A Survey of Semantics-based Approaches for Context Reasoning in Ambient Intelligence

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Artificial Intelligence Methods for Ambient Intelligence

Focus of the Survey

- AmI Frameworks and Systems that employ Web Ontology Languages to model context data
  - Reasoning approaches
  - How they address specific requirements of AmI
  - Advantages
  - Limitations
- Possible Future Research Directions
  - Non-monotonic reasoning
  - Partition-based Reasoning
  - Distributed Reasoning with Heterogeneous Context Data

Notion of Context

- Context can be described as

".. any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and application themselves.." [Dey and Abowd, 1999]

- Context Characteristics
  - Multiple heterogeneous formats
  - Dynamic
  - Unknown
  - Ambiguous
  - Imprecise
  - Erroneous

Context Reasoning (1/2)

- Role of Context Reasoning
  - Detect possible errors
  - Complete missing values
  - Decide about the quality and the validity of the sensed data.
- but also..
  - Transform raw context data into meaningful information
  - Make decisions that may lead to actions

Context Reasoning (2/2)

- Challenges
  - Reasoning with the highly dynamic and ambiguous context
  - Managing the potentially huge piece of context data, in a real-time fashion, taking into account the restricted computational, storage and communication capabilities of some mobile devices
  - Collective intelligence, by supporting information sharing, and distributed reasoning between the entities of the ambient environment.

Context Representation Models

- Key-value Models
  - e.g. typed attribute-value pairs
- Markup Scheme Models
  - e.g XML-based models
- Graphical Models
  - e.g. UML-like languages (CML)
- Object Oriented Models
  - e.g. Java-based models
- Logic-based Models
  - e.g. FOL-based models
- Ontology based models

The Ontology Model

- Web Ontology languages (RDFS, OWL) offer
  - enhanced representational capabilities
  - formal models that can be
    - shared
    - reused,
    - extended,
    - combined
- Semantic Web Rule Languages and Systems enable reasoning with
  - the available ontology data
  - the user's needs and preferences

Context Reasoning Approaches

- Ontological Reasoning
- Rule-based Reasoning
- Distributed Reasoning
- Additional Reasoning Techniques
  - Case-Based Reasoning
  - Offline Reasoning
  - Probabilistic Reasoning

Ontological Reasoning (1/3)

- **Context Broker Architecture** [Chen et al., 2003]
- **RDF-based model for context-aware reasoning in rich service environment** [Forstadius et al., 2005]
- **CG-Platform** [Patkos et al., 2007]
- **Context aware querying - Challenges for data management in ambient intelligence** [van Bunningen, 2004]
- **Semantic User Profiles and their Applications in a Mobile Environment** [von Hessling et al., 2005]
- **Pushing Doors for Modeling Contexts with OWL DL: a Case Study** [Turhan et al., 2006]

Ontological Reasoning (2/3)

- Semantic Web Query Languages
  - RQL, RDQL, TRIPLE
- DL-based Reasoning Engines
  - FaCT, RACER, Pellet
- Primary Uses in the AmI Domain
  - Retrieve information from the context knowledge base
  - Check consistency of the available context data
  - Derive implicit ontological knowledge
  - Semantic matching

Ontological Reasoning (3/3)

- Advantages
  - Integrate well with the ontology model
  - Low computational complexity (in most cases)
  - Powerful reasoning engines
- Limitations
  - Cannot deal with missing or ambiguous information
  - Cannot enable and reason with user-defined policies
  - Cannot support decision-making
- Conclusion

  Ontological reasoning may serve as a significant part of the overall reasoning process, but cannot serve as a standalone solution.

Rule-based Reasoning (1/3)

- **Service Oriented Context Aware Middleware (SOCAM)** [Gu et al., 2004]
- **Semantic Space** [Wang et al., 2004]
- **Ontology Based Context Modeling and Reasoning using OWL** [Wang et al., 2004]
- **Context Infrastructure for Gaia** [Ranganathan & Campbell, 2003]
- **eWallet - myCampus** [Gandon & Sadeh, 2004]
- **Semantic Context-Aware Access Control Framework** [Toninelli et al., 2006]
- **Context-Aware Service Adaptation Middleware (CARE)** [Agostini et al., 2006]

Rule-based Reasoning (2/3)

- Rule Languages
  - FOL, Logic Programming
- Rule-based Reasoning Engines
  - Jess, Jena2, XSB
- Primary Uses in the AmI Domain
  - Reason about the quality of context information
  - Derive higher level context
  - Reason with service invocation rules
  - Reason with privacy rules

Rule-based Reasoning (3/3)

- Advantages
  - Formal context reasoning models
  - Rule languages are typically easy to understand and widespread used
  - Most rule-based systems integrate well with the ontology model
  - Support for decision-making
- Limitations
  - Cannot inherently deal with uncertain or conflicting information
  - In some cases, in order to deal with possible conflicts, they has to build an additional priority mechanism on top of the main reasoning module.
- Conclusion

  FOL-based or Horn-based logic models suit better in cases, where we are certain about the quality of the collected data. Although they provide solutions to most of the reasoning tasks, they cannot meet all the reasoning requirements.

Distributed Reasoning (1/5)

- **sTuples** [Khushraj et al., 2004]
- **Semantic Spaces** [Krummenacher et al., 2005]
- **Managing Context Information in Mobile Devices** [Korpipaa et al., 2003]
- **OWL-SF - A Distributed Semantic Service Framework** [Mrohs, 2005]

Distributed Reasoning (2/5)

- Shared-memory model (*sTuples*, *Semantic Spaces*)
  - Logically-shared memory
  - SW ontology languages to represent context data and available services
  - Access to the shared memory space through agents with specific roles:
    - Managing addition, removal and updates of context data tuples
    - Recommending services to the user
    - Notifying the user about changes of context

Distributed Reasoning (3/5)

- Blackboard-based model [Korpipaa et al., 2003]
  - Central Context Manager stores context information from any available source
  - The CM may assign certain reasoning tasks to dedicated machines
  - Clients
    - query the CM to retrieve relevant context information
    - subscribe to context notification services
    - use higher-level context transparently

Distributed Reasoning (4/5)

- Common characteristic of the two models
  - Central storage / control entity
- Advantages of the two models
  - Asynchronous Communications
  - Better Control – Better Coordination
  - Both models have been thoroughly studied and used in various similar domains
- but in ambient domains..
  - Context may not be restricted to a small room
  - Unreliable and restricted wireless communications

    → **Communication with a central entity cannot be guaranteed**

Distributed Reasoning (5/5)

- OWL-SF Framework
  - Super Distributed Objects + OWL
  - OWL-SDOs
    - OWL-based representations of h/w and s/w entities (status, services, communication interface)
  - Deduction Servers
    - Responsible for collecting the status of SDOs and for building an integrated OWL description accessible to reasoning
    - Deduction Engine to coordinate reasoning tasks
    - OWL-DL Reasoner
    - Rule-based Reasoning Support
  - Limitations
    - Different entities are required to use common context representations
    - Need for dedicated reasoning servers

Other Reasoning Techniques (1/3)

- **AmbieSense** [Kofod-Petersen et al., 2005]
- **ec(h)o Audio Museum Guide** [Hatala et al., 2005]
- **MIRA** [Castro et al., 2000]
- **Service Oriented Context Aware Middleware (SOCAM)** [Gu et al., 2004]
- **Managing Context Information in Mobile Devices** [Korpipaa et al., 2003]

Other Reasoning Techniques (2/3)

- Case-Based Reasoning (*AmbieSense*)
  - To deal with the potentially vast amount of available context information
  - Classification of new sensed context based on already known similar contexts.
  - Reasoning mechanism split into two parts
    - Online part (user's mobile device)
    - Offline part (user's backbone system)

Other Reasoning Techniques (3/3)

- Probabilistic Reasoning
  - To deal with the ambiguity of context data
  - Context predicates with probability values
  - Bayesian network as the underlying reasoning mechanism
    - It allows representing causal relationships between various contexts
    - It recognizes higher-level context from lower-level context atoms

Possible Future Research Directions (1/3)

- Non-monotonic Context Reasoning
  - Formal models that embody the notions of
    - uncertainty
    - spatial – temporal change
    - incompleteness
  - Similar models have been studied and deployed in domains with similar requirements
    - e.g. Web, e-learning, business rules, security specifications, negotiation protocols, etc.
  - There are reasoning systems that combine non-monotonic rule languages with ontology data
  - Main challenge: **Higher Computational Complexity**

Relevant Study

- **Contextual Default Reasoning (Brewka et al, 2007)**

Possible Future Research Directions (2/3)

- Partition-based Reasoning
  - Partition the large knowledge bases into smaller pieces,
  - share these pieces with other computing devices, and
  - deploy some form of partition-based reasoning

Relevant Studies

- **A Scalable Approach for Partitioning OWL Knowledge Bases** [Guo & Heflin, 2006]
- **Partition-based logical reasoning for first-order and propositional theories** [Amir & McIlraith, 2005]

Possible Future Research Directions (3/3)

- Distributed Reasoning with Heterogeneous Context Data (Data Integration)
  - Local-As-View
    - Translate all the data in a common schema and perform centralized reasoning
  - Global-As-View
    - A global virtual schema is defined as a set of views over the data source schemas.
    - This enables writing queries and rules using the local language of each data source.
  - Both-As-View
    - Local schemas are mapped to each other using a sequence of schema transformations (mappings).

Relevant Studies

- **Distributed Description Logics** [Serafini & Tamlin, 2005]
- **Distributed Reasoning in a Peer-to-Peer Setting: Application to the Semantic Web** [Adjiman et al., 2006]

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Thank You!
Questions?