Towards a Methodology for Ontology-Driven Conceptual Modeling
ontological analysis of taxonomic relationships

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Summary

- Ontology and ontologies
- Basic notions of formal ontology
- Property kinds and ontological levels
- Ontology-driven conceptual modeling
- An example of *ontology-cleaning*
Conceptual Modeling: a Neglected Discipline

The main dangers:
- Focusing on *reasoning* rather than *representation*
  - (*procedures vs. data*)
- Focusing on *form* rather than *meaning*
- Focusing on *ad hoc solutions*
- Forgetting the role of *natural language*
Functional vs. Ontology-Driven Knowledge Engineering

• the functional view:
  
  *knowledge = what makes possible rational behavior*
  
  – focuses on *tasks* and problem-solving knowledge
  – prevents elicitation of related knowledge
  – prevents data independence

• The alternative:
  
  – Separate *domain analysis* from *task analysis* (data/procedures)
  – Isolate *invariant* aspects
  – Look for *distinctions*, strive for *generality*

  *Carve reality at its joints!*
An Interdisciplinary Approach

• Towards a unified *Ontology-driven Modelling Methodology* for databases, knowledge bases and OO-systems
  – *Grounded* in reality
  – *Transparent* to people
  – *Rigorous*
  – *General*

• Based on
  – *Logic*
  – *Philosophy*
  – *Linguistics*
The Ontological Level  
(Guarino 94)

<table>
<thead>
<tr>
<th>Level</th>
<th>Primitives</th>
<th>Interpretation</th>
<th>Main feature</th>
</tr>
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<tr>
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<td>Linguistic terms</td>
<td>Subjective</td>
<td>Language dependence</td>
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</table>
Against Ontological Neutrality

- **Fikes’ proposal:**
  - $\text{KRL} = \text{Logic} + \text{Ontology}$ (well-founded KRL)

- **General-purpose KRL:** the ontology constrains general knowledge-structuring primitives
  - Meta-level axioms for roles, attributes, properties, parts...
  - Primitives are **not arbitrary** unary or binary predicates
  - From the *epistemological level* to the *ontological level*

- **Specialized KRL:** the ontology constrains domain primitives
  - Object-level axioms for primitive concepts and roles
  - Ontology constrains their *intended semantics*
  - From the *ontological level* to the *conceptual level*
Ontology and ontologies
What is Ontology

• The study of being *qua being*: the study of possible

• The study of the *nature* of possible: ontology as the *theory of distinctions* among *possibilia*
Definitions

• Ontology (capital “o”):
  – a *philosophical discipline*.

• An ontology (lowercase “o”):
  – *specific artifact* designed with the purpose of
    *expressing the intended meaning of a vocabulary*
What is an ontology?

• A shared vocabulary

• Plus … A specification (actually, a characterization) of the intended meaning of that vocabulary

...i.e., an ontology accounts for the commitment of a language to a certain conceptualization

“An ontology is a specification of a conceptualization” [Gruber 95]
Models and Conceptualizations
Capturing Intended Meaning

• First order logic is **ontologically neutral**
• Logical KBs often rely on **natural language** to convey intended meaning
Intended Models

An ontology consisting of just a vocabulary is of little use - 
*Unintended interpretations* need to be excluded
What is a conceptualization?

Scene 1: blocks on a table

Conceptualization of scene 1:
\(<\{a, b, c, d, e\}, \{\text{on, above, clear, table}\}\>
What is a conceptualization?

Scene 2: a different arrangement of blocks

The same conceptualization?
What is a conceptualization

- **Conceptualization**: the formal structure of reality as perceived and organized by an agent, independently of:
  - the *vocabulary* used (i.e., the *language* used)
  - the actual occurrence of a specific *situation*
- Different situations involving the same objects, described by different vocabularies, may share the same conceptualization.

\[
\begin{array}{ccc}
L_E & \text{apple} & \text{same conceptualization} \\
L_I & \text{mela} & \\
\end{array}
\]
Relations vs. Conceptual Relations

\[ r_n \in 2^{D^n} \]

\[ \rho_n : W \rightarrow 2^{D^n} \quad (\text{Montague-style semantics}) \]

ordinary relations are defined on a domain \( D \):

conceptual relations are defined on a domain space \( <D, W> \)
Models vs. Ontological Commitments

• Let \( L \) be a language with vocabulary \( V \)

• **Model:** \(<S, I>\)

• **Ontological commitment:** \(<C, \mathcal{I}>\)

• \( S = <D, R> \) is a *world structure*
  – \( R \) is a set of relations on \( D, W \)

• \( C = <D, W, \mathcal{R}> \) is a *conceptualization*
  – \( \mathcal{R} \) is a set of conceptual relations on \( <D, W> \)

• \( I: V \rightarrow D \cup R \) *extensional interpretation*

• \( \mathcal{I}: V \rightarrow D \cup \mathcal{R} \) *intensional interpretation*
Ontologies *constrain* the intended meaning

Conceptualization $C$

Commitment $K = \langle C, I \rangle$

Language $L$

Models $M(L)$

Intended models $I_K(L)$

Ontology
Levels of *Ontological Depth*

- **Lexicon**  
  – Vocabulary with NL definitions
- **Simple Taxonomy**
- **Thesaurus**  
  – Taxonomy plus related-terms
- **Relational Model**  
  – Unconstrained use of arbitrary relations
- **Fully Axiomatized Theory**
Agents A and B can communicate only if their *intended* models overlap
Two different ontologies may overlap while their *intended* models do not (especially if the ontologies are not accurate enough)
The role of a top-level ontology (1)
The role or a top-level ontology (2)

- Bottom-up integration of domain-specific ontologies can *never* guarantee consistency of intended models (despite apparent logical consistency).
- A common top-level ontology
  - Simplifies domain-specific ontology design
  - Increases quality and understandability, and therefore
  - …encourages reuse
Hierarchies of ontologies

- Top-level ontology
- Domain ontology
- Task & problem-solving ontology
- Application ontology
From Ontology to Data

- Reference ontology (development time)
  - establishes consensus about meaning of terms
- Application ontology (development time)
  - Focuses on a particular application
  - limited by relevance choices related to a certain application

Conceptual model (run time)
- implements an ontology (Tbox)
- Describes constraints between terms to be checked at run time
  (terminological services)
- limited by expressive power of implementation medium

Database (Abox) (run time)
- Describes a specific (epistemic) state of affairs

A KB includes both
Ontologies vs. Knowledge Bases

• Knowledge bases
  – Assertional component
    • *reflects specific states of affairs/epistemic states*
    • designed for *problem-solving*
  – Terminological component (cf. database conceptual schemes)
    • *independent* of particular *states of affairs/epistemic states*
    • Limited expressivity to support just the *terminological services* needed at *run time*

• Ontologies
  – designed with the purpose of *establishing consensus* about terms at *development time*
  – higher expressivity (less stringent computational requirements)
Ontologies vs. Conceptual Schemas

• Conceptual schemas
  – not accessible at run time
  – not always have a formal semantics
  – attribute values are taken out of the UoD
  – only the constraints relevant for database update are specified
  – Risk to be detached from the database itself

• Ontologies
  – accessible at run time (at least in principle)
  – formal semantics
  – attribute values as first-class citizens
  – all the constraints relevant for characterizing the intended meaning are specified
Our Framework: 
*Ontology-Driven* 
Conceptual Modeling
Formal Ontology

• Theory of *formal distinctions and connections* within:
  – entities of the world, as we perceive it (*particulars*)
  – categories we use to talk about such entities (*universals*)

• Basic tools of *formal ontological analysis*:
  – *Theory of Parts and Wholes* (*Mereology*)
  – *Theory of Identity, Integrity, Essence*
  – *Theory of Dependence*

• Why *formal*?
  – Two meanings:
    • rigorous
    • general
  – Formal logic: connections between truths - neutral wrt *truth*
  – Formal ontology: connections between things - neutral wrt *reality* [Varzi 96]

• *Goal*: *characterizing* particulars and universals by means of formal properties and relations.
Approach

- Draw *fundamental notions* from Formal Ontology
- Establish a set of useful *property kinds*, based on behavior wrt above notions (*meta-properties*).
- Explore the *constraints* they impose on Information Systems design, and add further *modeling principles*
- Establish a minimal *top-level ontology* to drive conceptual modeling
Framework

Conceptualization

User

Methodology

Conceptual Model

Ontology

Minimal Top-Level Ontology

Ontology-Driven Modeling Principles

Useful Property Kinds

Formal Ontological Properties/Relations
Formal Ontological Analysis

- Mereology
- Identity, Unity, Essence
- Dependence
Mereology

• A possible primitive: *proper part-of* relation (PP)
  – asymmetric
  – transitive
  – \( P_{xy} = \text{def} PP_{xy} \lor x=y \)

• Some further axioms:

  *supplementation:* \( PP_{xy} \rightarrow \exists z \ ( PP_{zy} \land \neg z=x) \)

  *principle of sum:* \( \exists z \ ( PP_{xz} \land PP_{yz} \land \neg \exists w(PP_{wz} \land \neg (P_{wx} \lor P_{wy}))) \)

  *extensionality:* \( x = y \leftrightarrow (P_{wx} \leftrightarrow P_{wy}) \)

*Excluded models:*
The problems with General Extensional Mereology

• Generality of mereological sums
• Extensionality
  – different identifying properties while having the same parts
  – different parts while having the same identifying properties
• Admittability of atoms
Essence and Rigidity

• Certain entities have *essential* properties.
  – John must have a brain.
  – John must be a person.

• Certain properties are essential to *all* their instances (compare *being a person* with *having a brain*).

• These properties are *rigid* - if an entity is ever an instance of a rigid property, it must always be.
Formal Rigidity

• $\phi$ is rigid (+R): $\forall x \phi(x) \rightarrow \phi(x)$
  – e.g. Person, Apple

• $\phi$ is non-rigid (-R): $\exists x \phi(x) \land \neg \phi(x)$
  – e.g. Red, Male

• $\phi$ is anti-rigid (~R): $\forall x \phi(x) \rightarrow \neg \phi(x)$
  – e.g. Student, Agent
Dealing with Ontological Relativism

• Deciding about the meta-properties carried by a given property…

   Is up to YOU!

• But a common agreement must be achieved about the formal meaning (and practical utility) of meta-properties
Identity, Unity, Individuation

• What does it mean that two entities are the same?
• How can an entity change while keeping its identity?
• What conditions do affect (loss of) identity? Are some properties essential for keeping identity?
• When does an entity count as one? What counts as a whole? What makes it a whole?
• How can we individuate an entity within other entities? When does an entity count as an individual?
Identity and Unity

• Identity: is this my dog?

• Unity: is the collar part of my dog?
Identity as a *primitive* relation

Identity is a primitive equivalence relation that satisfies Leibniz’s rule.

In general, *identity can’t be defined.* What we can have are just *informative constraints* (identity criteria)

...related to relevant *classes* of entities

...which are ultimately the result of *our conceptualization* of reality.
Synchronic Identity

• A plausible criterion:

\[ x \text{ and } y \text{ are the same iff they have the same location } \]

• Exceptions:
  – Immaterial objects (holes…)
  – Events (singing while taking a shower…)
  – Constituting entities (the statue’s clay…)}
Diachronic Identity

• It’s hard, but terribly useful for commonsense
• Requires some notion of persistence
• In addition, the *sameness* (or continuity) of certain properties is required

Identity is *not* similarity!
Identity criteria

• **Classical formulation:**

\[ \phi(x) \land \phi(y) \rightarrow (\rho(x,y) \leftrightarrow x = y) \]

• **Generalization:**

\[ \phi(x,t) \land \phi(y,t') \rightarrow (\Gamma(x,y,t,t') \leftrightarrow x = y) \]

(synchronous: \( t = t' \); diachronic: \( t \neq t' \))

• In most cases, \( \Gamma \) is based on the *sameness* of certain *characteristic features*:

\[ \Gamma(x,y,t,t') = \forall z \ (\chi(x,z,t) \land \chi(y,z,t')) \]
A Stronger Notion: Global ICs

• **Local IC:**
  \[
  \phi(x,t) \land \phi(y,t') \rightarrow (\Gamma(x,y,t,t') \iff x = y)
  \]

• **Global IC (rigid properties only):**
  \[
  \phi(x,t) \rightarrow (\phi(y,t') \land \Gamma(x,y,t,t') \iff x = y)
  \]
Identity Conditions along Taxonomies

• Adding ICs:
  – Polygon: same edges, same angles
    • Triangle: two edges, one angle
      – Equilateral triangle: one angle

• Just inheriting ICs:
  – Person
    • Student
Identity meta-properties

• **Supplying** (global) identity (+O)
  – Having some “own” IC that doesn’t hold for a subsuming property

• **Carrying** (global) identity (+I)
  – Having an IC (either own or inherited)

• **Not carrying** (global) identity (-I)
Necessary/Sufficient ICs as Heuristics for Identity

• A rigid property supplies (global) identity (+I) if it supplies at least a necessary or a sufficient IC.

• A non-rigid property supplies local identity (+L) only if it supplies both necessary and sufficient ICs
  – same-wing-pattern for Butterfly:
    • Necessary and sufficient
  – same-registration-no. for Student:
    • Only sufficient (a student may register somewhere else)
Identity Disjointness Constraint

Besides being used for recognizing sortals, ICs impose constraints on them, making their ontological nature explicit:

Properties with incompatible ICs are disjoint

Examples:
• sets vs. ordered sets
• amounts of matter vs. assemblies
Are ordered-sets sets?

IC for set: *same members*

IC for ordered set: *same members, same order.*

Let \( D \) be a non-empty domain, \( \Pi(D) \) its power set and \( O(D) \) the set of all *ordered* subsets of \( D \).

\[ |\Pi(D)| < |O(D)| \rightarrow O(D) \not\subseteq \Pi(D) \]

An ordered set is a *structure*, not a set

Other examples:

- Castles and lumps of bricks
- Passengers and persons
No entity without identity (Quine)

• Every entity must instantiate a property that carries identity
  (therefore, every entity must instantiate a rigid property that *supplies* identity)
Unity and Unity Criteria
Unity Analysis

• What counts as a *whole*? What makes it a whole?
• In which sense are its parts *connected*? What are the properties of the connection relation?
• How is the whole isolated from the background? What are its *boundaries*?
• What is the role played by the parts with respect to the whole?
Unity Criteria

- An object \textit{a is a whole} under \(\omega\) iff \(\omega\) is an equivalence relation that binds together all the parts of \(a\), such that

\[
P(y,a) \land P(z,a) \leftrightarrow \omega(y,z)
\]

but not

\[
\omega(y,z) \leftrightarrow \exists x (P(y,x) \land P(z,x))
\]

- \(P\) is the \textit{part-of} relation
- \(\omega\) can be seen as a \textit{generalized indirect connection}
Kinds of Wholes

• Depending on the nature of \( \omega \), we can distinguish:

  – Topological wholes (a piece of coal, a lump of coal)
  – Morphological wholes (a ball, a constellation)
  – Functional wholes (a hammer, a bikini)

• Note that a whole can have parts that are themselves wholes (with a different \( \omega \))
Unity Disjointness Constraint

Properties with incompatible UCs are *disjoint*
Unity and Plurality

• *Ordinary objects*: wholes or sums of wholes
  – *Singular*: no wholes as proper parts
  – *Plural*: sums of wholes
    • *Plural wholes* (the sum is also a whole)
    • *Collections* (the sum is not a whole)

• “Fiat” objects: everything else
Individuality and Countability

• Individuality: identity + unity
• No entity without identity [Quine]: individuality only depends on unity

• Countability: a meta-property of properties whose instances are individuals
Unity Meta-Properties

• If all instances of a property $\phi$ are wholes under the same relation, $\phi$ carries unity (+U)
• When at least one instance of $\phi$ is not a whole, or when two instances of $\phi$ are wholes under different relations, $\phi$ does not carry unity (-U)
• When no instance of $\phi$ is a whole, $\phi$ carries anti-unity (~U)
Dependence
Dependence Analysis

- Can an entity exist alone?
- Does its existence imply the existence of something else? (rigid dependence)
- Does it imply the existence of some entities that are instances of a specific class? (generic dependence)
- Does the existence of $x$ at $t$ imply the existence of $y$ at some $t' > t$? (historical dependence)
- Does a property holding for $x$ depend on something else besides $x$? (property dependence)
Dependence Meta-Properties

• Our methodology currently uses only property dependence

• A property $\phi$ is dependent (+D) if:
  $\forall x \: \phi(x) \rightarrow \exists y \: \neg RD(x,y) \land \neg RD(y,x)$

• If there is at least one instance of the property that is not dependent, the property is not dependent (-D)

• Also exclude qualities (i.e. Red), entities that necessarily exist (the universe), and subsumed properties.
Part, Constitution, and Identity

- *Structure* may change identity
- *Mereological extensionality* is lost
- *Constitution* links the two entities
- Constitution is asymmetric (implies *dependence*)
Ontological Levels and IC/UC Kinds

• Physical
  – Atomic \((a \text{ minimal grain of matter})\)
  – Static \((a \text{ configuration, a situation})\)
  – Mereological \((an \text{ amount of matter, a collection})\)
  – Topological \((a \text{ piece of matter})\)
  – Morphological \((a \text{ cubic block, a constellation})\)
• Functional \((an \text{ artifact, a biological organ})\)
• Biological \((a \text{ human body})\)
• Intentional \((a \text{ person, a robot})\)
• Social \((a \text{ company})\)

✓ Correspond to different \textit{kinds} of IC/UC
✓ All levels except the mereological one have \textit{non-extensional} IC
✓ A \textit{generic dependence} relation links higher levels to their immediate inferior.
## Identity and unity conditions

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<tr>
<th>Level</th>
<th>Re-identification</th>
<th>Unity</th>
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<tr>
<td></td>
<td></td>
<td>Sufficient</td>
</tr>
<tr>
<td>Atomic</td>
<td>S/T continuity</td>
<td>No proper parts</td>
</tr>
<tr>
<td>Static</td>
<td>Same properties</td>
<td>All entities of the domain</td>
</tr>
<tr>
<td>Mereological</td>
<td>Same parts</td>
<td>NO</td>
</tr>
<tr>
<td>Topological</td>
<td></td>
<td>Maximal self-connectedness</td>
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<tr>
<td>Morphological</td>
<td></td>
<td>Relative proximity</td>
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<td>Functional</td>
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<td>Maximal functional self-connectedness</td>
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<td>Biological</td>
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<td>Biological unity</td>
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<tr>
<td>Intentional</td>
<td>Same intentional behaviour</td>
<td>Single intentional behaviour</td>
</tr>
<tr>
<td>Social</td>
<td>Same social behavior</td>
<td>Maximal social self-connectedness</td>
</tr>
</tbody>
</table>
How ontological levels simplify taxonomies

social-event ← communication-event
mental-event ← perceptual-event
physical-event

social-event ← communication-event
mental-event ← perceptual-event
physical-event
Impact of taxonomic constraints on ontology design

• *Stratification* replaces multiple inheritance in many cases:
  – *Simpler* taxonomies
  – *Moderate proliferation* of individuals
  – *Co-localization* of entities of different kind

• *Non-taxonomic relations* become important:
  – Dependence
  – Co-localization
  – Constitution
  – Participation

• *Type/role distinction* allows for isolation of *backbones* in the taxonomic structure
Using the meta-properties
Framework

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Ontology-Driven Modeling Principles

Useful Property Kinds

Formal Ontological Properties/Relations
Why bothering about this?

• Our *ontology-driven conceptual modelling* methodology requires analyzing all properties in an ontology according to their identity and unity meta-properties – This is a lot of work!

• Why perform this analysis?
  – Makes *modeling assumptions* clear, which:
    • Helps resolving known conflicts
    • Helps recognizing unknown conflicts
    • Results in more reusable ontologies
Resolving Ontological Conflicts

• Two well-known ontologies define:
  – Physical Object is-a Amount of Matter (WordNet)
  – Amount of Matter is a Physical Object (Pangloss)

• Amount of Matter
  – unstructured /scattered “stuff”
  – Identity: mereologically extensional
  – Unity: intrinsically none (anti-unity)

• Physical Object
  – Isolated material objects
  – Identity - two options:
    • Non-extensional
    • Extensional
  – Unity: Topological

Conclusion: the two concepts are disjoint. Physical objects are constituted by amounts of matter
Recognizing Unknown Conflicts

• Agreement:
  – An organization is a Social Entity

• Analysis:
  – Person 1: Social Entity +O+U+R -D
  – Person 2: Social Entity +O+U+R +D

• Problem?
  – Person 1: A social entity is a group of people who are together for some social reason.
  – Person 2: A social entity is an entity recognized by society, therefore +D
Property Kinds
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Useful Property Kinds

Formal Ontological Properties/Relations
Sortals, categories, and other properties

- **Sortals** (*horse, triangle, amount of matter, person, student...*)
  - Carry identity
  - Usually correspond to *nouns*
  - High organizational utility
  - Main subclasses: *types* and *roles*

- **Categories** (*universal, particular, event, substance...*)
  - No identity
  - Useful generalizations for sortals
  - Characterized by a set of (only necessary) formal properties
  - Good organizational utility

- **Other non-sortals** (*red, big, decomposable, eatable, dependent, singular...*)
  - No identity
  - Correspond to *adjectives*
  - Span across different sortals
  - Limited organizational utility (but high semantic value)
A formal ontology of properties

- Property
  - Non-sortal
    - Non-rigid
      - Anti-rigid
  - Sortal
    - Rigid
      - Category
        - Attribution
          - Formal Role
            - Material role
              - Phased sortal
                - Mixin
                  - Type
                    - Quasi-type
## Basic Property Kinds Table

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<th>I</th>
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<td>±</td>
<td>Material role</td>
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<td>Phased sortal</td>
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<td>±</td>
<td>Category</td>
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<td>Attribution</td>
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Type and Role specialization

• **Type** specialization (e.g. Living being → Person)
  – New features *affect identity*
  – Both necessary and sufficient ICs can be added while specializing types
    • Polygon: same edges, same angles
    • Triangle: two edges, one angle
    • Living being: same DNA, etc...
      • Zebra: same stripes

• **Role** specialization (e.g. Person → Student)
  – New features *don’t affect identity*
Further Property Kinds:
Common ICs/UCs
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Framework
Re-visiting abstraction relationships

- Taxonomic relationships (*generalization*)
- Membership relationships (*association*)
- Part-whole relationships (*aggregation*)
Taxonomic relationships
IS-A overloading

• **Reduction of sense:**
  1. A physical object is an amount of matter (Pangloss)
  2. An association is a group (WordNet)

• **Overgeneralization:**
  3. An amount of matter is a physical object (WordNet)
  4. A place is a physical object (µKosmos, WordNet)

• **Clash of senses:**
  5. A window is both an artifact and a place (µKosmos)
  6. A person is both a physical object and a living thing (Pangloss)
  7. A car is both a solid tangible thing and a physical device (CYC)
  8. An organization is both a social-being and a group (CYC)
  9. A communicative event is a physical, a mental, and a social event (µKosmos, Pangloss)
Subsumption Misused

• To express *disjunction*
  – Person is-a Legal-Agent
  – Company is-a Legal-Agent

• To express *constitution*
  – Person is-a Amount of Matter

• To express *multiple meanings*
  – Book is a physical-object
  – Book is a abstract-object
Assumptions

• No entity without identity

• Every entity must instantiate a rigid property with identity (a type)
Taxonomic Constraints

- $+R \not\in \sim R$
- $-I \not\in +I$
- $-U \not\in +U$
- $+U \not\in \sim U$
- $-D \not\in +D$

- Incompatible IC’s are disjoint
- Incompatible UC’s are disjoint

For these we introduced Common UC/IC
The *Backbone Taxonomy*

• Assumption: *no entity without identity*

• Since identity is supplied by types, every entity must instantiate a type

• The taxonomy of types spans the whole domain

• Together with categories, types form the *backbone taxonomy*, which represents the *invariant structure* of a domain (rigid properties spanning the whole domain)
An extended example
Framework

Conceptualization

User

Methodology

Conceptual Model

Ontology

Minimal Top-Level Ontology

Ontology-Driven Modeling Principles

Useful Property Kinds

Formal Ontological Properties/Relations
Property Analysis
Entity, Location

- **Entity**
  - Everything is an entity
  - -I-U-D+R
  - Category

- **Location**
  - A generalized region of space.
  - +O: by its parts (mereologically extensional).
  - ~U: no way to isolate a location
  - -D+R
  - Type
Property Analysis
Amount of Matter, Red

• Amount of Matter
  – unstructured /scattered “stuff” as lumps of clay or some bricks
  – +O: mereologically extensional
  – ~U: intrinsically no unity
  – -D+R
  – Type

• Red
  – Really Red-thing, the set of all red-colored entities
  – -I-U-D-R
  – Formal Attribution
Property Analysis
Agent, Group

• Agent
  – An entity playing a part in some event
  – -I-U: no universal IC/UC
  – +D: on the event/action participating in
  – ~R: no instance is necessarily an agent
  – Formal role

• Group
  – An unstructured collection of wholes
  – +O: same-members
  – ~U: unstructured, no unity.
  – -D+R
  – Type
Property Analysis
Physical Object, Living Being

• Physical Object
  – Isolated material objects.
  – +O: same spatial location (only synchronic, no common diachronic IC).
  – +U: Topological
  – -D+R
  – Type

• Living Being
  – +O: same-DNA (only nec.)
  – +U: biological unity
  – -D+R
  – Type
Property Analysis

Food, Animal

- Food
  - +I-O~U: amt. of matter
  - +D: something that eats it.
  - ~R: being food is not necessary...
  - Material Role

- Animal
  - +O: same-brain
  - +U: biological unity
  - -D+R
  - Type
Property Analysis
Legal Agent, Group of People

• Legal Agent
  – A legally recognized entity
  – +L: All legal systems have a defined IC, has-same-legal-ID
  – -U: no universal unity
  – +D: on the legal body that recognizes it
  – ~R: not necessary
  – Material Role

• Group of People
  – See Group
  – +I-O~U-D+R
  – Quasi-type
Property Analysis
Social Entity, Organization

• Social Entity
  – A group of people together for social reasons
  – -I: no universal IC
  – +U: social-connection
  – -D+R
  – category

• Organization
  – A group of people together, with roles that define some structure
  – +O: same-mission and way of operating
  – +U: functional
  – -D+R
  – Type
Property Analysis

Fruit

• Fruit
  – An individual fruit, such as an orange or banana
  – +O: same-plant, same-shape, etc. (only nec.)
  – +U: topological
  – -D+R
  – Type
Property Analysis
Apple, Red Apple

• Apple
  – +O: shape, color, skin pattern (only nec)
  – +U: topological
  – -D+R
  – Type

• Red-Apple
  – +I-O: from Apple
  – +U: from Apple
  – -D
  – ~R: no red apple is necessarily red
  – type-attribute mixin
Property Analysis
Vertebrate, Person

• Vertebrate
  – Really vertebrate-
    animal
  – A biological
    classification that adds
    new membership
    criteria (has-backbone)
  – +I-O: from animal
  – +U: from animal
  – -D+R
  – quasi-type

• Person
  – +O: same-fingerprint
  – +U: from animal
  – -D+R
  – Type
Property Analysis
Butterfly, Caterpillar

• Butterfly
  – +L: same-wing-pattern
  – +U: biological
  – -D
  – ~R: the *same entity* can be something else (a caterpillar)
  – Phased sortal

• Caterpillar
  – +L: spots, legs, color
  – +U: biological
  – -D
  – ~R: caterpillars become butterflies and change their IC
  – Phased sortal
Property Analysis

Country

• Country
  – A place recognized by convention as autonomous
  – +L: government, sub-regions
  – +U: countries are countable (heuristic)
  – -D
  – ~R: some countries do not exist as countries any more (e.g. Prussia) but are still places
  – Phased sortal
assign meta-properties
Remove non-rigid properties
Analyze taxonomic links

- ~U can’t subsume +U
- Living being can **change parts** and remain the same, but amounts of matter can not (incompatible ICs)
- Living being is **constituted** of matter
Analyze taxonomic links

- \(~U\) can’t subsume \(+U\)
- Living being can *change parts* and remain the same, but amounts of matter can not (incompatible ICs)
- Living being is *constituted* of matter
Analyze taxonomic links

- ~U can’t subsume +U
- Physical objects can change parts and remain the same, but amounts of matter can not (incompatible ICs)
- Physical object is *constituted* of matter
• ~U can’t subsume +U
• Physical objects can change parts and remain the same, but amounts of matter can not (incompatible ICs)
• Physical object is constituted of matter
Analyze taxonomic links

- Meta-properties fine
- **Rigidity-check** fails: when an entity stops being an animal, it does not stop being a physical object (when an animal dies, its body remains)
- Constitution again
Analyze taxonomic links

- Meta-properties fine
- **Rigidity-check** fails: when an entity stops being an animal, it does not stop being a physical object (when an animal dies, its body remains)
- Constitution again
Analyze taxonomic links

- ~U can’t subsume +U
- A group, and group of people, can’t change parts - it becomes a different group
- A social entity can change parts - it’s more than just a group (incompatible IC)
- Constitution again
- ~U can’t subsume +U
- A group, and group of people, can’t change parts - it becomes a different group
- A social entity can change parts - it’s more than just a group (incompatible IC)
- Constitution again

Analyize taxonomic links

- Location +O-U-D+R
- Physical object +O-U-D+R
- Amount of matter +O~U-D+R
- Group +O~U-D+R
- Group of people +I-O~U-D+R
- Social entity -I+U-D+R
- Vertebrate +I-O+U-D+R
- Organization +O+U-D+R
- Person +O+U-D+R
Analyze taxonomic links

- ~U can't subsume +U
- Same as for social entity.
- Note also the same group can constitute different organizations.

Entity

- Location +O-U-D+R
- Amount of matter +O<U-D+R
- Physical object +O+U-D+R
- Amount of matter +O~U-D+R
- Group +O~U-D+R
- Person +O+U-D+R
- Social entity -I+U-D+R
- Organization +O+U-D+R
- Group of people +I-O~U-D+R
- Vertebrate +I-O+U-D+R
- Apple +O+U-D+R
- Group of people
- Social entity
Analyze taxonomic links

- ~U can’t subsume +U
- Same as for social entity.
- Note also the same group can constitute different organizations.
Analyze Phased Sortals

- For phased sortals: what do they phase into?
- Country is anti-rigid because it is representing multiple senses of country: a geographical region and a political entity.
- Split the two senses into two concepts, both rigid, both types.
• There is a relationship between the two, but not subsumption.
Caterpillar phases into butterfly - a true phased sortal

There must be some property from which a single entity can uniquely claim identity across phases

Define a rigid property which subsumes only the phases of the same entity.
Analyze Phased Sortals

Entity

Location

Amount of matter

Physical object

Living being

Social entity

Group

Group of people

Geographical Region

Fruit

Apple

Lepidopteran

Vertebrate

Caterpillar

Butterfly

Lepidopteran

Vertebrate

Person

Organization
• ~R can’t subsume +R
• Really want a type restriction: all agents are animals or social entities.
• Subsumption is not disjunction!
- \(~R\) can’t subsume \(+R\)
- Really want a type restriction: all agents are animals or social entities.
- **Subsumption is not disjunction!**
- \( \sim R \) can’t subsume \(+R\)
- Another disjunction: all legal agents are countries, persons, or organizations
• ~R can’t subsume +R
• Another disjunction: all legal agents are countries, persons, or organizations
• ~R can’t subsume +R
• Apple is not necessarily food. A poison-apple, e.g., is still an apple.
• ~U can’t subsume +U
• Caterpillars are wholes, food is stuff.
- ~R can’t subsume +R
- Apple is not necessarily food. A poison-apple, e.g., is still an apple.
- ~U can’t subsume +U
- Caterpillars are wholes, food is stuff.
Analyze Attributions

- No violations
- Attributions are discouraged, can be confusing.
- Often better to use attribute values (i.e. Apple Color red)
The backbone taxonomy

- Entity
  - Location
    - Physical object
      - Fruit
        - Apple
      - Amount of matter
    - Living being
    - Social entity
      - Animal
        - Lepidopteran
      - Vertebrate
        - Vertebrae
    - Group of people
    - Group
  - Geographical Region
  - Organization
  - Person
    - Country
      - Location
  - Amount of matter
  - Living being
  - Social entity
  - Group
  - Physical object
  - Group of people
  - Fruit
Membership relationships
The Instance-of Relation (1)

- **Being instance-of something vs. being an instance.**
  - Being an instance is a relative status?
  - Temporal instances
    - Beethoven isn’t an “ultimate instance”, since “the young Beethoven” may be an instance of it...

- **Instance-of vs. class membership**
  - John is a member of “Person” → Person(John)
  - Tree1 is a member of “TheForest” → TheForest(Tree1) ??
    (violates usual intended interpretation of unary predicates: property shared by all instances of the corresponding class. Doesn’t pass the “is-a” test)
The Instance-of Relation (2)

How to decide whether something is an instance?

• Properties can be instances of meta-properties
• Hence, “being an instance” may be a subjective property
• But “being a particular” IS NOT!

• Particulars are always “ultimate” instances.
• Concrete entities are always particular or instances of an abstract class.
Part-whole relationships
Part-of vs. part-whole relations

- component/integral object
- member/collection
- portion/mass
- stuff/object
- place/area
- feature/activity
Attributes vs. Arbitrary Relations

• Woods’ example
  – John
    • age: 32
    • hits: Mary

• Internal vs. external relations
• Woods’ linguistic test
• The Attribute Consistency Principle:
  – Any X of Y is a X
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Abstract vs. Concrete Entities

• Concrete: located in space-time (regions of space-time are located in themselves)
• Abstract - two meanings:
  - Result of an abstraction process (something common to multiple exemplifications)
    ✧ Not located in space-time

• Mereological sums (of concrete entities) are concrete, the corresponding sets are abstract...
Particulars and Universals

• Universals
  – Have multiple exemplifications
  – All abstract

• Particulars:
  – Have no exemplifications
  – Can be either concrete or abstract

*Concrete entities are all particulars*
A Minimal Top-level Ontology

Entity

Particular
  Concrete particular
    Location
    Object
  Abstract particular
    Set
    Structure
...

Universal

Property
  Property Kinds...

Relation
Concrete particulars: the basic backbone

• Location
  – Region of space
  – Region of time

• Object
  – Substantial object
    • Individual (Thing) (independent)
    • Aggregate (no unity - extensionality)
    • Collection (sum of individuals - semi-extensionality)
  – Accidental object
    • Event (dependent on substance)
    • Feature (complex identity principles)
    • Physical quality (minimal identity principles)

• Object categories above are stratified according to their different ICs
Continuants vs. Occurrents

• Continuants
  – Have a spatial location (which may vary with time)
  – Have spatial parts
  – Don’t have a temporal location, nor temporal parts, since they *fully exist* in each interval of their lifetime (*time endurance*)
  – Depend on matter (most of them are also *constituted* by matter)
  – *Take part* to occurrents without being part of them.

• Occurrents
  – Are “generated” by continuants, according to the way they behave in time
  – Have a unique temporal location (spatial location usually undetermined)
  – Have temporal parts (*time perdurance*)
  – Depend on continuants, but continuants do not constitute them
  – Are rigidly dependent on their parts
Well-Founded Ontologies: Some Basic Design Principles

• **Be clear about the domain**
  – particulars (individuals)
  – universals (classes and relations)
  – linguistic entities (nouns, verbs, adjectives...)

• **Take identity seriously**
  – different identity criteria imply *disjoint classes*

• **Isolate a basic taxonomic structure**
  – only *sortals* like “person” (as opposite to “red”) are good candidates for being *taxons*

• **Make an explicit distinction between types and roles** (and other property kinds)
Announcing...

FOIS 2001
Formal Ontology in Information Systems

www.fois.org
On-going and future initiatives

• Projects
  – IEEE Standard Upper Ontology
  – OntoWeb
  – The *World Wise Web*

• Conferences
  – EKAW
  – EKAW ws on ontologies and text
  – EKAW ws on knowledge management