Programming Languages for Multiagent Systems

Multiagent Systems LS

Sistemi Multiagente LS

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1. Spaces for Programming Languages in Software Engineering
   - Paradigm Shifts
   - Examples

2. Spaces for Programming Languages in Multiagent Systems
   - Programming Agents
   - Programming MAS

3. Spaces for Programming Languages in the A&A Meta-model
   - Generality
   - Environment, Coordination, Organisation & Security

4. Remarkable Cases of (Programming) Languages for Multiagent Systems

Outline

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Paradigm Shifts in Software Engineering

New classes of programming languages

- New classes of programming languages come from paradigm shifts in Software Engineering[a]
  - new meta-models / new ontologies for artificial systems build up new spaces
  - new spaces have to be "filled" by some suitably-shaped new (class of) programming languages, incorporating a suitable and coherent set of new abstractions
- The typical procedure
  - first, existing languages are "stretched" far beyond their own limits, and become cluttered with incoherent abstractions and mechanisms
  - then, academical languages covering only some of the issues are proposed
  - finally, new well-founded languages are defined, which cover new spaces adequately and coherently

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The Problem of PL & SE Today

Things are running too fast

- New classes of programming languages emerge too fast from the needs of real-world software engineering
- However, technologies (like programming language frameworks) require a reasonable amount of time (and resources, in general) to be suitably developed and stabilised, before they are ready for SE practise

→ Most of the time, SE practitioners have to work with languages (and frameworks) they know well, but which do not support (or, incoherently / insufficiently support) required abstractions & mechanisms

→ This makes methodologies more and more important with respect to technologies, since they can help covering the “abstraction gap” in technologies

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An Example: CORBA & Distributed Objects

OOP technologies moving too slow

- As soon as OOP moved out of academia to enter SE practises, new needs had already emerged
- Distribution of software applications required new solutions, and created new spaces for programming languages
- Distributed objects were the first answer, and distributed infrastructures like CORBA were developed
- On the one hand, new (classes of) languages like IDL were introduced
- On the other hand, the development of a stable & reliable technology was so slow, that the first "usable" CORBA implementation (3.0) came too late, and never established itself as the standard reference technology

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Another Example: Java & Web Technologies

- What is the standard framework for distributed systems today?
  - Java, for distributed objects
  - The Web, for most distributed applications
- None of them, however, was born for this
  - Java was born as a programming language
    - today Java is typically conceived as a platform, or a distributed framework
  - The Web was born as a mere concept, implemented via HTML pages, server & browsers
    - today the Web is a sort of *cluster* of related technologies in ultra-fast growth
- Both of them suffer from a *lack of conceptual coherence*
  - in Java, syntax and basic language mechanisms are the only glue
  - in Web technologies, the client / server pattern is the only unifying model
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The Agent Abstraction

MAS programming languages have *agent* as a fundamental abstraction

- An agent programming language should support one (or more) agent definition(s)
  - so, straightforwardly supporting mobility in case of mobile agents, intelligence somehow in case of intelligent agents, . . . , by means of well-defined language constructs
- Required agent features play a fundamental role in defining language constructs

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Agent Architectures

MAS programming languages support agent *architectures*

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  - e.g., the BDI (Belief, Desire, Intention) architecture [Rao and Georgeff, 1991]
  - see Rosenschein's slides for some basic agent architectures
- Agent architectures influence possible agent features

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Agent Observable Behaviour

MAS programming languages support agent *model of action*

- Agents act
  - through either communication or pragmatical actions
- Altogether, these two sorts of action define the admissible space for agent's observable behaviour
  - a *communication language* defines how agents speak to each other
  - a "language of pragmatical actions" should define how an agent can act over its environment
- A full-fledged agent language should account for both languages
  - so little work on languages of pragmatical actions, however

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Agent Behaviour

Agent computation vs. agent interaction / coordination

- Agents have both an internal behaviour and an observable, external behaviour
  - this reproduce the "computation vs. interaction / coordination" dichotomy of standard programming languages
  - so, what is new here?
- Agent autonomy is new
  - the observable behaviour of an agent as a computational component is *driven* / *governed* by the agent itself
  - e.g., intelligent agents do practical reasoning—reasoning about actions—so that computation "computes" over the interaction space—in short, agent *coordination*

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Agent (Programming) Languages

Languages *to be*, languages *to interact*

- Agent programming languages should be either / both

  languages *to be* languages to define (agent) computational behaviour

  languages *to interact* languages to define (agent) interactive behaviour

Example: Agent Communication Languages (ACL)

- ACL are the easiest example of agent languages "to interact"
  - they just define how agents speak with each other
  - however, these languages may have some requirements on internal architecture / functioning of agents

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Agents Without Agent Languages

What if we do not have an agent language available?

- For either theoretical or practical reasons, it may happen
  - we may need an essential Prolog feature, or be required to use Java
- What we do need to do: *(1) define*
  - adopt an agent definition, along with the agent's required / desired features
  - choose agent architecture accordingly, and according to the MAS needs
  - define a model and the languages for agent actions, both communicative and pragmatical
- What we do need to do: *(2) map*
  - map agent features, architecture, and action model / languages upon the existing abstractions, mechanisms & constructs of the language chosen
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Outline

Programming the Interaction Space

The space of MAS interaction

- Languages to interact roughly define the space of (admissible) MAS interaction
- Languages to interact should not be merely seen from the viewpoint of the individual agent (*subjective viewpoint*)
- The overall view on the space of (admissible) MAS interaction is the MAS engineer's viewpoint (*objective viewpoint*)
  - *subjective* vs. *objective* viewpoint over interaction [Schumacher, 2001, Omicini and Ossowski, 2003]

Enabling / governing / constraining the space of MAS interaction

- A number of inter-disciplinary fields of study insist on the space of (system) interaction
  - coordination
  - organisation
  - security

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Coordination

Coordination in short

- Many different definitions around
  - we will talk about this later on in this course—we need to simplify, here
- In short, coordination is managing / governing interaction in any possible way, from any viewpoint
- Coordination has a typical "dynamic" acceptation
  - that is, enabling / governing interaction at execution time
- Coordination in MAS is even a more chaotic field
  - again, a useful definition to harness the many different acceptations in the field is subjective vs. objective coordination—the agent's vs. the engineer's viewpoint over coordination [Schumacher, 2001, Omicini and Ossowski, 2003]

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- It mainly concerns the structure of a system
    - it is mostly design-driven
- It affects and determines admissible / required interactions permissions / commitments / policies / violations / fines / rewards / ...
- Organisation is still enabling & ruling the space of MAS interaction
    - but with a more "static", structural flavour
    - such that most people mix-up "static" and "organisation" improperly
- Organisation in MAS is first of all, a model of responsibilities & power
    - typically based on the notion of *role*
    - requiring a model of communicative & pragmatical actions
    - e.g. RBAC-MAS [Omicini et al., 2005a]

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Coordination, Organisation & Security

Governing interaction in MAS

- Coordination, organisation & security all mean managing (MAS) interaction
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MAS Interaction Space in the A&A Meta-model

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- Agents *speak* with agents
- Agents *use* artifacts
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Artifacts as MAS computational entities

- Artifacts are computational entities
  - with a *computational* (internal) *behaviour*
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  - possibly covering *both* aspects
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Languages to be for artifacts

- Artifact computational behaviour is reactive
  - artifact languages should essentially be *event-driven*
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Programming Languages for Artifacts: A&A Features

A&A artifact features in languages

- An artifact language may deal with artifact's usage interface
- An artifact language may deal with artifact's operating instructions
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Other artifact features in languages

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- More or less the same holds for building agent workspace
- As a result, artifacts are our main places to model & engineer coordination, organisation & security in MAS

Programming Languages for Artifacts: The Environment

Artifacts & MAS Environment

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Layering Agent Workspace

A conceptual experiment

A layered taxonomy

- Individual artifacts
  - handling a single agent's interaction
- Social artifacts
  - handling interaction among a number of agents / artifacts
- Environment artifacts
  - handling interaction between MAS and the environment

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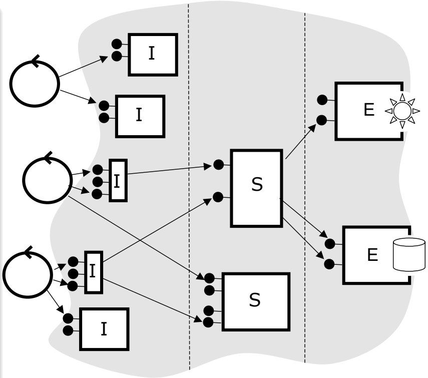

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- agents might reason about (coordination) artifacts, and possibly adapt their own behaviour, or change coordination policies

Artifact Languages for MAS Coordination

Languages for social artifacts

- Typically operational, event-driven languages for our "dynamic" perception of coordination
    - interaction happens, the artifact has just to capture interaction and to react appropriately
- Our example: ReSpecT
    - first-order logic (FOL) language
    - semantics given operationally [Omicini, 2006]
    - ongoing work on multiset rewriting semantics (with Maude)

Operational does not mean static, too

- coordinative behaviour may change at run-time
- agents might reason about (coordination) artifacts, and possibly adapt their own behaviour, or change coordination policies

Artifacts for MAS Environment

Environment artifacts

- Environment artifacts are the most natural place where to rule interaction between a MAS and its environment
  - on the basis of artifact reactivity to change
- Spatio-temporal fabric as a source of events
  - time time events for temporal concerns
  - space spatial events for topological concerns
- Resources as sources of events and targets of actions
  - like a database, or a temperature sensor
- Our (limited) example: Timed Tuple Centres [Omicini et al., 2005b]
  - coordination abstractions reactive to the passage of time
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Agent Communication Languages (ACL)

Speech acts

- Inspired by the work on human communication
- Communication based on direct exchange of messages between agents
  - specifying agent communicative actions
- Speaking agent acts to change the world around
  - in particular, to change the belief of another agent
- Every message has three fundamental parts

  performative the pragmatics of the communicative action

  content the syntax of the communicative action

  ontology the semantics of the communicative action

- Our examples, working as standard protocols for information exchange between agents

  KQML Knowledge Query Manipulation Language
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Programming languages for cognitive agents

- Mentalistic agents
  - either BDI or other cognitive architectures
- Facilities and structures to represent internal knowledge, goals, ...
- Architecture to implement practical reasoning
- Our examples

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Languages to program social / environment artifacts

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    `http://respect.alice.unibo.it/`
    [Omicini, 2006, Omicini and Denti, 2001]
- Tuple centres as coordinative artifacts
  - programmable tuple spaces
  - encapsulating coordination policies
- Logic tuple centres as awareness artifacts
- ReSpecT tuple centres as social artifacts
  - ReSpecT as the event-driven, logic-based language to program tuple centres behaviour
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Languages to program individual artifacts

- Our example: Agent Coordination Context (ACC)
  - individual artifact
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   - Generality
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4. Remarkable Cases of (Programming) Languages for Multiagent Systems

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