Introduction to the Reference Ontology *Basic Formal Ontology (BFO)*

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Outline

• Introduction
• BFO and the OBO Foundry
• The Basic Formal Ontology (BFO)
• Background of BFO
• Principles behind BFO
• Conclusion
INTRODUCTION
Ontologies Are Used For...

• Annotating data with controlled vocabulary ➔ avoid silos

• To allow computers to
  – Link heterogeneous data (e.g., text, image, databases)
  – Reason on data

• To help in
  – Scientific discovery (e.g., compare research data about mice and humans)
  – Search and find data (e.g., Internet, phone, maps)
  – NLP & AI applications (e.g., machine translation, robotics)
  – etc.
The Problem

• The very success of the approach leads to the creation of ever new controlled vocabularies – semantic silos – as ever more ontologies are created in *ad hoc* ways

• Every organization and sub-organization now wants to have its own “ontology”

→ The more this sort of Semantic Technology is successful, they more it fails

→ Limits interoperability of ontologies within and across domains
The Solution

• Using a common ontology framework
  – Upper-level ontology ➔ reference or foundational ontology for lower level ontologies
  – Heterogeneous data becomes
    • Retrievable
    • Comparable
    • Integratable
• Has to be strong enough to deal with any kind of entities
• Requires establishing a convention & getting everyone to follow it
BFO

• A simple upper-level ontology to support information integration in scientific research and other domains

• Defining a framework that will help to ensure consistency and non-redundancy of the ontologies created in its terms
<table>
<thead>
<tr>
<th><strong>top level</strong></th>
<th><strong>mid-level</strong></th>
<th><strong>domain level</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Formal Ontology (BFO)</strong></td>
<td><strong>Information Artifact Ontology (IAO)</strong></td>
<td><strong>Ontology for Biomedical Investigations (OBI)</strong></td>
</tr>
<tr>
<td>Anatomy Ontology (FMA*, CARO)</td>
<td>Environment Ontology (EnvO)</td>
<td>Infectious Disease Ontology (IDO*)</td>
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<tr>
<td>Cell Ontology (CL)</td>
<td>Cellular Component Ontology (FMA*, GO*)</td>
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<td>Subcellular Anatomy Ontology (SAO)</td>
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<tr>
<td>Sequence Ontology (SO*)</td>
<td></td>
<td>Molecular Function (GO*)</td>
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<td>Protein Ontology (PRO*)</td>
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</table>

Extension Strategy + Modular Organization
BFO AND THE OBO FOUNDRY
The Open Biological and Biomedical Ontologies (OBO) Foundry

• Common architecture of ontologies to support consistency, non-redundancy, modularity
• Based on BFO
• Compliance to the OBO Foundry Principles ➔ all ontologies built in the same way
• Coordination work between the different ontologies ➔ avoid redundancies
• Review process to be included
<table>
<thead>
<tr>
<th>RELATION TO TIME</th>
<th>CONTINUANT</th>
<th>OCCURRENT</th>
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<tbody>
<tr>
<td>GRANULARITY</td>
<td></td>
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<tr>
<td>ORGAN AND ORGANISM</td>
<td>Organism (NCBI Taxonomy)</td>
<td>Anatomical Entity (FMA, CARO)</td>
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<td>Biological Process (GO)</td>
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<td>Cell (CL)</td>
<td><strong>Cellular Component</strong> (FMA, GO)</td>
</tr>
<tr>
<td>MOLECULE</td>
<td>Molecule (ChEBI, SO, RnaO, PrO)</td>
<td><strong>Molecular Function</strong> (GO)</td>
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The Open Biomedical Ontologies (OBO) Foundry

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### Population-level ontologies

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<tr>
<td>COMPLEX OF ORGANISMS</td>
<td>Family, Community, Deme, Population</td>
<td>Population Phenotype</td>
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<td>GRANULARITY</td>
<td>INDEPENDENT</td>
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http://obofoundry.org

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<td>Cell (CL), Cell Component (FMA, GO)</td>
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<td>MOLECULE</td>
<td>Molecule (ChEBI, SO, RnaO, PrO)</td>
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Environment of population
Environment of single organism
Environment of cell
Molecular environment

http://obofoundry.org
THE BASIC FORMAL ONTOLOGY (BFO)
BFO 2.0
A Formal Upper-Level Ontology

• Limited to very general categories and relations ➔ completely domain neutral

• Provides a common neutral backbone for lower level ontologies
  – Was originally created to integrate biomedical ontologies
  – Now extended to other domains (e.g., emotions, military, finance)

• Formally defined categories and relations ➔ logical axioms and definitions

• OWL implementations
Neurological Disease Ontology (ND)

https://code.google.com/p/neurological-disease-ontology/
About BFO

• Created at the State University of NY at Buffalo
• Developed by philosopher Barry Smith and an interdisciplinary team (philosophers, logicians, computer scientists & 100+ members of the BFO discussion group)
• Widely Used
  – Ontologies (100+)
  – Institutions, groups & projects (40+)
• Actively developed (versions: BFO 1.0, BFO 1.1, BFO 2.0)
• Well documented
  – Specifications
  – Wide academic literature
BACKGROUND OF BFO
A Realist Ontology

• BFO represents the kinds of entities in reality and the relations between these entities
• Entity types are organized according to philosophical distinctions
• BFO is consistent with the scientific knowledge of the world

Scientific realism coupled with realism about the everyday world
Based on Aristotle’s Metaphysics

On the Aristotelian reading the *world itself* exhibits a species-genus structure independently of how we conceive it and we do our best to map this structure in our representations.
For Aristotle...

• The world is organized via types/universals/categories which are hierarchically organized

• Things are either
  – Substances
  – Accidents

• Which are either
  – Universal
  – Particular
Aristotle’s Ontological Square

<table>
<thead>
<tr>
<th></th>
<th>Substantial</th>
<th>Accidental</th>
</tr>
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<tbody>
<tr>
<td><strong>Universal</strong></td>
<td>Second substance</td>
<td>Second accident</td>
</tr>
<tr>
<td></td>
<td><em>man</em></td>
<td><em>headache</em></td>
</tr>
<tr>
<td></td>
<td><em>cat</em></td>
<td><em>sun-tan</em></td>
</tr>
<tr>
<td></td>
<td><em>ox</em></td>
<td><em>dread</em></td>
</tr>
<tr>
<td><strong>Particular</strong></td>
<td>First substance</td>
<td>First accident</td>
</tr>
<tr>
<td></td>
<td><em>this man</em></td>
<td><em>this headache</em></td>
</tr>
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<td></td>
<td><em>this ox</em></td>
<td><em>this dread</em></td>
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An Aristotelian Framework

• Genus-species hierarchies of
  – *Substance universals/objects*: what a thing is
    (things, substances, organisms, e.g., *cow*, *man*, *rock*, *planet*)
  – *Accidents*: how a thing is (e.g., *red*, *hot*, *suntanned*, *spinning*)

• *Universals* are instatiated in *particulars*

• *Substances* are the bearers of *accidents*
species, genera

instances

siamese cat mammal animal organism substance frog
Accidents: Species and instances

this individual accident of redness

(this token redness – here, now)
Substances are the *bearers* of accidents

= relations of inherence
(one-sided existential dependence)
Extension of Aristotle’s Ontological Square

• However, not everything in reality is either a substance or an accident
  – Holes
  – Boundaries

• We need more than the ontological square
Positive and Negative Parts

positive part
(made of matter)

negative part
or hole
(not made of matter)
Holes Involve Two Kinds of Boundaries

• Bona fide boundaries *which exist independently of our demarcating acts*

• Fiat boundaries *which exist only because we put them there* (non-physical boundaries)
Examples

• Of bona fide boundaries:
  an animal’s skin, the surface of the planet

• Of fiat boundaries:
  the plane separating the Northern and Southern hemispheres, the North Pole, some portion of airspace
Mountain

• Bona fide upper boundaries with a fiat base:
Where Does the Mountain Start?

... a mountain is not a substance

➔ Part of a substance separated from the whole by a fiat boundary
A Hole In The Ground

• Solid physical boundaries at the floor and walls
  but with a lid that is not made of matter
  (⇒ neither a substance nor an accident):

![Diagram of a hole with fiat boundary](image-url)
Fiat boundaries

Boundaries corresponding to physical discontinuities

Brain Regions
Aristotle 1.5

an ontology of substances + accidents + holes (and other entities not made of matter) + fiat and bona fide boundaries + artefacts and environments

(For more details: http://ontology.buffalo.edu/smith/IntroOntology_Course.html)
PRINCIPLES BEHIND BFO
Three Fundamental Dichotomies

Continuant (thing, quality ...) \iff \text{Occurrent (process, event)}

Dependent \iff \text{Independent}

Type \iff \text{Instance}
An entity that exists in full at any time in which it exists at all, persists through time while maintaining its identity, and has no temporal parts.

An entity that has temporal parts and that happens, unfolds or develops in time. Extended both in space (occupy a definite spatial location at every time during which they exist), and also in time.
depends_on

Continuant

Independent Continuant
thing

Dependent Continuant
quality

Occurrent
process, event

quality depends on bearer
depends_on

Continuant

Independent Continuant
thing

Dependent Continuant
quality, ...

Occurrent

process, event

event depends on participant

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Type-level relations presuppose the underlying instance-level relations

A part_of B =def. All instances of A are instance-level-parts-of some instance of B
  e.g. human heart part_of human

A has_participant B =def. All instances of A have an instance of B as instance-level participant
  e.g. cell binding has_participant cell
instance_of

types

Continuant

Independent Continuant

thing

Dependent Continuant

quality

Occurrent

process, event

instances
depends_on

Continuant

Independent Continuant
thing

Dependent Continuant
quality

Occurrent
process, event

temperature depends on bearer

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Specifically Dependent Continuants

- Quality, Pattern
- Realizable Dependent Continuant

if the bearer ceases to exist, then its quality, function, role ceases to exist

- the color of my skin
- the function of my heart to pump blood
- my weight
Specifically dependent continuants

- the *quality* of whiteness of this cheese
- your *role* as lecturer
- the *disposition* of this patient to experience diarrhea
"red" instantiates an instance of an eye (in a particular fly).

The particular case of redness (of a particular fly eye) depends on an instance of an eye (in a particular fly).
realization depends_on realizable
Continuant

Independent Continuant

Dependent Continuant

Non-realizable Dependent Continuant (\textit{quality})

Realizable Dependent Continuant (\textit{function, role, disposition})
Realizable dependent continuants

- plan
- function
- role
- disposition
- capability
- tendency

continuants
Their realizations

- execution
- expression
- exercise
- realization
- application
- course

{ occursents
Generically Dependent Continuants

if one bearer ceases to exist, then the entity can survive, because there are other bearers

(copyability)

the pdf file on my laptop
the DNA (sequence) in this chromosome
CONCLUSION
Benefits of BFO

• Small, simple, rigorously tested
• Large community of users and maintainers
• Top-down development methodology has been shown to work in many different domains
• Humanly intelligible
• Compatible with top-level of DOLCE
• A genuine top level
Using BFO to Model Definition

Contents

• Come to my next talk to learn about
  – The application of BFO to the creation of models for definition writing
References

• Barry Smith, *Ontological Engineering* course, University at Buffalo, “Ontology and the Semantic Web” slides, August 26, 2013
  (http://ncorwiki.buffalo.edu/index.php/Ontological_Engineering#August_26:_Basic_Introduction_to_Ontology)

• Barry Smith, *An Introduction to Ontology: From Aristotle to the Universal Core*, Training course in eight lectures
  (http://ontology.buffalo.edu/smith/IntroOntology_Course.html)
  — “1. Ontology as a Branch of Philosophy” slides
  — “7. Towards a Standard Upper Level Ontology” slides

• Barry Smith, *Introduction to Basic Formal Ontology (BFO) 2012*
  (http://www.youtube.com/watch?v=Yl6_M1sQEAQ&feature=youtu.be)