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| Basic Formal Ontology 2.0 |
| DRAFT SPECIFICATION AND USER’S GUIDE |
|  |
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2/12/2012 2:11 PM

**Summary of most important changes in BFO 2.0** as compared to BFO 1.1

* **Clarification of BFO:*object***

The document emphasizes that *Object*, *Fiat Object Part* and *Object Aggregate* are not intended to be exhaustive of *Material Entity*. Users are invited to propose new subcategories of *Material Entity.*

The document provides a more extensive account of what '*Object*' means (roughly: an object is a maximal causally unified material entity); it offers three paradigms of causal unity (for cells and organisms, for solid portions of matter, and for engineered artifacts)

* **Introduction of reciprocal dependence**

The document recognizes casew where multiple entities are reciprocally dependent on each other, for example between color hue, saturation and brightness; such cases can also involve reciprocal generic dependence as in the case of a disposition of a key to open a lock or some equivalent lock, and of the lock to be opened by this or some equivalent key.

* **New simplified treatment of boundaries and regions**

In BFO 1.1 the assumption was made that the external surface of a material entity such as a cell could be treated as if it were a boundary in the mathematical sense. The new document propounds the view that when we talk about external surfaces of material objects in this way then we are talking about something fiat. To be dealt with in a future version: fiat boundaries at different levels of granularity.

More generally, the focus in discussion of boundaries in BFO 2.0 is now on fiat boundaries, which means: boundaries for which there is no assumption that they coincide with physical discontinuities. The ontology of boundaries become more closely allied with the ontology of regions.

* **Revision of treatment of spatial location**

We generalize the treatment of ‘located\_in’ and remove from BFO the relation of ‘contain\_in’.

* **Treatment of process predications under the heading ‘process profiles’**

The document introduces the idea of a process profile to provide a means to deal with certain sorts of process measurement data. To assert, for example, that a given hart beating process is a 72 beats per minute process, is not to ascribe a quality to the process, but rather to assert that there is a certain structural part of the process, called a 'beat profile', which instantiates a certain determinate universal.

* **Relation of containment deprecated**

We provide a generalization of the **located\_in** relation as compared to earlier versions of BFO; the **contained\_in** relation is now deprecated.

* **For the future**

Treatment of frame-dependence of regions of space and of regions of time.

Treatment of boundary\_of relations (incl. fiat\_boundary\_of)

Exhaustive treatment of instance-level relations; definitions of type-level relations; rules for quantifying over universals.

Explicit treatment of the two kinds of causal relations (1) causal dependence, for example between the pressure and temperature of a portion of gas; (2) causal triggering, where a process is the trigger for a second process which is the realization of a disposition.

*Portion of energy* (potentially to be treated as child of *material entity*)

Co-Authors/ Acknowledgments

Mauricio Almeida, Mathias Brochhausen, Werner Ceusters, Randall Dipert, Albert Goldfain, Pierre Grenon, Janna Hastings, William Hogan, Ingvar Johansson, Chris Mungall, Robert Rovetto, Alan Ruttenberg, Mark Ressler, Stefan Schulz, Darren Natale, NAMES TO BE ADDED / Fabian Neuhaus,

Use of **boldface** indicates a label for an **instance-level relation.** Use of *italic* indicates a BFO term, which is a singular common noun or noun phrase representing a universal.

This document is both a specification and a user’s guide to BFO. Those parts of the BFO document which belong to the specification are indicated by the following formatting:

Elucidation: This style of formatting indicates that this text forms part of the BFO specification. Other text represents further explanations of the specification as well as background information.

The remaining part of the document provide guidance as to how BFO should be used, and also arguments as to why specific choices have been made in the BFO architecture.

BFO 2.0 will exist in various implementations, including FOL, CLIF and OWL. This document provides the basis for the FOL implementation and thus, indirectly, for the other implementions mentioned.

Literature citations are provided for purposes of preliminary orientation only. Thus axioms and definitions included in cited literature are not necessarily in conformity with the content of this document.

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# Introduction

This document is a guide for those using Basic Formal Ontology (BFO) as an upper-level ontology to support the creation of lower-level domain ontologies.

A *domain* is a portion of reality that forms the subject-matter of a single science or technology or mode of study; for example the domain of plant anatomy, of military targeting, of canon law. BFO is designed to be neutral with regard to the domains to which it is applied in order to support the interoperation of domain ontologies defined on its basis and thus to support consistent annotation of data across different domains. BFO also supports formal reasoning, and is associated with a set of common formal theories (for example of mereotopology [5] and of qualitative spatial reasoning [18]) which do not need to be redeveloped for each successive domain. For such benefits to be achievable, however, BFO must be capable of being applied to lower-level domains, and in what follows we document how such application is to be effected. We describe the conditions which must be satisfied by entities of given sorts if they are properly to be categorized as instantiating the different universals or types (we use these terms interchangeably in what follows) recognized by BFO, and we provide a summary of the associated relations. We use ‘category’ to refer to those universals at the most general and domain-neutral level. BFO treats only of categories in this sense. A *category* is a formal universal, as contrasted with the material universals represented in one or other domain ontology. BFO:*fiat object part* is a category in this sense; not however *organism* or *weapon*.

To specify these conditions we will utilize a semi-formalized English that has approximately the expressivity of first-order logic (FOL) with identity.

In the formulations below, we will use ‘*a*’, ‘*b*’, etc., for instances (spatio-temporal particulars), and ‘*r*’, ‘*r*′‘*t*,’ ‘*t*′’, etc., for regions (instants or intervals) of space and time, respectively. We use ‘*A*’, ‘*B*’, ‘*C*’, ‘*P*’, etc. for universals. We use ‘**has\_participant**’ and similar **bold-face** expressions to express relations involving instances, and ‘*part\_of*’ and similar *italicized* expressions to express relations exclusively involving universals. We also use*italic* tomark outBFO terms.

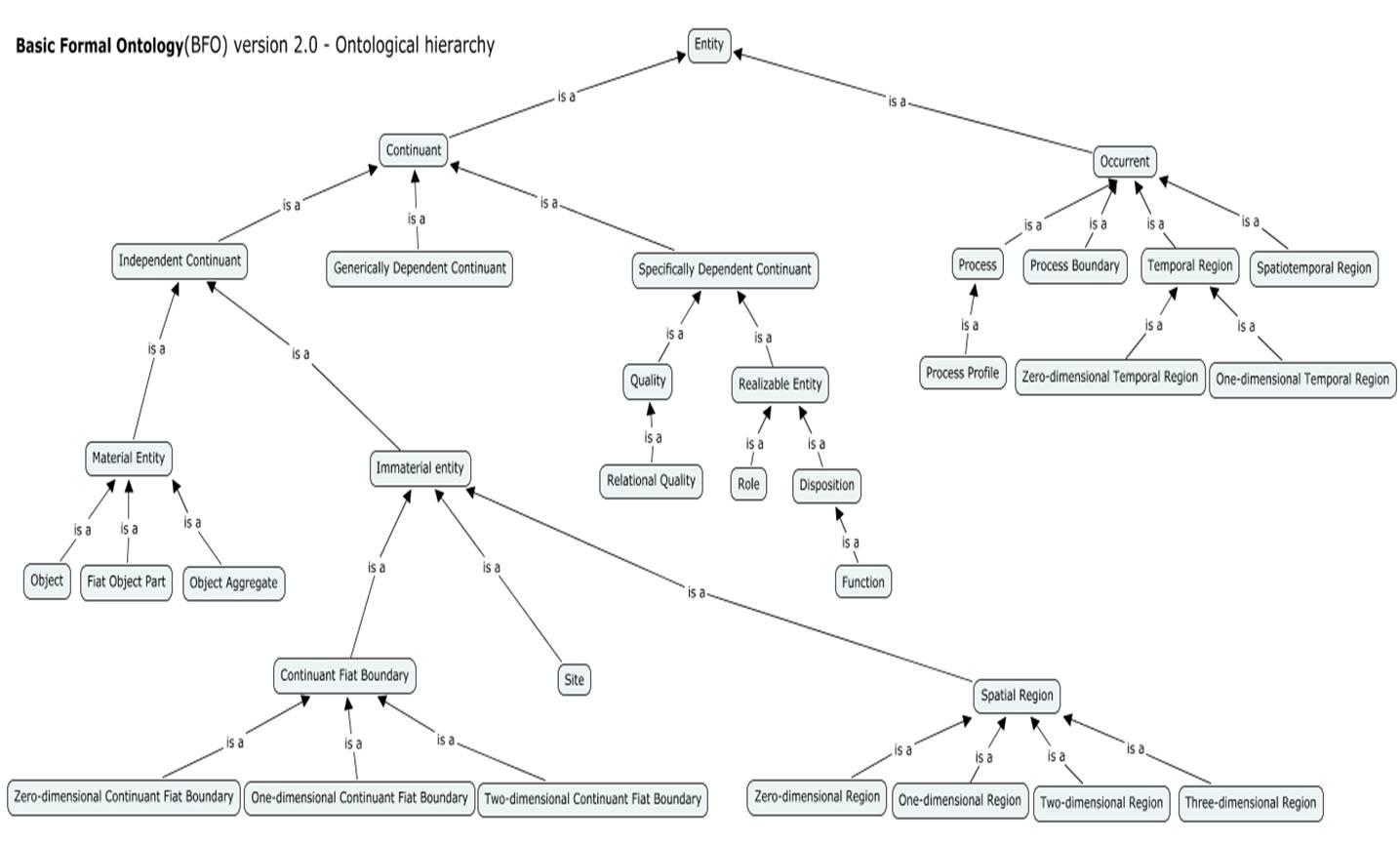


Figure 1: The BFO 2.0 *is\_a* Hierarchy

# 1. Entity

An entity is anything that exists. BFO assumes that entities can be divided into instances (your heart, my laptop) and universals or types (*heart*, *laptop*). On BFO’s usage of ‘instance’ and ‘universals’ see [19, 25]. BFO does not claim to be a complete coverage of all entities. It seeks only to provide coverage of those entities studied by empirical science and which affect or are involved in human activities such as data processing, planning and organization – coverage that is sufficiently broad to provide assistance to those engaged in building domain ontologies for purposes of data annotation and reasoning. We leave open the question of how, if at all, BFO would deal with numbers, sets, and other mathematical entities, and with propositions (conceived in the sense of ideal meanings). We foresee two avenues of future development in regard to these and other varieties of entities not currently covered by BFO. First, incremental expansion of BFO in future versions. Second, drawing on resources at lower levels in the ontology hierarchy. Thus BFO already provides (through the Information Artifact Ontology and the Ontology for Biomedical Investigations) the resources to deal with numerical measurement results and with certain other mathematical entities, and also with hypotheses and other logical entities generated in the course of empirical scientific research.

Entities are linked together in relations, at the level of both instances and types [16]. For example

**I: Instance-level relations**

Your heart (instance-level) **continuant\_part\_of** your body **at** *t*

Your heart beating (instance-level) **has\_participant** your heart

**II: Type-level relations**

Type: human heart continuant\_part­\_of human body

Type: human heart beating process has\_occurrent\_part beat profile

**III: Instance-type relations**

John’s heart **instantiates** *human heart.*

In this document we discuss relations of all three sorts; however, BFO 2.0 itself deals only with relations of sort I.

Note that relations of none of these sorts are first-class entities(to see why not, see the discussion of the Bradley regress in [20]). However, there are first-class entities, such as *relational qualities* and *relational processes* (see below), which are relational in the sense that they link multiple relata.

We use terms (such as ‘BFO:*object*’ or ‘Patrick Hayes’) to refer to entities, and relational expressions (such as ‘**has\_participant**’) to assert that relations obtain between such entities.For both terms and relational expressions in BFO we distinguish between *primitive* and *defined*. ‘Entity’ is an example of one such primitive term. Primitive terms in a highest-level ontology such as BFO are terms which are so basic to our understanding of reality that there is no way of defining them in a non-circular fashion. For these, therefore, we can provide only elucidations, supplemented by examples and by axioms.

Elucidation: An *entity* is anything that exists or has existed or will exist.

Examples: Julius Caesar, the Second World War, your body mass index, Verdi’s *Requiem*

All entities are either particular or universal. [19, 22, 23, 111]

No entity is both a particular and a universal.

Whether an entity is a particular or a universal is not a matter of arbitrary choice or of convenience.

In the [Information Artifact Ontology](http://code.google.com/p/information-artifact-ontology/), where universals are included among the targets of the IAO:**is\_about** relation. In this specification, however, we concentrate on particulars and on the instance-level relations that link them together [16]. That is, the categories referred to in this specification are in every case categories of particulars. A future version of BFO will provide a complementary treatment of universals.

***Is\_a* overloading**

In ordinary English the following assertions are equally grammatical:

a) a human being is a mammal

(b) a professor is a human being

(c) John is a human being

(d) a restaurant in Palo Alto is a restaurant

However, as Nicola Guarino has pointed out, the meaning of ‘is a’ is quite different in each case, and ontologies which do not take account of these differences are guilty of what he termed “‘*is a*’ overloading” [80]. Here only (a) and (b) properly concern the *is\_a* relation between universals or types. (c) is an example of instantiation and (d) an example of (roughly) the relation between some collection of particulars and a universal which holds when the former is a subset of the extension of the latter.

The opposition between (a) and (b) concerns the distinction between two kinds of *is\_a* relations:

1. between universals which are instantiated by their instances necessarily (also called ‘rigid’ universals) and thus, for each instance, are instantiated at all times at which the instance exists, for example: John is a human being; such universals are sometimes said to capture the nature or essence of their instances;
2. between universals one or both of which is not rigid in this sense, for example (again): a professor is a human being; these examples are dealt with further under ‘role’ below.

Note, again, that in our specification of BFO 2.0, universals fall outside our domain of discourse (with the minor exception of the elucidation of *generically dependent continuant*). The mentioned dichotomy between rigid and non-rigid universals should not be taken as implying any assertion according to which there might be higher-order universals (for instance *rigid universal*) of which first-order universals would somehow be instances.

**Universals and classes**

Universals have **instances**, which are in every case particulars (entities located in space and time). Universals also have extensions, which we can think of as collections of their instances (such extensions fall outside the scope of this specification).

Universalsthemselvesare those general entities which need to be recognized in order to formulate both scientific laws and analogous general assertions concerning (for example) material, social and informational artifacts.

Examples of universals in each of the mentioned realms include:

*Natural:* electron, molecule, cell, mouse, planet;

*Material artifacts*: vehicle, revolver, pipette, pizza

*Social artifact*: dollar, meter, traffic law, organization

*Information artifact*: database, ontology, email message, plan specification

Universals are most clearly illustrated by considering the general terms – such as ‘electron’ or ‘cell’ – employed by scientific theories in the formulation of general truths [19]. Thus universals include also the general entities referred to by general terms employed in domains such as engineering, commerce, administration and intelligence analysis. BFO was designed to work with entities within the province of the natural sciences, especially biology, but its coverage domain includes also social and psychological entities such as military units and counterinsurgency operations, mortgage contracts and relations of ownership, poems and experimental protocols.

It is not up to BFO to decide what universals exist in any given domain; this decision is made by domain experts [19], for example in forming their terminology. In all domains, types are those general or repeatable entities which correspond to terms that are reused in multiple different sorts of contexts to refer to multiple different particulars and on the basis of multiple different sorts of information.

**The pairwise disjointness (monohierarchy) principle**

The strategy for ontology building that is recommended by users of BFO involves the creation, first, of asserted *is\_a* hierarchies conforming to BFO. This is in reflection of a heuristic assumption according to which the realm of universals is organized by the *is\_a* relation into taxonomic hierarchies of more and less general. Each asserted hierarchy should further be subject to the principle of single inheritance (it is a monohierarchy [19]), so that every node in such a hierarchy has at most one immediate parent. All universals which are the immediate children of any given universal are thereby subject to the rule of pairwise disjointness. That is, no two universals on the same level within an asserted hierarchy should have instances in common. In some cases – for example in constructing an ontology of quarks – we can go further and build ontologies associated with the claim that the representations of universals are such that their immediate children are not only pairwise disjoint but also *jointly exhaustive*.

The monohierarchy principle reflects the general consensus that asserting multiple inheritance is poor ontological engineering practice.

However, once a set of what we can think of as normalized monohierarchies has been asserted, then an ontology developer can use reasoning to infer multiple inheritance [19, 83].

Examples of general terms which are unproblematically such that they do *not* represent universals include:

* thing that has been measured
* thing that is either a ﬂy or a music box
* organism belonging to the King of Spain
* case of pneumonia in man wearing uniform while riding bicycle on small boat with or

without fall from stairs

In some areas, for example government administration, we face the need for BFO-conformant ontologies where the divisions created are indeed subject to overlap. Thus a *professor* in a medical school may also be a *patient*. We shall see, however, that it is still possible to preserve the principal of pairwise disjointness by creating asserted hierarchy of the corresponding *roles*.

**Determinables and determinates**

In some cases universals are ultimate leaf nodes in a taxonomical hierarchy, called determinates (their ancestor universals are then called determinables). Examples are:

37.0°C temperature, 1.6 meter length, 4 kg mass.

Such determinate universals are non-rigid; thus the same instance may instantiate different determinate universals at different times. Thus while John’s weight (a certain *quality* instance inhering in John from the beginning to the end of his existence) instantiates the same determinable universal *weight* throughout its existence, it will instantiate different determinate weight universals, for example (as described, in the metric system of units): *4 kg weight* or *204 kg weight*, at different times. Note that the weights themselves are independent of whatever system of units is used in describing them. Thus the determinate universals here referred to would be insantiated even in the world in which the metric system of units – or any other system of units – had never existed.)

**Specializations**

In all areas of empirical inquiry we encounter general terms of two sorts. First are general terms which refer to universals or types – we provide more detail on what this means below – terms such as:

* animal
* tuberculosis
* surgical procedure
* disease

Second, are general terms used to refer to groups of entities which instantiate a given universal but do not correspond to the extension of any subuniversal of that universal because there is nothing intrinsic to the entities in question by virtue of which they are counted as belonging to the given group. Examples are:

* animal purchased by the Emperor
* tuberculosis diagnosed on a Wednesday
* surgical procedure performed on a patient from Stockholm

person identified as candidate for clinical trial #2056-555

* person who is signatory of Form 656-PPV
* painting by Leonardo da Vinci

Such terms represent what are called ‘specializations’ in [81]. They fall outside the coverage domain of BFO 2.0, but they may need to be included in application ontologies developed to interoperate with BFO 2.0 conformant-ontologies. The terms in question may then be defined as children of the corresponding lowest-level universals (for example, here: *animal*, *surgical procedure*, *disease*, *painting*).

**Role universals**

We distinguished above between rigid and non-rigid universals. One major family of examples of the latter involve roles, and ontologies developed for administrative purposes may consist entirely of representatives of entities of this sort. Thus ‘professor’ (defined as: a human being who has the professor role) denotes a non-rigid universal and so also do ‘nurse’, ‘student’, ‘colonel’, ‘taxpayer’, and so forth. (These terms are all, in the jargon of philosophy, phase sortals.) By using role terms in definitions, we can create a BFO conformant treatment of such entities drawing on the fact that, while an instance of professor may be simultaneously an instance of trade union member, no instance of the type professor role is also (at any time) an instance of the type trade union member role (any more than any instance of the type color is at any time an instance of the type length).

In an ontology of employment positions terms should thus be defined in terms of roles, which enables us to do justice to the fact that individuals instantiate the corresponding universals – *professor*, *sergeant*, *nurse* – only during certain phases in their lives.

John **instance\_of** *student* **at** *t*,

is thus a shorthand form of:

John **instance\_of** *person***at** *t* & John **has\_role** *student\_role* **at** *t.*

**Universals defined historically**

Another important family of universals are those defined by reference to historical conditions, for example: *biological father*, *phosphorylated protein*, *retired major general*, and so forth. For such terms, in contrast to role universals, there is no simple rule for formulating definitions. In the case of ‘biological father’, for example, the definition would need to involve reference not only to the fact that each instance is a male organism, but also to the fact that the organism in question was the instigator of a process of fertilization which led to the birth of a second organism.

Why insist on such complex definitions? Why not simply introduce ‘biological father’ as another primitive term referring to a subtype of ‘human being’? The answer turns on the methodology for ontology creation, interoperation and quality control which BFO aims to support, and which is designed to bring it about that the methodology tracks instances in reality in a way that is conformant with our scientific understanding [67]. Briefly, the underlying idea is that users of BFO are constrained in the creation of domain ontologies in such a way as to promote consistency in ontology development [19, 78].

## The instantiation relation

The **instance\_of** relation holds between particulars and universals. It comes in two forms, for continuants (*C*, *C*1, …) and occurrents (*P*, *P*1, …) as follows [16]:

*c***instance\_of***C***at***t* means: that the particular *continuant* entity *c* **instantiates** the universal *C*

*p***instance\_of***P* means: that the particular *occurrent* entity *p* **instantiates** the universal *P.*

Examples are: John **instance\_of** *adult* **at** 2012, this laptop **instance\_of** *laptop* **at** 2012, 2012 **instance\_of** *temporal region*, John’s birth **instance\_of** *process.*

The *is\_a* relation is the subtype or subuniversal relation between universals or types.

*C is\_a C*1means: for all *c*, *t*, if *c***instance\_of***C***at***t*then *c***instance\_of***C*1**at***t*

*P is\_a P*1means: for all *p*, if *p***instance\_of***P*then *p***instance\_of***P*1

where ‘*C*’*,* ‘*C*1’ stand for *continuant* types and ‘*P*’, ‘*P*1’ for *occurrent* types.

Examples are: house is\_a building, symphony is\_a musical work of art, promenade is\_a dance step, promise is\_a speech act

General terms corresponding to types are those general terms which are used to refer to particulars in a way that picks out what is intrinsic to (some would say essential to) the particular in question. Types in the domains of natural sciences are marked further by the fact that the corresponding terms are used in the formulation of general scientific laws.

**Definitions for terms and definitions for relational expressions**

We distinguish between *terms* and *relational expressions*. Definitions of terms are required to be always of the form:

an *A* = Def. a *B* which *D*s

where ‘*A*’ is the term to be defined, ‘*B*’ is its immediate parent in the relevant BFO-conformant ontology hierarchy, and ‘*D*’is the differentiating criterion specifying what it is about certain *B*s in virtue of which they are *A*’*s*.

Examples (taken from the Foundational Model of Anatomy (FMA) [44]) are as follows:

Cell = def. Anatomical structure which has as its boundary the external surface of a maximally connected plasma membrane.

Nucleated cell = def. Cell which has as its direct part a maximally connected part of protoplasm.

Anatomical boundary entity =def. Immaterial anatomical entity of one less dimension than the anatomical entity it bounds or demarcates from another anatomical entity.

Anatomical surface =def. Anatomical boundary entity which has two spatial dimensions.

Definitions for relational expressions are statements of necessary and sufficient conditions for the corresponding relation to hold. Examples are provided below, and in [16].

**The dichotomy of ‘continuant’ and ‘occurrent’**

The dichotomy between continuant and occurrent ontologies forms the central organizing axis of the BFO ontology. We can describe this dichotomy as follows, following Zemach [60], who distinguishes between

* non-continuant entities (NCs), which Zemach calls ‘events’, and which are defined by the fact that they can be sliced along any spatial and temporal dimensions to yield parts (for example the first year of the life of your table; the entire life of your table top – as contrasted with the life of your table legs – and so forth).

An event is an entity that exists, in its entirety, in the area defined by its spatiotemporal boundaries, and each part of this area contains a *part* of the whole event. There are obviously indefinitely many ways to carve the world into events, some of which are useful and interesting (e.g., for the physicist) and some of which – the vast majority – seem to us to create hodge-podge collections of no interest whatsoever. [60, pp. 233 f.]

continuant entities which can be sliced to yield parts only along the spatial dimension, yielding for example the parts of your table which we call its legs, its top, its nails. ‘My desk stretches from the window to the door. It has spatial parts, and can be sliced (in space) in two. With respect to time, however, a thing is a continuant.’ [60, p. 240]

Thus you, for example, are a continuant, and your arms and legs are parts of you; your childhood, however, is not a part of you; rather, it is a part of your life. Continuants, as matter of definition, are entities which have no parts along the time axis; in this sense continuants are extended only along the three spatial dimensions, not however along the temporal dimension.

BFO generalizes from the above above all by allowing not only *things* (such as pencils and people) as continuants, but also entities that are dependent on things such as qualities and dispositions.

## Relations of parthood

As our starting point in understanding the parthood relation, we take the axioms of Simple Extensional Mereology as defined in [46]. We then, following Zemach, define two subkinds of parthood, namely parthood as it obtains between continuants – called **continuant\_part\_of** – and parthood as it obtains between occurrents – called **occurrent\_part\_of**, as follows.

Elucidation: *a* **continuant\_part\_of** *b* **at** *t* =Def. *a* is a part of *b* at *t* & *t* is a time & *a* and *b* are continuants

Domain: continuant

Range: continuant

Examples: Mary’s arm **continuant\_part\_of** Mary in the time prior to her operation; the Northern hemisphere is a part of the planet Earth at all times at which the planet Earth exists.

Elucidation: *a* **occurrent\_part\_of** *b* =Def. *a* is a part of *b* & *a* and *b* are continuants

Domain: occurrent

Range: occurrent

Examples: Mary’s 5th birthday **occurrent\_part\_of** Mary’s life; the first set of the tennis match **occurrent\_part\_of** the tennis match.

Note that ‘part\_of’ in BFO signifies always: ‘proper or improper part’. Thus every entity is, trivially, a part of itself. We appreciate that this is counterintuitive for some users, since it implies for example that President Obama is a part of himself – however it brings benefits in simplifying the logical formalism, and it captures an important feature of identity, namely that it is the limit case of mereological inclusion. Proper parthood can be easily defined, as follows:

For continuants:

Definition: *a* **proper\_continuant\_part\_of** *b* **at** *t* =Def. *a* **continuant\_part\_of** *b* **at** *t* & *a* and *b* are not identical

For occurrents:

Definition: *a* **proper\_occurrent\_part\_of** *b* =Def. *a* **occurrent\_part\_of** *b* & *a* and *b* are not identical

**BFO relations defined in terms of parthood**

For continuants:

Definition: *a* has\_part *b* at *t* = Def. *b* continuant\_part\_of*a* at *t*

For occurrents:

Definition: *a* **has\_part** *b* = Def. *b* **occurrent\_part\_of** *a ­­­­–* for occurrents

The above are instance-level relations; we will supply the associated type-level relations in a later version of this document, along the lines set forth in [16].

# 2. Continuant

The continuant branch of BFO 2.0 incorporates both material and immaterial continuants extended and potentially moving in space, and the spatial regions at which they are located and through which they move. (The approach is similar to the two-leveled approaches developed in [69, 70], though it avoids the reference to ‘quantities of matter’ or ‘bare matter’ which form their starting point.)

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

Continuants can preserve their identity even while gaining and losing material parts. Continuants are contrasted with occurrents, which unfold themselves in successive **temporal parts** phases [60].

Axiom: if *a* is a *continuant* and *b* is part of*a* then *b* is a *continuant.*

If an occurrent occupies a 2-minute temporal region, then the occurrent is the sum of two non-overlapping **temporal parts** (see below), each of 1-minute duration. *Continuants* have no **temporal parts** in this sense. Rather, continuants have spatial parts.

BFO’s treatment of continuants and occurrents – as also its treatment of regions, below – thus rests on a dichotomy between space and time, and on the view that there are two perspectives on reality – earlier called the ‘SNAP’ and ‘SPAN’ perspectives, both of which are essential to the non-reductionist representation of reality as we understand it from the best available science [30]. At the same time, however, this dichotomy itself needs to be understood in such a way as to be consistent with those elements of our scientific understanding – including the physics of relativity – with which it might seem to stand in conflict. It must be consistent, above all, with what we know from physics about the entanglements of space and time both with each other, and with matter and causality. The starting point for our approach in this connection is well-captured by Simons:

the evidence that relativity theory forces us to abandon the ontology of continuants and events is slight and circumstantial. It is true that Minkowski diagrams represent time as simply another dimension along with the spatial ones, but we cannot argue from a diagram, which is only a convenient form of representation. A closer examination of the concepts and principles of relativity shows that they rest squarely on the ontology of things and events. A *world-line* is a sum of events, all of which involve a single *material body*; any two events on the same world-line are *genidentical.* That which cannot be accelerated up to or beyond the speed of light is something with a non-zero mass. But only a continuant can have a mass. In like fashion, the measuring rods and clocks of special relativity, which travel round from place to place, are as assuredly continuants as the emission and absorption of light signals are events. Nor does relativity entail that large continuants have temporal as well as spatial parts. It simply means that the questions as to which parts large continuants have at a given time have no absolute answer, but depend on fixing which events (such as gains and losses of parts) occur simultaneously. Whether body of gas A detaches itself from a large star before, after, or simultaneously with the falling of body of gas B into the star, may depend on the inertial frame chosen. ([46], pp. 126 f.; compare also [55, pp. 128-32])

**Excursus on frames**

The four dimensions of the spacetime continuum are not homogeneous – rather there is one time-like and three space-like dimensions. This heterogeneity is sufficient, for the purposes of BFO, to justify our division of reality in a way that distinguishes spatial and temporal regions. In a future version, however, we will need to do justice to the fact that there are multiple ways of dividing up the spacetime continuum into spatial and temporal regions, corresponding to multiple frames that might be used by different observers. We believe that all current users of BFO are not dealing with the sorts of physical data for which frame dependence is an issue, and the frames that they are using can be calibrated, where necessary, by using the simple mappings we use when for example translating between Eastern Standard Time and Greenwich Mean Time). We note, in anticipation of steps to be taken in the future, that spatiotemporal regions are frame-independent, and also that very many of the assertions formulated using BFO terms are themselves frame-independent; thus for example relations of parthood between material entities are *intrinsic*, in the sense that if *a* is part of *b* at some time in one frame, then *a* is part of *b* at some time in all frames.

Theorem: if *a* is a *continuant* and *a* is part of*b* then *b* is a *continuant*.

Axiom: if *a* is a *continuant*, then there is some temporal interval (referred to below as a *one-dimensional temporal region*) during which *a* exists.

Note: *Continuants* may persist for very short periods of time (as for example in the case of a highly unstable isotope).

## Relation of specific dependence

Specific dependence (henceforth: **s-dependence**) is a relation that obtains between one entity and another when the first entity cannot exist unless the second entity exists also. Given entities may stand in multiple s-dependence relations to other entities.

As a purely terminological matter, only dependence relations involving at least one specifically dependent entity are cases of s-dependence. Thus the relation between a boundary and that which it bounds, or between a site and its host, are not examples of s-dependence.

Elucidation: To say that *a* **s**-**depends on** *b* is to say that

*a*and *b* do not share common parts

*&* *a* is of its nature such that it cannot exist unless *b* exists

*& a* is not a boundary of *b* and *a* is not a site of which *b* is the host [64].

Domain: dependent continuant; process

Range:

for one-sided s-dependence: independent continuant;

for reciprocal s-dependence: dependent continuant; process

Examples: The dependence of a pain on the organism that is experiencing the pain, the dependence of a shape on the shaped object, the dependence of a gait on the walking object.

If *a* **s-depends on** *b*we can also say that *a*’sexistencenecessitates the existence of *b* [66], or that *a* is of necessity associated with some *b* *because* *a* is an instance of a certain universal*.*

For continuants, if b is such that a **s-depends on** b, then if b ceases to exist, so also does a. The ceasing to exist of a occurs as a matter of necessity (it is in a sense immediate and automatic). Thus **s-dependence** is different from the sort of dependence which is involved, for instance, when we assert that an organism is dependent on food or shelter; or that a child is dependent on its mother. Your body is dependent on molecules of oxygen for its life, not however for its existence. Similar **s-dependence** is different from the sort of dependence that is involved when we assert that every object requires, at any given time t, some spatial region at which it is **located** at that time. (We use ‘**located\_at**’ for dependence of this sort.)

For occurrents, **s-dependence** obtains between every process and its participants in the sense that, as a matter of necessity, this process could not have existed unless these or those participants existed also. A *process* may have a succession of participants at different phases of its unfolding (thus there may be different players on the field at different times during the course of a football game); but the *process* **s-depends** on all of these players nonetheless.

**S-dependence** is thus just one type of dependence among many; it is what, in the literature, is referred to as ‘existential dependence’ [65], since it has to do with the parasitism among entities *for their existence*; there are other types of dependence, including **generic dependence** which is dealt with below. Other types of dependence not addressed in BFO 2.0 include:

* frame dependence (of spatial and temporal regions on spatiotemporal regions)
* dependence for origin (e.g. an artifact such as a spark plug depends on human designers and engineers for the *origin* of its existence, not however for its *continued existence*; you depend similarly on your parents for your origin, not however for your continued existence; the boundary of Iraq depended on certain decisions made by the British and French diplomats [Sir Mark Sykes](http://en.wikipedia.org/wiki/Mark_Sykes) and [François Georges-Picot](http://en.wikipedia.org/wiki/Fran%C3%A7ois_Georges-Picot) in 1916; it does not, however, depend on Sykes and Picot for its continued existence.

Theorem: an *entity* does not **s-depend** on any of its partsor on anything it is partof.

As we shall see when we consider the parts of *qualities* such as color and tone below, the parts of a dependent entity may reciprocally **s-depend** on each other. This idea has not hitherto been explicitly recognized in BFO, but it is documented at length in the literature on specific dependence [1, 2, 3, 6, 20, 46].

## Relation of specific dependence indexed by time

Definition: *a* **s-depends on** *b* **at** *t =* Def. *a* exists **at** *t* & *a* **s-depends on** *b*

Axiom: If *a* **s-depends** on something **at** *t*, then *a* **s-depends** at every time at which it exists.

Axiom: If *a* **s-depends** on *b* **at** *t* and *a* is a continuant, then *a* **s-depends** on*b* at every time at which it exists.

An *s-dependent continuant entity* cannot migrate from one independent continuant bearer to another.

The entities which **s-depend** include

* *dependent continuants*, which **s-depend** in every case on one or more *independent continuants* which are their bearers, and which may in addition stand in **s-dependence** relations among themselves;
* *occurrents*, which **s-depend** in every caseon one or more *independent continuants* which **participate** in them, and which may in addition stand in **s-dependence** relationsto other dependent entities, including *qualities*, *dispositions*, and *occurrents* (see [46, chapter 8; 20, 22] and the discussion of *process profiles*, below).

**Types of s-dependence**

Examples of **one-sided s-dependence** of a *dependent continuant* on an independent continuant:

* an **instance** of *headache* **s-depends** on an **instance** of *head*
* an **instance** of *temperature* **s-depends** on some organism
* an **instance** of *seeing* (a relational process) **s-depends** on some organism and on some seen entity, which may be an occurrent or a continuant
* a process of cell death **s-depends** on a cell

Examples of **reciprocal s-dependence** between *dependent continuants*:

* the two-sided reciprocal **s-dependence** of the *roles* of husband and wife [20]
* the three-sided reciprocal **s-dependence** of the hue, saturation and brightness of a color [45]
* the three-sided reciprocal **s-dependence** of the pitch, timbre and volume of a tone [45]

Note that reciprocally dependent entities are in every case also one-sidedly dependent on some relevant bearers. This is why you can’t change a smile, for example, without changing the face upon which the smile depends.

Examples of **one-sided s-dependence** of an *occurrent* on an *independent continuant*:

* the one-sided dependence of a handwave on a hand
* the one-sided dependence of a football match on the players, the ground, the ball

Examples of **one-sided s-dependence** of one *occurrent* on multiple *independent continuants*:

* a relational *process* of hitting a ball with a cricket bat
* a relational *process* of paying cash to a merchant in exchange for a bag of figs

Examples of **one-sided s-dependence** of one *occurrent* on another

* a *process* of answering a question is dependent on a prior *process* of asking a question
* a *process* of obeying a command is dependent on a prior *process* of issuing a command

Examples of **reciprocal s-dependence** between *occurrents*:

* a process of playing with the white pieces in a game of chess is reciprocally dependent on a process of playing with the black pieces in the same game of chess
* a process of buying and the associated process of selling
* a process of increasing the volume of a portion of gas while temperature remains constant and the associated process of decreasing the pressure exerted by the gas

An entity – for example an act of communication – can **s-depend** on more than one entity. Complex phenomena for example in the psychological and social realms (such as inferring, commanding and requesting) or in the realm of multi-organismal biological processes (such as infection and resistance), will involve multiple families of dependence relations, involving both continuants and occurrents [1, 4, 28].

As the examples under the heading of one-sided **s-dependence** among *occurrents* show, the relation of **s-dependence** does not in every case require simultaneous existence of its relata. Note the difference between such cases and the cases of universals defined historically referred to above; the act of answering depends existentially on the prior act of questioning; the human being who was baptized or who answered a question does not depend existentially on the prior act of baptism or answering. He would still exist even if these acts had never taken place. A phosphorylated protein molecule might still exist even though it had never been phosphorylated.

## 2.1 Independent Continuant

Definition: *A* is an *independent continuant* = Def. *a* is a *continuant* which is such that there is no *b* such that *a* **s-depends on** *b.*

Examples: an atom, a molecule, an organism, a heart, a chair, the bottom right portion of a human torso, a leg; the interior of your mouth; a spatial region; an orchestra.

Axiom: Every *independent continuant* is such that there are *entities* which is **s-depend** on it.

Examples of such entities that are **s-dependent** on *independent continuants* are: qualities, dispositions, processes.

### 2.1.1 Material entity

Elucidation: A *material entity* is an *independent continuant* that has some portion of matter as proper or improper **part.**

Examples: a photon, a human being, the undetached arm of a human being, an aggregate of human beings.

Every *material entity* is localized in space.

Every *material entity* can move in space.

Axiom: Every *entity* which has a *material entity* as part is a *material entity*



Figure 2: Subtypes of independent continuant

Theorem: every *entity* of which a *material entity* is part is also a *material entity.*

‘Matter’ is intended to encompass both mass and energy (we will address the ontological treatment of portions of energy in a later version of BFO). A portion of matter is anything that includes elementary particles among its proper or improper parts: quarks and leptons, including electrons, as the smallest particles thus far discovered; baryons (including protons and neutrons) at a higher level of granularity; atoms and molecules at still higher levels, forming the cells, organs, organisms and other material entities studied by biologists, the portions of rock studied by geologists, the fossils studied by paleontologists, and so on.

*Independent continuants* are three-dimensional entities (entities extended in three spatial dimensions), as contrasted with the *processe* in which they participate, which are four-dimensional entities (entities extended also along the dimension of time).

According to the FMA, *material entities* may have *immaterial entities* as parts – including the *entities* identified below as *sites*; for example the interior (or ‘lumen’) of your small intestine is a part of your body. BFO 2.0 embodies a decision to follow the FMA here, but this is just a terminological matter, and may be corrected on the basis of community feedback. Thus we allow **continuant\_part\_of** to include such material-immaterial crossings, and recommend the use of the more specific relation of **material\_part\_of** where they need to be ruled out.

**Subtypes of material entity**

In what follows we define three children of ‘material entity’ – namely ‘object’, ‘object aggregate’; and ‘fiat object part’. Those using BFO for molecular biology and related matters may wish to use ‘material entity’ solely, and not concern themselves with these subdivisions. Those using BFO to deal with entities at higher levels of granularity – for example organisms, populations, organizations, institutions, will require the distinction between *object* and *object aggregate*. Those using BFO to deal with what the FMA calls regional parts – for example the wall of the cervical, thoracic and abdominal parts of the esophagus, respectively [44] – will require to distinguish between *object* and *fiat object part*.

Some might argue that the mentioned threefold distinction could be recreated by corresponding upper level domain ontologies according to need, for example the distinction between ‘organism’, ‘population of organisms’, and ‘regional part of organism’ in an upper level ontology for biology. Since this would mean that multiple different domain ontologies would be called upon, in effect, to reinvent the same wheel over and over again, and so we provide the corresponding distinctions within BFO in what we hope is a suitably robust framework.

#### 2.1.1.1 Object

BFO rests on the presupposition that at multiple micro-, meso- and macroscopic scales reality exhibits certain stable, spatially separated or separable material units, combined or combinable into aggregates of various sorts (for example organisms into what are called ‘populations’). Such units play a central role in almost all domains of natural science from particle physics to cosmology. Many scientific laws govern the units in question, employing general terms (such as ‘molecule’ or ‘planet’) referring to the types and subtypes of units, and also to the types and subtypes of the processes through which such units develop and interact. The division of reality into such *natural units* is at the heart of biological science, as also is the fact that these units may form higher-level units (as cells form multicellular organisms) and that they may also form *aggregates* of units, for example as cells form portions of tissue and organs form families, herds, breeds, species, and so on.

At the same time, the division of certain portions of reality into *engineered units* (manufactured artifacts) is the basis of modern industrial technology, which rests on the distributed mass production of engineered parts through division of labor and on their assembly into larger, compound units such as cars and laptops. The division of portions of reality into units is one starting point for the phenomenon of *counting*.

Examples of units of special importance for the purposes of natural science include: atom, molecule, organelle, cell, organism, grain of sand, planet, star. These *material entities* are candidate examples of what are called ‘*objects*’ in BFO 2.0. Such units are sometimes referred to as ‘grains’ [74], and are associated with specific ‘levels of granularity’ in what is seen as a layered structure of reality, with units at lower and more fine-grained levels being combined as parts into grains at higher, coarse-grained levels. Our proposals here are consistent with but are formulated independently of such granularity considerations.

**Elucidation of ‘object’**

The following elucidation documents a set of conditions to be used when deciding whether entities of a given type should be represented as *objects* in the BFO sense. It is provided as precursor to a formal theory (of qualitative mereotopology [5, 22, 36, 37, 39]) of BFO:*object*.

In what follows we consider three candidate groups of examples of objects in the BFO sense, namely:

1. organisms, cells and potentially also biological entities of certain other sorts, including organs
2. portions of solid matter such as rocks and lumps of iron
3. engineered artifacts such as watches and cars.

Material entities under all of these headings are all *causally relatively isolated entities* in Ingarden’s sense [47, 13]. This means that they are both *structured* through a certain type of causal unity and *maximal* relative to this type of causal unity.

We first characterize causal unity in general, we then distinguish three types of causal unity corresponding to the three candidate families of BFO:*objects* (cells and organisms, solid portions of matter, machines and other engineered artifacts) listed above. We then describe what it is for an entity to be maximal relative to one or other of these types, and formulate in these terms an elucidation of ‘object’. (We must bear in mind throughout that the aggregates of those microparticles which form the low-level parts of such causally structured units for limited periods in their existence may survive the loss of causal unity, for example as occurs during phase transitions from solid to liquid to gas.)

Elucidation: *a* is *causally unified* means: *a* is a material entity which is such that its material parts are tied together in such a way that, in environments typical for *entities* of the type in question,

* if *b,* a **continuant part** *a* in the interior of *a* at *t*,islarger than a certain threshold size (which will be determined differently from case to case, depending on factors such as porosity of external cover) and is moved in space to be at *t′* ata location on the exterior of the spatial region that had been occupied by *a* at *t*,then *either a*’s other parts will be moved in coordinated fashion *or a* will be damaged (be affected, for example, by breakage or tearing) in the interval between *t* and *t′*.
* causal changes in one part of *a* can have consequences for other parts of *a* without the mediation of any entity that lies on the exterior of *a.*

Material entities with no proper material parts would satisfy these conditions trivially. Candidate examples of types of causal unity for material entities of more complex sorts are as follows (this is not intended to be an exhaustive list):

CU1: Causal unity via physical covering

Here the parts in the interior of the unified entity are combined together causally through a common membrane or other physical covering – what the FMA refers to as a ‘bona fide anatomical surface’ [44]. The latter points outwards toward and may serve a protective function in relation to what lies on the exterior of the entity [13, 47].

Note that the physical covering may have holes (for example pores in your skin, shafts penetrating the planet’s outer crust, sockets where conduits to other entities are connected allowing transport of electric current or of liquids or gases). The physical covering is nonetheless *connected* in the sense that (a) between every two points on its surface a continuous path can be traced which does not leave this surface, and also (b) the covering serves as a barrier preventing entities above a certain size threshold from entering from the outside or escaping from the inside [107, 77].

Some organs in the interior of complex organisms manifest a causal unity of this type. Organs can survive detachment from their surroundings, for example in the case of transplant, with their membranes intact. The FMA [44] defines ‘organ’ as follows:

An anatomical structure which has as its direct parts portions of two or more types of tissue or two or more types of cardinal organ part which constitute a maximally connected anatomical structure demarcated predominantly by a bona fide anatomical surface. Examples: femur, biceps, liver, heart, skin, tracheobronchial tree, ovary.

CU2: Causal unity via internal physical forces

Here the material parts of a material entity are combined together causally by sufficiently strong physical forces, for example, by fundamental forces of strong and weak interaction, by covalent or ionic bonds, by metallic bonding, or more generally by forces of a type which makes the overall sum of forces strong enough to act in such a way as to hold the object together relative to the strength of attractive or destructive forces in its ordinary environmental neighborhood. (Few solid portions of matter in our everyday environment would survive very long on the face of a neutron star, but luckily that is not our everyday environment.) In the case of larger portions of matter the constituent atoms are tightly bound to each other in a geometric lattice, either regularly (as in the case of portions of metal) or irregularly (as in an amorphous solid such as a portion of glass). Examples: *atoms*, *molecules*, *grains of sand*, *lumps of iron.*

CU3: Causal unity via engineered assembly of components

Here the material parts of a material entity are combined together via mechanical assemblies joined for example through screws or other fasteners. The assemblies often involve parts which are reciprocally engineered to fit together, as in the case of dovetail joints, balls and bearings, nuts and bolts. A causal unity of this sort can be interrupted for a time, as when a watch is disassembled for repair, and then recreated in its original state. The parts of an automobile, including the moving parts, constitute an object because of their relative rigidity: while these parts may move with respect to each other, a given gear cannot move e.g., 10 ft., while the other parts do not.

We can now elucidate what it means for a material entity to be *maximal* relative to one or other of these three types of causal unity, and thereby define *object*, as follows

Elucidation: *a* is *maximal* relative to some criterion of causal unity CU*n* means:

*a* is causally unified relative to CU*n* at *t*

&if for some *t* and *b* (*a* **continuant\_part\_of** *b* **at** *t*& *b* is causally unified relative to the same CU*n*) then *a* and *b* are identical

Examples:

relative to the causal unity criterion CU1: a cell or organism is maximal; your lower torso falls short of maximality; a pair of cells exceeds maximality.

relative to the causal unity criterion CU2: a continuous dumbbell-shaped lump of iron is maximal; the connecting portion falls short of maximality; a pair of such dumbbell-shaped lumps exceeds maximality.

relative to the causal unity criterion CU3: an armored vehicle is maximal; the portions of armor of an armored vehicle falls short of maximality; a pair of armored vehicles exceeds maximality.

**Definition of BFO:*object***

We cannot define ‘object’ in BFO simply by asserting that an entity is an object if and only if it is maximal relative to some causal unity criterion. This is because objects under all three of the headings around which our discussions are focused may have other, smaller objects as parts. A spark plug is an object; when inserted into a car to replace a defective spark plug, then it remains an object, but ceases to be maximal. Importantly, however, the spark plug as installed still instantiates a universal many instances of which aremaximal. This suggests that we define object as follows:

Definition: *a* is an *object =*Def. *a* is a *material entity* which

manifests causal unity of one or other of the types CU*n* listed above

& is of a type (a material universal) instances of which are maximalrelative to this criterion of causal unity.

Objects can be joined to other objects

Each *object* is such that there are *entities* of which we can assert unproblematically that they lie in its interior, and other *entities* of which we can assert unproblematically that they lie in its exterior. This may not be so for *entities* lying at or near the boundary between the interior and exterior. This means that two objects – for example the two cells depicted in Figure 3 – may be such that there are material entities crossing their boundaries which belong determinately to neither cell. Something similar obtains in certain cases of conjoined twins (see below).



Figure 3: [An example of cell adhesion](http://php.med.unsw.edu.au/cellbiology/index.php?title=File:Cell_adhesion_summary.png)

Some instances of any given BFO:*object* universal – for example *cell* or *organism* or *laptop –* are separated by spatial gaps from other instances of this same *object* universal. The spatial gaps may be filled by a medium, for example of air or water. (There are cells not attached to other cells; there are spatially separated organisms, such as you and me. Peas in a pea pod are initially attached to the interior of the pea pod covering. Sperm initially float freely from each other; some sperm become fused with oocytes through a membrane fusion process.)

**Objects may contain other objects as parts**

They may do this, for example,

* by containing atoms and molecules as parts
* by containing cells as parts, for instance the collection of blood cells in your body;
* by containing objects which are bonded to other objects of the same type in such a way that they cannot (for the relevant period of time) move separately, as in the case of the cells in your epithelium or the atoms in a molecule.
* by containing objects which are connected by conduits or tracts which may themselves have covering membranes*.*

Clearly, *objects* may contain also *object aggregates* as parts. Some *objects*¸as we saw, may also have immaterial parts (the lumen of your gut) [34].

**Conjoined twins**

Some objects may change type from one time to the next (a fetus becomes a baby, which in turn becomes a child). Conjoined twins may be successfully separated. Two boats may be combined to form a single multihulled boat.

Whether each one of a pair of conjoined twins is or is not an object is not a trivial question, and the treatment of this case ontologically should be viewed as an experimental matter, with different alternatives tested in use to see which yields the most coherent solution for different sorts of cases. Different types of conjoined twins will need to be treated differently, and that in cases where twins do not share vital organs an identification of each one of the pair as an object will yield a workable solution. Certainly, the maximal CU1-causally unified material entity here is the whole which they together form; accepting each twin as an object even prior to separation, however – thus as an instance of the material universal *human being* – is consistent with our elucidation of BFO:*object*.

#### 2.1.1.2 Object aggregate

In this document we concentrate on the use of ‘aggregate’ as it appears in the term ‘object aggregate’. However, ‘aggregate’ should be understood as being applicable to all continuant BFO categories. Thus for each BFO category X, the user of BFO has at his disposal also the category *aggregate of X* [51].

Elucidation: *a* is an *object aggregate* means: *a* is a *material entity* consisting exactly of a plurality of *objects* as **continuant parts**.

More formally:

If *a* is an *object aggregate*, then if *a* exists at *t*, there are *objects o*1, …,*o*n at *t* such that:

for all *x* (*x* **continuant\_part\_of** *a* **at** *t* iff *x* overlaps some *o*i **at** *t*)

An entity *a* is an object aggregate if and only if there is a mutually exhaustive and pairwise disjoint partition of *a* into objects [63].

Examples: a symphony orchestra, the aggregate of bearings in a constant velocity axle joint, the nitrogen atoms in the atmosphere, a collection of cells in a blood biobank.

The objects which form the proximal parts of an aggregate – those parts which determine the aggregate as an aggregate – are called its **member parts** (sometimes referred to as ‘granular parts’).

Different sorts of examples will be aggregates satisfying further conditions, for example an organization is an aggregate whose **member parts** have roles of specific types (for example in a jazz band, a chess club, a football team); a swarm of bees is an aggregate of members who are linked together through natural bonds.

## Relation of membership

This relation is defined not only for objects but for BFO categories in general, as follows:

Definition: *a* **member\_part\_of** *b* **at** *t* =Def. there is a mutually exhaustive and pairwise disjoint partition of *a* into entities of category X: *x*1, …,*x*n with *a = xi* for some *i.*

Domain: entity in category X

Range: aggregate of X

Theorem: if *a* member\_part\_of *b* at *t* then *a* continuant\_part\_of *b* at *t.*

Examples: trees in a forest; pieces in a chess set.

Object aggregates may be defined through physical attachment (the aggregate of atoms in a lump of granite), or through physical containment (the aggregate of molecules of carbon dioxide in a sealed container, the aggregate of blood cells in your body). Object aggregates may be defined by fiat – for example in the case of the aggregate of members of an organization, or via attributive delimitations such as: the patients in this hospital, the restaurants in Palo Alto, your collection of Meissen ceramic plates.

[76] provides a formal treatment of aggregates (there called ‘collections’) that is consistent with the above. However, the formalization provided assumes that membership in a collection is fixed over time. As is true for all material entities (for example: you), object aggregates may gain and lose parts while remaining numerically identical (one and the same individual) over time, and for some aggregates, especially in cases where membership is determined by fiat (for example a baseball team, a congressional committee) membership may change with time.

#### 2.1.1.3 Fiat object part

Clearly not all material entities form separated or separable natural units in the way described above (see and [12]), and so there is – in dealing with limbs demarcated within a body, of mountains demarcated within mountain ranges, and so forth – a need for some way to do justice to those material entities here called fiat object parts.



Figure 4: [Mount Everest from space](http://www.webstuffscan.com/wp-content/uploads/2007/01/mount%20everest%20from%20space.jpg)

Definition: *a* is a *fiat object part* = Def. *a* is a *material entity* that is a **proper continuant\_part** of an *object* and that is not itself an *object.*

Examples: the upper and lower lobes of the left lung, the dorsal and ventral surfaces of the body, the Western hemisphere of the Earth, the FMA:*regional parts* of an intact human body.

Since *fiat object parts* are *material entities*, they are also extended in space in three dimensions (in contrast to *fiat continuant boundaries*, introduced below).

Fiat object parts are contrasted with bona fide object parts, which are themselves objects (for example a cell is a bona fide object part of a multi-cellular organism), and are marked by bona fide boundaries, on in other words by *physical discontinuities* [8, 9], for example between the surface of your skin, or of your laptop, and the surrounding body of air. Most examples of fiat object parts are associated with theoretically drawn divisions, for example the division of the brain into regions, the division of the planet into hemispheres, or with divisions drawn by cognitive subjects for practical reasons, such as the division of a cake (before slicing) into (what will become) slices (**member parts** of an *object aggregate*). However, this does not mean that fiat object parts are dependent for their existence on divisions or delineations effected by cognitive subjects. If, for example, it is correct to conceive geological layers of the Earth as fiat object parts of the Earth, then even though these layers were first delineated in recent times, still they existed long before such delineation and what holds of these layers (for example that the oldest layers are also the lowest layers) did not begin to hold because of our acts of delineation.

**Treatment of *material entity* in BFO**

Examples viewed by some as problematic cases for the trichotomy of *fiat object part*, *object*, and *object aggregate* include:

a mussel on (and attached to) a rock, a slime mold, a pizza, a cloud, a galaxy, a railway train with engine and multiple carriages, [a clonal stand of quaking aspen](http://scienceblogs.com/evolvingthoughts/2007/08/what_is_an_individual.php), a bacterial community (biofilm), a broken femur.

Note that, as Aristotle already clearly recognized, such problematic cases – which lie at or near the penumbra of instances defined by the categories in question – need not invalidate these categories. The existence of grey objects does not prove that there are not objects which are black and objects which are white; the existence of mules does not prove that there are not objects which are donkeys and objects which are horses. It does, however, show that the examples in question need to be addressed carefully in order to show how they can be fitted into the proposed scheme – that the scheme requires additional subdivisions [29, ] or amendments.

Where users of BFO need to annotate data pertaining to such problematic cases, then they may in every case use BFO:*material entity* in formulating the corresponding annotations. In the case of the following examples:

a solar flare, an epidemic, a hurricane, a forest fire, a puff of smoke, a sea wave, an energy wave.

we plan to provide further analyses in the course of developing the next version of BFO.

Already it is clear that BFO or its conformant domain-ontologies will in due course need to recognize also other sub-universals of *material entity*, in addition to *object, object aggregate* and *fiat object part* – for instance: *aggregate of fiat object parts* [29, 82]. Thus the treatment of *material entity* in BFO 2.0 should not be associated with any closure axiom pertaining to the three distinguished categories, and the existing treatment of the three identified sub-universals should not be associated with any claim to exhaustivity.

We will provide a strategy for dealing with such sub-universals in a later version of this document. Briefly, the proposal is that a central repository will be created where users of BFO can create BFO-conformant extensions (extending BFO in ways that meet the criterion that they are formal- rather than domain-ontological). The terms in this repository can then be adopted by others according to need, and incorporated into BFO if adopted by multiple communities of users.

### 2.1.2 Immaterial entity

The roots of BFO’s treatment of ‘immaterial entity’ lie in the application of theories of qualitative spatial reasoning to the geospatial world, for example as outlined in [49], in the treatment of holes by Casati and Varzi [48], and in the treatment of cavities in the FMA [43, 44, 34, 35].

Rosse and Mejino provide the following rationale for including terms for surfaces, lines, and points in the FMA:

Although anatomical texts and medical terminologies with an anatomical content deal only superﬁcially, if at all, with anatomical surfaces, lines, and points, it is nevertheless necessary to represent these entities explicitly and comprehensively in the FMA in order to describe boundary and adjacency relationships of material physical anatomical entities and spaces. [43]

*Immaterial entities* are divided into two subgroups:

1. *boundaries* and *sites*, which bound, or are demarcated in relation, to *material entities*, and which can thus change location, shape and size and as their material hosts move or change shape or size (for example: your nasal passage; the hold of a ship; the boundary of Wales (which moves with the rotation of the Earth) [38, 7, 10]);
2. *spatial regions*, which exist independently of *material entities*, and which thus do not change.

Immaterial entities under 1. are in some cases **continuant parts** of their material hosts. Thus the hold of a ship, for example, is part of the ship. Immaterial entities under both 1. and 2. can be of zero, one, two or three dimensions.

We define:

Definition: a is an immaterial entity = Def. a is an independent continuant that has no material entities as parts.

#### 2.1.2.1 Continuant fiat boundary

Definition: *a* is a *continuant fiat boundary =* Def. *a* is an *immaterial entity* that is of zero, one or two dimensions and does not include a spatial region as part.

Axiom: A continuant fiat boundary is of *n* dimensions iff it is located at some *n-*dimensional spatial region.

Every continuant fiat boundary is **located at** some spatial region at every time at which it exists (but not necessarily at the same spatial region from one time to the next).

All material entities are of three dimensions. Intuitively, a continuant fiat boundary is a boundary of some material entity (for example: the plane separating the Northern and Southern hemispheres; the North Pole), or it is a boundary of some immaterial entity (for example of some portion of airspace).

Three basic kinds of continuant fiat boundary can be distinguished (together with various combination kinds [29]):

* fiat boundaries (often rectilinear) which delineate fiat parts within the interiors of material entities – for example the fiat boundary between the northern and southern hemispheres of the Earth; the North Pole; the fiat boundary which separates Utah from Colorado
* fiat boundaries which delineate holes or cavities, for example fiat boundaries of the type referred to by the FMA as ‘plane of anatomical orifice’.

An example of a combination fiat boundary would be the border of Israel, which contains both rectilinear fiat boundaries for example along the border with Egypt and fiat boundaries tracking physical discontinuities for example on the Mediterranean side and along the borders with Syria and Jordan.

Note that boundaries are dependent entities, but they are not dependent in either of the senses (of s- and g-dependence) identified elsewhere in this document.

##### 2.1.2.1.1 Zero-dimensional continuant fiat boundary

Elucidation: a zero-dimensional continuant fiat boundary is a fiat point whose location is defined in relation to some material entity.

Examples: the geographic North Pole; the quadripoint where the boundaries of Colorado, Utah, New Mexico, and Arizona meet, the point of origin of some spatial coordinate system.

##### 2.1.2.1.2 One-dimensional continuant fiat boundary

Elucidation: a one-dimensional continuant fiat boundary is a continuous fiat line whose location is defined in relation to some material entity.

Examples: The Equator, all geopolitical boundaries, all lines of latitude and longitude, the median sulcus of your tongue, the line separating the outer surface of the mucosa of the lower lip from the outer surface of the skin of the chin.

To say that a one-dimensional continuant fiat boundary is *continuous* is to assert that it includes no gaps (that it is a single straight or curved line, with no breaks).

##### 2.1.2.1.3 Two-dimensional continuant fiat boundary

Elucidation: a two-dimensional continuant fiat boundary (surface) is a self-connected fiat surface whose location is defined in relation to some material entity.

‘Self-connected’ is to be understood in the (topological) sense; thus an entity *a* is self-connected if and only if: given any two points in *a*, a continuous line can be traced in *a* which connects these points.

From this it follows that a two-dimensional continuant fiat boundary (surface) may have holes, as for example in the case of the surface of one side of a compact disk.

##### 2.1.2.1.4 Site

Definition: *a* is a *site* = Def. *a* is a three-dimensional *immaterial entity* that is (partially or wholly) bounded by a *material entity* or a three-dimensional immaterial part thereof.

Examples: a hole in the interior of a portion of cheese, a rabbit hole, the interior of your bedroom, the Grand Canyon, the Piazza San Marco, an air traffic control region defined in the airspace above an airport, the interior of a kangaroo pouch, your left nostril (a fiat part – the opening – of your left nasal cavity), the lumen of your gut, the hold of a ship, the cockpit of an aircraft, the interior of the trunk of your car, the interior of your refrigerator, the interior of your office, [Manhattan Canyon](http://www.flickr.com/photos/tonyshi/4385628183/))

Note: *Sites* may be bounded by various combinations of boundaries of different sorts [9]. Thus the Mont Blanc Tunnel is bounded by fiat surfaces at either end. Each immaterial entity coincides at any given time with some spatial region, but, as in the case of material entities, which spatial region this is may vary with time. As the ship moves through space, so its hold moves also. As you pinch and unpinch your nose, so your nasal passages shrink and expand.

To say that ‘detergent is pumped into the tank’ is to assert that the detergent is pumped into the cavity which forms the interior of the tank (rather than into the metal which bounds this cavity, or into the contents of the tank – since the tank may be empty).

The region of class A controlled airspace associated with any given airport is a site, since it is a three-dimensional part of the site formed by the sum of this region with the portion of the class E region that is bounded by the surface of the Earth (see Figure 5).



Figure 5: [Airspace classes](http://ontology.buffalo.edu/smith/varia/controlledairspace/glos_aclass.jpg)

Cavities within what OGMS calls the ‘extended organism’ are sites; they are, following the FMA, parts of the organism if they are part of its anatomical *Bauplan* [43, 44]*.* A cavity formed by a swallowed drug-capsule that is half-filled with powder is for this reason not a part of the organism.



Figure 6: Examples of types of site:

1: the interior of an egg; 2: the interior of a snail’s shell; 3: the environment of a pasturing cow

#### 2.1.2.2 Spatial region

We recommend that users of BFOregionterms specify the coordinate frame in terms of which their spatial and temporal data is formulated. When dealing with spatial regions on the surface of the Earth, for example, this will be the coordinate frame of latitude and longitude, potentially supplemented by the dimension of altitude (height above sea level). Lines of latitude and longitude are two-dimensional object boundaries which move as the planet rotates and as it moves in orbiting the sun; however, they are by definition at rest relative to the coordinate frame which they determine.

Figure : Examples of types of site

Given terminology of spatial frames, we can elucidate ‘space’ in a way close to that which was provided in BFO 1.1, as the maximal **instance** of the universal *spatial region*, relative to some frame, as follows:

Elucidation: A spatial region is a continuant entity that is a continuant\_part\_of spaceR as defined relative to some frame R.

‘Maximal’, in the above, means that any instance entity including spaceR as proper part is not a spatial region. Space is, in common parlance, the whole of space. The term ‘space’ is the name of a certain particular. As we shall see below, spacetime and time, similarly, are maximal instances of spatiotemporal and temporal region, respectively.

Axiom: All **continuant parts** of *spatial regions* are *spatial regions*.

Spatial regions have no qualities except shape and size.

*Object boundaries* and *sites* are distinguished from the spatial regions which they occupy at any given time as follows:

(1) *Object boundaries* and *sites* move when their material host moves, and they change shape or size when their material host changes shape or size.

(2) *Spatial regions* are by definition at rest relative to the pertinent coordinate frame.

##### 2.1.2.2.1 Zero-dimensional spatial region

Elucidation: A *zero-dimensional spatial region* is a point in space.

##### 2.1.2.2.2 One-dimensional spatial region

Elucidation: A *one-dimensional spatial region* is a line or aggregate of lines stretching from one point in space to another

Examples: an edge of a cube-shaped portion of space.

A line is a connected one-dimensional spatial region.

##### 2.1.2.2.3 Two-dimensional spatial region

Definition: A *two-dimensional spatial region* is a spatial region that is of two dimensions.

Examples: the surface of a sphere-shaped part of space, an infinitely thin plane in space.

A surface is a connected one-dimensional spatial region.

##### 2.1.2.2.4 Three-dimensional spatial region (a spatial volume)

Definition: A *three-dimensional spatial region* is a spatial region that is self-connected and of three dimensions.

Examples: a cube-shaped region of space, a sphere-shaped region of space,

## The located\_at relation

Elucidation: a**located\_at**r**at**t

Domain: material entity

Range: spatial region

This is a primitive relation between an *independent continuant*, a spatial region which it occupies, and a time. This is a relation of exact location; the size, shape, orientation and location of *a* fit exactly to the size, shape and location of *r.* If there are cavities in the interior of *a* then there are corresponding holes in the interior of *r.*

Clearly, normal usage will involve not assertions of exact location, but rather more liberal statements for example: John is in London, Mary is in her hotel room, Carlo is in his mother’s womb, which will involve assertions of which are formulated using the **located\_in** relation as defined below.

Axiom: every region is **located\_at** itself at all times.

Axiom: if *a* **located at** *r* **at** *t* & *a′* **continuant\_part\_of** *a* **at** *t*, then there is some *r′* which is **continuant\_part\_of** *r* & such that *a′* **located\_at** *r′* **at** t.

## The located\_in relation

The **located\_in** relation links independent continuants which are not spatial regions. To understand it, we must first introduce what we shall call the ‘convex hull’ of a spatial region

Definition: r+**convex\_closure *r* =def.** r+is the smallest continuous convex spatial region including *r* as part

where ‘convex’ signifies having a boundary which everywhere curves outward, like the boundary of a sphere, and where ‘continuous’ signifies that there are no holes or cracks within the interior[52].

Definition: a**located\_in** b **at**t = Def. a and b are independent continuants, and the region **at** which a is **located at** t is a (proper or improper) **continuant\_part\_of** the **convex closure** of the region **at** which b is **located at** t.

Domain: independent continuant

Range: independent continuant

Examples: your arm **located\_in** your body; this stem cell **located\_in** this portion of bone marrow; this portion of cocaine **located\_in** this portion of blood; Mary **located\_in** Salzburg; the Empire State Building **located\_in** New York.

Axiom: **Located\_in** is transitive

*a* **located\_in** *b* at *t* and *b* **located\_in** *c* at *t*, then *a* **located\_in** *c*

For all material entities *a* and *b*, parthood implies location:

Axiom: if *a* **continuant\_part\_of** *b* **at** *t*, then *a* is **continuant\_located\_in** *b* **at** *t.*

Sites and boundaries, too, may stand in the **located\_in** relation, as for example when we say that 5th Avenue is **located in** New York, or that a portion of the Franco-German boundary is **located in** the Rhein valley. Notethat *object aggregates*, *aggregate of sites* can also stand in the **located\_in** relation.

**Problem cases for the located\_in relation**

As pointed out in [52] there are problem cases for this account, in that, for example an insect located near the stem of a wine glass would be counted as **located\_in** the wine glass; similarly crumbs placed in the hole of a donut would be counted as **located\_in** the donut. Briefly, users of **located\_in** should use an intuitive test to the effect that: if *a* is not in the interior of *b* but is rather in some hole or cavity attached to *b*’s outer boundary, then *a* **located­\_in** *b* will obtain only if this hole is a fillable hole in the sense defined by Casati and Varzi [52]. The cup-shaped hole in the wine glass is fillable in this sense; not however the concave spaces around the stem.

**Chaining rules**

Axiom: for all independent continuants *a*, *b*, and *c*: if *a* **continuant\_part\_of** *b* **at** *t* & *b* **located\_in** *c* **at** *t*, then *a* **located\_in** *c* **at** *t*

Axiom: for all independent continuants *a*, *b*, and *c*: if *a* **located\_in** *b* **at** *t* & *b* **continuant\_part\_of** *c* **at** *t*, then *a* **located\_in** *c* **at** *t*

## 2.2 Specifically dependent continuant

Definition: *a* is a *specifically dependent continuant =* Def. *a* is a *continuant* which **s-depends** on some independent *continuant*.

Examples: of one-sided *specifically dependent continuants*: the mass of this tomato, the color of this tomato, the smell of this portion of mozzarella, the disposition of this fish to decay, the role of being a doctor, the function of this heart: to pump blood, the shape of this region of space.

Examples: of *relational dependent continuants* (multiple bearers): John’s love for Mary, the ownership relation between John and this statue, the relation of authority between John and his subordinates.

John’s ownership of the statue is an instance of the ownership relation. It starts to exist at a certain time and ceases to exist at some later time.

Examples: of reciprocal *specifically dependent continuants*: the function of this key to open this lock and the reciprocally dependent disposition of this lock: to be opened by this key; the reciprocal dependence of the role *predator* and the role *prey* as played by two organisms in a given interaction; the reciprocal dependence of proton donors and acceptors in chemical reactions [79].

Question: Are reciprocal specifically dependent continuants always realizables and never qualities?

Sub-types of *specifically dependent continuant* recognized by BFO are:



Definition: *a* **inheres\_in** *b* **at** *t* =Def. *a* is a dependent continuant & *b* is an independent continuant & *a* **s-depends on** *b* **at** *t*

**Inherence** is a subrelation of **s-dependence** which holds between a *dependent continuant* and an *independent continuant*. Since dependent continuants cannot migrate from one bearer to another, we do not need to include the qualifier ‘**at** *t*’. If *a* **s-depends on** *b* at some time, then *a* **s-depends on** *b* at all times at which *a* exists.

For example, consider the particular instance of openness inhering in my mouth at *t* as I prepare to take a bite out of a donut, followed by a closedness at *t*+1 when I bite the donut and start chewing. The openness instance is then shortlived, and to say that **s-depends** on my mouth at all times at which it exists, means: at all times during this short life. Every time you make a fist, you make a new (instance of the universal) fist.(Every time your hand has the fist-shaped quality, there is created a new instance of the universal fist-shaped quality.)

Axiom: If *a* **s-dependent** on something, then *a* is not a *material entity.*

Intuitively inherenceholds only where the **s-dependent** entity or entities have no material parts. The accused in a court of law has an **s-dependent** role, but he himself is a human being, and thus not an **s-dependent** entity.

Definition: *a* **bearer\_of** *b* **at** *t =*Def. *b* **s-depends on** *a* & *a* is an *independent continuant* & *b* exists at *t.*

**Bearer\_of** in contrast to inherence, is time-indexed, since if *a* is a bearer of some *b* only at some time during which *a* exists, but *b* cannot similarly inhere in *a* only at some times during which *b* exists.

See also the discussion of **has\_material\_basis\_in** below.

**No s-dependence of higher order**

BFO does not recognize **s-dependence** of higher order. Thus there are no **s-dependence** structures of this sort:

*a*

*b*

*c*

Figure 8: Higher-order dependence

If *a* is dependent on *b* and *b* is dependent on *c* then it must be that there obtains some structure as in Figure 9:

*a*

*b*

*c*

Figure 9: Reciprocal dependence

Here *a* and *b* areboth (one-sidedly) dependent on *c* and (reciprocally) dependent on each other. Thus for BFO there are, for example, no qualities of roles; and similarly there are no roles of qualities; however, there are qualities – such as the quality of pressure and temperature of a body of gas in a certain container – which are both dependent on each other and on their common bearer.

There are no dispositions of qualities and no functions of dispositions. And there are no higher order processes in which processes themselves would change. (See the section on Process Profiles below.) In all such cases, the recommendation on developers of BFO-conformant ontologies is to seek a relevant relatumin the underlying material bearer (the *thing* or *res*).

Qualities of qualities are qualities of the underlying bearer

The shape of the redness on John’s arm, for example, is not a quality of the redness, it is, like the redness itself, a quality of a certain (fiat) portion of the surface of the arm.

Axiom: if *a* s-depends on *b* & *b* s-depends on *c* then *a* s-depends on *c*.

John’s *role* of husband to Mary is dependent on Mary’s *role* of wife to John, and both are dependent on the *object aggregate* comprising John and Mary as **member parts** joined together through the *relational quality* of being married.

### 2.2.1 Quality

BFO 2.0 distinguishes two major familiars of *s-dependent continuants*, namely *qualities* and *realizable dependent continuants.* (Again, no claims are made as to the exhaustiveness of this classification.) Solubility, in order to be realized or manifested, requires a dissolving process in which some solid piece of salt or sugar participates. Their crystalline quality, in contrast, does not stand in need of any realization process of this sort.

Elucidation: a *quality* is a *specifically dependent continuant* that, in contrast to roles and dispositions, does not require any further process in order to be realized.

Examples: the color of a tomato, the ambient temperature of a portion of air, the length of the circumference of your waist, the shape of a nose, the mass of a piece of gold, the weight of a chimpanzee.

Note that in the above list of examples we encounter a further type of dependence, turning on the fact that, for example, the color of a tomato depends in some sense on processes involving photons. This type of dependence is not part of the BFO 2.0 specification, but will be treated in the future.

*Quality* is a rigid universal;

Axiom: If an *entity* is a *quality* at any time that it exists, then it is a *quality* at every time that it exists.

Definition: *a* **quality\_of** *b* **at** *t =* Def. *a* is a quality & *b* is a material entity & *a* **s-depends\_on** *b* **at** *t*

Qualities of spatial regions are restricted to qualities of size and shape.

#### 2.2.1.1 Relational quality

There are relational qualities, which have a plurality of *independent continuants* as their bearers [6].

Definition: *a* is a *relational quality =* Def. for some independent continuants *b*, *c* and for some time *t*: *a* **quality\_of** *b* **at** *t* & *a* **quality\_of** *c* **at** *t*.

Examples: a marriage bond, an instance of love, an obligation between one person and another.

Note that this definition is not meant to be applicable to relational processes such as kissing or hitting discussed below. It is also not meant to apply to internal relations such as comparatives (*larger-than*, *heavier-than …*). Where internal relations obtain there is, in the jargon, *no extra ingredient of being*. If John is taller than Mary, then this is accounted for exclusively in terms of John’s and Mary’s respective height qualities, and in terms of the fact (not an extra entity in the BFO sense) that each of these heights instantiates a certain determinate height universal and that the totality of such universals form a certain linear order. (If Mary is a *human being*thenthere is similarly no extra entity – for example, no instance of the relation of instantiation – that is needed to make this true.)

### 2.2.2 Realizable entity

Elucidation: To say that *a* is a *realizable entity* is to say that *a* is a *specifically dependent continuant* that inheres in some *material entity* and is of a type instances of which are **realized** in *processes* of a correlated type.

Examples: the role of being a doctor, the function of your reproductive organs, the disposition of your blood to coagulate, the disposition of this piece of metal to conduct electricity.

Here examples of correlated process types are, respectively: diagnosing, inseminating, formation of a clot, transmission of an electric current.

## Relation of realization

Elucidation: to say that *a* **realizes** *b* **at** *t* is to assert that

there is some material entity *c*

& *a* is a process in which *c* **participates at** temporal interval *t*

& *b* is a disposition or role of which *c* is **bearer at** *t*

& the type instantiated by a is correlated with the type instantiated by *b*.

Theorem: if a realizable entity is realized in a process *p*, then the bearer of *a* participates in *p*.

Axiom: All *realizable dependent continuants* have *material entities* or *sites* as their **bearers**.

There are reciprocal *realizable dependent continuants* (e.g. husband/wife; complementary dispositions (for example of key and lock), as described in [28, 79]).

**Role (Externally-Grounded Realizable entity)**

Elucidation: *a* is a *role* means: *a* is a *realizable entity* which exists because its bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be, and is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed.

Examples:

* the priest role
* the student role
* the role of subject in a clinical trial
* the role of a stone in marking a boundary

‘Role’ is another name for what we might call an extrinsic or externally-grounded realizable entity. An entity has a certain role not because of the way it itself is, but because of something that happens or obtains externally, for example a student is enrolled in an institution of learning, a patient is enrolled in a clinical trial.

**Optionality of Roles**

Because a role is not a consequence of the in-built physical make-up of its bearer, roles are *optional* in the sense that the bearer of a role can lose this role without being thereby physically changed. If the role ceases to exist, then it is not the case that the bearer must also cease to exist. The bearer is not existentially dependent on the role.

Roles characteristically involve some form of social ascription or imputation.

**Having a role vs. playing a role**

An entity can play a role, as when a passenger plays the role of a pilot on a commercial plane in an emergency, or a pyramidal neuron plays the role occupied by a damaged stellar neuron in the brain; but neither the person nor the pyramidal neuron have those roles.

#### Disposition (Internally-Grounded Realizable entity)

Elucidation: *a* is a disposition means: *a* is a realizable entity which is such that (1) if it ceases to exist, then its bearer is physically changed, and (2) its realization occurs when and because this bearer is in some special physical circumstances, and (3) this realization occurs in virtue of the bearer’s physical make-up.

Examples:

* an atom of element X has the disposition to decay to an atom of element Y
* the cell wall is disposed to filter chemicals in endocitosis and exocitosis
* certain people have a predisposition to colon cancer
* children are innately disposed to categorize objects in certain ways.

Unlike roles, dispositions are not optional. If an entity is a certain way, then it has a certain disposition, and if its physical makeup is changed then it may lose that disposition. A disposition can for this reason also be referred to as an *internally-grounded realizable entity*. That is, it is a realizable entity that is a reflection of the (in-built or acquired) physical make-up of the *material entity* in which it **inheres**.

Axiom: If *a* is a *realizable entity* then *a* **s-depends** on some *material entity.*

Dispositions exist along a strength continuum. Weaker forms of disposition are realized in only a fraction of triggering cases. These forms occur in a significant number of *entities* of a similar type.

Each disposition type is associated with one or more characteristic realization process types – types which are instantiated by those processes in which the respective disposition instance is realized. Dispositions may also be associated with characteristic trigger process types – instantiated by processes (for example of being dropped on a hard surface) in which they are realized. The term ‘causality’ is often applied to rerfer to such trigger-and-realization process pairs.

Diseases are dispositions according to OGMS [27]. We are referring to disposition also when we consider genetic and other risk factors for specific diseases. These are predispositions to disease – in other words they are dispositions to acquire certain further dispositions. The realization of such a predisposition consists in processes which change the physical makeup of its bearer in such a way that parts of this bearer then serve as the physical basis for a disease.

#### Function

Elucidation: A *function* is 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.

* the function of amylase in saliva to break down starch into sugar
* the function of a hammer to drive in nails
* the function of a heart pacemaker to regulate the beating of a heart through electricity

Functions are realized in processes called functionings. Each function has a bearer with a specific type of physical make-up. This is something which, in the biological case, the bearer is of a type which has naturally evolved to carry this function (as in a hypothalamus secreting hormones). In the artifact case, it is something which the bearer is of a type which is the result of design (as in an Erlenmeyer flask designed to hold liquid) or also (as in the case of penicillin) has been deliberately selected for. The cavity (site) in the interior of the flask does not have a function in its own right, but only by inheritance from its material host.

It is not accidental or arbitrary that a given eye has the function to see or that a given screwdriver has been designed and constructed with the function of fastening screws. Rather, these functions are integral to these *entities* in virtue of the fact that the latter have evolved, or been constructed, to have a corresponding physical make-up. Thus the heart’s function is to pump blood, and not merely to produce thumping sounds. The latter are by-products of the heart’s proper functioning. The screwdriver’s function is in addition bound together with the disposition of the screw: the two are reciprocally dependent on each other (a case of reciprocal generic dependence – see below – since the screwdriver function can be realized with the aid of many different screws).

Like dispositions of other sorts, a function is an internally-grounded realizable entity: it is such that, if it ceases to exist, then its bearer is physically changed. In some cases an entity may preserve its function even while it is physically changed in ways which make it unable to function. For a lung or attic fan to be non-functioning is an indication that the physical make-up of these things has changed – in the case of the lung perhaps because of a cancerous lesion; in the case of the attic fan because of a missing screw. But these entities then still *have their functions*; it is simply that they are unable to exercise these functions until the physical defect is rectified, for example through clinical intervention or mechanical repair. The entities would *lose* their function only if they were changed drastically, for example, in the case of the lung, through the death of the host organism.

We have distinguished two varieties of function, artifactual function and biological function. These are not asserted subtypes of BFO:*function* however, since the same function – for example: to pump, to transport – can exist both in artifacts and in biological entities. The asserted subtypes of function that would be needed in order to yield a separate monoheirarchy are not artifactual function, biological function, etc., but rather transporting function, pumping function, etc.

**Defined relations**

Definition: *a* **role\_of** *b* **at** *t =*Def. *a* is a *role* and *a* **inheres\_in** *b* **at** *t*

Definition: *a* **disposition\_of** *b* **at** *t =*Def. *a* is a *disposition* and *a* **inheres\_in** *b* **at** *t*

Definition: *a* **function\_of** *b* **at** *t =*Def. *a* is a *function* and *a* **inheres\_in** *b* **at** *t*

Definition: *a* **has\_role** *b* **at** *t =*Def. *b* **role\_of** *a* **at** *t*

Definition: *a* has\_disposition *b* at *t =*Def. *b* disposition\_of *a* at *t*

Definition: *a* has\_function *b* at *t =*Def. *b* function\_of *a* at *t*

**Material basis**

Dispositions (and thus also functions) are introduced into BFO in order to provide a means for referring to what we can think of as the potentials or powers of things in the world without the need to quantify over putative ‘possible worlds’ or ‘possible objects’. Whenever a disposition exists, then it is a disposition of some thing, namely its material bearer. Dispositions exist in every case because there is some corresponding portion of reality that is non-dispositional in nature, which we call the material basis of the disposition. This portion of reality is not in every case identical with the bearer of the disposition. The relevant relation can be elucidated as follows:

Elucidation: *a* **has\_material\_basis** *b* **at** *t* means:

*a* is a *disposition*

& b is a *material entity*

& there is some *c* **bearer\_of** *a* **at** *t*

& *b* **continuant\_part\_of** *c* at *t*

& *c* **has\_disposition** *d* at *t* because *b* **continuant\_part\_of** *c* at *t*

Examples: the material basis of John’s disposition to cough is the viral infection in John’s upper respiratory tract; the material basis of the disposition to wear unevenly of John’s tires is the worn suspension of his car.

### 2.3 Generically dependent continuant

Definition: *a* **g-depends on** *b* **at** *t*1=Def. *a* exists **at** *t*1 and *b* exists **at** *t*1

& for some type *B* it holds that (*b* **instantiates** *B* at *t*1)

& necessarily, for all *t* (if *a* exists **at *t*** then some **instance\_of** *B* exists **at** *t*)

& not (*a* **s-depends\_on** *b*)

Domain: generically dependent continuant

Range: independent continuant

Axiom: if *a* **g-depends on** *b* at some time *t*, then *a* **g-depends** on something at all times at which it exists.

Definition: *a i*s a *generically dependent continuant* = Def. *a* is a *continuant* that **generically depends** on one or more other *entities*.

Examples: the pdf file on your laptop, the pdf file that is a copy thereof on my laptop; the sequence of this protein molecule; the sequence that is a copy thereof in that protein molecule.

As we saw, BFO’s *specifically dependent continuants* are subject to the axiom of non-migration – they cannot migrate from one bearer to another. *Generically dependent continuants*, in contrast, can in a sense migrate, namely through a process of exact copying which allows, for example, the very same information artifact to be saved to multiple storage devices.

We can think of *generically dependent continuants*, intuitively, as complex continuant patterns (complex qualities) of the sort created by authors or designers, or (in the case of DNA sequences) through the processes of evolution. Further examples of *generically dependent continuants* include: the chessboard pattern, the Coca Cola logo, the pattern of a traffic sign. Each such pattern exists only if it is concretized in some counterpart *specifically dependent continuant* – the pattern of black and white squares on this wooden chessboard here before me; the pattern of red and white swirls on the label of this Coca Cola bottle; the pattern of paint on this traffic signboard.

Such patterns can be highly complex. A certain pattern (of letters of the alphabet and associated punctuation and spacing) which is a work of literature is concretized in the patterns of ink marks in this and that particular *copy* of the work. When you create a novel then in addition to creating an **s-dependent** pattern of inkmarks on your manuscript, you create also a particular instance of the *generically dependent continuant* type *novel*. When you print further copies in book form, then you create multiple particular instances of the *independent continuant* type *book.*

## Relation of concretization

Definition: *a* **concretizes** *b* **at** *t =* Def. *a* is a specifically *dependent continuant* & *b* is a *generically dependent continuant* & for some *material entity c, a* **s-depends** on *c* **at** *t* and *b* **g-depends** on *c* **at** *t*, and if *b* migrates from bearer *c* to another bearer *d* than a copy of *a* will be created in *d.*

The data in your database are patterns instantiated as **s-dependent** quality instances in your hard drive. The database itself is an aggregate of such patterns. When you create the database you create a particular instance of the *generically dependent continuant* type *database*. Each entry in the database is an instance of the *generically dependent continuant* type *datum*.

Data, databases, pdf files, novels, and other information artifacts are thus analogous to other created artifacts such as paintings or sculptures. They differ from the latter, however, in that, once they have been created, they can exist in many copies. These many copies exist because of a templating process. Only where such a templating process exists do we have the sorts of patterns which are *generically dependent* continuants.

*Generically dependent continuants* can be **concretized** in multiple ways; you may concretize a poem as a pattern of memory traces in your head. You may concretize a piece of software by installing it in your computer. You may concretize a recipe which you find in a cookbook by turning it into a plan which exists as a *realizable dependent continuant* in your head.

Axiom: if *a* **g-depends** on *b* at some time, then there is some *c*,which isa **concretization** of *a* and which **s-depends** on *b.*

**Works of Music and Experimental Protocols**

In the case of a work of music such as Beethoven’s *9th Symphony*, there is a certain abstract pattern, a *generically dependent continuant*, which we shall call #9. #9 is an **instance** of the type *symphony*, which is itself a subtype of the type *musical work*. #9 is **concretized** in certain *specifically dependent continuant* patterns of ink marks that we find in printed copies of the *score*, or (for example) in certain *specifically dependent continuant* patterns of grooves in vinyl disks. The score is an **instance** of the *generically dependent continuant* type *plan specification*, specifying how to create a corresponding *musical performance*. This *plan specification* is **concretized** in distributed fashion in the form of a network of subplans distributed across the minds of the conductor and the members of the orchestra, together forming a plan to create a musical performance of #9. This complex *realizable dependent continuant* is then **realized** when conductor and orchestra work together to create a certain pattern of air vibrations conforming to the score and audible to an audience through certain associated patterns of excitations of their auditory nerves. One consequence of the above is that we cannot in fact listen to Beethoven’s 9th Symphony, but rather only to performances thereof.

Analogously, when a research team decides to perform an experiment following a published protocol, the protocol itself is a *generically dependent continuant* **instance** of the type *plan specification*. The leader of the research team concretizes this protocol in her mind to create that specifically dependent realizable *continuant* which is her plan for carrying out this experiment. At the same time she creates a series of sub-protocols, which are plan specifications for each of her various team members. Each of the latter is then concretized in the mind of the appropriate team member as a plan for carrying out corresponding subactivities within the experiment. The experiment itself is the total *realization* of these plans, having outputs such as publications, databases, and so forth, as described in the [Ontology for Biomedical Investigations](http://obi-ontology.org/page/Main_Page) (OBI).

# 3. Occurrent

The realm of occurrents is less pervasively marked by the presence of natural units than is the case in the realm of independent continuants. Thus there is here no counterpart of ‘object’. In BFO 1.0 ‘process’ served as such a counterpart. In version 2.0 ‘process’ is the occurrent counterpart of ‘material entity’. Those natural – as contrasted with engineered, which here means: deliberately executed – units which do exist in the realm of occurrents are typically either parasitic on the existence of natural units on the continuant side (for example in the cases of births and deaths, and of similar object-bound process boundaries), or they are fiat in nature. Thus we can count *lives*; we can count football games; we can count chemical reactions performed in experiments or in chemical manufacturing. We cannot count the processes taking place, for instance, in an episode of insect mating behavior.

Even where natural units are identifiable, for example cycles in a cyclical process such as the beating of a heart or an organism’s sleep/wake cycle, the processes in question form a sequence with no discontinuities (temporal gaps) of the sort that we find for instance where billiard balls or zebrafish or planets are separated by clear spatial gaps. Lives of organisms are process units, but they too unfold in a continuous series from other, prior processes such as fertilization, and they unfold in turn in continuous series of post-life processes such as post-mortem decay. Clear examples of boundaries of processes are almost always of the fiat sort (midnight, a time of death as declared in an operating theater or on a death certificate, the initiation of a state of war).

Processes can be arbitrarily summed and divided. In particular, we can identify sub-processes – temporal parts – which are fiat segments occupying constituent temporal intervals of the temporal interval occupied by the process as a whole. Occurents are processes, or the boundaries of processes, or temporal or spatial temporal regions.

## Relation of temporal parthood

We introduced above the relation **occurrent\_part\_of**. We can now identify in its terms the sub-relation **temporal\_part\_of** which holds between two occurrents when the former is a phase or subprocess (a slice or segment) of the latter:

Elucidation: To say that *a* is a **temporal\_part\_of** *b* is to say that:

*a* **occurrent\_part\_of** *b* & *a*

& *b* are *occurrents*

& for some *temporal region r*, *a* **occupies** *r*

& *b* **occupies** a region including *r* as **occurrent\_part**

& during this region *r*, *a* and *b* are identical.

This doesn't have to be an elucidation - you have define projection relations.

a temporal\_part\_of b

=def

does not exist z, st.

z occurrent part of b and not z occurrent part of a and the projection of z to temporal region  overlaps the projection of a to temporal region.

The elucidation above suffers from there being no notion of identity during a temporal region "during r a and b are identical".

-Alan

*a* is, in other words, exactly the restriction of *b* to *r*. The process of a footballer’s heart beating once is an **occurrent part** but not a **temporal part** of a game of football.

Examples: your heart beating from 4pm to 5pm today is a **temporal part** of the *process* of your heart beating; the 4th year of your life is a **temporal part** of your life. The first quarter of a game of football is a **temporal part**ofthe whole game.

Temporal parts are often referred to as as stages or phases of an occurrent.

Definition: *a* is an occurrent entity =def. *a* is an entity that has temporal parts.

Since *temporal regions* are **temporal parts** (though not **temporal proper parts**) of themselves, this means, in particular, that *zero-dimensional temporal regions* (temporal instants) are also *occurrents*.

Subtypes of *occurrent* are:

process

process profile

process boundary

temporal region

zero-dimensional temporal region

one-dimensional temporal region

spatiotemporal region

**Projection relations**

Elucidation: To say that each spatiotemporal region *r* **projects\_onto** some temporal region *t* is to say that *t* serves as the temporal extension of *r.*

Elucidation: To say that spatiotemporal region *r* **projects\_onto** spatial region *s* **at** *t* is to say that *s* serves as the spatial extent of *r* **at** *t.*

Every spatiotempoeral region projects onto some time region, and at every time instant within its extent onto some spatial region (all of this relative to some frame).

## Occupies relation

Elucidation: a**occupies** r. This is a primitive relation between an *occurrent* and a *temporal* *or spatiotemporal region* which it exactly occupies.

The **occupies** relation is the counterpart, on the *occurrent* side, of the relation **located\_at.**

**Histories**

The *history* of a *material entity* is the totality of processes taking place in the spatiotemporal region **occupied** by the *entity*, including processes on the surface of the entity or within the cavities to which it serves as host. (See the OGMS definition of ‘[*extended organism*](http://berkeleybop.org/obo/OGMS:0000087)’ and also the treatment of embryontology in [13].) The history of a *material entity* will include, on the above account, the movements of neutrinos within the interior of the entity as they pass through.

Synonyms of *history* are:‘course’, ‘trajectory’. In the case of organisms histories are what we normally call ‘lives’ [15]. In the case of sentient organisms lives will include also the experiences of the organism.

A revision is being contemplated for a future version of BFO which would define the history of an entity as the sum of processes in which that entity is the major participant (or ‘agent’).

The relation between a material entity and its history should be one-to-one. Histories are thus very special kinds of processes, cince not only is it the case that, for any material entity *a*, there is exactly one process which is the history of *a*, but also is it the case that for every history there is exactly one material entity which it is the history of.

Histories are additive. Thus for any two material entities *a* and *b,* thehistory of the sum of *a* and *b* is the sum of their histories.

## 3.1. Process

Definition: *p* is a *process* = Def. *a* is an *occurrent* that has **temporal proper parts** and **s-depends** on one or more material entities.

Examples: the life of an organism, a process of sleeping, a process of cell-division, a beating of the heart, a process of meiosis, the course of a disease, the flight of a bird, your process of aging.

Just as there are relational qualities, so also there are relational processes, which **s-depend** on multiple material entities as their relata.

Examples of relational processes: John seeing Mary [1, 4], a moving body’s crashing into a wall, a game of snooker, the videotaping of an explosion.

### 3.1.1 Process boundary

Definition: *p* is a *process boundary* =Def. *p* is a **temporal part** of a*process* &  *p* has no**proper temporal parts.**

Axiom:Every process boundary **occuplies** *zero-dimensional temporal region.*

Example: the boundary between the 2nd and 3rd year of your life.

## Relation of participation

Elucidation**: has\_participant is an** instance-level relation between an occurrent, an independent continuant, and a time at which the continuant participates in some way in the occurrent.

Domain**:** occurrent

Range**:** independent continuant, specifically dependent continuant, generically dependent continuant

Axiom: if *a* **has\_participant** *b***at** *t* then *a* is an *occurrent*

Axiom: if *a* **has\_participant** *b***at** *t* then *b* is a continuant

Axiom: if *a* **has\_participant** *b***at** *t* then *b* exists **at** *t*

**Participation always involves some material entity**

Axiom: if *a* **has\_participant** *b***at** *t* & *b* is a *specifically* *dependent continuant*, then

there is some *material entity c*, *b* **s-depends on** *c* & *a* **s-depends on** *c*

Axiom: if *a* **has\_participant** *b***at** *t* & *b* is a *generically dependent continuant*, then

there is some *material entity c*, *b* **g-depends on** *c* & *a* **s-depends on** *c*

Thus both specifically and generically dependent entities participate in processes – for example when a file is copied from one hard drive to another – but only *via* the bearers of their specifically dependent concretizations. The underlying idea is that when something changes, then a material entity changes. All change supervenes in this sense on material change.

Spatial regions do not participate in processes.

On the participation of qualities in processes see the treatment of qualitative change, below.

### 3.1.2 Process profiles

**The problem of process qualities**

In the case of a body moving with a constant speed, we can distinguish at least the following elements of an ontological analysis:

1. the body (*object*) that is moving
2. the *process* of moving
3. the *temporal region* **occupied** by this process
4. the *spatiotemporal region* **occupied** by this process (trajectory of the motion)
5. the speed, referred to by means of
6. an expression such as ‘3.12 m/s’.

Each of items (1)-(4) and (6) instantiates a readily identifiable BFO category. (6) is an information artifact, thus a BFO:*generically dependent continuant*. In regard to item (5), it has been proposed that BFO recognize a new category of *process quality*, a counterpart on the occurrent side of *qualities* on the side of continuants. To see the problems with such an approach, consider the following scenario, which is designed to illustrate the contrasting logico-ontological orders governing the continuant (three-dimensional) and occurrent (four-dimensional) realms [14, 21, 30, 31, 32, 33].

Imagine, first, John, an *object*, who, on a certain day, either does or does not go on a one-month diet. In the former case John’s determinable weight quality will decrease; in the latter case this quality will remain constant. In either case John will remain at the end of the month *the same object* as he was on the day in question.

In the case of a *process*, in contrast, no parallel scenario is imaginable. Of course we can imagine John’s *life* as varying under two different scenarios –*life with diet* and *life without diet*. But then, however small the variation from one imagined life to another, we are imagining *different* individual processes.

Someone might argue that John’s life would remain *the same process* if John had gone on a diet in one case and did not in another. This life would be different in certain respects, they say, but it would still be John’s life. One and the same process would simply have different subprocesses and unfold differently through time. But what then is meant here by ‘*same process*’?If *a* and *b* are indeed the *same process*, then *a* and *b* are identical, and then so also are all their parts. If *a* and *b* are have different subprocesses as parts, then they are *different processes*, and thus *different lives* – each of which (in its respective possible world) is referred to as ‘John’s life’.

**Why processes do not change**

As Galton and Mizoguchi point out [53], persuasive arguments can be found in the literature (e.g., [54, 55, 56, 57, 62]) that events cannot change. Processes do not change, because processes *are* changes (they are changes which unfold, for example, with different rates or intensities. They are changes in those *continuant entities* which are their participants.

When people say: *let’s speed up the process*, what they mean is: let’s ensure that some process on-going is one which will be quicker than that process which would have occurred had we not made some specific extra effort.

The difference in logico-ontological order as between continuants and occurrents is captured in the fact that instance-level parthood and other instance-level relations on the side of continuants are indexed by time; not however on the side of occurrents. For example, if *a* **instantiates** *larva* at *t*, then it does not follow that *a* **instantiates***larva* *simpliciter*. For occurrents, in contrast, instantiation relations always hold *simpliciter*. This is because, while *continuants* can change their type from one time to the next (an embryo becomes a fetus becomes an infant), *occurrents* can never change in this way. Certainly an *occurrent* can be unfolding in different ways at different times during its entire course. A process of running can, for example, be described as having speed *v*1 at one time and then as having a different speed *v*2 at a later time. But there is then nothing in the realm of occurrents which changes; rather, there is (*simpliciter*, un-time-indexedly) a process with two different parts. It is as incorrect to describe the process itself as changing, as it would be to describe, say, a strip of colored ribbon as changingbecause it is red at one end and blue at the other.

Certainly we can *talk* as if, given, say, a running with speed *v* process, then there is some attribute of this process in addition to the running itself. But then this attribute is not an extra first-class entity in addition to the running process itself. Compare the way in which, if you have three apples in a box, then you do not have four first-class entities, namely the three apples, and the number 3.

**The solution to the problem**

Yet still, there is a genuine need on the part of the users of BFO for the resources to annotate data deriving from processes of measurement. Our response to this need draws on the insight that to predicate, for instance, ‘has speed 3.12 m/s’, to a process of motion is to assert, not that that the process has some special quality (which the same process, in another scenario, could conceivably have lacked), but rather that the process in question *is of a certain determinate type*. BFO has insisted from the very beginning that process *p* has speed *v* is analogous not to: rabbit *r* has weight *w,* but rather to rabbit *r* **instance\_of** universal: *rabbit.*

There is a problem with an approach along these lines, however,which turns on the fact that the processes with which we have to deal are often highly complex. John’s running process, for example, might incorporate simultaneously instances of the quantitative universals

* 1. *m/s motion process*,

*burning 9.2 calories per minute process*

*utilizing 30.12 liters of oxygen per kilometer process*

in addition to qualitative universals such as:

*running process*

*cardiovascular exercise process*

*compression sock testing process*

and so on. (Compare also Figure 10.)



Figure 10: Representations of sample process profiles in the domain of cardiology ([Cardiac Cycle, Left Ventricle](http://en.wikipedia.org/wiki/Cardiac_cycle))

The proposed solution thus threatens a consequence which conflicts with the BFO pairwise disjointness (monohierarchy) principle according to which ontologies should be created on the basis of the assumption of single inheritance, with multiple inheritance polyhierarchies being generated from such ontologies according to need [19, 83].

How, then, is BFO to do justice to the need to annotate data in which speed or other putative qualities are ascribed to processes? The answer lies in the recognition that, when measuring a process, it is in fact always only certain *structural dimensions* of the corresponding whole processes to which the measurement datum directly relates. In the mentioned case these would include structural dimensions pertaining to *speed of motion*, *energy consumed*, *oxygen consumed*, and so forth*.* We shall in what follows call such structural dimensions *process profiles.* The proposal can be summarized as follows: when measuring, we always focus on one such structural dimension of the measured process, and ignore, or strip away in a process of selective abstraction, the other dimensions. When measuring continuants this process of selective abstraction yields representations of qualities (of height, weight, and so on). When measuring processes it yields representations of process profiles.

**Structural dimensions of qualities**

Compare, to fix our ideas, the structural dimensions that we find in the world of continuant qualities. Here, familiarly, we can distinguish in every color quality instance three dimensions of variation, corresponding to three inseparable parts – of hue, brightness and saturation – tied together in a three-sided reciprocal **s-dependence** relation. An instance of color‑hue cannot of its nature exist, except as bound up with some instance of brightness and saturation; instances of brightness and saturation, similarly, cannot exist except as bound up with some specific instance of hue [106, 107, 110], yielding a dependence structure of the sort depicted in [1, 3, 20], where *a*, *b*, *c*, are instances of three distinct universals each such instance capable of being measured separately.



Figure 11: Three-sided reciprocal dependence of the three structural parts of a color instance:   
hue (α), brightness (β) and saturation (γ),

Analogous dependence structures are found also in other sensory domains, for example in the three-sided reciprocal dependence of the pitch, timbre and loudness which are the three structural parts of a tone instance, and similar analyses can be used to describe the structures of cognitive and linguistic acts of a range of different sorts [1, 58, 59].

To say that there are three dimensions of variation within each instance of color or tone is to assert that each such instance includes three structural parts – ‘structural’ in the sense that the parts in question cannot exist except in the context of some whole of the given sort, including those other structural parts upon which they are reciprocally dependent. Such structural parts can be, again, separated out by the observer through a process of selective attention – as when we measure the loudness of successive tones and ignore their timbre or pitch.

**The idea of process profiles**

We can now introduce, by analogy, the idea of a process profile, which is a structural part of a process that is of the sort that can be measured on the basis of selective abstraction. Process profiles are parts of processes, but they are parts not in the sense of ‘pieces’ (separable parts), but rather in the sense of inseparable structural parts. They are entities which cannot exist except in the context of a surrounding whole of a certain specific sort [20].

For processes of each given sort, for example of bodily motion or of human metabolism, there is a repertoire of such process profiles, and it is entities of this sort which are represented in many of the assertions we make about processes. This idea has been advanced already under a different terminology in the studies referenced in [50] on the variables encoded in physiology models used in the study of physiological processes and represented in biophysical measurement data. Two particularly important process profiles for medical purposes are those of respiration rate and pulse rate (documented in the [Vital Sign Ontology](http://www.acsu.buffalo.edu/~ag33/vso.html)).

Process profiles in human development are identified in the Anatomical Transformation Abstraction (ATA) of the Foundational Model of Anatomy, which represents the ‘time-dependent morphological transformations of the entities represented in the taxonomy during the human life cycle’ from prenatal development to post-natal growth and aging’ [43]. These transformations are represented by mathematical equations – thus they involve not everything that is going on in morphological transformations, growth and so on, but rather, again, only certain structural parts.

The key to representing given process measurement data, now, is to create ontologies of the process profiles represented by the measurement charts in the salient domains. In the simplest case, such charts plot values against the time axis, values representing for example qualities of the underlying participants along some given quality dimension. Bruno’s diary of his daily weight measurements represents the weight gain-and-loss profile of his dieting process. His diary of calories consumed represents a complementary process profile; it plots the measured values of successive portions of the food he eats).

Some examples of such quantitative (measurable) process profile types, with associated subtypes, include:

speed profile

constant speed profile

2 mph constant speed profile

3 mph constant speed profile

increasing speed profile

acceleration profile

constant acceleration profile

32ft/s2 acceleration profile

33 ft/s2 acceleration profile

increasing acceleration profile

temperature process profile

constant temperature profile

63°C constant temperature profile

rising temperature profile

falling temperature profile

and so on.

The types and subtypes here are analogous to the types and subtypes of qualities recognized by BFO-conformant ontologies on the continuant side described in the section on determinable and determinate universals above, for example:

length

6 cm length

7 cm length

Here the reader must bear in mind that in both sets of examples the determinate universals in question, while they need to be formulated using a specific unit of measure, are in fact unit-specification independent.

There are also non-quantitative process profiles, such as auditory process profiles (for example that part of a given process of a heart’s beating which consist in the generation of audible signals detectible by a given auditory monitoring device). More subtle examples of non-quantitative process profiles are provided by those cases where symbologies exist for the recording of (the corresponding structural dimensions of) processes of given sorts, for instance the profile of a chess game as captured in one or other of the standard chess notations is a process profile in the sense intended here, as also is the choreography profile of a dance as captured in one or other of the standard choreographic notations.

We shall argue, now, that it is process profiles, and not surrounding whole processes, which instantiate the corresponding (*3.12 m/s*, *9.2 calories/minute*, *63 beats per minute*) universals represented in many different sorts of process measurement data. Thus while such quantitative values are associated *directly* with process profiles, they are associated with the relevant whole processes only in a secondary sense.

**Four-dimensional process shapes**

As Johansson pointed out in his [42], processes involving motion or change of shape or size – any given instance of your walking, for example – must have a certain *determinable 4-dimensional process shape*. But which *determinate* shape is instantiated will of course vary from instance to instance.

Your specific process of walking is not itself an instance of the universal *four-dimensional process shape*. Rather its process shape – this particular instance, the four-dimensional shape profile that belongs to it, and to it alone, as structural part – is an instance of the universal *four-dimensional process shape profile*.

**Rates and beat process profiles**

One important set of process measurement results predicate *rates* to processes, for example the 60 beats per minute rate which is the rate at which John’s heart is beating. The account we proposed is intended to apply not only to heart beat processes, but to beating processes in general, including for example drumming processes, orbiting processes, vibrating processes, and so on.

Every beating process, however, complex, includes what we shall call a beat process profile instance as structural part. Each such process profile instance instantiates determinable beat process profile universals. The beat process profile can, for example, be *regular* (where a rate can be assigned in the simplest possible fashion by dividing the number of cycles by the length of the temporal region occupied by the beating process); but a beat process profile instance can also be an *increasing* beat profile, a *decreasing* beat profile, an *accelerating* beat profile, as well as one or other of many types of irregular beat profile. (Some of the latter, when they are detected through measurement of heart beat processes, may be clinically significant.)

In addition to such determinable universals, there are also determinate universals such as:

3 bpm beat profile

4 bpm beat profile

and so on.

**Recommendation for annotation of simple process measurement results**

Elucidation: We can now elucidate what is meant by ‘process profile’ as follows:

*a* is a process profile means: *a*­ is a process of the sort that can be represented by a chart plotting measurement results on a single dimension against a time axis.

We use ‘can’ to do justice to the fact that process profiles existed even before artifacts of measurement were first created, and even in those places where measurement is *per accidens* not possible, or where appropriate measurement technology does not (yet) exist.

We introduce the relation **process\_profile­\_of** between a process profile and a surrounding whole process.

Elucidation: *a* **process\_profile\_of** *b* holds when

*a* is a *process profile*

& *b* is a *process*

& *a* **proper** **continuant**\_**part\_of** *b*

& *a* and *b* **occupy** the same *temporal region*

Domain: *process profile*

Range: *process*

To assert, now, that a beating process *has rate 4 bpm*, is to assert that there is some beat process profile which is a **part of** this process and which **occupies** the same temporal interval as this process and which **instantiates** the determinate universal: *4bpm beat profile*.

More generally:

‘*p* has F of value *n* as measured in unit *u*’ abbreviates:

there is some *process profile* *p*o such that

*p*o **process\_profile\_of** *p*

& *p*o **instance\_of** the determinate *process profile* type: F with magnitude *n* as measured in unit *u*.

Here to assert that a process profile is of determinate type F with magnitude *n* as measured in unit *u* is to assert that measuring technology for measuring process profiles of determinable type F in units *u* would yield output: *n* when applied under ideal conditions to a process profile of the given process profile type.

Should we recognize States as Static Process Profiles?

**Comparing Qualities and Comparing Process Profiles**

A further issue that we can now address is that of data involving comparison of process profiles (for example to the effect that one process is quicker, or more intense, or of higher frequency, than the other process. Here, too, it is useful to begin with the counterpart case on the side of qualities.

**Comparative qualities**

For a given determinable quality universal Q, we employ ‘DSU(Q)’ as an abbreviation for ‘the determinate sub-universals of Q’. For example if Q is the quality universal *length*, then DSU(Q) comprises such determinate quality universals as: 1 cm-length, 1.5 cm-length, 2 cm-length, and so on. Again, quality universals are referred to here in a way that involves specification of a unit of measure; however, the universals themselves are clearly independent of such specification as the same process profile universal could be reformulated in terms of a different unit of measure.

*1.5cm length* is a universal; a range, say *between 1-2 cm length* is also a universal. These universals are in a sense social constructions, reflecting certain decisions as to what ‘cm’, for example, means. But they are universals nonetheless, and instances of these universals existed long before the relevant social constructions were decided upon.

Since the qualities in DSU(Q) can here be ordered linearly in reflection of the real number measures used to described them, we can define ‘shorter-in-length than’ in terms of ‘less than’ for real numbers. In this sense the structure of DSU(Q) explains how length qualities relate to each other.

**Comparing process profiles**

And now the parallel case on the side of occurrent side can be described as follows. For a given determinable process profile universal P, we employ ‘DSU(P)’ as an abbreviation for ‘the determinate sub-universals of P’. For example if P is the process profile universal *regular beat*, then DSU(P) comprises such determinate process profile universals as: 1beat per minute (bpm), 1.5 bpm, 2 bpm, 3 bp(90 seconds), and so on. Again, process profile universals are referred to here in a way that involves specification of a unit of measure; however, the universals themselves are clearly independent of such specification.

And again: DSU(P) is ordered linearly, so that there is an isomorphism from  DSU(P) to the real numbers, and we can define ‘beats faster than’ accordingly in terms of ‘greater than’ for real numbers, and there is a sense in which the structure of DSU(P) explains how beat processes relate to each other in terms of faster and shorter.

For many process profile types we can distinguish an associated static (or ‘null’) process profile type. Thus for example a null beat profile is a beat profile in which there are zero beats per interval of time; a null speed profile is one in which speed is zero; a null acceleration profile is one in which acceleration is zero, and so on.

**Summing Process Profiles**

The auditory process profile of the morse code signal for ‘SOS’ has the following structure:

|  |
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| . . . – – – . . . |

This is built by concatenation out of successive basic auditory process profiles of three types, called dots, dashes, and spaces (null auditory process profiles), respectively. Between each dot or dash within a single letter there is a single space; between successive letters there are three spaces. Clearly, the process profiles here can be combined in arbitrary strings. If one morse code string is followed by another, then the auditory process profile of their sum is equal to the sum of their respective auditory process profiles. The heart beating process is the sum of two mutually dependent systolic and diastolic processes (along the lines depicted in ).

There seems to be a general law for process profiles:

Given any processes *p*1*, … p*n which share a specific type T of process profile and which do not overlap in time:

T-process-profile (*p*1*+…+p*n) = T-process-profile(*p*1) + … + T-process-profile(*p*n)

Note that, in the morse code and similar cases, summation of process profiles has an exact counterpart in the linear composition of *generically dependent* information artifacts (alphanumeric strings) on the continuant side.

**Qualitative change process profiles**

Suppose an entity has a quality – such as temperature – which changes with time. Then there is a process profile which is the history of these changes. Thus we have two subtypes of process profile which we can rather easily define: *rate process profiles* and *qualitative change process profiles.*

**Planning and process profiles**

Many of the process profiles discussed above have been quantitative in nature – they are processes of the kind which are represented in charts with data plotted against the time axis along axes denominated numerically. But there are also qualitative process profiles, for example as illustrated in the domain of plan specifications such as experimental protocols or clinical guidelines. Plan specifications are, roughly, specifications of conditionally nested process profiles.

## 3.2 Spatiotemporal region

Elucidation: A *spatiotemporal region* is an *occurrent* entity that is **part** of spacetime.

‘Spacetime’ here refers to the maximal **instance** of the universal *spatiotemporal region.*

Examples: the *spatiotemporal region* **occupied** by a human life, the *spatiotemporal region* **occupied** by the development of a cancer tumor, the *spatiotemporal region* **occupied** by a *process* of cellular meiosis.

Axiom: All **parts** of spatiotemporal regions are spatiotemporal regions.

Axiom: A spatiotemporal region can be **occupied\_by** a process.

Axiom: Each spatiotemporal region **projects\_onto** some temporal region

Axiom: Each spatiotemporal region **projects\_onto** somespatial region **at** t

The projection relation will need to be defined in each case in terms of the frame employed.

Axiom: Every *temporal* or *spatiotemporal region* *r* is such that *r* **occupies** *r.*

Axiom: Every *occurrent* **occupies** some **spatiotemporal region.**

Theorem: Every *occurrent* **occupies** some *temporal region*.

Trivially, every *spatiotemporal* or *temporal region* **occupies** itself.

## 3.3 Temporal region

Given a temporal reference frame R, we can define ‘timeR’ as the maximal **instance** of the universal *temporal region*.

Elucidation: A *temporal region* is an *occurrent* entity that is **part** of time as defined relative to some reference frame.

Axiom: All parts of temporal regions are temporal regions.

A temporal region is an *occurrent entity* upon which a process can be projected. Temporal regions are introduced in BFO to provide a basis for consistent representation of temporal data, for example as described in [68].

### 3.3.1 Zero-dimensional temporal region

Elucidation: A *zero-dimensional temporal region* is a temporal region that is without extent.

Examples: a temporal region that is occupied by a process boundary; right now; the moment at which a finger is detached in an industrial accident; the moment at which a child is born, the moment of death.

Synonym: temporal instant.

### 3.3.2 One-dimensional temporal region

Elucidation: A *one-dimensional temporal region* is a temporal region that is extended.

Example: the temporal region during which a process occurs.

A temporal interval is a special kind of *temporal region*, namely one that is self-connected (is without gaps or breaks).

## The precedes relation

See discussion in [16].

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|  |

**BFO Relations**

Need to deal with all the RO relations

New primitive relations:

Projects\_onto

What else?

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