Ontology-Based Context Modeling

Reto Krummenacher, Thomas Strang
Background

Digital Enterprise Research Institute

- Applying semantics to Web services to achieve (semi-) automatic discovery, composition, …

- Non-functional and dynamic aspects of service descriptions and goals/tasks to execute

- Middleware for ‘Internet of Services’: semantic tuplespaces
  • Management tasks / Non-functional properties
  • Self-Representation
  • Reflection, scalability trade-offs
Overview

1. Ontologies: Some Basic Facts
2. Modeling Criteria
3. The Survey
4. Challenges & Problems
Ontologies
Some Basic Facts
Ontologies are

„explicit formal specifications of the terms in a domain and the relations among them“

Modeling characteristics

– semi-structured with clear model semantics (not OO)
– modeling facilities for concepts and properties (not Logic)

Projecting real-life entities onto machine-understandable data constructs
Benefits

• Interoperability
  – high-level, explicit specification (understanding)
  – reusability, applicability (speed of implementation)
  – data and system integration (in the large)

• Validity and compatibility checking, formal constraints

• Reasoning
  – validation of models and instances
  – derivation of instances & relations (implicit knowledge)
    • the system can infer more about the big picture
  – knowledge interpretation and evaluation
Ontology Languages

- Two branches of languages
  - First-Order Logic (FOL)
    - Description Logics (DL; e.g. OWL-DL) subsets of FOL
  - Logic Programming (LP)

- FOL, DL
  - open world, no unique name assumption
  - subsumption reasoning, consistency checking, classification

- LP
  - closed world, unique name assumption
  - query answering, consequence finding (rules systems)
    ? – child(?x) AND gender(?x,male).
Success factors for context modeling ontologies
Modeling Criteria: Context (1)

• Comparability of data values
  – heterogeneity of coding systems, units and values

• Traceability
  – provenance (trust)
  – computational source for derived context

• Logging, history
  – decisions based on the past
  – monitoring (detecting unlikely changes)
Modeling Criteria: Context (2)

- Quality
  - e.g. mean error, standard deviation

- Satisfiability (constraint modeling)
  - restrictions and constraints on acceptable values

- Inference, derivation
  - high-order context (situations, activities…)
    - inWater, moving $\rightarrow$ swimming
  - new contextual types based on primitive values
    - show the relationship of speed with distance and time
Modeling Criteria: Ontology (3)

- Reusability
  - simple and small ontologies (DC, FOAF)
  - genericity: domain independent (upper ontologies)

- Consistency
  - no contradictions (neither implicit nor explicit)

- Completeness, redundancy
  - cover the whole domain
  - but do not redefine explicit/implicit knowledge
Modeling Criteria: Ontology (4)

• Readability
  – humans develop ontologies, humans choose ontologies
  – understandable, intuitive relations and terms
  – not important for machines, but...
  – very relevant factor for reuse, and adaptation

• Language, formalism
  – choose the right language for the problem
  – choose the right reasoning support for the problem
    • compatibility of formalism
    • decidability (FOL + LP!!!)
The Survey
### Survey: Ontologies

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MobiLife</td>
<td>Classification-based situational reasoning for task-oriented mobile service discovery</td>
</tr>
<tr>
<td>ConOnto</td>
<td>Negotiation Context Information in Context-Aware Systems</td>
</tr>
<tr>
<td>SCAFOS / SCALA</td>
<td>A first-order logic model for context-awareness in distributed sensor-driven systems</td>
</tr>
<tr>
<td>CONON / ULCO</td>
<td>Ontology-Based Context Modeling and Reasoning using OWL;</td>
</tr>
<tr>
<td>Metamodel for Context</td>
<td>A Metamodel Approach to Context Information</td>
</tr>
<tr>
<td>CAPNET</td>
<td>RDF based Model for Context aware Reasoning in Rich Service Environments</td>
</tr>
<tr>
<td>CARE</td>
<td>Loosely Coupling Ontological Reasoning with Efficient Middleware for Context-awareness</td>
</tr>
<tr>
<td>SOUPA</td>
<td>SOUPA: Standard Ontology for Ubiquitous and Pervasive Computing</td>
</tr>
<tr>
<td>MAS / mySAM</td>
<td>Representing Context in an Agent Architecture for Context-Based Decision Making</td>
</tr>
<tr>
<td>CDF</td>
<td>Context Description Framework for the Semantic Web</td>
</tr>
<tr>
<td>CAMidO</td>
<td>CAMidO, A Context-Aware Middleware Based on Ontology Meta-Model</td>
</tr>
<tr>
<td>GAIA</td>
<td>A infrastructure for context-awareness based on first order logic</td>
</tr>
<tr>
<td>VTT Finland</td>
<td>A resource and context model for mobile middleware</td>
</tr>
<tr>
<td>VBO</td>
<td>Managing Context Information in Mobile Devices</td>
</tr>
<tr>
<td>CoOL / ASC</td>
<td>CoOL: A Context Ontology Language to enable Contextual Interoperability</td>
</tr>
<tr>
<td>DOLCE-DnS</td>
<td>Understanding the Semantic Web through Descriptions and Situations</td>
</tr>
<tr>
<td>CoDAMoS</td>
<td>Towards an extensible context ontology for Ambient Intelligence</td>
</tr>
<tr>
<td>GAS</td>
<td>GAS ontology: an ontology for collaboration among ubiquitous computing devices</td>
</tr>
<tr>
<td>CWI-Context</td>
<td>Modeling Adaptation in Web Services Execution using Context Ontologies</td>
</tr>
</tbody>
</table>
Survey: Introduction

• Aims to show
  – the state of the art
  – deployed features and factors that lack support
  – examples of work done and work to be done

• Definitively not a complete list of efforts
  – new examples monthly...

• Difficult to find complete information about models
  – ontologies not publicly available
  – lack of complete descriptions
Survey: Observations (1)

• Genericity:
  – abstract vocabularies to describe context values
    • ConOnto (ContextView, ContextFeature),
    • ASC (Aspects, Scales, ContextInformation)
  – upper ontologies to model entities involved in context-aware systems: Person, Location, Environment, Application, Device…
    • SOUPA, CONON, CoDAMoS (user, service, platform,…)

• Context information is not (only) profiles
  – profiles with values (formalized) in ontologies
  – key-value approaches with (formalized) values
Survey: Observations (2)

• Comparability
  – seldom explicitly integrated (values not at the core)
  – how to compare non-countable values?
  – counter-example ASC: focus on the values

• Traceability
  – VTT Finland framework attaches attribute source
    • no further modeling of sources
  – CONON tags values with type of source
    • sensed, derived, aggregated, deduced
Survey: Observations (3)

• Logging, history
  – often done by use of timestamps
  – GAIA: integrates relational database for temporal queries (values regularly stored in RDBMS)

• Quality
  – Most clearly recognized meta-context
    • probability, confidence, meanError
    • bayesian reasoning, fuzzy logic
    • quality ontologies
Survey: Observations (4)

- Satisfiability
  - logical expressions (rules)
  - external services (application and Web service bindings)
  - again: of particular interest for non-countable values

- Derivation, inference
  - integration of derivation rules, axiomatic expressions
    - activity(sleeping) <- location(inBed) AND eyes(closed)
  - inter/intra operations of ASC
    - Speed = Interoperation(Distance, Time)
Survey: Observations (5)

- Most models rely on FOL (in fact OWL-DL)
  - subsumption reasoning, entity hierarchies, model checking

- LP is chosen for inclusion of context rules
  
  \[
  \forall X \text{ suggestion}(X, \text{drink}) \leftarrow \\
  X: \text{human}[\text{activity}\rightarrow \text{running}] \text{ and } \\
  T: \text{temperature}[\text{value}\rightarrow V, \text{unit}\rightarrow \text{Celsius}] \text{ and } V > 20 .
  \]

- Few combined solutions for schema and value modeling (FOL) and the integration of derivation and user rules (LP)

- Interesting: CDF extension to RDF
  - trueInContext, contextProbability properties
Survey: Conclusions

• Quality and timestamps recognized as important

• Provenance needs more attention
  – yet more important in large-scale distributed settings
  – also a prerequisite for trust measures

• Interoperability crucial
  – solid ontology modeling
  – comparability, constraints modeling (satisfiability)
  – especially in open pervasive environments and the “Internet of Services”
Challenges & Problems
Challenges and Problems

- Top-down creation
  - the applications determine the models
  - resulting ontology on a per case basis. Reusability?

- Applications become globally reachable
  - not some tiny tool on a mobile device
  - need for standardization, or integration, mapping

- Accessibility
  - Reuse of ontologies requires that they are available
  - Lack of publicly available ontologies: a human-caused problem
Challenges and Problems

• Open topic in the Semantic Web community
  – combination of FOL and LP
    • causes undecidability, ongoing research
      – Description Logic Programs
      – SWRL (OWL + RuleML), RIF (W3C WG)
      – WSML-Full
    – scalability, performance of reasoners
    – distributed querying and reasoning

• Future: “Internet of Services”?
  – context-aware discovery, composition, negotiation
  – combination of functional and non-functional aspects
Thank you.

Reto Krummenacher
Digital Enterprise Research Institute
University of Innsbruck
reto.krummenacher@deri.at
9th Int’l Conference on Ubiquitous Computing (UbiComp 2007)
16.-19. Sept 2007 in Innsbruck, Austria