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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 Entit.*

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 abbrevations.

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

Portions of energy.

**Acknowledgments/Co-Authors**

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**References**

Literature citations are provided for purposes of preliminary orientation only. Axioms and definitions included therein 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.

BFO is designed to be neutral with regard to the lower-level 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 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.

# 1. Entity

For both terms and relation expressions in BFO we distinguish between *primitive* and *defined*. 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.

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

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). Because BFO is the ontology that forms the basis of the [Information Artifact Ontology](http://code.google.com/p/information-artifact-ontology/) and universals are included among the targets of the IAO:**about** relation, BFO must include universals within its domain of discourse.

We use ‘universal’ and ‘type’ as synonyms. We occasionally employ ‘category’ as an informal expression to refer to higher-level universals of the sort to which BFO terms refer. BFO:*fiat object part* is a category in this sense; not however *organism* or *weapon.*

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’ or ‘collection’) of their **instances** (understood along the lines proposed in [62, see also 11, 63] as mereological sums of their constituent singletons). Thus extensions are one special sort of class. These and related technical terms of ontology are elucidated further in [19, 25, 17].

**Attributive classes**

Often, language is used to refer to subgroups of entities which instantiate a given universal but do not correspond to the extension of any subuniversal. Examples are:

*animal owned by the emperor*

*tuberculosis diagnosed on a Wednesday*

*surgical procedure performed in Albania*

[*disease mentioned in the Koran*](http://corpus.quran.com/concept.jsp?id=disease)*.*

We refer to such subgroups as ‘attributive classes’ (labeled ‘defined classes’ in [25]).

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

**Attributive role classes**

One major set of examples of attributive classes involve roles. Thus ‘professor’ (defined as: a *human being* who has the *professor role*) denotes an attributive class, and so also do ‘nurse’, ‘student’, ‘colonel’ and so forth. An ontology of employment positions in an organization might employ terms referring to attributive classes for simplicity’s sake, but these terms should be *defined* in terms of roles nonetheless, This is because the members attributive classes *professor*, *student*, *dean*, and so forth, applies only during a certain phase in the lives of the particular human beings in question.

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(*a*, *t*) =Def. *a* **has\_role** student role **at** *t*

Here ‘student (John, *t*)’ means: John is a **member\_of** the attributive class *student* **at** *t.* ‘*t*’ here can refer to either an instant or an interval of time.

**Attributive historical classes**

Attributive classes also include what we will call historical classes – classes whose members satisfy some historical condition, for example: *biological father*, *person identified as candidate for clinical trial #2056-555*, *person who has visited Pittsburgh*,or *artifact created by Da Vinci.*

For ‘biological father’, the correct form of definition is roughly 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* **output\_of** *d*

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

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

Why insist on such complex definitions? Why not simply introduce into our ontology another primitive term, ‘biological father’ as a child of ‘human being’? The answer turns on the methodology for consistent ontology creation and ontology quality evaluation 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].

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.

Note that terms referring to attributive classes are distinguished from mere abbreviations – for example ‘bodily feature’ 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’. Such abbreviations should be used where there is no appropriate genus represented within the relevant BFO-conformant domain ontology.

**Species-Genus Definitions**

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

an *S* = Def. a *G* which *C*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.

## Relations of parthood

**Elucidation of primitive relations**

*a* **part\_of** *b* **at** *t* – the parthood relation where the relata are *continuants*

*a* **part\_of** *b –* the parthood relation where the relata are *occurrent*s

The mereology used in each case is Simple Extensional Mereology as defined in [46].

Note that ‘part\_of’ in BFO signifies always: ‘proper or improper part’. Thus every entity is, trivially, a **part** of itself.

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

*a* **has\_part** *b* **at** *t* = Def. *b* **part\_of** *a* **at** *t –* forcontinuants

*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].

# 2. Continuant

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

Continuants are contrasted with occurrents, which unfold themselves in their 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*, each of 1-minute duration. *Continuants* have no temporal parts in this sense. Rather, continuants have spatial parts. Continuants are three-dimensional (spatial) entities. Occurrents are four-dimensional (spatiotemporal) entities.

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

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].

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

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 an 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.* **S-dependence** is thus just one type of dependence only; 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, some of which may be dealt with below, for example the type of **generic dependence** involved in information artifacts. Other types of dependence include causal dependence (e.g. between measurable qualities such as pressure and temperature), and the frame dependence (of spatial and temporal regions on spatiotemporal regions).

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 hithtero been explicitly recognized in BFO, but it is documented at length in the literature on specific dependence [1, 2, 3, 6, 20, 46].

If *a* **s-depends**, then it **s-depends** at every time at which it exists. 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).

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
* a smile smiles only in a human face
* 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 very 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.

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 does not depend existentially on the prior act of baptism.

## 2.1 *Independent Continuant*

*A* is an *independent continuant* = Def. *a* is a *continuant* which is such that there is no *b* on which *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-dependent** 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 extended in 3 spatial dimensions.

Examples: human beings, undetached arms of human beings, aggregates 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’ here is intended in the sense of physics, as something which 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 the material universe at meso- and macroscopic scales is to a large degree made up of separate or stable, spatially separated or separable units, combined or combinable into aggregates of various sorts (for example into what are called ‘populations’). Many scientific laws govern the units in question, and these units play a central role in almost all domains of natural science from particle physics to cosmology. The division of reality into such stable natural units, and the fact that these units form aggregates such as *families*, *herds*, *populations*, *breeds, species*, and so on, is at the heart of biological science*.* 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 2 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 often referred to as ‘grains’, 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. In what follows, however, we shall formulate our proposals independently of any granularity considerations.

**Elucidation of BFO:*object***

The following elucidation is provided not as part of a formal theory (of qualitative mereotopology [5, 5, 22, 36, 37, 39]), but rather as a set of conditions to be used when deciding whether entities of a given type should be represented as *objects* in the BFO sense.

**Preamble on the strategy**

Material entities fall into different groups, for instance

* of portions of solid matter, portions of liquid, portions of gas
* collections of microparticles (which can survive through phase transitions from solid to liquid to gas)

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

1. organisms and cells
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 define 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’.

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*,larger than a certain threshold size, is in the interior of *a* at *t* and is moved in space to be at a location on the exterior of *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 subparts 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 cover is nonetheless *connected* in the sense that, between every two points on its surface a continuous path can be traced which does not leave this surface.

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 by van der Waals forces). In the case of larger portions of matter the constituent atoms are tightly bound to each other either 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. Thus a raindrop on the car is not part of it (nothing prevents it from being moved many feet away from the car) while the oil in the crankcase, and various gears, are parts of the car.

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

*a* is an *object =*Def. *a* is *maximal* relative to some criterion of causal unity CU*n*

Thus each one of a pair of conjoined twins sharing vital organs is, prior to separation, not maximal relative to the CU1 type of causal unity. Rather, the maximal material entity here is the whole which they together form. Fiat object parts can be distinguished within this whole, and in cases of successful separation these fiat object parts are the precursors of the two objects which result from separation.

Elucidation: an *object* is a *material entity* which manifests causal unity of one or other of the types listed above (or of some other type to be distinguished in the future) and is maximal relative to the corresponding type of causal unity.

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. (See Figure 3)



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 adjacent to or attached to other cells; there are spatially separated organisms, such as you and me.)

**Objects may contain other objects as parts**

They may do this for example

* by containing atoms and molecules as parts
* by containing object aggregates as parts, for instance the collection of blood cells in your body is an object aggregate;
* 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.
* in the case of organs (inside an organism) and some types of engineered constituents (inside a physical artifact) parts may be separate (for example they may float in some portion of liquid) or they may be connected together through conduits or tracts which may themselves have covering membranes which themselves lie in the interior of the object*.*

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.

#### 2.1.1.2 Object aggregate

In this document we concentrate on the term ‘object aggregate’. However, the term ‘aggregate’ should be understood as being applicable to all continuant BFO categories. Thus for each such 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 *objectso*1, …,*o*n at *t* such that:

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

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’.

As is true for all material entities (for example: you), object aggregates may gain and lose object parts while remaining numerically identical (one and the same individual) over time.

Candidate: Examples: a symphony orchestra, the aggregate of bearings in a crank shaft,

#### 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, relative to the object’s type of causal unity, not maximal.

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]. 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 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 truths about these layers (for example that the oldest layers are also the lowest layers) did not become true because of any acts of delineation.

**Relations between *object*, *fiat object part* and *object aggregate***

If an entity is in one of the three categories – object, fiat object part, object aggregate – at any given time in its existence, then it is so at all times. A leaf (plant organ) falls from a tree. A uterus is explanted. An atom becomes bound up with other atoms in a molecule. A cell becomes bound with another cell in an organism (both cells preserve their existence). A cell divides into two cells (the first cell ceases to exist).

Note that *object* and *fiat object part* are by definition disjoint (in the sense that they are such as to share no instances in common). However we do not assert that *object* and *fiat object part* are disjoint from *object aggregate.* A pair of parts of your body – for example a pair of blood cells in your leg, may simultaneously be both a *fiat object part* of your body and an *object aggregate.* A watch is simultaneously both an *object* and an *aggregate* of its component parts.

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

Examples of problematic cases which might call forth such extensions 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 polypeptide chain, 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 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 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 (embracing terms which meet the criterion that they are formal- rather than domain-ontological, and associating them with suitable definitions and examples). 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. *sites* and *boundaries*, which are tied to *material entities*, and which can thus change size, shape and location as their material hosts move(for example: the boundary of Wales; your nasal passage; the hull of a ship [38, 7, 10]);
2. *spatial regions*, which exist independently of *material entities*, and which thus do not change.

Immaterial entities under the former headings are in some cases **parts** of their material hosts. Immaterial entities under both headings 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.

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 under the heading ‘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 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.

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*, there is a continuous line 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 this room, the Grand Canyon, the Piazza San Marco, an air traffic control region defined in the airspace above an airport, a kangaroo pouch, your left nostril, the hull 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 hull moves also. As you pinch and unpinch your nose, your nostril dilates and expands.

The class A region of controlled airspace 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 **4**).



Figure 4: [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 created by an incision with a knife 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

In a later version of this document we will document the way in which every spatial and every temporal region is dependent on a reference frame. (Spatiotemporal regions, in contrast, are independent of reference frame.)

We recommend that users of BFO:*spatial region* specify the coordinate frame which they are employing. 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, they are at rest relative to their coordinate frame. Lines of latitude and longitude are two-dimensional object boundaries which can move; however, they are by definition at rest relative to the coordinate frame which they determine.

Elucidation: A *spatial region* is, intuitively, a zero-, one-, two- or three-dimensional part of the space in which objects move and are located.

Spatial regions have no qualities except shape, size and relative location.

*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 this 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.

When the dependence of spatial regions on reference frames is documented, then we will document also the relations between spatial regions defined relative to the (reference frame that is determined by the Earth), and the corresponding sites and continuant fiat boundaries.

##### 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,

## Location relations

**Located\_at**

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

This is a primitive relation between an *independent continuant*, a spatial region which it occupies, and a time.

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.*

**Located\_in**

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

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.

## 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 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 additional condition is needed see [52].)

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*

## Relation of specific dependence

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

*a* is a *specifically dependent continuant =* Def. *a* is a *continuant* which **s-depends** on some entity.

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



Examples: 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 function of this key to open this lock and the reciprocally dependent disposition of this lock: to be opened by this key, John’s love for Mary.

*a* **inheres in** *b =*Def. *a* is a *dependent continuant* & *b* is an *independent continuant* & *a* **s-depends on** *b*

**Inherence** is a subrelation of **s-dependence** which holds between a *dependent continuant* and an *independent continuant*. 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).

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

*a* **bearer\_of** *b* **at** *t =*Def. *b* **s-depends on** *a* **at** *t*or *b* **g-depends\_on** *a* **at** *t*

‘Bearer’ is a shorthand term of convenience.

### 2.2.1 Quality

Elucidation: a *quality* is an *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 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, for example: *loves*, *taller\_than*, which have a plurality of *independent continuants* as their bearers.

*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* & *a* and *b* have no **parts** in common

### 2.2.2 Realizable entity

*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.

## Relation of realization

Elucidation: if *a* **realizes** *b* **at** *t*, then there is some *material entity c* & *a* is a *process* in which *c* **participates at** *t* & *b* is a *disposition* or *role* of which *c* is **bearer***.*

Note that *t* here ranges over *temporal intervals*, rather than over instants of time (*temporal boundaries*).

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

Axiom: if a realizable entity is realized in a process *p*, then its bearer participates in *p*.

#### 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. Examples include:

* the role of an instance of a chemical compound to serve as analyte in an experiment
* the role of a stone in marking a boundary
* the role of a priest in baptizing an infant

**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. Candidate non-social roles however include positional roles – for example a given protein plays the role of peripheral membrane protein. The roles of a bacteria in giving rise to an infection, or of a portion of water in helping to initiate the growth process of a seed, are also positional in this sense. In both cases we have many examples (of bacteria, of portions of water) only some of which are in the position where they play, respectively, the infecting and the growth-supporting roles.

**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. This physical basis is referred to be OGMS as a *disorder*.

#### 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 has naturally evolved to have (as in a hypothalamus secreting hormones). In the artifact case, it is something which the bearer has been constructed to have (as in an Erlenmeyer flask designed to hold liquid) or also (as in the case of penicillin) 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 make thumping produce 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 by being permanently removed from the body in the case of the lung, or by being irreparably crushed in the case of the attic fan.

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:

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

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

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

### 2.3 Generically *dependent continuant*

*a* **g-depends on** *b* **at** *t*1=Def. *a* exists **at** *t*1and *b* exists **at** *t*1 and for some type *B* it holds that (*b* **instantiates** *B* **at** *t*1) and necessarily, for all *t* (if *a* exists **at *t*** then some **instance\_of** *B* exists **at** *t*)

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

*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 in my laptop; the sequence of this protein molecule; the sequence that is a copy thereof in that protein molecule.

Where 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* are able to migrate, through a process of exact copying. The *very same pdf file* can be saved to multiple storage devices, and thus it can exist in multiple copies.

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; your social security number; your recipe for spaghetti carbonara.

Such patterns can be highly complex. The pattern of letters of the alphabet and associated punctuation and spacing which is the novel *Robinson Crusoe* is concretized in the patterns of ink marks in this and that particular *copy* of the novel. 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 an exact 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 that are all of equal value. 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.

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 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 which are fiat segments occupying constituent temporal intervals of the temporal interval occupied by the process as a whole – for example your heart-beating from 4pm to 5pm today; the 4th year of your life.

Elucidation: an *occurrent* is a particular *entity* that has **temporal parts**.

Examples: the life of an organism, a surgical, the spatiotemporal setting occupied by a process of cellular meiosis, the most interesting part of 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.

## Relation of temporal parthood

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.**

**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)’.)

In the case of organisms histories are what we normally call ‘lives’ [15], and 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 for instance the movements of neutrinos within the interior of the entity as they pass through.

A revision is contemplated which would define the history of an entity as the sum of processes in which that entity is the major participant.

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 thinking about Mary [4,1], John worrying about Mary, a moving body causing another body to move.

### 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.

*a* **has\_participant** *b* = Def. *a* is an *occurrent* & *b* is a material entity & *a***s-depends on** *b.*

### 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:

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 determinate speed, a real-number magnitude 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 process itself would remain 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]) 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 type 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, have speed *v*1 at one time and then have a different speed *v*2 at a later time. But there is then nothing in the realm of *occurrents* which *changes*; rather, there is (*simpliciter*, un-time-indexedly) a process with two different parts.

**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 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*, 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 *velocity 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 dimensions of processes has a counterpart in the world of continuant qualities. Here, familiar, we can distinguish in every color quality instance three dimensions of variation, corresponding to three inseparable color quality parts of hue, brightness and saturation, 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 [49, 50, 52], yielding a dependence structure of the sort depicted in Figure 6 [1, 3, 20]:



Figure 6: 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 means 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 dimensions 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)
* velocity profile

constant velocity profile

2 mph constant velocity profile

3 mph constant velocity profile

increasing velocity profile

* acceleration profile

constant velocity 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, but with the relevant whole processes only in a secondary sense.

**Four-dimensional process shapes**

Just as universals in general can be relatively determinable (as in the case of *color*) or determinate (as in the case of *orange of specific hue rgb(204, 90, 64)*, 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), 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, 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 velocity profile is one in which velocity is zero; a null acceleration profile is one in which acceleration is zero, and so on.

Processes with null process profiles are often called ‘states’ (state of rest, state of uniform motion, …). ‘States’ are special sorts of processes (they are processes in which, along the relevant dimension, nothing happens). Such states can be highly complex: consider the case in which two equal and opposite dispositions of attraction and repulsion can counterbalance each other – the dispositions are realized but there is no movement.

For every continuant entity there is what we might call its existence profile, which is a process profile which is a part of the history of the entity in question, and which has only one state, called ‘exists’.

**Summing Process Profiles**

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

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

This is built by summation 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 7).



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. He, too, it is useful to begin with the counterpart case on the side of 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.

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.

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.

## 3.2 Spatiotemporal region

Def. An *occurrent* entity that can be **occupied\_by** a processes.

Each *spatiotemporal region* **projects\_onto** some *temporal region.*

Each *spatiotemporal region* **projects\_onto some** *spatial region* **at** *t.*

The projection relations must be defined in every 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 setting occupied by a process of cellular meiosis.

## 3.3 Temporal region

Elucidation. An *occurrent* entity that is part of time (defined always in relation to some reference frame).

A temporal region is an *occurrent entity* upon which a process can be projected.

### 3.3.1 Zero-dimensional temporal region

A temporal boundary of a temporal region.

Examples: 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

Example: the temporal region during which a process occurs.

C:\Users\phismith\Downloads\all.tif

|  |
| --- |
|  |

**BFO Relations**

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

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