Building Ontologies with Basic Formal Ontology

Barry Smith
Federal Big Data Working Group
August 31, 2015
Preamble

The Yosemite Project for Healthcare Information Interoperability

David Booth, HRG and Rancho BioSciences
Conor Dowling, Caregraf
Michel Dumontier, Stanford University
Josh Mandel, Harvard University
Claude Nanjo, Cognitive Medical Systems
Rafael Richards, Veterans Affairs

9-Jul-2015
These slides: http://tinyurl.com/YosemiteRoadmap20150709slides

http://YosemiteProject.org/
Interoperability Roadmap

Healthcare Information Interoperability

Standardize the Standards

Incentivize

RDF as a Universal Information Representation

Crowdsourced Translations

http://YosemiteProject.org/
RDF graph

English assertions:

Patient319 has name "John Doe".
Patient319 has systolic blood pressure observation Obs_001.
Obs_001 value was 120.
Obs_001 units was mmHg.

RDF* assertions ("triples"):

ex:patient319 foaf:name "John Doe" .
ex:obs_001 v:value 120 .
ex:obs_001 v:units v:mmHg .

*Namespace definitions omitted
Different source formats, same RDF

HL7 v2.x

```
OBX|1|CE|3727-0^BP systolic, sitting|120|mmHg|
```

Maps to

FHIR

```
<Observation
  xmlns="http://hl7.org/fhir">
  <system value="http://loinc.org"/>
  <code value="3727-0"/>
  <display value="BP systolic, sitting"/>
  <value value="120"/>
  <units value="mmHg"/>
</Observation>
```

Maps to

RDF graph
Why RDF?

"Captures information content, not syntax"
"Multi-schema friendly"
"Allows diverse data to be connected and harmonized"
"Good for model transformation"
"Supports inference"

- Endorsed by over 100 thought leaders in healthcare and technology as the best available candidate for a universal healthcare exchange language
  - See http://YosemiteManifesto.org/

http://dbooth.org/2014/why-rdf/
RDF and OWL enable semantic bridges between standards

- Goal: a cohesive mesh of standards that act as a single comprehensive standard
Needed: Collaborative Standards Hub

- Cross between BioPortal, GitHub, WikiData, Web Protege, CIIMI repository, HL7 model forge, UMLS Semantic Network and Metathesaurus
  - Next generation BioPortal?
Welcome to BioPortal! For help using BioPortal, click on this icon.
Class Search

Search for a class in multiple ontologies

obesity

[advanced options]

Obesity - Systematized Nomenclature of Medicine - Clinical Terms (SNOMEDCT)
http://purl.bioontology.org/ontology/SNOMEDCT/414916001

details  visualize  22 more from this ontology

Obesity - National Cancer Institute Thesaurus (NCIT)
http://ncicb.nci.nih.gov/xml/owl/EVS/Thesaurus.owl#C3283

Having a high amount of body fat (body mass index [BMI] of 30 or more).

details  visualize  4 more from this ontology

obesity - Human Disease Ontology (DOID)
http://purl.obolibrary.org/obo/DOID_9970

OMIM mapping confirmed by DO. [SN].

details  visualize
Class Search
Search for a class in multiple ontologies

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Obesity - Systematized Nomenclature of Medicine - Clinical Terms (SNOMEDCT)
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Obesity - Human Disease Ontology (DOID)
http://purl.obolibrary.org/obo/DOID_9970
OMIM mapping confirmed by DO. [SN].

Additional References from other Ontologies

Obesity - Natural Products Ontology (NATPRO)
http://www.owl-ontologies.com/NPOntology.owl#DOID_9970

Obesity, unspecified - Suggested Ontology for Pharmacogenomics (SOPHARM)
http://www.loria.fr/~coulet/ontology/sopharm/version2.1/disease_ontology.owl#DOID_1480
**Obesity - Medical Dictionary for Regulatory Activities (MEDDRA)**

[Link](http://purl.bioontology.org/ontology/MEDDRA/1001458)

**Obesity - Human Phenotype Ontology (HP)**

[Link](http://purl.obolibrary.org/obo/HP_0001513)

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**Additional References from other Ontologies**

**Obesity - Bone Dysplasia Ontology (BDO)**

[Link](http://purl.obolibrary.org/obo/BDO_0001513)

An eating-related disorder in which excess body fat has accumulated to such an extent that health may be negatively affected. It is commonly defined as a body mass index (weight divided by height squared) of ...

---

**Obesity - Experimental Factor Ontology (EFO)**

[Link](http://www.ebi.ac.uk/efo/EFO_0001023)

An eating-related disorder in which excess body fat has accumulated to such an extent that health may be negatively affected. It is commonly defined as a body mass index (weight divided by height squared) of ...
Obesity - Medical Subject Headings (MeSH)
http://purl.bioontology.org/ontology/MeSH/D00765
A status with body weight that is grossly above the acceptable or desirable weight, usually due to accumulation of excess fats in the body. The standards may vary with age, sex, genetic or cultural background. …

details - visualize - 3 more from this ontology

Additional References from other Ontologies

Obesity - Robert Hoehndorf Version of MeSH (RH-MESH)
http://phenomrowser.net/ontologies/mesh/mesh.owl#P0007.100.100.160.120.396.500

details - visualize - 15 more from this ontology

Obesity - Online Mendelian Inheritance in Man (OMIM)
http://purl.bioontology.org/ontology/OMIM/MTHU000250

details - visualize - 31 more from this ontology

Obesity - International Classification of Diseases, Version 10 (ICD10)
http://purl.bioontology.org/ontology/ICD10/ES6

details - visualize - 2 more from this ontology

Obesity - Read Codes, Clinical Terms Version 3 (CTV3) (RCD)
http://purl.bioontology.org/ontology/RCD/C380

details - visualize - 9 more from this ontology

Obesity - Neuroscience Information Framework (NIF) Standard Ontology (NIFSTD)
http://ontology.neuroinfo.org/NIF/Dysfunction/NIF-Dysfunction.owl#Dys_Dys_20000303
An eating-related disorder in which excess body fat has accumulated to such an extent that health may be negatively affected. It is commonly defined as a body mass index (weight divided by height squared) of …

details - visualize - 3 more from this ontology

OBESITY - Coding Symbols for a Thesaurus of Adverse Reaction Terms (COSTART)
http://purl.bioontology.org/ontology/COSTART/
OBESITY - World Health Organization (WHO) Adverse Reaction Terminology (WHO-ART)
http://purl.bioontology.org/ontology/WHO/0397

details • visualize

obesity - Physician Data Query (PDQ)
http://purl.bioontology.org/ontology/PDQ/CDR00004607910

details • visualize

Obesity - Common Terminology Criteria for Adverse Events (CTCAE)

details • visualize

obesity - Computer Retrieval of Information on Scientific Projects Thesaurus (CRISP)
http://purl.bioontology.org/ontology/CRISP/0467-3154

excessively high accumulation of body fat or adipose tissue in relation to lean body mass; the amount of body fat (or adiposity) includes concern for both the distribution of fat throughout the body and the ... 

details • visualize

Obesity - MedlinePlus Health Topics (MEDLINEPLUS)
http://purl.bioontology.org/ontology/MEDLINEPLUS/C0028754

Obesity means having too much body fat. It is different from being overweight which means weighing too much. The weight may come from muscle, bone, fat, and/or body water. Both terms mean that a person's ... 

details • visualize • 1 more from this ontology

Obesity - Portfolio Management Application (PMA)
http://www.bioontology.org/prma.owl#PMA_956

excessively high accumulation of body fat or adipose tissue in relation to lean body mass; the amount of body fat (or adiposity) includes concern for both the distribution of fat throughout the body and the ... 

details • visualize • 1 more from this ontology

Obesity - Neuroscience Information Framework (NIF) Dysfunction Ontology (NIFDYS)
http://ontology.neuroinfo.org/NIF/Dysfunction/NIF Dysfunction.owl#mhc_dys_20090302

An eating-related disorder in which excess body fat has accumulated to such an extent that health may be negatively affected. It is commonly defined as a body mass index (weight divided by height squared) of ... 

details • visualize • 1 more from this ontology
Obesity - Bleeding History Phenotype Ontology (BHO)
http://www.semanticweb.org/ontologies/2010/10/BHO.owl#Obesity

details • visualize

Obesity - Gden Ontology (GALEN)
http://www.co-ode.org/ontologies/gales#Obesity

details • visualize

Obesity - Resource of Asian Primary Immunodeficiency Diseases (RAPID) Phenotype Ontology (RPO)
http://www.semanticweb.org/ontologies/2012/5/ontology/133652855128556165.owl#Obesity

details • visualize

Obesity - Alzheimer's disease ontology (ADO)
http://scil.fraunhofer.de/Alzheimer-Ontology/obesity

details • visualize • 1 more from this ontology

Obesity - KB Bio 101 (AURA)
http://www.projecthalo.com/aura#Obesity

details • visualize

Obesity - Bilingual Ontology of Alzheimer's Disease and Related Disorders (ONTOAD)
http://de-ontologies.org/ontologies/Alzheimer%20Disease

Excès de poids par augmentation des graisses stockées dans le corps. Elle peut provenir de facteurs héréditaires, d'une alimentation mal équilibrée et trop importante, ou de problèmes hormonaux.

L'obésité ...

details • visualize • 2 more from this ontology

Obesity - Human Dermatological Disease Ontology (DERM0)
http://purl.obolibrary.org/obo/DERM0_0000002

details • visualize

http://purl.bioontology.org/ontology/NDFRT/n000000002200

details • visualize

Large body habitus artifact - Radiology Lexicon (RADLEX)
http://www.nlm-ontologies.com/RADLEX.owl#BMI11305

An artifact resulting from a patient with a large body size or body mass.

details • visualize
**obese - Mammalian Phenotype Ontology (MP)**
http://purl.obolibrary.org/obo/MP_0001261
  - details
  - visualize

**Obesity, unspecified - International Classification of Diseases, Version 9 - Clinical Modification (ICD9CM)**
http://purl.bioontology.org/ontology/ICD9CM/278.00
  - details
  - visualize
  - 1 more from this ontology

**Other obesity - International Classification of Diseases, Version 10 - Clinical Modification (ICD10CM)**
http://purl.bioontology.org/ontology/ICD10CM/E66.8
  - details
  - visualize
  - 1 more from this ontology

**Genetic obesity - Orphanet Rare Disease Ontology (ORDO)**
http://www.orpha.net/ORDO/Orphanet_77828
  - details
  - visualize
  - 1 more from this ontology

**Truncal obesity - Fanconi Anemia Ontology (IFAR)**
http://www.semanticweb.org/ontologies/2012/11/abnormalities.owl#phenodb:0048
  GROWTH and BUILD: Other growth characteristics > Truncal obesity
  - details
  - visualize

**Generalized obesity - Disease core ontology applied to Rare Diseases (HRDO)**
http://www.limics.org/hrdo/rdf#sgn_id_53100
  - details
  - visualize
  - 1 more from this ontology

**Constitutional obesity - Systematized Nomenclature of Medicine, International Version (SNMI)**
http://purl.bioontology.org/ontology/SNMI/D6-11110
  - details
  - visualize
  - 1 more from this ontology
John Fox (Director, OpenClinical)

As a user and teacher of ontological methods in medicine and engineering I have for years warned my students that the design of domain ontologies is a black art with no theoretical foundations and few practical principles.
Linked Open Data: from Musicbrainz to Mouse Genome Informatics
Building Ontologies with Basic Formal Ontology

By Robert Arp, Barry Smith and Andrew D. Spear

Overview
In the era of “big data,” science is increasingly information driven, and the potential for computers to store, manage, and integrate massive amounts of data has given rise to such new disciplinary fields as biomedical informatics. Applied ontology offers a strategy for the organization of scientific information in computer-tractable form, drawing on concepts not only from computer and information science but also from linguistics, logic, and philosophy. This book provides an introduction to the field of applied ontology that is of particular relevance to biomedicine, covering theoretical components of ontologies, best practices for ontology design, and examples of biomedical ontologies in use.

After defining an ontology as a representation of the types of entities in a given domain, the book distinguishes between different kinds of ontologies and taxonomies, and shows how applied ontology supports the analysis of such areas as biological, social, and legal systems.
John Fox, OpenClinical

As a user and teacher of ontological methods in medicine and engineering I have for years warned my students that the design of domain ontologies is a black art with no theoretical foundations and few practical principles. ... I now have a much more positive story for my students. ... In the journey from black art to a truly scientific theory for ontology design, this book is an important milestone.
Table of Contents

1 What Is an Ontology?
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6 Introduction to Basic Formal Ontology II: Occurrents
7 The Ontology of Relations
8 Basic Formal Ontology at Work

Appendix on Implementation / Glossary
Background to BFO

The Gene Ontology (GO) is a controlled, logically structured vocabulary to be used for consistent tagging of omics data and literature

• to make these data discoverable, combinable and analyzable with the aid of computers

Uses of ‘ontology’ in PubMed abstracts
GO’s three sub-ontologies

Gene Ontologies

- Biological process
  - Development
  - Pattern specification
  - Axis specification
  - Adaxial/abaxial pattern formation
  - Adaxial/abaxial axis specification

- Molecular function
  - Binding
  - Nucleic acid binding
  - DNA binding
  - Transcription factor activity
  - Transcription regulator activity

- Cellular component
  - Organelle
  - Membrane-bound organelle
  - Intracellular organelle
  - Intracellular membrane-bound organelle
  - Nucleus
  - Intracellular

cellular component
molecular function
biological process
2004: extending GO with new ontology modules to provide representations of proteins, species, populations, sequences, metabolism, development, diseases, symptoms, anatomy, ...
2004: extending GO with new ontology modules to provide representations of proteins, species, populations, sequences, metabolism, development, diseases, symptoms, anatomy, ...

The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration

Barry Smith¹, Michael Ashburner², Cornelius Rosse³, Jonathan Bard⁴, William Bug⁵, Werner Ceusters⁶, Louis J Goldberg⁷,
<table>
<thead>
<tr>
<th>RELATION TO TIME</th>
<th>CONTINUANT</th>
<th>OCCURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRANULARITY</td>
<td>INDEPENDENT</td>
<td>DEPENDENT</td>
</tr>
<tr>
<td>ORGAN AND ORGANISM</td>
<td>Organism (NCBI Taxonomy)</td>
<td>Anatomical Entity (FMA, CARO)</td>
</tr>
<tr>
<td>CELL AND CELLULAR COMPONENT</td>
<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>
</tr>
</tbody>
</table>

**Original OBO (Open Biomedical Ontologies) Foundry**
(Gene Ontology in yellow)
OBO Foundry grows to encompass further domains

<table>
<thead>
<tr>
<th>Environment Ontology</th>
<th>IAO</th>
<th>OBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organism (NCBI Taxonomy)</td>
<td>Anatomical Entity (FMA, CARO)</td>
<td>Organ Function (FMP, CPRO)</td>
</tr>
<tr>
<td>Cellular Component (FMA, GO)</td>
<td>Cellular Function (GO)</td>
<td>Phenotypic Quality (PATO)</td>
</tr>
<tr>
<td>Molecular Function (GO)</td>
<td>Molecular Process (GO)</td>
<td>Biological Process (GO)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population and Community Ontology (PCO)</th>
<th>Population Phenotype</th>
<th>Population Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organism (NCBI Taxonomy)</td>
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<td>Molecular Function (GO)</td>
<td>Molecular Process (GO)</td>
<td></td>
</tr>
<tr>
<td>Environments (ENVO)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Populations, Communities (PCO)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information Artifacts (IAO)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiments and Investigations (OBI)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RDF and OWL enable semantic bridges between standards

- Goal: a cohesive mesh of standards that act as a single comprehensive standard
A cohesive hierarchy of standards OBO Foundry ontologies extending downwards from BFO

<table>
<thead>
<tr>
<th>Basic Formal Ontology (BFO)</th>
<th>Anatomy Ontology (FMA*, CARO)</th>
<th>Disease Ontology (OGMS, IDO, HDO, HPO)</th>
<th>Information Artifact Ontology (IAO)</th>
<th>Biological Process Ontology (GO)</th>
<th>Ontology of Biomedical Investigations (OBI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cell Ontology (CL)</td>
<td>Subcellular Anatomy Ontology (SAO)</td>
<td>Sequence Ontology (SO)</td>
<td>Molecular Function Ontology (GO)</td>
<td>Experiment, Assay, Measurement Process, ...</td>
</tr>
<tr>
<td></td>
<td>Protein Ontology (PRO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BFO and the 3 Gene Ontologies (GO)

Continuant

Independent Continuant
Dependent Continuant

Occurrent

biological process

cell component
molecular function
<table>
<thead>
<tr>
<th>RELATION TO TIME</th>
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<th>OCCURRENCE</th>
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### Rationale of OBO Foundry Coverage

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<th>Granularity</th>
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<th>Continuant</th>
<th>Occurrent</th>
</tr>
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</tbody>
</table>
How to build an ontology

import BFO into ontology editor such as Protégé
work with domain experts to create an initial mid-level classification
find ~50 most commonly used terms corresponding to types in reality
arrange these terms into an informal is_a hierarchy according to this universality principle
    $A \textit{ is}_a B \equiv \text{every instance of } A \text{ is an instance of } B$
fill in missing terms to give a complete hierarchy
(leave it to domain experts to populate the lower levels of the hierarchy)
Example: The Cell Ontology

For Project: DC_CL

Asserted Hierarchy

owl:Thing

Entity

Continuant

DependentContinuant

IndependentContinuant

FlatObjectPart

Object

Biological_Macromolecule

Cell

CD11c_Low_Plasmacytoid_Dendritic_Cell

CD11c_Negative_Plasmacytoid_Dendritic_Cell

Conventional_Dendritic_Cell

CD8_alpha_Neg_CD11b_Neg_Dendritic_Cell

Immature_CD8_alpha_Neg_CD11b_Neg_Dendritic_Cell

Mature_CD8_alpha_Neg_CD11b_Neg_Dendritic_Cell
examples of the BFO/OBO Foundry approach extended into other domains

<table>
<thead>
<tr>
<th>NIF Standard</th>
<th>Neuroscience Information Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>eagle-I</td>
<td>Integrated Semantic Framework / CTSA Connect</td>
</tr>
<tr>
<td>IDO Core / IDO extensions</td>
<td>Infectious Disease Ontology Suite</td>
</tr>
<tr>
<td>cROP / Planteome</td>
<td>Common Reference Ontologies for Plants</td>
</tr>
</tbody>
</table>
Common Reference Ontologies for Plants (cROP)
Examples of BFO/OBO Foundry approach extended into yet further domains

<table>
<thead>
<tr>
<th>UNEP Ontology Framework</th>
<th>United Nations Environment Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS National Map Ontologies</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>Joint Doctrine Ontologies</td>
<td>US Air Force Research Labs / Training and Doctrine Command (TRADOC)</td>
</tr>
<tr>
<td>TRIP Ontologies</td>
<td>Federal Highway Administration (FHWA) Transportation Research Informatics Platform (TRIP)</td>
</tr>
</tbody>
</table>
Ontologies re-using BFO

ACGT Master Ontology (ACGT MO)
Alzheimer Disease Ontology (ADO)
Adverse Event Ontology (AEO)
Adverse Event Reporting Ontology (AERO)
AFO Foundational Ontology
Actionable Intelligence Retrieval System (AIRS)
Bank Ontology
Beta Cell Genomics Application Ontology (BCGO)
BioAssay Ontology
Bioinformatics Web Service Ontology
Biological Collections Ontology (BCO)
Biomedical Ethics Ontology
Biomedical Grid Terminology (BiomedGT, retired)
BioTop: A Biomedical Top-Domain Ontology
BIRNlex: controlled terminology for annotation of BIRN data sources
Blood Ontology (BLO)
Body Fluids Ontology (BFLO)
Bone Dysplasia Ontology
Cancer Cell Ontology (OncoCL)
Cancer Chemoprevention Ontology (CanCo)
Cardiovascular Disease Ontology (CVDO)
Cell Behavior Ontology (CBO)
Cell Cycle Ontology
Cell Expression, Localization, Development and Anatomy Ontology (CFIDA)

Environment Ontology (ENVO)
Epidemiology Ontology (EO)
Epilepsy and Seizure Ontology (EPSO)
Evolution Ontology (EO)
Experimental Factor Ontology (EFO)
EXperimental ACTioins Biomedical Protocol Ontology (EXACT2)
Exposé: An Ontology for Data Mining Experiments
Flybase Drosophila Anatomy Ontology (FBBt)
Fission Yeast Phenotype Ontology (FYPO)
Flower-Visiting Domain Ontology (FV),
Flower-Visiting Behavior Application Ontology (FVB)
Foundational Model of Anatomy (FMA) Ontology
Gastrointestinal Endoscopy Ontology (GIEO)
Gene Regulation Ontology (GRO)
General Information Model (GIM)
Genomic Feature and Variation Ontology (GFVO)
Gestalt: Federated Access to Cyber Observables for Detection of Targeted Attack
Health Data Ontology Trunk (HDOT)
Human Interaction Network Ontology (HINO)
Human Physiology Simulation Ontology (HuPSON)
Infectious Disease Ontology (IDO)
Information Artifact Ontology (IAO)
Informed Consent Ontology (ICO)
Interaction Network Ontology (INO)
BFO

• A simple, small top-level ontology to support information integration in scientific research
• Thoroughly tested in over 150 ontology development projects
• Large cadre of ontology development experts trained to use it
• No abstracta (numbers, propositions, …)
• No overlap with domain ontologies
BFO Occurrent Ontology

- Processual Entity
  - Process
  - Process Boundary
  - Processual Context

- Spatiotemporal Region
  - Scattered Spatiotemporal Region
  - Connected Spatial Region
    - Spatiotemporal Instant
    - Spatiotemporal Interval

- Temporal Region
  - Scattered Temporal Region
  - Connected Temporal Region
    - Temporal Instant
    - Temporal Interval
BFO implementations

BFO 2.0 OWL (W3C Web Ontology Language (OWL) 2)
BFO 2.0 CLIF (draft) (Common Logic (CL) standard ISO 24707)

See: https://github.com/BFO-ontology/BFO
DOLCE, SUMO, BFO

DOLCE: Domain Ontology for Linguistic and Cognitive Engineering
SUMO: Suggested Upper Merged Ontology
BFO: Basic Formal Ontology (used by ontology projects, especially in biology)
Benefits of coordination

No need to reinvent the wheel
Can profit from lessons learned through mistakes made by others
Can more easily reuse what is made by others
Can more easily inspect and criticize results of others’ work
Leads to innovations in tools and strategies for combining, reusing, and re-engineering ontologies
Building Ontologies with Basic Formal Ontology

By Robert Arp, Barry Smith and Andrew D. Spear

Overview

In the era of “big data,” science is increasingly information driven, and the potential for computers to store, manage, and integrate massive amounts of data has given rise to such new disciplinary fields as biomedical informatics. Applied ontology offers a strategy for the organization of scientific information in computer-tractable form, drawing on concepts not only from computer and information science but also from linguistics, logic, and philosophy. This book provides an introduction to the field of applied ontology that is of particular relevance to biomedicine, covering theoretical components of ontologies, best practices for ontology design, and examples of biomedical ontologies in use.

After defining an ontology as a representation of the types of entities in a given domain, the book distinguishes between different kinds of ontologies and taxonomies, and shows how applied ontology can be used to model the structure of concepts in a clear and precise way.