Towards Representing Change in the BFO

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Abstract. The Basic Formal Ontology (BFO) is an upper ontology that embraces both continuants and occurrents. Continuants can persist through time while undergoing changes through their participation in processes. Processes are held not to change as they are said to *be* changes. Yet, the BFO is silent about what sorts of changes might exist: *history* is the only type that is subsumed by *process*. Although representing and tracking instance data by means of the BFO's time-indexed relations allows one to infer that some change must have happened in the portion of reality described by the data, change is not explicitly represented. When a change exists, there must be a change of something. However, when *the color of that flower* (a quality inhering in, but distinct from, *that flower*) instantiates red at one time, and brown at a later time, then that change, alone, is not a process under the current definitions and axioms of the BFO. This is because qualities can participate in a process p, but never by itself: p must have a material entity as participant. Furthermore, processes can only have other processes and process boundaries as parts; if the BFO would accept the change of qualities, or specifically dependent continuants in general, as occurrents, though not processes, then such change cannot be *occurrent-part-of* a process. In this paper we explore the basis of a theory, and the beginnings of an axiomatization thereof, as an extension to the BFO that recognizes *change* as a subtype of occurrent so that instances thereof *happen-in* processes and *happen-to* continuants whereby these continuants participate in the processes these changes *happen-in*. We anticipate re-expressing the ideas presented here as axioms expressed in terms of processes and participation in a future revision of the BFO-FOL axioms that currently prevent a tighter integration.

Keywords. Basic Formal Ontology, change, process

1. Introduction

The Basic Formal Ontology (BFO) is usually described as an ontology that recognizes two radically distinct sorts of entities: (a) continuants, elucidated as entities that persist, endure or continue to exist through time while maintaining their identity, and (b) occurrents, elucidated as entities that (b1) unfold themselves in time (processes), or are (b2) the start or end of entities of type b1 (process boundaries), or are (b3) temporal regions or (b4) spatiotemporal regions. An entity is thereby elucidated as anything that exists, has existed or will exist. Rather than embracing one specific ontological perspective such as perdurantism, endurantism, eternalism, three-dimensionalism or four-dimensionalism, the BFO, as a representational artifact, includes elements from

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several perspectives [1, 2], thereby defending a position described as '*realist perspectivalism*' [3] and '*moderate pluralism*' [4]. Key in this position is the view that reality should not be seen as consisting of one ontology, but as a combination of one SPAN ontology which is home for the occurrents (the temporally extending ones thereof '*spanning'* time) and multiple SNAP ontologies, each one of which to be considered as a '*snapshot'* of the continuants that exist at a specific time but nevertheless can persist through time while undergoing changes [5]. Change is, however, not explicitly represented in the BFO. In this paper, we propose an extension to the BFO that attempts to make the relationships between processes and continuants on the one hand, and change on the other hand, more explicit.

The paper is structured as follows. In section 2 we review the few papers that discuss change in the context of the BFO. Of the two distinct entities explored in the early literature of the BFO, i.e. *process* and *event*, the latter only found its way into the BFO in the form of *process boundary* [4]. We present our proposal for change as an extension to the BFO in section 3. The proposal is formulated so as to remain consistent with the current definitions, elucidations and axioms in BFO2020-FOL that govern the relationships between processes and other entities [6]; it rests on the introduction of a new occurrent universal, i.e. *change*. This approach is partly motivated by some surprising findings about what is actually implied by the current BFO axiomatization of which an analysis is provided in section 4. Using these results, we justify the chosen strategy in section 5 and follow this by a discussion on directions for further investigations, including a suggestion to the authors of the BFO to revise the current axiomatization and elucidation of *process*.

2. 'Change' in the History of the BFO

Although representing and tracking instance data [7] by means of the BFO's time-indexed relations allows one to infer that some change must have happened in the portion of reality described by the data – e.g. from '***participates-in***(*man*, act of walking, *i1*) & ***participates-in***(*man*, act of running, *i3*)', or from '***member-part-of***(*Mr. Potter*, *2C, i1*) & ¬***member-part-of***(*Mr. Potter, 2C, i4*)' [8] – change is not explicitly represented in the BFO itself. In the BFO literature, change is discussed in terms of two types of occurrent: *process* and *event*.

The position with respect to processes and changes has changed over the years. In 2004, the position seemed to be that changes are entities in their own right: '*We also considered changes as entity in their own right, and argued that they require an ontological treatment in their own right as processual entities.*' [5, p160]. It was however not made clear what their perceived relation was to processes, as we can read in relation to the SNAP/SPAN distinction '*The former deals with successions of instantaneous snapshots of the world, the latter with changes and processes as such*' [5, p137] and also '*BFO endorses a view according to which the world contains occurrents, more familiarly referred to as processes, events, activities, changes*' [5, p140]. The authors also proposed a hierarchy of *processual entities* encompassing *processes*, *fiat parts* (of processes), (process) *aggregates*, *settings* and *events*, but not *changes* [5, p142]. In 2007, the same authors followed a similar discourse, e.g. by stating that occurrents are '*entities which occur, which happen to continuants, more familiarly referred to as processes, events, activities, changes, happenings*' [4, p36], although there is also the more explicit '*changes are processes*' [4, p34], however inverted in 2012: '*processes are changes*' [9,

p478]. Consistent throughout he literature is that processes don't change '[…] *because if two processes should differ with regard to even the smallest part, then these two processes are non-identical*' [10, p122].

'Event' is described as '*The beginnings and endings of processes and the crossings of transition thresholds within processes – all entities which exhaust themselves in single instants of time*' [5, p64]. While '*crossings of transition thresholds within processes*' are thus far not addressed in the BFO, the '*beginnings and endings of processes*' are represented as process boundaries, defined as a temporal part of a process such that a process boundary does not have a proper temporal part itself ([esh-1] – note that references of the form [xxx-n] correspond to existing axioms in BFO2020-FOL [6]) and temporally occupies a temporal instant ([lyx-2] and [esh-1]).

Several sorts of changes are discussed in [5], including qualitative change, spatial and locational change, and substantial change. A substantial change '*occurs when substances are created or destroyed, as when a substance is divided up so as to produce a plurality of substances or when a plurality of substances is fused or merged*' [5, p157]. Qualitative change was said to come in various modes, such as '*change in determinables*' (e.g. color changes), '*qualitative creation*' (e.g. acquisition of a role), and '*qualitative destruction*' (e.g. loss of function). None of these changes made it thus far to the BFO as currently available, not as 'change', not as 'process'.

3. Towards an Explicit Representation of Change in the BFO

Our goal is to have an extension to the BFO that is able to represent explicitly any sort of change that must have occurred when a proposition that is true at one time, is not true at another time, or as phrased in [11]: '*a change in a thing is a change in the descriptions (truly) borne by the thing*'. The changes in scope of our theory thus include (1) intrinsic changes (e.g. processes involving gain or loss of parts or transformations, in which a continuant changes what universal it instantiates), (2) changes brought about through some entity's participation in processes by means of which that entity alters its relation to other entities (e.g. moving from one place to another), or (3) changes by way of which some entity's relation to something else is changed because of processes involving another entity (e.g. becoming poorer because of a stock market crash, or becoming uncle when one's sibling becomes father).

One obvious way to go would be to expand the process taxonomy of the BFO. Some attempts have been made, but without wide adoption thus far. One suggestion was to include '*process profile*' as a subtype of process [9]. Instances thereof would be proper occurrent parts of a process that correspond to changes '*in one or other structural dimension*' of the process itself (and not participants thereof) – e.g. speed, acceleration, production rate, … – along which processes can be compared. Process profile figured as universal in BFO 2.0 but is omitted in BFO2020. Another proposal involved relations reflecting a BFO-compatible realist interpretation of three known aspectual notions used to classify verbal phrases: homeomericity, cumulativity and telicity [12]. For the two other aspects, instantaneity and atomicity, no satisfactory realist interpretation was found. In an attempt to provide identity criteria for BFO processes, Toyoshima & Barton [13] explored whether various sorts of changes – quite close to the ones listed in section 2 and analyzed in [11] – that naturally come to mind when discussing processes, would be acceptable in the BFO: simple changes such as changes in specifically dependent continuants (SDCs) and motions, and substantial changes such as going in or out of

existence, mereological changes and changes in generically dependent continuants. An example of a 'simple process' that they provide is:

D1 SDCC(p) =def. PRO(p) ∧ ∃ sdc PSDC(p,sdc)
'p is a specifically dependent change" means: p is a process and there exist sdc such that p is a change of sdc'.
'*specifically dependent continuant change =def a process that is a change of an independent continuant with respect to a single specifically dependent continuant thereof*' [13]

However, Toyoshima & Barton's verbal definition for SDC change in D1 is too general as it would include immaterial entities, boundaries and sites, which we will see are per BFO axioms disallowed as sole participants in a process. A defense to this objection might be formulated in terms of the distinction they make between *direct change*, i.e. a change in a SDC that inheres in an independent continuant (IC), and *indirect change*, i.e. a change in an SDC that inheres in *some part* of an IC. When the immaterial entity is part of some material entity, this could be acceptable, but for sites such as air corridors, matters are less clear [14]. Their formulation of the formal representation provided in D1 requires more caution as the explicit mention of an IC, let alone a material entity, is left out; D1 is also not compatible with BFO2020-FOL because it lacks temporal indexing.

3.1. Strategy

Nevertheless, our approach follows similar lines of thought as Toyoshima & Barton's analysis [13] by taking also as starting point the various sorts of changes that continuants, according to the underlying theory of the BFO, can undergo through their participation in processes. This is also in line with the changes discussed in [5]. Our axiomatization deviates from the formal definitions provided in both works by adhering more closely to the style used in the axiomatization of the BFO theory in BFO2020-FOL, in the first place by using appropriate time-indexed relations, but also taking into account that the axioms do not completely cover the theory. We choose to not propose changes to BFO2020-FOL at this time. Instead we introduce *change* as a universal that is directly subsumed by *occurrent* and develop a representation which relates changes to processes in a way that is fully compatible with the existing BFO2020-FOL axioms.

Essential are the observations described and further detailed in section 4. One is that, under the current elucidation of process, all processes must have at least in some temporal part a material entity as participant. Although BFO processes can have specifically (SDC) and generically dependent continuants (GDC) as participants, and also immaterial entities such as sites, they cannot be the *only* participants of a process. As explained in section 4, a mere change of an SDC cannot be a process or be part of a process. This is because of the axiomatic restrictions on what can be part of processes (i.e. only processes and process boundaries), and what they can be part of (i.e. only processes). It is therefore not possible to have process itself be the explicit vehicle of all sorts of changes.

3.2. Results

Figure 1 depicts the top-hierarchy for change, while Table 1 lists the entities and their definitions that make up this hierarchy, The axiomatization in CLIF (work in progress and constant change) is available in [15]. In the descriptions that follow, references of

the form '[xxx-nn]' correspond to the indices associated with the change axioms by means of the 'cl:comment' construct of CLIF [15], while references of the form [xxx-n], as before, correspond to existing axioms in BFO2020-FOL [6].

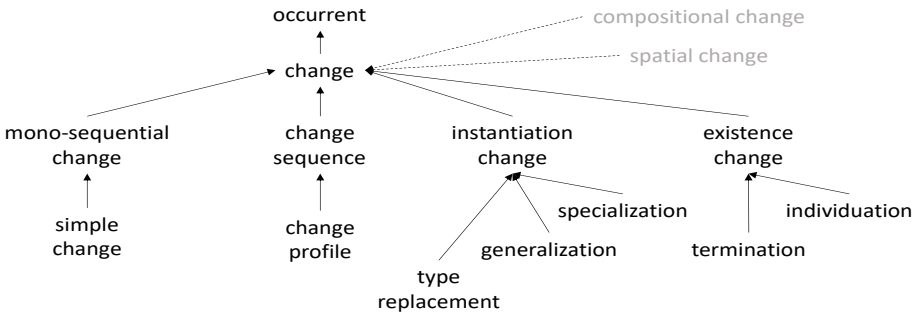

Figure 1. Change hierarchy. Dashed lines and grey indicate directions for future work.

Table 1. Core entities in the proposed change theory

Entity	Definition / Elucidation
occurrent	
change	*occurrent* that happens (1) to at least one *continuant c* that is not a *spatial region* and (2) in a *process p* such that in the course of *p* some *particular* comes in or goes out of existence or exhibits a difference in some relation to another *entity*, including differences in instantiation.
mono-sequential change	**change** *c* all whose *occurrent parts* that are **changes** stand in the **temporal layer-of** relation to *c*
simple change	**mono-sequential change** that **happens to** precisely one *continuant* and has no **change** as *proper occurrent part*
change sequence	**change** whose *proper-temporal parts* that are **mono-sequential changes** are temporally ordered
change profile	**change sequence** whose sequence parts are **mono-sequential changes** all of which are **simple changes** that **happen to** the same *continuant*
instantiation change	**change** in some *continuant's instantiation* of some *universal*
specialization	**instantiation change** expanding the number of *universals* a *continuant instantiates*
generalization	**instantiation change** diminishing the number of *universals* a *continuant instantiates*
type replacement	**instantiation change** to a *continuant* c keeping the number of *universals* c *instantiates* constant
existence change	**change** that brings a *continuant* (but not a *spatial region*), *process* or *process-boundary* in or out of existence
individuation	**existence change** that brings a *particular* (of the 3 types above) in existence
termination	**existence change** that brings a *particular* (idem) out of existence
spatial change	**change** in the *spatial occupation* of some *continuant*
compositional change	**change** in which some *continuant* gains or loses some part

Legend: terms in bold denote universals and relations proposed in this work; terms in italics denote, or are syntactic variations of, the technical terms used in the BFO. Discussions about spatial changes and compositional changes, though listed in Table 1 for completeness, are beyond the scope of this paper.

3.2.1. Change and its Relation to Processes and Temporal Regions

We define a *change* as an occurrent that happens (1) to at least one continuant *c* that is not a spatial region and (2) in a process *p* such that in the course of *p* some particular

comes in or goes out of existence or exhibits a difference in some relation to another entity. This definition is broad enough to include the sorts of changes we wish to be able to represent as mentioned in section 2.

We define a family of three 'happens' relations each one of which relates a change to a distinct sort of entity represented in the BFO. Roughly, changes *happen in* processes and *happen to* continuants whereby these continuants participate in processes (1) these changes *happen in* or (2) occupy a temporal region that temporally overlaps the temporal regions these changes *happen throughout*. *Happens-throughout* links a change to a temporal region [htr-01] in such a way that there is precisely one temporal region at which a change *happens-throughout* [htr-04], and that at any time *t* a change *ch* exists, *t* is a temporal part of the temporal region throughout which *ch* happens [htr-05]. *Happens-throughout* is thus a relation that specializes *exists-throughout* [htr-02]; furthermore, if *x exists-throughout t* and *x* is a *change*, then *x happens-throughout t* [htr-03]. A particular *p exists-throughout t* iff every temporal-region at which *p* exists is a temporal part of *t* [ett-02]. This relation is a more specialized version of the *exists-at* relation of BFO. Whereas '*p exists-at t*' means that *p* exists at any time *tp* that is a temporal part of *t*, it does not exclude that it can also be the case that *p* exists at times which are not temporal part of *t*. *Exists-throughout* is not equivalent to the *ExistsDuring* defined in [5, p148] which is equivalent to BFO's *exists-at*, and created because *ExistsAt* at that time was restricted to temporal instants, a distinction that is now abandoned.

The 'throughout' versions of exists and happens, in combination with *first-instant-of* and *last-instant-of*, allow one to make assertions about when a particular comes in, respectively goes out, existence, two types of changes we discuss in section 3.2.2. When *p* is a process, '*p exists-throughout t*', is equivalent with '*p occupies-temporal-region t*' [ett-03] [tao-1]. The latter cannot be used for changes as axiom [lyx-2] restricts *occupies-temporal-region* to domain process or process-boundary and range temporal-region.

The second 'happens' relation is *happens-to* which is time-indexed and has domain change and range continuant except spatial region, i.e. the continuant to which the change happens [cha-02]. This relation had to be introduced because none of the five existing BFO relations that relate an occurrent with any type of continuant that is not a spatial region would be applicable: *has-participant*, *realizes*, *occurs-in*, *history-of* and *concretizes* all restrict continuants to processes.

The third relation in the family is *happens-in* which is not time-indexed and has domain change and range process [cha-03]. It provides a sense of parthood between changes and processes since, as forced by the BFO and documented in section 4.1, *occurrent-part* cannot be used between them. *Happens-in* and *happens-to* are intimately related: if a change *ch* exists, then there exists also a process *p* in which *ch* happens, and a continuant *c* to which *ch* happens [cha-04] and which also participates in *p* [cha-05] [cha-06] [cha-07]. This allows a less literal interpretation to the statements in earlier BFO-related papers that '*processes are changes*' [9, p478] and '*changes are processes*' [4, p34] in the sense that there is no change without there being some process. At the same time, our position remains neutral, as BFO does, whether the continued existence without any change counts as process as well.

3.2.2. Existence Changes: Changes that Bring Continuants in or out of Existence

The only existence changes [ext-02] we considered thus far are individuations [ind-01] (f.i. the coming into existence of a sunburn that *happens-in* a process of sunbathing and

happens-to some skin) and terminations [ter-01] (f.i. the going out of existence of a skin laceration that *happens-in* a process of healing and *happens-to* some skin), both of which only *happen-to* continuants [ext-03]. This does of course not mean that processes do not have beginnings or endings, rather that this is not expressed by relating the change to the process by means of *happens-to*.

Individuates-at is the relation that obtains between a particular – i.e. process or continuant but not spatial region – on the one hand, and temporal region on the other hand [ind-02]. A particular *individuates-at* the first instant of the temporal region throughout which it exists [ind-03]. If that particular is a continuant, it *individuates-at* the last instant of the temporal region throughout which the individuation happens [ind-04]. Individuations are then tied to processes in the following manner: a particular *x individuates-at* a time which is the last instant of the temporal region throughout which some individuation *s* happens; if *x* is a continuant, then *s happens-to x*; if *x* is a process, then *s happens-to* some continuant *c* which *participates-in x* [ind-05]. When a continuant is brought into existence, then the individuation *happens-in* the process that creates the continuant. When it is a process *p* that comes into existence, then the individuation temporally overlaps with the process *p2* that brings *p* into being, or *happens-in p2*. An example of the former would be a collision in which a moving object *c1* hits with force a second object *c2* at rest such that *c2* starts to move itself. An example of the latter is a person starting to run.

Ceases-to-exist-at is defined in a similar way: it has as domain process or continuant but not spatial region and range temporal region [ter-02]. A particular ceases to exist at the last instant of the temporal region throughout which it exists [ter-03]. If a termination *happens-to* a continuant, that continuant *ceases-to-exist-at* the last instant of the temporal region throughout which the termination happens [ter-04] and reciprocally, if a continuant *ceases-to-exist-at* some time, a termination happens to it at that time [ter-05]. If a process *ceases-to-exist-at t*, it exists for the last time at *t* [ter-06]. We leave open the question of over what precise temporal region an individuation or termination exists.

3.2.3. Instantiation Changes

An instantiation change is a change [ins-01] that happens to a continuant *c* when not all the universals instantiated by *c* prior to the change are instantiated by *c* after the change or vice versa [ins-02]. This accounts for the fact that most continuants do not just instantiate one universal, but rather a number of universals, and not only universals that stand in what we could call a subtype relation. A bent spine for example would instantiate both the universal spine and the universal disorder, plus all universals these two universals are subtypes of. Instantiation changes are only defined for continuants because no occurrent changes type [ayr-1]. Instantiation changes were earlier proposed under the name 'transformations' with the accompanying relation 'transformation-of' [16] but never became defined in the BFO.

We defined three sorts of instantiation changes: specializations [spe-01], generalizations [gen-01], and type replacements [trp-01]. Specializations are such that if a specialization happens to a continuant, that continuant gains a type [spe-03] and if a continuant gains a type, a specialization happens to it [spe-04]. The change that happens-to a spine when becoming pathologically bent and thus becoming an instance of disorder is an example of a specialization as the spine gains the type *disorder*. The relation gains-type is time-indexed and has domain continuant and range universal [spe-02]. It is

defined as follows: *c gains-type u at t* iff *c* becomes instance of a type while keeping all existing instantiations [spe-05]. Generalizations are defined similarly [gen-02] [gen-03] [gen-04] whereby the relation *loses-type* holds between a continuant *c*, a universal and a temporal region when *c* doesn't instantiate anymore the universal it instantiated before and doesn't gain a type [gen-05]. An example would be when a bent spine is healed: it then lost the type *disorder*. Type-replacements are also covered in a similar manner [trp-02] [trp-03] [trp-04], whereby the quaternary relation *c replaces-type u1 for u2 at t* holds whenever all the universals (except *u1*) *c* instantiates before the replacement are also instantiated by *c* (in addition to *u2*) after the replacement [trp-05]. An example of such change *c* is the increase that *happens-to* the body temperature *tp* inhering in a person *p* that participates in some running *r* in which *c* happens: the universal temperature-of-97°F instantiated by *tp* at t_1 is replaced by the universal temperature-of-98°F instantiated by *tp* at t_2.

3.2.4. Mono-Sequential Changes

A mono-sequential change *cc* is defined as a change [cch-01] of which each occurrent part *cp* that is an instance of change stands in the *temporal-layer-of* relation to *cc* [cch-02]. The definition is formulated this way because we remain for the time being silent about whether changes can have occurrent parts which are not changes (compare with processes that in addition to having other processes as occurrent parts, can have process boundaries as occurrent parts). The binary relation *a temporal-layer-of b* holds iff *a* is an occurrent part of *b*, both *a* and *b exist-throughout* the same temporal region, but neither instantiate temporal region [tlo-01]. The relation is transitive [tlo-02] and antisymmetric [tlo-03]. An example would be the change that *happens-to* a hand when suddenly making a fist to initiate a blow or start a fight: while the fist is being formed (a spatial change of the hand), a spatial change *happens-to* each finger and thumb of the hand as they each participate simultaneously in an individual flexing process – i.e. each of these spatial changes *happen-throughout* the same temporal region – and therefor this particular fist-making is an instance of mono-sequential-change. If, however, one makes a fist by flexing the fingers one by one, that instance of 'slow' fist-making does not involve a mono-sequential change. The binary relation *x mono-sequential-change-of y* has domain composite change and range continuant [cch-03] and holds when all occurrent parts of *x* that are changes happen to *y* [cch-04] [cch-05].

Inspired by Toyoshima & Barton [13], we define a simple-change as a change [sch-01] that happens-to precisely one continuant [sch-02] and does not have other changes as temporal parts [sch-03]. Simple changes are, according to this definition, thus also mono-sequential changes.

A change sequence is a change [chs-01] whose proper-temporal parts that are also mono-sequential changes are temporally ordered [chs-03]. Examples are the 'slow' fist-making just described, and the sequences that happen when taking an image with a charge-coupled device (CCD). In such process, various changes happen in sequence such as, for example, when a photon ceases to exist and a free electron-hole pair is created, when a circuit connecting those to a capacitor is opened, how the charge on the capacitor changes as each electron accumulates, when the circuit is closed at the end of an exposure. Or when two other processes start, i.e. a counter and a voltage ramp, the stop of the counter when the voltage ramp produces a voltage equal to that on the exposure capacitor. Finally, how the charge in the capacitor changes to 0 when a circuit to ground is opened.

The binary relation *is-sequence-part-of* has domain also mono-sequential change and range change sequence [chs-02]. Change profiles [chp-02] are change sequences [chp-01] whose sequence parts are also mono-sequential changes all of which are simple changes that happen to the same continuant [chp-03]. When the binary *relation x is-change-profile-of y* holds, then all sequence parts of *x* that are also mono-sequential changes are composed of simple changes that happen to y [chp-04]. An example is the change that happens in a process of rolling a snowball: the compositional change brought about by the accumulation of snow happens simultaneously with the spatial change brought about by the rolling through the snow.

As a last example, Fig2 describes how our change theory fits the change case 3 documented in [8]: '*A flower is red in the summer. As time passes, the color changes. In autumn the flower is brown*'.

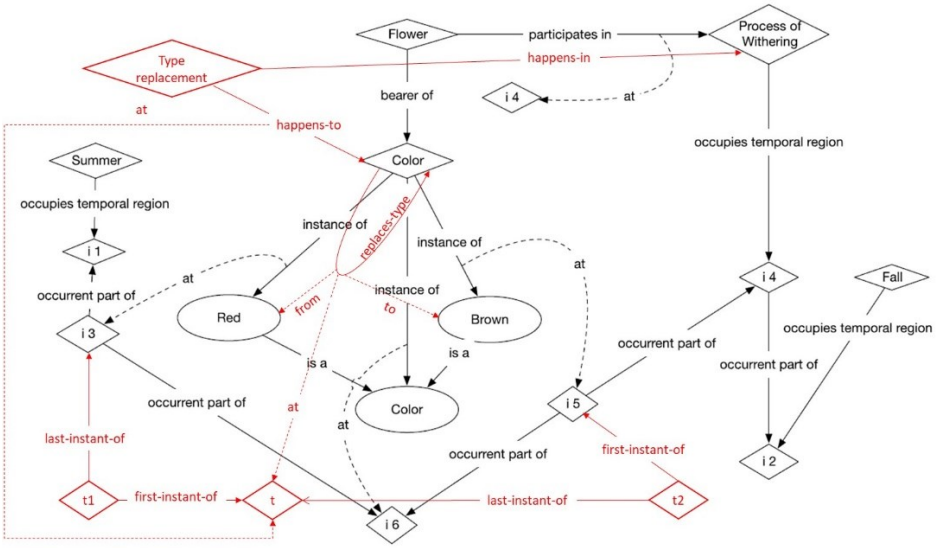

Figure 2. Superposition of change theory relations (red) over BFO relations (black) in change case 3 in [8]: '*A flower is red in the summer. As time passes, the color changes. In autumn the flower is brown*'). Ovals are universals, diamonds are particulars.

3.2.5. Validation

The axiomatization as currently provided has been checked for consistency using three different theorem provers (Vampire, Prover9, and Z3) which were each given resources that have demonstrated, in the past, sufficient to identify inconsistencies. However, we have no formal proof of consistency at this time. We will do so when our axiomatization is complete.

4. Process in BFO2020

The purpose of this section is to provide a detailed account for why the various sorts of changes that exist cannot straightforwardly be represented as BFO processes. Our findings are also relevant for authors of domain ontologies that use the BFO as upper

ontology, but perhaps have not paid attention to the axiomatization. We start with the elucidation of process, explore some of its consequences, and observe that the elucidation does not parallel the axiomatization. We also show that the BFO is quite restrictive in what processes can be composed of. We conclude by demonstrating that BFO allows for processes *p* for which it is not the case that if *p occupies-temporal-region t*, that then any temporal part of *t* is temporally occupied by a temporal part of *p* and this despite axiom [tao-1] which stipulates that '*p occupies-temporal-region t* iff every part of p temporally occupies a part of t, and there isn't a smaller part of t that p occupies'.

4.1. Temporal and Occurrent Parthood

The elucidation of process states that every process p '*is an occurrent that has some temporal proper part and for some time t, p has some material entity as participant at t*'. Fig3 is an attempt to visualize this elucidation. It shows a temporal interval *tr* (dashed rectangle) together with four smaller intervals picked out of the infinite number of smaller intervals that one could pick out and that all are proper temporal parts of *tr*. Because of the four intervals, Fig3 implicitly also depicts five more intervals, i.e. tr_{1+2}, tr_{1+2+3}, tr_{2+3}, tr_{2+3+4}, and tr_{3+4}, and in total thus 9 distinct intervals.

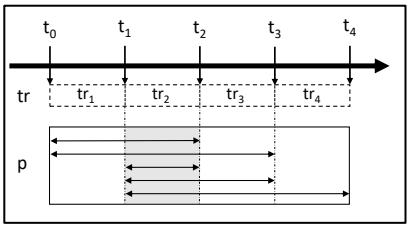

Figure 3. BFO2020 occurrent spanning a temporal region of four adjacent temporal intervals.

Next, Fig3 depicts an occurrent *p* (solid rectangle) that temporally occupies *tr*. Note that because, as we shall see, the elucidation of process alone does not contain all necessary conditions for an entity to be a process, we merely explore the possibility that *p* is a process. For sure, *p* satisfies the elucidation of process because (1) it has some temporal proper part (pick the part that temporally occupies tr_2), and (2) there is a material entity *m* that participates in *p* at tr_2 (this participation at said time being depicted by the grey area). It does not seem unreasonable to ask whether occurrent *p*, in analogy with *tr*, also has nine proper temporal parts each one of which occupies the corresponding temporal parts of *tr* delineated in Fig3. The elucidation allows us to assess which of those nine temporal proper parts would be processes. Under the assumption that there are no other material participants in *p*, five satisfy the elucidated requirement that they have, at some time, a material entity as participant. They are depicted in Fig3 by the double arrows inside the box depicting *p*.

However, axiom [trl-1] in BFO2020-FOL requires a process to have a participant at every time it exists. Thus, if it is only at tr_2 that *p* has a participant – call that part p_{tr2} – then our initial proposal that *p* is a process would be false. And then it would also be false that p_{tr2} as occurrent part of *p* is a process. That is because axiom [csk-1] stipulates that the only entities that a process can be an occurrent part of are other processes. Thus if p_{tr2} is an occurrent part of *p*, it can't be a process. And if p_{tr2} is not a process, there is nothing that can participate in it since per axiom [ild-1] only processes can have participants.

To conclude this section, it should now be clear that the elucidation of process comes with a caveat to the effect that the requirement for a process to have at some time a material entity as participant is elucidated, but not enforced through axioms. An additional complexity is that the temporal region occupied by a process does not need to

be a temporal interval, but must have per axiom [fzy-1] at least one temporal interval as temporal part. This means it is possible that there is a process that exists at two disjoint intervals, the sum of which we might call a 'scattered temporal region'. Although BFO2020, in contradistinction to BFO1.1, does not include a term for scattered temporal regions, it still sanctions their existence as witnessed f.i. by the elucidation of zero-dimensional temporal region as '*a temporal region that is a whole consisting of one or more separated temporal instants as parts*'. That increases the number of possible processes that are temporal parts of *p* in Fig3 to two more, i.e. the ones occupying tr_{1+2+4} and tr_{2+4}.

4.2. Participation

Participation is quite vaguely – and even circularly – elucidated in the BFO: '*p has participant c at t means: p is a process, c is a continuant and c participates in p some way at t*' (with the further note that spatial regions do not participate in processes). There are thus far no relations in the BFO that could be used to express more precise ways of *participation* similar to what is proposed in certain linguistic theories under names as 'case roles' or 'thematic roles'. The closest thing in the BFO is the fact that bearers of realizable entities participate in their realization and so *imply* some manner of participation.

Let us return to process *p* in Fig3 and postulate that *p* is indeed a process by assuming that the continuous participation requirement forced by axiom [trl-1] is fulfilled by any of the allowed entities per axiom [ild-1], i.e. any independent continuant (IC) except a spatial region, specifically dependent continuant (SDC) or generically dependent continuant (GDC). We can then zoom in on what must be the case with *p* at the temporal regions tr_1, tr_3, and tr_4. If some SDC *s* participates in *p*, or in some p_x which is an occurrent part of *p*, then *s* must satisfy axiom [cgn-1]. That axiom requires that at every time *t* that *s* participates in some process there is a part t_p of *t* during which there is some IC that *s* specifically depends on and that participates in that process at t_p. This can be satisfied in the process *p* of Fig3 in a number of ways.

In case *s* participates in *p* at tr_1, tr_3, and tr_4, and depends on *m* that participates in *p* at tr_2, then [cgn-1] is satisfied if and only if *s* also participates in *p* at some temporal part of tr_2. This is depicted in Fig4. It shows a process *p* that occupies temporal region $tr_{1+2+3+4}$ and which exists (1) at part of the temporal region at which *m* exists, and (2) at part of the temporal region at which *s*, which depends on *m*, exists, this temporal region being itself a proper temporal part of the temporal region at which *m* exists.

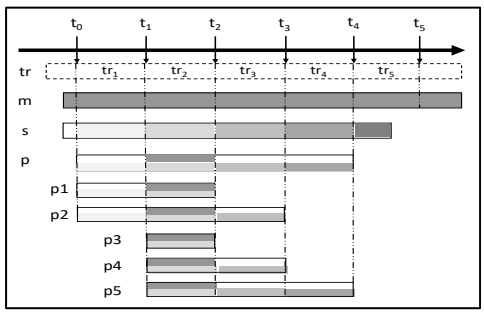

Figure 4. Existence and participation of a material entity m and a specifically dependent continuant s in a process p and its parts p1-p5 that are processes.

While *s* keeps its identity during its existence, we postulate that it instantiates a different SDC universal at each tr_n-interval (depicted by the distinct shades of grey). Participation of *m* and *s* in process *p*, as well as in each of the processes p_1 to p_5 which are legitimately proper-temporal-parts of *p*, is depicted by the various shades of grey inside the rectangles, the top horizontal half for *m*, which participates in *p* only at tr_2, and the bottom half for *s*, which participates

throughout. An example would be that *m* is a banana and s its color, which instantiates a distinct color green, yellow, brown, …) in each of the temporal regions.

Axiom [cgn-1] can also be satisfied in different ways than depicted in Fig4. For example, *s* might not depend on *m* but on another material entity m_2 that then must participate in some occurrent part of *p*. When there is such m_2, then *s* can also be a relational quality and depend on both *m* and m_2. Axiom [trl-1] can also be satisfied if more than one SDC participates in *p*, whether or not each one dependent on *m*, or on distinct material entities. If a GDC *g* participates in *p*, then either (1) an SDC *sg* which is a concretization of *g* and some bearer *m3* of *sg* need to participate in *p* at some time, or (2) another process *q* which is the concretization of *g* needs to be an occurrent part of p (axiom [ffm-1]). Or, a site might participate in *p* as long as there is also some material entity participating in it.

Now that we have established that *p* and p_1 to p_5 in Fig4 satisfy the elucidation of process and its axioms to be genuine processes, and that p_1 to p_5 are occurrent parts of *p*, the question is: what universal would be instantiated by the tentative occurrent parts of *p* that occupy the temporal regions tr_1, tr_3, tr_4 and tr_{3+4}, and that we could call *the first quarter of p*, *the third quarter of p*, *the fourth quarter of p*, and *the second half of p* respectively? Well, in light of the elucidation of process, these quarters and second half of *p* are not processes at all because the material entity *m* does not participate in *p* at the corresponding temporal regions! And because of axiom [ccz-1] which stipulates that the only occurrent parts a process can have are other processes or process boundaries, they are also not temporal parts of *p*!

So now it should also be clear that the combination of the elucidation of process and the process axioms make it so that processes cannot be cut up in temporal parts as freely as one can do with temporal regions. That '*The first quarter of a game of football is a temporal part of the whole game*' [9, p476] is not because it is a mere part of that game, but because the first quarter of the game is a process in its own right as it satisfies both the elucidation of process and all axioms: there are at all the time material entities participating in it, e.g. the ball and the players. It is because of that that it can stand in the BFO2020 temporal-parthood relation with the entire game. The first quarter of *p* in Fig4 on the other hand, is, oddly as it may sound, not a temporal part of *p* in terms of the BFO because, not being a process, it is not an occurrent part of *p* per [ccz-1] and therefore also not a temporal part since all temporal parts are occurrent parts (axiom [bal-1]). Thus *p* is process, and p_1 to p_5 are processes that all are temporal parts of *p*, p_3 thereby being also a proper temporal part of p_1, p_2, p_4 and p_5, but there is no such thing that we could label 'p_{tr1}' in Fig4. Yet, *p* exists-at that first quarter without there being a 'proper temporal part of p' temporally occupying that first quarter.

5. Discussion

The literature about events and processes, endurantism and perdurantism, three- and four-dimensional ontologies etc. is quite vast. We briefly discussed the position of these alternative views from the perspective of the BFO in section 2 with as major references [3-5]. A more extensive comparison is provided in [13] so does not need to be discussed here. Worth mentioning though is that we have taken a pure ontological stance and are not led by how the occurrence of changes nor processes are grammaticalized in language or cognitively assessed, a strategy followed in f.i. [17]. Neither are we concerned here

with the question whether processes ought to be distinguished from events (see f.i. [18]) for the simple reason that the BFO is thus far silent about it.

In a variety of cases we have deliberately left open some aspects of the change-theory. It remains neutral to what the BFO is neutral or silent about, f.i. the true nature of time, thus whether it is dense or discrete. In addition, it remains neutral (in general) about whether changes *happen throughout* extended temporal regions or time-instants. However, change sequences cannot happen throughout single instants. We remain neutral about whether they (in general) happen throughout extended zero-dimensional regions (i.e. regions consisting of separated temporal instants) or one-dimensional regions (i.e. regions that have a temporal interval and zero or more temporal instants or intervals as part). For changes in general we remain neutral, at least in the current axiomatization, about the nature of the temporal region at which a change *happens to* a continuant. For some sorts of changes, the latter is only a proper temporal part of the temporal region the change happens throughout, f.i. when a change happens to more than one continuant as in certain mono-sequential changes. For other sorts of changes, that temporal region might be identical to the temporal region the change happens throughout. Type replacements would be an example of that (see Fig2): the particular *color* which is the color of some particular *flower* exists throughout the entire temporal region *i6* under the assumption that no other colors than red and brown are instantiated. The particular *type replacement* exists throughout temporal region *t* and happens to *color* such that *color* instantiates red at the first instant t_1 of *t* and brown at the last instant t_2 of *t*. Type replacements are thus a second type of change that cannot happen throughout a single instant. This is because the relation *replaces-type(c u1 u2 t)* – in our example ***(replaces-type** color red brown t)* – is defined so that it can only hold when *c* does not instantiate u_2 at the first instant t_1 of *t* and does not instantiate u_1 at the last instant t_2 of *t* while all other universals instantiated by *c* at t_1 are also instantiated by *c* at t_2. We are neutral about what happens 'in between' even about whether there is such an 'in between' or, as discussed in [11], a 'transition period' at all.

5.1. Future Work

We plan to expand the theory in several directions. We plan to include spatial change and compositional change which has thus far been left unaddressed. This will include their interrelation with existence changes and instantiation changes. Compositional changes such as gaining and losing parts will invariably lead to mono-sequential changes and change sequences that exhibit certain patterns. The loss of a body part through amputation, for example, will make that body part undergo a type replacement, i.e. from fiat object part to object. We also intend to include changes such as increases and decreases for continuants that instantiate universals whose instances are totally or partially ordered.

A collaborative effort is required with BFO users and developers. Users might like to see shortcut relationships that make it easier to create instance data. *Individuates-at* and *ceases-to-exist-at*, as currently defined, take a temporal instant as 2nd argument. While we believe that this is accurate and serves useful reasoning purposes, it is practically impossible to make a single assertion at that level of precision. Conjunctions of the sort expressing when an entity came into existence such as '*(individuates-at c t1) & (proper-temporal-part-of t1 t2) & (is-about june-15-2024-3.15pm t2)*', can do the trick, but might be too cumbersome.

The BFO developers, on the other hand, might reflect on whether the findings discussed in section 4 require some changes in the BFO itself. A revision of the elucidation of process, or a more precise axiomatization, is in order. Also the existence of some unintended consequences of the current axiomatization involving certain relations between temporal instants and intervals might require a revision as problems have been acknowledged already on the BFO2020 github issue tracker. In the context of change-sequences, it would be useful to have a BFO axiom to the effect that if there are two intervals that meet, there is a larger interval that is the sum. But it would have to deal with the case where the last instant of the first is identical with the first instant of the second, while it is part of neither interval. In that case the two intervals wouldn't sum to a new interval. Such a general axiom would help in crafting axioms specifying the conditions under which changes are occurrent parts of change sequences whereas the current change sequence axioms are weaker and only specify what is the case for the occurrent parts of change sequences.

What also requires consideration, perhaps most importantly, is the extent to which – and even whether at all – changes should be universals distinct from processes. We took an extreme position by introducing change as a new type of occurrent as this approach does not require any change in the BFO as currently published. A consequence is, however, that it forced us to introduce relations which, to a certain degree, mimic relations in which processes are one of the relata. It is easy to see that *happens-to* mimics, to a certain degree, participation, *happens-in* occurrent-parthood, and *happens-throughout* occupies-temporal-region. For compositional changes that happen to material entities, we don't see any reason why such changes shouldn't be processes. We also believe that it is desirous to be able to isolate, as a process, mere changes in specifically and generically dependent continuants. An issue here is that processes occupy spatiotemporal regions, and it isn't clear what the spatiotemporal region occupied by a process consisting of solely a dependent continuant change would be, absent an independent continuant defining that space. A potential solution that merges changes and processes would be to replace the weak requirement that material entities must participate only at some times by a stronger one requiring that they should participate at all times any of their dependent entities participate.

Rephrasing the change theory to be solely in terms of processes would avoid a duplication of entities to the effect that for any individuation there would be a creative process, for a termination a destructive process, etc. This, however, would require a formal discussion with, and approval of the BFO custodians, steps that thus far have not been taken. It is also therefore that our axiomatization is not yet complete, and that, while we have made a best effort to determine whether the theory is inconsistent, we have not developed yet a constructive proof.

6. Conclusion

We have proposed a change theory that is compatible with the current axiomatization of BFO2020-FOL and its definitions and elucidations. That effort has resulted in the identification of, in our opinion, some unfortunate consequences of the BFO axiomatization. Given the choice of modifying the current axiomatization of processes versus introducing new universals, we considered the latter less disruptive at this stage of development. However, we do not rule out re-expressing the ideas presented here as

axioms expressed in terms of processes and participation in a future revision of BFO-FOL.

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