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   - 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
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4. Remarkable Cases of (Programming) Languages for Multiagent Systems
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Spaces for PL in SE

Paradigm Shifts

New classes of programming languages

- New classes of programming languages come from paradigm shifts in Software Engineering:
  - 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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Andrea Omicini (Università di Bologna)
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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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- 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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- Agents have (essential) features, but they are built around an agent architecture, which defines both its internal structure, and its functioning.

- An agent programming language should support one (or more) agent architecture(s)
  - e.g., the BDI (Belief, Desire, Intention) architecture [Rao and Georgeff, 1991]
  - see Rosenschein’s slides for some basic agent architectures

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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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- 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
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MAS programming languages support agent *model of action*

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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
  - computation the inner functioning of a computational component
  - interaction actions determining the observable behaviour of a computational component

- 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”
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  - 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
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  - define a model and the languages for agent actions, both communicative and pragmatical

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  - map agent features, architecture, and action model / languages upon the existing abstractions, mechanisms & constructs of the language chosen
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Outline

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
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

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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

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Organisation

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- Again, a not-so-clear and shared definition
- 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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- Agents *speak* with agents
- Agents *use* artifacts
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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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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
- An artifact language may deal with artifact's function description

Other artifact features in languages

- An artifact language may allow an artifact to be inspectable, controllable, malleable/forgeable, linkable, ...
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- Artifacts are our conceptual tools to model, articulate and shape MAS environment
  - to govern the agent interaction space
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- Artifacts are our conceptual tools to model, articulate and shape 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

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Artifacts for MAS Coordination

Social artifacts

- Social artifacts are the most natural place where to rule social interaction within a MAS on the basis of (objective) coordination concerns.
- Coordination policies could be distributed upon social artifacts, and there encapsulated.
  - Inspectability: there, coordination policies could be explicitly represented and made available for inspection.
  - Controllability: functioning of coordination engine could be controllable by engineers / agents.
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- Typically operational, event-driven languages for our “dynamic” perception of coordination
  - Interaction happens, the artifact has just to capture interaction and to react appropriately
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  - Ongoing work on multiset rewriting semantics (with Maude)

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  - space 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]
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- 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 events for temporal concerns
  - space 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
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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
  - 3APL Programming language for cognitive agents
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  - programmable tuple spaces
  - encapsulating coordination policies

- Logic tuple centres as awareness artifacts

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Non-Agent Programming Languages

Building the agent abstraction layer

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  - Prolog: programming logic agents in Prolog
  - Java: programming simple agents in Java; examples in TuCSoN

Agents using artifacts

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   - Paradigm Shifts
   - Examples

2. Spaces for Programming Languages in Multiagent Systems
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Conclusions

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Andrea Omicini
andrea.omicini@unibo.it

Ingegneria Due
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