# Agent-Oriented Software Engineering

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## Outline

- Part 1: What is Agent-Oriented Software Engineering (AOSE)
  - Why it is important
  - Key concepts.
- Part 2: Agent-methodologies
  - Key Concepts
  - The Gaia Methodology
  - Case Study
- Part 3: Implementing agents
  - Intra-agent vs. inter-agent issues
  - Multiagent infrastructures
- Part 4: Conclusions and Open Research directions.



## Part 1

- What is Agent-Oriented Software Engineering



## What is Software Engineering

- Software is pervasive and critical:
  - It cannot be built without a disciplined, engineered, approach
- There is a need to model and engineer both:
  - The development process:
    - Controllable, well documented, and reproducible ways of producing software;
  - The software:
    - Well-defined quality level (e.g., % of errors and performances);
    - Enabling reuse and maintenance.
- Requires:
  - Methodologies → Abstractions, and tools.



## Software Engineering Abstractions

- Software deals with "abstract" entities, having a real-world counterpart:
  - Numbers, dates, names, persons, documents ...
- In what terms should we model them in software?
  - Data, functions, objects, agents ...
  - I.e., what are the **ABSTRACTIONS** that we have to use to model software?
- May depend on the available technologies!
  - Use OO abstractions for OO programming envs.;
  - Not necessarily: use OO abstractions because they are better, even for COBOL programming envs.

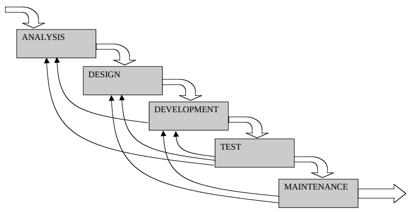


## Methodologies

- A methodology for software development:
  - Is intended to give discipline to software development.
  - Defines the abstractions to use to model software:
    - Data-oriented methodologies, object-oriented ones ...
    - Define the MINDSET of the methodology.
  - Disciplines the software process:
    - What to produce and when;
    - Which artifacts to produce.

## The Classical “Cascade” Process

- The phases of software development:
  - Independent of programming paradigm;
  - Methodologies are typically organized around this classical process.
    - Inputs, outputs, internal activities of “phases”






## Tools

- Notation tools:
  - To represent the outcomes of the software development phases:
    - Diagrams, equations, figures …
- Formal models:
  - To prove properties of software prior to development
    - Lambda and pi calculus, UNITY, Petri-nets, Z ….
- CASE (Computer Aided Software Engineering) tools:
  - Based on notations and models, to facilitate activities:
    - Simulators, rapid prototyping, code generators.



## Example: Object-oriented Software Engineering (OOSE)

- Abstractions:
  - Objects, classes, inheritance, services.
- Methodologies:
  - Object-oriented analysis and design, RUP, OPEN, etc..;
  - Centered around the object-oriented abstractions.
- Tools (Modeling Techniques):
  - UML (standard), E-R, class lattices, finite state automata, visual languages …



## Why Agent-Oriented Software Engineering?

- Software engineering is necessary to discipline:
  - Software systems and software processes;
  - Any approach relies on a set of abstractions and on related methodologies and tools
- Agent-based computing:
  - Introduces novel abstractions
    - Requires clarifying the set of necessary abstractions
    - Requires adapting methodologies and producing new tools
- Novel, specific agent-oriented software engineering approaches are needed!



## What are Agents?

- There has been some debate
  - On what an agent is, and what could be appropriately called an agent
- Two main viewpoints (centered on different perspectives on autonomy):
  - The (strong) Artificial Intelligence viewpoint:
    - An agent must be, proactive, intelligent, and it must converse instead of doing client-server computing
  - The (weak) Software Engineering Viewpoint
    - An agent is a software component with internal (either reactive or proactive) threads of execution, and that can be engaged in complex and stateful interactions protocols



## What are Multiagent Systems?

- Again….
  - The (strong) artificial intelligence viewpoint
    - A multiagent system is a society of individuals (AI software agents) that interact by exchanging knowledge and by negotiating with each other to achieve either their own interest or some global goal
  - The (weak) software engineering viewpoint
    - A multiagent system is a software systems made up of multiple independent and encapsulated loci of control (i.e., the agents) interacting with each other in the context of a specific application viewpoint….

## The SE Viewpoint on Agent-oriented Computing

- We commit to it because:
  - It focuses on the characteristics of agents that have impact on software development
    - Concurrency, interaction, multiple loci of control
    - Intelligence can be seen as a peculiar form of control independence; conversations as a peculiar form of interaction
  - It is much more general:
    - Does not exclude the strong AI viewpoint
    - Several software systems, even if never conceived as agents-based one, can be indeed characterised in terms of weak multi-agent systems
- Let's better characterize the SE perspective on agents…

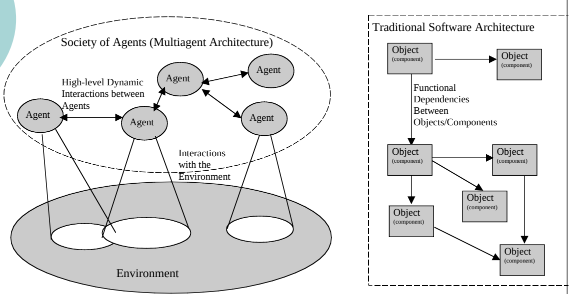


## SE Implications of Agent Characteristics

- Autonomy
  - Control encapsulation as a dimension of modularity
  - Conceptually simpler to tackle than a single (or multiple inter-dependent) locus of control
- Situatedness
  - Clear separation of concerns between:
    - the active computational parts of the system (the agents)
    - the resources of the environment
- Sociality
  - Not a single characterising protocol of interaction (e.g., client-server)
  - Interaction protocols as an additional SE dimension
- Openness
  - Controlling self-interested agents, malicious behaviors, and badly programmed agents
  - Dynamic re-organization of software architecture
- Mobility and Locality
  - Additional dimension of autonomous behavior
  - Improve locality in interactions



## MAS vs. OOSE Characterisation






## Agent-Oriented Abstractions

- The development of a multiagent system should fruitfully exploit **abstractions** coherent with the above characterization:
  - **Agents,** autonomous entities, independent loci of control, situated in an environment, interacting with each other
  - **Environment**, the world of resources agents perceive
  - **Interaction protocols**, as the acts of interactions between agents
- In addition, there may be the need of abstracting:
  - The **local context** where an agent lives (e.g., a sub-organization of agents) to handle mobility & opennes
- Such abstractions translates into concrete entities of the software system



## Agent-Oriented Methodologies

- There is need for SE methodologies
  - Centered around specific agent-oriented abstractions
    - E.g., Agents, environments, interaction protocols
  - The adoption of OO methodologies would produce mismatches
    - Classes, objects, client-servers: little to do with agents!
- Each methodology may introduce further abstractions
  - Around which to model software and to organize the software process
    - E.g., roles, organizations, responsibilities, beliefs, desires and intentions…
  - Not directly translating into concrete entities of the software system
    - E.g. the concept of role is an aspect of an agent, not an agent



## Agent-Oriented Tools

- SE requires tools to
  - represent software
    - E.g., interaction diagrams, E-R diagrams, etc.
  - verify properties
    - E.g., petri nets, formal notations, etc.
- AOSE requires
  - Specific agent-oriented tools
    - E.g., UML per se is not suitable to model agent systems and their interactions (object-oriented abstractions not agent-oriented ones)

## Why Agents and Multiagent Systems?

- Other lectures may have already outlined the advantages of (intelligent) agents and of multiagent systems, and their possible applications
  - Autonomy for delegation (do work on our behalf)
  - Monitor our environments
  - More efficient interaction and resource management
- Here, we state that
  - **Agent-based computing, and the abstractions it uses, represent a new and general-purpose software engineering paradigm!**



## There is much more to agent-oriented software engineering

- AOSE is not only for "agent systems."
  - Most of today's software systems have characteristics that are very similar to those of agents and multiagent systems
  - The agent abstractions, the methodologies, and the tools of AOSE suit such software systems
- AOSE is suitable for a wide class of scenarios and applications!
  - Agents' "artificial Intelligence" features may be important but are not central
- But of course…
  - AOSE may sometimes be too "high-level" for simple complex systems…



## Agents and Multiagent Systems are (Virtually) Everywhere!

- Examples of components that can be modelled (and **observed**) in terms of agents:
  - Autonomous network processes;
  - Computing-based sensors;
  - PDAs;
  - Robots.
- Example of software systems that can be modelled as multiagent systems:
  - Internet applications;
  - P2P systems;
  - Sensor networks;
  - Pervasive computing systems.



## Summarizing

- A software engineering paradigm defines:
  - The mindset, the set of abstractions to be used in software development and, consequently,
  - Methodologies and tools
  - The range of applicability
- Agent-oriented software engineering defines
  - Abstractions of agents, environment, interaction protocols, context
  - Of course, also specific methodologies and tools (in the following of the tutorial)
  - Appears to be applicable to a very wide rage of distributed computing applications….



## Part 2

- Agent-oriented Methodologies
- The Gaia Methodology



## What is a methodology ?

To evaluate a methodology, we need to recall what a methodology is:

**1:** a body of methods, rules, and postulates employed by a discipline**:** a particular procedure or set of procedures

**2 :** the analysis of the principles or procedures of inquiry in a particular field

(Merriam-Webster)

•But when referring to software:

•A methodology is the set of guidelines for covering the whole lifecycle of system development both technically and managerially.

## Agent-oriented Methodologies

- They have the goal of
  - Guiding in the process of developing a multiagent systems
  - Starting from collection of requirements, to analisys, to design, and possibly to implementation
- An agent-oriented methodology defines the abstractions to use to model software:
  - Typically, agents, environments, protocols..
  - Plus additional methodology-specific abstractions
- And disciplines the software process:
  - What models and artifacts to produce and when
    - Model: an abstract representation of some aspect of interest of the software
    - Artifact: documents describing the characteristic of the software



## Agent-oriented Methodologies

- A Variety of Methodology exists and have been proposed so far
  - Gaia (Zambonelli, Jennings, Wooldridge)
  - Prometeus (Winikoff and Pagdam)
  - SODA (Omicini)
  - ADELFE (Gleizes)
  - Etc.
- Exploiting abstractions that made them more suited to specific scenarios or to others..
- We focus on Gaia because is the reference one (i.e., the one any new proposal compares to) and the more general one
  - Ok, I am not an impartial judge…



## The Gaia Methodology

- It is "THE" AOSE Methodology
  - Firstly proposed by Jennings and Wooldridge in 1999
  - Extended and modified by Zambonelli in 2000
  - Final Stable Version in 2003 by Zambonelli, Jennings, Wooldridge
  - Many other researchers are working towards further extensions…
- Key Goals
  - Starting from the requirements (what one wants a software system to do)
  - Guide developers to a well-defined design for the multiagent system
  - The programmers can easily implement
  - Able to model and deal with the characteristics of complex and open multiagent systems

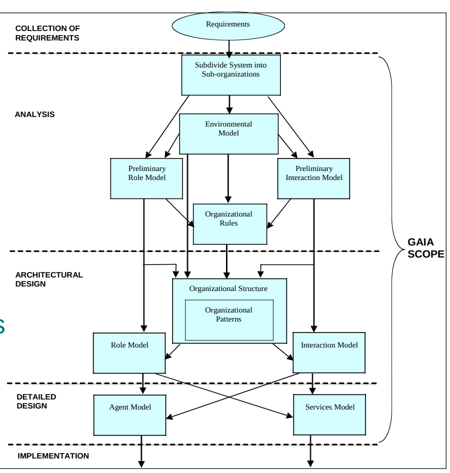


## Key Characteristics of Gaia

- Exploits organizational abstractions
  - Conceive a multiagent systems as an organization of individual, each of which playing specific roles in that organization
  - And interacting accordingly to its role
- Introduces a clear set of abstractions
  - Roles, organizational rules, organizational structures
  - Useful to understand and model complex and open multiagent systems
- Abstract from implementation issues



## Structure of Gaia Process




## A Case Study: Distributed Project Review

- The ministry for research publish a call for funding research
  - Scientists must "submit" a research proposal, e.g., in the form of a scientific article (paper)
- A number of scientists (called reviewers or referees") review the papers and give marks
  - It has to complete a document called "review form"
  - To ensure fairness, the reviewers must be anonymous, expert, and must be willing to do the review,
  - Also, each project should receive a minimum number of review from different scientists
- Eventually, all accepted project/papers will sign a contract, will receive the funds, and will publish the results on a book

## The Case Study: Why Agents?

- It is a typical case of distributed workflow management
  - There are actions to do on common documents
  - According to specific rules
- Each of the human actors involved in the process
  - Could be supported by a personal agents
  - Helping him to submit documents, filling in, respect deadlines, etc.
- Let's see how we could develop this using the Gaia methodology..



## Gaia Analysis (1)

- Once we know what the problem to solve is
- **First: Sub-organizations**
  - See if it can easily conceived as a set of loosely interacting problems
  - To be devoted to different sub-organization
  - And let's focus on the different sub-organizations
  - "Divide et impera"
- **Second: Environment**
  - Analyze the operational environment
  - See how it can be modeled in terms of an agent environment
  - Resources to be accessed and how
  - So as to obtain an "environmental" model



## Case Study Analisys (1)

- First: Sub-organizations
  - There are clearly different organizations in time
    - The submission of paper,
    - The review of paper
    - The Contractual phase for accepted ones
- Second: Environment
  - The environment is clearly a computational environment of digital resources
  - Filled in with papers and review forms
    - And possible with "user profiles" describing the attitudes, expertises, and possibly the conflicts of interest of scientists



## Gaia Analysis (2)

- **Third: Roles**
  - See what "roles" must be played in the organization
  - A role defines a "responsibility" center in the organization, with a set of expected behaviors
  - So that its goals can be achieved
  - Defines the attributes and the responsibility of each role, reasoning in terms of "sub-goals"
  - So as to define the "role model", i.e., the list specifying the characteristics of the various roles
- **Fourth: Protocols**
  - See how roles must interact with each other so as to fulfill expectations
  - Analyze these interaction protocols
  - So as to define an "interaction model", i.e., the list specifying the characteristics of the various protocols



## Case Study Analysis (2)

- **Third: Roles**
  - There are clearly such roles such as
    - "chair" (who received submissions and control the review process)
    - "author" (who send submissions)
    - "reviewer" (who receive papers to review and send back review forms)
  - Each with different permissions related to the environment (e.g., authors cannot access review forms) and with different responsibilities (reviewers must fill in the review form in due time)
- **Fourth: Protocols**
  - Protocols can be easily identified
    - "submit paper FROM author TO chair"
    - "send paper to review FROM chair TO"
    - Etc.



## Gaia Analysis (3)

- **Fifth: Organizational Rules**
  - Analyze what "global" rules exists in the system that should rule all the interactions and the behavior between roles
  - These defines sorts of "social rules" or "laws" to be enacted in the organization
  - The list of all identified rules, that we call "organizational rules", define the last model of the analysis

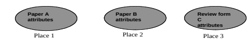
## Case Study Analysis (3)

- **Fifth: Organizational Rules**
  - The process should clearly occur according to some rules ensuring fairness of the process
  - An author should not also act as reviewer for his own projects, or for those of his “friends”
  - A reviewer should not give two review for the same project
  - Each project should receive the same minimal number of review
  - And other you may think of…



## Gaia Analysys: Graphical Representation of Models

- Environment
- Roles
- Interactions
- Organizational Rules




$\neg(\text{REVIEWER}(paper(x)) \mid \text{AUTHOR}(paper(x)))$

$\text{REVIEWER}(paper(i))^{2+}, i = 1, \dots, number\_of\_submitted\_papers$

| Protocol Name: **Receive Paper** | | |
|---|---|---|
| Initiator: **??** (PC Chair or PC Member) | Partner: **Reviewer** | Input: **Paper info** |
| Description: When a paper has to be assigned to a reviewer it (by someone undefined at this stage) it will be proposed by sending paper info to one of the potential reviewer | | Output: **No, don’t review OR Yes, I review it, send me the full paper** |



## From Analysis to Design

- Once all the analysis model are in place
  - We can start reasoning at how organizing them into a concrete architecture
- An “agent architecture” in Gaia is
  - A full specification of the **structure of the organization**
  - With full specifications on all the roles involved
  - With full specification on all interaction involved
- It is important to note that in Gaia
  - Role and Interaction models are “preliminar”
  - They cannot be completed without choosing the final structure of the organization
    - Defining all patterns of interactions
    - Introducing further “organizational” roles
    - Arranging the structure so that the organizational rules are properly enacted



## From Analysis to Design in the Case Study

- The final organizational of the review process may imply
  - Multi-level hierarchies to select papers (if there are a lot of submissions the “chair” must be supported by “co-chairs”)
  - A Negotiation process to select reviewers (it is a difficult process, and agent could help in that to march papers with appropriate reviewers)
  - A structure that avoid cheating (where an authors is somehow allowed to act as reviewer of its own project)
- Then, it is clear that the analysis could not have determines the final structure and a definitive listing of roles and protocols

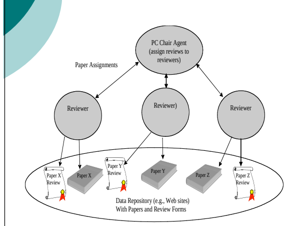


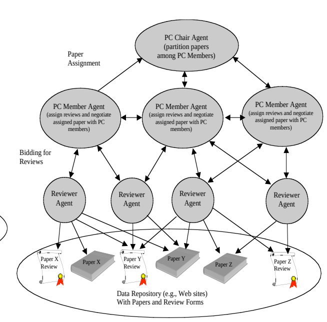
## Gaia Architecture Design (1)

- Aimed at determining the final architecture of the system
- The architecture, i.e., the organizational structure consists in
  - The **topology** of interaction of all roles involved
    - Hierarchies, Collectives, Multilevel…
    - Which roles interact with which
  - The “**control regime**” of interactions
    - What type of interactions? Why?
    - Control interactions, Work partitioning, work specialization, negotiations, open markets, etc.



## Case Study: Possible Organizational Structures



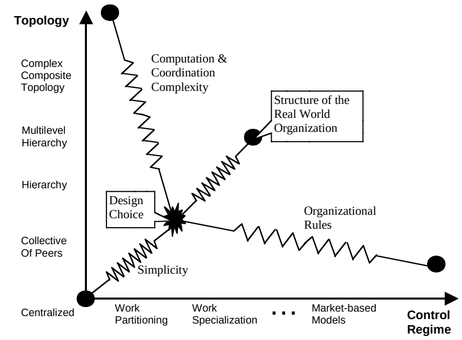



## Gaia Architecture Design (2)

- What "forces" determines/influence the organizational structure?
- Simplicity
  - Simple structures are always preferable
- The Real-World organization
  - Trying to mimic the real-world organization minimizes conceptual complexity
- Complexity of the problem
  - Calls for distributed structures, with many components involved
- The need to enact organizational rules with small effort
  - Calls for exploiting negotiations as much as possible,
  - Also to deal with open systems,



## Choosing the Organizational Structure






## Gaia Architecture Design (3)

- It is important to note that in the definition of the organizational structure
  - This can be composed from a set of known "organizational patterns"
  - So that previous experiences can be re-used
- Once the organizational structure is decided
  - Complete the role model
  - Additional roles may have been introduced due to the specific structure chosen
- Complete the interaction model
  - To account for all interactions between all roles in a detailed way



## Gaia Detailed Design

- Devoted to transform "roles" and "interaction protocols" into more concrete components, easy to be implemented
- Roles becomes agents
  - With internal knowledge, a context, internal activities, and services to be provided
  - Sometimes, it is possibly thinking at compacting the execution of several roles into a single agent
  - Clearly, we can define "agent classes" and see what and how many instances for these classes must be created
- Interaction protocols becomes sequence of messages
  - To be exchanged between specific agents
  - Having specific content and ontologies
- And the final specifications go to the programmers…



## About Gaia Notations

- Gaia adopt a custom notation for its models
  - However, Gaia does not prescribe this
  - Any other graphical or textual notations (e.g. UML or whatever) can be used or can complement the Gaia one



## Part 3:

- Implementation Issues and Multiagent Infrastructures

## Issues in Implementing Agents and Multiagent Systems

- How can we move from agent-based design to concrete agent code?
- Methodologies should abstract from:
  - Internal agent architecture
  - Communication architecture
  - Implementation tools
- However, depending on tools the effort from design to implementation changes:
  - It depends on how much abstractions are close to the abstractions of agent-oriented design
  - The methodology could strongly invite to exploit a specific infrastructure



## Intra-agent Issues: Implementing Agents

- We have two main categories of tools to implement agents:
  - Object-oriented tools: are very much related to the object-oriented approach, e.g., Aglet;
  - BDI toolkits: are based on the BDI model (e.g., Jade).
- The choice of the tool to adopt is hard and there is no general answer:
  - Performances;
  - Maintenance;
  - … and many other issues.
- We have already discussed about Aglets and JADE agent implementation models, so we skip them now…



## Inter-agent Issues: Implementing Multiagent Systems

- Inter-agent implementation aspects are orthogonal to intra-agent ones
  - Given a set of agents
    - With internal architecture
    - With specified interaction patterns
  - How can we glue them together?
    - Letting agents know each other
  - How to enable interactions?
    - Promoting spontaneous interoperability
  - How to rule interactions?
    - Preventing malicious or self-interested behaviours?



## Multiagent Infrastructures

- Enabling and ruling interactions is mostly a matter of the **infrastructure**
- The "**middleware**" layer supporting communication and coordination activities
  - Not simply a passive layer
  - But a layer of communication and coordination middleware "services"
    - Actively supporting the execution of interaction protocols
    - Providing for helping agents move in unknown worlds
    - Providing for proactively controlling, and possibly influencing interactions



## Communication vs. Coordination Infrastructures

- Communication Infrastructures
  - Middleware layer mainly devoted to provide communication facilities
    - Routing messages, facilitators, etc.
    - FIPA defines a communication infrastructure
  - Communication enabling
- Coordination Infrastructure
  - Middleware layer mainly devoted to orchestrate interactions
    - Synchronization, and constraints on interactions
    - MARS and Tucson are coordination infrastructures
  - Activities ruling

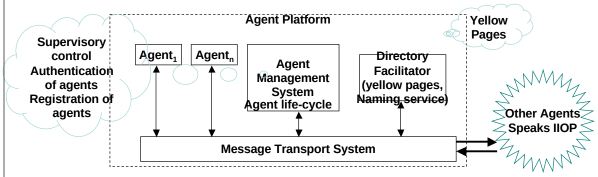


## Communication Infrastructure

- Agent in a MAS have to interact with each other, requiring
  - Finding other agents
    - Directory services in the infrastructure keep track of which agents are around, and what are their characteristics (e.g., services provided)
  - Re-routing message
    - Facilitator agents (parts of the infrastructure) can
      - receive messages to be delivered to agents with specific characteristics, and re-route them
  - Control on ACL protocols
    - The execution of a single protocol can be controlled in terms of a finite state machine

## FIPA Specifications for Communication Infrastructures

- The Foundation for Intelligent Physical Agents
- Specifies STANDARDS for multiagent infrastructures
  - to interoperate and be managed
- Formally specified ACL
  - Specifies encoding, semantics, and pragmatics of messages
- Includes: mobility, security, ontology, Human-Agent comm.
- FIPA reference architecture (see below)






## JADE (Java Agent DEvelopment Framework)

- JADE – A FIPA-compliant Agent Framework
  - http://sharon.cselt.it/projects/jade/
- Is a software framework
  - simplifies the implementation of multi-agent systems
  - Attempts to be very efficient
  - Fully implemented in Java and fully distributed under LGPL
  - Mostly oriented to ***AGENT COMMUNICATIONS*** (via ACL)
- Definitely the most used systems
  - AND IT IS ITALIAN!!!
  - Developed by UNIPR and TELECOM-IT

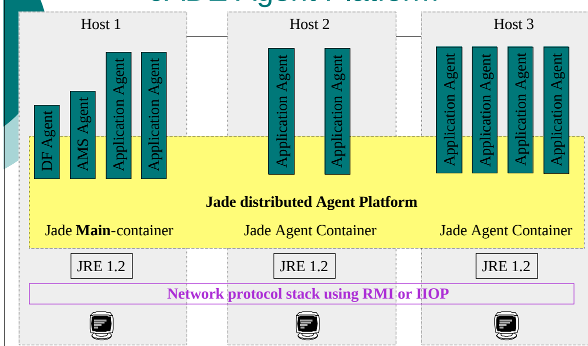
JADE

## JADE continued

- Is the middleware for MAS (Multi-Agent Systems)
  - Target users: agent programmers for MAS
  - Agent services
    - life-cycle (to handle creation and death of agents), yellow-pages (naming service), message transport (to have different platforms interoperate)
  - Agent Communication Languages
    - Support for Speech Act and Negotiation protocols
    - Support for Shared Ontologies
  - Tools to support debugging phase
    - remote monitoring agent, dummy agent, sniffer agent
  - Designed to support scalability
    - (from debugging to deployment)
    - from small scale to large scale

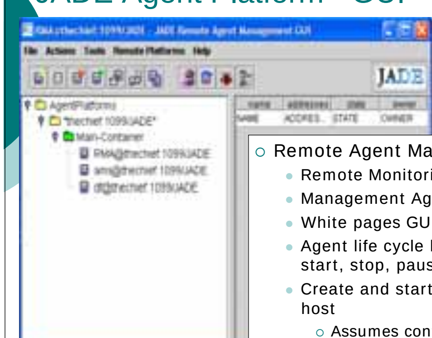


## Distributed architecture of a JADE Agent Platform






## JADE Agent Platform - GUI



- Remote Agent Management
  - Remote Monitoring Agent
  - Management Agent
  - White pages GUI – to find agents
  - Agent life cycle handling allowing start, stop, pause, migrate, etc.
  - Create and start agents on remote host
    - Assumes container already registered
  - Naturally uses ACL for communication



## JADE Communication Sub-system

- Every agent has a private queue of ACL messages created and filled by the JADE communication sub-system
- Designed as a chameleon to achieve the lowest cost for message passing
  - The mechanism is selected according to the situation
  - The overheads depend on the receiver's location and the cache status
- If you send a message to another agent and the sub-system can't find target, then it sends it to the AMS to handle
- Graphics tools to analyse agent communications

## JADE Interaction Protocols

- Interaction protocols are the FIPA way to manage interactions.
- JADE provides support for FIPA generic interaction protocols, e.g.:
  - FIPA Contract net;
  - FIPA English and Dutch auctions.
- JADE implements interaction protocols as FSM behaviors.
- Graphics Tools to Analyse Protocols

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## Software Engineering with Communication Infrastructures

- All application problems are to be identified and designed in terms of
  - Internal agent behaviors and inter-agent interaction protocols
  - These include, from the intra-agent engineering viewpoint:
    - Controlling the global interactions
    - Controlling self-interested behaviours
- Advantages:
  - All in the system is an agents
  - The engineering of the system does not imply the engineering of the infrastructure
  - A standard has already emerged (FIPA)
- Drawbacks:
  - The design is hardly re-tunable
  - Global problems spread into internal agents' code

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## Coordination Infrastructures

- The infrastructure is more than a support to communication
  - Other than enabling interactions...
  - It can embed the “laws” to which interaction must obey
    - E.g., to specify which agents can execute which protocols and when
    - E.g., Gaia organizational rules
  - It can control the adherence of the MAS behavior to the laws
    - E.g., to prevent malicious behaviors
  - Such laws can be re-configured depending on the application problem
    - E.g., English vs. Vickery auctions have different rules

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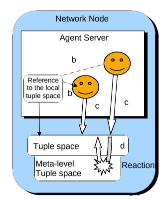
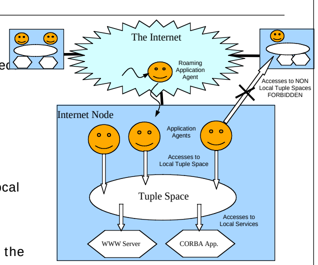
## The MARS Coordination Infrastructure

- Mobile Agent Reactive Spaces
  - Developed at the University of Modena e Reggio Emilia
  - Ported on different agent systems (*Aglets*, *Java2Go*, *SOMA, JADE*)
  - Strictly related to TUCSON
- One shared data space on each node
- **“Tuple spaces”**
  - Attributed-based access to local resources
- Programmable tuple spaces
  - Based on the original idea of programmable coordination media (Omicini & Denti 98)
  - A “meta-level” can control and monitor all agent interactions




## MARS Features

- Mobile agents roam the Internet
  - On each node, they conne to a local tuple space
- They can access it to retrieve/put data
  - Data can be accessed via attributes
  - Mediated interactions between agents via the local tuple space
  - Coordination and various interactions protocols as sequences of accesses to the tuple space
- Access to local resources
  - appears to agents as access to data in the tuple space

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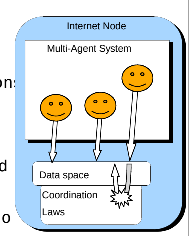
## Programmable Coordination in MARS

- The Tuple space of MARS is fully programmable
  - It can control and influence all interactions
- The data space can embed the coordination laws
  - Ruling, other than enabling, interaction
- Global control on the behavior of the MAS can be enacted
  - Interaction actions can be influenced and constrained
  - Control of self-interested behavior and errors
- Ease of maintenance
  - To change the behavior of the MAS, no need of changing agents, only coordination laws
  - e.g., from English to Vickery auction

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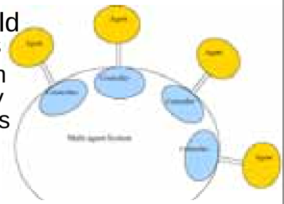
## Example of Coordination Infrastructures: Fishmarket

- Each agents in a MAS
  - Is dynamically attached a controller module
  - In charge of controlling its external actions (i.e., protocol execution)
- Inspired by real-world fish market auctions
  - Fishers participate in auctions by implicitly respecting local rules
  - There is an implicit (institutional) control





## Software Engineering with Coordination Infrastructure (1)

- Clear separation of concerns
  - Intra-agent goals
  - Global MAS goals and global rules of the organizations
  - Such separation of concerns has to reflect in analysis and design
- Example: the ***Gaia methodology version 2***
  - Explicitly tuned to open MAS
  - Implicitly assuming the presence of a coordination infrastructure
    - Identification of global organizational rules as a primary abstraction in the software process



## Software Engineering with Coordination Infrastructure (2)

- Advantages
  - Separation of concerns reduces complexity in analysis and design
    - Inter-agent issues separated from intra-agent ones
  - Design for adaptivity perspective
    - Agents and rules can change independently
  - Intelligence in the infrastructure
    - A trend in the scenario of distributed computing
- Drawbacks
  - Implement both agents and infrastructural programs
  - Agents are no longer the only active components of the systems
    - No longer homogeneous
  - Lack of standardization



## Institutions

- May basic researches in the area of MAS recognize that:
  - Agents do not live and interact in a virgin world
    - Agents live in a society, and as that they have to respect the rules of a society
    - Agents live in an organization, which can effectively executed only in respect of organizational patterns of interactions
- In general: Multiagent systems represent ***institutions***
  - Where agents must conform to a set of expected behavior in their interactions
  - Such an approach requires the introduction of a conceptual coordination infrastructure during analysis and design (as in Gaia v. 2)



## Part 4

- Conclusions and Open Issues



## Open Issues in AOSE

- Engineering MAS for Mobility & Ubiquity
  - What models and methodologies? What infrastructures?
- Emergent Behavior: Dynamic systems & Complexity
  - Relations between MAS and complex systems
  - Exploiting emergence behavior in MAS
- MAS as Social Systems
  - Relations with social networks and social organizations
  - Self-organization
  - Performance models
- Performance models for MAS
  - How to “measure” a MAS
  - In terms of complexity and efficiency?

## Conclusions

- In our humble opinion, agents will become the dominant paradigm in software engineering
  - AOSE abstractions and methodologies apply to a wide range of scenarios
- Several assessed research works already exist
  - Modeling work
  - Methodologies
  - Implementation Tools
- Still, there are a number of fascinating and largely unexplored open research directions…
  - Ubiquity, self-organization, performance….