Formal Ontology and Principles of Knowledge Organization: An Axiomatic Approach

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Ontology

Two meanings:

a) (Formal) Ontology as a research area
b) Ontology as a system of organized knowledge.

ad b) Various degrees of formality possible. In the strongest sense an ontology is an axiomatized and formally represented theory.
Formal Ontology 1

Science/discipline which is concerned with a systematic development of axiomatic theories describing forms and modes of being of the world at different levels of granularity and abstraction.
Formal Ontology 2

is concerned with:

a) Principles for developing category systems
b) Development of top level ontologies
c) Usage of top level ontologies as a framework
   i) to specify domains (domain specification)
   ii) to analyse the entities of a domain (analytical aspect)
   iii) construction of categorizations of a domain and
        of formal axiomatizations (synthetic aspect)
Formal Ontology 3

Interdisciplinary Relations

Philosophy → Logic → Artif. Intelligence → Cognitive Science

Formal Ontology
A category is presented by a linguistic expression F describing a system of conditions which can be

- predicated of entities (pred(C,e))
- satisfied by entities (sat(e,C))
- instantiated by entities (e:C)
Individuals are items that are

- not instantiable
- singular beings
- numerical one
Categories and Individuals 3

category: independent of space and time

Concrete Individuals: in space and time

Category(Frog)
Ontologies

Ontologies as knowledge bases

- An ontology is an axiomatization of a conceptualization represented in a formal language:
  \[ \text{Ont}(D) = (\text{Conc}(D), \text{Rel}(D), \text{Ax}(\text{Conc}(D) \cup \text{Rel}(D))) \]
  \[ \text{Ax}(\text{Conc}(D) \cup \text{Rel}(D)) \] exhibits a set of expressions of a formal language, defining the concepts and relations implicitly.

- Formal languages for representation:
  - logic languages (FOL, DL, CL, OWL)
  - graph-based systems (semantic nets, conceptual graphs, OBO-format)
GFO 1

GFO admits various types of categories

- Aristotelian Universal
- Platonic Universal
- Concept
- Symbol
Onto-Axiomatic Method 1

Development of an ontology for a domain D
Steps:
(1) Domain Specification
(2) Conceptualization
(3) Axiomatization
(4) Implementation

This method uses GFO as a framework.
Onto-Axiomatic Method 2

1. step: Informal knowledge \(\rightarrow\) Domain Specification
2. Step: Domain Specification \(\rightarrow\) Conceptualization
3. Step: Conceptualization \(\rightarrow\) Axiomatization

3. Step described in more detail:

Given: Conceptu(D) = (Conc(D), Rel(D)) of a domain D, and a logical formal language L.

The concepts and relations from Conc(D) are divided into:
- primitive concepts and relations: PrimConc(D) \(\cup\) PrimRel(D)
- derived concepts and relations: DefConc(D) \(\cup\) DefRel(D)
Onto-Axiomatic Method 3

Derived concepts $C(x)$ and relations are introduced by definitions that use primitive concepts and relations

$$C(x) \leftrightarrow \Phi(x, P(1), \ldots, P(m), R(1), \ldots, R(n)), \text{ P(i), R(j) are primitive.}$$

The primitive concepts and relations are specified by axioms which define the semantics of these relations and predicates implicitly.

(Axiomatic Method by D. Hilbert).

The onto-axiomatic method integrates the axiomatic method with a top level ontology TLO.
Onto-Axiomatic Method 4

The core of the onto-axiomatic method consists in a construction of an axiomization out of a conceptualization
Conceptu(D) = (Conc(D), Rel(D)) and a top level ontology.
In our framework this top level ontology is GFO.

Conceptu(D) ⊗ GFO ∈ Ax(Conceptu(D))
The construction ⊗ is called ontological foundation

Forms of ontological foundation:
- ontological embedding,
- ontological reduction
Onto-Axiomatic Method 5

Simplest form of ontological foundation is embedding. *Ontological embedding.*

of Conceptu(D) = (Conc(D), Rel(D)) in GFO.

Task: Find a function \( f \) from \( \text{Conc}(D) \) into \( \text{Conc}(\text{GFO}) \) such that for \( c \) in \( \text{Conc}(D) \) holds *\( c \) is-a \( f(c) \).*

Example: *house* \( \in \) \( \text{Conc}(D) \), *material object* \( \in \) \( \text{Conc}(\text{GFO}) \),

\[ f(\text{house}) = \text{material object} \]

*house is-a* \( f(\text{house}) = \text{material object} *\)
Onto-Axiomatic Method 6

Conc(D)                                  GFO

House                                     Material Object

is-a
Conceptualizations 1

Graduated Conceptualizations provide a refinement of conceptualizations

- Let $\text{Conceptu}(D) = (\text{Conc}(D), \text{Rel}(D))$ be a conceptualization of the domain $D$.
- The set $\text{Conc}(D)$ can be classified into
  - principal categories ($\text{PC}$)
  - elementary categories ($\text{EC}$)
  - aspectual categories ($\text{AC}$)

$\text{PC} \subseteq \text{EC} \subseteq \text{AC}$ (graduated conceptualization)
Conceptualizations 2

- Aspectual Categories
  - are derived from elementary categories
  - uses basic categories as dimensions
  - uses facet analysis
Conceptualizations 3 (Examples)

Classical Biology

- *Principal categories* (first order):
  organism (autopoietic systems)
- *principal categories* (second order):
  species

- *Elementary categories*:
  Kingdom, Order, Family, Genus, Species.
Conceptualizations 4 (Examples)

Aspectual derivatives
  African elephant (elementary).
  Open-ended set of aspectual derivatives:

  - African elephants in South Africa of a certain location during a certain time interval.
  - African elephants living in Zoos of Germany.
Conceptualizations 5 (Example)

- African elephants used by Hannibal in invading the Roman empire.

- General principle: Take a natural language sentence $F$ in which the term “African elephant” occurs, $F(Ae)$. Consider the collection of all Afr. elephants which occur in all situations making the sentence $F$ true.
Levels of Reality

- Objective ideal entities (numbers, ideas, sets,..) Platonic ideas
- Immanent Universals (dependent on the material stratum)
- Concepts (dependent on the psychological and the social stratum.)

Entities independent of time and space

Psychological Stratum

Social Stratum

Material Stratum
Information Crisis 1

The *information crisis* describes the present situation caused by

- Increase of generation of information
- New information technologies
- Internet
- Increasing of memory capacity
- Copy and transfer of digital texts
- Creation of virtual worlds.
- ...

These processes lead to an information overload.
STATEMENT OF THE PROBLEM AND RATIONALE FOR CONCEPT

- Increasing complexity of multidimensional problems and resulting need to integrate diverse data and information sources in resolving problems must be:
  a) disciplinary (all disciplines),
  b) Intersectorial (gov., industry, academia, public),
  c) international (even for local or national problems there are usually some international dimensions)

- Proliferation of databases and digital information at all these levels make finding, understanding, and using all of the relevant information extremely difficult, if not impossible

- Numerous barriers to effective integration exist
Towards a Solution
Development of a Conceptual Superstructure or Scaffolding (Cognitive Panorama)

Potential Applications,
In research, Policymaking, Business Planning, Education,...
Examples, Summary, E: Summary of broad applicability
The cognitive panorama is a superstructure, introduced in that defines and identifies topics as logical places, displays relations and connections within these topics or issues.

The proposed cognitive panorama allows us to embody and map concepts in their context and develop common frames of reference. Such a conceptual superstructure helps us to locate and become aware of what we know or miss, where we are, and what we think, and where we miss, underuse or manipulate information.
Information Crisis 5

Orientation / Generalization

P A N O R A M A

context-

subject-

SPACES

object-
Information Crisis 6

Theses:

- Information overload is caused by a lack of organization of knowledge and by insufficient methods for abstraction and interpretation of data.
- Statistical correlation of data does not imply causation, and a deeper understanding of data can only be achieved by/through theories or models.
- The onto-axiomatic method, top level ontologies, and phenotype ontologies are the basic means for a principled organization of knowledge, and for abstraction and interpretation of data.
- The cognitive panorama can be reconstructed within the framework of the onto-axiomatic method.
Information, according to the axiomatic method, is organized as follows:

I. Data $\rightarrow$ Concepts $\rightarrow$ Knowledge (propositions)
   (levels of abstraction between data and knowledge)

II. Organization of Knowledge
   (levels of abstraction within the knowledge level)
   Domain-knowledge $\rightarrow$ Upper Domain Knowledge $\rightarrow$ Top Level Knowledge
   Domain Knowledge = elementary and aspectual knowledge
Integration and Unification 2

Conceptualizations and knowledge

General Concepts

Elementary Domain Concepts

Aspectual Domain Concepts

General Knowledge

Elementary Domain Knowledge

Aspectual Domain Knowledge
Example 1: GFO-Bio

Ontological foundation of biological knowledge
(embedding in GFO)
Example 2: Surgical Ontologies

General Formal Ontology (GFO)

SOCAS (Surgical Ontology for CAS)

Domain level core ontology

Disease Ontology

External Ontologies

FESSOnt

MLSOnt

Domain level component ontologies

SWOnt

PatientOnt

... ...

Discipline specific ontologies

Instruments

Activities

Repository ontologies

Abstraction level

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Example 3: Visual Perception

Physical energy pattern → Excitation pattern on the retina → Phenomenal object
Example 3 cont.: Visual Perception 2

- Energy pattern
- Excitation pattern of the retina
- Primordial components:
  - edges, lines, colours, component surfaces, component boundaries, etc.
- Intermediate constituents:
  - surfaces, (complete) boundaries, illumination,…
- Phenomenal Object/Entity
- Whole situation or situoid (a situation or situoid can be comprehended as a whole)
- Concepts
- Knowledge
Problems and Future Research

Problem 1 Elaboration of the Integration Schema

Problem 2 Development of Data Acquisition Ontologies

Problem 3 Development of Phenotype/Property Ontologies
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Cognitive Panorama

http://benking.de/ceptualinstitute/visualization.htm

End

Thank you!