Reasoning about Context in Ambient Intelligence Environments

Grigoris Antoniou
Institute of Computer Science, FORTH
Department of Computer Science, University of Crete
Overview

- AmI @ FORTH
- Experience with Context Reasoning
- AI for AmI
Introduction

- The vision of Ambient Intelligence assumes a shift in computing towards a multiplicity of communicating devices disappearing into the background, providing an intelligent environment, where the emphasis is on the human factor.

- Realizing this vision requires the integration of expertise from a multitude of disciplines.

- Despite the rapid advancement of these fields, existing approaches have difficulty in meeting the real-world challenges imposed by developing ambient information systems.
Context in AmI

- **Aim of AmI systems**
  - right information to the right users, at the right time, in the right place, and on the right device
  - Requirement:
    - thorough knowledge and understanding of context

- **Context in Ambient Intelligence**
  - “.. 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 application themselves..” [Dey and Abowd, 1999]
Activities

- Creation of small-scale experimental AmI spaces
  - AmI Sandbox
  - Smart Office
- Building a new facility for R&D in AmI technologies
- R&D through competitive funded projects at national and European level
Aml Sandbox (1/3)

- An experimental space within ICS-FORTH
  - 6 rooms (~ 100m²)

- Installation, testing and integration of a large variety of technologies and applications

- Allows researchers from different domains to bring together and share their know-how and resources
Aml Sandbox (2/3)

Main goals

► Experimentation in a creative, flexible and informal setting
► Acquisition of hands-on experience
► 1st step towards the Aml Facility
Installed Technologies

- Computer vision system, comprising 8 cameras
- Surround speaker system with 8 speakers
- Various computer-operated lights (neon, spot lights, floor and desk lamps) using both the DMX and X10 protocols
- Computer-operated air-condition
- Various screens and high definition TVs, including touch screens
- One large front projection screen created by 2 ceiling-mounted short-throw projectors
- One back projection screen
- Several sensors (distance, temperature, etc.) and actuators
- Desktop and mobile RFID readers
- Interactive table
- Access control systems (IRIS Scanner, RFID, …)
- Positioning system through wireless access points
- Various robotic systems
The AmI Sandbox
Smart Office

Augmenting an existing office space with AmI technologies

► Multiple interconnected displays
  ■ Large screen
  ■ e-Desktop
  ■ e-Frame

► Smart table
► Controllable lights
► Computer vision camera
► e-pens
► Distance sensor
► Laser keyboard
The Smart Office

- Projector
- Camera
- Wiimote
- Lights
- e-frame
- Laser kbd
- Microphone
- Camera
- Meeting table
- Switches
- RFID reader 1 (under table)
- RFID reader 2 (under table)
- Distance sensor
- Speakers (under table)
- Desktop
- Extended desktop
- big screen
- RFID reader 3 (on wall)
Aml Facility

- New building (~ 3,000m²)
  - Basement, ground floor, 1st floor
- Fully accessible by people with disabilities

Includes:
- Simulation spaces
- Laboratories for R&D in Aml technologies
- Offices
  - Permanent research staff & visitors
Aml Facility – Blueprints

Basement

1st floor

Ground floor

Basement
Aml Facility – Simulation Spaces

Garden

Home

Doctor’s office

Office

Class

Exhibition

Entertainment space
Simulated home environment

- 2 floors (staircase + elevator)
  - living room
  - Kitchen
  - house office
  - 2 bedrooms
    - adults & children
  - 2 bathrooms

- Scenarios
  - local, remote and automated home control
  - safety and security
  - health monitoring
  - independent living
  - (tele)working
  - entertainment

- Fully accessible by the elderly & people with disabilities
Components under development

- Aml software and hardware architectures
- Middleware
- Context management and reasoning
- Environment sensing technologies & sensor fusion
- Access control, information and communications security
- Seamless and intuitive user-environment interaction
- Speech recognition and speaker localization
- Computer vision subsystem for multiple user localization and gesture recognition
- Dynamic surround sound playing system
- Environmental control
Overview

- AmI @ FORTH
- Experience with Context Reasoning
- AI for AmI
Contextual Reasoning in Ambient Intelligence

- **Challenges**
  - Imperfect nature of the available context information
    - Unknown, ambiguous, imprecise, erroneous
  - Special characteristics of ambient environments
    - Agents with different goals, computing and perceptive capabilities, and vocabularies
    - Highly dynamic and open environments
    - Distributed context knowledge
    - Unreliable and restricted wireless communications

- **Limitations of current AmI systems**
  - No formal model for reasoning with imperfect context
  - Centralized architectures → No support for distributed reasoning
Motivating Aml Scenario

Dr. Amber is located in the ‘RA201’ university classroom reading his e-mails on his laptop. It is Tuesday, the time is 7.50 p.m., and he has just finished with a lecture for course CS566. His context-aware mobile phone receives an incoming call, but it is not in silent mode.

Dr. Amber’s phone is configured to take decisions about whether it should ring in case of incoming calls based on its context and Dr. Amber’s preferences:

- The phone should ring, unless it is in silent mode or Dr. Amber is busy with some important activity.
- A lecture at the university is one such important activity.

The mobile phone is not aware of Dr. Amber’s current activity. It attempts to infer the activity using two rules:

- If there is a scheduled lecture for a course at this time, and Dr. Amber (actually his mobile phone) is currently located in a classroom, then Dr. Amber is possibly giving a lecture.
- If Dr. Amber is located in a classroom, but there is no class activity taking place in the classroom, Dr. Amber is rather not giving a lecture.
Information about scheduled events is imported from Dr. Amber’s laptop. According to his calendar, there is a scheduled class event for Tuesdays from 7.00 to 8.00 pm.

The localization service possesses knowledge about Dr. Amber's current position. In this case it 'knows' that Dr. Amber is currently located in 'RA201'.
The classroom manager 'knows' that the classroom projector is off, and imports knowledge about the presence of people in the classroom from an external person detection service; in the specific case the service detects only one person (Dr. Amber) in the classroom. Based on this information, the classroom manager can infer that there is no class activity in the classroom.
Based on the context information imported from the laptop and the localization service the phone infers that Dr. Amber is giving a lecture. The information from the classroom manager leads to a contradictory conclusion. The knowledge of the classroom manager is considered more accurate than the knowledge of the laptop, so the phone determines that Dr. Amber is not currently giving a lecture, therefore it reaches to the 'ring' decision.
Scenario Characteristics

- **Assumptions**
  - available communication means (wireless network)
  - each agent aware of the type and quality of imported knowledge
  - each agent has some computing and reasoning capabilities
  - each agent willing to disclose part of its local knowledge

- **Challenges**
  - context is incomplete, imprecise, ambiguous
  - restricted computing capabilities
  - distinct vocabulary used by each agent
  - light communication load for making quick decisions
Modeling the AmI scenario

- **Phone** ($P_1$)
  - Local facts and rules
    
    $r_{11}^1: \rightarrow \text{incoming\_call}$
    
    $r_{12}^1: \rightarrow \text{normal\_mode}$
    
    $r_{13}^1: \text{incoming\_call}, \text{normal\_mode}, \neg\text{important\_activity} \rightarrow \text{ring}$
    
    $r_{14}^1: \text{lecture} \rightarrow \text{important\_activity}$

  - Mapping rules
    
    $r_{15}^m: \text{scheduled(CS566)}_2, \text{location(RA201)}_3 \Rightarrow \text{lecture}$
    
    $r_{16}^m: \neg\text{class\_activity}_4 \Rightarrow \neg\text{lecture}$

  - Preference relation
    
    $T_1 = [P_3, P_4, P_2]$
    
    $P_2: \text{laptop}, P_3: \text{localization service}, P_4: \text{classroom manager}$
Modeling the AmI Scenario

- **Laptop (P\textsubscript{2})**
  
  \( r_{21}^1: \rightarrow \text{day}(Tuesday) \)
  
  \( r_{22}^1: \rightarrow \text{time}(19.50) \)
  
  \( r_{23}^1: \text{day}(Tuesday), \text{time}(X), 19.00 < X < 20.00 \rightarrow \text{scheduled(CS566)} \)

- **Localization Service (P\textsubscript{3})**
  
  \( r_{41}^1: \rightarrow \text{location(RA201)} \)

- **Classroom Manager (P\textsubscript{4})**
  
  \( r_{41}^1: \rightarrow \text{projector(off)} \)
  
  \( r_{42}^\text{m}: \rightarrow \text{detected}(X)_5, X<2, \text{projector(off)} \Rightarrow \neg \text{class_activity} \)

- **Person Detection Service (P\textsubscript{5})**
  
  \( r_{51}^1: \rightarrow \text{detected}(1) \)
Algorithm Characteristics

- Variation of defeasible logic
  - Lightweight NMR
  - Cycle detection
- Argumentation semantics
- Complexity analysis
- Reasoning variants depending on application characteristics
  - E.g. privacy concerns
Running the Scenario

- In the AmI Sandbox
- Using cameras, localization etc. through middleware services
- Running the algorithms on small devices (e.g. mobile phone) in a distributed fashion
- Implementation based on lightweight Prolog system
Approach

● Mobile DR-Prolog
  ► Application implemented in J2ME (Java 2 Micro Edition)
  ► Runs on Cell Phones & PDAs supporting J2ME (almost all nowadays)

● Defeasible Reasoning Capabilities
  ► Integrates foreign prolog interpreter
  ► On top of which runs DR-Prolog
Reasoning Engine

- **TuPrologME**
  - Prolog Interpreter
    - Implemented using Java 2 Micro Edition (J2ME)
    - Lightweight implementation for performance
    - Provides API for application integration
    - [http://www.alice.unibo.it/xwiki/bin/view/Tuprolog/TuprologMe](http://www.alice.unibo.it/xwiki/bin/view/Tuprolog/TuprologMe)

- **DR-Prolog**
  - Defeasible Reasoning capabilities
  - Using a lighter version of the DR-Prolog metaprogram
    - Written in Prolog & loaded to the TuProlog Engine
Technologies Used

- Interconnection with other devices through:
  - WiFi 802.11b/g
  - Bluetooth
  - Internet Connection (e.g. 3G, GPRS etc.)

- Java sockets use the above connections where available to connect with servers, URLs or other mobile devices implementing the Mobile DR-Prolog Service.
Bluetooth is important because it provides

- Discovery of Devices in Proximity
  - Bluetooth range 10-15 meters
  - Up to 100 meters (class A devices)

- Service Discovery capabilities
  - On the discovered devices

- Widespread use on almost any electronic device
  - Mobile phones
  - Pda
  - Laptops, desktops
  - Sensors, gps etc.
Interconnection with other Devices can be supported easily

- GPS Receiver
  - Bluetooth enabled
- Various Sensors
  - Eg RFID
- Parse messages from these devices to extract knowledge such as
  - coordinates, sensor measurements etc.
- Conversion into DR-Prolog Facts & loading in KB
Circles are mobile devices
Oval nodes are server computers, eg. Desktop versions of DR-Prolog
Cylinder nodes are computers or websites with Knowledge Base Data, Theories, etc in DR-Prolog syntax.
Connections: Message exchange (Blue: queries & their results, Red: facts)
- Bluetooth, wifi, or through Internet using 3G, GPRS etc.
Social Scenario 1

- User with Bluetooth enabled cellphone passing by a classroom
- Bluetooth Server with lecture and lesson information for that classroom attempts to connect to cellphone
- Cellphone based on profile information either notifies the user or rejects the info:
  - E.g. based on course registration etc.
- Based on the above Cellphone should inform user for this announcement
Social Scenario 2

- User with Bluetooth enabled cellphone sitting at ICS lobby; profile entry e.g.
  - hobby('tennis').
  - hobby(X),tournament(X,...) => notifyUser(activity,X...)

- Lobby computer eg:
  - tournament('tennis','location','date')...

- Based on the above
  - Cellphone should inform user for this activity

- Send the ‘event’ to closeFriends via SMS
  - Based on profile entries of the receiver he will be notified or not! (reasoning on sms data received on certain port from the DR-Prolog mobile application)
Lessons Learnt

- A lot of non-logic related work required
  - Infrastructure
  - Middleware
  - Need for Facility!

- Technical difficulties
  - Scenario with SMS, not calls

- Performance no challenge for small applications
  - Combination with large portions of knowledge from (semantic) Web will be the challenge
Overview

- AmI @ FORTH
- Experience with Context Reasoning
- AI for AmI
AI for Aml

- Context representation
- Context reasoning
- Privacy
- Planning
- Coordination
Context Representation

- Use semantic web languages to model
  - User profiles
  - Devices
  - Rooms
  - Activities

- Challenge: the usual one
  - tradeoff between expressivity and efficiency
Context Reasoning

- Distributed
- Heterogeneous
  - Different types of information call for different reasoning methods
- Inconsistency and imperfection tolerant
- Dynamic
  - E.g. reasoning about stream input
- Efficient
Privacy

- A major concern!
- Lightweight access control languages
- Blend in other languages/operations
  - E.g. in our context reasoning algorithm
Planning

- **Reasoning about action** is a well-formed subfield of AI.
  - But the classical planning problem adopted a number of restrictive assumptions to delimit the domain.

- The Aml environment is **open** and **highly dynamic**.

- World knowledge in Aml is **incomplete**.

- Plan generation must preserve a level of **uncertainty**.

- Exogenous events occur in Aml environments.
Coordination

- A **device-rich** environment that places users in the center of attention.

- Devices need to **coordinate** their actions, **cooperate** in generating plans and **collaborate** during execution.

- A **decentralized self-organizing infrastructure** is a non-trivial challenge for the realization of the AmI vision.
Tomorrow, Now!
APPENDIX
Smart-desktop

- **Leather desktop**
  - Extendable interface (when opened)

- **Input**
  - RFID-augmented objects
  - Vision-based left/right switches
  - Distance sensor for up/down motion
  - IR pens (using the Wiimote)
  - Vision-based object position tracking

- **Output**
  - Projection (on the desktop)
  - 2 speakers
  - Sounds + speech synthesis

- **Used for:**
  - Logging in the system
  - Running applications
Ambient presentation

- Uses standard PowerPoint slides
- Coordinated slide change
- Replicated drawing on the current slide
- Can adapt to the current state / size of the smart desktop
- Can change the lighting conditions

Output
- Multiple screens
  - desktop, large LCD, laptop

Input
- Start/stop: RFID tag (ICS-FORTH leaflet)
- Next / previous: right/left gesture
- Drawing: IR pen (can change pen color using the pens’ RFID tag)
E-mail

- Shows the e-mails of the person who logged in

- Can adapt to the current state / size of the smart desktop
  - Standard size: mails’ list
  - Extended: mails’ list + selected mail’s content

- Output
  - Smart desktop

- Input
  - Start: RFID tag (envelope)
  - Next / previous mail: right/left gesture
  - Use slider: distance sensor
  - Buttons press: IR pen (click)
  - Send predefined e-mail: RFID tag (photo or ID card)
Mobile photo

- Get photo using the mobile phone and drag it on any display

Output
- Smart desktop, LCD screen, Archie

Input
- Mobile phone recognition: RFID tag (envelope)
- Mobile phone position: Vision
- Photo drag: IR pen
Archie: Interartive display

- Monitor e-mail account and visualise e-mail semantics
  - Number of e-mails
  - Number of e-mails from specific people

- Junk e-mail
  - Virus-infected e-mails
  - Unsent drafts
  - Receipt of specific e-mail
  - Urgent e-mail

- Output
  - Archie

- Input
  - E-mail account
  - Touch
Video conference

- Video conference

- Button presses around the table result in the camera turning to face the button’s position

- Output
  - Large screen
  - Smart desktop

- Input
  - Camera
  - Multidirectional microphone
  - Buttons
High noon: Multiplayer Game

- 7-player game
- Gun fighting duel
- 2 opponents / teams
  - Left/right side of table
  - 3 buttons each (up, down, fire)
- 1 moderator (optional)
  - Undead
  - 1 button (show up / fire)

Output
- LCD screen

Input
- Buttons around the table
One-button start

- Turn on all devices
  - TV, PCs, projector, monitors, RFID readers, ..

- Connect devices via Bluetooth

- Run required processes / applications in each PC
  - In the appropriate order