Rule-based Contextual Reasoning in Ambient Intelligence

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Outline

- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- R-CoRe – A Distributed Approach
- Centralized vs. Distributed Reasoning
- Open Problems
Ambient Intelligence

- **Goal**: Transform our living and working environments into smart spaces
- **Requirement**: Augment environments with sensing, computing, communication and reasoning capabilities
Context

Context is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and application, including the user and applications themselves

[Dey and Abowd, 1999]
Context Representation

- **Key-value models**
  - Service: list of attributes in a key-value manner

- **Markup scheme models**
  - XML-based

- **Graphical models**
  - UML like

- **Object oriented models**
  - Context data encapsulated in data objects

- **Logic-based models**
  - First Order Logic, Logic Programming

- **Ontology-based models**
  - Based on Description Logics
Contextual Reasoning

Aims
- Inference of high-level context knowledge
- Consistency checking
- Context-aware decision making

Challenges
- Imperfect context information
- Heterogeneous entities
- Highly dynamic and open environments
- Distributed context information
- Unreliable wireless communications
- ...restricted by the range of transmitters
Contextual Reasoning (cont’d)

- Approaches
  - Ontological reasoning
    - DL rules used to derive implicit knowledge
    - Natural integration with ontology model
    - Limited reasoning capabilities
  - Rule-based reasoning
    - More expressive rule languages
    - FOL, Logic Programming, Defeasible Logic
  - Probabilistic reasoning
    - Explicit model uncertainty, confidence values, causal relationships
    - Rich expressive capabilities
    - High complexity
Rule-based Contextual Reasoning

- **Benefits**
  - Simplicity & Flexibility
  - Formality
  - Expressiveness
  - Modularity
  - High-level abstraction & Information hiding
  - Integration with ontology languages
Outline

- Context and Contextual Reasoning in Ambient Intelligence
- **A Centralized Reasoning Framework**
- R-CoRe – A Distributed Approach
- Centralized vs. Distributed Reasoning
- Open Problems
Aims & Architecture

- Part of a large-scale Ambient Intelligence facility developed for the needs of the ICS-FORTH Ambient Intelligence Programme

- Design Goals
  - efficient representation, monitoring, dissemination of context
  - reasoning about the available information
  - context-aware decisions
Rule Types

- **Inference rules**
  - Triggered by new assertions in the KB
  - Assert new relations in the KB

- **Action rules**
  - Reactive (to events) or Triggered (by assertions in the KB)
  - Assert new relations in the KB
  - Determine and send commands for actions

- **Rule Scheme (ECA)**

  \[
  \text{event}(E), /* received from middleware and added as fact in KB */
  \text{precondition}(C1),..., \text{precondition}(Ck) /* relations in KB */
  \rightarrow \text{action}(A1),..., \text{action}(An) /* functions for KB update or commands for actions sent to middleware */
  \]
Special Features

- Seamless Interaction
  - Adjust services to user’s context
  - Achieved through
    - Sensing – keep track of user’s context
    - high-level context inference – identify state / situation
    - context-aware reasoning – situation-based policies

- Vast amount of context information
  - Context Classification
  - Context Segmentation

- Inconsistency Resolution
  - Conflicts due to competing policies
  - Priority-based rule classification
Outline

- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- **R-CoRe: A Distributed Approach**
- Centralized vs. Distributed Reasoning
- Demo
Features & Underlying Technologies

- **R-CoRe**: A Rule-based Contextual Reasoning Platform for AmI
- Developed with SnT Luxembourg for the needs of the CoPAInS (Conviviality and Privacy in Ambient Intelligence Systems) project
  - Funded by FNR Luxembourg

- **Main Features**
  - Distributed
  - Rule-based
  - Non-monotonic
  - Preference-based conflict resolution
  - Dynamic & Adaptive

- **Underlying technologies**
  - Multi-Context Systems
  - Contextual Defeasible Logic (CDL)
  - Keveree
Multi-Context Systems: The *magic box* example
Multi-Context Systems: The *magic box* example

- None of the observers can make out the depth of the box
Multi-Context Systems: The *magic box* example

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- Mr. 1’s beliefs may regard concepts that are meaningless for Mr. 2 and vice versa
Multi-Context Systems: The *magic box* example

- None of the observers can make out the depth of the box
- Mr. 1’s beliefs may regard concepts that are meaningless for Mr. 2 and vice versa
- Mr. 1 and Mr. 2 may use common concepts but interpret them in different ways
Multi-Context Systems: The *magic box* example

- None of the observers can make out the depth of the box.
- Mr. 1’s beliefs may regard concepts that are meaningless for Mr.2 and vice versa.
- Mr. 1 and Mr. 2 may use common concepts but interpret them in different ways.
- The observers may have partial access to each other’s beliefs about the box.
Multi-Context Systems: Intuitions and Model

- **Context**
  - A *partial* and *approximate* theory of the world from some individual’s *perspective*
  - A logical theory – a set of axioms and inference rules

- **Multi-Context Systems**
  - *Distributed context theories* connected through *mappings* that enable information flow between different contexts
  - Mappings modeled as inference rules with premises and consequences in different contexts
Nonmonotonic MCS

- MCS enriched with **nonmonotonic** features to handle imperfections, e.g. incomplete knowledge, inconsistencies
Contextual Defeasible Logic

A Defeasible MCS $C$ is a collection of contexts $C_i$

Each context $C_i$ is a tuple $(V_i, R_i, T_i)$

- $V_i$: vocabulary used by $C_i$
- $R_i$: set of rules
- $T_i$: preference ordering on $C$

$V_i$: a set of literals of the form $a, \neg a$
Contextual Defeasible Logic (cont’d)

Three types of rules in $R_i$

- Strict local rules
  
  \[ r_i^l : (c_i : a_1), \ldots, (c_i : a_{n-1}) \rightarrow (c_i : a_n) \]

- Defeasible local rules
  
  \[ r_i^d : (c_i : a_1), \ldots, (c_i : a_{n-1}) \Rightarrow (c_i : a_n) \]

- Mapping rules
  
  \[ r_i^m : (c_j : a_1), \ldots, (c_k : a_{n-1}) \Rightarrow (c_i : a_n) \]

$T_i$ is a partial preference ordering on $C$
modeled as a Directed Acyclic Graph
AAL Example Scenario

- **SMS System**
- **Home Care System**
- **Medical Profile**
- **Wearable Health Bracelet**
- **Activity Recognition**

**Rule-based Contextual Reasoning in Ambient Intelligence**
Example Scenario in CDL terms

\[ r_{\text{sms}}^m : (hcs: \text{emergency}) \implies (sms: \text{dispatchSMS}) \]
Example Scenario in CDL terms

\[ r_{\text{sms}}^m : (\text{hcs} : \text{emergency}) \implies (\text{sms} : \text{dispatchSMS}) \]

\[ r_{\text{hcs}}^{m1} : (\text{br} : \text{normalPulse}) \implies (\text{hcs} : \neg \text{emergency}) \]

\[ r_{\text{hcs}}^{m2} : (\text{arm} : \text{lyingOnFloor}), (\text{med} : \text{proneToHA}) \implies (\text{hcs} : \text{emergency}) \]
Example Scenario in CDL terms

\[ r_{med}^{1} : \rightarrow (med : proneToHA) \]

\[ r_{sms}^{m} : (hcs : emergency) \Rightarrow (sms : dispatchSMS) \]

\[ r_{hcs}^{m1} : (br : normalPulse) \Rightarrow (hcs : \neg emergency) \]

\[ r_{hcs}^{m2} : (arm : lyingOnFloor), (med : proneToHA) \Rightarrow (hcs : emergency) \]
Example Scenario in CDL terms

\[ r_{med}^1 : \rightarrow (med : \text{proneToHA}) \]

\[ r_{sms}^m : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS}) \]

\[ r_{hcs}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]

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Rule-based Contextual Reasoning in Ambient Intelligence
Example Scenario in CDL terms

\[ r_{med}^1 : \rightarrow (med : proneToHA) \]

\[ r_{sms}^m : (hcs : emergency) \Rightarrow (sms : dispatchSMS) \]

\[ r_{br}^1 : \rightarrow (br : normalPulse) \]

\[ r_{hcs}^{m1} : (br : normalPulse) \Rightarrow (hcs : \neg emergency) \]

\[ r_{hcs}^{m2} : (arm : lyingOnFloor), (med : proneToHA) \Rightarrow (hcs : emergency) \]

\[ r_{arm}^1 : \rightarrow (arm : lyingOnFloor) \]
Distributed Query Evaluation

- When a context receives a query for one of its local literals $q$
  - Evaluates answer based on local knowledge
  - If not possible
    - Collects relevant information from other contexts through mappings
    - Checks applicability of rules for and against $q$
  - Evaluates answer based on
    - Applicable rules
    - Preferences
Example Scenario: Query Evaluation

- $r_{med}^{1} : \rightarrow (med : \text{proneToHA})$
- $r_{br}^{1} : \rightarrow (br : \text{normalPulse})$
- $r_{sms}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS})$
- $r_{hcs}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency})$
- $r_{hcs}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency})$
- $r_{arm}^{1} : \rightarrow (arm : \text{lyingOnFloor})$

Rule-based Contextual Reasoning in Ambient Intelligence
Example Scenario: Query Evaluation

$r_{med}^{1} : \rightarrow (med: proneToHA)$

$r_{sms}^{m} : (hcs: emergency) \Rightarrow (sms: dispatchSMS)$

$r_{br}^{1} : \rightarrow (br: normalPulse)$

$r_{hcs}^{m1} : (br: normalPulse) \Rightarrow (hcs: \neg emergency)$

$r_{hcs}^{m2} : (arm: lyingOnFloor), (med: proneToHA) \Rightarrow (hcs: emergency)$
Example Scenario: Query Evaluation

\[ r_{med}^1 : \rightarrow (med : \text{proneToHA}) \]

\[ r_{br}^1 : \rightarrow (br : \text{normalPulse}) \]

\[ r_{sms}^m : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS}) \]

\[ r_{hcs}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]

\[ r_{hcs}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency}) \]

Rule-based Contextual Reasoning in Ambient Intelligence
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Example Scenario: Query Evaluation

- **Rule 1:** $r_{med}^1 : \rightarrow (med : proneToHA)$
  - $r_{sms}^m : (hcs : emergency) \Rightarrow (sms : dispatchSMS)$

- **Rule 2:** $r_{br}^1 : \rightarrow (br : normalPulse)$

- **Rule 3:** $r_{hcs}^m : (br : normalPulse) \Rightarrow (hcs : \neg emergency)$

- **Rule 4:** $r_{hcs}^m : (arm : lyingOnFloor), (med : proneToHA) \Rightarrow (hcs : emergency)$

- **Rule 5:** $r_{arm}^1 : \rightarrow (arm : lyingOnFloor)$
Example Scenario: Query Evaluation

\[ r_{\text{med}}^{1} : \rightarrow (med : \text{proneToHA}) \]

\[ r_{\text{sms}}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS}) \]

\[ r_{\text{br}}^{1} : \rightarrow (br : \text{normalPulse}) \]

\[ r_{\text{hcs}}^{m_{1}} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]

\[ r_{\text{hcs}}^{m_{2}} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency}) \]

Rule-based Contextual Reasoning in Ambient Intelligence
Example Scenario: Query Evaluation

\[ r_{\text{med}}^1 : \rightarrow (\text{med} : \text{proneToHA}) \]

\[ r_{\text{sms}}^m : (hcs : \text{emergency}) \Rightarrow (\text{sms} : \text{dispatchSMS}) \]

\[ r_{\text{br}}^1 : \rightarrow (\text{br} : \text{normalPulse}) \]

\[ r_{\text{hcs}}^{m1} : (\text{br} : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]

\[ r_{\text{hcs}}^{m2} : (\text{arm} : \text{lyingOnFloor}), (\text{med} : \text{proneToHA}) \Rightarrow (hcs : \text{emergency}) \]

Rule-based Contextual Reasoning in Ambient Intelligence
Example Scenario: Query Evaluation

\[ r_{\text{sms}}^{m} : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS}) \]

\[ r_{\text{hcs}}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]
\[ r_{\text{hcs}}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \Rightarrow (hcs : \text{emergency}) \]

\[ T_{\text{hcs}} = [med, arm, br] \]
Example Scenario: Query Evaluation

\[ r_{\text{sms}}^m : (hcs : \text{emergency}) \Rightarrow (sms : \text{dispatchSMS}) \]

\[ r_{\text{hcs}}^{m1} : (br : \text{normalPulse}) \Rightarrow (hcs : \neg \text{emergency}) \]

\[ r_{\text{hcs}}^{m2} : (arm : \text{lyingOnFloor}), (med : \text{proneToHA}) \quad T_{\text{hcs}} = [med, arm, br] \]

\[ \Rightarrow (hcs : \text{emergency}) \]

Rule-based Contextual Reasoning in Ambient Intelligence
Open source project available at: www.kevoree.org

- Enables distributed reconfigurable software development
- Any sensor, software application, web service can be represented as a **component** (with I/O) in Kevoree
- The set of services/applications offered by a single entity (e.g. device) is represented as a Kevoree **node**
- **Channels** represent different types of communication among components (TCP/IP, email, SMS, etc.)

A Kevoree component

Input ports

Output ports
Kevoree in R-CoRe

- Each entity (mobile computing device) is implemented as a Kevoree node.
- Each context is implemented as a Kevoree component.
- Kevoree channels enable exchange of information (messages) between different components.
- Kevoree’s adaptive and auto-discovery capabilities enable detecting new nodes and adapting to any context changes.
Rule-based Contextual Reasoning in Ambient Intelligence

R-CoRe Architecture

- Knowledge Base (Context)
  - Local Rules
  - Mapping rules
  - Preferences
- Query Servants

Input: QueryIn, ConsoleIn
Output: QueryOut, ConsoleOut
Example Scenario: in R-CoRe terms

```
Interceptor:
Another component we developed to capture and display all the interactions (Queries/responses)

Query components:
Each one corresponds to the context of a different entity
```

Rule-based Contextual Reasoning in Ambient Intelligence
**Example Scenario: in R-CoRe terms (cont’d)**

<table>
<thead>
<tr>
<th>File Name</th>
<th>File contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>smsModuleKB.txt</td>
<td>M1: (hcs:emergency) → (sms:dispatchSMS)</td>
</tr>
<tr>
<td>BraceletKB.txt</td>
<td>$L_1$: → (br:normalPulse)</td>
</tr>
<tr>
<td>MedProfileKB.txt</td>
<td>$L_1$: → (med:proneToHA)</td>
</tr>
<tr>
<td>ArmKB.txt</td>
<td>$L_1$: → (arm:lyingOnFloor)</td>
</tr>
<tr>
<td>HCSKB.txt</td>
<td>M1: (br:normalPulse) → ¬(hcs:emergency)</td>
</tr>
<tr>
<td></td>
<td>M2: (arm:lyingOnFloor), (med:proneToHA) ⇒ (has:emergency)</td>
</tr>
<tr>
<td>HCSPref.txt</td>
<td>med, arm, br</td>
</tr>
</tbody>
</table>

Rule bases and preferences in the example scenario.
R-CoRe: Demo

You can download the demo and test it yourself from https://github.com/securityandtrust/ruleml13
A Smart Classroom Scenario
A Social Mobile Computing Scenario

User A at university

User B downtown

User C at FORTH

CS585 canceled

SW lecture
tennis tourn.

CS585 canceled

CS585 canceled

CS585 canceled

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- Context and Contextual Reasoning in Ambient Intelligence
- A Centralized Reasoning Framework
- R-CoRe: A Distributed Approach
- **Centralized vs. Distributed Reasoning**
- Open Problems
Centralized vs. Distributed Reasoning

- Distribution of knowledge
- Reasoning with the whole picture
- Scalability

- Computational Issues
  - Single powerful computer
    vs.
  - Devices with limited resources

- Communication Issues
  - Small size of messages
    vs.
  - Small number of messages

- Points of failure
- Privacy
Outline

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Open Problems

- **Privacy – Security**
  - Open environments
  - Unnoticeable access to personal data

- **Conviviality**
  - Means and incentives for cooperation
  - Reconciling conviviality with privacy

- **Planning**
  - Common plans
  - Efficient Plan Execution

- **Learning**
  - Identify user’s needs and intentions
  - Computational Benefits

- **Verification & Validation**
Rule-based Contextual Reasoning in Ambient Intelligence