Ontologies for spatial reasoning, action and interaction

Basic problem statement, techniques under development, and plans

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Problem focus

- Spatial assistance systems
- Route planning and navigation
- Real-world environments involving ‘common-sense’ entities
- Interfacing with geographic information
- Interfacing with language technology
- Interfacing with visual presentations (maps)
- Interfacing with robotic sensor data
- Embodied systems
- Human-Robot Interaction
Bremen Autonomous Wheelchair

Qualitative Information
“In front to the right is the seminar room”

Quantitative information

Symbolic information
[door_1 recognized]
Basis for the use of ontologies and ontological engineering

- High degree of interoperability between diverse knowledge-rich systems
  - knowledge of the human world (*commonsense*)
  - knowledge of the robot world (*programmed, emergent*)
  - geo-knowledge (*GML, other standards*)
  - spatial knowledge (*spatial calculi*)
  - knowledge of language (*Generalized Upper Model*)
Fundamental issue

- The ontologies present are diverse:
  - different methodologies
  - different motivations
  - different domains of application
  - different worlds
  - different purposes
  - different communities
Methodological starting point

- There is no sense in which a simple ‘merging’ of the ontologies involved is a sensible strategy to follow
Many perspectives on ‘reality’: many ontologies

Ontologically diverse
Ontological diversity

inter-ontology mappings

Way description

landmarks

event types

choremes

route graphs

CASL

time

landmarks

event types

choremes

route graphs

CASL

CASL

CASL

CASL

Bateman/Mossakowski 2006
Essential properties we are currently developing

- Perspectivalism
  - Objects
  - Activities
  - Artifacts: spatial artifacts
  - Language

- Granular partitions

- Plug-and-play spatial theories
Essential ingredients we are drawing on

- **Existing ontologies**
  - DOLCE  
    (for cross-category binding and axiomatization)
  - BFO  
    (for sites, niches and places and for SNAP/SPAN)
  - GUM  
    (generalized upper model for linguistic semantics)
Essential ingredients we are drawing on

- **Formal and computational tools**
  - **CASL**
    Common Algebraic Specification Language
    (for specification, structuring and relating)
  - **HETS**
    Heterogeneous Tool Set
    (for connecting to a range of reasoners)
  - sublanguages of CASL
    (e.g., CASL-DL, modal CASL)
  - **OWL-DL**
Formalization choice: CASL
Common Algebraic Specification Language

- de facto standard for specification of functional requirements in software development
- developed by the “Common Framework Initiative” (COFI), an open international collaboration
- approved by IFIP WG 1.3 “Foundations of Systems Specifications”
CASL language constructs

- Basic specification: \( \text{spec} \) SpecName = Spec
- Extension: Spec1 then Spec2
- Union: Spec1 and Spec2
- Translations: Spec with SymbolMappings
- Parameterization: \( \text{spec} \) Spec1 [Spec2] = Spec
- Views:

  \[ \text{view} \ \text{View} : \ Spec1 \ \text{to} \ Spec2 = \text{SymbolMapping} \]

  \( (\text{theory morphisms}) \)
Example: PSL specification ...

\[
\text{spec PSL\_subactivity = PartialOrder with } _\leq \rightarrow \text{subactivity, Elem } \rightarrow \text{activity}
\]
\[
\text{then}
\]
\[
\ldots \text{%% axioms for discreteness}
\]
\[
\text{end}
\]


\textbf{subActivity}: This relation is isomorphic to a discrete partial ordering on the set of activities.
CASL sublanguages and environment

Graph of CASL sublanguages and extensions

basic specs

Static Analysis + Tools

signatures

Theorem Provers
Isabelle
SPASS

architectural

Static Analysis + Tools

development graphs

Bateman/Mossakowski 2006
spec PRIMITIVES =
  %% Basic Categories
sorts  PD, PED, S, SL, T, TL < PT
free  type  PT ::= sort PD, PED, S, SL, T, TL
end

spec GENPARTHOD [sort s] =
  pred  P : s × s
  ∀x, y, z : s
  • P(x, x)
  • P(x, y) ∧ P(y, x) → x = y
  • P(x, y) ∧ P(y, z) → P(x, z)
end

<table>
<thead>
<tr>
<th>DOLCE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>Particular</td>
</tr>
<tr>
<td>PD</td>
<td>Perdurant, Occurrence</td>
</tr>
<tr>
<td>PED</td>
<td>Physical Endurant</td>
</tr>
<tr>
<td>S</td>
<td>Space Region</td>
</tr>
<tr>
<td>SL</td>
<td>Spatial Location</td>
</tr>
<tr>
<td>T</td>
<td>Time Interval</td>
</tr>
<tr>
<td>TL</td>
<td>Temporal Location</td>
</tr>
</tbody>
</table>

%(Ad11)%
%(Ad12)%
%(Ad13)%
spec GenMereology [sort s] =
GenParthood [sort s]

then
preds PP(x, y; s) ⇔ P(x, y) ∧ ¬ P(y, x);
O(x, y; s) ⇔ ∃ z; s • P(z, x) ∧ P(z, y);
At(x; s) ⇔ ¬ ∃ y; s • PP(y, x);

then
%%% Ground Axioms (2)
∀ x, y; s
• ¬ P(x, y) ⇒ (∃ z; s • P(z, x) ∧ ¬ O(z, y))
• ∃ z; s • At(z) ∧ P(z, x)

then %\ref{implies}
∀ x, y, su, s'd', p, p', d, d'; s
• (∀ z'; s • At(z') ⇒ P(z', x) ⇒ P(z', y)) ⇒ P(x, y)
• (∀ z; s • O(z, x) ⇔ O(z, y)) ⇒ x = y
end

DOLCE
% (Dd1.Proper.Part)%
% (Dd2.Overlap)%
% (Dd3.Atom)%
spec  MEREOLOGY = PRIMITIVES
then
%%%Ad7, Ad8, Ad9 and Ad10 are generated by
%%% instantiation of GenMereology
   GENMEREOLOGY [sort T]
then
   GENMEREOLOGY [sort S]
then
   GENMEREOLOGY [sort PD]
end
Lüttich & Mossakowski (FOIS 2004)

Development Graph showing dependencies between specifications and proof obligations
The DOLCE ontology in CASL

spec PreDolce =
    Mereology_and_TemporalPart
    and Temporary_Mereology
    and Participation
    and Constitution
    and Dependence
    and Direct_Quality
    and Temporary_Quale
    and Immediate_Quale
end

spec Dolce =
    PreDolce
    and Taxonomy
end

work continuing...
Ontology construction

- Axioms are grouped into logically appropriate theories
- Theories may be extended via parameterization to achieve semantic re-use
- Theories may be created and related by views: theory morphisms

Only with this availability of working with meaningful interrelationships can the complexity of distinct axiomatized ontologies really be harnessed.
Generalized Upper Model: Version 3 (2004-)

Penman Upper Model (1989)
Merged Upper Model (1994)

220 classes
86 properties
OWL-DL (ALCHN)

Methodology:
disjoint categories iff there is a specifiable difference in linguistic reflexes (grammaticized semantics)
The Generalized Upper Model

- continues to be used for interacting with our natural language components. Because of the link to language, it is relatively straightforward to understand (continuing development since 1985).
- Until the beginning of the current project in 2002, it was under seriously axiomatized.
- We are now in the middle of a complete update with axiomatization and explicit links to DOLCE (via D&S and quality spaces)
- note that this does not mean that it becomes merged with DOLCE!

Relation to proposals for simple Common Subset?
Summary of work in progress: with interest in cooperative development

- comprehensive formalization of spatial calculi
  - correctness of composition tables
  - theory morphisms among different calculi
  - inheritance of tools along theory/logic morphisms

- formal integration of ontologies
  - via colimits of theories
  - consistency of integrated ontologies

- content development and interrelation of ontologies
Approaches to ‘simplifying’ the ontologist’s life...

- Making sure that each component of a library of theories only specifies the axioms which are relevant at that point (cf. John Sowa: “That is the whole point of Ockham’s razor: eliminate any axioms that are not absolutely essential to the task at hand.”)

- Making sure that unnecessary detail is hidden in ‘upstream’ libraries: CASL

- Possibilities for ‘common subsets’:
  - packages such as our spatial calculi
  - packages such as DOLCE’s ‘constitution’, ‘participation’, ‘quality spaces’, BFO’s ‘sites’
  - language-based generic ontology (GUM)