Context Reasoning

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27 March, 2014
Paper:

Focus on:
Various existing methods for modelling context information used by context-aware applications and reasoning techniques for context information.
Context models

- Introduction
- Object-role based models of context information
- Spatial models of context information
- Ontology-based models of context information
- Situation modelling and reasoning
- Uncertainty of Context Information
- Hybrid context models
Definition

*Context* is any information that can be used to characterize the situation of an entity.

Definition

A system is *context-aware* if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.

Definition

*Context modelling* is a way of formalising and normalizing context, using a model.
Context modelling

Importance:

- Reduces the complexity of context-aware applications
- Improves their maintainability and evolvability.
- Context can be expensive - Re-use and resharing is important.
- Consistency checking and sound reasoning.
Requirements of good context model:

- Heterogeneity and mobility - E.g. difference in update rates (sensor input vs user provided); static vs dynamic data; mobility issues.
- Relationships and dependencies - Resolve and utilize context dependencies.
- Timeliness - Context histories, use past states.
- Imperfection - Quality and accuracy of data.
- Reasoning - Evaluate change and derive higher level information.
- Usability of modelling formalisms - Ease of use
- Efficient context provisioning - Easy access to context, both primary and secondary.
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Context modelling

Two levels of modelling abstraction:
- Fact
  - Defines relationship between key entities
  - Modelled using Context Modelling Language (CML) and others
- Situation
  - Modelled in terms of facts and other situations
  - Higher programming abstraction than facts.
Context Modelling Language (CML)

- Fact based
- Extends Object Role Modelling (ORM) to support:
  - Classifications of fact types according to source and persistence
  - Can handle ambiguous context information
  - Quality metadata
  - Temporal fact types (histories)
  - Deals with dependencies
CML example

\[ \text{located near}(p,d) \text{ iff located at}(p,11) \]
\[ \text{and located at } (d,12) \]
\[ \text{and } 11 = 12 \]

\[ \text{engaged in}(p1,a) \text{ dependsOn located at}(p2,l) \]
\[ \text{iff } p1 = p2 \]
CML: Support for reasoning

- Ability to support uncertain information.
- Evaluated against a set of facts and variable bindings to give: true, false or possible true.
- Can be extended to support situations.

Definition

Situations are logical expressions defining abstract classes of context.
CML Evaluation

Strengths:

- Captures imperfect and historical information.
- Relational representation and situation abstraction support runtime representation and querying.
- Supports various stages of software engineering process.

Weaknesses:

- “Flat” information model.
- Requires specific context model for each application.
- Does not support interoperability as found in ontology-based models.
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Spatial Context Models

- “Where you are, who you are with and what resources are nearby”
- Most spatial context models are fact-based.
- Location either predefined (static) or obtained (dynamic).
Spatial Context Models

Representations:

- Geometric coordinates: Can be used hierarchically.
- Symbolic coordinates: Reasoning about inclusion and distances requires explicit information.
Spatial Context Models

Tiers of spatial ontologies:

- **Tier 0**: Ontology of physical reality - One world assumption.
- **Tier 1**: For a single item, observation $\rightarrow$ Value
- **Tier 2**: Value $\rightarrow$ location and boundary of physical body.
- **Tier 3**: Social interactions and hierarchy.
- **Tier 4**: Rule modelling for reasoning.
Spatial Context Models: Reasoning

- Three spatial queries: Position, range and nearest neighbour.
- Can use spatial database support.
- Mostly for spatial queries.
Spatial Context Models: Evaluation

Strengths:
- Geometric models - simple mapping to map data
- Symbolic models - easy to build and perceive
- Spatial partitioning can be used for large data.

Weaknesses:
- Large effort to gather spatial data.
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Definition
An ontology is a formal and explicit specification of a shared conceptualization, i.e. a description of concepts and their relationships.

- Usually done using OWL-DL language.
Ontology based model: Context modelling

- A domain is modelled by:
  - Classes
  - Individuals
  - Characteristics of individuals (datatype properties)
  - Relations between individuals (object properties)

- Complex descriptions are represented by composing elementary ones using operators - Provides expressive formalism and well-suited for knowledge sharing.

\[
\text{BusinessMeeting} \sqsubseteq \text{Activity} \sqcap \geq 2\text{hasActor} \sqcap \forall\text{hasActor.Employee} \sqcap \\
\exists\text{hasLocation.(ConfRoom} \sqcap \text{CompanyBuilding).}
\]
Ontology based model: Reasoning

- Automatically derive new knowledge about current context.
- Detect possible inconsistencies in the context information.
Ontology based model: Evaluation

Strengths:
- Capacity of modelling relations and hierarchical data
- Formal semantics
- Automatic reasoning for consistency checking and recognition of high-level context data.

Weaknesses:
- Expressiveness limitations: Unable to express complex descriptions.
- Performance issues
- Lack of support for uncertainty
- Lack of support for temporal reasoning.
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Situations

Definition

Situations are high level abstractions from low-level context information.

- Derivation of higher level context from raw sensory values.
- Semantic interpretations of lower level context, i.e. low-level context to system actions.
- Specified at design time and recognized/learned at run time.
- Easy to define and maintain.
Situations: Example

Example: "in a meeting".

- Co-location of people and agenda information.
- Co-location of filled coffee cups in a room.
- Weight sensors on the floor.
- Devices in the room (lights, projector and powerpoint on PC)
- Sounds and noises.
- Cameras ("watch" meeting room activity)
Reasoning on situations

- Using various logic techniques:
  - Propositional and first-order logic.
  - Ontological reasoning (description logic).
- Using machine learning techniques:
  - Often used for activity recognition
  - Requires training period which often requires human intervention
Relationships between situations

- Relationship define the search space for potential situations
- Approaches
  - Only define “situations of interest”
  - Define a complete situation model which shows transitions between situations.
  - Explicitly define model situation relationships.
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Uncertainty

- Imprecise and conflicting data exists.
- Different entities need to cope with uncertainty:
  - Sensors
  - Entities that infer from other basic sensed contexts
  - Applications that adapt how they behave on the basis of uncertain contexts
- Need model for uncertainty
Uncertainty: Measurement

Quality indicators:
- Resolution: e.g. 50 feet from xyz location
- Freshness: Time elapsed since measurement
- Confidence: Probability of correctness
Uncertainty: Reasoning

- Improving the quality of context information
- Inferring new kinds of context information
- Models:
  - Fuzzy logic
  - Probabilistic logic
  - Bayesian networks
  - Hidden Markov Models
  - Dempster Shafer Theory
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Existing hybrid models

- Hybrid fact-based/ontological model: combine CML model advantages (handling ambiguous and imperfect context information) with interoperability support and various types of reasoning provided by ontological models.
- Loosely coupled markup-based/ontological model: handles ambiguous information, efficient reasoning technique.
- Hierarchical spatial/ontological model: scalable, efficient reasoning techniques, expressive
Thank you!