Multiagent Systems

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Outline

- Multiagent Systems
  - Motivations
  - Multiagent systems vs. Object and Service Systems
  - Applications
- Agent Communication and Coordination
  - Coordination and Communication models
  - Collaboration and Competition
  - Negotiation
- Agent Infrastructures
  - The JADE Infrastructure
  - The TUCSON and MARS Infrastructures
- Conclusions and Open Issues

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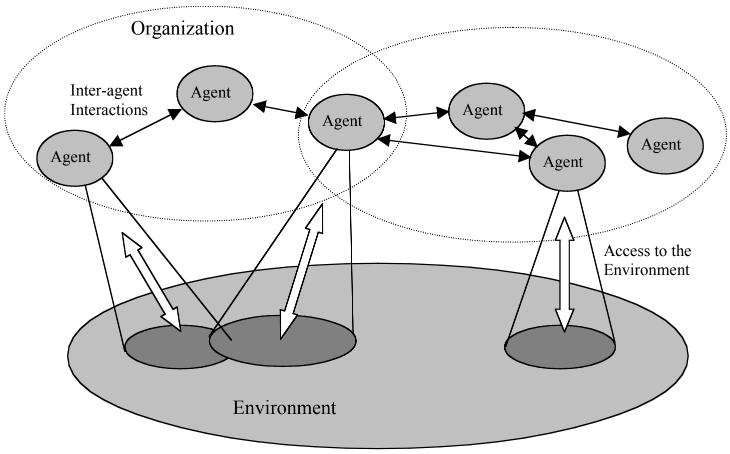
Part 1

- Multiagent Systems

Multiagent Systems

- System or “organizations” of interacting autonomous agents
- Possibly distributed
  - over multiple computers and/or
  - in an environment
- Possibly belonging to different stakeholders or different organization
  - Composite multiagent systems
  - Open applications
- Collaborating and/or Competing
  - Striving at a shared global goal
  - Self-interested agents striving at maximising their own utility
  - According to various topologies of interactiong networks
- Each Interacting with an environment
  - And possibly indirectly interacting with each other via the mediation of the environment

Characterization of a MAS



Why Multiagent Systems? (1)

- A single agent has finite rationality
  - Limit on the amount of knowledge he can rationally handle in a given time
  - Require splitting a decision between more agents
  - E.g., an agent in charge of analyzing a very large search space
- Distribution
  - Several problems are intrinsically distributed
  - Knowledge can be acquired only in loco
  - Require more agents to be allocated where the knowledge can be obtained
  - E.g., agents devoted to the control of physical processes must monitor in loco

Why Multiagent Systems? (2)

- Interactions between personal agents
  - Many problems requires components of different stakeholders/organizations to interact
  - So, the problem is intrinsically composed of multiple agents
  - E.g., an E-commerce site require both the buyer and the seller, which will be represented by two different agents interacting with each other
- Multiagent organizations for real-world organizations
  - Software systems devoted to support the work of some human organization (e.g., a work group or a network enterprise)
  - Should somehow "mimic" the structure of the real-world organization to minimize conceptual mismatch between the real-world and the software organization

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Why Multiagent Systems? (3)

- More in general…
- It is easier to think in terms of "multiagent systems" to solve complex problems rather than in terms of "multi-object" or "service composition" systems…"
  - After all, we live every day in a world which goes on by interactions of autonomous agents (humans), each with limited rationality and interacting with each other to achieve a common goal or a self-interest goal
  - This is how we live at work, with friends, when playing sports…

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Why Multiagent Systems? (4)

- Multiagent systems are "paradigmatic" of modern distributed systems
  - Made up of decentralized autonomous components (sensors, peers, mobile devices, etc.)
  - Interacting with each other in complex way (P2P networks, MANETs, pervasive computing environments)
  - Situated in some environment, computational or physical
- We can this at these are sorts of multiagent systems

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Object and Service Systems vs. Multiagent Systems (1)

- Objects and services are functional entities, agents are goal-oriented entities
  - In a multi-object and service system, objects and services participate by providing functions
  - In a multiagent systems, agent participate by providing the capability of achieving a goal in autonomy
- Objects and services are not autonomous, agents do are
  - The execution of an object or servic is typically subject to a global flow of control (the orchestration scheme, the business plan), determined by the sequence of services invocations
  - The execution of an agent is autonomous, subject to its own internal decision

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Object and Service Systems vs. Multiagent Systems (2)

- Objects are not situated, agents are
  - In object and service systems, “everything is an object”
  - Agents, instead, live in a world of other agents and environmental resources
  - Maps more easily our normal perception of the world
- Objects interact via client-server, agents communicate and coordinate
  - In a object systems, the mean of interaction is service request
  - In service system, complex contractual interactions can be statically determined
  - Agents interact via
    - Exchanging knowledge via communication messages
    - Coordinating their actions (e.g., negotiate the execution of tasks, synchronize on their execution on the access to resources, etc.)
    - And possibly interact via a shared environment

Object and Service Systems vs. Multiagent Systems (3)

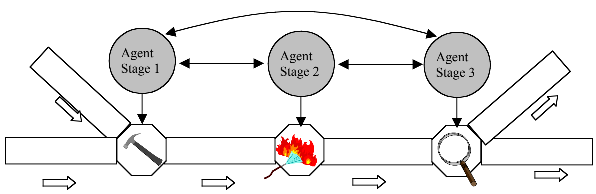
- Objects are mechanical entities
  - The way of interacting in object-based systems resemble that of a mechanical system
  - Actions-reactions
  - Chain effects
  - They manage data and not knowledge
- Services can be a bit more social, but are not autonomous
- Agents are social
  - Autonomously entities that interact not because they are forced to
  - But because this helps either their own selfish goal or a global goal
  - Interactions resemble social interactions…exchange of knowledge, negotiation for actions, competitions for resources..
- Multiagent systems are social systems
  - “Agent organizations” “agent societies”

Applications of Multiagent Systems

- Distributed Control of Physical Processes
- Resource Management
- E-Commerce
- Workflow Management
- Multiagent Simulation
- Optimization

Control of Physical Processes

- Agents embedded in computer-based control systems
  - Devoted to control/asses the working of a specific tool in an autonomous way
  - Agents interact with each other to agree on common global working of a systems
- Example: manufacturing pipeline
  - Various agents devoted to control various stages of the pipeline
  - Interacting so as to ensure it overall works well → COOPERATION!



Control of Physical Processes: Where to Apply

- Industry
  - To control production of goods
    - Daimler Chrysler has already deployed multiagent systems to automate part of its manufacturing process
  - Agent control the allocation of pieces so as to overall optimize efficiency
- Home and Offices
  - To control heating systems or the air-conditioning systems
  - A multiagent system can save a lot of energy
- Traffic Control
  - Agents assigned to semaphores with the aim of maximizing local throughput
  - Depending on traffic conditions, agents can cooperate to each other to maximize global throughput

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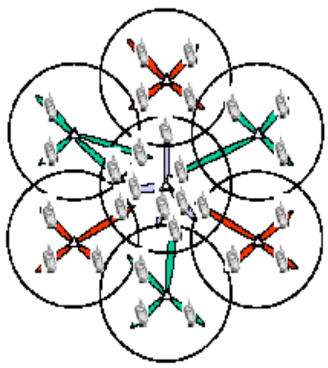
Resource Management

- Each agent devoted to maximize the utility/ exploitation of a specific resource, in autonomy
  - Interacting with each other so as to ensure that the exploitation of the resource ensemble is overall balanced
- Example: allocation of channels in cellular networks
  - Some phone calls can be allocated to multiple cells
  - Cells are controlled by agents which interact with each other to agree on who gets a call
  - Competition and "economic approaches" can be a good solution to get the maximal utility



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Resource Management: Where to Apply

- Cellular Networks (see previous slide)
- Power Grid
  - Agents allocated on each power plant
  - Monitor the production and the consume of electronic power
  - The agents interact with each other so as to ensure that all potential power is exploited
  - Agent limits cooperatively limit overall resource consumption to avoid blackouts
- Computers Grid
  - To distribute computationally intensive applications and task on a network of computers
  - So as to minimize execution time

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E-commerce

- Commercial transactions can be delegated to agents
  - Each belonging to a specific commercial actor
  - In charge of acquiring goods on the network (physical or digital goods)
  - Agents interact with each other to negotiate and eventually to perform the transaction
- Example: e-auctions
  - There is not need for humans to attend auctions (and they do not want to be bored of)
  - The work can be delegated to agents
  - Look for a resource
  - Ask the auctioneer agents
  - Place bids
  - Agents compete with each other

Auctions at the fishmarket (courtesy of Pablo Noriega)

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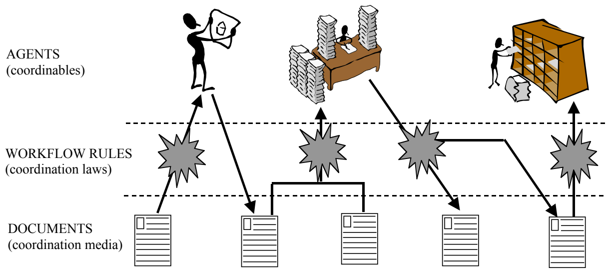
E-Commerce: Where to Apply

- Personal assistant agents
  - Sent to the Internet to buy things on our behalf
- B2B Agents
  - To perform commercial transactions
  - To take care of supply chains management
- A note:
  - Several experiments shows that agents can do better in commercial transactions than humans
  - Can handle more knowledge
  - Can take more rationale decisions

Workflow Management

- Agents acting as avatars of humans in a distributed workflow process
  - Agents control that the overall process proceed according to specified rules
  - Ensuring consistency of the process
- Example:
  - Control the production of a complex multi-author document



Agents for Workflow Management

- Where to apply
  - In humans organization
  - To support complex or decentralized coordination activities
- In temporary coalitions (e.g., dynamic network enterprises)
  - To support effective coordination in the absence of previous experience of coordination
- In scientific research
  - To control and coordinate the execution of complex experiments by distributed research groups

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Simulations

- Analytical (e.g., equation-based) simulations
  - Models the dynamics of a real-world system as a dynamical system
  - Analyze the evolution of the systems as evolution in the phase space
  - Problems: difficult to model the system properly, difficult to analyze its evolution, do not capture enough details,
- Multiagent simulations
  - Models the real-world system in terms of its composing agents
  - Execute the system by having all its components execute in autonomy and interact with each other
  - Advantages: easy to model (agents may have simply behaviors), Easy to analyze ("run and see"), more realistic
- Example: traffic management
  - Do not model the dynamic of flow in a street
  - Models each and every car as an "goal-oriented" autonomous entity

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Simulations: Where to Apply

- Traffic simulations
- Ecosystems simulations
  - Agents are the animals of the ecosystem
  - Looking for food
- Social simulations
  - Panic scenarios (how do people behave when escaping from a stadium?)
  - Economic scenarios (how do an economy behave in specific situations?)
  - Epidemic scenarios (how do an infection propagate based on the behaviour of infected people?)
- Entertainment-oriented simulations
  - Videogames (e.g., Quake Arena)
  - Special effects (e.g., “The Lord of The Ring” movie)

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Optimization

- Instead of the more traditional “Operation Research” analytical approaches
  - Which globally parameterize and model the system
  - And analyze the possible parameter space
- Multiagent optimization
  - Rely on agents analyzing a local solution
  - And interacting with each other to build together a global solution
- Examples:
  - Ant-based agent systems for minimum path selection

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Part 2

- Agent communication and coordination

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Multiagent Interactions: Key Concepts

- Communication
  - Agents exchange information
  - “I have completed my task”
  - “I have the file Millennium.mp3”
  - “Do you have the file Millennium.mp3”
- Synchronization
  - Agent schedule their activities
  - “Wait!” “Go!” “Do not access file Millennium.mp3”
- Agent Coordination
  - Agents orchestrate their activities
  - May include (but not necessarily) exchange of information
  - May include synchronization
  - “I do task T1 and you do task T2 concurrently”
- Interaction Protocol
  - The sequence of event/messages that compose an interactions

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Types of Interactions

- Collaborative
  - Agents cooperate together towards the achievement of some common application goals
  - Agents can trust each other (they tell the truth and they will do what they say)
- Competitive (non collaborative)
  - Agents interact together only to achieve their own interests
  - They do not necessarily tell the truth, and they cannot trust each other
- Collaborative competition
  - Agents compete each other but for the sake of achieving some global goal
  - They trust each other but they exploit sorts of “competitive negotiations” to interact

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Means of Interactions

- What actual forms do agent interactions take
  - Direct: agents directly communicate with each other by exchanging messages
  - Indirect (or stigmergic): agents interact indirectly by accessing
    - Some common information space or
    - The environment in which they situate

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Agent Communication Languages

- A direct way of interactions, with formalized "communication acts"
  - Grounded in sociology and adapted by the artificial intelligence community
- Messages between agents are considered "speech acts" or "performative"
  - What is the scope of the message ("I want to inform you that…" "I request you that…"
  - What is its content ("..that I know where the Millenium.mp3 file is")
- Some people say that an software component can be considered an agent only if it is capable of conversations with agent communication languages
  - I do not agree, too restricted definition!

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Structure of an ACL Message

- Semantically defined standard vocabulary and syntax
  - Agent exchange
  - String-based messages
- An ACL Message
  - Structured message, targeted for flexible communication
  - Performative (INFORM, QUERY, REFUSE, …)
  - Addressing: TO and FROM
  - ConversationID – Used to link messages in same conversation
  - In reply to – Sender uses to help distinguish answers
  - Reply with – Another field to help distinguish answers
  - Reply by – Used to set a time limit on an answer
  - Language – Specifies which language is used in the content
  - Ontology – Specifies which ontology is used in the content
  - Protocol – Specifies the protocol
  - Content – This is the main content of the message

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Agent Communication Example

```
INFORM
:sender antagent
:receiver bob martin
:protocol status
:conversation_id example6
:reply_with  275
:reply_by wed 3pm
:language lisp
:ontology  ant
:content   (target
              (project "1hour")
              (platform "computer15")
              (author      "sean"))
              (time "8/07/01   4pm")
              (message "build failed")
              (target "compile")
           )
```

Primary Intent
Inform, Request, Failure, Refuse, ...

Addressing
broadcast, forwarding, ...

Dialogue Coordination
expected vs exceptional response

Detailed action or request
problem specific
language, ontology, request

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Interaction Protocols

- In general, an interaction protocol is
  - A sequence of messages between agents
  - With determined types of "performatives" exchange with each agents
  - And with determined content
  - Aimed at some form of coordination between agents
- An interaction protocol may also involve multiple agents
- Many types of interaction protocols have been standardised
  - E.g., client-server, contract-net, various types of auctions, etc.
- It is also possible to implement interaction protocols also via indirect interactions
  - In this case, the protocol specifies the sequence of access to the shared dataspace or the shared environment to be performed by agents

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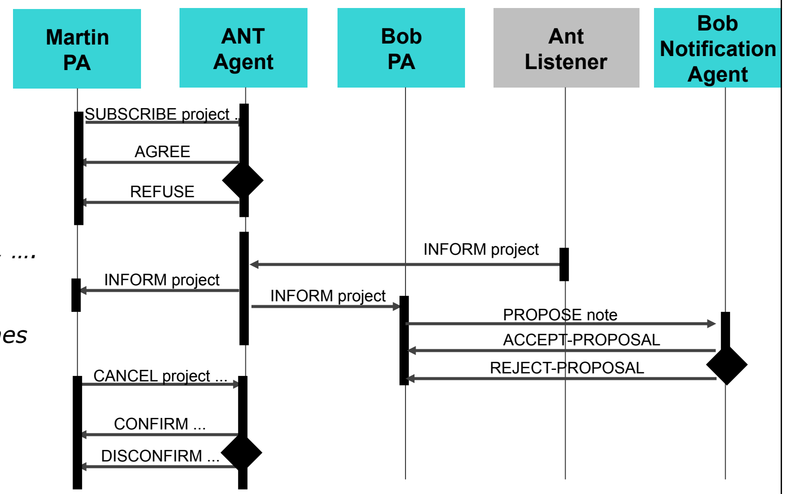
Protocols: Allowed Message Patterns



Standards
contract-net, auctions, planning, negotiation, management, ….

Tools
State Machines
Workflow
UML

Models
Meetings
Organizations
Context

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The Ontology Problem

- How can agents understand each other?
  - In a closed world, the programmer knows what knowledge terms (variables, data, string) means
  - And can build its agents accordingly
- In an open world, where agents developed by different stakeholders have to interact with each other
  - How can they understand with each other?
  - The meaning of the terms must be the same for all agents
- Agents have to rely on shared common “ontologies”, i.e., common perception of the world

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Ontologies

- An ontology is an
  - *"explicit formal specification of how to represent the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them"*
- In other words, an ontology for a software world is a set of "terms", each intended to represent a specific concept, put in specific types of relations with each other
  - For software agents (as well as for the Web) an common ontology represents a common ground with which to share common knowledge in an understandable way
  - And with which to reasons together about the "things" and the "fact" of their world
- RDF and the various XML specifications are simply ways to define Web ontologies for specific domaing
  - Multiagent systems can similarly define shared ontologies for, e.g., electronic commerce

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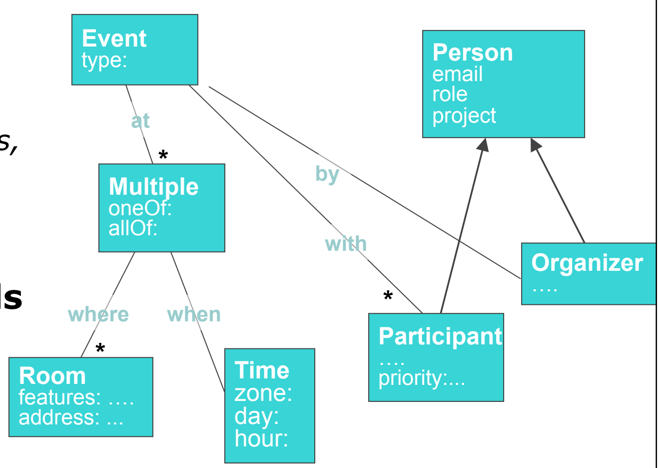
Ontology: Terms & Relationships

Standards
Shopping, Events, Travel, People, Organizations, Roles, Context, …

Tools & Models
UML, XML, AUML, DAML, OIL, RDF, Protégé, …



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Negotiation Protocols

- Many types of interaction protocols are "common sense" also for non-agent applications
  - Client-server, simple exchange of information, synchronization commands
- However, agent autonomy and sociality enables agents to be able to "negotiate" with each other during execution
  - Negotiation protocols are of primary importance in multiagent systems
  - And find a variety of important applications in modern scenarios

Multiagent Negotiation

- "Negotiation is an economically-inspired form of distributed decision making where two or more partners jointly search a space of possible solutions to reach a common consensus" P. Maes
- Negotiation is a sort of dynamic agreement between two or more agents on how to act
- Competitive negotiation
  - Each agents tries to get the best for its own local utility
  - E.g., agents competing for a good on an Internet auction
- Non Competitive negotiation
  - Each agents cooperate to maximize the global utility
  - E.g., agents negotiate for resource allocation so as to maximize the overall resource exploitation

Why Multiagent Negotiation?

- Agents typically have goals to achieve in a dynamic environment
  - Do not have a priori encoded solutions to deal with
  - The most appropriate action must be dynamically evaluated
  - And must be agreed with other agents
- Economics and Game Theory tell us that
  - Good equilibrium solutions can be reached based on negotiation
  - Both in the case of competitive and non-competitive interactions

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Elements of Multiagent Negotiation

- A Negotiation between agents usually imply
  - A Protocol
    - The “rules of the game”
    - Determining how (with which sequence of messages) agents can participate in the negotiation
  - A Strategy
    - Each agent evaluates internally how to act, in accord to the rules, and based on its own goals

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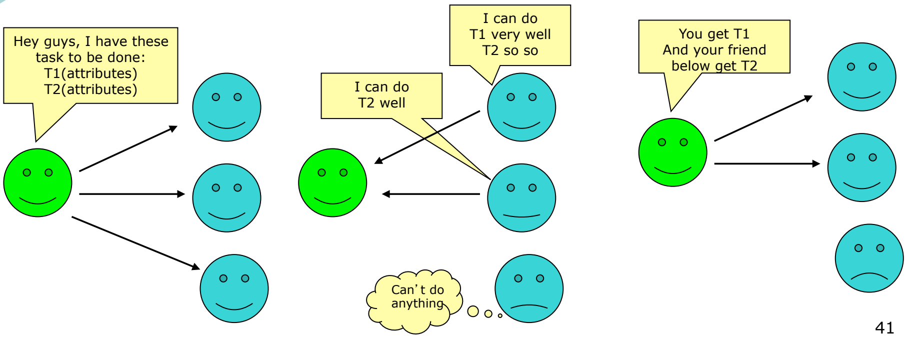
Cooperative Multiagent Negotiation: The Contract Net Protocol

- Useful to allocate in a satisfactory (sub-optimal) ways tasks in a complex multiagent system
- Cooperative:
  - It assumes that agents are willing to cooperate and are sincere
- Contract
  - The two agents reach a sort of agreement which correspond to a sort of contract



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Cooperative Multiagent Negotiation: The Contract Net

- The Contract Net
  - A "Manager" agent has a set of sub-task to allocate to other agents
  - It inform all other agents about these tasks (type of task, description, specific requirements, deadline, etc)
  - And ask all other agents to "bid" for that
- Prospective contractors
  - Place a bid specifying how they would be able to do that works (in what time, with what efficiency and accuracy)
  - For instance, an agent that would be able to do a task but it is already in charge of other task will make a weak bid
- For each task, the manager
  - Assign the task to the best bidder ("Sign the contract")
  - And possibly repeat this until all tasks are assigned
- Clearly
  - All agents can possibly act as Manager or Bidders
  - There could be multiple chains of contracts
  - An agent could be a manager for a task and a bidder for other task

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Applications of the Contract Net

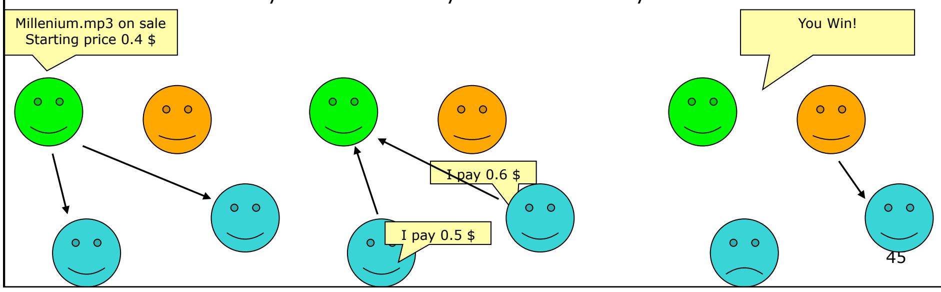
- Task and Service Allocation in General
  - Cellular networks:
    - if a cell is saturated by phone calls,
    - it may ask neighbor cells to bid for tasks such as data transfers, normal phone calls, video calls, etc.
    - Similar considerations apply to IP networks
  - Manufacturing Process
    - A stage in the process which process items and then has to pass the items to the next state in the pipeline
    - when multiple machines can perform the next state
    - The contract net always select the best machines
    - E.g., consider the example of a set of car painting machines. The bid can be based on the currently loaded color and on the cost of changing the color cartdridge
  - In Supply Chains
    - to determine the better contractor to supply a service or a good

Non Cooperative Multiagent Negotiation: Auctions

- Agents compete to access a “good”
  - A task, a digital resource, an information, or a physical artifact
- Valuable for their own interests
  - They need it to maximize their own utility
  - They can “pay” to get it
- They engage in an auction

The Actors of an Auction

- The seller (or the sellers)
  - Make a good available for sale
  - Wants to get the maximum possible price
- The Buyers (“Bidder”)
  - Place “bids” on the good to buy it (“Hey, I pay 10 dollars!”)
  - Try to get the good at the lowest price
- The Auctioneer
  - Control the execution of the auction
  - Enact the rules and check cheaters
  - Decide who wins
  - May not be necessary in collaborative systems



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Types of Auctions

- English auction “ascending price”
  - The one we all know…
  - Start with the lowest acceptable price
  - Reach a price which is nearly (but never) the maximum anyone is willing to pay
- Dutch auction “descending price”
  - Starts with an excessive price
  - Lower the price monotonically
  - The first who bid wins
  - Can get higher prices than the English
- American auction (“first sealed bid”)
  - Secret bid
  - The highest wins
  - The value of the bid is usually the price of the highest bid
- Fishmarket auction (Double auction with multiple sellers)
  - The bidders increments the price
  - The sellers decrement the price
  - Eventually, a buyer and a sellers agree on a common price which satisfy both

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Applications of Auctions

- In Electronic commerce
  - A very effective way to establish the right prices for things
  - We humans do not want to participate in such a boring process
  - But agents can be delegated of that!
- In resource management systems
  - By assigning virtual “prices” to resources
  - Economic laws tell us that nice balancing in resource exploitations will be reached

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Combinatorial Auctions

- The agents wants to bid for a specific combination of goods/resources
  - Flight + Hotel + Theatre Tickets
  - A communication path across multiple carriers
  - Air traffic control
- In these cases:
  - The Bidder should carefully evaluate its bid (economic theories)
  - The Auctioneer should reserve a whole bunch of goods for individual bids, or it can propose alternative combinations

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Combinatorial Auctions in Traffic Management (2)

- Do we really need redlights in intersections?
  - Little adaptivity
  - Low efficiency
- Even if there is no room to install a roundabout, some seems to be able to get rid of redlights

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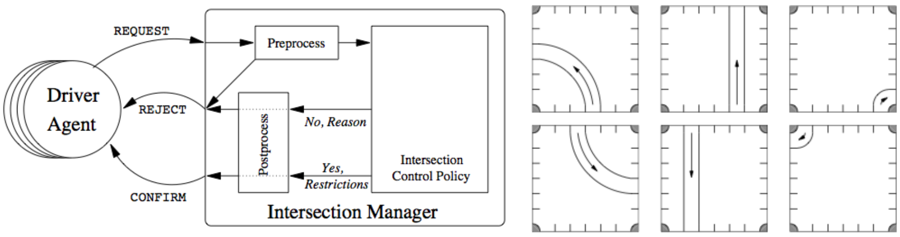
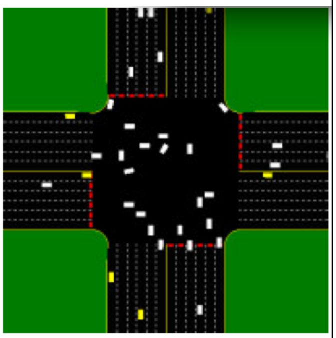
Combinatorial Auctions in Traffic Management (2)

- If we see a intersection like a resource
  - We could have vehicles "bid" to reserve the intersection
  - And an agent on the crossing to act as auctioneer
- However
  - A single vehicle do not need the whole intersection
  - But only those sections needed to safely cross
  - So let's consider the intersection a composite resource



Combinatorial Auctions in Traffic Management (3)

- Eventually (P. Stone, Univ. Texas, 2008)
  - We can obtain dramatic efficienc
  - Reduce queues
  - Increase safety



- Related Applications
  - Air traffic control (it is being adopted!)
  - Schedule of composite hospital services

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Other Negotiation Protocols

- Matrix Games and Prisoner Dilemma
  - Agents decide the best action to take on the basis of a personal revenue that may depend of other agents' behaviors
  - The system will reach the "Nash Equilibrium"
- Nature-inspired
  - Relying on the fact that the evolution of simple interactions in the system will eventually lead to stable satisfactory equilibria
  - E.g., "diffusion-inspired" models for resource management
- Tete-à-Tete
  - Whatever type of "discussion" two agents may engage in to negotiate the what to do…
  - E.g., "You have three task and I have one, let's share them!"

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Indirect Agent Interactions

- Two agents may indirectly interact
  - By accessing a common shared dataspace
    - E.g. a shared “knowledge blackboard” or a “tuple space”
  - By accessing a common shared environment
    - E.g., a physical environment or a computational environment

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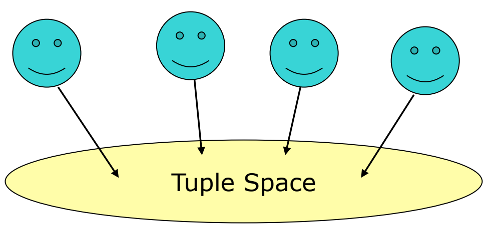
Tuple Spaces

- Shared containers “bags” of tuples
  - Data structures with multiple fields
  - In Java agent systems, tuples spaces can be containers of objects
- Agent typically get a reference to a tuple space (via a Discovery service of the middleware) and
  - Put tuples in the tuple space
  - Read or extract tuples from it



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The Tuple Space Model

- Primitives to put, read, extract tuples
  write(int 7, char 'f', float 2.78);
  read(int a?, char c?, float 3.14);
  take(int 7, char 'f', float)

- Associative access to tuples: "**pattern matching**" of tuples with a provided **template tuple** (a tuple with some non-defined fields), e.g.:
  the template tuple ***(int i?, char 'f', float 2.78)*** *matches with the tuple* ***(int 7, char 'f', float 2.78)***

- Associative access is a sort of attribute-based access
  - One specify the structure and some attributed of the data it is interested in
  - The tuple space get the tuple with the matching attributed and return it to the requesting agents

- It is also a **coordination** model
  - synchronization over tuple occurrence in the tuple repositories
  - an input operation blocks if no match occurs)

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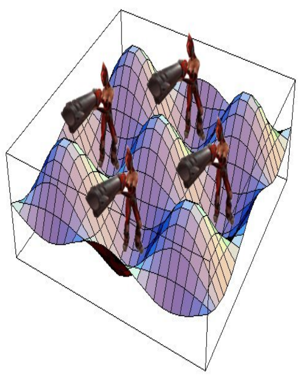
Pheromone and Field-based Interactions

- Agents interact indirectly with each other by
  - Spreading sort of "gravitational" fields or "chemical pheromones" in the environment
  - Physical (e.g., a room) or computational (e.g., a network)
  - And being influenced in their behavior by the local "concentration" or by the "gradient" of fields or pheromones in the environment



- Will get back to this in detail later on in the course…

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Part 3

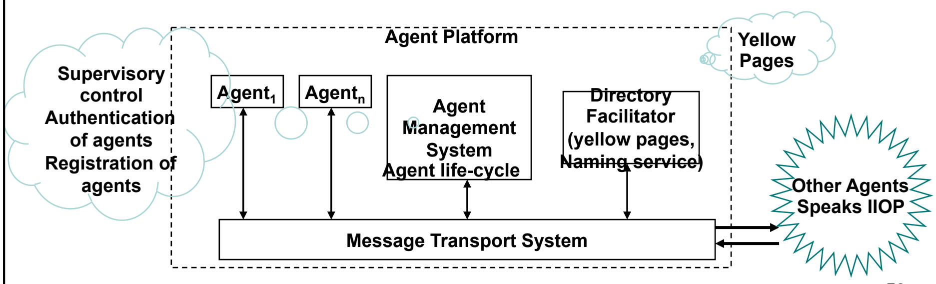
- Agent Infrastructures
  - The JADE and the MARS examples

Agent Infrastructures

- The Overall ensemble of software components (e.g., the software framework) needed to develop, deploy, execute, agents and multiagent applications
- The **"Agent Middleware"**
  - Various types of services provided
  - Various types of interaction models and protocols supported
- In its basic, do not different to much from SOA middleware
- Various types of infrastructures for various types of applications
  - **Simulation**: e.g., Unreal Tournament Softbots for Videogaming, Jack Agents as used to implement ogres in "The Lord of the Ring" movie
  - Java Agent for **Mobile Systems** (e.g., the Aglet agent system) and **Web-based Systems** (e.g., the JADE system + J2EE)
  - **Control of physical processes**. Light weight agent systems for embedded computers.
  - **Complex data management**. Intelligence knowledge-oriented agents for complex data management (e.g., the RETSINA multiagent infrastructure)

FIPA Specifications

- 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)



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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 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

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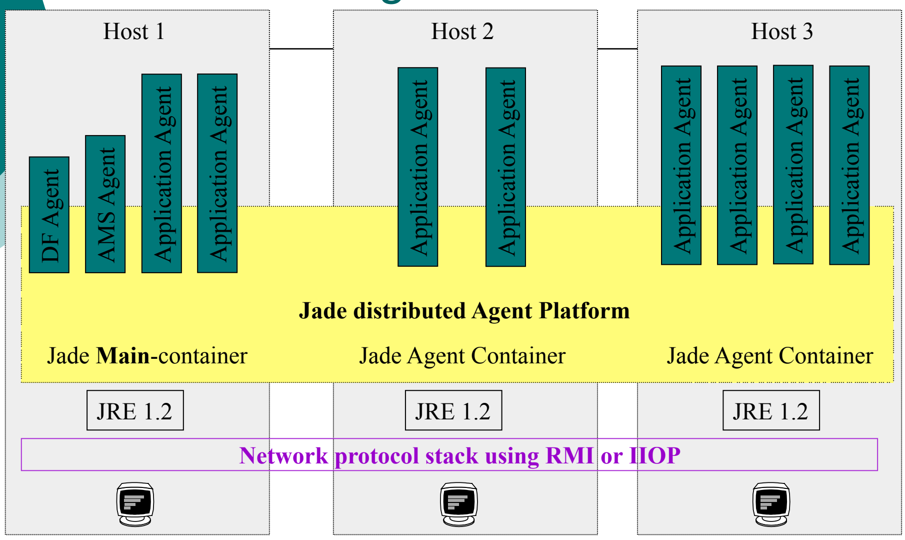
Distributed architecture of a JADE Agent Platform



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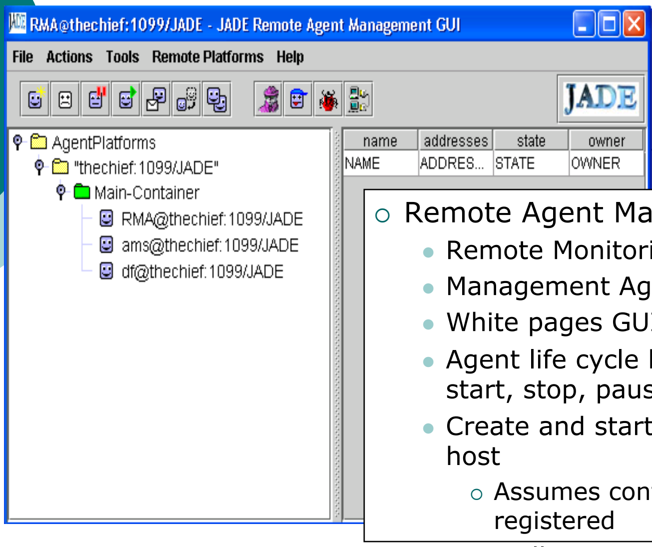
JADE Agent Platform - GUI



- 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

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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

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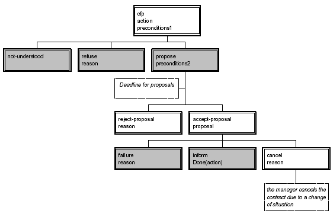
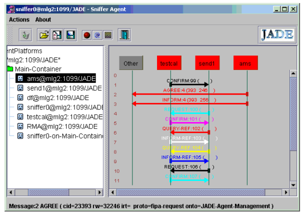
JADE Interaction Protocols

- 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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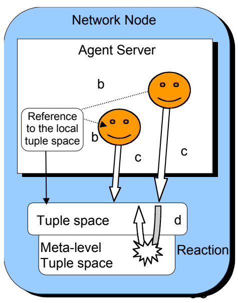
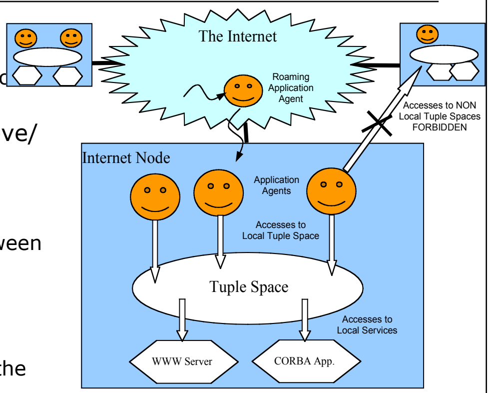
The MARS Infrastructure

- Mobile Agent Reactive Spaces
  - Developed at the University of Modena e Reggio Emilia
  - Ported on different agent systems (*Aglets*, *Java2Go*, *SOMA, JADE*)
- One shared data space on each node
- **"Tuple spaces"**
  - Attributed-based access to local resources
- Programmable tuple spaces
  - A "meta-level" can control and monitor all agent interactions



MARS Features

- Mobile agents roam the Internet
  - On each node, they connect 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



Part 4

- Related and Open Issues

Related Issues (1)

- Agent-oriented Software Engineering
  - The discipline of building multiagent systems
- How can we face the process of
  - Starting from a problem
  - Identifying the agents that must be involved
  - Their interactions and negotiation
  - Their interactions with the environment
  - The overall architecture of the system
- It is a matter of exploiting
  - Methodologies
  - Guidelines
  - Tools

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Related Issues (2)

- Multiagent systems and complex systems
  - Can multiagent systems lead to complex emergent behaviors?
  - YES! → cellular automata, ant-systems, etc.
- Complex vs. Simple Agents
  - We can conceive systems with many simple reactive agents, leading to collective intelligence, and relying on system adaptivity
  - As well as systems with few complex – "very intelligent" – agents
- Multiagent systems and social networks
  - How systems of autonomous entities network with each other?
  - What is the structure of social networks?
- Multiagent systems and natural systems
  - Multiagent systems as a metaphor for naturally inspired systems
  - Useful to solve several classes of problems
- Naturally inspired interaction models
  - Can nature give us source of inspiration for other types of interactions models
  - Suitable to solve complex application problems?

- We will analyze next in the course…

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Open Issues

- So many open issues…
  - Security and Trust
  - Monitoring of Distributed Agent Systems
  - CASE and Programming Tools for building Multiagent systems
  - Novel simple infrastructures for Multiagent systems
  - Evolving multiagent systems
- It's a very active research area…