Chapter 5

Introduction to Basic Formal Ontology: Continuants

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Introduction to Basic Formal Ontology I: Continuants

In previous chapters we have discussed how making use of a formal (or top-level or domain-neutral) ontology can be helpful in constructing domain ontologies that are interoperable, rigorous, and clear. We argued that issues such as terminology selection, term definition, and classification can all be better addressed in the context of a top-level ontology, and also suggested that use of a top-level ontology brings benefits when it comes to sharing ontology content, governance of ontology development, and developing expertise.

Multiple ontologies working together within the framework of the Open Biological and Biomedical Ontologies (OBO) Foundry (formerly the Open Biomedical Ontologies Foundry) initiative utilize Basic Formal Ontology (BFO) as a starting point for the categorization of entities and relationships in their respective domains of research. This includes inter alia the Cell Ontology, the Foundational Model of Anatomy, the Protein Ontology, the Ontology for General Medical Science, and the Ontology for Biomedical Investigations. Like other top-level ontologies—and in harmony with the principle of fallibilism—BFO has been and is still subject to ongoing review and to multiple different sorts of testing by the developers and users of these and many other ontologies supporting empirical science. BFO has been modified, and we hope improved, as a result of the lessons learned by the many groups who have been applying the ontology to particular domains, and also in reflection of considerable input from external critics. In this chapter we will introduce the categories of BFO along with their definitions, focusing on version 2.0 of the ontology that was released for comment in 2014. We will also describe how these categories can be applied to an existing domain ontology by what might be thought of as a process of reverse engineering.

Some Basic Features of BFO

BFO is an upper-level ontology developed to support integration of data obtained through scientific research. It is deliberately designed to be very small, in order that it should be able to represent in consistent fashion those upper-level categories common to domain ontologies developed by scientists in different fields. It is small, too, in order to allow exercise of the benefits of modularity and of the division of expertise; a top-level ontology should not contain terms like “cell,” “death,” or “plant” that properly belong in domain-specific ontology modules of narrower scope.

Because of its generality and small size, BFO will not in and of itself address the terminological needs of those working in specific domains; it provides rather a starting point for work by those with specialist knowledge. Nor will BFO provide complete answers to many of the quasi-philosophical questions that arise in the course of domain-specific ontology development—questions such as “what is an organization?” or “what is life?” or “what is a work of art?” or “what is an action?” This does not mean that answers to such questions cannot be expressed within the BFO framework. In some cases—as we shall see in our discussion of information artifacts to follow—such debates, involving both BFO developers and users, have led to the recognition of the need to extend BFO itself, though still without departing from the narrow confines of what is domain neutral.

BFO assists domain ontologists by providing a common top-level structure to support the interoperability of the multiple domain ontologies created in its terms. In this way it helps to bring about a situation in which information compiled in separate repositories can form part of a common framework for the categorization of, and for reasoning about, the entities in the corresponding domains. This will be achieved, of course, only if informaticians, data managers, researchers, and curators of experimental literature and data, do in fact utilize BFO in their work. At the same time, however, the adoption of BFO has been shown to bring benefits that provide additional justification for its use. Thus, for example, its use promotes portability of expertise, so that those who have once been trained in use of BFO in one domain can more easily apply their skills in other areas. It also provides a starting point for ontology development, which allows those new to ontology to move more quickly to the sorts of domain-specific questions which belong to their respective areas of expertise by providing a set of ready-made answers to the abstract questions with which top-level ontology is concerned. Thus many people use BFO-based ontologies without being aware that they are doing so; the BFO components of these ontologies remain invisible to them in their work, in much the same way that the engine of a car is most of the time unnoticed by the driver.

In previous chapters we have discussed the distinction between universals and particulars, and we have stressed that the primary goal of scientific ontologies is the representation of universals and the relations between them. Ontologies, like scientific theories, are concerned with capturing knowledge of what is general. The terms in BFO, and in the ontologies developed on its basis, should thus be understood, in the first place, as representing universals. This is not because of an interest in universals for their own sake. The ultimate goal of scientific ontologies is to support the work of scientists in *classifying particulars*, for example, the sorts of particulars they observe in their experiments. BFO supports the construction of classificatory hierarchies to aid in reasoning about such particulars. It provides a set of preconfigured high-level taxonomic distinctions that can serve as an off-ramp for the population of representations of universals at lower levels of generality. BFO is thus designed to help ensure that the domain ontologies built on its basis represent the universals in their respective domains in a consistent and coherently structured fashion.

Basic Types of Entity: Continuant and Occurrent

BFO takes as its starting point an interest in the workings of reality from the point of view of those who are engaged in scientific research. We take reality to be comprised of entities—using “entity” in a sense that is common among both philosophers and scientific researchers to refer to anything at all that exists in any way at all.

We then divide entities into two categories, namely:

• *Continuants*: entities that *continue* or *persist* through time, including (1) independent objects (for example, things such as you and me); (2) dependent continuants, including qualities (such as your temperature and my height), and functions (such as the function of this switch to turn on this light); together with (3) the spatial regions these entities occupy at any given time;

• *Occurrents*: entities that *occur or happen*, variously referred to as “events” or “processes” or “happenings,” which we take to comprise not only (1) the processes that unfold in successive phases but also (2) the boundaries or thresholds at the beginnings or ends of such processes, as well as (3) the temporal and spatiotemporal regions in which these processes occur.

These two types of entities do not exist side by side with each other in any simple sense. Rather, in keeping with the doctrine of perspectivalism outlined in chapter 3, they correspond to two distinct and complementary perspectives on one and the same reality, neither of which can do full justice to those features of reality represented by the other. In describing this reality, we customarily draw on both of these perspectives simultaneously, as when we make assertions such as

• there are cells (continuants) engaging in processes of meiosis (occurrents);

• there are people (continuants) having surgeries (occurrents) performed on them by other people (continuants);

• there are amino acid chains (continuants) that participate in processes of folding (occurrents), which result in new structures (continuants) that themselves participate in processes of posttranslational modification (occurrents) resulting in typical three-dimensional amino acid chain structures (continuants);

• there is the Earth (continuant) that orbits (occurrent) the Sun (continuant).

Note how, in each such case, we talk about particulars, such as particular things and particular processes by using general terms such as “amino acid chain” or “orbit” referring to universals.

[Insert figure 5.1]

In what follows, we will describe the *is\_a* hierarchy of BFO types and subtypes, beginning with the top-level categories and working downward through the subtypes, first for *continuants* and then, in chapter 6, for *occurrents*. We will proceed in order of diminishing concreteness, beginning with independent continuants and material entities.

BFO: Continuant

Continuants in BFO are entities that *continue to exist through time*; they may gain and lose parts (for instance, as an organism gains and loses cells), but at each point in time at which they exist at all they nonetheless exist completely. Thus you may lose an arm, but you—all of you, at whatever time you exist—will still exist completely, and this is so in times both before and after the loss of the arm. The loss of an arm may be more painful than, but it is ontologically comparable to, the loss of a single hair. This is in contrast to *processes* (which form the main subcategory of continuants), which unfold themselves through time in successive temporal parts or phases. Because no two distinct phases exist simultaneously, there is no time at which a process exists as a whole. Rather, it exists at any given point in time only in some correspondingly short-lived stage or slice.

The continuant portion of BFO consists of representations of entities that (1) persist, endure, or continue to exist through time while maintaining their identity, and (2) have no temporal parts. Note that this is not a *definition* of “continuant.” This term is so basic to our understanding of reality that it is not possible to provide a definition that does not itself use terms, like “persist” or “endure,” which are equivalent in meaning. Any attempted definition will thus be circular. We provide, instead, what we can think of as an elucidation of what we mean by the term “continuant,” together with examples designed to illustrate the sorts of entities to which the term is to be applied. (And where “BFO:” terms are introduced in what follows in the absence of a definition, this is because a similar policy is being applied in these cases as well.)

While continuants do not have temporal parts, each continuant will be associated with a life or, in BFO parlance, a *history*—an entity belonging to the realm of occurrents, and thus the sort of thing that can have temporal parts.

Examples of continuants include a tomato, the qualities of the tomato—for example, its weight or temperature or color, and the region of space occupied by a tomato at any given time. BFO’s *continuant* has subtypes intended to capture all of these types of continuant. Its three immediate subtypes or “children” are: *independent continuant, specifically dependent continuant,* and *generically dependent continuant.*

BFO: Independent Continuant

An *independent continuant* is a *continuant* entity that is the bearer of qualities. If a continuant entity *a* is the bearer of quality *b*, then we also say that *b inheres in a.* Thus the color *b* of tomato *a inheres in* tomato *a*. Inherence itself can be defined as a kind of one-sided dependence, more precisely as that sort of one-sided dependence that obtains among qualities, dispositions, and roles (an explanation follows) on the one hand and independent continuants on the other. There are other uses of the word “dependence,” some of which will concern us in what follows (for instance in our treatment of the relation between a boundary and that which it bounds). For the moment, however, it is crucial to understand the very specific sense of “dependence” upon which BFO relies, a sense of dependence that implies that the dependent entity is secondary (has diminished concreteness) in relation to the independent continuant that is its bearer. The latter is a three-dimensional thing that has material parts. The dependent entity, by contrast, has no material parts but is rather parasitic on the material thing that supports it. Material things cannot be parasitic on (or ontologically secondary to) other entities in this sense. (There is nothing more concrete than material things.) And from this it follows that an independent continuant, while it is an entity in which other entities (such as qualities) inhere, cannot itself inhere in anything.

Independent continuants are such that their identity and existence can be maintained through gain and loss of parts, and also, as we shall see, through changes in their qualities, and through gain and loss of dispositions, and of roles. Tomato *a* may be left out in the sun and lose its moisture; tomato *a* may once have been green, but is now red; tomato *a* may be frozen, and thereby lose its disposition to ripen; and tomato *a* may be selected by the chef, and thereby acquire the role of garnish to your steak.

Types of independent continuants to be dealt within in what follows include organisms and their parts—for example, your heart and the collection of your limbs; the *boundaries* of organisms—for example, your fingertips (the sorts of things used to take impressions called “fingerprints”); and *places*, such as the Grand Canyon. BFO correspondingly distinguishes two subtypes of independent continuant: *material entity* and *immaterial entity.*

BFO: Material Entity

A BFO: *material entity* is an independent continuant that has some portion of matter as part. It is thus an independent continuant that is spatially extended in three dimensions, and that continues to exist through some interval of time, however short. Examples of BFO: *material entity* are organisms such as human beings, undetached arms of human beings, and aggregates of human beings such as, for example, a dance troupe or a baseball team. These three sets of examples correspond to the three principal subtypes of material entity distinguished by BFO, namely:

• BFO: *object*

• BFO: *fiat object part*

• BFO: *object aggregate*

together with various combinations that will be discussed.

BFO: Object

Nature is organized as a hierarchy of nested units. From microphysical particles to planetary bodies, there are units or grains in the order of reality—referred to in what follows as “objects.” Examples are atoms, molecules, organelles, cells, organs, organisms, planets, and stars.

An *object* is a material entity that is

1. spatially extended in three dimensions;

2. causally unified, meaning its parts are tied together by relations of connection in such a way that if one part of the object is moved in space then its other parts will likely be moved also (the parts share in this sense what we can think of as a *common fate*);

3. maximally self-connected (which means intuitively that the different parts of the object are tied together in a certain way and that anything that is tied to these parts in the same way is itself part of the object).1

An organism is an object in this sense, as is a single cell, an egg (including all its contents), a space ship (including all its contents), and a planet. Two people shaking hands, in contrast, do not form an object, nor does one person joined together with his hat. This is because the connections are in both cases too weak to join the parts together in the sense required. Your (attached) head does not form an object even though the connections between its parts are physically sufficiently strong for objecthood. This is because your head, unlike your body as a whole, is not maximal in the sense required.

In many cases, an object enjoys the requisite sort of self-connectedness in virtue of possessing a physical covering layer or membrane, a container that holds the parts inside it together. The covering layer may have holes or cavities but these are in normal circumstances too small to allow the objects contained within it to escape. The covering layer is itself both topologically self-connected and maximal. It is self-connected in the sense that, selecting any portion of the layer, we can trace a continuous (though not always straight, given that the surface may include holes) line to any other portion of the layer without needing to go outside it. And it is maximal in the sense that every portion of matter to which we can trace a similarly continuous line is included as part of the layer.

A tomato is an object in this sense, not however the two halves of a tomato before separation. A human being, too, is an object. And as both of these examples show, the fact that the surface of an object must be self-connected does not imply that the surface does not contain holes—for example, pores, or your mouth—through which particles of matter can penetrate in one or other direction. An organ such as your heart or brain is an object in this sense, and so also is a fetus. Each of these entities is connected by physical conduits to its surrounding host organism. But these connections are relatively weak, and (as we know from experience) the object in question is able to survive its disconnection.

The possession of a maximally self-connected outer boundary—called an *object boundary* in the BFO ontology—works well as a criterion of objecthood for macroscopic objects, which means, roughly, for independent continuants at least as large as a cell nucleus. However, it cannot be applied to serve as such a criterion for objects at finer grains—roughly, of single molecules or smaller. At such levels the criterion of causal unity plays a more central role. This criterion is applied both internally, where it relates to the ways in which the different parts of the object are related to each other, and externally, where it has to do with the ways in which the object as a whole interacts causally with other objects.

Even where an object has a maximally connected physical *outer* boundary, it may still include in its interior parts that are not connected to its other parts. An example is provided by the blood cells in your body. These are parts of your body, though they are not connected to the other parts.2 The bacteria that form your microbiome are located in the interior of your body, but they are neither connected to your body nor a part thereof.3 They do, however, in virtue of the surrounding membrane that is your skin, share a common fate.

Objects are the bedrock upon which dependent continuants and occurrents depend for their existence. An object is an entity that can exist and be what it is regardless of what other objects exist. Thus, a doorknob is an object because it can be removed from a door and still exist with all its parts intact. It can be moved from one place to another, and survive even when the objects around it are destroyed, removed, or replaced. Organisms, which as we saw are objects in the BFO sense, can certainly be said to depend on other objects (for example, on oxygen, water, drugs, food for sustenance, and so forth); these senses of “dependence” are not however of significance for us here.

We said that BFO continuants *exist in full at any time in which they exist at all*. Again: if Jill loses her arm, then she still exists as a whole—with all the parts that she currently has—and if her arm survives this loss, it is now a *separate object*. It is no longer a part of Jill. The reason for insisting on this point is that something similar is not true in the case of BFO’s *occurrents*. The first set of a tennis match may now be in the past, but it is still part of the whole tennis match, and will indeed always remain so, just as the first three years of your life are still and will always remain a part of your life. Lives, in this sense, and processes in general, have temporal parts. Continuants do not have temporal parts.

Not only do the relations between an occurrent and its parts hold atemporally, but so also do the relations between an occurrent and its qualities. Occurrents, as we shall see, behave differently, from a logical point of view, from the ways continuants behave.

BFO: Object Aggregate

An *object aggregate* is a *material entity* that is made up of a collection of objects and whose parts are exactly exhausted by the objects that form this collection. In addition the objects forming an object aggregate are separate from each other in the sense that they share no parts in common.

Examples of object aggregates are: a heap of stones, a group of commuters on the subway, a population of bacteria in your blood, a flock of geese, the collection of patients in a hospital. The degree of unity of such entities is, we might say, weaker than that possessed by objects proper—compare a heap of stones to a single stone. In some types of object aggregates, the objects themselves may interact dynamically, as, for example, in the case of a symphony orchestra, or an infantry battalion going into battle.

Organizations such as symphony orchestras or tenants’ associations are object aggregates of a special sort, in which specific objects (specific human beings), play specific roles (for example, president, secretary, treasurer, member, and so on). (See our discussion of roles that follows.)

BFO: Fiat Object Part

A *fiat object part* is a *material entity* that is a proper part of some larger object, but is not demarcated from the remainder of this object by any physical discontinuities (thus it is not itself an object). Examples of fiat object parts include your upper torso, the handle of a solid metal spoon, the Western hemisphere of the planet Earth, the diaphysis of a long bone (see figure 5.2)

[Insert figure 5.2]

Fiat object parts are to be contrasted with those object parts that are objects in their own right, and which thus have complete physical outer boundaries of their own, for example, the blood cells in your veins and arteries or the individual sardines in a can of sardines. We use the term “fiat” to draw attention to the fact that the boundaries in question are standardly the reflection of decisions on the part of, for example, the drawer of a map or the theorist identifying regions of different sorts within a domain of continuous variation. Such divisions are drawn even where there are no physical discontinuities to which the dividing lines correspond. As we shall see in our discussion of fiat object boundaries to follow, some boundaries of this sort exist even in the absence of any decision by a cognitive agent.

Combination Object-Entities

BFO makes no claim to the effect that objects, object aggregates, and fiat object parts provide an exhaustive classification of the types of material entity. Thus, for example, if John owns two neighboring apartment buildings, but sells the top floor of one of them, then it may be that what he owns is the sum of an object together with a fiat object part. If Mary is studying knee injuries in a population of patients then it may be that the target of her study is an aggregate of fiat object parts.

Combination entities of this sort4 provide no special challenges to BFO. They are not included explicitly as subtypes in BFO 2.0, though they could be included in future versions of the ontology if there is a corresponding need on the part of BFO’s users. We may distinguish further subtypes of fiat entities analogously also in the realm of two-dimensional surfaces (for example, Arizona is a fiat part of the two-dimensional surface that is the continental United States, which may in turn be a fiat part of the two-dimensional surface of the planet Earth).

BFO: Specifically Dependent Continuant

In line with our strategy of moving through BFOs *is\_a* hierarchy in order of diminishing concreteness, we deal next what BFO calls *specifically* and *generically dependent continuants*. A *specifically dependent continuant* is a *continuant* entity that depends on one or more specific independent continuants for its existence. Dependent continuants exhibit *existential dependence* in the sense that, in order for a dependent continuant to exist, some other entity in which it inheres (intuitively, an entity enjoying a larger degree of concreteness) must exist also.

Examples of specifically dependent continuants include the color of this tomato, the pain in your left elbow, the mass of this cloud, the smell of this piece of mozzarella, the disposition of this fish to decay, your role of being a doctor, the function of your heart to pump blood, and the quality of a specific pixel array on your screen. The mass of this cloud could not exist without this cloud and the color of this tomato could not exist without this tomato.

In BFO, *specifically dependent continuants* are subclassified as follows:

BFO: *quality*

• BFO: *relational quality*

• BFO: *realizable entity*

• BFO: *role*

• BFO: *disposition*

• BFO: *function*

A *specifically dependent continuant* is a *dependent continuant* that depends on some specific independent continuant that is its bearer. Thus a specifically dependent continuant is such that it cannot migrate from one bearer to another. My suntan is specifically dependent on me. It cannot also be *your* suntan, however closely similar the two distinct instances of the suntan type might be. Similarly, the mass of your car exists only so long as the car exists, and that very instance of *mass* can only exist as the mass of this specific car, and not of some other car. As we shall see, this is not true of generically dependent continuants, which are defined by the fact that they can migrate from one bearer to another.

BFO: Quality

There are two types of *specifically dependent continuant*: *quality* and *realizable entity*. Qualities are contrasted with realizables in that the former, if they inhere in an entity at all, are fully exhibited or manifested or realized in that entity. The latter, in contrast, can inhere without being realized, and can be realized to different degrees (including different degrees of likelihood).

What all qualities have in common is that they inhere in, and so depend on, other entities; in order for a quality to exist some other entity or entities—specifically, one or more independent continuants, must also exist. Examples of qualities include the mass of this kidney, the color of this portion of blood, and the shape of this hand. Notice that, in each of these cases, the quality is referred to as standing in a relationship to some other independent continuant entity, such as a kidney, a portion of blood, a hand. This is because of the dependent nature of qualities. There cannot be color without it being the color *of something*, and there cannot be mass without it being the mass *of something*. In particular, it is BFO independent continuants that qualities depend on (or as we also say: inhere in). Qualities may inhere in one independent continuant—for example, the shape quality of this glass cube; or they may inhere in multiple independent continuants—for example, the quality of *being siblings* or *being competitive with* that might inhere in John and Mary; the quality of being angry that might inhere in an aggregate of persons we call a mob.

Qualities may depend also on entities of other types; thus, for example, the quality of your heart, of *beating with a certain rate*, is dependent not only on your heart, but also on the beating process in which the heart participates.

Often, it is the qualities of objects and their parts that we refer to as differentiae when formulating definitions. Why is our sun classified as a star? Because it shares certain qualities with other celestial bodies already identified as stars, such as being self-luminous, being plasmatic, having a size, mass, and temperature within a certain range, and so on.

Qualities in BFO can be ordered into those more or less general, for example, as follows:

quality

 color

  red

   dark red

    RGB 990033 dark red

or

  body temperature

   elevated body temperature

    body temperate in the range 37.6° and 38° Celsius

     body temperature of 37.8° Celsius

Note that to assert that a body temperature quality of 37.8° Celsius inheres in a certain body does not imply that the body has a temperature of 37.8° Celsius uniformly through all its parts. Rather, different temperature qualities will be detectable in different parts of the body, and the “37.8° Celsius” represents an average of these.

More general qualities are called “determinables” in the philosophical literature, and the corresponding least general qualities are called “determinates.” Typically, determinable qualities—for example, *mass*—hold of independent continuants as a matter of necessity. (You cannot, as a matter of necessity, exist without your mass.) Determinate qualities—for example, *mass of 70 kg*—hold only contingently. A red nose need not be red, but it must have some color. We can think of the necessary or essential determinable qualities as constants within the architecture of their bearers, while the determinate qualities vary with time. You always have your temperature, but the value of your temperature varies from one time to the next.

BFO: Relational Quality

Relational qualities have a plurality of independent continuants as their bearers. Examples include a marriage bond, an instance of love, being a parent of, and so on, all of which obtain between one person and another. From the BFO perspective there is both the relational-quality universal *marriage bond* (an entity that might be included in a domain ontology for social reality) as well as the specific instances of this universal obtaining between (and so specifically depending upon) John and Mary, Bill and Sally, and so forth.

Relations That Do and Relations That Do Not Have Instances

By contrast with BFO’s *relational qualities*, relations such as **instance\_of** or **part\_of** (discussed in more detail in chapter 7), are relations for which it does not make sense to speak of instances. They are not entities in their own right. If it is true that Mary is a human being then there is no extra entity—for example, no instance of the relation of instantiation—that is needed to make this true. If it is true that Mary’s heart is **part\_of** Mary, then similarly there is no extra entity in addition to Mary and her heart that is needed to make it true that this relation obtains. BFO adopts this view of relations for reasons of practical utility. (We have, for instance, no data pertaining to different instances of the parthood relation.)

Internal relations such as comparatives (*taller-than*, *larger-than*, *heavier-than . . .*) are also not entities in their own right, as BFO conceives them.5 If John is taller than Mary, then this is accounted for exclusively in terms of John’s and Mary’s respective height qualities, and in terms of the fact that each of these heights instantiates a certain determinate height universal and that the totality of such universals form a certain linear order. (And we note that “fact” here is not being used as a technical term, and thus also not as referring to an extra entity in the BFO sense.)

BFO: Realizable Entity

Like qualities, *realizable entities* are *specifically dependent continuants* that inhere in one or more independent continuants. Realizable entities are *in* (inhere in) their bearers in just the same way that qualities are in their bearers. In contrast to qualities, however, realizable entities are exhibited only through certain characteristic processes of realization.

A *realizable entity* is thus defined as a specifically dependent continuant that has at least one independent continuant entity as its bearer, and whose instances can be realized (manifested, actualized, executed) in associated processes of specific correlated types in which the bearer participates.

Examples of *realizable entity* include the role of being a doctor, the functions of the reproductive organs, the disposition of a portion of blood to coagulate, the disposition of a portion of metal to conduct electricity. Entities in each of these types are in each case associated with entities of corresponding process types in which they are realized (executed, manifested, actualized). Thus, for example, the role of a doctor is realized when he examines or treats patients; the function of a reproductive organ is realized in copulation or insemination.

Realizable entities are entities of a type whose instances are such that in the course of their existence they contain periods of actualization, when they are manifested through processes in which their bearers participate. But they may also exhibit periods of dormancy, when they exist by inhering in their bearers but without being manifested—as, for example, in the case of those diseases which are marked by periods of latency, and by the many occupational roles that are not realized because the bearer is, for example, asleep. Some realizable entities are realized during all the times when the bearer exists, as, for example, in the continuous functioning of a mammal’s heart and lungs; other realizable entities are realized hardly at all, as, for example, in the case of sperm, which are nevertheless the bearers of a function—to carry male genes to a female’s egg—that are entities *of a type* some (an important few) of whose instances do indeed contain periods of actualization.

We saw that an animal is classified as a mammal in virtue of possessing certain qualities (being a vertebrate, being warm blooded); but there are characteristics of mammals that involve not qualities but realizables. For example, a (female) mammal is capable of giving birth to live young, and capable of lactating, even if in particular cases these dispositions are never realized. Some realizables, as again in the case of the function of a sperm to penetrate an ovum, may be such that they can be manifested only once in their lifetime. Others, for example, the function of a spark plug in an internal combustion engine, can be manifested over and over again.

BFO distinguishes two principal types of *realizable entity*: *role* and *disposition,* with one subtype of *disposition*, namely *function.* Other subtypes of realizable entity distinguished in the ontological literature include *capabilities* and *tendencies*.6

BFO: Role

A *role* is an externally grounded *realizable entity*, that is, it is a realizable entity that is possessed by its bearer because of some external circumstances (for example, the bearer has been assigned the role by some other persons, who have roles of their own which grant them a certain authority). A role is thus always optional; the bearer does not have to be in the given external circumstances.

Each instance of *role* is a realizable entity that (1) exists because the bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be (optionality), and (2) is not such that, if this realizable entity ceases to exist, then the physical make-up of the bearer is thereby changed (external grounding).

A role is a realizable entity whose manifestation brings about some result or end. This result is not essential to its bearer in virtue of the kind of thing that it is. Thus it is not essential to Jim that he is a nurse, or to Mary that she is a bankrupt or a baroness or a bodyguard. But Jim and Mary have these roles because they are in certain associated kinds of natural, social, or institutional contexts. A role can cease to exist without the physical make-up of the bearer thereby being changed. An entity has a role not because of the way it itself is, but because of something that happens or obtains externally.

Further examples include the role of an instance of a chemical compound to serve as analyte in an experiment, the role of a portion of penicillin to serve as a drug, and the role of a stone in marking a boundary.

As we shall see, roles are distinct from another type of realizable entity, called functions. A heart has the function of pumping blood, but in certain circumstances that same heart can play the role of dinner for a lion or of plastinated prop in a museum display. A portion of water does not have any function per se, but it does play many different roles, for example, in a hydroelectric experiment, or in washing clothes, or in helping to initiate the growth process of a seed. Many prominent types of role involve social ascription. A person can play the role of lawyer or of surrogate to a patient, but it is not necessary for persons that they be lawyers or surrogates.

Note, here, that it is the role that is ontologically prior. “Lawyer role,” “surrogate role,” “nurse role,” and so on, all refer to universals in BFO’s terms. “Lawyer,” “surrogate,” “nurse,” however, refer merely to defined classes. If a person has the role of lawyer, then we can refer to the person in two ways, as person, or as lawyer. The latter usage can be defined as follows:

*lawyer*(*x*) = def. *person*(*x*) and for some *y*(lawyer-role(*y*) and *x* **has\_role** *y*)

This definition can serve as a template for very many role-related defined classes.

When once the class *lawyer* has been defined, however, then it may be used in BFO-based ontologies in many of the same ways these ontologies use terms representing universals, thus, for example, in assertions of the form: *lawyer* *is\_a* *person.*

BFO:*roles* are specifically dependent instances. A role exists only when some specific independent continuant serves as its bearer. Roles in this sense, like qualities, cannot migrate from one bearer to another. The term “role” can, however, be used in a different sense in contexts such as Jane’s being the seventh person to fill the role of director of this institute, or Joe’s being the third person to play a particular role in a play. “Role” in this sense is being used to designate what BFO calls a *generically* dependent continuant.

BFO: Disposition

It is common for researchers to make claims such as

• element X has a disposition to decay into 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.

All of these are examples of dispositions in BFO’s sense. A *disposition* is a *realizable entity* in virtue of which—for example, through appropriate triggers—a process of a certain kind occurs (or can occur or is likely to occur) in the independent continuant in which the disposition inheres. This process is called the *realization* of the disposition. The trigger might consist in the objects being placed in a certain environment or being subjected to certain external influence, or it may be some internal event within the object itself.

Unlike a role, a *disposition* is a realizable entity that is such that, if it ceases to exist, then its bearer is physically changed. Dispositions are in this sense (and in contrast to what is the case with roles) not optional. If an entity is physically a certain way, then it has a certain disposition, and if it ceases to be that way, then it loses that disposition. A disposition can thus be conceived of as an *internally grounded* realizable entity. That is, it is a realizable entity that exists because of certain features of the physical make-up of the independent continuant that is its bearer. One can think of the latter as the material basis of the disposition in question. Note that this material basis will exist even though its associated disposition is never realized.

Dispositions are variable along a continuum from weaker to stronger. Dispositions at the weaker end of the spectrum are not realized in every suitable triggering situation, but only in some fraction of relevant cases. Examples include

• a hemophiliac’s disposition to bleed an abnormally large amount of blood, and

• the disposition of a person who smokes two packs of cigarettes a day throughout adulthood to die of a disease at a below average age.

Clearly, we are often referring to more or less weak forms of disposition when we consider genetic and other risk factors for specific diseases.

By contrast, we can distinguish a strong form of disposition, a *sure-fire disposition*, which is reliably executed whenever its bearer is in the conditions appropriate for a disposition of the corresponding type. Examples include

• the disposition of a piece of stretched elastic to contract when released,

• the disposition of a sheet of glass to break if struck with a sledgehammer moving at 100 feet per second,

• the disposition of a diploid cell to become haploid following meiosis, and

• the disposition of a magnet to attract iron filings.

Incorporation of dispositions into the BFO ontology provides a means to deal with those aspects of reality that involve possibility or potentiality without the need for complicated appeals to modal logics or possible worlds. At the same time, the ontological commitment to dispositions itself faces the problem as to how dispositions are to be individuated. If John has the disposition to scratch his nose, does he also have the disposition to scratch his nose *when awake*, or *in the presence of Mary*, or *during a full moon*? How, in other words, are dispositions to be counted? How is one disposition to be distinguished from another? BFO’s approach to answering such questions is highly practical. BFO has been created to serve the annotation of data deriving from scientific experiments. BFO itself does not provide a taxonomy of dispositions; it does not itself legislate concerning which types of dispositions exist, or how they are to be individuated. Rather, it leaves this task to the specific sciences. Those involved in scientific practice have at their disposal at each stage a limited repertory of terms for representing the salient types of dispositions, and it is this set of evolving repertories that will serve as starting point for ontology building in the spirit of BFO. Scientific practice does not reduce the massive diversity in the number of ways in which the totality of dispositions can be divided up, nor does it solve all problems concerning how dispositions are identified or individuated; but it does solve the practical problem of providing us with a means to represent those dispositions in each given domain that are salient to scientific advance.

BFO: Function

A *function* is a special kind of disposition.7 It is a realizable entity whose realization is an end-directed activity of its bearer that occurs because this bearer is (a) of a specific kind and (b) in the kind or kinds of contexts that it is made or selected for. Thus 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 of how it came into being—either through natural selection (in the case of biological entities) or through intentional design (in the case of artifacts).8 Roughly, the entities in question came into being in order to perform activities of a certain sort, called “functionings.” Examples include

• the function of amylase in saliva to break down starch into sugar,

• the function of a sperm to penetrate an ovum,

• the function of a hammer to drive in nails,

• the function of a pen to write, and

• the function of a heart pacemaker to regulate the beating of a heart by means of electricity.

Each function has a bearer with a specific type of physical make-up. This is something that, in the biological case, the bearer has evolved to have (as in a hypothalamus secreting hormones) and, in the artifact case, something that the bearer has been designed and built to have (as an Erlenmeyer flask is designed to hold liquid).

It is not accidental or arbitrary that the eye has the function to see or that a screwdriver has the function of fastening screws. Rather, eyes and screwdrivers exist because they perform these functions. Their functions are integral to the entities in question in virtue of the fact that the latter have evolved, or been constructed, to have the physical make-up needed to perform or realize them. It is because of its physical make-up that your heart’s function is to pump blood and not, for example, to produce thumping sounds—the latter are mere byproducts of your heart’s functioning.

Like dispositions in general, therefore, functions are internally grounded realizable entities: a function is such that if it ceases to exist, then its bearer is physically changed. If a lung or attic fan becomes nonfunctioning, then this indicates that the physical makeup of these things has changed. In the case of the lung this might be due to a cancerous lesion; in the case of the attic fan to a rusted exhaust screen.9

BFO: Specifically Dependent Continuant: Summary

Examples of the different kinds of specifically dependent continuant recognized by BFO are

• this negative charge is a *quality* of this phosphate ion,

• this adhesion is a *quality* of the water in this flask,

• John’s obligation to pay Susan is a *relational quality* that obtains between John and Susan,

• to detoxify its containing organism is a *function* of this liver,

• to produce portions of glycogen is a *function* of this endoplasmic reticulum,

• this bacterium in this case of cholera has the *role* of pathogen,

• this person in this clinical trial has the *role* of subject,

• this rattlesnake has the *disposition* to strike when threatened, and

• this structure of mature bamboo scaffolding has the *disposition* to be cyclone-resistant.

The BFO ontology of dispositions serves as the basis for the treatment of diseases in the BFO-based Ontology for General Medical Science.10 To say that a human being has a case of influenza, for example, is to say that he or she has a complex disposition that is realized, inter alia, in acute inflammation, weakness, dizziness, and fever. A person may also have a *pre*disposition to some disease without in fact having the disease. Many persons, for example, have a predisposition to colon cancer; we may have this predisposition for the whole of our lives without ever developing the disease of colon cancer itself. In this case we have a disposition (already now) to acquire a further disposition at a later time. In a similar way, each healthy adult human being has a disposition to walk. A human fetus has a predisposition to walk; that is, she has a disposition to acquire the disposition to walk at a later stage in her life.

Reciprocal Dependence among Realizable Dependent Continuants

Consider the cases of husband and wife, or of doctor and patient. Here pairs of reciprocally dependent roles are involved, whereby the first role in each reciprocal pair can be realized only if the second is realized also. We encounter analogous reciprocally dependent pairs of functions in the realm of artifacts. Consider a key and the associated lock. The key has a disposition to unlock the lock, while the lock itself has the disposition to be unlocked by that very key. Both dispositions are manifested in the same process, namely, in the key’s unlocking of the lock. What underlies these complementary dispositions is the key’s disposition to transmit torque when rotated, the lock’s disposition to release when unlatched, and a relation between the material and shape qualities of the lock and key that confers these dispositions (the key must fit the lock and must be of sufficient hardness to enable transmission of torque to the lock’s lever).

Reciprocally dependent pairs of functions are present throughout the natural world. Consider the case of sperm and egg. Here biological functions have evolved in complementary dependence upon each other. Each cannot realize its primary function unless the other does so also.11

BFO: Generically Dependent Continuant

To say that one entity is *specifically dependent on* another is to assert that the first entity is as a matter of necessity such that it cannot exist unless the second entity exists. BFO’s specifically dependent continuants are thus subject to what we might call the axiom of nonmigration: they cannot migrate from one bearer to another. Some dependent continuants seem, however, to be capable of such migration, as, for example, when you copy a pdf file from one computer to another. Clearly the pdf file is *dependent* on some bearer; for the pdf file to exist, there must be some physical storage device on which it has been saved. But equally clearly, the pdf file can be *moved* from one storage device to another. The very same pdf file can be saved to multiple storage devices, and thus it—the numerically identical information entity—can exist in multiple copies.

To do justice to this and many similar phenomena BFO incorporates the category of *generically dependent continuant*, defined as a continuant that is dependent on one or other independent continuants that can serve as its bearer. More formally we define *generic* *dependence* as follows:

*a* generically depends on *b* = def. *a* exists and *b* exists and: for some type *B*, *b* is an instance of *B* and necessarily (if *a* exists then some *B* exists)

and we define *generically dependent continuant* on this basis:

*a* is a generically dependent continuant = def. there is some *b* such that *a* is generically dependent on *b*

If *A* is a subtype of generically dependent continuant, then every instance of *A* requires some instance of independent continuant subtype *B*, whereby which instance (or instances) of *B* serves as bearer can change from time to time.

There are two large families of examples of such entities—in the domains of information artifacts and of biological sequences respectively. And while BFO itself does not contain terms like “information artifact” or “DNA sequence,” terms like these are found in the Information Artifact Ontology (IAO)12 and Sequence Ontology (SO),13 both of which are BFO conformant.

We can think of generically dependent continuants, intuitively, as complex continuant patterns of the sort created by authors or designers, or (in the case of DNA sequences) through the processes of evolution. Generically dependent continuants thus include, for example, the Coca Cola trademark, the pattern that is your signature, a square arrangement of sixty-four alternating black and white squares. Each such pattern exists only if it is *concretized* in some counterpart specifically-dependent continuant—the pattern of red and white swirls on the label of this Coca Cola bottle; the pattern of ink marks you just created by signing this piece of paper; the pattern of black-and-white squares on this chessboard.

Such patterns can be highly complex. The pattern of letters of the alphabet and associated spacing which is the novel *Robinson Crusoe* is concretized in the patterns of ink marks in this (and that) particular *copy* of the novel. Generically dependent continuants can be concretized in multiple ways; you may concretize a novel in your head.14 You may concretize a piece of software by installing it in your computer. You may concretize a cake recipe that you find in a cookbook by reading it, and your concretization may then serve as the starting point for a process of creating a plan, which exists as a realizable dependent continuant in your head and is realized in your baking of a cake.

Generically dependent continuants may be found in the realm of nucleic acid and other biological sequences. Other generically dependent continuants are information entities created by human beings. The data in your database, for example, are patterns in some medium—for instance in your hard drive—with a certain kind of provenance. The database itself is an aggregate of such patterns. When you create the database you create a particular entity (what BFO calls an “instance”) of the generically dependent continuant type *database.* This will be concretized in your hard drive as a certain complex quality (of magnetic excitation)—a specifically dependent continuant. Similarly each entry in the database is an instance of the generically dependent continuant type *datum*, which will be concretized in your hard drive as a certain part-quality of that whole quality that is the concretization of the database as a whole.

Databases, novels, dramatic scripts, musical scores, and other information entities are in some ways analogous to other created artifacts such as paintings or sculptures. They differ from the latter in that, once having been created, they can exist in many copies that are all of equal value. The novel *Robinson Crusoe* is an instance of the type *novel*, each printed copy is an instance of the type *book.* The novel *Robinson Crusoe* is a generically dependent continuant instance, an *abstract pattern*, made concrete through the acts involved in printing successive copies. In each of these copies there inheres a certain complex quality (of a certain quantity of bound paper and associated small piles of printer’s ink), and each such complex quality concretizes the generically dependent continuant that is Defoe’s novel.

In this way we can do justice to the fact that there is only one *Robinson Crusoe*, which does not change when additional copies are printed.

In the case of a work of music such as Beethoven’s *Symphony No. 9,* there is again a certain abstract pattern, a generically dependent continuant instance of the type *symphony*, which is itself a subtype of the type *musical work*, which is concretized in certain specifically dependent patterns of ink marks that we find in a printed copy of the score or in certain specifically dependent patterns of grooves in a vinyl disk. The symphony is *realized* (manifested, performed) in those occurrent patterns of air vibrations that are instances of the type *musical performance.* The score itself is an instance of the generically dependent continuant type *plan specification*, which is concretized in the minds of the conductor and the members of the orchestra when they read and understand the score. This allows them to create (and to realize as they perform) a plan, which is a complex, realizable dependent continuant that exists (in slightly different but mutually compatible forms) in the minds of multiple human beings; it is realized when conductor and orchestra work together to create the already mentioned pattern of air vibrations.

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 as a complex quality in her mind by reading it, and creates on this basis that specifically dependent realizable continuant that is a plan for carrying out this experiment. At the same time she creates a series of subprotocols, plan specifications for her various team members, which are concretized by them as plans for carrying out their corresponding parts of the experiment. The experiment itself is the synchronized realization of these plans.

BFO: Immaterial Entity

Having dealt with BFO’s specifically and generically dependent entities, we now return to the other major subclass of BFO’s *independent continuant*, namely *immaterial entity*, defined as an independent continuant that contains no material entities as parts. Even to speak of “immaterial entities” may sound, at first, counter-intuitive. However, consideration of cases makes it clear that there are entities in reality that although not themselves material are nonetheless important for our manipulation and cognition of what is material. A good example set of such entities is found in the domain of anatomy, where the boundaries of, for instance, organs and portions of tissue are no less salient than the entities that they bound. Rosse and Mejino provide the following rationale for including terms for immaterial entities such as surfaces, lines, and points in the Foundational Model of Anatomy (FMA) ontology: “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.”15

*\note(immaterial entity)[Immaterial entities* divide into two major subgroups:

1. *Boundaries* and *sites*, which bound, or are demarcated in relation to, *material entities*, and which can thus change location, shape and size as their material hosts move or change shape or size (for example, your waste, the boundary of Wales [which moves with the rotation of the Earth]; your nasal passage, the hold of a ship);

2. *Spatial regions*, which exist independently of *material entities*, and which thus do not change.*]*

*note(continuant part of)[*Immaterial entities listed */\**under 1. *\*/*are in some cases **continuant parts** of their material hosts. Thus the hold of a ship, for example, is a part of the ship; the hold may itself have parts, which may have names (used, for example, by ship stow planners, customs inspectors, smugglers, and the like). Immaterial entities under both 1. and 2. can be of zero, one, two, or three dimensions.

Sites, such as the kitchen of a restaurant on a ship, are analogous to material entities in that they are of three dimensions and can move through space. When they do so they will occupy successively different spatial regions. One site may move through another site, for instance the interior of a railway carriage may move through the Mont Blanc tunnel. By contrast, spatial regions never move through each other, because spatial regions never move. (More precisely, they are, by definition, at rest relative to the pertinent frame of reference, as will be discussed.)

BFO: Continuant Fiat Boundary (including Zero-, One-, and Two-Dimensional Continuant Fiat Boundary)

A *continuant fiat boundary* is an *immaterial entity* that is of zero, one, or two dimensions and does not include a *spatial region* as part. Intuitively, *note(continuant fiat boundary)[*a *continuant fiat boundary* is a boundary of some material entity that exists exactly where that object meets its surroundings. For BFO: *objects* larger than molecules, the *fiat object boundary* is its maximally connected two-dimensional surface, for example, the surface of the earth, or the surface of a cell membrane. However, a fiat boundary can also be the boundary of an immaterial entity, such as a site (for example, the boundary of a portion of airspace into which only military aircraft are allowed to fly).

In the simplest cases such as rocks or baseballs, and even in topologically more complex cases such as donuts or wedding rings or bird cages, there is little difficulty in determining where the corresponding object boundary lies. In the case of compartmentalized objects such as mammals, buildings, and refrigerators, however, we may face options as to whether to include the compartments (cavities) within the object as *parts* of the object or as *holes*. Consider, for example, your digestive tract. On one view your body is topologically analogous to a donut; your digestive tract is a hole running through the middle. On the view espoused in the FMA, however, which is the de facto standard human-anatomy ontology, the digestive tract is not a *hole in* but rather a *part of* the organism—a part that is not made of matter. Similarly the interior of your freezer compartment is not a *hole in* but is rather a *part of* your refrigerator. Whichever option we take will determine what is to be counted as the “outer” boundary of the object in question and thus also of the object’s shape.

Note that the sense of “boundary” that is presupposed in the preceding is one according to which boundaries have no material parts. Entities with material parts are in every case spatially of three dimensions. Continuant boundaries as we conceive them are always of lower dimension.

Consider a rectangular block of marble. The surface of the block is a boundary of two dimensions, its edges are of one dimension, and its corners are of zero dimension. Each of these boundaries is dependent on the cuboid, but in a sense of “dependence”—which we can call “boundary dependence”—that is different from the sense employed when dealing with specifically and generically dependent continuants above. Briefly, we can say that a boundary *a* of an object *b* is boundary-dependent on this object if and only if it is necessarily such that it can exist only if *either b* exists *or* there exists some part of *b* that includes *a* as part. To see what is at issue here, imagine that there is some capsule of a supremely powerful corrosive acid inside the marble block that is eating the marble away, by degrees, from the inside. As the marble is progressively destroyed its boundaries are at first unaffected. They will continue to exist for just as long as there is at least *some* remaining part of the block that includes them as part. Since this remaining part can be arbitrarily thin, there is a sense in which the boundary itself is of zero thickness.

[Insert figure 5.3]

It will be clear from the preceding discussion that the sense of “boundary” intended here—which is close to the mathematical sense of the term—is distinct from that which is involved when we refer to a skin or membrane as the boundary of an organism or cell. Material boundaries in this latter sense—boundaries with thickness—themselves have boundaries (on either side) of the type at issue here.16

Continuant fiat boundaries admit of different dimensions. A *two-dimensional continuant fiat boundary* (surface) is a self-connected fiat surface whose location is defined in relation to some material entity*.* Examples of this type of boundary include any surface of a continuant material object that segments that object off from the rest of its environment, such as the boundary of the block of marble in the example just discussed. A *one-dimensional continuant fiat boundary* is a continuous fiat line whose location is defined in relation to some material entity; for example, the Greenwich meridian, the Equator, and geopolitical boundaries of nations and states. Finally, a *zero-dimensional continuant fiat boundary* is a fiat point whose location is defined in relation to some material entity. Examples include the North Pole and the point of origin of a spatial coordinate system.

Boundaries and Granularity

Why, now, does BFO refer to object boundaries as *fiat*, given that the outer boundary of, for example, a tomato or a block of marble or a table in our living room does not depend for its existence on any decision or on any drawing of boundaries by any cognitive agent? The answer to this question turns*]]as(one-dimensional continuant fiat boundary)[]* on BFO’s treatment of the phenomenon of granularity.

If we examine the surface of the table with a powerful microscope, then it will appear that there is no boundary there at all, in either the *mathematical* or the *thin layer* sense just distinguished. Rather, there is just (something like) a cloud of microparticles oscillating at high velocities in the vicinity of what, when we use the naked eye, we like to call the surface of the table. In a famous passage by the physicist Eddington on what he called “My Two Tables,” the view that there are no boundaries of (middle-sized) objects—and so there are no corresponding (middle-sized) objects for them to bound—is defended explicitly. Table 1, as Eddington sees it, is the ordinary solid table made of wood; table 2 is what he called his “scientific table”: “My scientific table is mostly emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing about with great speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself. [The scientific table] supports my writing paper as satisfactorily as table No. 1; for when I lay the paper on it the little electric particles with their headlong speed keep on hitting the underside, so that the paper is maintained in shuttlecock fashion at nearly steady level.”17

Eddington here expresses the sort of reductionist point of view that we rejected in chapter 3 (especially the section on adequatism). For him only the scientific table exists; table 1 is for him something like a convenient fiction. From the adequatist point of view defended by BFO, in contrast, denying that the two tables have just the same degree of reality is a mistake, since the two tables are in fact one and the same object—it is merely that they are viewed at different levels of granularity. Table 1 and table 2 have the same degree of reality in the same way as do, for example, the City of Toronto depicted on a large- and a small-scale map (where the former shows items at the order of magnitude of single streets and houses, the latter only major highways and neighborhood divisions).

The fiat object boundaries of tables and tomatoes exist, because the tables and tomatoes exist, as is seen when these objects are viewed from the perspective of medium-sized-object granularity. These fiat object boundaries are referred to (implicitly or explicitly) when we apply the commonsensical distinction between what is in the interior and what is in the exterior of the objects in question. Something similar occurs also when we use a map to determine what is in the interior and what is in the exterior of some parcel of real estate. This does not mean that those who wish to embrace a reductionist view cannot use BFO to support their work in ontology development. Reductionists who wish to follow Eddington can simply ignore (not use) those parts of BFO pertaining to boundaries at higher levels of granularity. For most users of BFO however, and especially users of BFO in areas of biology and the health sciences, its adequatist framework provides them precisely with the resources they need to deal ontologically with collected data pertaining to boundaries in both of the two distinguished senses. This is clear from the large number of terms for surface boundaries (in addition to surface layers) found in the FMA. Representing surface boundaries is important, too, in areas such as perceptual psychology—for example, in experiments on vision that gather data pertaining to surface colors and to perceptual surfaces of different shapes and textures.

The issue here pertains to distinctions of granularity in scientific research and in clinical practice, in engineering, administration, and other practical disciplines. Different scientific specialties explore the same domains of reality at different levels of granularity, and what are counted as objects on one level of granularity may appear to scientists working on another level of granularity as object aggregates. To describe BFO as an “adequatist” ontology is to say that it is designed to support the work of scientists and engineers at multiple scales and levels of aggregation, and thereby also to support the integration of data relating to such multiple levels. Different BFO users may address the problem of such integration in different ways. Some may be able to ignore this problem because they focus exclusively on one level of granularity. Others may need to annotate each of BFO’s material entity types with explicit reference to the level of granularity at issue, and work is ongoing to create an extension of BFO 2.0 in which resources for such explicit reference will be provided.18

BFO: Site

A *site* is, intuitively, an immaterial entity in which objects—such as molecules of air or water, or a bear—are or can be contained.

[Insert figure 5.4]

A site exists because there is some material entity in relation to which it is defined, providing, for example, the floor and walls and ceiling that allow containment by forming the *retainer* for the site. Each site will thus have a characteristic spatial shape in virtue of this physical retainer. But the site itself, while it exists because of this retainer, does not contain the retainer as part. The site is, rather, the *hole* that is contained by the retainer. A BFO: *site* can now be defined as follows:

site = def. a three-dimensional *immaterial entity* that either 1. is (partially or wholly) bounded by a *material entity* or 2. is a three-dimensional immaterial part of an entity satisfying 1

Examples include your nasal cavity, your veins (cavities through which blood flows), the Suez Canal (trench), the lumen of your gastrointestinal tract, the interior of your aorta, the interior of your office, the trunk of your car, the Piazza San Marco, a kangaroo pouch, the inside of your shoe, your eye socket, the cruciform slot of a Philips head screw.

All of these examples are at the levels of granularity accessible to ordinary human perception. The Protein Ontology Consortium is developing a sub-ontology representing amino acid sites that are the locations of post-translational modifications.19 We leave open the question whether there are BFO: *sites* at other levels of granularity. Are, for example, black holes BFO: *sites*? Such questions will need to be addressed empirically, in light of the consequences of applying BFO to corresponding domains.

Every site will at any given moment coincide with some spatial region. But the site is not *identical* with the spatial region with which it coincides, because the site but not the spatial region is ontologically (site-) dependent upon its retainer. In the case of mobile sites (for example, a ship’s cargo hold) the site in question will cycle through a continuous multiplicity of spatial regions as its retainer, the ship, moves. While at any given moment the hold will be co-extensive with some spatial region, it is not *identical* to that spatial region, because the hold remains what it is even after the ship and the sites for which its interior walls serve as retainers have moved so as to occupy new spatial regions. Spatial regions cannot move since it is spatial regions in and through which movement occurs.

A site is typically associated with some medium such as the body of air that is partially or completely enclosed by its retainer. Thus, the nasal cavity is a site that is formed by the exterior boundaries of the inner membranes and parts of the nose that give this site its characteristic spatial shape. The site serves as container for a succession of molecules of oxygen and nasal flora. Similarly, the skull is a site that contains the cranial cavity, the brain, and the cerebrospinal fluid that entirely fills the cavities that are enclosed by the skull walls and the brain, taken together.

BFO: Spatial Region (including Zero-, One-, Two-, and Three-Dimensional Spatial Regions)

A spatial region is a continuant entity that is a part of space (by which we mean: a part of the maximal or total space, or in other words of the whole of space). Both material and immaterial entities occupy regions of space; processes occur in space. When an object moves from one place to another, then it occupies a continuous series of different three-dimensional spatial regions at different times. As we know from the theory of relativity, however, there are no spatial regions except as defined relative to some frame of reference, an issue we discuss in the next section.

BFO recognizes four different sorts of spatial regions in its ontology, of three, two, one and zero dimensions. Just as, from the ontological realist perspective, there are objects (independent continuants such as you and me) so there are three-dimensional spatial regions that such objects occupy. And just as for BFO there are surfaces of objects (for example, the two-dimensional external fiat boundary of your body) so there are two-dimensional spatial regions that these boundaries occupy and one- and zero-dimensional spatial regions that are the boundaries of these boundaries.

BFO thus incorporates two levels of continuants—with *spatial regions* on one level and *material entities* and *sites* (with their respective boundaries) on the other, the former providing, as it were, the spatial receptacles for the latter. Such a two-level approach is common in the literature on spatial reasoning.20

BFO is a boundary-tolerant ontology.21 It incorporates terms for spatial regions of zero, one, two, and three dimensions (points, lines, areas, and surfaces, respectively) and also terms for the objects, fiat object boundaries, and sites that occupy the corresponding spatial regions. (As we shall see, BFO adopts a similar two-level theory in its treatment of temporal entities.) One rationale for recognizing the two levels of objects and the regions they occupy turns on the way in which the part-whole structures of objects reflect the part-whole structures of the corresponding spatial regions. In decomposing an object into its constituent parts we also decompose the spatial region occupied by the object into the spatial regions occupied by these parts at any given time. If two parts of the object are connected to each other, then so also are the corresponding spatial regions (and this is true independent of the frame of reference we are using to determine the reference of spatial region identifiers in any given case).

In accepting sites into its ontology in addition to spatial regions, BFO is acknowledging also two distinct location relations involving independent continuants of

1. **containment**, between an independent continuant and a site that contains it (for example, between a chick and the interior of an egg, or between a group of drinkers and the interior of a pub), and

2. **location**, between any independent continuant entity and the corresponding spatial region—whereby every independent continuant is, at any given time, associated with the spatial region at which it is located at that time.

Independent continuants may have many qualities (such as shape, size, mass, density, reflectance, electric charge, and so forth), stand in many different sorts of relations to other entities, and be such that many realizable dependent continuants inhere in them.

Spatial regions, in contrast, are continuants of a peculiar (“abstract”) sort. There is a sense in which they have qualities of shape and size, but the primary BFO relation here is one of instantiation between a spatial region instance and the corresponding spatial region universal. Spatial regions can be said to have the quality of being size *m because* they instantiate the universal *spatial region of size m*.22 The corresponding qualities, accordingly, are “defined qualities,” and form a special subfamily of defined classes in the BFO framework.

Spatial regions do not inhere in any other entities; and they are inert, in the sense that no realizables inhere in them. Spatial regions are thus unique kinds of entities in BFO. They are entities in the full sense; however, they are neither material entities of the sort that they provide locations for, nor are they dependent on such concrete material entities in the way that qualities and realizables are.

As we have seen, while some determinable qualities—such as *mass*—hold of independent continuants as a matter of necessity, the corresponding qualities of lower generality such as *mass of 70 kg* hold only contingently. When it comes to qualities and relations of spatial regions, in contrast, all hold as a matter of necessity at all scales. A spatial region cannot change its shape, since if it did then this would mean that it had ceased to exist and had been replaced by some other spatial region. Similarly a spatial region cannot change its relations (for example, of adjacency or parthood) to other spatial relations.

The four subtypes of BFO: spatial region are as follows:

1. BFO: *zero-dimensional region* is a spatial region with no dimensions, also called a spatial point.

2. BFO: *one-dimensional region* is a spatial region with one dimension, also called a spatial line.

3. BFO: *two-dimensional region* is a spatial region with two dimensions, also called a spatial surface.

4. BFO: *three-dimensional region* is a spatial region with three dimensions, also called a spatial volume.

Spatial Regions and Frames of Reference

As pointed out above, spatial regions cannot be specified absolutely but always only relative to some reference frame, and work is ongoing to create a future version of BFO in which such reference frames will be incorporated explicitly. For most current users of BFO, however, the effects of special relativity are not significant and thus they can safely make the assumption that there is a single Euclidean frame of reference that they all—modulo trivial differences, for example, as to choice of origin, or of coordinates used—share in common.

A reference frame is, in first approximation, a system of coordinates with an origin and units. And (to our knowledge) all coordinate systems employed by current users of BFO are easily convertible one into another. This is because significant problems of conversion between coordinate systems arise only where frames of reference are in motion relative to each other. When we are all working with what is effectively the same Newtonian frame because we are dealing with objects and spatial regions close to or on the surface of the Earth, such relative motion is insignificant. In some cases a system of coordinates is specified in an experimental protocol—for instance when observations are being made of animal behavior using coordinates defined relative to a specific forest. Users of BFO should document such specifications explicitly when employing BFO spatial region terms in annotations. In other cases the coordinates are provided by some standard, as for instance in the case of the representation of latitude and longitude on a map. The map then divides up the represented land and sea surfaces into (roughly) rectangular two-dimensional spatial regions, and we can think of the lines themselves as representing one-dimensional spatial regions, and of the points where they intersect as representing zero-dimensional spatial regions.

The spatial regions defined by a reference frame are always at rest relative to this frame. Thus in the cases normally treated by biologists and clinical scientists the spatial regions they refer to (for example, a lab bench or hospital ward) can be assumed to be at rest—they can be treated as if they were absolute containers for the things and events observed—and all space-related measurements, for example, of speed or of relative distance can be directly compared.

In the future we anticipate that BFO will be used in support of domain ontologies developed for many different types of research, some of which may involve frames of reference that are not at rest relative to each other. A space transport ontology, for example, might include a reference frame that, because it is in motion relative to the earth, is not trivially interconvertible with the standard Newtonian frames used by biologists. Such conversions can be made, but may be quite complex—as, for example, where demarcations of spatial regions in terms of the World Geodetic System (WGS-84) need to be converted into demarcations in accordance with the International Celestial Reference System (ICRS) maintained by the International Astronomical Union (IAU).

Where, as in some areas of physics, BFO-based domain ontologies contain representations of spatial regions that are defined in terms of what are called noninvariant frames of reference, a special situation arises, since convertibility here may not be achievable. Future versions of BFO will be required to provide appropriate means to support the development of domain ontologies of this sort, and as we shall see, analogous issues will arise also with regard to BFO categories of temporal region.

A BFO Continuant Classification

Having outlined the *continuant* perspective of BFO, we conclude by providing a simple illustration of how BFO might be used to provide a classification of the qualities, functions, and dispositions relating to the human heart.

• this human heart **instance of** *object,*

• this heart’s surface **instance of** *fiat object boundary,*

• this collection of four hearts in a biobank **instance of** *object aggregate,*

• this superior vena cava **instance of** *fiat object part,*

• this biopsy sample of the septum of the heart **instance of** *material entity,*

• this mediastinum **instance of** *site,*

• this mass of 250 grams **instance of** *quality,*

• this disposition to deteriorate over time **instance of** *disposition,*

• this disposition to pump blood **instance of** *function,*

• this role of serving as plastinated prop **instance of** *role*.

Further Reading on Basic Formal Ontology

Basic Formal Ontology website: <http://www.ifomis.org/bfo>.

Chapters 5, 6, and parts of 7 are based on the draft specification of BFO 2.0, which contains also formal definitions of the terms introduced in these chapters as well as associated axioms and theorems and considerable further explanatory material. This specification, which can be found at <http://ifomis.uni-saarland.de/bfo/>, will be updated at intervals in advance of the official release of BFO 2.0.

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Figure 5.1

The hierarchy of BFO continuants

Figure 5.2

A long bone such as a femur divided into three different types of fiat parts: *epiphysis*, *diaphysis* and *metaphysis*

*Source:* From http://medical-dictionary.thefreedictionary.com/epiphysis, originally published in Miller-Keane and Marie T. O’Toole, *Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health*, 7th ed. (London: Elsevier, 2003).

Figure 5.3

A block of marble with corrosive acid eating outward toward its boundary

Figure 5.4

A site containing a bear

*Source:* Barry Smith and Achille Varzi, “Surrounding Space: The Ontology of Organism-Environment Relations,” *Theory in Biosciences* 121 (2002): 139–162

{Notes\_begin}

5 Introduction to Basic Formal Ontology I

The material in this chapter and chapters 6 and 7 is intended as an introduction to the categories and relations in BFO version 2.0 based on the documentation at <http://ifomis.uni-saarland.de/bfo/>. This includes formal definitions of the terms introduced in these chapters as well as associated axioms and theorems and further explanatory material.

1. A more formal and rigorous treatment of the notions of “maximal” and “causal unity” is provided in the BFO 2.0 Specification referred to above.

2. Peter Simons talks in this connection of the parts inside an object being “welded” together in “Real Wholes, Real Parts: Mereology without Algebra,” *Journal of Philosophy* 103, no. 5 (2006): 597–613. The case of blood cells shows, however, that not all parts of an object need be connected to the remainder.

3. Stefan Schulz, Anand Kumar, and Thomas Bittner, “Biomedical Ontologies: What *part-of* Is and Isn’t,” *Journal of Biomedical Informatics* 39, no. 3 (2006): 350–361.

4. Discussed in the following papers by Lars Vogt, Peter Grobe, Björn Quast, and Thomas Bartolomaeus: “Top-Level Categories of Constitutively Organized Material Entities— Suggestions for a Formal Top-Level Ontology,” *PLoS ONE* 6, no. 4 (2011): e18794; “Accommodating Ontologies to Biological Reality—Top-Level Categories of Cumulative-Constitutively Organized Material Entities,” *PLoS ONE* 7, no. 1 (2012): e30004; and “ Fiat or Bona Fide Boundary—A Matter of Granular Perspective,” *PLoS ONE* 7, no. 12 (2012): e48603.

5. Kevin Mulligan, “Relations—Through Thick and Thin,” *Erkenntnis* 48 (1998): 325–353.

6. See Ludger Jansen, “The Ontology of Tendencies and Medical Information Science,” *The Monist* 90 (2007): 534–555.

7. A proposal according to which *function* would be recognized by BFO as a sibling of *realizable entity* rather than of *disposition* is currently under review. See Johannes Röhl and Ludger Jansen, “Why Functions Are Not Special Dispositions: An Improved Classification of Realizables in Top-Level Ontologies,” *Journal of Biomedical Semantics* 5, no. 27 (2014), 77–89.

8. There is a large and complex philosophical literature on functions; a useful overview for our purposes here is Jerome C. Wakefield, “Biological Function and Dysfunction,” *Handbook of Evolutionary Psychology*, ed. David M. Buss (New York: Wiley, 2005), 878–902.

9. Röhl and Jansen, “Why Functions Are Not Special Dispositions.”

10. See https://code.google.com/p/ogms/, accessed September 14, 2014, and Richard H. Scheuermann, Werner Ceusters, and Barry Smith, “Toward an Ontological Treatment of Disease and Diagnosis,” in *Proceedings of the 2009 AMIA Summit on Translational Bioinformatics* (Washington, DC: AMIA, 2009), 116–120.

11. Consider also the case of complementary dispositions in the realm of infectious diseases discussed in Albert Goldfain, Barry Smith, and Lindsay G. Cowell, “Dispositions and the Infectious Disease Ontology,” in *Formal Ontology in Information Systems: Proceedings of the Sixth International Conference* (FOIS 2010), ed. Antony Galton and Riichiro Mizoguchi (Amsterdam: IOS Press, 2010), 400–413. As OGMS is developed by extension from BFO, so IDO (the Infectious Disease Ontology) is developed in its turn from OGMS.

12. See https://code.google.com/p/information-artifact-ontology/, last accessed September 29, 2014.

13. See http://www.sequenceontology.org/, last accessed September 29, 2014.

14. For a detailed consideration of the nature of literary works and the ways in which they are concretized, see Roman Ingarden, *The Literary Work of Art* (Evanston, IL: Northwestern University Press, 1974).

15. Cornelius Rosse and J. L. V. Mejino Jr., “The Foundational Model of Anatomy Ontology,” in *Anatomy Ontologies for Bioinformatics: Principles and Practice*, vol. 6, ed. A. Burger, D. Davidson, and R. Baldock (London: Springer, 2007), 59–117.

16. On this topic see Avrum Stroll, *Surfaces* (Minneapolis: University of Minnesota Press, 1988); and Peter Simons, “Faces, Boundaries, and Thin Layers,” in *Certainty and Surface in Epistemology and Philosophical Method*, Problems in Contemporary Philosophy, vol. 32 (Lewiston, NY: Mellen Press, 1991).

17. Arthur Eddington, *The Nature of the Physical World* (Cambridge: 1928), viii.

18. See, for example, Anand Kumar, Barry Smith, and Daniel Novotny, “Biomedical Informatics and Granularity,” *Functional and Comparative Genomics* 5 (2004): 501–508.

19. Jonathan P. Bona, Alan Ruttenberg, and Jenny Rouleau, “Representing Modification Sites in PRO,” forthcoming in *Proceedings of the 2014International Conference on Biomedical Ontology* (CEUR Proceedings) (2015).

20. See, for example, Brandon Bennett, “Space, Time, Matter and Things,” in *Formal Ontology in Information Systems: Proceedings of the Fourth International Conference* (FOIS 2001), ed. C. Welty and B. Smith (New York: ACM, 2001), 105–116.

21. See Anthony Cohn and Achille Varzi, “Mereotopological Connection,” *Journal of Philosophical Logic* 32, no. 4 (2003): 357–390.

22. See Barry Smith, “Classifying Processes: An Essay in Applied Ontology,” *Ratio* 25, no. 4 (2012): 463–488.

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