

Programming Languages for Multiagent Systems

Advanced Topics in Agent-Oriented Computing

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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



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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 considered as a platform, or a distributed system
 - The Web was born as a mere concept, implemented via HTML pages, server & browsers
 - today the Web is a sort of *de facto* standard technology 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
 - conceptual integrity is lost in principle



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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

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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 others
 - 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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 - 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



Agent Observable Behaviour

MAS programming languages support agent *model of action*

- Agents act
 - through either communication or pragmatical actions
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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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- computation: the inner functioning of a computational component
- interaction: actions determining the observable behaviour of a computational component
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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 important features that define the behaviour of agents



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 “they just define how agents speak with each other”
 “they are the only languages where agents can communicate with
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 “to interact” means “to be able to communicate with each other”
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 information with each other”



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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
 - thus building an *agent abstraction layer* over our non-agent language foundation



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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

- A number of inter-disciplinary fields of study insist on the space of (system) interaction
 - Computer Science
 - Engineering
 - Economics
 - Law



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Artificial Intelligence

Computer Science

Mathematics

Philosophy



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Coordination

Coordination in short

- Many different definitions around
 - no time to explain everything 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” acceptance
 - 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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Organisation

Organisation in short

- 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
 - our example here is RBAC-MAS [Omicini et al., 2005a]



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Organisation

Organisation in short

- 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
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Security in short

- You may not believe it, but also security means managing interaction
 - *you cannot see / do / say this, you can say / do / see that*
- Typically, security has both “static” and “dynamic” flavours
 - *a design-time plus a run-time acceptance*
- But tends to enforce a “negative” interpretation over interaction
 - *“this is not allowed”*
- In this sense, it is dual to both coordination and organisation
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Coordination, Organisation & Security

Governing interaction in MAS

- Coordination, organisation & security all mean managing (MAS) interaction
- They all are meant to shape the space of admissible MAS interactions
 - to define its admissible space at design-time (organisation/security flavour)
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 - could artifacts, and the A&A meta-model help on this?



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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**
 - Environment, Coordination, Organisation & Security
- 4 Remarkable Cases of (Programming) Languages for Multiagent Systems



MAS Interaction Space in the A&A Meta-model

MAS interaction & A&A

- Agents *speak* with agents
- Agents *use* artifacts
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 - these three sentences completely describe interaction *within* a MAS in the A&A meta-model
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Programming Languages for Artifacts

Artifacts as MAS computational entities

- Artifacts are computational entities
 - with a *computational* (internal) *behaviour*
 - and an *interactive* (observable) *behaviour*
- Artifact programming languages are required
 - possibly covering *both* aspects
 - *to be* artifact, and *to interact* with agents and other artifacts



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Programming Languages for Artifacts: Computation

Languages to be for artifacts

- Artifact computational behaviour is reactive
 - artifact languages should essentially be *event-driven*
- Artifacts belong to the agent interaction space within a MAS
 - artifact languages should be able to compute over MAS interaction
- Given the prominence of interaction in computation, artifact languages are likely to embody *both* aspects altogether



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- Artifact interactive behaviour deals with agents and artifacts
 - artifact languages should provide operations for agents to use them
 - artifact languages should provide links for artifacts to link with them
- Artifacts work as mediators between agents and the environment
 - artifact languages should be able to react to environment events, and to observe / compute over them
- In the overall, artifacts may subsume agent's pragmatistical actions, as well as environment's events & change
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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
- 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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Programming Languages for Artifacts: The Environment

Artifacts & MAS Environment

- Artifacts are our conceptual tools to model, articulate and shape MAS environment
 - to govern the agent interaction space
 - to build up the agent workspace

Artifacts for coordination, organisation & security

- Governing the interaction space essentially means coordination, organisation & security
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 - to build up the agent workspace

Artifacts for coordination, organisation & security

- Governing the interaction space essentially means coordination, organisation & security
- 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



Layering Agent Workspace

A conceptual experiment

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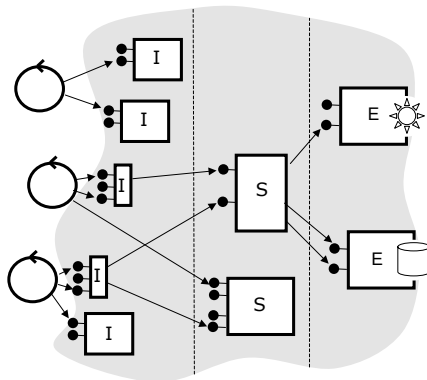


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Artifacts for MAS Organisation / Security

Individual artifacts

- Individual artifacts are the most natural place where to rule individual agent interaction within a MAS
 - on the basis of organisational / security concerns
- If an individual artifact is the only way by which an agent can interact within a MAS
 - organisation there, role, permissions, obligations, policies, etc., should be encapsulated
 - security working as a filter for any perception / action / communication between the agent, MAS and the environment
 - autonomy it could work as the harmoniser between the clashing needs of agent autonomy and MAS control
 - boundaries it could be used as a criterion for determining whether an agent belongs to a MAS
- Our example: Agent Coordination Contexts (ACC)
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Artifact Languages for MAS Organisation / Security

Languages for individual artifacts

- Declarative languages (KR-style) for our “quasi static” perception of organisation
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- Operational languages for modelling actions
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- organisation structure may change at run-time
- agents might reason about (organisation) artifacts, and possibly adapt their own behaviour, or change organisation structures



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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
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- coordinative behaviour may change at run-time
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Artifacts for MAS Environment

Environment artifacts

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 - 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]
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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 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
 - Timed ReSpecT for time-aware coordination policies



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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

3APL Programming language for cognitive agents

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Jason Java-based interpreter for an extended version of
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Artifact Programming Languages: Coordination

Languages to program social / environment artifacts

- Our example: ReSpecT
 - Programming language for cognitive agents
<http://respect.alice.unibo.it/>
[Omicini, 2006, Omicini and Denti, 2001]
- Tuple centres as coordinative artifacts
 - programmable tuple spaces
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- Logic tuple centres as awareness artifacts
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Languages to program individual artifacts

- Our example: Agent Coordination Context (ACC)
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Non-Agent Programming Languages

Building the agent abstraction layer

- Our examples

Prolog programming logic agents in Prolog

Java programming simple agents in Java: examples in TuCSoN

Agents using artifacts

- Our examples

Building logic agents using Prolog: simple concrete examples in our system

<http://www.dcs.bcl.ac.uk/~dcs/papers/2002/02-01-01.pdf> [Lorenz et al., 2002]

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Prolog

Prolog agents use artifacts to communicate. The artifacts are represented by Prolog terms. The artifacts are used to represent the state of the environment and the state of the agents.

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<http://tuprolog.alice.unibo.it/> [Denti et al., 2005]

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Programming Languages for Multiagent Systems

Advanced Topics in Agent-Oriented Computing

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