Context Reasoning II

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Pervasive Computing

Give the right information
  ... to the right users
  ... at the right time
  ... on the right device

We need context!
Context Reasoning

Why?

- Imperfection and uncertainty:
  - Unknown
  - Ambiguous
  - Imprecise
  - Erroneous
Context Reasoning

Goals:

• Reason about dynamic and ambiguous context information
• Manage large amounts of context data in real-time
• Collective intelligence and distributed reasoning
Context Reasoning

General Strategies:
• Ontological
• Rule-Based
• Distributed
Ontological Reasoning

- Capable of expressing a formal context model that can be shared, reused, and extended
- Typically Semantic Web; SW query languages and reasoning engines available
- Goals:
  - retrieve relevant information
  - check consistency
  - derive implicit knowledge
Ontological Reasoning

Example: CONON (CONtext Ontology)

- OWL-encoded for modeling context in pervasive computing environments
- Location, user, activity, computational entity
Figure 2. Partial definition of a specific ontology for home domain
CONON: Goals

- Check consistency of context
- Deduce implicit context from low-level data
- Ontology reasoning with a restricted set of first-order formulas
- Allow user-defined formulas
- Example: smart phone
<table>
<thead>
<tr>
<th>Situation</th>
<th>Reasoning Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeping</td>
<td>(?u locatedIn Bedroom) ^ (Bedroom lightLevel LOW) ^ (Bedroom drapeStatus CLOSED) [?u situation SLEEPING]</td>
</tr>
<tr>
<td>Showering</td>
<td>(?u locatedIn Bathroom) ^ (WaterHeater locatedIn Bathroom) ^ (Bathroom doorStatus CLOSED) ^ (WaterHeater status ON) [?u situation SHOWERING]</td>
</tr>
<tr>
<td>Cooking</td>
<td>(?u locatedIn Kitchen) ^ (ElectricOven locatedIn Kitchen) ^ (ElectricOven status ON) [?u situation COOKING]</td>
</tr>
<tr>
<td>Watching-TV</td>
<td>(?u locatedIn LivingRoom) ^ (TVSet locatedIn LivingRoom) ^ (TVSet status ON) [?u situation WATCHINGTV]</td>
</tr>
<tr>
<td>Having-Dinner</td>
<td>(?u locatedIn DiningRoom) ^ (?v locatedIn DiningRoom) ^ (?u owl:differentFrom ?v) [?u situation HAVINGDINNER]</td>
</tr>
</tbody>
</table>
CONON: Prototype

- Context reasoners using Jena2 engine
- Several context datasets from 1K to 10K RDF triples (S-V-O predicate)
- Performance depends on context information size, complexity of rules
- Could perform intensive reasoning offline or on a central server
Ontological Reasoning: Summary

• Advantages
  • Integrates easily with the widely-used ontology model of context
  • Relatively low computational complexity

• Disadvantages
  • Cannot handle missing or ambiguous information
  • Does not provide support for decision making
Rule-Based Reasoning

- Another formal model for context
- Use first-order predicates and logic to derive new information given context data
- Requires conflict resolution for competing rules
- Logic engines available, but may need modifications
Rule-Based Reasoning

Example: Gaia

- Context information represented as predicates
- Set of rules to deduce higher-level knowledge
- Rules are re-evaluated upon change in context
- Focus on encoding and resolving uncertainty within “Active Spaces”
Gaia: Context Predicates

- Predicates are helpful because they can be plugged into rules directly
- Use ontologies to check validity, define translations between environments
- Each predicate has a confidence value

location(Jeff, in, room 3015)  light(room 3220, dim)
activity(room 3102, meeting)  office(Jeff, room 3216)
Probabilistic and Fuzzy Logic

- Allows statements like:
  \[ \text{prob}(E) < \frac{1}{3} \]
  \[ \text{prob}(E) \geq 2 \times \text{prob}(F) \]

- Fuzzy logic is similar, but with degrees of membership rather than probability
Bayesian Networks

• Directed acyclic graphs
• Nodes are variables representing events
• Edges are causal relationships
• Each value a variable can take corresponds to a predicate
• Initialize with prior probabilities of root nodes and conditional probabilities of non-root nodes
Architecture

- API designed to allow developers concentrate on developing rules and networks
- Allows plugging in different reasoning strategies
- Infrastructure auto-updates with current context information
Resolving Uncertainty

• In sensing context
  • Example: RFID tags
• In inferring context
  • Example: authentication, room activity
• In using uncertain context information
  • Example: troubleshooting
Rule-Based Reasoning

• Advantages
  • Provide a formal model
  • Easy to understand, widely used, and can integrate with an ontology model
  • Work well with data of known quality

• Disadvantages
  • Difficult to handle dynamic, ambiguous, and imperfect information
  • Had to build additional reasoning mechanisms to handle conflicts and uncertainty
Distributed Reasoning

- Many different entities available to collect, process, and change context information
- Same context, different viewpoints
- Example: CARE middleware
CARE middleware

- Goal: support context-aware adaptation of internet services for mobile users
- Efficiency and scalability critical
- Each entity has an associated profile
  - “Shallow” context data
  - Ontology-based context data
- User and service provider declare rules
CARE middleware

- Both rule-based and ontological
- May require retrieving data from different entities to evaluate
- TBox: definition of classes and relations, static
- ABox: individual objects in domain
Experimental Results

- Task: realization of an instance *CurrentActivity* in the *Activity* class
- Response time grows exponentially normally, but linearly with a priori realization in Abox
- When TBox and ABox are both large (500, 2000), on the order of seconds
Distributed Reasoning

• Advantages
  • Combine different device capabilities
  • Potential to speed up reasoning process

• Disadvantages
  • Scalability to large contexts
  • Tied to client-server architecture
Discussion

• We need context models that can deal with imperfect data!
• Tradeoff between completeness and performance
• Scalability is a continuing issue, but performing processing in advance helps considerably
References