Context Reasoning

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Context Reasoning

Paper:
A survey of Context Modelling and Reasoning Techniques.
Bettini et al.

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

Introduction

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.

Context modelling

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

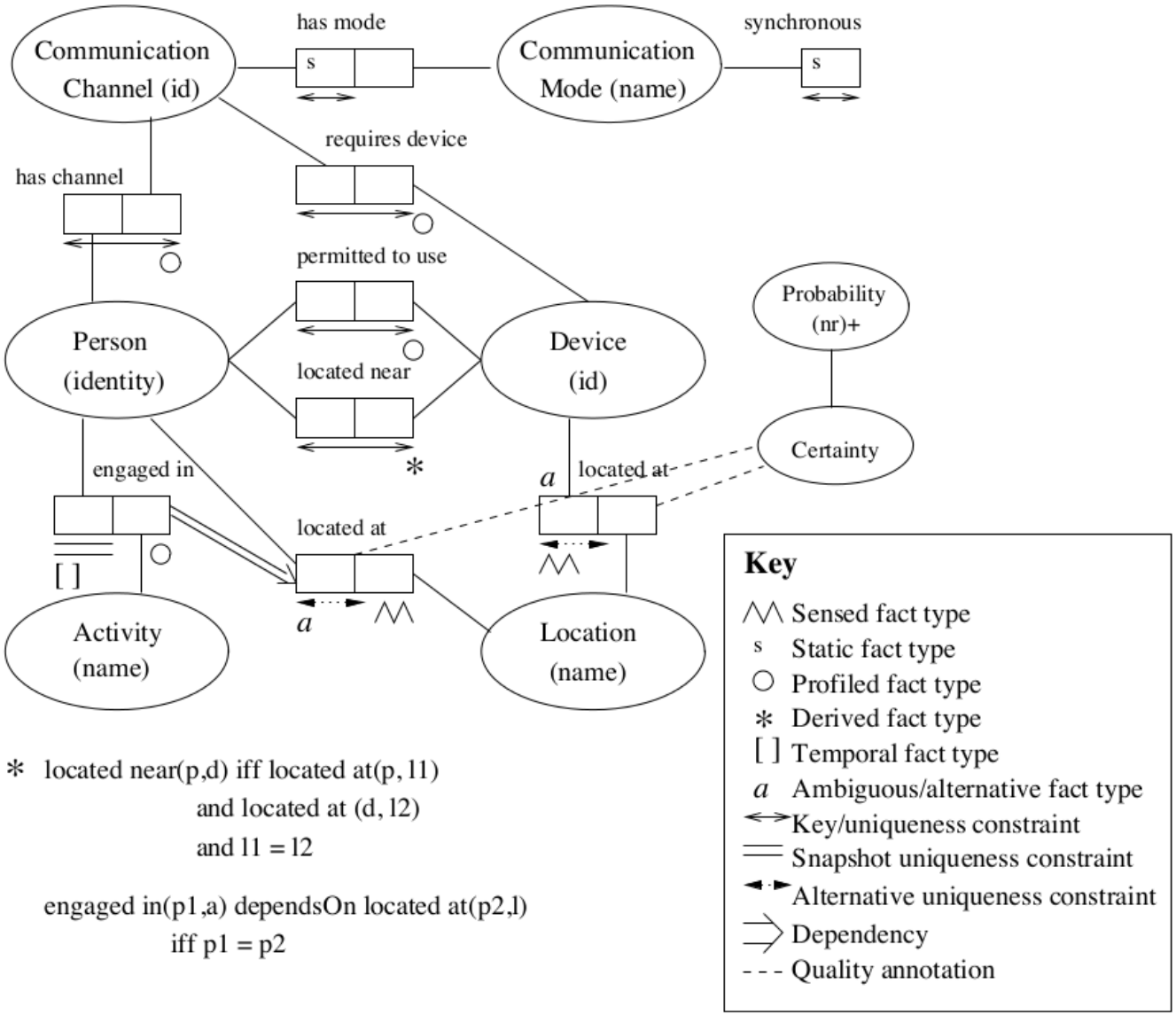
Two levels of modelling abstraction:

- 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


Communication Channel (id)
has mode
s
Communication Mode (name)
synchronous
s
requires device
has channel
permitted to use
Person (identity)
located near
Device (id)
Probability (nr)+
Certainty
engaged in
a
located at
located at
[ ]
Activity (name)
a
Location (name)
Key
Sensed fact type
s Static fact type
Profiled fact type
* Derived fact type
[ ] Temporal fact type
a Ambiguous/alternative fact type
Key/uniqueness constraint
Snapshot uniqueness constraint
Alternative uniqueness constraint
Dependency
Quality annotation
* located near(p,d) iff located at(p, l1)
and located at (d, l2)
and l1 = l2
engaged in(p1,a) dependsOn located at(p2,l)
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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Ontology

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.

$$\texttt{BusinessMeeting} \sqsubseteq \texttt{Activity} \sqcap \geq 2\,\texttt{hasActor} \sqcap \forall \texttt{hasActor.Employee} \sqcap \exists \texttt{hasLocation.(ConfRoom} \sqcap \texttt{CompanyBuilding)}.$$

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 Moels
  - 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!