Programming Languages for Multiagent Systems

Multiagent Systems LS

Sistemi Multiagente LS

Andrea Omicini

andrea.omicini@unibo.it

Ingegneria Due

Alma Mater Studiorum—Università di Bologna a Cesena

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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[1]
  - 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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[1] SE here is taken in its broadest acceptation as the science of building

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

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

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
  - conceptual integrity is lost in principle

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

Agent Architectures

MAS programming languages support agent *architectures*

- 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
- Agent architectures influence possible agent features

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

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*

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

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

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

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]

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
  - e.g. RBAC-MAS [Omicini et al., 2005a]

Security

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- plus a run-time acceptation
- But tends to enforce a "negative" interpretation over interaction
  - "this is not allowed"
- It is then dual to both coordination and organisation
- So, in MAS at least, they should to be looked at altogether

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)
  - to govern its dynamics at run-time (coordination/security flavour)
- An overall view is then required
  - could artifacts, and the A&A meta-model help on this?

MAS Interaction Space in the A&A Meta-model

MAS interaction & A&A

- Agents *speak* with agents
- Agents *use* artifacts
- Artifacts *link* with artifacts
- Artifacts *manifest* to agents
  - these four sentences completely describe interaction *within* a MAS in the A&A meta-model
- What about programming languages now?
  - what about languages to be and languages to interact?

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

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

Programming Languages for Artifacts: Interaction

Languages to interact for artifacts

- 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 pragmatical actions, as well as environment's events & change
  - thus providing the basis for an engineering discipline of MAS interaction

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, ...

Programming Languages for A&A Agents

A&A agents deal with artifacts

- An agent programming language may deal with artifact's usage interface for artifact use
- An agent programming language may deal with artifact's operating instructions for practical reasoning about artifacts
- An agent programming language may deal with artifact's function description for artifact selection

Other features for agent programming languages

- An agent programming language may allow an A&A agent to inspect, control, forge, compose, ..., artifacts of a MAS

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

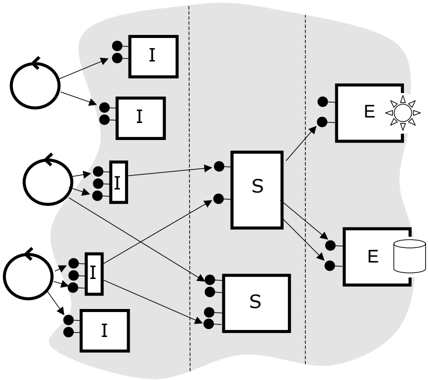
- Governing the interaction space essentially means coordination, organisation & security
- More or less the same holds for building agent workspace
- As a result, artifacts are our main places to model & engineer coordination, organisation & security in MAS

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



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)
  - infrastructural abstraction associated to each agent entering a MAS

Artifact Languages for MAS Organisation / Security

Languages for individual artifacts

- Declarative languages (KR-style) for our "quasi static" perception of organisation
- Formal languages (like process algebras) for action / policy denotation
- Operational languages for modelling actions
- Our example: Agent Coordination Contexts (ACC)
  - first-order logic (FOL) rules [Ricci et al., 2006a]
  - process algebra denotation [Omicini et al., 2006]

Declarative does not mean static, actually

- organisation structure may change at run-time
- agents might reason about (organisation) artifacts, and possibly adapt their own behaviour, or change organisation structures

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

  malleability: coordination policies could be amenable to change by agents / engineers
- Our example: Tuple Centres [Omicini and Denti, 2001]
  - coordination abstractions for MAS coordination
  - logic tuple centres for coordinative / awareness artifacts
  - ReSpecT tuple centres for A&A [Omicini, 2006]

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
  - Timed ReSpecT for time-aware coordination policies

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
  `http://www.cs.umbc.edu/kqml/` [Labrou and Finin, 1997]
  FIPA ACL: FIPA Agent Communication Language
  `http://www.fipa.org/repository/aclspecs.html`
  [FIPA ACL, 2002]

Agent Oriented Programming Languages (AOP)

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
  `http://www.cs.uu.nl/3apl/`
  [Dastani et al., 2004, Dastani et al., 2005]

  Jason Java-based interpreter for an extended version of AgentSpeak(L) for programming BDI agents
  `http://jason.sourceforge.net/`
  [Rao, 1996, Bordini and Hübner, 2006]

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
  - 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
  - Timed ReSpecT as an event-driven language to react to environment change

Artifact Programming Languages: Organisation / Security

Languages to program individual artifacts

- Our example: Agent Coordination Context (ACC)
  - individual artifact
  - associated to each individual agent in a MAS
  - filtering every interaction of its associated agent
- RBAC-MAS as the organisational model [Omicini et al., 2006]
- Languages for policy specification & enaction
  - logic-based [Ricci et al., 2006a]
  - process algebra [Omicini et al., 2005a]

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

  tuProlog logic agents using ReSpecT tuple centres: examples in tuProlog
  `http://tuprolog.alice.unibo.it/` [Denti et al., 2005]

  simpA extending Java towards A&A agents & artifacts: examples in simpA
  `http://www.alice.unibo.it:16080/projects/simpa/`

  Java/TuCSoN simple Java agents using TuCSoN tuple centres and ACC

  Jason/CArtAgO Jason agents using CArtAgO artifacts
  `http://www.alice.unibo.it:16080/projects/cartago/`
  [Ricci et al., 2006b, Ricci et al., 2006c]

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