

Realizable Entities in Basic Formal Ontology

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ABSTRACT

Numerous research groups are now utilizing Basic Formal Ontology (BFO) as an upper-level framework to assist in the organization and integration of biomedical and other types of information. In this paper, we attempt to elucidate the categories of *role*, *disposition*, *function*, and *capability* in BFO by means of definitions and examples. We also discuss *tendency* as one variety of disposition, and introduce the defined classes *artifactual function* and *biological function*, providing definitions for each. Our motivation is to help advance the coherent ontological treatment of these categories and to shed light on BFO's general structure and use.

1 Introduction

The ontologies which together form the Open Biomedical Ontologies (OBO) Foundry¹—including the Gene Ontology, the Foundational Model of Anatomy, the Protein Ontology, and the Ontology for Biomedical Investigations—utilize Basic Formal Ontology (BFO) to assist in the categorization of entities and relationships in their respective domains of research. Individuals and groups in organizations such as BioPAX,² Science Commons,³ Ontology Works,⁴ the National Cancer Institute,⁵ and Computer Task Group,⁶ also utilize BFO in their work.

BFO is an upper-level ontology developed to support integration of data obtained through scientific research. It is deliberately designed to be very small, so that it may represent in a consistent fashion those upper-level categories common to domain ontologies developed by scientists in different fields. It is also kept small in order to exercise the principles of modularity and to allow 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.

BFO adopts a view of reality as comprising (1) continuants, entities that continue or persist through time, such as objects, qualities, and functions, and (2) occurrents, the events or happenings in which continuants participate.^{7,8} The subtypes of continuant and occurrent represented in BFO are presented in Figures 1 and 2, respectively.⁹

continuant
 independent continuant
 material entity
 object
 fiat object part
 object aggregate
 object boundary
 site
 dependent continuant
 generically dependent continuant
 specifically dependent continuant
 quality
 realizable entity
 role
 disposition
 capability
 function
 spatial region
 zero-dimensional region
 one-dimensional region
 two-dimensional region
 three-dimensional region

Figure 1: Continuants in BFO 1.1

occurrent
 processual entity
 process
 process boundary
 process aggregate
 fiat process part
 processual context, deprecated
 spatiotemporal region
 scattered spatiotemporal region
 connected spatiotemporal region
 spatiotemporal instant
 spatiotemporal interval
 temporal region
 scattered temporal region
 connected temporal region
 temporal instant
 temporal interval

Figure 2: Occurrents in BFO 1.1

2 Function, Role, and Other Terminological Confusions

The term ‘function’ is used to describe both biological entities¹⁰ and human-designed artifacts.^{11, 12} Consider, for example, assertions such as:

- the function of the kidney is to filter out waste and water which become urine,
- the function of the protein tyrosine phosphatase SHP-1 is to control intracellular phosphotyrosine levels in lymphocytes,
- a three-gene operon (CmeABC) functions as a multidrug efflux system in *Campylobacter jejuni*,
- the function of a potometer is to measure water uptake in a tube, such as a leafy shoot, and
- a retort functions to distill substances in the lab.

Functions play a central role in virtually all of the biomedical disciplines, even if some thinkers deny their existence.¹³ One of the three constituent ontologies of the Gene Ontology (GO) is devoted to the representation of molecular functions associated with genes and gene products.¹⁴ Functions are invoked in standard definitions of health and disease—for example, the work of Boorse¹⁵—as well as classifications of disabilities. An example is the World Health Organization’s International Classification of Functions, Disabilities and Health (ICF).¹⁶

The term ‘function’ is sometimes used interchangeably with the term ‘role’ as, for example, when Zhou and Ouyang tell us that “GATA-3 plays a central role in regulating Th1 and Th2 cell differentiation”; but then a few lines later note that they will “review the function of GATA-3 in Th1 and Th2 cell differentiation.”¹⁷ In the glossary of his recent book on molecular biology, Hunter defines function as: “the role that a structure plays in the processes of a living thing”.¹⁸

Analogous issues arise with regard to the terms ‘disposition’, ‘tendency’, and ‘capability’, as in:

blood has the tendency or disposition to coagulate,

the uranium pile has the disposition or tendency to chain react,

that patient has suicidal dispositions or tendencies,

after myocardial infarction, human bone marrow cells have regenerative tendencies or capabilities,

and

nitridergic peptides are encoded by the gene disposition or capability in *Drosophila melanogaster*.

Such confusion is important, since it highlights inconsistent thinking about biological and clinical phenomena. It stands in the way of coherent computer representations of data, and serves as an obstacle to understanding influential ontologies such as the GO.

3 Basic Formal Ontology (BFO)

In BFO, all entities are divided into continuants and occurrents. Continuants can be either independent or dependent. The principle examples of independent continuants are the objects we see around us every

day. These serve as the bearers or carriers of dependent continuants such as qualities and realizable entities.

Dependent continuants are related to their bearers by inherence. Inherence is defined as a one-sided, existential dependence relation. This means that, in order for a dependent continuant to exist, some other independent continuant must exist to serve as its bearer. When inherence is specific, dependent continuants are termed specific dependent continuants. For example, an instance of a quality such as round or red is termed a specific dependent continuant since it cannot exist except as a quality of a specific independent continuant such as this ball or that rash. The redness of this ball cannot become (and could not have been) the redness of that ball. Thus, specifically dependent continuants, such as qualities, functions, roles, and dispositions can exist only insofar as they are the qualities, functions, roles, and dispositions of specific independent continuants. For example:

- negative charge is a quality of this phosphate,
- adhesion is the quality of the water in this flask,
- detoxification is a function of the liver,
- production of glycogen is a function of the endoplasmic reticulum,
- pathogen is the role of this bacterium in cholera,
- human subject is the role of this person in the clinical trial,
- a threatened rattlesnake is disposed to strike, and
- mature bamboo scaffolding has the disposition to be cyclone-resistant.

Specifically dependent continuants, such as headaches or talents, cannot migrate from one bearer to another, as contrasted with generically dependent continuants, such as the pdf file on your laptop, which can exist in a multiplicity of bearers.

Cross-cutting the division between dependent and independent entities is the division between types and instances. The terms used in biological ontologies such as the Gene Ontology refer to types; experiments carried out by biologists in their labs refer to corresponding instances. Scientific theories are concerned, not with particular instances of things, but rather with universals or types. Data is gathered to reflect the shared universal features of instances. Cells, cell nuclei, cell membranes and so on form types that scientists refer to, not by virtue of this or that cell, but rather by virtue of the universal features shared by cells observed in many different contexts.

4 Realizable Entity

Functions, roles, dispositions and capabilities are associated with certain kinds of processes or activities in which they can be realized. For example:

- a screwdriver's function is realized in the actual process of turning a screw,
- the function of the camera eye is realized when a picture is taken,
- a person's role as a stenographer is realized during the trial proceedings in a court room,
- the Waterford crystal's fragile disposition is realized as it smashes on the floor, and
- the wooden door's capability to expand is realized in the hot and humid months of summer.

Functions, roles, dispositions and capabilities are *realizable entities* in BFO. A *realizable entity* is defined as a specifically dependent continuant that has an independent continuant entity as its bearer, and whose instances can be realized (manifested, actualized, executed) in associated processes in which the bearer participates.

Typically an instance of a realizable entity is realized throughout the course of its existence. However it may exhibit periods of dormancy, when it exists by inhering in its bearer but is not manifested—as, for example, in the case of diseases which are marked by periods of dormancy, or by many occupational roles, which are not realized when the bearer is asleep. Some realizables, such as the function of a sperm to penetrate an ovum, may be such that they can be manifested only once in their lifetime; or, as again in the case of sperm, they may be such that they are realized only in very rare cases. Others, such as the function of the heart to pump blood, are realized continuously.

The above implies an absolute distinction between being the bearer of a realizable entity, and exercising or realizing this entity in some activity or process, as in:

- the person has the role of nurse, and exercises this role when administering a prescribed drug to a patient in the hospital,
- each atom of element A has the disposition to become an atom of element B in radioactive decay, and this disposition is realized when element B comes into existence from A, and
- the ladle has the function of holding liquids, but may never exercise this function because it sits packaged on the shelf of a stock room.

We are now in a position where we can define the three sub-types of realizable entities recognized by BFO—role, disposition, function, and capability.

5 Role (Externally-Grounded Realizable Entity)

A role is a realizable entity which exists because the 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.¹⁹

‘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 portion of penicillin to act as a drug,
- the role of bacteria in causing infection, and
- the role of a stone in marking a boundary.

Roles are optional. A person can lose the role of student without being physically changed. Because a role is not a reflection of the in-built physical make-up of its bearer, there are therapeutic and prophylactic roles, and input and output roles. For example, the primary function—or input role—of mitochondria is to produce adenosine triphosphate (ATP).²⁰ However, given that they produce high levels of oxidative stress, these same mitochondria play an output role in Alzheimer’s disease. 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 plasticized prop in a museum display. Water does not have any function *per se*, but it does play many different roles, for example in helping to initiate the growth process of a seed, or in a hydroelectric experiment, or in washing clothes.

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 that they be lawyers or surrogates.

There is also a distinction between *having* a role and *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. In contrast to ‘function’ (which we define shortly) the term ‘role’ designates a realizable entity whose manifestation brings about some result or end that is not typical of its bearer in virtue of the latter’s physical make-up.

In the narrow sense that concerns us here, roles are specifically dependent instances. A role exists only when some independent continuant serves as its bearer. For example: Jane Doe’s present role as director of this institute, or Joe Brown’s role in that play being performed tonight on Broadway. The term ‘role’ can be used in a broader sense in contexts such as Jane is the seventh person to fill the role of director of our institute.

6 Disposition (Internally-Grounded Realizable Entity)

It is common to find researchers making claims like:

- 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 endocytosis and exocytosis,
- certain people have a disposition to develop colon cancer, and
- children are innately disposed to categorize objects in certain ways.

(1) A *disposition* is a realizable entity which is such that, if it ceases to exist, then its bearer is physically changed, and whose realization occurs in virtue of the bearer’s physical make-up when this bearer is in some special physical circumstances.²¹

Unlike roles, dispositions are not optional. If an entity is a certain way, then it has a certain disposition, and if it ceases to be that way, then it loses that disposition. A disposition is also known 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.

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 such that there exists a statistical, concomitant correlation present between two entities, if they are in certain circumstances. Examples of weaker forms of disposition include:

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

- a person who smokes two packs of cigarettes a day throughout adulthood has the disposition to die of a disease earlier than average, and
- crime has the disposition to rise in heavily populated cities during the summer months.

Further, we are referring to weaker forms of disposition when we consider genetic and other risk factors for specific diseases.

By contrast, we can distinguish a stronger form of disposition, known as a sure-fire disposition, which is generally executed as a rule. Examples of sure-fire disposition include:

- the skin has the sure-fire disposition to be penetrated by a needle when a phlebotomist takes blood,
- a car windshield has a sure-fire disposition to break if it is struck with a sledgehammer moving at 100 feet per second, and
- a cell has the sure-fire disposition to become diploid following mitosis,
- a magnet has a sure-fire disposition to produce an electrical field.

7 Function

A function is a disposition that exists in virtue of the bearer's physical make-up,^{22, 23} 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, and
- 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) and, in the artifact case, something which the bearer has been constructed to have (as in an Erlenmeyer flask designed to hold liquid).

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, for example, because of its physical make-up the heart's function is to pump blood and not merely to thump or produce sounds, which are by-products of the heart's proper functioning.²⁴

Like disposition, a function is an internally-grounded realizable entity: it is such that if it ceases to exist, then its bearer is physically changed. A non-functioning lung or attic fan would indicate that the physical make-up of these things had changed—in the case of the lung, possibly a cancerous lesion; in the case of the attic fan, possibly a screw missing. These entities would still have their function, but they

would not be capable of functioning until the physical change is rectified. The entities would lose their function 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. Thus, if a continuant has a function, then it is built to exercise this function reliably on the basis of its physical make-up. But again, a function need not in every case be exercised or manifested: its bearer may be broken, or it may never be in the right kind of context, or provided with the right kind of input.

We can distinguish two varieties of function, artifactual function and biological function.

8.1 Artifactual Function

An artifactual function is a function whose bearer's physical make-up has been designed and made intentionally (typically by one or more human beings) to function in a certain way, and whose instances are similarly designed and made intentionally, and do indeed reliably function in this way.²⁵ (Dipert, 1993; McLaughlin, 2001). Examples include:

- the function of a pycnometer to hold liquid,
- the function of a fan to circulate air, and
- the function of a Bunsen burner to produce a flame.

8.2 Biological Function

A biological function is a function whose bearer is part of an organism, and exists and has the physical make-up it has because it has evolved that way and contributes to the organism's realization of a life plan appropriate to an organism of its type.

A biological function is a function whose bearer is part of an organism, and that bearer's existence and physical make-up is due to having evolved in a way that contributes to the organism's fulfillment of an appropriate life-plan. Examples include:

- the function of a mitochondrion in the production of ATP, and
- the function of the wax-producing mirror gland of the worker honey bee to produce beeswax.

Note that we do not define biological function in terms of giving rise to processes conducive to an organism's survival. This is because the manifestations of biological functions are not in every case beneficial to the survival of the corresponding organism, as in organisms that die when they reproduce, such as *Arabis laevigata* and *Octopus luteus*. Rather, functions are such that their realizations contribute to the corresponding organism's fulfillment of a life that is typical or characteristic for an organism of its kind.

Biological functions are, according to the proposed definition, attributed to parts of organisms and not to whole organisms themselves; thus, your heart, liver, and other bodily organs have functions, but you yourself do not. It is not appropriate to say that the queen bee and the worker bee have functions they perform in the hive, despite that fact that they are genetically programmed to perform their specific tasks. Rather, the queen and worker bees have roles they fulfill, and parts of their bodies have functions which are performed in the maintenance of the hive. Support for this view is provided by the fact that

the queen and worker bees can lose their roles when the hive is attacked, and can take on soldier bee roles in defense of the hive, if necessary.²⁶

The dichotomy between biological and artifactual function is reflected in the construction of two domain ontologies. Thus, the ontologies of artifactual and biological functions have already been proposed as a complement to the Gene Ontology's molecular function and biological process ontologies.

Taking account of what has been communicated thus far, from the point of view defended by BFO, we should correctly state:

- the (or a) function of the heart is to pump blood,
- the role of the surrogate is to stand in for the patient,
- blood has the disposition to coagulate, and
- that patient has suicidal tendencies.\

8 Conclusion

Given that numerous research groups are now utilizing BFO as an upper-level framework to assist in the organization and integration of biomedical information, it is important to distinguish clearly between the types of realizable entities that significantly feature in domain ontologies for the sciences. We hope to have provided more detailed classification of terms that will assist scientific researchers as they develop high-quality domain ontologies.

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REFERENCES

- ¹ <http://www.obofoundry.org/>.
- ² BioPAX, <http://www.biopax.org/>; also see BioPAX-OBO at <http://neurocommons.org/page/BiopAX-OBO>.
- ³ Science Commons, <http://sciencecommons.org/>.
- ⁴ Ontology Works, <http://www.ontologyworks.com/>.
- ⁵ National Cancer Institute, <http://www.cancer.gov/>.
- ⁶ Computer Task Group, <http://www.ctg.com/>.
- ⁷ Grenon, P. and Smith, B. (2004) SNAP and SPAN: Towards dynamic spatial ontology. *Spatial Cognition and Computation*, **4**, 99–104.
- ⁸ Smith, B. and Grenon, P. (2004) The cornucopia of formal-ontological relations. *Dialectica*, **58**, 279–296.
- ⁹ See Holger Stenzhorn (<http://www.ifo-mis.org/bfo>).

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- ¹⁰ Ariew, A. and Perlman, M. (2002) Introduction. In A. Ariew, R. Cummins, and M. Perlman, eds., *Functions: New Essays in the Philosophy of Psychology and Biology*, Oxford University Press, New York, 1–7.
- ¹¹ Dipert, R. (1993) *Artifacts, Art Works, and Agency*. Temple University Press, Philadelphia.
- ¹² Perlman, M. (2004) The modern philosophical resurrection of teleology. *The Monist*, 87, 3–51.
- ¹³ Shrager, J. (2003) The fiction of function. *Bioinformatics*, **19**, 1934–1936; Churchland, P. (1995) *The Engine of Reason, the Seat of the Soul: A Philosophical Journey into the Brain*. MIT Press, Cambridge, MA.
- ¹⁴ <http://www.geneontology.org/>.
- ¹⁵ See Hamann, B. (2006) *Disease: Identification, Prevention, and Control*. McGraw-Hill, New York; Boorse, C. (1975) On the distinction between disease and illness. *Philosophy and Public Affairs*, **5**, 49–68.
- ¹⁶ WHO (N.D.) International Classification of Functions, Disabilities and Health (ICF) at: <http://www.who.int/classifications/icf/en/>.
- ¹⁷ Zhou, M. and Ouyang, W. (2003) The function role of GATA-3 in Th1 and Th2 differentiation. *Immunological Research*, 28, 25.
- ¹⁸ Hunter, L. (2009) *The Processes of Life: An Introduction to Molecular Biology*. MIT Press, Cambridge, MA.
- ¹⁹ <http://www.ifomis.org/bfo>.
- ²⁰ Evans, T., Zhu, X., Lee, H., Preville, L., Webber, K., Casadesus, G., Perry, G., and Smith, M. (2006) Alzheimer's disease: A deregulated cell cycle disease. In M. Sun, ed., *Research Progress in Alzheimer's Disease and Dementia* (pp. 109–122). Nova Publishers, New York.
- ²¹ Jansen, L. (2007) Tendencies and other realizable in medical information sciences. Available at: <http://ontology.buffalo.edu/bfo/Tendencies.pdf>.
- ²² Johansson, I., Smith, B., Munn, K., Tsikolia, N., Elsner, K., Ernst, D., and Siebert, D. (2005) Functional anatomy: A taxonomic proposal. *Acta Biotheoretica*, 53, 53–66.
- ²³ Mizoguchi, R. and Kitamura, Y. (Forthcoming) A functional ontology of artifacts. *The Monist*.
- ²⁴ Millikan, R. (1984) *Language, Thought, and Other Biological Categories*. MIT Press, Cambridge, MA. Chapters 1 and 2.
- ²⁵ McLaughlin, P. (2001) *What Functions Explain: Functional Explanation and Self-Reproducing Systems*. Cambridge University Press, Cambridge, UK. Chapter 3, 42–62.
- ²⁶ Breed, M., Robinson, G., and Page, R. (2003) Division of labor during honey bee colony defense. *Behavioral Ecology and Sociobiology*, 27, 395–401.