A Context-Aware Multi-Agent System for AmI Environments

Andrei Olaru

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- The Problem
- Objectives
- Related Work
- Solution
- - Agent Behavior
- - System Topology
- - Context Representation
- Model
- A New Platform
- Conclusions
- Future Work
- Publications

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overview

Defining the Problem (1)

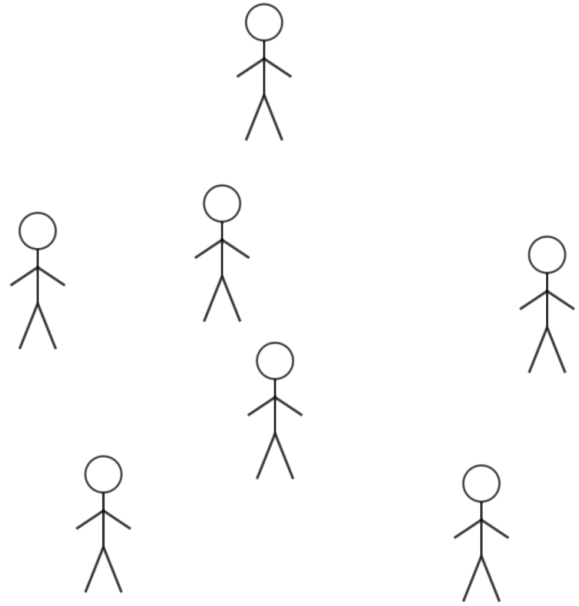
· Ambient Intelligence – or AmI – is the vision of a future ubiquitous electronic environment that supports people in their daily tasks, in a proactive and context-aware, but "invisible" and non-intrusive manner [Ramos et al., 2008, Weiser, 1995, Ducatel et al., 2001]

· Context is any information that can be used to characterize the situation of an entity [Dey, 2001]. Context-awareness is the property of an application that makes it adapt its behavior depending on context.

· AmI environments are characterized by a large number of interconnected heterogeneous devices with generally limited storage and performance.

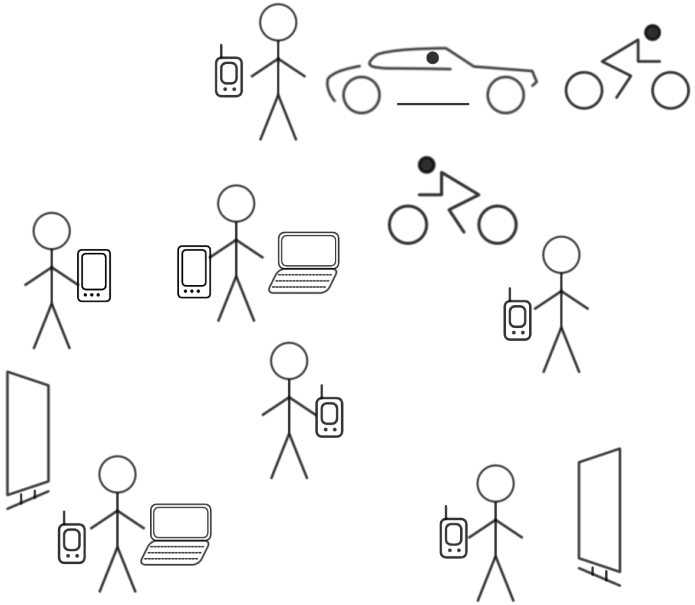
· we can get insights on the features of Ambient Intelligence by means of scenarios and existing Ambient Intelligence projects.

Defining the Problem (2)



We see AmI as a large number of People

Defining the Problem (2)



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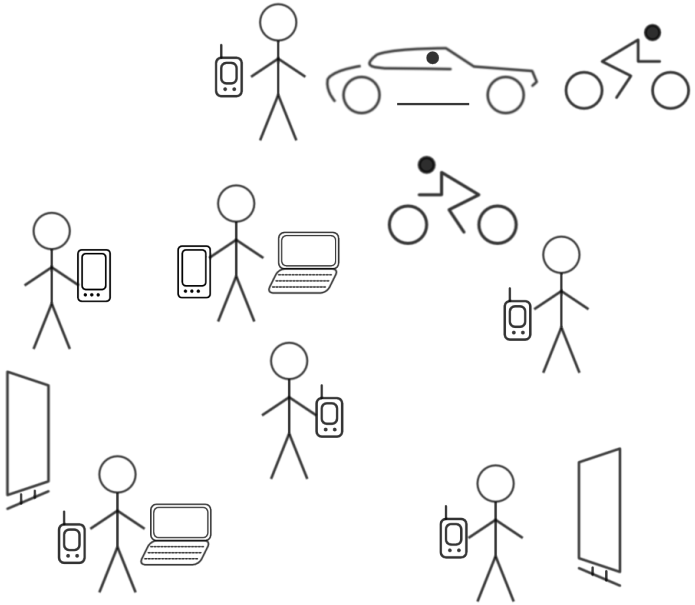

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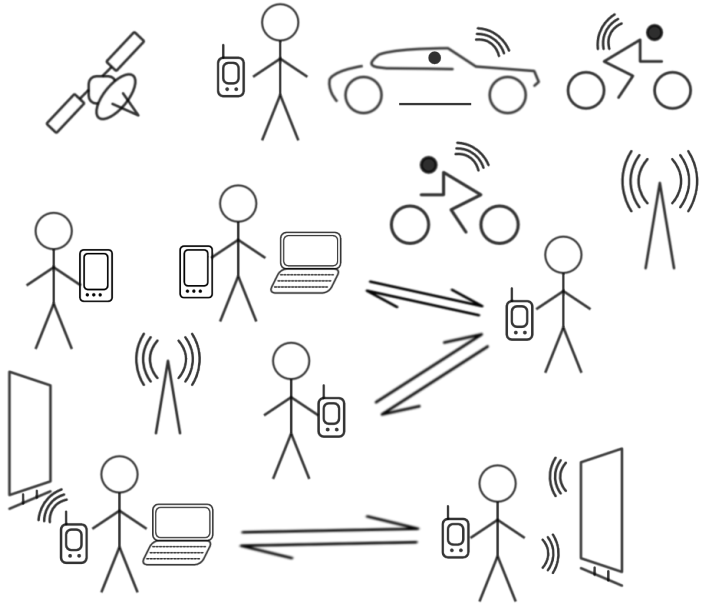

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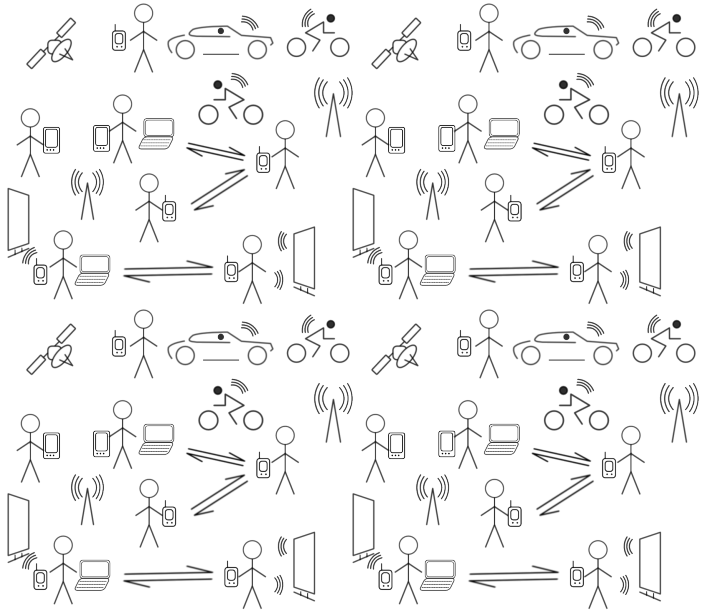

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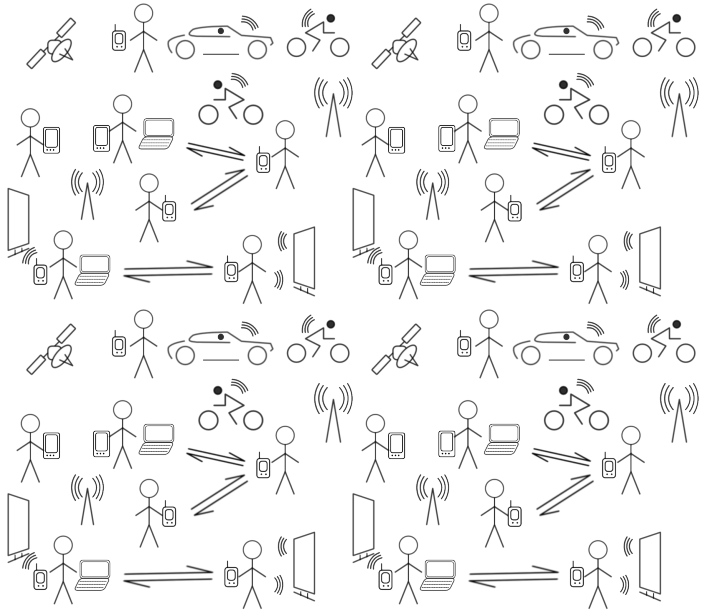

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We see an AmI system as organized on several layers:

- intelligent interfaces
- application
- interoperability
- network
- hardware

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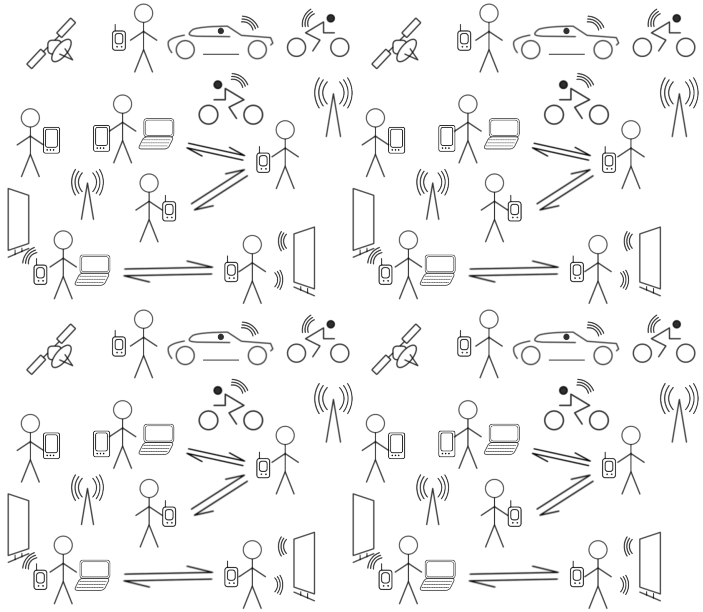

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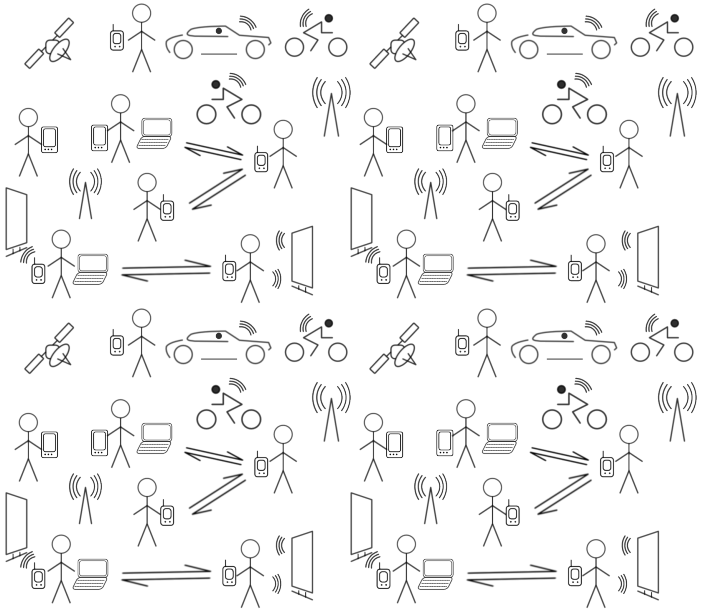

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Defining the Problem (3)

AmI challenges for the application layer:

· How to make AmI reliable and dependable?

· How to manage the large quantity of information generated by sensors and devices?

· How to provide the relevant information to the interested user?

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Elements of a solution:

- software agents
- context-awareness
- elements of self-organization

Our goal: build a context-aware multi-agent system for application layer of an Ambient Intelligence system.

Objectives of the thesis

Our goal: build a context-aware multi-agent system for application layer of an Ambient Intelligence system.

Main objectives of the thesis:

- propose a model of the multi-agent system;
- conceive scenarios that emphasize the requirements of real-scale Ambient Intelligence systems;
- design and implement a simulation testbed to serve for experiments with AmI applications;
- validation of the model by implementation and testing.

Multi-agent systems for Ambient Intelligence:

- centered on the user, using centralized components and application-specific reasoning:
  - iDorm [Hagras et al., 2004] – learning user behavior
  - EasyMeeting [Chen et al., 2004] – managing devices in a smart room
  - MyCampus [Sadeh et al., 2005] – management of personal information
  - ASK-IT [Spanoudakis and Moraitis, 2006] – assistance of elderly people
  - DALICA [Costantini et al., 2008] – dissemination of information on cultural assets
  - ALZ-MAS, Fusion [Corchado et al., 2008, Tapia et al., 2010] – remote healthcare for Alzheimer patients
- focused on system distribution
  - SpatialAgent [Satoh, 2004] – use of mobile agents
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  - AmbieAgents [Lech and Wienhofen, 2005] – agents for the management of context
  - CAMPUS framework [El Fallah Seghrouchni et al., 2008] – scalable, layered architecture for context sensing and ambient services
- Non-agent-based systems:
  - CASAS, MUSE [Crandall and Cook, 2009, Lyons et al., 2010] – smart home projects
  - Archipel, ALADDIN, PERSONA – care for elderly/disabled people [Bauchet et al., 2009, Perakis et al., 2009, Soler et al., 2010]

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· Context processing and representation

- centralized infrastructures, oriented toward physical context [Hong and Landay, 2001, Harter et al., 2002, Lech and Wienhofen, 2005, Henricksen and Indulska, 2006, Baldauf et al., 2007, Feng et al., 2004]
- representations based on tuples, rules, or ontologies [Perttunen et al., 2009, Strang and Linnhoff-Popien, 2004]
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· most context processing systems see the processing of context as being one-way – the applications do not insert context information into the system

· Our solution: a general-purpose multi-agent system in which context-awareness is integrated so that agents naturally manage and share context information.

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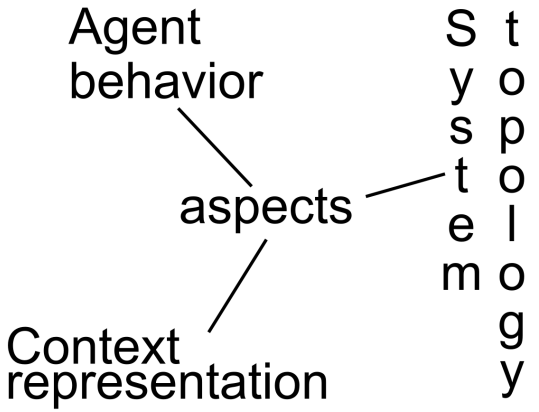
· Three aspects of the solution:



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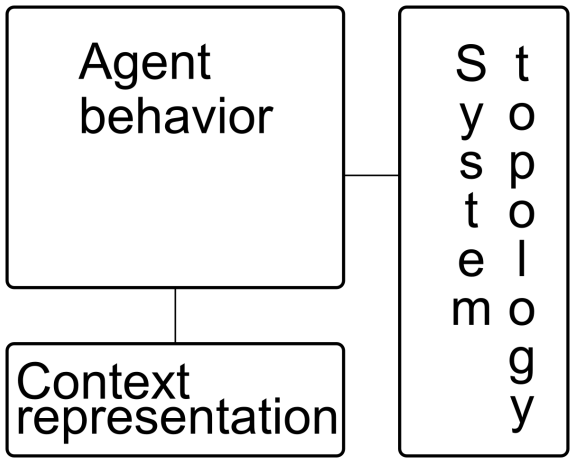

· Question: in an Ambient Intelligent system involving many users and devices, how to deliver the interesting information to the interested users?

· Requirements:

- decentralized system
- adaptability to the capabilities of the device
- context-awareness
- reliability

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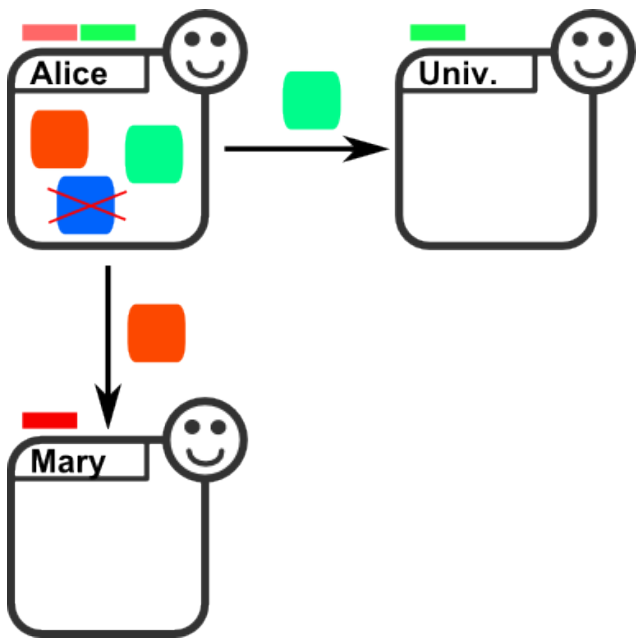
· Original solution:

- local behavior: send interesting pieces of information to neighbor agents that are potentially interested in that information.

· measures of context with which relevance is computed:

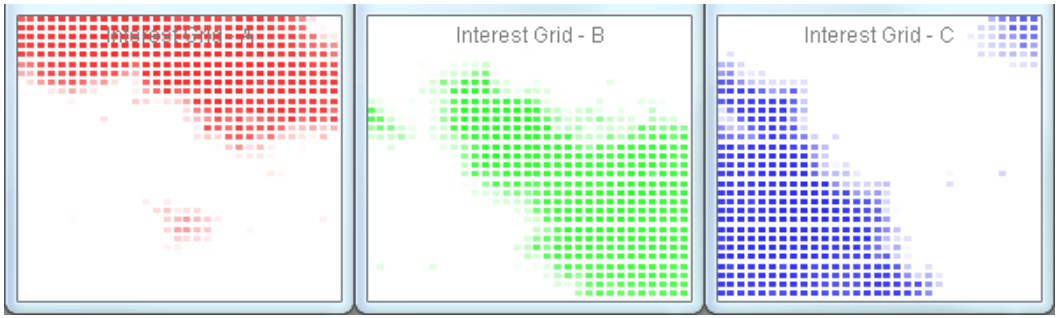
- pressure – directly affects relevance;
- specialty – similarity with agent's specialty improves relevance;
- persistence – old information is discarded;
- locality – information originating farther is less relevant.

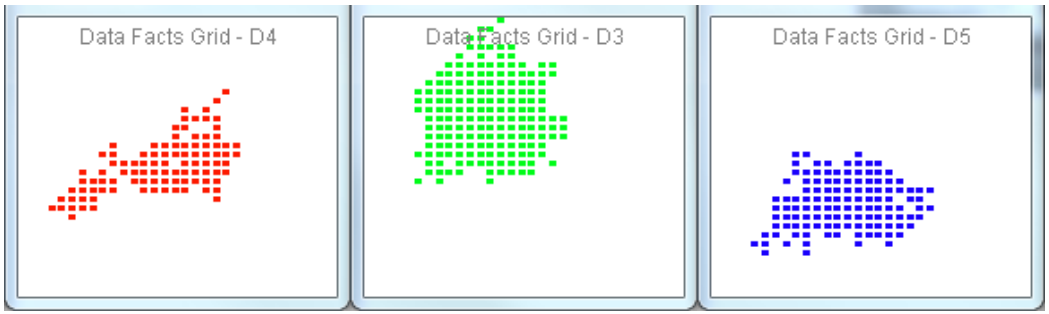
· also use positive and negative feedback loops, "forgetting", learning



Results from experiments with the AmIciTy:Mi project:

pre-existing areas of specialty:





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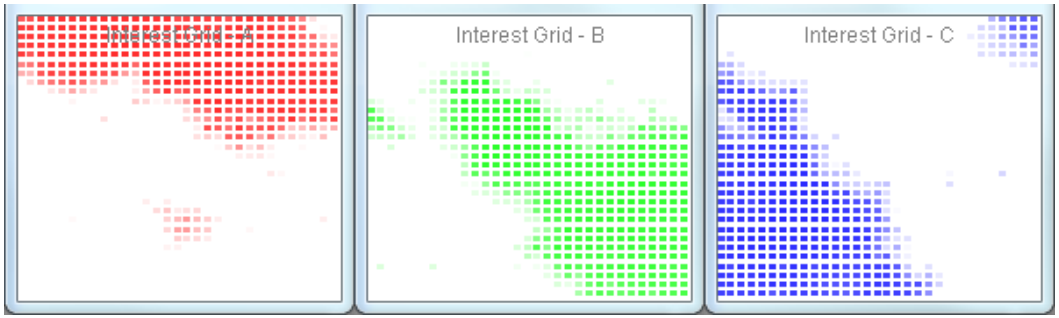

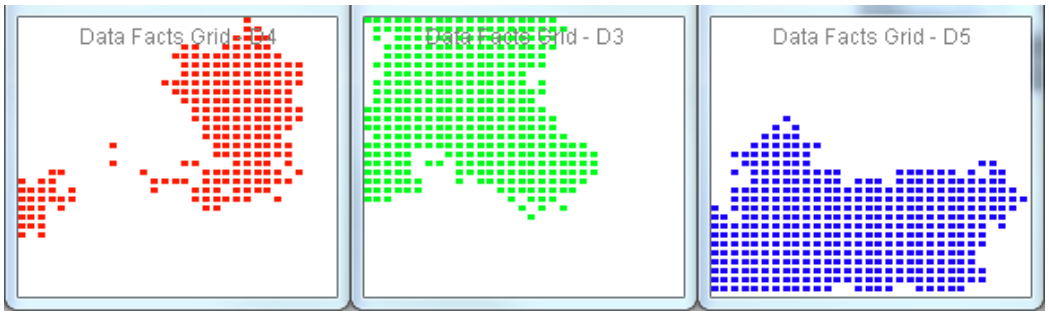

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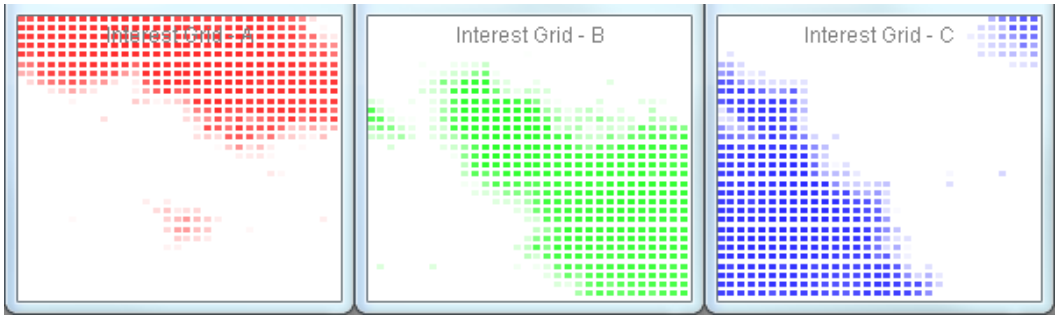

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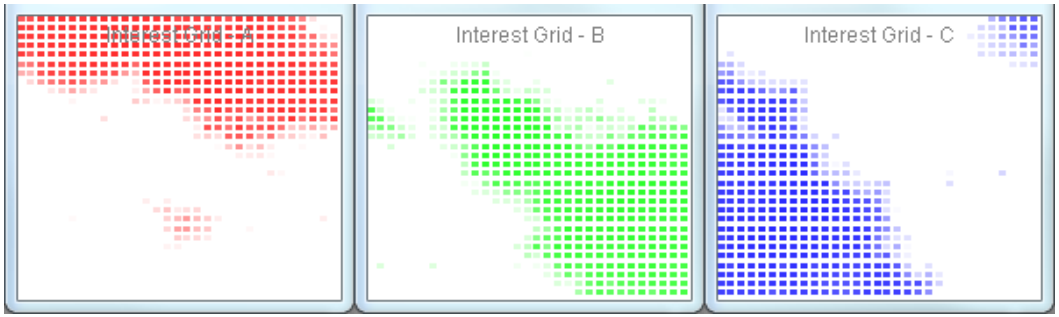

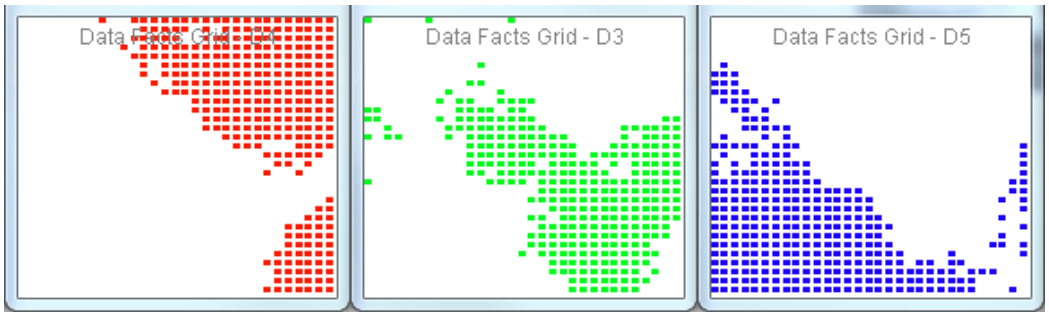

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But: must improve topology and context representation.

· Question: what should be the neighborhood relations in a multi-agent system for Ambient Intelligence?

· Elements of the solution:

- the CLAIM agent-oriented programming language [Suna and El Fallah Seghrouchni, 2004]
- aspects of context: space, computational resources, time, social relations, user activity
- decentralization of the system

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· Original solution:

- mapping of the hierarchies of agents to the hierarchical structure of context.
- topology induced by context: If two agents share context then they are neighbors.

A first validation through the Ao Dai prototype – Agent-Oriented Design for Ambient Intelligence:

- Scenario: a user arrives for the first time on the floor of an AmI enabled building; the AmI system must guide the user and provide help in finding computational resources;
- agents are assigned to different elements of context – places, devices, services, users;
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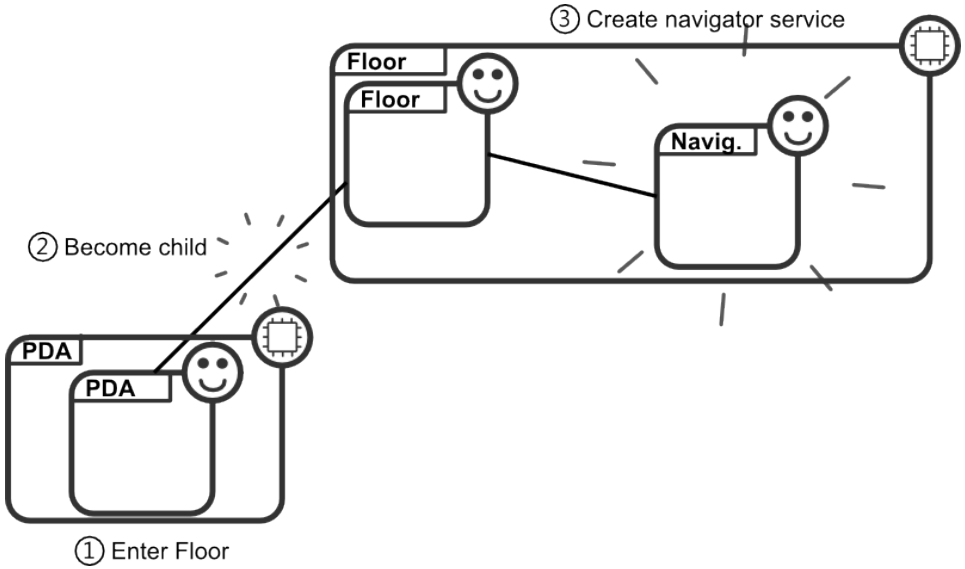

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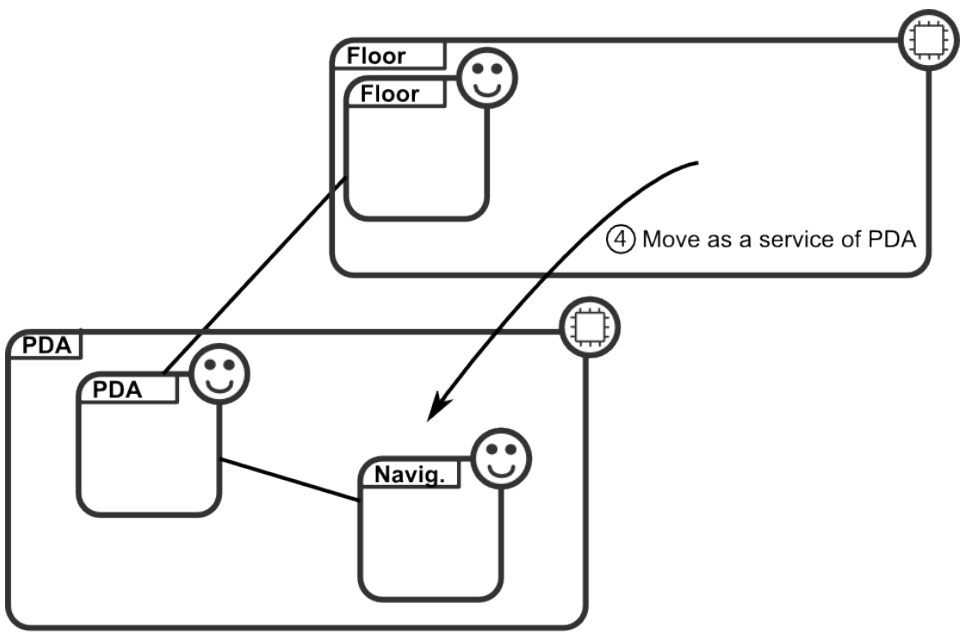

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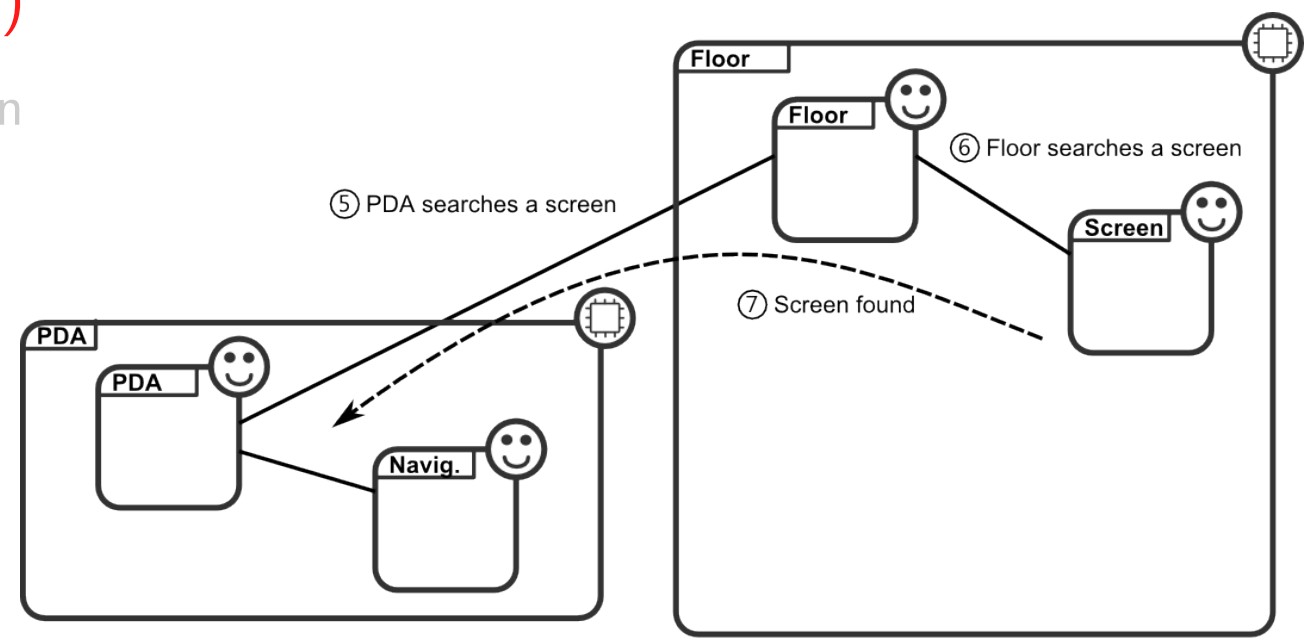

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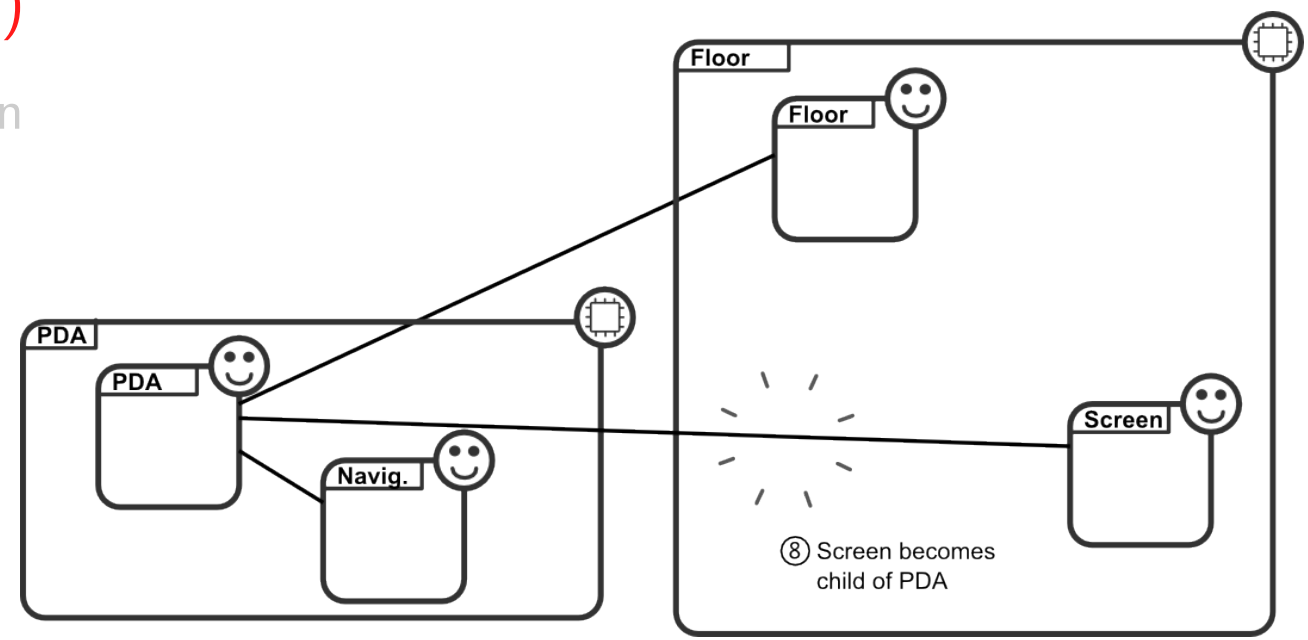

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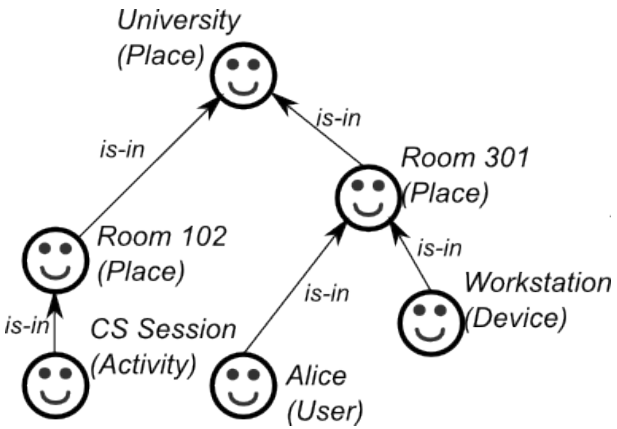

· Extension for more types of context:

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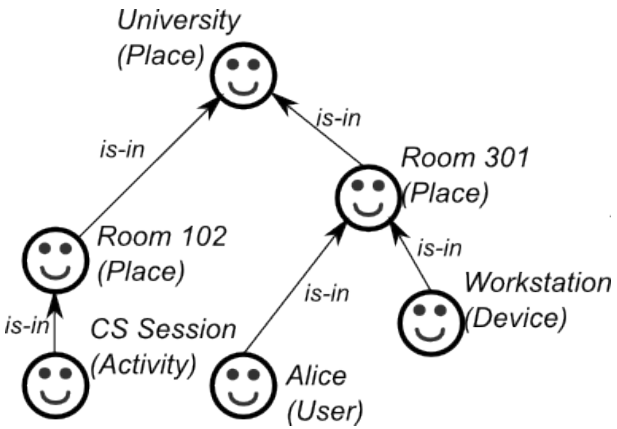
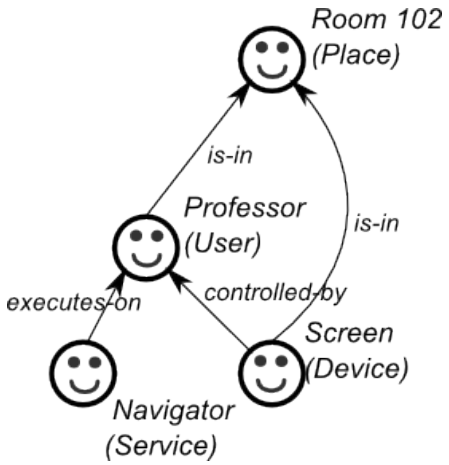
- computational ← relations *controlled-by, executes-on*
- social
- activity





· Extension for more types of context:

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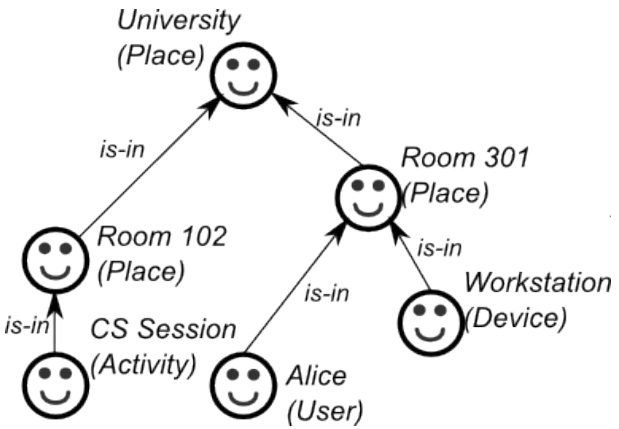
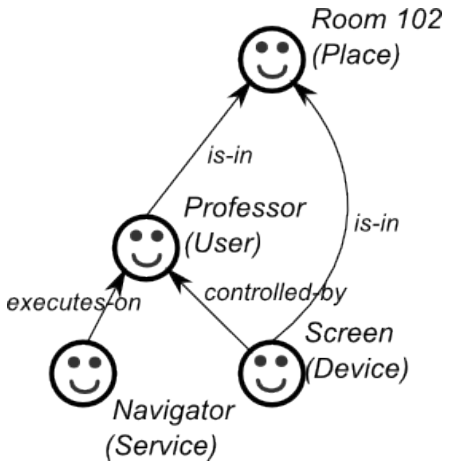
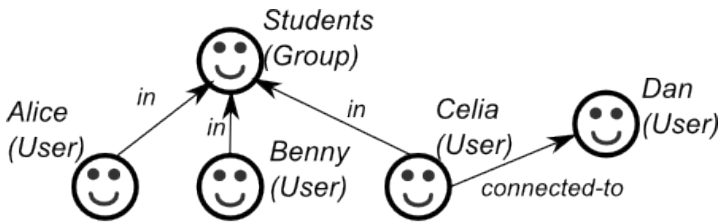
- social ← relations *in, connected-to*
- activity







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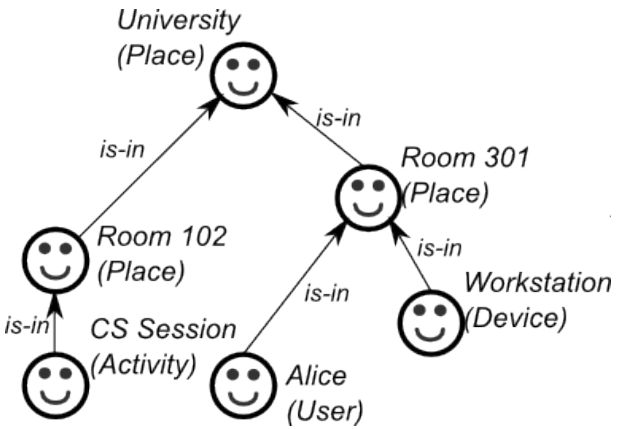
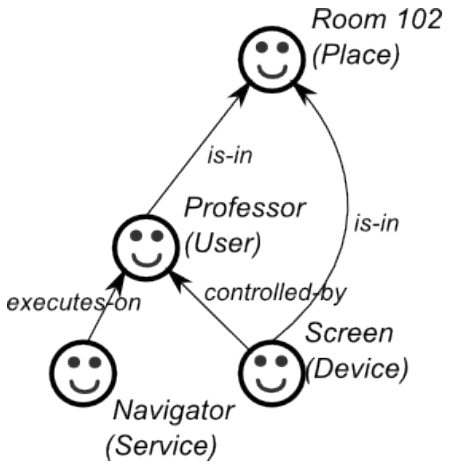
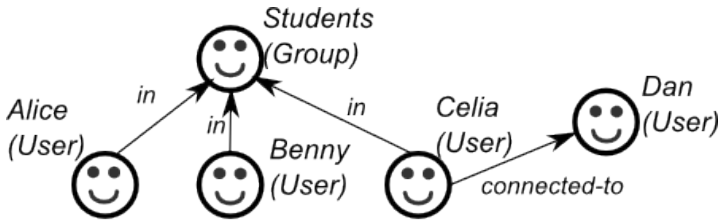
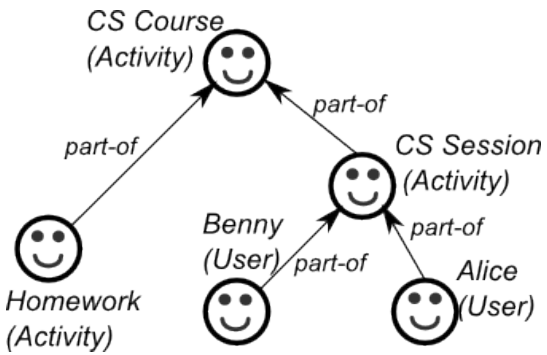
- social ← relations *in, connected-to*
- activity ← relation *part-of*









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· Question: how to represent context information in a general and flexible manner, without the need of centralized components?

· Requirements for the representation:

- open
- flexible
- general
- exchangeable
- distributed

· Question: how to represent context information in a general and flexible manner, without the need of centralized components?

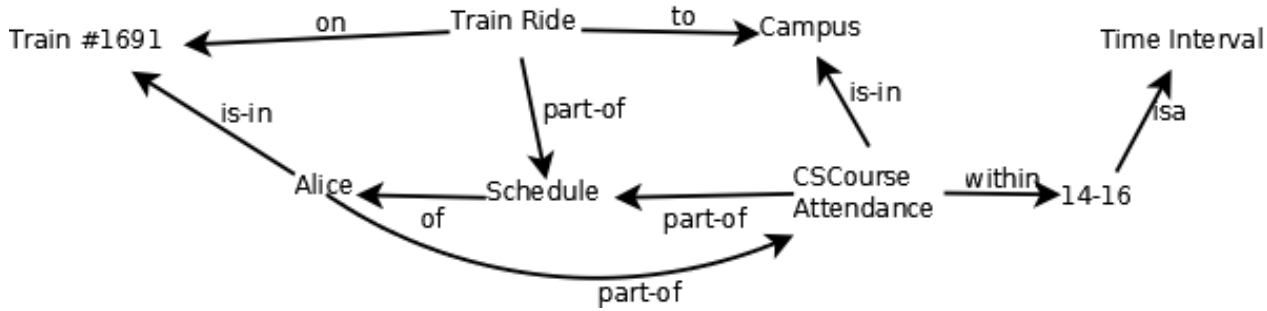
· Requirements for the representation:

- open
- flexible
- general
- exchangeable
- distributed

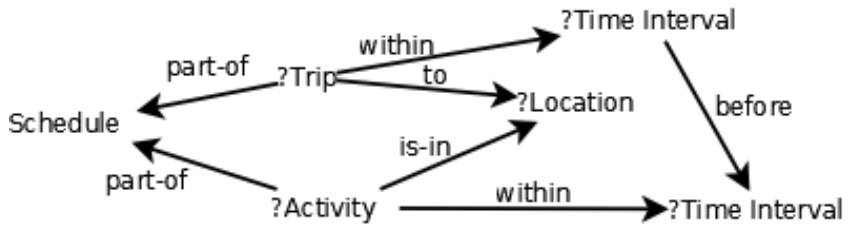
· Original solution:

- represent context information using graphs;
- use context patterns – graphs with generic elements – to represent situations;
- use matching to detect the current situation of the agent.

· Example: Alice is on a train on her way to her CS Course. Her agent is interested in when she get to the course.



Context Graph



Context pattern: a graph that contains nodes label with a question mark "?".

*Read "?*Time interval*" as "? $\xrightarrow{isa}$ *Time Interval*"

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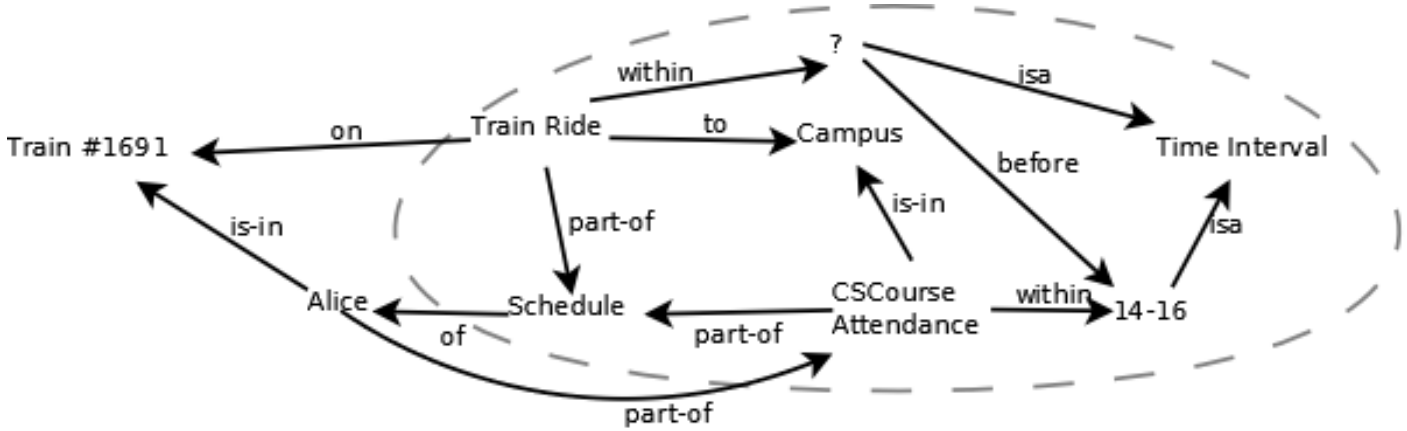
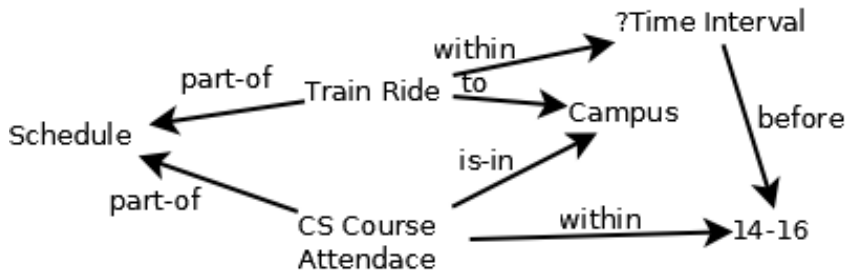
· result of the pattern matching:



Context Graph + Matched Subgraph + Unmatched part



Pattern matched part + Unmatched part

· we have conceived a matching algorithm that is based on growing of matches, considering both graph structure and the labels of nodes and edges.

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Elements of the proposed model:

- the container graph – complete graph;

$$ContainerGraph = (Containers, Connections)$$

$$Connections = \{\forall(C_i, C_j) \mid C_i, C_j \in Containers\}$$

- agent locations – assignment of agents to containers

$$AgentLocations \subset Agents \times Containers \times \{resides\text{-}on\}$$

- agent relations – context-based neighborhood relations (for context-awareness outside the agent

$$AgentGraph = (Agents, Relations)$$

$AgentRelations = \{(A_i, A_j, Relation)\}, Relation \in \{is\text{-}in, part\text{-}of, etc.\}$.

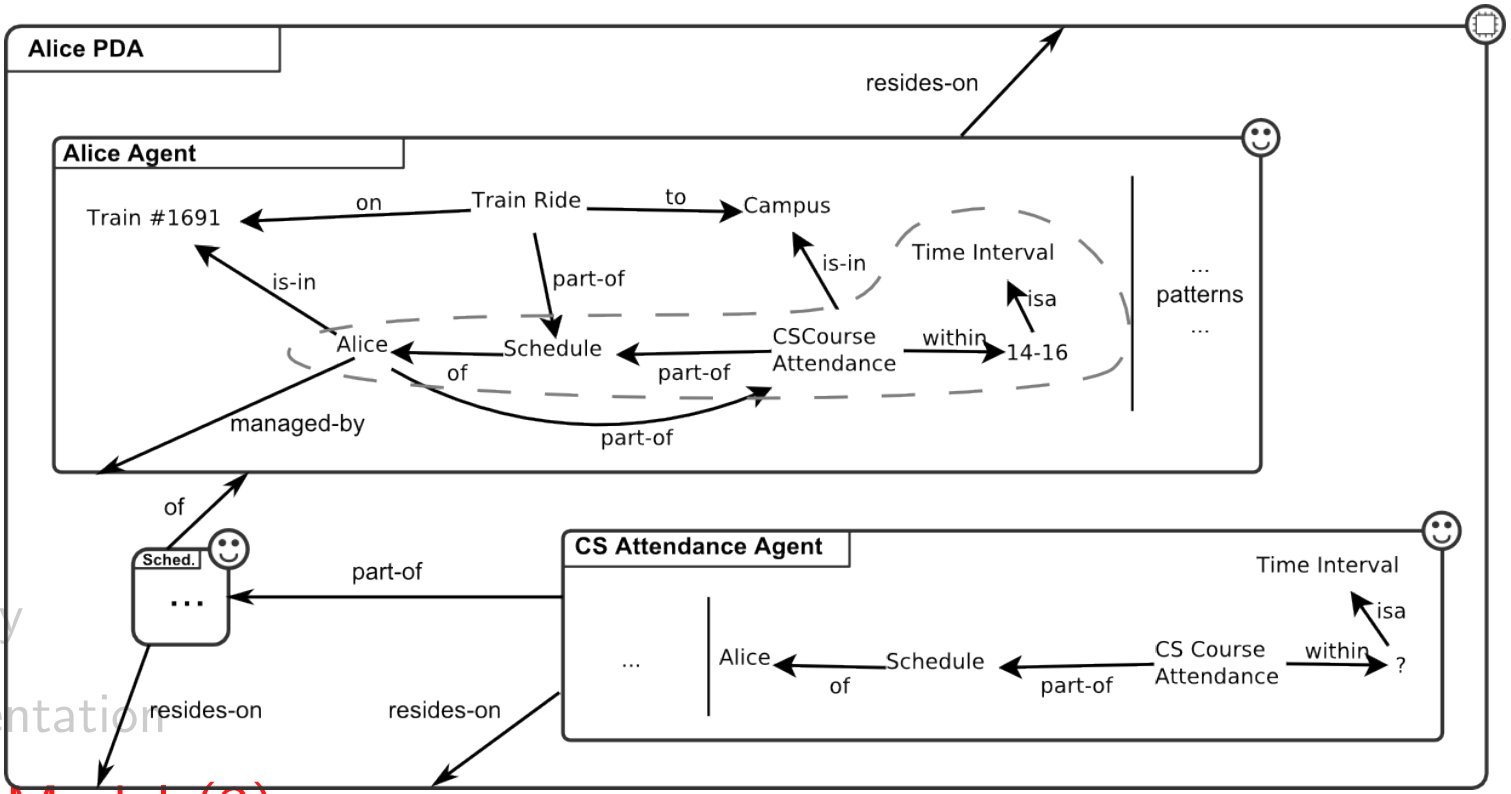
- individual agents:

$$A(Name, CG_A, Patterns, \mathcal{R}, I, Goallist) \in Agents$$

· An agent $A(Name, CG_A, Patterns, \mathcal{R}, I, Goallist)$ is defined by:

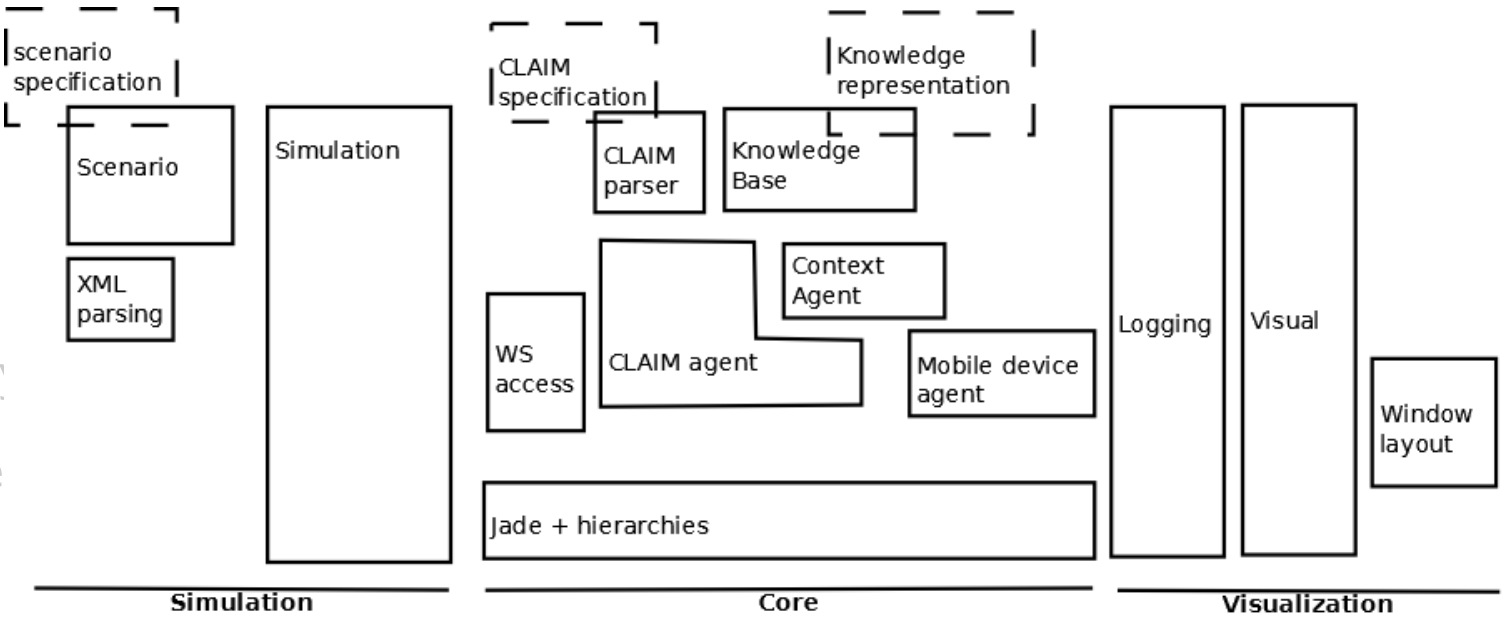
- *Name* – its name;
- CG_A – its context graph – context information characterizing the current situation of the agent;
- *Patterns* – a set of patterns – represent situations that the agents can recognize (for context-awareness inside the agent);
- $\mathcal{R}$ the relations with other agents (incoming or outgoing);
- $I = \{(Agent, s, factor)$ – tuples indicating the estimated amount of interest that other agents have for a pattern;
- *Goallist* – the list of pieces of information (subgraphs of CG_A) to disseminate (inform goals) to other agents; a measure of importance is assigned to each goal;

· Example:



The Ao Dai platform

- conceptual successor of the Ao Dai prototype
- underpinned by JADE Agent Development Framework

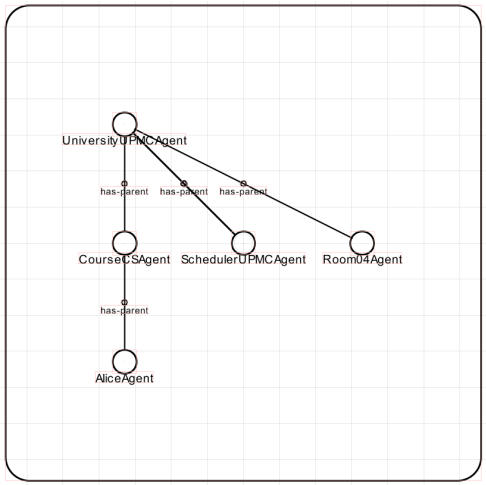


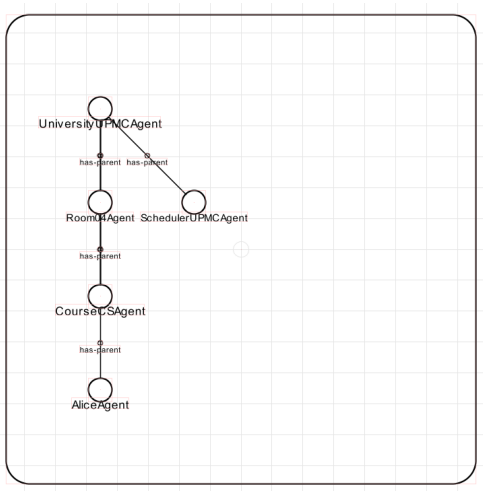
- uses S-CLAIM – AOP language with simplified semantics and cleaner syntax

CourseAgent.adf2 agent definition file

```
1.  (agent Course ?courseName ?parent
2.    (behavior
3.       ...
4.       (reactive registerUser
5.          (receive assistsUser ?agentName ?userName)
6.          (addK (struct knowledge
                userAgent ?userName ?agentName))
7.       )
8.    ...
9.    )
10. )
```

- tools for the visualization of the agent structure





- repeatable simulation based on XML-files, describing agent deployment and simulation events

scenario.xml

```
1. <scen:timeline>
2.   <scen:event time="2000" >
3.     <scen:CLAIMMessage>
4.       <scen:to>SchedulerUPMCAgent</scen:to>
5.       <scen:protocol>newSchedule</scen:protocol>
6.       <scen:content>( struct message newSchedule
          ( struct knowledge scheduledTo
          CSCourse Room04 ) )</scen:content>
7.     </scen:CLAIMMessage> </scen:event>
8.   </scen:timeline>
```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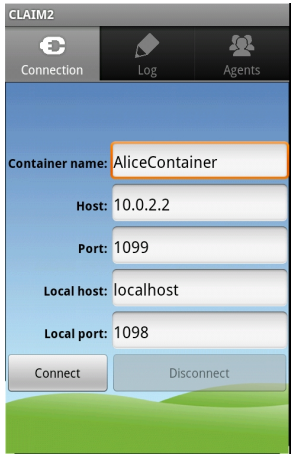
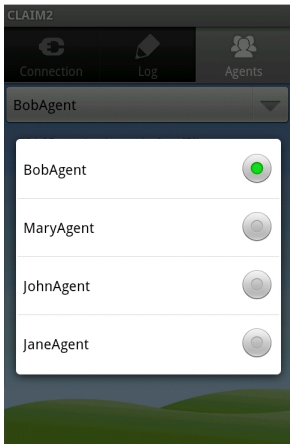
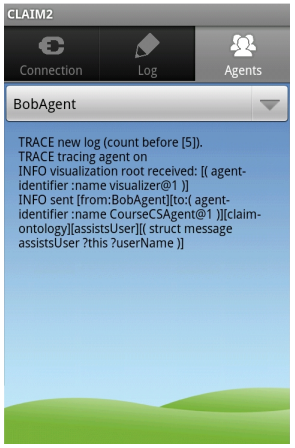


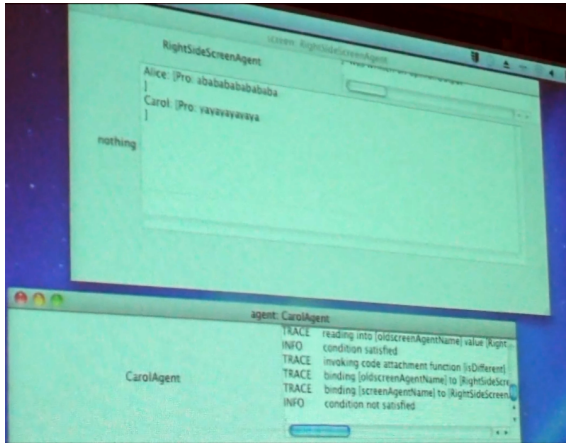


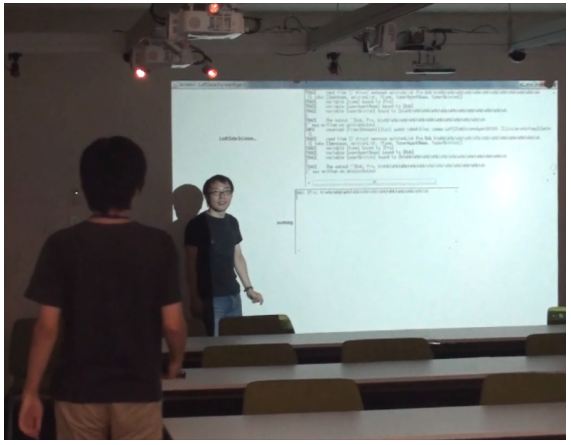


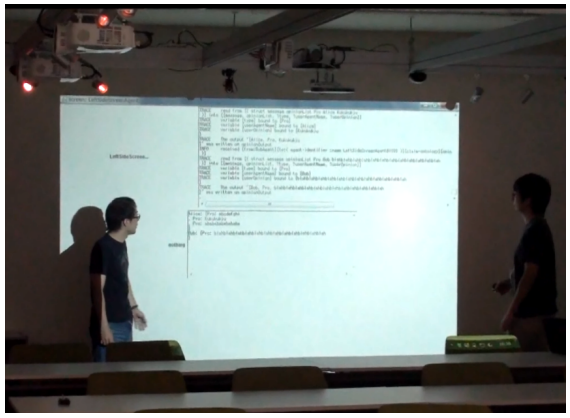
· support for deployment on mobile devices

· support for web services. Example call:

```
(send ?testAgent
   (struct message echoService helloWorld)
   http://localhost:8080/wsig/ws/
)
```







· integration with the SmartRoom at Honiden Lab, in Tokyo – featuring control of lights and screens, and detection and localization of people

· interoperation by means of web services

· successful simulation of a basic scenario

Contributions (1):

- we have proposed an agent behavior for the local sharing of information with global, coherent, results
- we have proposed context measures for the control of the spreading of information through a large multi-agent system: pressure, specialty, and persistence;
- we have designed and implemented a simulation testbed for multi-agent systems formed of a large number of agents, featuring tools for repeatable simulation and system visualization and evaluation – the AmIciTy:Mi project;
- we have conceived agent types and relations for a context-oriented system topology, based on mapping context structure to agent hierarchy;
- we have validated the context-oriented topology through a first experiment – the Ao Dai prototype – an agent-based AmI system for the assistance of a user in navigation and locating computational resources;

Contributions (2):

- we have proposed a formalism based on context graphs and patterns for the representation of context information and for the recognition of the agent's situation;
- we have conceived an algorithm for matching context patterns against context graphs, also allowing partial matches;
- we have proposed a model that unifies context-awareness inside the agent (context graph + context patterns) with context-awareness outside the agent (context-based topology);
- we have simplified and improved the semantics and syntax of the CLAIM AOP language, having as result the language S-CLAIM;
- we have designed and implemented the Ao Dai multi-agent platform for AmI applications that uses S-CLAIM and graph-based knowledge bases for agents, and also features tools for repeatable simulation and for the visualization of the system's evolution.

The main lines of future work for this research relate to:

- extension of the AmIciTy:Mi project for the research of multi-agent systems formed of a large number of agents, with the inclusion of heterogeneous agents, moving agents, new measures for context, and new methods of evaluation;
- further development of the Ao Dai platform for AmI applications, including addition of algorithmic functionality libraries, new knowledge representations, and goal-oriented behavior;
- further testing and evaluation of the developed concepts, and detection of applications for which they are most appropriate;
- implementation of new scenarios and of real-life AmI applications using the developed platform and concepts.

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- The Problem
- Objectives
- Related Work
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- - Agent Behavior
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- - Context Representation
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Thank You!

Any Questions?

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