *man* and processes in which he participates

Table 4: Classes, Particulars, and Relations used to Formalize Case 4

The *man* participates in an *act of locomotion* [18].

1. **instance of**(*man*, person, *i)*
2. **instance of**(*act of locomotion*, process, *i)*
3. **participates in**(*man*, *act of locomotion*, *i)*

This process is comprised of **proper occurrent parts** [23] – an *act of walking*, *act of accelerating*, and *act of running*. The man **participates in** each. *Figure 7* illustrates our formalization of the case.

4. **proper occurrent part of**(*act of walking*, *act of locomotion*)

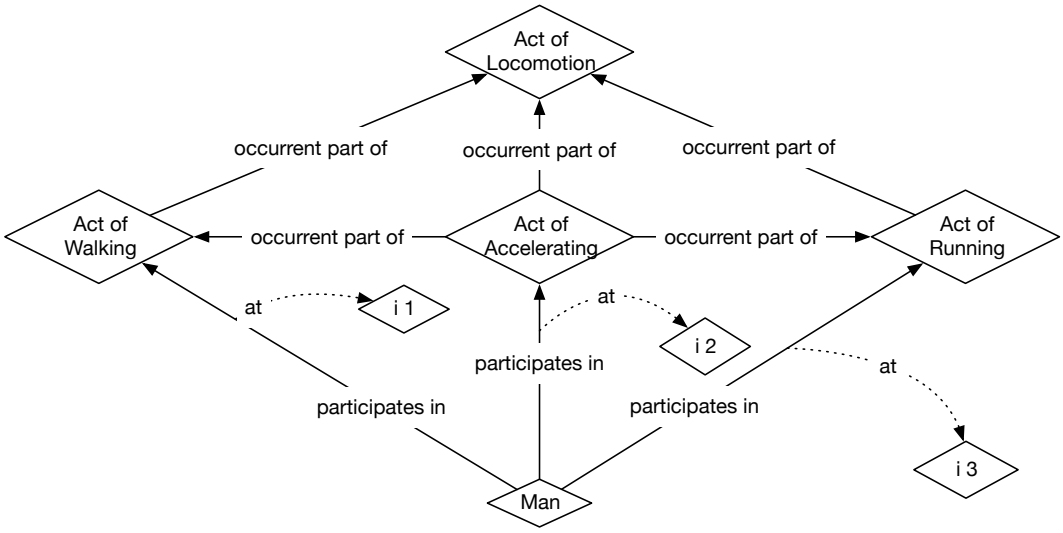

Figure 7: Man Moving with Increasing Speed in Case 4

5. **proper occurrent part of**(*act of accelerating*, *act of locomotion*)
6. **proper occurrent part of**(*act of running*, *act of locomotion*)
7. **proper occurrent part of**(*act of accelerating*, *act of walking*)
8. **proper occurrent part of**(*act of accelerating*, *act of running*)
9. **participates in**(*man*, *act of walking*, *i1*)
10. **participates in**(*man*, *act of accelerating*, *i2*)
11. **participates in**(*man*, *act of running*, *i3*)

While our characterization of this case is general, complementary refinements could be added. For example, the man's changing speed at times during this case might be represented as measurements taken at temporal parts of the interval. *Figure 3* provides a recipe for characterizing measurements using instances of generically dependent continuant. as evidenced in the next case. Moreover, our analysis of the next case illustrates a further complementary characterization of changing motion.

4.4 Event Change

CASE 5: *A man is walking to the station, but before he gets there, he turns around and goes home.*
GOAL: *The example aims to show if and how the ontology models change in goal-directed activities.*
FOCUS: *An activity/event is not completed and another activity/event is completed instead.*

The man commits himself to a plan to walk to the station, which is specified in terms of actions he might take and the objective he seeks. Prior to arriving at the station, the man abandons his initial plan, and forms another, this time to turn around and walk home. As before, the man's plan to walk home is specified in terms of actions he might take and the objective he seeks. In this case, the man achieves his objective.

Class	**Definition or Elucidation**
plan	a realizable entity that **inheres in** a bearer who is committed to realizing it as a planned process
plan specification	an information entity with action specifications and objective specifications as **continuant parts** that, when concretized, is **realized** in a process in that the bearer tries to achieve the objectives by taking the actions specified
information content entity	a generically dependent entity that depends on some artifact and stands in a relation of aboutness to some entity
action specification	an information entity that **describes** an action the bearer will take
objective specification	an information entity that **describes** an intended process endpoint. When **continuant part of** a plan specification the concretization is **realized** in a planned process in which the bearer tries to effect the world so that the process endpoint is achieved
facility	a material entity that is designed as a building or campus dedicated to some specific purpose
planned process	a process that **realizes** a plan that is the **concretization** of a plan specification

Particulars	**Descriptions**
man	the person who bears some male gender in the scenario
plan 1	the plan that the *man* forms to walk to the *station*

plan 2	the plan that the *man* forms to turn around and walk *home*
station plan specification	the plan specification having **continuant part** *station action specification* and *station objective specification*
station action specification	an action specification describing the steps the *man* intends to take to walk to the *station*
station objective specification	the objective specification describing reaching the *station* as the objective of the *station plan specification*
home plan specification	the plan specification having parts *home action specification* and *home objective specification*
home action specification	the action specification describing the steps the *man* intends to take to turn around and walk *home*
home objective specification	the objective specification describing reaching *home* as the objective of the *home objective plan*
station	the facility to which the *man* initially intends to walk
home	the facility to which the *man* later walks
station description	the information content entity describing the *station*, that is **continuant part of** the *station objective specification*
home description	the information content entity describing the *man's home*, that is **continuant part of** the *home objective specification*
4mph walk	the process during which the *man* walks at a uniform velocity of 4 mph
3mph walk	the process during which the *man* walks at a uniform velocity of 3 mph
180 turn	the process during which the *man* turns 180 degrees
i1	interval during which the *station plan specification* exists, and during which the *station action specification* and *objective specification* are **proper continuant part**s of the *station plan specification*
i2	interval during which is *station plan specification* **concretized by** *plan 1*
i3	interval during which the *man* **participates** in the *4mph walk* process

i4	interval during which the *man* **participates in** the *180 turn* process
i5	interval during which the *man* **participates in** the *3mph walk* process
i6	interval during which *home plan specification* is **concretized by** *plan 2*
i7	interval during which the *home plan specification* exists, and during which the *home action specification* and *objective specification* are **proper continuant parts** of the *home plan specification*

Relations	**Descriptions**
concretized by	holds between *station plan specification*, *home plan specification*, and *plan 1* and *plan 2*, respectively
proper continuant part of at	holds between *action* and *objective specifications* and *plan specifications*, as well as between descriptions and *objective specifications*
exists at	holds between *plan specifications* and the temporal intervals at which they exist
is about	holds between descriptions and the entities they describe
bearer of	holds between the *man* and *plan 1* and *plan 2*
prescribes	holds between an action specification and the processes that the specification prescribes
achieves planned objective	holds between a planned process and objective specification when the criteria specified in the objective specification are met at the end of the planned process
participates in	holds between *man* and the processes in which he participates

Table 5: Classes, Particulars, and Relations Used to Formalize Case 5

The *man* bears *plan 1* [25,26], which is a concretization of *station plan specification*. *Station plan specification* has continuant part both an *action specification* that *prescribes* the steps the *man* might take to walk to the *station* and the *objective specification* that describes the goal of *plan 1*:

1. **is a**(plan, realizable entity)
2. **is a**(plan specification, information content entity)
3. **instance of**(*plan 1*, plan, *i)*
4. **instance of**(*station plan specification*, plan specification, *i2*)
5. **instance of**(*station action specification*, action specification, *i2*)
6. **instance of**(*station objective specification*, objective specification, *i2*)
7. **inheres in**(*plan 1*, *man*)
8. **concretized by**(*station plan specification*, *plan 1*, *i3*)
9. **continuant part of**(*station action specification*, *station plan specification*, *i2*)
10. **continuant part of**(*station objective specification*, *station plan specification*, *i2*)

Station is an **instance of** facility [18]. Because *plan 1* is an **instance of** realizable entity, it is not strictly speaking about anything, as only information content entities may be about some entity. Nevertheless, there is an **instance of** information content entity that is **part of** the *station objective specification* and **concretized by** *plan 1*, which includes the *station* in its description. We can thus say *man*'s *plan 1* (derivatively) **is about** the *station*. Moreover, the *station action specification* includes the walking plan he intends to take in pursuit of that objective. Additionally, the *man* **participates in** a *4mph walk*:

11. **instance of**(*station*, facility, *i)*
12. **instance of**(*station description*, information content entity, *i)*
13. **continuant part of**(*station description*, *station objective specification*, *i2*)
14. **described by**(*station*, *station description*)
15. **participates in**(*man*, *4mph walk*, *i4*)

At some time, the *man* forms *plan 2* to walk back *home*, then **participates in** an **instance of** *180 turn*¸ then **participates in** a *3mph walk* until he arrives *home*:

16. **instance of**(*plan 2*, plan, *i)*
17. **instance of**(*home plan specification*, plan specification, *i)*
18. **instance of**(*home action specification*, action specification, *i6*)
19. **instance of**(*home objective specification*, objective specification, *i6*)
20. **continuant part of**(*home action specification*, *home plan specification*, *i6*)
21. **continuant part of**(*home objective specification*, *home plan specification*, *i6*)
22. **inheres in**(*plan 2*, *man*)
23. **concretized by**(*home plan specification*, *plan 2*, *i6*)
24. **prescribes**(*home plan specification*, *180 turn*)

25. **prescribes**(*home plan specification*, *3mph walk*)
26. **participates in**(*man*, *180 turn*, *i4*)
27. **participates in**(*man*, *3mph walk*, *i5*)
28. **realized in**(*plan 2*, *180 turn*)
29. **realized in**(*plan 2*, *3mph walk*)

The *man's home* is a facility. There is an **instance of** information content entity that is **part of** the *home objective specification* and **concretized by** *plan 2*, where *plan 2* includes *home* in its description. We can thus say the *man's plan 2* **is** (derivatively) **about** the *home*. As before, the *home action specification* includes the walking plan the *man* intends to take. In this case, the *man* does achieve his planned objective, which we can represent by the *man's* **participating in** an **instance of** *planned process* and bearing an **achieves objective** relation to the *home objective specification*, which we import from [21,22].

30. **is a**(planned process, process)
31. **instance of**(*planned process*, planned process, *i)*
32. **instance of**(*home*, facility, *i)*
33. **instance of**(*home description*, information content entity, *i7*)
34. **continuant part of**(*home description*, *home objective specification*, *i7*)
35. **described by**(*home*, *home description*)
36. **participates in**(*man*, *planned process*, *i6*)
37. **achieves planned objective**(*planned process*, *home objective specification*)

For further specification of the *man's* walk, formalizations of distance measurement using BFO and its extensions illustrated in *Figure 3* can be leveraged to describe how far the *man* traveled in his initial trip before turning back.

4.5 Concept Evolution

CASE 6: *A marriage is a contract that is regulated by civil and social constraints. These constraints can change but the meaning of marriage continues over time.*
GOAL: *The example aims to show if and how the ontology models the evolution of the meaning of a term.*
FOCUS: *The continuity/discontinuity of the meaning of marriage in the presence of changing qualifications.*

Speaking of 'the meaning' of marriage is spurious. Like most words, 'marriage' is polysemous. It can refer to a process in which spouses participate; it can refer to information content entities (i.e. the *idea* of marriage in the minds of particular people, or as represented in legal documents); and it can refer to a pair of mutually dependent spousal roles and their associated powers and privileges. Some uses of 'marriage' pull together all three meanings, as when we speak of

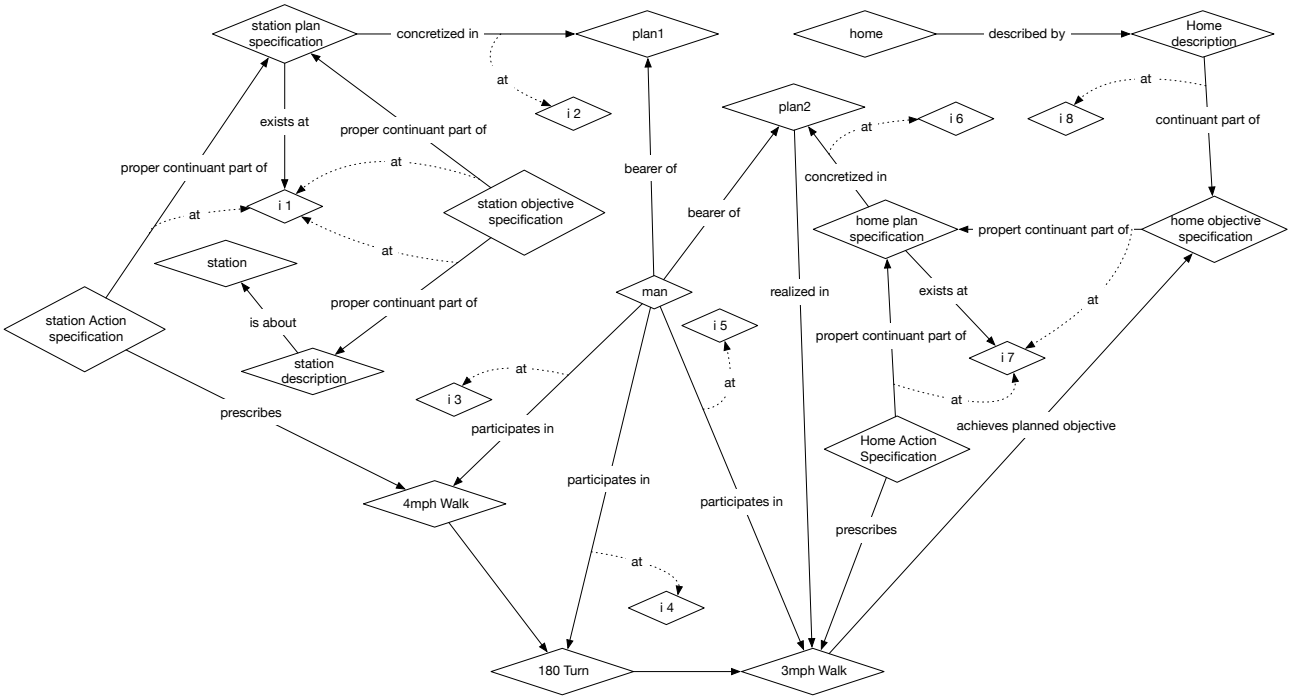

Figure 8: Man Walking to Station, then Home in Case 5

the institution of marriage and denote a set of practices (processes) realizing marital powers (roles) that are prescribed by social or religious doctrine and law (information content entities). In representing marriage, we should take care not to conflate these different notions. As Groucho Marx once quipped: "Marriage is a wonderful institution, but who wants to live in an institution?"

Marriage license regulations vary by geographical region, population, and organizational affiliation. In the U.S., for example, marriage requirements, laws, and associated rights are established by states. All states impose eligibility requirements on individuals. For example, individuals entering marriage must have the capacity to consent to the arrangement and must be above a certain age. States also impose eligibility requirements on the couple. For example, at least one member of the union must be a U.S. citizen, before 1967 several states prohibited interracial marriage, and until 2015 several prohibited same-sex marriage [28]. Governments also grant obligations to spouses - married partners bear financial responsibilities to one another - and privileges - married partners are not required to testify against one another in court. Obligations and privileges can, like eligibility requirements, be changed by governing agencies.

We focus on the present status of a marriage contract issued in the U.S. between 1967 and 2015, and subsequent legal changes after 2015.

Class	**Definition or Elucidation**
document	a collection of information content entities intended to be understood together as a whole
government	an organization that exercises executive, legislative, or judicial authority over a region
marriage license	a document issued by a government, which legally binds agents as spouses, and invests them with associated **instances of** deontic role
deontic declaration	a social act that creates or **revokes** a deontic role
social act	a planned process that is carried out by a person or an organization, and is self-generated, directed towards another person or an aggregate of persons, an organization or an aggregate of organizations, and that needs to be perceived
deontic role	a role that **inheres in** a person and that is externally grounded in the normative expectations that other persons within a social context have concerning how that person should behave
action regulation	an information content entity that **prescribes** an act as required, prohibited, or permitted, and is the **output of** an act that **realizes** some authority role
authority role	a role that is **realized** by actions that create, modify, transfer, or eliminate action regulations or other authority roles, and **inheres in** an agent in virtue of collective acceptance of that agent's ability to issue binding directives

Particulars	**Descriptions**
U.S. Supreme Court	the branch of government able to legally create or **revoke** deontic powers of *state government*
deontic declaration 1	the deontic declaration that **has specified output** *marriage license*
deontic declaration 2	the deontic declaration that **has specified output** *action regulation 1*
deontic declaration 3	the deontic declaration that **legally revokes** *deontic role 1* and *deontic role 3*

deontic role 1	the deontic role **inhering in** *Alex* **realized in** *Alex* legally refraining from testifying against *Bailey* in court
deontic role 2	the deontic role **inhering in** *Alex* **realized in** *Alex's* legal permission to file income taxes jointly with *Bailey*
deontic role 3	the deontic role **inhering in** *Bailey* **realized in** *Bailey* legally refraining from testifying against Alex in court
deontic role 4	the deontic role **inhering in** *Bailey* **realized in** *Bailey's* legal permission to file income taxes jointly with *Alex*
marriage license	the marriage license issued by *state government*, which legally binds *Alex* and *Bailey* together as spouses, and invests them with associated instances of deontic role
state government	the government **participating in** the marriage of *Alex* and *Bailey*
Alex	the person entering acquiring a *marriage license* with *Bailey*
Bailey	the person entering acquiring a *marriage license* with *Alex*
marriage licensure document	a document describing the objective of issuing, and steps that must be taken to issue *marriage license*
action regulation 1	an action regulation requiring *state government* to issue **instances of** marriage license for consenting same-sex couples
authority role 1	an authority role borne by *state government*, **prescribed by** *action regulation 1*
i1	the interval during which *state government*, *Alex*, and *Bailey* **participate in** *deontic declaration 1* resulting in the creation of *marriage contract*
i2	the interval during which *U.S. Supreme Court* **participates in** *deontic declaration 2* requiring *state government* to recognize same-sex marriage
i3	the interval during which *state government* **legally revokes** *deontic role 1* and *deontic role 3*

Relations	**Descriptions**

participates in	holds between agents and **instances of** deontic declaration
has specified input	holds between *deontic declaration 1* and *marriage licensure document*
has specified output	holds between **instances of** deontic declaration and document, and *action regulation 1*
inheres in	holds between **instances of** deontic role and *Alex* and *Bailey*, respectively
prescribes	holds between *action regulation 1* and *authority role 1*
legally revokes	holds between *deontic declaration 3* and *deontic role 1* and *deontic role 3*

Table 6: Classes, Particulars, and Relations Used to Formalize Case 6

The *marriage license* is an instance of the class marriage license, which is a subclass of document [29,30 31,32]. *State government*, which issues the *marriage license*, is an instance of government, which is a type of organization able to exercise judicial, legislative, or executive authority over a site.

1. **is a**(document, information content entity)
2. **is a**(marriage license, document)
3. **is a**(government, organization)
4. **instance of**(*marriage license*, marriage license, *i*)
5. **instance of**(*state government*, government, *i*)

State government **participates in** *deontic declaration 1* , a type of social act [28,29,30] which **has specified input** a *marriage licensure document* that has, as part, a plan specification. This plan specification **describes** the intended legal entities created according to the objective specification, as well as the manner in which the deontic declaration should be performed to achieve that objective – as described by the action specification. For simplicity, we do not include these continuant parts of *marriage licensure document*. The *deontic declaration 1*, moreover, **has specified output** the *marriage license*:

6. **is a**(deontic declaration, social act)
7. **instance of**(*deontic declaration 1*, deontic declaration, *i1*)
8. **participates in**(*state government*, *deontic declaration 1*, *i1*)
9. **has specified input**(*deontic declaration 1*, *marriage licensure document*)
10. **has specified output**(*deontic declaration 1*, *marriage license*)

Alex and *Bailey* each **participates in** *deontic declaration 1* as well. Instances of deontic declaration involve the creation or revoking of deontic roles. Instances of deontic role **inhere in** persons or organizations, but are externally grounded in the normative expectations others have concerning how bearers should behave. In this case, instances of deontic role **inhere in** *Alex* and *Bailey*, respectively. These respective roles are **realized in** processes typically associated with marriage, such as filing taxes jointly and making medical decisions on behalf of the spouse. For simplicity, we focus on only two such deontic roles each for *Alex* and *Bailey*.

11. **instance of**(*Alex*, person, *i*)
12. **instance of**(*Bailey*, person, *i*)
13. **participates in**(*Alex*, *deontic declaration 1*, *i1*)
14. **participates in**(*Bailey*, *deontic declaration 1*, *i1*)
15. **is a**(deontic role, role)
16. **instance of**(*deontic role 1*, deontic role, *i1*)
17. **instance of**(*deontic role 2*, deontic role, *i1*)
18. **instance of**(*deontic role 3*, deontic role, *i1*)
19. **instance of**(*deontic role 4*, deontic role, *i1*)
20. **inheres in**(*deontic role 1*, *Alex*)
21. **inheres in**(*deontic role 2*, *Alex*)
22. **inheres in**(*deontic role 3*, *Bailey*)
23. **inheres in**(*deontic role 4*, *Bailey*)

At some point, following *deontic declaration 1* that results in the *state government* issuing *marriage license* for *Alex* and *Bailey*, the *U.S. Supreme Court* **participates in** *deontic declaration 2* resulting in all state prohibitions on same-sex marriage being deemed unconstitutional. *Deontic declaration 2* **has specified output** *action regulation 1* permitting the authorization of same-sex marriage. This prescription sanctions new realizations of state and local agent **instances of** authority role relevant to marriage contracts, by broadening the class of those eligible to participate in an act of marrying.

24. **instance of**(*U.S. Supreme Court*, organization, *i*)
25. **instance of**(*deontic declaration 2*, deontic declaration, *i2*)
26. **participates in**(*U.S. Supreme Court*, *deontic declaration 2*, *i2*)
27. **is a**(action regulation, information content entity)
28. **instance of**(*action regulation*, action regulation, *i2*)
29. **has specified output**(*deontic declaration 2*, *action regulation 1*)
30. **is a**(authority role, role)

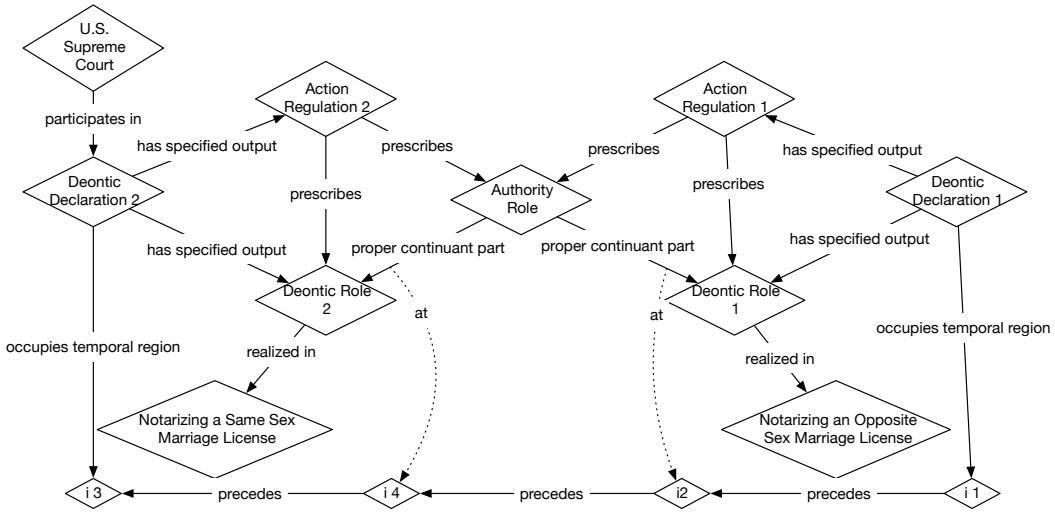

Figure 9: Changing Deontic Roles in Case 6

31. **instance of**(*authority role 1*, authority role, *i2*)
32. **prescribes**(*action regulation*, *authority role 1*)
33. **inheres in**(*authority role 1*, *state government 1*)

The expansion of sanctioned realizations of **instances of** authority role by *state government* does not undermine that *Alex* and *Bailey* have a *marriage license*. This is because **instances of** deontic role borne by *Alex* and *Bailey* are not altered by *action regulation 1*, since *action regulation 1* targets eligibility constraints on marriage.

As discussed, governments may alter marriage contracts in another way, by changing spousal obligations and powers. To illustrate, suppose *state government* **participates in** *deontic declaration 3* which **legally revokes** the *deontic role 1* that **inheres in** *Alex* and *deontic role 2* that **inheres in** *Bailey*, which we assume correspond to privileges bearers have to refrain from testifying against their spouse. This results in *Alex* and *Bailey* losing these respective roles, though they maintain *deontic role 2* and *deontic role 4*.

34. **participates in**(*state government*, *deontic declaration 3*, *i3*)
35. **legally revokes**(*deontic declaration 3*, *deontic role 1*, *i3*)
36. **legally revokes**(*deontic declaration 3*, *deontic role 3*, *i3*)
37. $\exists t$ **occurrent part of**(t, *i3*) $\wedge\neg$**exists at**(*deontic role 1*, t) $\wedge\neg$**exists at**(*deontic role 3*, t)

At least two types of change to marriage licenses can be represented with BFO, reflecting changes to eligibility requirements – which either narrow or extend

participants – or changes to associated roles – which either narrow or extend spousal rights and obligations. In each case, the meaning of marriage, in some sense, remains the same.

5. Ontology Usage and Community Impact

BFO is committed to there being a single reality, with scientific investigation often resulting in clarifications of our picture of this reality. As science updates, ontology should follow. Other *conceptions*, past or present, of the way the world is, or might be, are merely informational entities and impose no further ontological commitments.

As the core architecture of OBO and IOF [1,2], BFO is widely used across a range of scientific disciplines. BFO is, for example, used extensively in the biomedical domain [33], providing domain specialists foundational support when modeling phenotypes [34], disease [35,36,37], diagnosis [38,39], and resistance [40]. BFO is presently used in over 350 ontology products, and with its recent standardization, this number will no doubt increase in the coming years.

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Appendix

Relation Name and Source[16]	**Definition or Elucidation**
is about(IAO)	A primitive relation that relates an information artifact to an entity.
uses measurement unit(CCO)	y *uses measurement unit* x iff y is an **instance of** information bearing entity and x is an **instance of** measurement unit, such that x describes the magnitude of measured physical quantity mentioned in y.
is a measurement unit of(CCO)	x *is measurement unit of* y iff y is an **instance of** information content entity and x is an **instance of** measurement unit, such that x describes the magnitude of measured physical quantity mentioned in y.
has integer value(CCO)	A relation holding between an information bearing entity and an integer
describes(CCO)	x *describes* y iff x is an **instance of** information content entity, and y is an **instance of** entity, such that x is about the characteristics by which y can be recognized or visualized.
achieves planned objective(OBI)	This relation obtains between a planned process and a objective specification when the criteria specified in the objective specification are met at the end of the planned process.

[16]These relations come from ontologies using Basic Formal Ontology (BFO), including: The Common Core Ontologies (CCO), The Ontology for Biomedical Investigations (OBI), The Information Artifact Ontology (IAO), and The Ontology of Document Acts (D-Acts).

prescribes(CCO)	x *prescribes* y iff x is an **instance of** information content entity and y is an **instance of** entity, such that x serves as a rule or guide for y if y an occurrent, or x serves as a model for y if y is a continuant.
has text value(CCO)	A relationship between an information bearing entity and a string representation.
has specified output(OBI)	A relation between a planned process and a continuant which **participates in** that process. The presence of the continuant at the end of the process is explicitly specified in the objective specification which the process realizes the concretization of.
legally revokes(D-Acts)	d socio-legally revokes s if s **participates** in d and at the end of d s no longer exists. s going out of existence is complete and unlike the going out of existence for material entities which are always transformed into something else. After the declaration nothing is left of the socio-legal generically dependent continuant in question.

Table 8: Relations Used in Cases from Other BFO-Conformant Ontologies