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

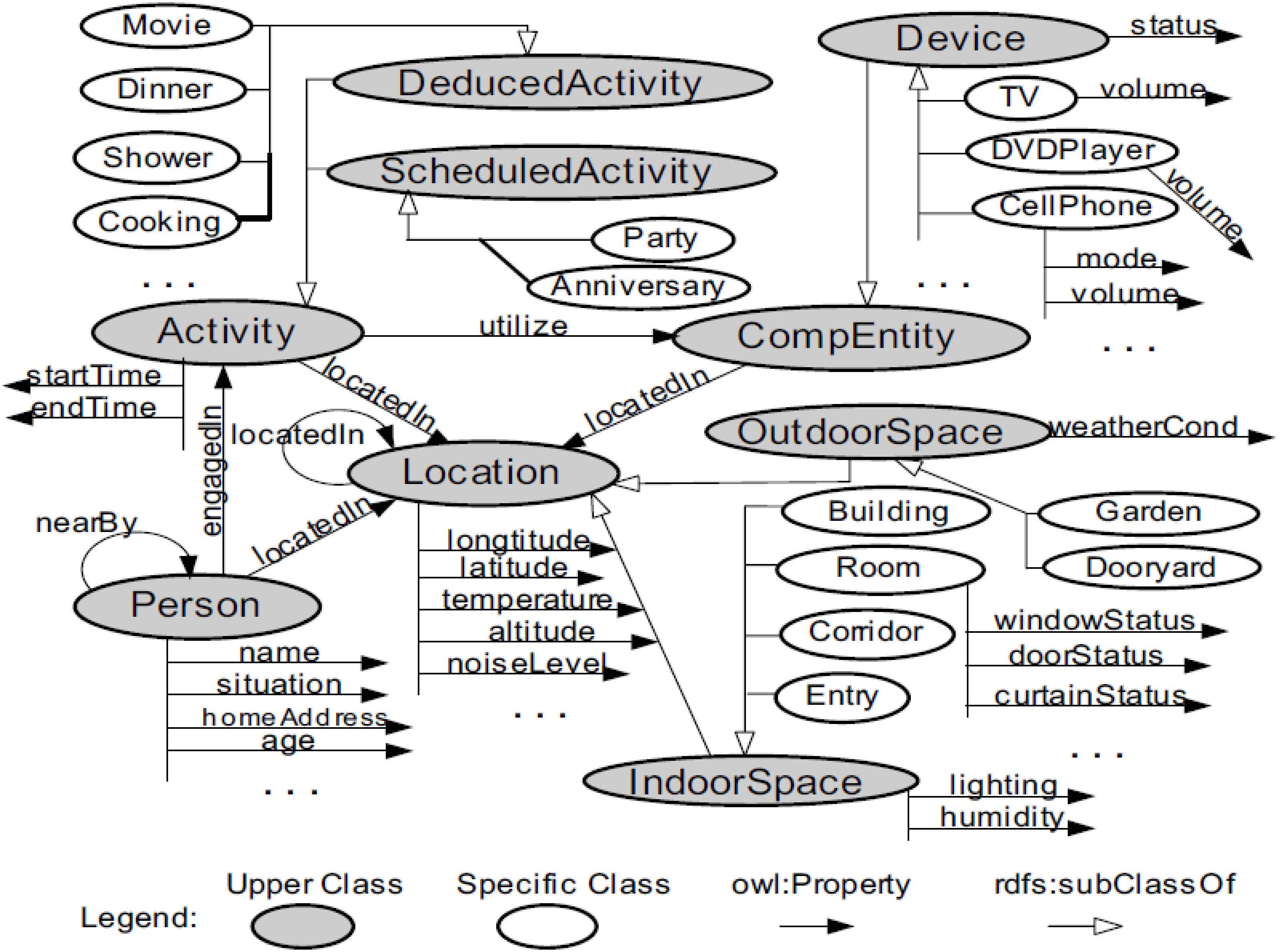

Figure 2. Partial definition of a specific ontology for home domain

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 3. User-defined context reasoning rules

Situation	Reasoning Rules
Sleeping	(?u locatedIn Bedroom) $\wedge$ (Bedroom lightLevel LOW) $\wedge$ (Bedroom drapeStatus CLOSED) $\Rightarrow$ (?u situation SLEEPING)
Shower-ing	(?u locatedIn Bathroom) $\wedge$ (WaterHeater locatedIn Bathroom) $\wedge$ (Bathroom doorStatus CLOSED) $\wedge$ (WaterHeater status ON) $\Rightarrow$ (?u situation SHOWERING)
Cooking	(?u locatedIn Kitchen) $\wedge$ (ElectricOven locatedIn Kitchen) $\wedge$ (ElectricOven status ON) $\Rightarrow$ (?u situation COOKING)
Watching-TV	(?u locatedIn LivingRoom) $\wedge$ (TVSet locatedIn LivingRoom) $\wedge$ (TVSet status ON) $\Rightarrow$ (?u situation WATCHINGTV)
Having-Dinner	(?u locatedIn DiningRoom) $\wedge$ (?v locatedIn DiningRoom) $\wedge$ (?u owl:differentFrom ?v) $\Rightarrow$ (?u situation HAVINGDINNER)

CONON: Prototype

- Context reasoners using Jena2 engine
- Several context datasets from 1K to 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:

$$prob(E) < 1/3$$
$$prob(E) >= 2 * prob(F)$$

- 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
- Scalabiilty is a continuing issue, but performing processing in advance helps considerably

References

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