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| Basic Formal Ontology 2.0 |
| DRAFT DOCUMENT |
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**Summary of most important changes**

**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**

For example between the disposition of a key to open a lock, and of the lock to be opened by the key.

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

In BFO 1.1 the assumption was made 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 embraces the view that when we talk about a 'surface' there, then we are talking about something fiat.

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The focus in discussion of boundaries is now on fiat boundaries, which means: boundaries for which there is no assumption that they coincide with physical discontinuities. Boundaries thus become more closely allied with spatial regions.

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

To assert, for example, that this 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 the determinate universal: 72 beats per minute process.

* **Still missing**

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

Treatment of syntax for attributive classes and abbreviations.

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

Portions of energy.

**Co-Authors/ Acknowledgments**

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**References**

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

Use of **boldface** indicates a label for an **instance-level relation.** Use of *italic* indicates a BFO term.

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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 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. The application of a formal ontology such as BFO brings benefits of reuse, supporting 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 recognized by BFO and we provide a summary of the associated relations.

To specify these conditions we will utilize a semi-formalized English that has approximately the expressivity of first-order logic (FOL) with identity. In a future document we will provide a formalized treatment of these specifications using FOL; a parallel effort is also underway using OWL.

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 time and space, respectively. We use ‘*A*’, ‘*B*’, ‘*C*’, ‘*P*’, etc. for universals and attributive classes. We use ‘**part\_of**’ and similar **bold-face** expressions to express relations involving instances, and ‘*part\_of*’ and similar *italicized* expressions to express relations exclusively involving universals and attributive classes.

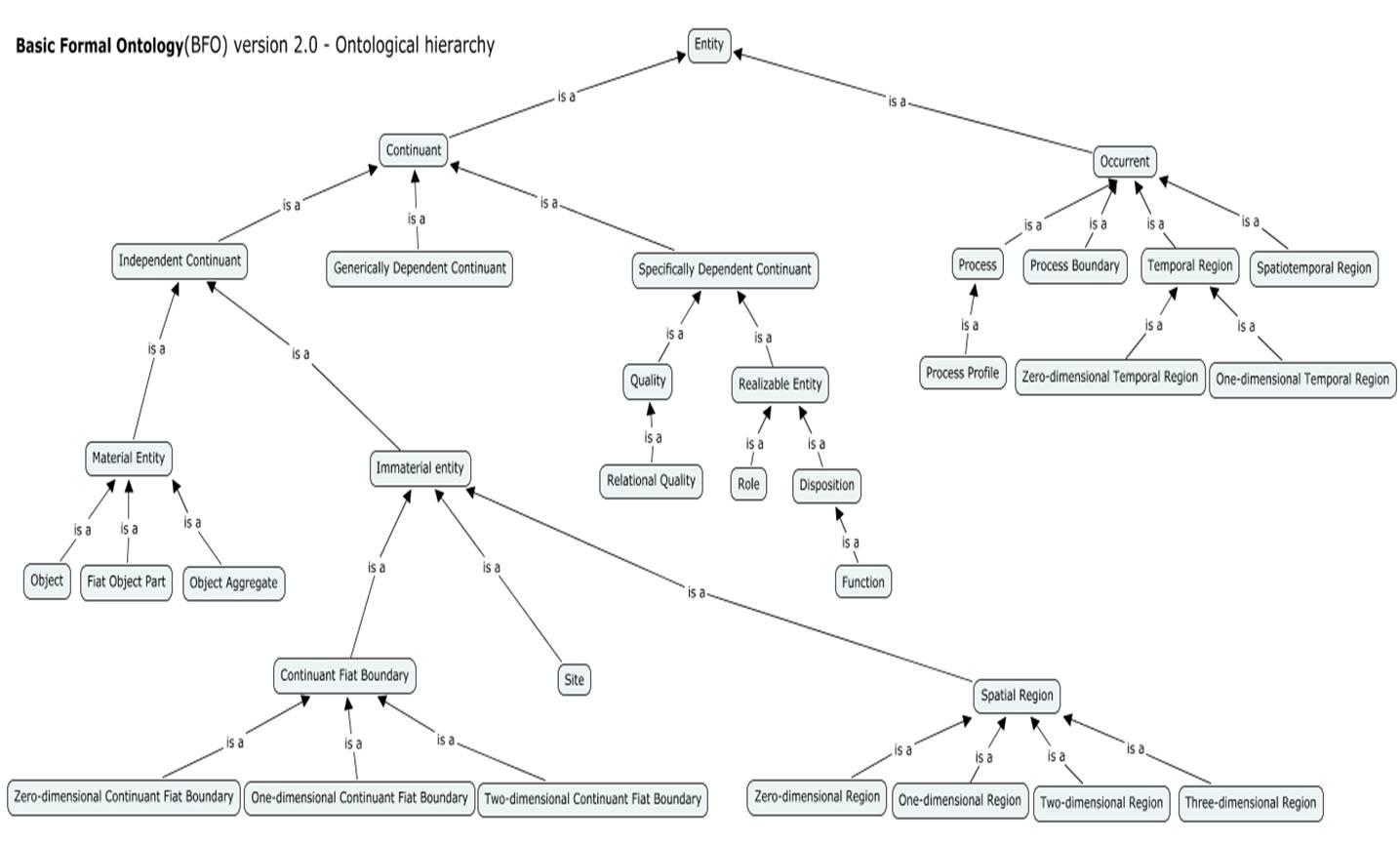


Figure : BFO 2.0 *is\_a* Hierarchy. Not included here: *class, universal*

# 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 ‘type’ see [25,19]

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

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

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

Type: *human heart* *part-of*type: *human body*

Type: *human heart beating process has\_part* type: *beat profile*

Your heart **instantiates** type: *human heart.*

Relations of these sorts are not BFO:*entities* (to see why not, see the discussion of the Bradley regress in [20]). However, there are entities, such as relational qualities (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 ‘**is\_a**’ or ‘*part of*’) to express relations 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. The former 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.

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

Axiom: All entities are either particular or universal (and not both). [22, 19, 23, 71]

In this document we concentrate primarily on entities which are particulars and on the relations between particulars elsewhere called ‘instance-level relations’ [16]. That is, the categories discussed below are in every case categories of particulars (their extensions are groups or collections of particulars in reality). In a later version of this document we will provide more details of BFO’s treatment of universals, as employed *inter alia* 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.

We use ‘universal’ and ‘type’ as synonyms.

Elucidation: A *category* is a formal universal, of the sort to which BFO terms refer, as contrasted with a material universal, which is the sort of universal referred to in one or other domain ontology. BFO:*fiat object part* is a category in this sense; not however *organism* or *weapon*, which are *material universals*.

**Universals and classes**

Universals have **instances**, which are in every case particulars (entities located in space and time). Universals also have extensions, which are the classes (in the sense of ‘set’) of their **instances**. (Thus extensions are one special sort of class. These and related technical terms of ontology are elucidated further in [19, 25, 17].)

The terms in BFO and in the domain ontologies defined on its basis consist of terms representing what is general in reality. This means: terms employed by scientific theories in the formulation of general truths [19], together with analogous terms employed in domains such as engineering, commerce, administration and intelligence analysis, and including also those highly general organizing terms (such as ‘object’ or ‘process’) which are required to BFO is intended to be; thus it is designed to work not only with entities within the province of the natural sciences but also with social and psychological entities such as contracts and marriages, relations of ownership and friendship, poems and experimental protocols.

In all of these areas 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 owned by the Emperor
* tuberculosis diagnosed on a Wednesday
* surgical procedure performed on an un-insured patient
* [disease mentioned in the Koran](http://corpus.quran.com/concept.jsp?id=disease).

We refer to such groups as ‘attributive classes’ (labeled ‘defined classes’ in [25]), since whether or not an entity is an element of such a subgroup is a product of external attribution; it is a matter of fiat [8]. Attributive classes are subclasses of the extensions of the universals in terms of which they are defined.

Terms referring to such attributive classes often need to be included in domain ontologies. The terms in question should then be *defined* as children of the lowest-level universal or genus (here: *animal*, *tuberculosis*, *surgical procedure*, and *disease* respectively), and they should be marked in the ontology by means of some annotation identifying them as attributive classes [19].

(We distinguish both groups of terms from mere abbreviations, discussed below.)

Attributive classes are distinguished from aggregates(see the section on BFO:*object aggregate* below) in that the former are analogous to sets in the mathematical sense, where the latter are continuant entities which are mereological sums of other, simultaneously existing continuant entities. Thus some attributive classes include entities that exist at different times. We shall say that attributive classes have elements, where aggregates have members.

Because attributive classes are defined in terms of universals, the relation of **elementhood** is in some ways analogous to that of **instantiation**. Because aggregates are mereological wholes, the **membership** relation (see below) is a specialization of the **part\_of** relation.

**Attributive role classes**

One major set of examples of attributive classes involve roles, and ontologies developed for administrative purposes may consist entirely of representatives of classes of this sort. Thus ‘professor’ (defined as: a *human being* who has the *professor role*) denotes an attributive class, and so also do ‘nurse’, ‘student’, ‘colonel’, ‘taxpayer’, and so forth. An ontology of employment positions in an organization might be built out of terms referring to attributive classes for simplicity’s sake, but these terms should be *defined* in terms of roles nonetheless, in order to do justice to the fact that individuals belong to attributive classes such as *professor*, *student*, *dean*, only during certain phases in their lives.

Terms designating attribute classes may thus also be referred to as ‘phase sortals’. The correct form for defining phase sortal expressions designating attribute classes and involving reference to roles is as follows:

student(John, *t*)

is a shorthand form of:

John **element\_of** *attributive role class:* *student* **at** *t*,

where, for each role universal *B*,

Definition: *a***element\_of** *B* **at** *t* =Def. *a* **has\_role** *B* **at** *t*

**Attributive historical classes**

Attributive classes also include what we will call historical classes – classes whose elements satisfy some historical condition, for example: *biological father*, *person identified as candidate for clinical trial #2056-555*, *person who has visited Pittsburgh*, *person* *who is signatory of Form 656-PPV,* or *painting by Leonardo da Vinci.*

The correct form of definition can be illustrated for the ‘biological father’ case as follows:

biological\_father (*a*) = Def. *a* instantiates the universal *human being*

& *a* is male

& there is some zygote *b*

& there is some child *c*

& there is some process of fertilization *d*

& *b* is the output of*d*

& *a* **agent\_of** *d*

& *c* **=** *b*.

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 is designed 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].

A future version of this document will provide information on how terms representing attributive classes can be used to simplify the definitions created in BFO-conformant ontologies.

Attributive class terms may be formed *ad libitum*, but only if the genus in terms of which they are defined is a material universal.This restriction implies that terms referring to attributive classes must be distinguished from mere abbreviations – for example ‘bodily feature’, which is used in the [Ontology for General Medical Science](http://code.google.com/p/ogms/) (OGMS) as an abbreviation for: ‘either bodily constituent or bodily quality or bodily process’.

## 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:

Elucidation:

*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: 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.

Elucidation:

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

What counts as a type in a given domain is a matter for domain ontologists to determine. 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 collections of particulars and on the basis of multiple different sorts of information. 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.

## The is\_a relation

It is commonly assumed in the literature of knowledge representation that the *is\_a* relation can be identified with the subset or set inclusion relation with which we are familiar from mathematical set theory. **Instance\_of** functions on this reading as a counterpart of the usual set-theoretic elementhood relation. Unfortunately, set-theoretic inclusion is a much more inclusive relation than the *is\_a* relation between types because it admits cases such as:

tennis ball *is\_a* entity not containing a violin as part

pizza *is\_a* entity that is either a pizza or a bottle of wine.

Moreover, because sets are timeless entities, the identification of *is\_a* with set-theoretic inclusion also fails to take account of time, so that when applied to classes of continuants it yields false positives such as *adult is\_a child* (because every element of the set of *adults* is also an element of the set of *children*).

On the basis of our distinction between universals and classes, above, we can now see how these problems are resolved. The relation *is\_a* holds exclusively between universals. The *subclass* relation holds exclusively between classes. When formulated in OWL, universals are in effect identified with those classes which are their extensions; hence the difference between *is\_a* and *subclass* becomes invisible. However, when building ontologies the difference should be taken into account nonetheless; most simply by including in the asserted part of the ontology only those relations which hold between universals, and allow other sorts of relations to be inferred by the reasoner [19].

## The element\_of relation

Elucidation: the **element\_of** relation between a class and its elements is to be understood in the usual set-theoretical sense.

Domain: entity.

Range: class

Examples: Patrick Hayes is an element of the class of human beings; Julius Caesar is an element of the class of human beings; John’s oophorectomy, performed yesterday, is an element of the class of oophorectomies.

## The subclass relation

Definition: *a* **subclass** *b =*Def. *a* is a class & *b* is a class & all elements of *a* are elements of *b*

Domain: class

Range: class

Examples: the singleton class {Patrick Hayes} is a subclass of the class of human beings; the class of human beings is a subclass of the class of mammals; the class of oophorectomies performed in Pittsburgh is a subclass of the class of processes involving more than one human being as participant.

**Inclusion of class, element\_of and subclass in BFO**

We have provided some documentation of and *class*,**element\_of** and **subclass** in the above. However, we do not include these in BFO, just as we do not include ‘number’. The reason is that these terms are already well-defined in other, familiar and well-understood resources.

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

We distinguish between *terms*, which are labels for universals and attributive classes, and *relational expressions*, which are labels for relations [16].

Definitions are statements of necessary and sufficient conditions for the relation to hold which follow the normal rules of logic.

Definitions of terms are required to be always of the form:

an *S* = Def. a *G* which *D*s

where ‘S’ (for: species) is the term to be defined, ‘G’ (for: genus) is the immediate parent term of ‘S’ in the relevant BFO-conformant ontology. ‘D’ (for: differentia) provides the species-criterion; that is, it specifies what it is about certain G’s which makes them S’s.

Terms in BFO conformant domain ontologies are defined using species-genus definitions in which the genus is below either *continuant* or *occurrent* in the BFO hierarchy*.* Attributive classes are defined by using as genus any universal from a BFO-conformant domain ontology.

Definitions for relational expressions are statements of necessary and sufficient conditions for the relation to hold which follow the normal rules of logic. Examples are provided below.

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

We have employed in the above the dichotomy between continuant and occurrent ontologies, which forms the central organizing axis of the BFO ontology. We can describe this dichotomy as follows, following Zemach [60] (and simplifying somewhat), 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 life of your table top as contrasted with the life of your table legs, and so forth)
* continuant entities, which Zemach calls ‘things’, and 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.

As Zemach puts it:

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. Any filled chunk of spacetime is an event. [60, pp. 233 f.]

The second ontology consists of continuant (formerly ‘BFL: SNAP’) ontologies. This

is the one we use most and that comes almost naturally to us. … The entities it recognizes are continuous in time and bound in space. We may call them *continuants in time* (CTs) or, simply, *things.* We normally regard almost every object we come across as a CT: this chair, my pencil, my friend Richard Roe, the tree around the corner, the fly that crawls on the page. This is not to say that all these cannot be re-categorized and regarded as events. They certainly can be. ‘This chair’, e.g., can be used to name an NC [non-continuant], and some philosophers do use it in this way: they say that they see a temporal slice of the chair and sit on another temporal slice of it. But this is not the most common way of using ‘this chair’ or ‘Fido’. Normally we *do not* regard chairs and dogs as NCs. We consider them to be not events but a very different kind of entity, and the names we give them, in our language, obey a grammar which is fundamentally dissimilar to the grammar of names of events. A thing, I said, is bound in space. 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]

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

Elucidation: *a* is a continuant means: *a* is an entity that is bound in space.

Elucidation: *a* is an occurrent entity means: *a* is an entity that is bound in time.

## 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, and parthood as it obtains between occurrents, as follows (where are dealing, in each case, with relations among particulars):

Definition: *a* **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 **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 Earth exists

Definition: *a* **part\_of** *b* =Def. *a* is a part of *b* & *t* is a time & *a* and *b* are continuants

Domain: occurrent

Range: occurrent

Examples: Mary’s 5th birthday **part\_of** Mary’s life; the first set of the tennis match **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\_part\_of** *b* **at** *t* =Def. *a* **part\_of** *b* **at** *t* & *a* and *b* are not identical

For occurrents:

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

**BFO relations defined in terms of part-of**

for continuants:

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

for occurrents:

Definition: *a* **has\_part** *b* = Def. *b* **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]. For instance-level relations should inverses can be unproblematically defined. (Not however for type-level relations [16].)

# 2. Continuant

The BFO continuant ontology (formerly called ‘SNAP-BFO’, as contrasted to the ‘SPAN-BFO’ occurrent ontology) 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 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. *Continuants*, as BFO understands them, are three-dimensional entities (entities extended in three spatial dimensions); *occurrents* are four-dimensional entities (entities extended also in the dimension of time).

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 a non-reductionist representation of reality as we understand it from the best available science. 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 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 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])

The four dimensions of the spacetime continuum are not homogeneous – rather there is one time-like and three space-like dimensions – and this suffices for the purposes of BFO in dividing reality in a way that distinguishes spatial and temporal regions, and sees continuants as being located in the former as they persist identically through time. What BFO on the other hand needs to do justice to is the fact that there are multiple ways of dividing up the spacetime continuum into spatial and temporal regions that BFO postulates, corresponding to the multiple frames of reference that might be used by different observers. We return to this issue when we address the issue of regions below.

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 *one-dimensional temporal region* (some temporal interval) during which *a* exists. (See the discussion of the relation **located\_at** below.)

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.

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 [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*.*

If *b* is such that *a* **s-depends on** *b*, then if *b* ceases to exist, so also does *a*. The ceasing to exist is here a matter of necessity (thus 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, on 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.)

**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 include:

* causal dependence (e.g. between measurable qualities such as pressure and temperature that vary in tandem with each other), and the 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 fiat 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 **parts** or on anything it is **part** of.

As we shall see when we consider the **parts** of *qualities* such as color and tone below, the **parts** of a dependent entity may **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.

A *dependent continuant* (s-dependent continuant entity) cannot migrate from one independent continuant bearer to another. An *occurrent* (every *occurrent* is s-dependent on the independent continuants who participate in it) 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 *occurrent* **s-depends** on all of these players nonetheless, since **s-dependence** for *occurrents* is not indexed by time.

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* e.g. on some organism
* an **instance** of *seeing* (a relational process) 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]
* three-sided reciprocal **s-dependence** of the hue, saturation and brightness of a color [45]
* 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 the pitch of a tone, for example, without changing the string of the banjo upon which the tone depends.

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), multiple dependence relations will obtain, 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 historical attributive classes 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.

## 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 **s-dependent** entities 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.**

Thus every *material entity* is localized in space.

Every *material entity* can move in space.

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

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



Figure : 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 this document). 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.

We are exploring the formalization of a view according to which *material entities* may have *immaterial entities* as **parts** – including the *entities* identified below as *sites*; for example, according to the FMA, the interior (or ‘lumen’) of your small intestine is a part of you.

#### 2.1.1.1 Object

BFO rests on the presupposition that at meso- and macroscopic scales reality is to a large degree made up of 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*. Clearly not all material entities form separated or separable natural units in this way (see Figure 3 and [12]).



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

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 called ‘*objects*’ in BFO. Such units are sometimes referred to as ‘grains’ [73], 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.

**Preamble on the strategy for elucidation of ‘BFO:*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* 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 aggregates of microparticles which form parts of such causally structured units for limited periods in their existence may survive the loss of causal unity for example as this occurs through 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 a part *b* in the interior of *a* at *t* larger than a certain threshold size (which will be determined differently from case to case, depending on factors such as porosity of external cover) 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 serves as 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 granularity threshold from entering from the outside or escaping from the inside [67].

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 overall sum of forces strong enough act to hold the object together relative to the strength of attractive or destructive forces in its ordinary environmental neighborhood. (None of us remains objects very long on the face of a neutron star, but luckily that isn’t our ordinary 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* (*a* **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

**Definition of BFO:*object***

How, now, are we to define ‘object’ in BFO? Note, first that we cannot simply assert that an entity is an object if and only if it is maximal relative to some causal unity criterion. This is because, as we shall see below, objects may have other 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 4 – may be such that there are material entities crossing their boundaries which belong determinately to neither cell. Something similar may obtain in certain cases of conjoined twins (see below).



Figure : [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* may also have immaterial parts (the lumen of your gut). [34]

Axiom: Objects retain their objecthood for as long as they exist.

A human body continues to exist even after being buried in a pile of cement. A watch that has been taken apart for repair ceases to exist for as long as it is disassembled.

Some objects may change type from one time to the next (a fetus becomes a baby, which in turn becomes a child).

**Conjoined twins**

Whether each one of a pair of conjoined twins is or is not an object is not a trivial question, and we recommend that the treatment of this case ontologically should be treated as an experimental matter, with different alternatives tested in use to see which yields the most coherent global solution. Tentatively, we assume that 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 material entity here is the whole which they together form; accepting each twin as an object, however – thus as an instance of the material universal *human being* – causes no problems for the definition 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 **parts**.

More formally:

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

for all *x* (*x* **part of** *a* **at** *t* iff *x* overlaps some *o*i **at** *t*)

An entity *a* is an object aggregate *a* is a 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 parts of an aggregate are called its **members**.

## Relation of membership

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

Definition: *a* **member\_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.*

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

Domain: entity in category X

Range: aggregate of X

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 there 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. We will provide further material on this in a later version of this document.

#### 2.1.1.3 Fiat object part

*a* is a *fiat object part* = Def. *a* is a *material entity* that is a **proper part** of an *object* and that is not an *object.*

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

Examples of *fiat object parts*: 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.

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, 8], 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. 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 of potentially problematic cases for the trichotomy of *object*, *fiat object part* and *object aggregate* include: a mussel on (and attached to) a rock, a slime mold, a slice of cake, 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.

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.

However it is clear that BFO will in due course need to recognize other sub-universals of *material entity*, in addition to *object, object aggregate* and *fiat object part* – for instance: *aggregate of fiat object parts* [29]. Thus BFO:*material entity* 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 the treatment of cavities in the FMA [43, 44, 34, 35].

*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 size, shape and location as their material hosts move (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 **parts** of their material hosts. Immaterial entities under both 1. and 2. can be of zero, one, two or three dimensions.

We define:

*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

*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):

* fiat boundaries which closely coincide with the material surfaces of material entities or with other physical discontinuities; when we program a telesurgical device for purposes of targeting an incision through the surface of your skin, then we might represent this surface as a two-dimensional plane (for the purposes of the device, the differences between this two-dimensional fiat plane and the actual surface fall below the threshold of granularity [11])
* 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.

##### 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.

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).

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.

##### 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’ here and in what follows is to be understood in the following (topological) sense; thus to assert that an entity *a* is self-connected is to assert that 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.

Examples: see Table 1.

|  |
| --- |
| Table 1. Fragment of Foundational Model of Anatomy  [http://fme.biostr.washington.edu:8080/FME/images/minus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=9&ec=0#9)Anatomical boundary entity                     [http://fme.biostr.washington.edu:8080/FME/images/minus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=11&ec=0#11)Anatomical surface                          [http://fme.biostr.washington.edu:8080/FME/images/plus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=14&ec=1#14)Bona fide anatomical surface                          [http://fme.biostr.washington.edu:8080/FME/images/minus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=15&ec=0#15)Anatomical plane                               [http://fme.biostr.washington.edu:8080/FME/images/minus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=16&ec=0#16)Anchored anatomical plane                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifCraniocervical plane                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifCervicothoracic plane                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifThoraco-abdominal plane                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifOccipital plane                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifInterspinous plane                                    [http://fme.biostr.washington.edu:8080/FME/images/plus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=23&ec=1#23)Plane of anatomical orifice                                    [http://fme.biostr.washington.edu:8080/FME/images/plus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=24&ec=1#24)Anatomical transverse plane                                    [http://fme.biostr.washington.edu:8080/FME/images/plus.gif](http://fme.biostr.washington.edu:8080/FME/menu.jsp?id=25&ec=1#25)Plane of anatomical junction                                    http://fme.biostr.washington.edu:8080/FME/images/leaf.gifSagittal midplane of body |

2.1.2.1.4 Site

*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, the hold of a ship, the lumen of your gut, 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 in part by fiat boundaries, as for instance the Mont Blanc Tunnel is bounded by fiat boundaries 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, 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 organisms anatomical *Bauplan* [43, 44]*.*Thus a cavity formed by a swallowed drug-capsule that is half-filled with powder is not a **part** of the organism.



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

Figure : Examples of types of site

#### 2.1.2.3 Spatial region

On why the FMA includes terms for surfaces, lines, and points:

Even without presenting the deﬁnitions of these classes and listing their deﬁning differential attributes, the logic and rationale for establishing these high level abstract classes should become apparent. 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]

We recommend that users of BFO:*spatial region* specify the coordinate frame which they are employing. In a later version of this document we will specify the way in which this should be done. Spatiotemporal regions, in contrast, are independent of reference frame.

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). Such coordinate frames can be associated with a Newtonian or a relativistic frame of reference. The reference frame might be defined in relation to a moving object such as the earth, in which case the corresponding spatial regions move with the movement of the earth. However, these spatial regions are at rest relative to their coordinate frame. 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.

Elucidation: A *spatial region* is a *continuant* entity that is **part** of space.

‘Space’ here refers to a largest **instance** of the universal *spatial region* as defined in relation to some specific reference frame.

Axiom: All **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 region which they occupy at any given time in the sense that (1) the former move when their material host moves, and they change shape or size when their material host changes shape or size; (2) the latter must be specifiable in terms of some system of coordinates, and they are by definition at rest relative to the pertinent coordinate frame.

##### 2.1.2.3.1 Zero-dimensional spatial region

Elucidation: a point in space.

##### 2.1.2.3.2 One-dimensional spatial region (aka spatial line)

Elucidation: a continuous line stretching from one point in space to another

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

##### 2.1.2.3.3 Two-dimensional spatial region (aka spatial volume)

Def. a self-connected spatial region of two dimensions.

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

##### 2.1.2.3.4 Three-dimensional spatial region

Def. a self-connected spatial region 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 cavities in the interior of *r.*

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

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

## The located\_in relation

Definition: a**located\_in** b **at**t = Def. a and b are independent continuants, and the region occupied by a is a (proper or improper) **part**\_of the region occupied by b.

Domain: independent continuant

Range: spatial region

Examples: your heart **located\_in** your body; this stem cell **located\_in** this portion of bone marrow; this portion of cocaine **located\_in** this portion of blood.

Axiom: **Located\_in** is transitive

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

if *a* **part\_of** *b* **at** *t*, then *a* is **located\_in** *b* at *t.*

**Chaining rules**

for all material entities *a*, *b*, and *c*: if *a* **part\_of** *b* **at** *t* & *b* **located\_in** *c* **at** *t*, then *a* **located\_in** *c* **at** *t*

for all material entities *a*, *b*, and *c*: if *a* **located\_in** *b* **at** *t* & *b* **part\_of** *c* **at** *t*, then *a* **located\_in** *c* **at** *t*

## Relation of containment

Elucidation: *a* **contained\_in** *b* **at** *t* means:

*a* is a *material entity*

& *b* is a *site*

& for all *spatial regions r*1*, r*2, if *a* **located\_at** *r*1 **at** *t* and *b* **located\_at** *r*2 **at** *t*, then *r*1 **part\_of** the convex closure of *r*2

& if *b* is moved a sufficient distance in space then this will cause *a* to be moved also in virtue of its position in relation to *b*.

To see why this last condition is needed see [52]. The condition is designed to exclude cases where, for example, an object is placed in the hole of a donut.

A *site* is something in which a *material entity* can be contained.

Note that there are other sub-universals of *immaterial entity*, in addition to *site*, *continuant fiat boundary* and *spatial region*. For instance: *aggregate of sites*, *aggregate of spatial regions*. The part of space occupied by a pair of non-adjacent cubes is not a spatial region but an aggregate of spatial regions.

All parts of spatial regions are fiat parts, since no boundaries of spatial regions are physical discontinuities.

## 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.

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.

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.Intuitively inherenceholds only where the s-dependent entity or entities involved have what was traditionally referred to as a ‘lesser degree of being’ than the associated independent continuant bearers (as a color has a lesser degree of being than a colored thing).

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* at some time, then *a* need not be a bearer of *b* at all times, since *b* might cease to exist.

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

**No dependence of higher order**

BFO does not recognize dependence of higher order; thus there are no qualities of roles; no dispositions of qualities; no functions of dispositions (and no processes in which processes themselves change – see the section on Process Profiles below). Rather, in all such cases, the recommendation on developers of BFO-conformant ontologies is to seek a relevant relatumin the underlying independent continuant bearer (the *thing*  or *res*). Thus the following axioms hold:

Qualities of qualities are qualities of the underlying bearer.

The shape of the redness on John’s arm is not a quality of the redness, it is, like the redness itself a quality of a certain 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*.

Axiom: if *a* **s-depends on** *b*& *b* **s-depends on** *c* then *a* and *b* are reciprocally **s-dependent** on each other.

John’s *role* of being married to Mary is dependent on Mary’s *role* of being married to John, and both are dependent on the *object aggregate* comprising John and Mary as **parts**.

### 2.2.1 Quality

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.

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.

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.

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

For some qualities, e.g. surface color, **s-dependence** is not on the material bearer but rather on its surface.

*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, shape and location.

#### 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* & *b* and *c* have no **parts** in common.

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

Compare also the discussions of relational processes and of comparatives, below.

### 2.2.2 Realizable entity

Elucidation: To say that *a* is a realizable entity = Def. *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 its bearer participates in *p*.

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

#### 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.

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

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

**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. Most of the roles we here distinguish 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 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 disposition to develop 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 *independent continuant* in which it **inheres**.

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 – instantiated by those processes in which it 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.

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

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. Examples include:

* 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.

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).

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 can distinguish two varieties of function, artifactual function and biological function. These are not subtypes of BFO:*function* however, since the same function – for example: to pump – can exist both in artifacts and in biological entities. Rather the relevant difference in type exists here on the side of the respective bearers.

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*

The above are offered to the user for purposes of convenience only.

**Material basis**

Dispositions (and thus also functions) are introduced into BFO in order to provide a means for referring 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 bearer. Dispositions exist, however, 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:

*a* **has\_material\_basis** *b* **at** temporal interval *t* means:

*a* is a disposition

& *b* is a *material entity*

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

& *b* **part\_of** *c* **at** *t*

& *c* **has\_disposition** *d***at** *t* because *b* **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 (generic dependence on dependent continuants to be documented in the future)

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*.

Example: 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 what we might call 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 the very same pdf file 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

*a* **concretizes** *b* **at** *t =* Def. *a* is a specifically *dependent continuant* & *b* is a *generically dependent continuant* & for some *independent continuant 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,* a **concretization** of *a*, 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 its *score*, or 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. 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, plan specifications for her various team members. These plan specifications are concretized in the minds of the team members as plans for carrying out corresponding subactivities within the experiment. The experiment itself is a *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. 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.

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 separating billiard balls or zebrafish or planets by clear spatial gaps. Lives of organisms are process units, but they too unfold in a continuous series from other pre-life 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).

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.

## Relation of temporal parthood

We introduced above the relation **part\_of** for occurrents. We can now define in its terms the sub-relation **temporal\_part\_of** which holds between two occurrents when the former is a phase or subprocess of the latter:

Elucidation: To say that *a* is a **temporal\_part\_of** *b* is to say that *a* **part\_of** *b* & *a* and *b* are *occurrents* & for some *spatiotemporal* or *temporal region r*, *a* **occupies** *r* & *b* **occupies** a region including *r* as **part**.

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.

Examples: the life of an organism, a surgical procedure, the spatiotemporal setting occupied by a process of cellular meiosis, Van Gogh’s life, the spatiotemporal region occupied by the development of a cancer tumor.

Since *temporal regions* are **temporal parts** of themselves this means, in particular, that *zero-dimensional temporal regions* 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**

*spatiotemporal region* **projects\_onto** *temporal region*

*spatiotemporal region* **projects\_onto** *spatial region* **at** *t*

## 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.**

Trivially, every spatiotemporal or temporal region occupies itself.

**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)’.)

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. If, for example, you experienced the Second World War, then the Second World War is in this sense a part of (or better: is involved in) your history. 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.

A revision is being contemplated for a future version of this document 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.

## 3.1. Process

*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, the process of sleeping, the process of cell-division, a beating of the heart, the process of meiosis, the course of a disease, the flight of a bird, the 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: John seeing Mary [1, 4], a moving body’s crashing into a wall.

### 3.1.1 Process boundary

*p* is a *process boundary* = Def. *p* is an *occurrent* entity which separates one *process* from another immediately succeeding *process* & **occupies** a *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

**Has\_participant** is a sub-relation of **s-dependence**, which satisfies:

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

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

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

Axioms: if *a* **has\_participant** *b***at** *t* then *a* **s-depends on** *b*

Generically dependent entities participate in processes – for example when a file is copied from one hard drive to another – only *via* their specifically dependent concretizations.

### 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* that is occupied by this process (trajectory of the motion)
5. the speed, referred to by means of
6. an expression (information artifact, thus a BFO:*generically dependent continuant*) such as ‘3.12 m/s’.

Items (1)-(4) and (6) correspond directly to readily identifiable BFO categories. In regard to item (5), it has been proposed that BFO recognize a new category of *process quality*, the counterpart on the occurrent side of qualities of continuants. To see the problems with such an approach, consider the following scenario, which is designed to illustrate the contrasting logico-ontological orders which rule on the continuant (three-dimension) and occurrent (four-dimensional) side of BFO [14, 21, 30, 31, 32, 33].

Imagine, first, an *independent continuant*, John, an *object*, who, on a certain day, either does or does not go on a one-month diet. In the former case his 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 individual object* as he was on the day in question.

In the case of a process, in contrast, no parallel scenario is imaginable. This is because there is no way that the process which is John’s *life* could be imagined to vary under two different scenarios – for example life with diet, life without diet – while remaining one and the same individual process. If something varied, then the process itself would be a *different* process.

**Why processes do not change**

Processes do not change, because processes *are* changes (they *are* changes, for example, with certain rates, and happening at certain times and in certain orders). They are changes in those *independent continuants* which are their participants.

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. 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:

The argument is essentially that the event as a whole occupies an interval of time; if in its early stages the event has a certain property which it lacks in its later stages, then it is not the event as a whole which either has the property or lacks it, but rather one part of the event has the property and another part lacks it. Hence […] the event does not change.

For *continuants*, predications may need to be time-indexed in order to be true. 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 (e.g. a fetus becomes an embryo becomes an infant …), *occurrents* can never change their type from one time to the next. Certainly an *occurrent* can for example involve parts which are of different sorts in different times. A process of movement 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. With the change in speed the continuant participant process thereby undergoes a change in speed (for example in the speed with which some person is running). 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.

**The solution to the problem**

The treatment we propose rests 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 a 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*. The assertion that process *p* has speed *v* is thus analogous not to: rabbit *r* has weight *w,* but rather to rabbit *r* **instance\_of** the universal: *rabbit.*

But we can imagine, now, that process *p* is an instance not only of the universal *3.12 m/s motion process*, but also of the universal *burning 9.2 calories per minute process*, *utilizing 30.12 liters of oxygen per kilometer process,* and so on. (It may also instantiate universals such as: *running process*, be a *cardiovascular exercise process*, and many more.) The proposed solution thus threatens a consequence which conflicts with the BFO rule of thumb that ontologies should as far as possible avoid assertions of relations between universals which imply multiple inheritance [19].

How, then, is BFO to do justice to the need to annotate data in which speed or other putative qualities are ascribed to bodily motions or other 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 for example reciprocally dependent structural parts pertaining to *speed of motion*, *energy consumed*, *oxygen consumed.* We shall in what follows call such structural dimensions *process profiles.*

**Structural dimensions of qualities**

The idea of process profiles as structural parts of processes has a counterpart in the world of continuant qualities. Here, familiarly, we can distinguish in every color quality three dimensions of variation, corresponding to three inseparable parts – of hue, brightness and saturation – of each color quality instance, tied together in a three-sided reciprocal 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 [67, 68, 70], yielding a dependence structure of the sort depicted in Figure 7 [1, 3, 20]:



Figure 7: Three-sided reciprocal dependence

where *a*, *b*, *c*, are instances of the three universals of hue (α), brightness (β) and saturation (γ), respectively.

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 dimensions of a tone, 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. 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 content of a surrounding whole of this given sort. They are inseparable in the sense that, for example, for any given instance of your heart functioning as a pump, the relevant motion and auditory profiles would necessarily be associated with some determinate blood output profile.

There are, now, analogous structural parts of processes, which we call ‘process profiles’. The idea is that 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 to which many of the assertions we make about processes are directed. 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 are those of respiration rate and pulse rate, as documented in the [Vital Sign Ontology](http://www.acsu.buffalo.edu/~ag33/vso.html). Bruno’s diary of weight gain and loss data represents a quantitative process profile of Bruno’s dieting process.

Some examples of quantitative (measurable) process profile types, with subtypes provide for illustrative purposes, include:

* four-dimensional process shape profile (trajectory)
* speed profile

constant speed profile

2 mph constant speed profile

3 mph constant speed profile

increasing speed profile

* acceleration profile

constant acceleration profile

0 ft/s2 acceleration profile

32ft/s2 acceleration profile

33 ft/s2 acceleration profile

increasing acceleration profile

The types and subtypes here are analogous to the types and subtypes of qualities recognized by BFO-conformant ontologies on the continuant side, for example:

length

6 cm length

7 cm length

The user must however bear in mind, in both sets of cases, the subtypes 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 is audible (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.

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].

As we shall see, it is process profiles, not the circumcluding whole process, which instantiate the corresponding (*3.12 m/s*, *9.2 calories/minute*) universals represented in many different sorts of process measurement data. Thus while quantitative values, and units of measure, are associated *directly* with process profiles, they are associated with the relevant whole processes only in a secondary sense.

**Four-dimensional process shapes**

Just as universals in general can be determinable (as in the case of *color*) or determinate (as in the case of *orange of specific RGB hue (204, 90, 64)* [71], so also we can distinguish determinable and determinate process profile universals*.*

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 *determinable4-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**

In the draft [Towards a Definition of Rate](http://ontology.buffalo.edu/bfo/rates.docx), we use the beat profile example to provide a preliminary account of one important set of process predications, namely predications of *rates* to processes, including processes whose rates are changing discontinuously or continuously. The account is intended to apply to all processes with beat process profiles, including not only heart beat processes, but also for example drumming processes, and simple cyclical processes (birthdays, …). Every beating process is a beating process in virtue of its including some beat profile as a structural, organizing process part. In addition to the *regular* beat profile (where a rate can be assigned in the simplest possible fashion), there is also an increasing beat profile, a decreasing beat profile, an accelerating beat profile, as well as many other types of irregular beat profile, some of which, for example, when they are detected in measurements of heart beat processes, may be clinically significant.

**How to deal with predications of processes**

Each process profile is an instance-level **part** of some corresponding whole process. We can define:

*a* **process\_profile\_of** *b =* Def. *a* and *b* are processes

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

& there is some process *c* which is part of *b* and which is such that

*a*, *b* and *c* **occupy** the same temporal region

&*a­* **s-depends** on *c.*

*a* is a *process profile* = Def. for some process *b*, *a* **process\_profile\_of** *b*

To assert, now, that a beating process *has rate 4 bpm*, is to assert that there is some beat 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 **part\_of** *p*

& *p*o **occupies** the same *temporal interval* as *p*

& *p*o **instance\_of** the determinable *process profile* type: F

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

**States as Static Process Profiles**

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:

|  |
| --- |
| **. . . – – – . . .** |

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 Figure 8).



Figure : [Cardiac Cycle, Left Ventricle](http://en.wikipedia.org/wiki/Cardiac_cycle)

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.

**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 that 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.

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, 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.

**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: An *occurrent* entity that is **part** of spacetime.

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

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** some*spatial region* **at** *t*

where the **projection** relation is defined in each case in terms of the reference frame employed.

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.

## 3.3 Temporal region

Elucidation: An *occurrent* entity that is **part** of time

‘Time’ here refers to a largest **instance** of the universal *temporal region* as defined in relation to some specific 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 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 connected temporal region (which means: a region that it without gaps or breaks) that is extended.

Example: the temporal region during which a process occurs.

Synonym: temporal interval.

## The precedes relation

See discussion in [16].

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|  |
| --- |
|  |

**BFO Relations**

To be dealt with in the next version of this document.

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