Challenges for Context Management Systems imposed by Context Inference

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Agenda

- Introduction
- Requirements for Future Context Management Systems
- Creation, Storage and Access of Context Inference Rules
- Integration of Inference with Context Management Systems
- Conclusions and Outlook
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Introduction
Why Context Inference?

- Not for everything there are sensors
- Usage of available information to estimate **high-level context**

- Examples:
  - Situation
  - Activity
  - Mood
  - Danger
  - ...

- Useful for:
  - Professional Monitoring
  - Ambient Assisted Living
  - Smart Environments
  - ...

While out of the house sensor data belong to the elderly person is relayed back to the home station.

Data from around the home is sent, processed and stored in the home station.

All data storage and processing is done by the home station.

Carers can access various levels of data in home system.
Introduction
Why Context Inference? Use Case

Activity recognition and Proactive Service Execution

Tuesday: Tom has a meeting. He activates his out-of-office mail.

Tom selects ‘print’ on pda while in his meeting.

Tuesday: Tom switches off the lights as he leaves.
Introduction
Why Context Inference? Use Cases

Tom has a meeting. He activates his out-of-office mail.

Tom switches off the lights as he leaves.

Friday: The system remembers Tom's behaviour and automatically prints the agenda in the meeting.
Introduction

Context Inference: How?

Bayesian Networks
- Causal Relations
- Transition Probabilities

Meeting Room
- Gyro
- Magnetometer
- Accelerometer

Office
- NavShoe
- Ubisense
- GNSS
- ... (other sensors)

Nearest Printer

High-level activity
- Being in a Meeting
- Interaction

Time
- Schedule
- Calendar
- Clock
- Microphone
- Service Mgmt
- Light switch
- Walking

Current Indoor Location
- Being in a meeting
- Meeting Room
- Office

Used Services

Schedule

Calendar

Meeting Room
Agenda

Introduction

Requirements for Future Context Management Systems (CMSs)

Creation, Storage and Access of Context Inference Rules

Integration of Inference with Context Management Systems

Conclusions and Outlook
Requirements for Future Context Management Systems

State of the art

- Efficient Context Modeling and Semantics → main target
- Distributed Context Management → some prototypes
- Context Source Management → seldom generic
- Context Inference → only on algorithmic level
- Preference handling → Concept discussions
- History of Context → Available in some projects
- Context Event Management → Usually available
- Group context → Concept phase
- Context privacy & security → Seldom implemented
- Quality of context → Conceptually available
Requirements for Future Context Management Systems
Adaptation to New Needs

- Providing concepts and architecture
- Analysing and optimizing performance in component interactions
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Creation, Storage & Access of Context Inference Rules

Rule Creation

\[ p(x_i^k | Pa_i = Pa'_i, S^h, D) = \frac{a_{ijk} + N_{ijk}}{a_{ij} + N_{ij}} \]

<table>
<thead>
<tr>
<th>+ Relatively fast, „cheap“</th>
<th>+ Accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>- un-intelligent, does not recognise limits</td>
<td>- Time/Cost intensive → not personalized</td>
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Setting Constraints:
- Machine learning
  - Node hierarchies
  - Penalizing edges
  - Cutting nodes
- Access rights

Checking the Outcome:
- Adding semantics to learnt concepts
- Provision as template
Creation, Storage & Access of Context Inference Rules
More Rule Creation

More sources of rules in a CMS:
- Usage of templates, adapted to a user by incremental personalisation
- External providers

Triggering of Rule Learning:

<table>
<thead>
<tr>
<th></th>
<th>Batch-Process</th>
<th>On-Demand</th>
<th>Incremental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Update</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Resource usage</td>
<td>--</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Response time</td>
<td>+</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>Up-to-date information</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

→ A combination of all approaches is necessary
Creation, Storage & Access of Context Inference Rules
Storage
1) Context providers as external services: registration for input, provision of output info
2) Centrally on backend servers inside the CMS
3) On mobile user devices managed by the distributed CMS

➔ Combination of (2) and (3) for:
   ➔ Access control
   ➔ Privacy protection
   ➔ Up-to-date rules
   ➔ Reduced communication
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Inference in Context Management Systems
Reducing inference duration: The Bayeslet concept

- Object Orientation:
  - Encapsulation
  - Modularity
  - Polymorphism
- Dynamically Pluggable
  - Sensor-Concept units
  - Causal influence
- Reduces:
  - Nodes
  - Value Ranges
  - Edges

Diagram:
- Current indoor location
- High-level activity
- Interaction
  - Used services
  - Service Mgmt
- Time
  - Clock
  - Schedule
  - Calendar
- Motion
  - Gyro
  - Magnetometer
  - Accelerometer
  - GNSS
  - Ubisense
  - NavShoe

Used services
- User services
- Interaction
Inference in Context Management Systems

Inference Scheduling

Options:

- **Continuous Inference**
  - Advantages: Always recent inferred information
  - Drawbacks: High resource cost, possibly unused information

- **On-Demand Inference**
  - Advantages: resource efficient
  - Drawbacks: higher response times
    no subscription possible

Possible solutions:

- Enable subscription by splitting it to subscriptions for every input node
- Continuous inference based on the update of the input node
Inference in Context Management Systems

Inference Scheduling

Hybrid Solution:
Continuous Inference upon request – On-Demand Inference where possible
Inference in Context Management Systems

Update Frequency

The update frequency of an inference rule $f_{\text{inference}}$, depends on the update frequency of its input information $f_{\text{input}_i}$.

$$\max_i (f_{\text{input}_i}) \leq f_{\text{inference}} \leq \sum_i f_{\text{input}_i}$$

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**Situation**

**Context Information**

**Sensor Measurements**

**Smaller VR, Lower sampling rate**

**High sampling rate, discrete, many values**

**Time & range continuous**

**Hierarchical Inference**

**Slower Changes**

- Clustering and run-time value range processing
- Projections and context modeling

**Fast Changes**
High-level Activity Inference
Hierarchical Inference

- Low level algorithms widely used & necessary:
  - Coordinate based location techniques
  - E.g. Particle Filters for tracking or situation analysis

- Making the result available to and usable in Bayeslets – probabilities, soft outcome necessary

1. Enhance the precision based on high-frequent absolute location
2. Assign semantics to clusters of related locations
3. Use this information for further inference
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Conclusions and Outlook

1. When and how should CIRs be created?
   → combination of batch and incremental learning + human expertise

2. Where should they be stored and how accessed?
   → mobile, but backed up

3. How can inference time be reduced?
   → Bayeslet concept, reducing rule size

4. How has inference to be scheduled or triggered?
   → on-demand and continuous inference, results stored in CMS

5. When has inference to be updated based on its input?
   → upon change of already semantically enriched information, not raw data

Next Steps:

⇒ Realistic Testing
⇒ Smart Device User interaction incorporated as expert knowledge.