Coordination Technologies for Internet Agents

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Part 1: Outline

- Features of Internet agents
- Interactions in Internet agent applications
- The role of ACLs and CORBA
- Survey of several interaction models
  - direct interaction
  - meetings
  - blackboards
  - tuple spaces
- Impact in case study application

Internet Applications

- The Internet no longer used as a simple
  - communication infrastructure OR
  - information repository
- The Internet as a *global distributed computing system*
  - traditional distributed applications executed at a world-wide scale
  - new application areas
- Communication, computation and data management intertwined in several application areas
  - E-commerce
  - Information Retrieval
  - CSCW

Internet Agents

- Autonomous (*task-oriented*)
  - execute in *autonomy* to achieve a *goal*
- Network-aware (*location-aware*)
  - conscious about the *distribution* of the environment
- Mobile
  - can proactively roam through Internet sites (changing their *execution environment*)
  - mobile devices can be abstracted as mobile Internet agents
- Interactive
  - inter-agent interactions
  - agent-environment interactions

Autonomy

- Process-based and Object-based applications
  - global goal achieved via a *global control scheme* for the application entities
  - design by *delegation of control*
- Agent-based applications
  - sub-goals assigned to autonomous agents which try to achieve in autonomy their own goal
  - design by *delegation of responsibility*
- In the Internet autonomy is necessary since
  - global control at a world-wide scale cannot be implemented
  - unpredictability requires dynamic decisions
  - efficiency and reliability encourage decentralization

Network-Awareness

- Traditional approaches to distributed programming enforces transparency
  - abstraction of a single virtual computing system
- In the Internet it is unfeasible
  - to hide physical distribution
  - to build/abstract a single global virtual machine, due to decentralized management
- Network-awareness
  - application components are aware of a multiplicity of computing resources distributed over the network

Mobility

- In traditional distributed system
  - mobility managed by the run-time support transparently to applications
- In Internet applications
  - application components can migrate across computing environments
- Motivation
  - save of bandwidth (local access to data and services)
  - robustness (independency from connection flaws)
  - models mobile users and mobile devices
  - manageable abstraction makes application design simpler

Interactivity

- Multiagent systems (MAS)
  - a multiplicity of agents interact to achieve a common goal
  - inter-agent and agent-environment interactions
  - individual and social tasks towards the global MAS task
- Users
  - users might want to interact with agents (with MAS)
- External entities
  - foreign agents
  - Web services
  - CORBA applications
  - legacy systems

Enabling Interaction

- Agents must *interoperate* despite
  - heterogeneity of
    - source
    - representation of the domain
    - architecture, language, technology
    - attitude, BDI, knowledge
  - unpredictability of behaviour due to
    - pro-activity (agents can say “do”)
    - autonomy (agents can say “no”)
    - mobility (agents can say “go”)
- SW infrastructures to enable interaction
  - Middleware

Middleware

- quite a generic term …
  - protocols and SW for open, distributed, heterogeneous architectures (ISO-OSI layer 7)
  - examples: interapplication protocols, scripting languages, document-oriented frameworks, …
- ensuring global features of the interaction space
  - interoperability
  - security
  - transactionality
  - …

CORBA

- Common Object Request Broker Architecture
  - ORB
  - Distributed CORBA Object
  - Interface Definition Language
    - Interface Repository
  - CORBA services
    - Security, Transactions, Persistency, …
- Benefits
  - network transparency, self-describing system, static/dynamic method invocation, embedded security and transactions, separation between interface and implementation (legacy), …

Enabling Communication

- Agents exchange information
  - Enabling interaction is not enough
  - Communication is interaction *plus* information
- Communication issues
  - communication *language*
    - syntax, semantics, ontology
  - communication *acts* (speech acts)
    - performatives
- Agent Communication Languages (*ACL*)
- Mediators, Ontologies

Agent Communication Languages

- Speech-act languages
  - KQML *vs.* FIPA
- KQML
  - tenth of performatives + communication language (KIF, SQL, …)
  - Virtual Knowledge Base for beliefs and goals
  - pragmatics
- FIPA
  - 6 performatives + performative composition
  - formal semantics (from Arcol)
  - strong requirements on agents
- *Conversational* model for agent interaction

Enabling Mobility

- Infrastructures for mobile agent support
- Modelling/enabling the interaction between an agent and an execution environment
  - trusting/entering/living in/leaving an environment
- Examples of systems
  - Ara, Aglets, Ambit, D'Agent, ffMain, MOLE, PageSpace, Mars, SOMA, TuCSoN, …
  - different interaction issues addressed
- We focus on *systems*

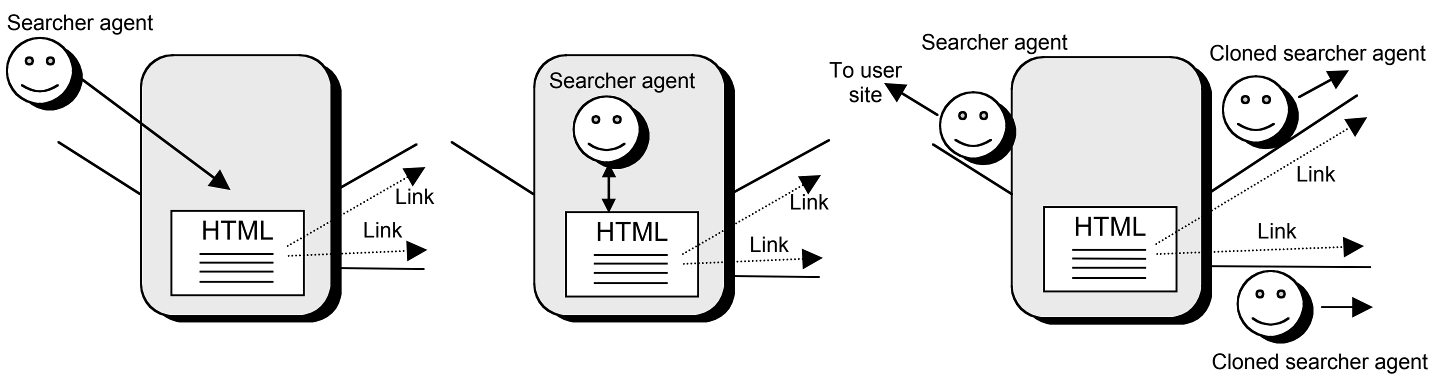
Interaction Models: a Taxonomy

- Temporal uncoupling
  - no activity synchronization
  - no time co-presence
- Spatial/Name uncoupling
  - no mutual knowledge (*e.g.* name identifier)

Spatial \ Temporal	Coupled	Uncoupled
Coupled	Direct *Aglets* *D'Agents*	Blackboard-Based *Ambit* *ffMain*
Uncoupled	Meeting-Oriented *Ara* *MOLE*	Linda-like *PageSpace* *TuCSoN* *MARS*

Case Study: Distributed Information Retrieval

- Agents reach remote sites to access and analyze HTML pages
- Cloning to follow remote links (possibly interesting) ⇨ dynamic tree of mobile agents
- After a visit, agents come back with the URLs of interests (*e.g.* matching a keyword)



Interaction in the Case Study

- With the local execution environment:
  – retrieve info on local HTML files
- Facts:
  – require access control
  – heterogeneity of execution environments
- Inter-agent
  – avoid duplicated visits on the same sites (due to cross-references in HTML pages)
- Facts
  – agents are dynamically created
  – cannot foresee their number and location

Case Study: Sample Code in Aglets *(simplified)*

```
Public class ExplorerAgent extends Aglet {
boolean _clone = false;      boolean visited = false;      String keyword = null;
URL destination = null;      URL home_URL = "atp://my.site" Vector new_destinations;
….
public void onCreation(Object args) {
    destination = (URL)((Object[]) args)[0]; keyword = (String)((Object[]) args)[1];
    dispatch(destination);}
….
public void run()
{   // CHECKS IF ALREADY VISITED:        INTER-AGENT COORDINATION
    if(visited) dispatch(home_URL);  // the agent has nothing to do on this site
    // RETRIEVES LOCAL HTML FILES:       AGENT-ENVIRONMENT COORDINATION
    // search for the keyword in the HTML files and for other interesting sites
    // for instance, is a Vector of references to HTML files has been retrieved:
            If (HTMLFiles.search_keyword(keyword)) …..
            new_destinations = this.extractUniqueURLs(HTMLFiles); …..
    // create clones and send them to the computed destinations
    for(int i=0; i < destinations.size(); i++)   {
            clone();
            if(_clone) // the  _clone variable can be set to true in the OnClone() method
                    dispacth((URL)new_destinations.elementAt(i);} // goes to a new destination
    dispatch(home_URL); // the original agent comes back home
}
```

Direct Interaction Models

- Peer-to-peer agent communication (message-passing)
- Client-server access to services (RPC, RMI)
- Systems: most of Java-agent systems (*Aglets*, *D'Agents*, …)
- Spatial coupling
  - entities have to know each other to interact
- Temporal coupling
  - synchronization of the activities during interaction

Direct Interaction: Pro & Cons

- Advantages
  - well-known and understood model
  - several tools available
  - sometimes very efficient
- Drawbacks
  - how to deal with agent unpredictability
    - e.g.: mobility (tracing, forwarding, only-once messages, performances)
  - how to deal with security
    - agent exchange message without mediation
  - how to scale up communication protocols & patterns
    - combinatorial explosion of communication channels

Case Study: Direct Interaction

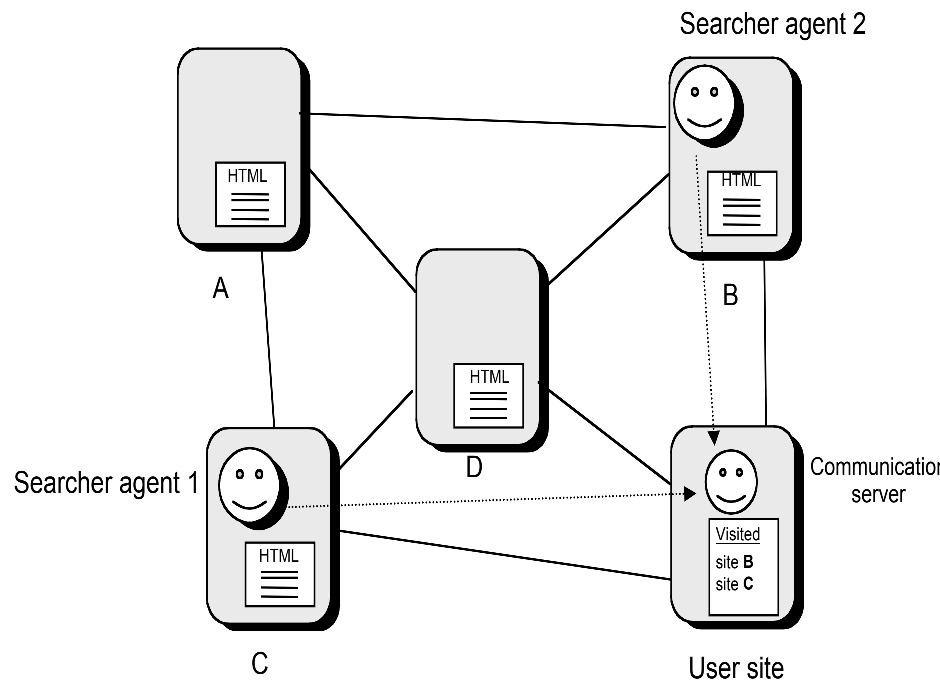
- Avoiding multiple visits
  - agents cannot communicate directly with each other easily
    - who they are?
    - where they are?
- Access to local resources via a WWW server
  - should the agent explicitly navigates to all local links to retrieve all HTML files?
  - complex solution!

```
URL starting_point = new URL (“www.starting.site”);
Vector other_local_HTML_files = recursively_parse(starting_point);
// the code of the recursively_parse method may be rather complex and time
consuming….
```

Case Study : Direct Interaction Design

- Application-level definition of a specialized communication server
  - agents ask to it about previous visits to a site

```
Message msg = new Message(my_id, today, local_URL);
AgletProxy com_ser = getAgletContext.getAgletProxy(URL,
                                                    com_ser_id);

visited = com_ser.sendMessage(msg);
```



- Drawbacks
  - centralisation
  - unreliability

Meetings

- "*Agora*" for agent interactions
- meetings are opened by application agents (always-open meetings abstract the role of services)
- an agent can join a meeting and there communicate with other entities in the meeting
- Systems: *Telescript*, *Ara*, *MOLE* (to some extent)
- Spatial uncoupling
  - only meeting point must be known to enable interactions
- Temporal coupling
  - agents must be on the same place at the same time to interact

Meetings: Pro & Cons

- Advantages
  - locally constrained meetings lead to predictable performances in interactions
  - meetings mediate all interactions and achieve good application-level control over them
- Drawbacks
  - limitation of the agents’ autonomy
  - who, where and when to open meeting points for an application?

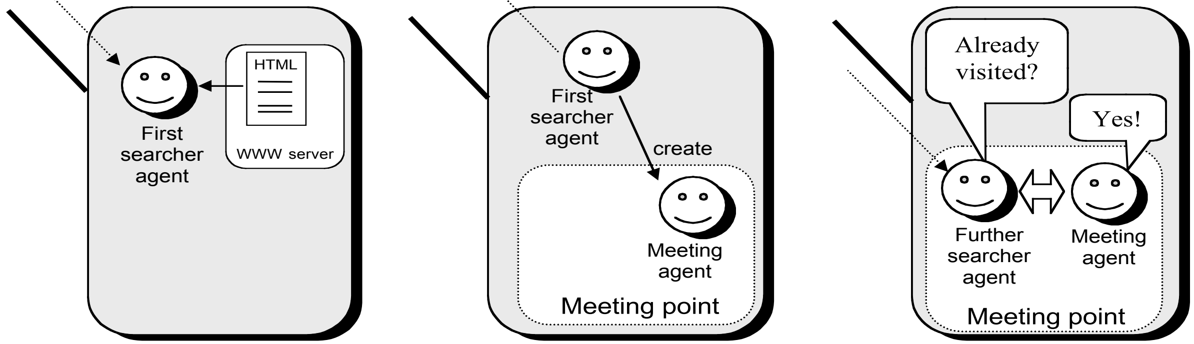
Case Study: Meetings

- Avoiding multiple visits
  - Other agents must explicitly open meeting point to get notified of already visited sites
  - Where to create meeting point?
    - one site: centralisation
    - selected given sites: requires agent knowledge
    - all visited sites: spamming of meetings
- Access to local data
  - An always-open meeting on a site can abstract a local WWW service

Case Study: Meeting Design

- The first agent on a node creates a meeting point
- Further agents arriving on that site will enter the meeting point and will get notified of a previous visit
- Advantages
  - fully decentralised
- Drawbacks
  - security and garbage collection of meetings

```
//aglet-like code for meetings
Message msg = new Message(my_id, today);
meet_ag =context.Meet(meeting_agent_id);
if(meet_ag == null)
{  meet = context.createMeeting(meeting_classURL,
                                meeting_agent_id);
   meet.StoreMessage(msg);     }
else   visited = meet_ag.sendMessage(my_id, today);
```



Blackboard-based Interaction

- Each node/domain of nodes should provide for a shared information space to be used by agents to store and retrieve information
- Wherever agents are, they can exploit the blackboard to communicate with other application agents
- Systems: *ffMAIN* (http-based), *Ambit* (file-based)
- Temporal uncoupling
  - messages can be left on and retrieved from blackboards at any time
- Spatial coupling:
  - requires agreement on message identifiers (e.g., URLs in ffMAIN, filenames in Ambit)

Blackboards: Pros & Cons

- Advantages
  - temporal uncoupling make it easier for agent to communicate while preserving their autonomy
  - security (all interactions can be monitored by the blackboard)

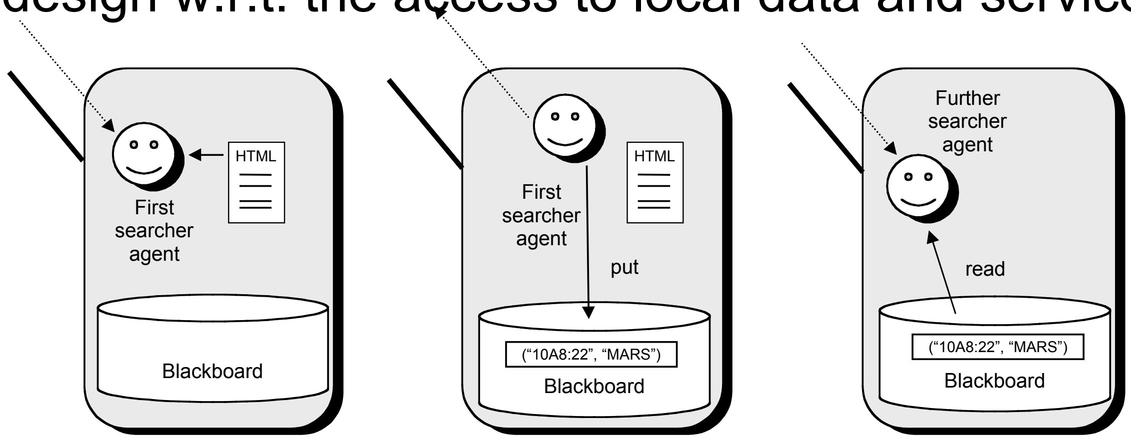
- Drawbacks
  - spatial coupling increases application complexity due to a priori agreements on message identifier
  - complex interaction protocols may be difficult to implement
  - requires a specific infrastructure for the Internet

Case Study: Blackboards

- Avoiding multiple visits
  - the blackboard can be used as a mailbox
- Access to local data
  - A blackboard can publish data about its public files and information on locally available services
  - Requires a standard way to identify information
  - How can agents selectively retrieve HTML files only?

Case Study: Blackboard-based Design

- Agents get/put messages to avoid multiple visits
- Agents access the local blackboard to discover the presence of HTML pages in the site
- Advantages
  - simple design w.r.t. inter-agent coordination
- Drawbacks
  - complex design w.r.t. the access to local data and services



Tuple Space Interaction

- Each node/domain of nodes should provide for a tuple space to be used by agents to store and retrieve tuples via a Linda-like interface
- Wherever agents are, they can exploit the local tuple space to communicate with other application agents
- Systems: *JavaSpaces, T Spaces, PageSpace, MARS, TuCSoN, Lime*
- Temporal uncoupling
  - as in the blackboard case
- Spatial coupling
  - associative access to tuples does not require strong a priori agreements or knowledge

Tuple Spaces: Pros & Cons

- Advantages
  - full uncoupling suits both mobility of application components and uncertainty of the Internet environments
  - security (inter-agent interactions can be monitored by the blackboard)
  - simplicity of communication primitives

- Drawbacks
  - requires a specific infrastructure for the Internet

Case Study: Tuple Spaces

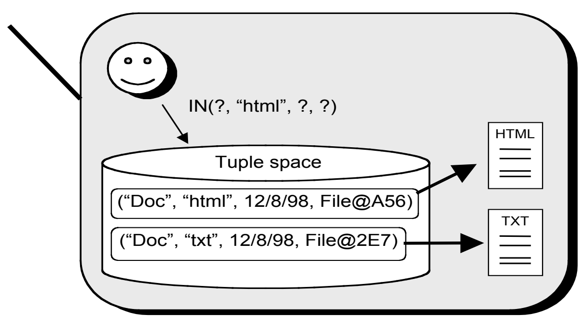
- Avoiding multiple visits
  - agents must check if the tuple space contains tuples left by other agents in a previous visit (similar to the blackboard case)
- Access to local data
  - the tuple space can publish data and information on locally available services
  - associative access eases the retrieval of this information

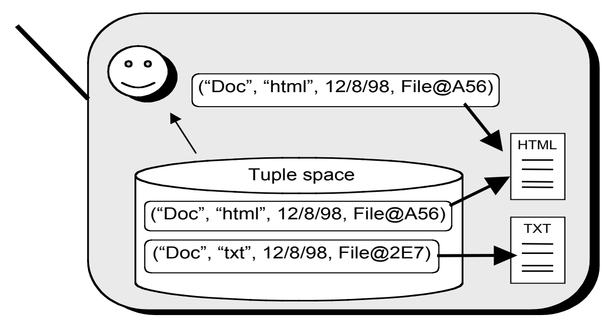
Case Study: Tuple-based Design

- previous visits of other applications agents
- info on all HTML pages via a single requests

```
if(!(visited = inp(my_application_id, when ?))
      out(my_application_it, System.GetTime());



HTMLFiles = read_all("Doc","html",date?,name?);
```

- Advantages
  – security for interactions
  – very simple agent design





Summarizing

- Coupled interaction do not suit Internet agents
  - difficult to directly interact at a world-wide scale
  - odd and complex design choices
- Tuple-based models suitable for the Internet
  - uncoupling suits autonomy, mobility and dynamicity
  - associativity suits uncertainty of the Internet
  - can lead to simpler application design
- Actually, it is a *coordination model*
  - clear separation between interaction and computation
  - clear definition of interaction laws
  - shift from *enabling interaction* to *ruling interactions*

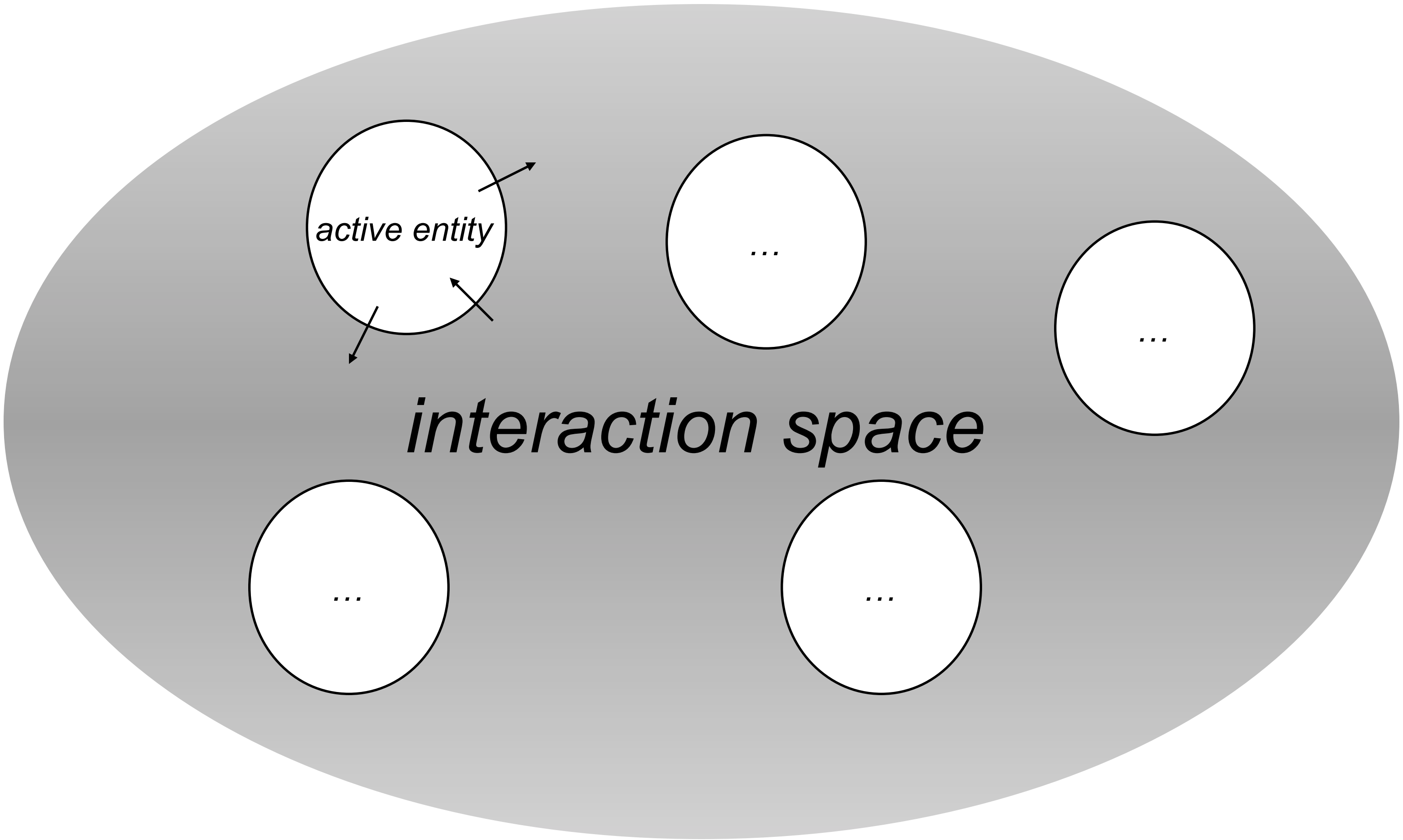
Part 2: Outline

- Coordination Models
  - definitions
  - motivations
  - the software engineering perspective
- Survey of existing systems
  - JavaSpaces
  - Lime
  - MARS
  - PageSpace
  - T Spaces
  - TuCSoN
- Open issues and research directions

What is Coordination?

- “Coordination is managing dependencies between activities” (Malone & Crowston)
  - interdisciplinary issue
- “Coordination is constraining the interaction” (Wegner)“
  - CS viewpoint
- Coordination is the process of building programs by gluing together active pieces” => “A coordination model is the glue that binds together activities into an ensemble” (Carriero & Gelernter)
- “A coordination model provides a framework in which the interaction of active and independent entities … can be expressed” (Ciancarini)
  - how to express interaction

The Interaction Space



What is a Coordination Model?

- A conceptual framework to model the space of interaction
- An ontology for coordination models
  - Coordinables
    - the entities (agents, processes, objects, components, and so on) whose mutual interaction is ruled by the model
  - Coordination media
    - the abstractions enabling and ruling the interaction among the coordinables
  - Coordination laws
    - the rules governing the interaction among coordinables as well as the behaviour of the coordination media
    - communication, coordination, meta-coordination languages

Coordinables

- A coordination model defines
  - what is a coordinable to it
- No interest in the coordinable's inner structure
  - coordination concerns interaction
- Definition *on the boundary*
  - observable behaviour
- *Admissible coordination entity*
  - any entity expressing through the model's communication and coordination languages

Coordination Language

- Acts of communication
  - speech acts
    - convey information
    - change the world
- A coordination model should define
  - both the *syntax*
  - and the *semantics* of the
- *Admissible coordination primitives*
  - semantics expressed in terms of effects on the interaction space
  - input, output, and interaction events

Communication Language

- A communication language
  - conveys information
- A coordination model *may* define
  - the *syntax*
  - but NOT the *semantics*

  of the admissible sentences of the communication language
- Relation with coordination language
  - admissible sentences associated to any admissible primitive

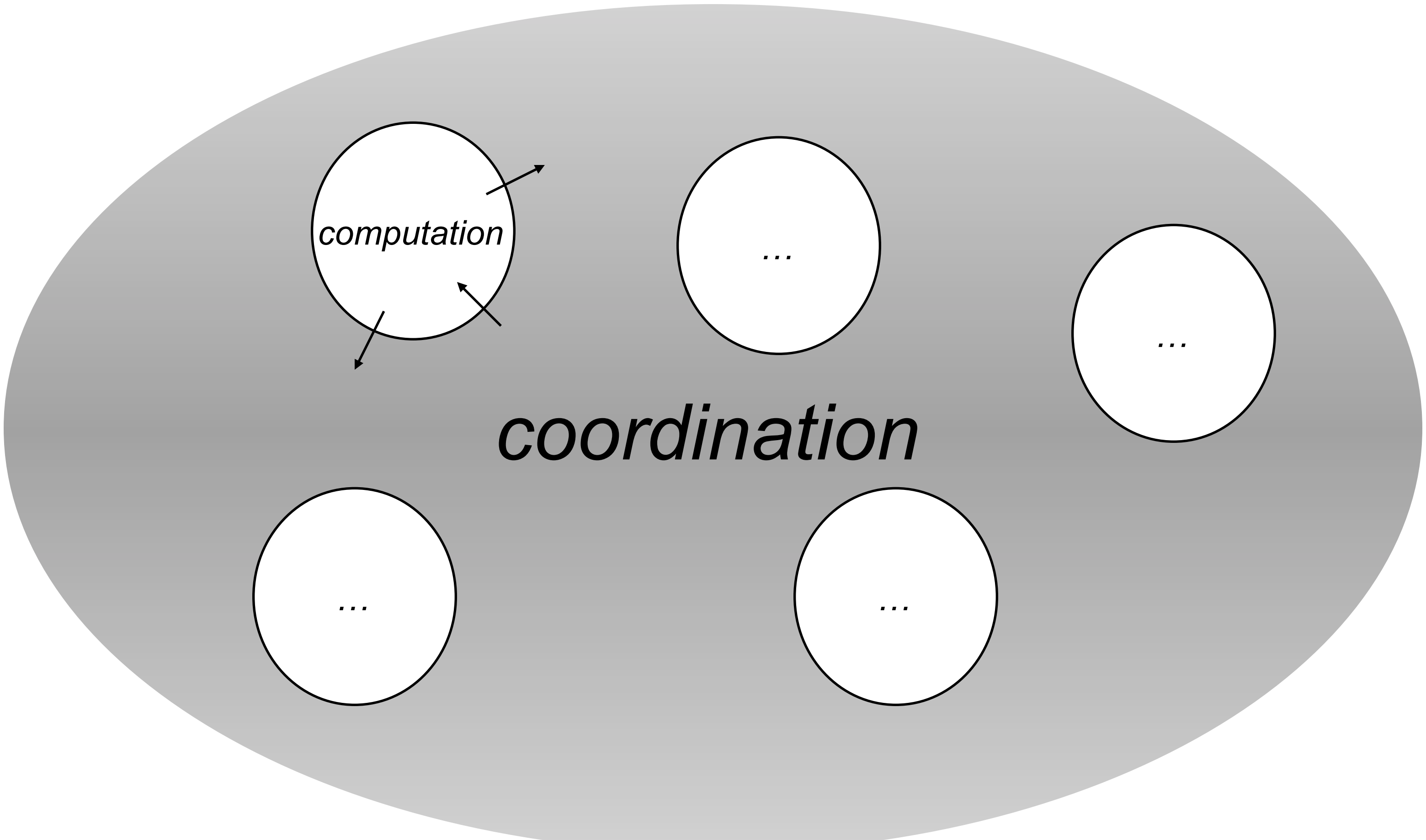
Coordination Media

- Populating the interaction space
  – channels, monitors, connectors, blackboards, …
- A coordination model defines
  – what is a coordination medium to it
- Full definition
  – observable & inner behaviour
  – state transitions
- Given a model, are the coordination media
  – a multiplicity in number/kind?
  – global or local, private or public?
  – physically distributed/centralised?
  – fixed in their behaviour?
  – inspectable?
  – dynamically modifiable?

Coordination Laws

- Rules governing the space of agent interaction
- Defined in terms of
  - communication & coordination languages
- Determined by
  - coordination media behaviour
- Given a model, are the coordination laws
  - completely fixed a-priori by the model?
  - generally fixed but specialisable by need?
  - fully programmable?
  - implicitly/explicitly represented?
  - inspectable?
  - dynamically modifiable?
  - globally/locally affecting the interaction space?
  - physically distributed/centralised?

Coordination: Ruling the Interaction Space



Enabling vs. Ruling Interaction

- ACL, middleware, mediators, …
  - *enabling* interaction/communication
  - *defining* the interaction space
  - agents can interoperate and exchange information to achieve their *individual tasks*
- Coordination models and languages
  - *ruling* interaction/communication
  - *governing* the interaction space
  - agents can be combined in societies pursuing *social tasks* as a whole

Social Tasks

- Agents' task in a MAS
  - individual and social tasks
- Example: conference management system
  - each referee reviews at least ten papers
    - individual: can be defined in terms of a single agent's task
  - each paper is ensured to have at least three reviews
    - social: *cannot* be defined in terms of any single agent's task
- How do we build social tasks? *(I)*
  - typical solution: *ad hoc* meta-level agent
    - inelegant, ineffective
    - an agent, oh, really?
      - do we need it
      - can we do it?
  - a symptom, rather than a solution
    - we have no suitable abstractions

Coordination Models: Engineering the Interaction Space

- Engineering viewpoint
  - how to rule agent societies?
  - how to design and implement collective behaviour?
- Coordination
  - ruling the interaction space
- Agent interaction space
  - space of communication ⇨ space of coordination
- How do we build social tasks? *(II)*
  - exploiting coordination models to shape the space of agent interaction

Why a Coordination Model?

- Engineering the interaction space
  - agent languages and architectures for engineering individual agents
  - coordination models and languages for engineering agent societies
- Need for specific high-level abstractions and powerful mechanisms
  - to support the design and development of multiagent systems as far as interaction is concerned
- Suggesting/supporting new methodologies
  - for the construction of open, distributed, heterogeneous, and mobile systems
- Intrinsically providing systems with features
  - e.g., flexibility, security, support for heterogeneity, intelligence, …

Multiagent System Engineering: the Coordination Viewpoint

- Individual & social tasks
  - driving the design
- Impact on the design
  - individual tasks ⇨ design of single agents
  - social tasks ⇨ design of
    - agent interaction protocols
    - agent interaction rules
- How do we build social tasks? *(III)*
  - defining agent societies
    - around coordination media
  - ruling agent societies so as to make them behave as we require
    - by defining and implementing the suitable coordination laws

Engineered Design

- Defining both individual and social tasks
- Designing individual agents and societies
  - task-oriented design (delegation of *responsibility*)
- Designing individual interaction protocols
  - in terms of
    - communication & coordination languages
  - according to
    - agent’s features (task, domain representation & knowledge, …)
    - agent’s involvement/commitment in societies
- Defining coordination laws
  - in terms of
    - abstractions and tools provided by the coordination model

Computation *vs.* Coordination

- Coordination *languages*
  - “Clean separation between computation and coordination”
  - WOW!!! … so what?!?
- Separation at the *language* level
- Coordination models should provide
  - clean separation between computation and coordination at the *design* level
    - agents should *not* care of coordination details
- Example: conference management system
  - each paper is ensured to have at least three reviews
    - well, it *could* actually be defined in terms of each single agent’s task: every agent should worry about this, and embed a complex verification protocol, negotiate with other agents, *etc.*
    - this would mix coordination and computation issues at the agent design level
  - *coupled design*: bad engineering

Incremental MAS Development

- Coordination media as independent component
  - embedding coordination laws
  - reusable
  - incrementally modifiable
- Example: conference management system
  - each paper is ensured to have at least three reviews
    AND
    at least two referees from two different institutes
    - when computation and coordination issues are mixed in the agent's design (*coupled* design)
      - agents have to be re-designed to embed the new coordination policy
    - when a suitably-powerful coordination model allows coordination laws to be embodied into coordination media (*uncoupled* design)
      - agents are not affected
      - coordination media can be re-defined (possibly *incrementally refined*) so as to embed the new coordination policy

Control-driven vs. Data Driven Coordination

- Control-driven vs. Data-driven (Papadopoulos & Arbab)
  - focus on *communication actions/events*
  - focus on *communication data*
- Control-driven models
  - max. flexibility and control
  - coordination as configuring a communication topology, BUT
  - low level of abstraction
    - not suitable for information-based or high-level symbolic systems
  - require full control of the interaction space
    - not suitable for open & unpredictable systems
- Internet MAS calls for data-driven models

Tuple-based coordination

- Communication based on tuples
  - communication language
    - tuple language T
    - tuple template language TT
    - template function τ: TT $\rightarrow 2^{T}$
  - C-Linda example
    - *("ok",30) $\in$ τ("ok",?i)*
- Tuple repositories as coordination media
  - tuple containers
  - associative access to tuples
  - reactive behaviour
- Coordination by
  - reading, writing, consuming tuples in the tuple repositories
  - synchronising over tuple occurrence in the tuple repositories

Benefits of Tuple-based Coordination

- Generative communication
  - spatial/temporal uncoupling
- Expressive communication abstractions
  - information-based design
- Associative access
  - good for incomplete/dynamic knowledge
- Computation vs. coordination
  - simple protocol design (*perhaps*…)

The Linda Model

- The coordination media
  - (Multiple) tuple spaces
    - globally accessible abstractions
- The coordination language
    - out, rd, in, rdp, inp
    - some notation for addressing a single tuple space at a time
- Relationship with the communication language
    - out(T), rd(TT), in(TT), rdp(TT), inp(TT)
- Limits of the model
  - fixed behaviour of the coordination media
  - limited expressiveness in terms of coordination laws
  - not enough control for Internet applications

Tuple-based Coordination on the Internet

- Definition of the coordinables
  - several entities involved in applications
  - what the coordinables are?
    - Mobile agents, WWW services, CORBA applications, etc.
- Definition of the coordination media
  - how many? Where?
  - how can they refereed and accessed?
- Definition of Coordination and Communication Languages
  - object-oriented, logic, DBMS oriented models….
- Definition of the coordination laws
  - fixed versus programmable

Coordinables in the Internet

- Different solutions possible
- All entities becomes coordinables
  - application agents
  - “agentification” of other entities
    - e.f. interface agents to make a WWW server interact accordingly to the Linda model
- All entities but application agents are reflected in the tuple space
  - the tuple space provides Linda-like access to other applications and services
- The tuple space as an additional Internet service
  - no specific accommodation of other entities w.r.t. the coordination model

Coordination Media in the Internet

- Where are tuple spaces? How agents access them?
- Transparent approach
  - tuple spaces are referred in a location-independent way and in a network-unaware way (e.g. object references)
- Implicit approach
  - tuple spaces associated to each node/domain of nodes
  - tuple spaces are not explicitly referred
  - agent implicitly access the local tuple space
- Explicit approach
  - agents access to tuple spaces in a network-aware way, e.g., via URLs
  - mixes of implicit and explicit approaches are possible

Tuple Space Models and Coordination Languages

- Which tuple space model?
  - classical Linda model (tuples as structured data types)
  - object-oriented tuple space model (tuples as objects and with object fields)
  - logic tuple space model (tuples as logic atoms)
- Which coordination language?
  - basic Linda primitives (in, out, rd, inp, outp)
  - collective operations on tuples (in_all, rd_all …)
  - asynchronous operation (rd_future, notify)

Coordination Laws

- Fixed coordination laws
  - basic pattern-matching (defined fields are primitives data types that, if actual, must have the same value)
  - object-matching (e.g., equality of Java serialised form, tuple sub-classing)
  - unification
- Programmability of the Coordination language
  - primitives overriding (the default behaviour of a primitive can be changed)
  - adding of new primitives
- Programmability of the Coordination media
  - full monitoring of access events (who, what, on which tuple)
  - which behaviour in response to which access event

Tuple-based Coordination: Summary of Systems

	Coordinables	Coordination Media	Coordination Language	Coordination Laws
JavaSpaces	Java Agents	OO referencing	OO (Java) Linda primitives	Fixed (object-matching)
Lime	Abstract mobile components	Implicit access (to agent-own tuple space)	Linda	Fixed (pattern-matching)
MARS	Java mobile agents	Implicit access (to local tuple space)	OO (Java) Linda primitives	Programmable (Java reactions)
PageSpace	Agent + Services	OO referencing	OO (Java) Linda primitives	Fixed (object-matching)
T Spaces	Agent, PDA	OO referencing	Linda + user-defined primitives	Programmable (primitives overriding)
TuCSoN	Heterogeneous (possibly mobile) Internet agents	implicit access (to local tuple space) + URL referencing	Logic-oriented Linda	Programmable (FOL reactions)

JavaSpaces

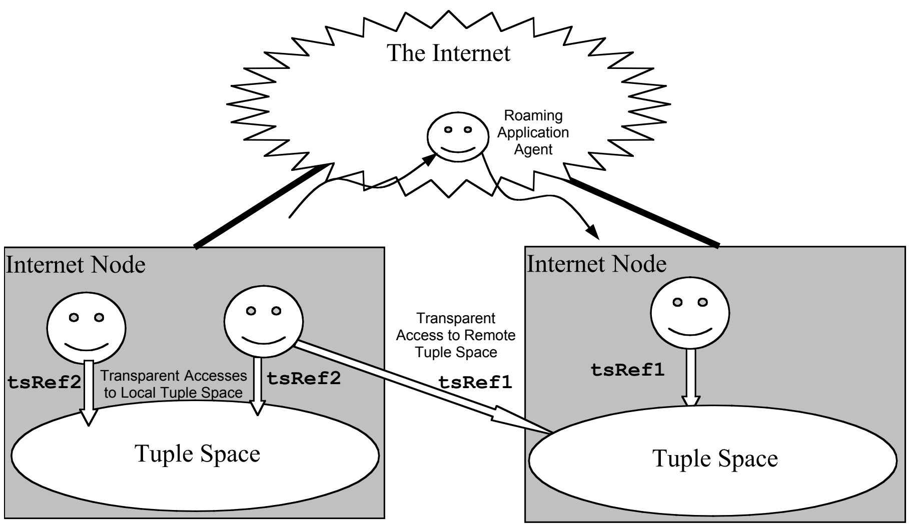
- SUN Microsystems
- Object-oriented tuple space model
- Event notification mechanisms
- Enabling technology for JINI

- Coordinables:
  - not specifically tuned to Internet agents
  - coordinables as generic Java components
  - In JINI, JavaSpaces used for associative access/lookup network data and services by distributed components

JavaSpaces: Coordination Media

- Tuple spaces as Java objects
- Location independence
  - tuple spaces identified and accessed via object-references
  - accesses are network-unaware (no matter where agent is)

- How to retrieve JavaSpaces references?
  - Private application objects
  - Lookup services



JavaSpaces: Coordination Language

- Object-oriented Linda operations
- JavaSpaces interface
  - *`Read (Entry tmp, Tr txn, long lease)`*
  - *`Take (Entry tmp, Tr txn, long lease)`*
  - *`Write (Entry e, Tr txn, long timeout)`*
  - `txn` can specify a transactions (*all-or-nothing* semantics)
  - *`lease`* blocking time for operations
  - *`timeout`* time to live for tuples
- The object tuple *`tmp`*:
  - subclass of *`Entry`*; its instance variable are the tuple fields;

```
SubEntry mytuple = new SubEntry ();
mytuple.field1= O1, mytuple.field2= null, etc…
read(mytuple, null, 0)
```

JavaSpaces: Event Notification

- No programmable coordination laws
  - fixed object-oriented pattern-matching
- Reactive event notification
- Agents can register in a space as interested in a tuple matching a template, and require to be notified about its insertion

  notify(template, null, listener, lease.FOREVER, null)
  - the listener will be sent an event it has to handle when a matching tuple will be inserted in the space
- Can catch a limited set of events!

Case Study: Brief Summary

- Agents visits Internet sites to analyze HTML pages
- Agents clone themselves to follow interesting links

- Avoiding multiple visits
  - use of tuple spaces to store information about previous visits

- Access to local data
  - use tuple spaces to retrieve information on local services, files, and to access to services through the tuple space

Case Study in JavaSpaces

- Inter-agent coordination
  - how can they agree on which space to use for advertise each other of visited sites?
    - single home space? Centralization!
    - distributed spaces? How to look them up?
- When accessing to local resources
  - if there is a local tuple space for local resources
    - the tuple space can be used to access to files
  - otherwise
    - tuple space to be used to look up local services
    - local services accessed in a client-server fashion
- Complex design
  - agents have to explicitly discover tuple spaces and services

JavaSpaces: Sample Code

```
class FileEntry extends AbstractEntry
{ // tuple fields
  public String PathName;  public String Extension;
  public Date ModificationTime; public File ActualFile;

// Tuple constructor. The order of the parameters defines the tuple field order
public FileEntry(String name, String extension, Date modificationTime, File file)
{               PathName = name; Extension = extension;
                ModificationTime = modificationTime; ActualFile = file;      }
}
….
FileEntry FilePattern = new FileEntry(null, “html”, null, null);
// creation of the template tuple
FileEntry HTMLFile = LocalSpace.read(FilePattern, null, NO_WAIT);
// access to the local tuple space referred by the LocalSpace interface
// returns a matching FileEntry tuple, if any
//however, the reference has to be somehow explicitly initialised by the agent

if (HTMLFile != null)     // if a matching tuple is found
                {         // can access the tuple fields
                          String found_name = HTMLFile.PathName;
                          …...
```

T Spaces

- IBM research
- “a network communication buffer with database capabilities”
  - extensible Linda interface
  - a single interface for enabling communication between all entities in a network (middleware)
  - database oriented
- Coordinables
  - all the entities in a network can connect to T Spaces
  - all interactions (e.g., service requests, message-passing, database queries) occur via T Spaces

T Spaces: Coordination Media

- T Spaces servers handles all T Spaces
  - T Spaces lifecycle
  - servers identified via URLs:

```
TupleSpace ts = new
TupleSpace(”newTS",myhost.com)
// ask TS creation to the server on myhost.com
// new TS locally created
```

  - directory service for T Spaces and servers
  - no limits on the number of T Spaces
- For Internet applications:
  - all servers have to maintain information about all other servers in the Internet
  - scalability?

T Spaces: Coordination Language

- Linda-like model and operations

  in/read(int, "Franco", float), out(6,"Andrea",7.3)

- tuple fields are dynamically added to generic tuples

  Tuple t1 = new Tuple()

  t1.add(field1) …

- Collective operations on tuple

  scan, consumingScan, countN

- Database-oriented queries
  - tuple fields can be named and indexed

  Tuple r=ts.scan(new IndexQuery("f",new Integer(8)));

  // return tuples whose field named "f" has value 8

T Spaces: Coordination Laws

- New operations (commands) can be added on a T Space and the behavior of operations can be changed
- Complex management
  - for a *T Space, a TSFactory* can manage several *TSHandler*, each devoted to a new/overridden operation on the space
  - several TSFActory can be stacked for incremental refinement
  - definition and installation of handlers and operations rather complex and verbose
- Event notification
  - all types of event, not only write as in *JavaSpaces*

Case Study in T Spaces

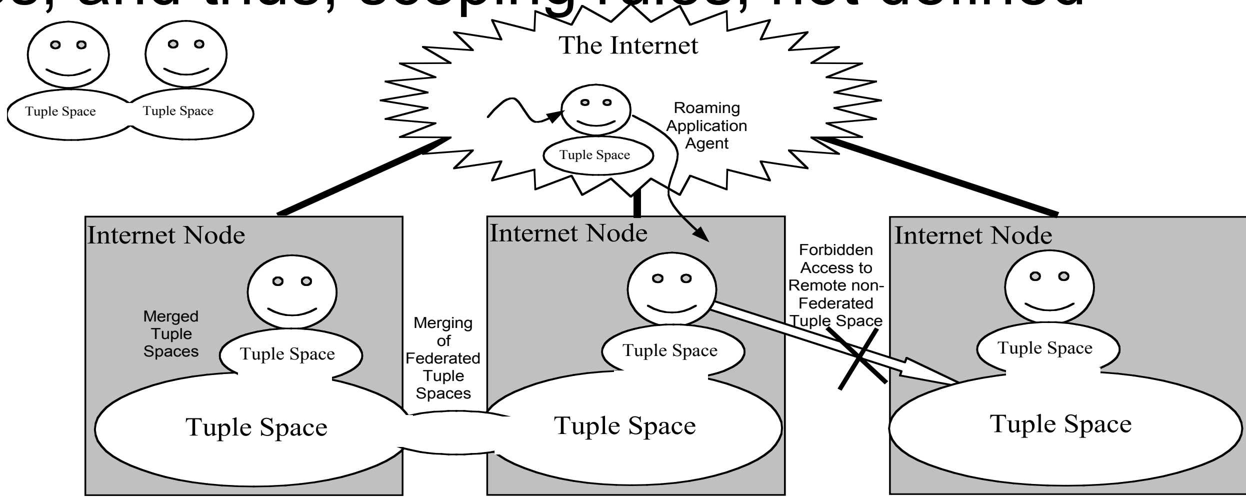
- Inter-agent coordination
  - they can refer to the local T Space server and create a private T Space on the visited nodes to interact
  - they can add handlers on the private T Spaces to handle more complex coordination rules than the simple “avoid multiple visits”
- When accessing to local services
  - a local T Space can host the needed services
  - agents must discover which services (handlers) are available on a local T Space OR
  - they can simply lookup services and then access them

Lime

- Washington University, St. Louis
- currently a model, not an implemented system
- formalised with Mobile UNITY
- Goal
  - unifying interaction model for devices, users, and agents
- Coordinables
  - all mobile entities carry on 1 or several associated tuple spaces
  - host have a local tuple space, possibly federated with other tuple spaces (and becoming a single one)
  - do not assume/require a fixed network infrastructure

Lime: Coordination Media

- Interactions through the local tuple space
- Merging tuple spaces in case of meetings
  - connection in case of mobile devices
  - execution of an agent on a node/federation of nodes
  - only tuple spaces with the same name are shared
- Naming rules, and thus, scoping rules, not defined



Lime: Coordination Language

- Linda-like operations on tuple spaces

  T.in(template), S.out(tuple)

  // T, S names of tuples spaces

  - What would these names be in the Internet?

- Specification of tuple locations:
  - one can specify where a tuple must be located

  T.out[L](tuple)

  // when L merges, the tuple flows to L’s tuple space

  - one can specify from where a tuple must be retrieved

  T.rd[F,T](template)

  // in location F, read tuples whose location is T

Lime: Coordination Laws

- Introduction of a reactive statement

  ```
  S.reactsTo(C,T)
  // execute C when a tuple matching T is found in S
  ```

  – the reactsTo statement register the reaction in S

  – the only event that can trigger a reaction is the introduction of a tuple in the tuple space (i.e., an out operation)

- Reactions can be annotated with locations

  – however, reactions takes place in the local tuple space only

- Weaker reactive mechanism provided

  ```
  T.upon(C,T)
  ```

  – similar to JavaSpaces' notify mechanism

Case Study in Lime

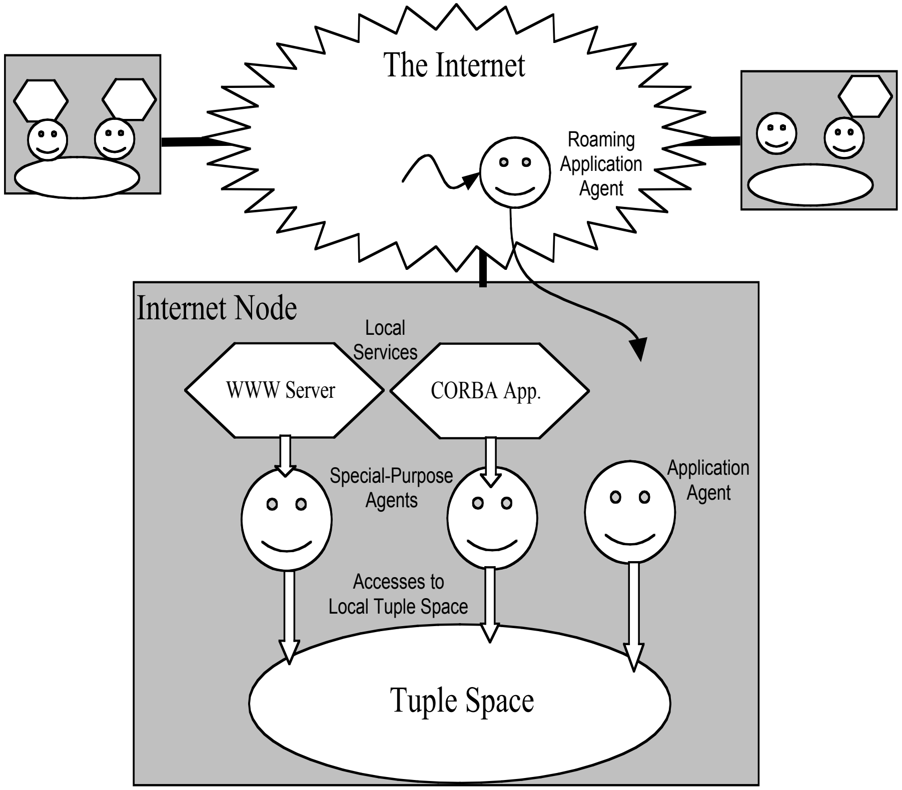
- Inter-agent coordination
  - merging of agent tuple space with the one of the current host
  - possible tuples left by other agents having visited the node flow towards the agent tuple space
  - the agent can check or being notified about this incoming tuples
- Accessing to the resources on a node
  - via the merged tuple space, the agent can interact with a "service agent" on a node, to request services and retrieve results
- Control Problems
  - tuple space merging and tuple locations: global naming?
  - accesses to tuple spaces: global ACLs?

PageSpace

- TU Berlin & University of Bologna
- Tuple-based middleware for coordinating components and agents in the Web scenario
- All the components of the Web scenario are given the possibility of interacting and coordinating
- More structured than T Spaces
  – Definition of different classes of special-purpose agents
  – Reference Architecture for Interactive Web applications

The PageSpace Reference Architecture

- Special-purpose agents with different roles
  - user interface (applet-based) agents
  - homeagents, as persistent representation of users
  - legacy application interface agents
  - control-agents
  - application specific agents



PageSpace: Coordination Media

- First proposal similar to JavaSpaces
  - tuple spaces accessed via object-references in a location unaware fashion
  - no emphasis on mobility and network-awareness
- Evolution
  - global hierarchy of nested tuple spaces
  - global naming of tuple spaces
    space1, space1/space2 ...
  - agents can bind a tuple space reference to a given tuple space:

```
TupleSpace ts = new TupleSpace();
ts.join("Space1/Space2")
```

- Still location unaware

PageSpace: Coordination Language

- The *Jada* coordination language
  - a simple yet effective object-oriented implementation of Linda (similar to JavaSpaces one)
  - Basic Linda operations

    `Tuple t new Tuple("Hello", new Integer(1));`

    `out(t), in(t) read(t)`
  - Additional operation for tuple collections

    `readAll, InAll`

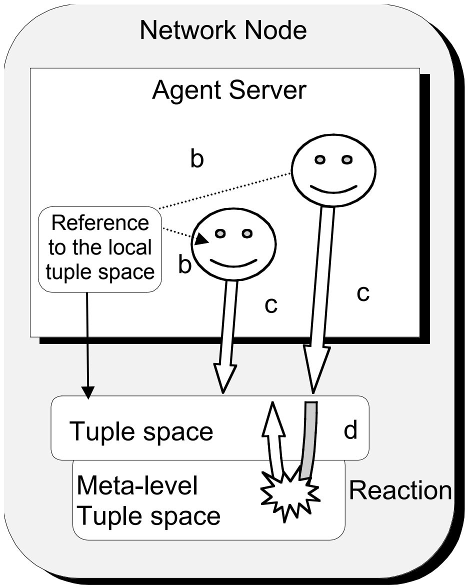
- Coordination laws
  - object-oriented pattern-matching
  - no programmable coordination laws

Case Study in PageSpace

- Inter-agent coordination
  - they can refer to a well-known tuple spaces to avoid multiple visits or
  - can create private tuple spaces on the visited nodes to interact
- When accessing to local services
  - a local tuple space on a node can be used to interact with the needed services on that node
  - agents must discover which services are available on a node and how they have to interact with them

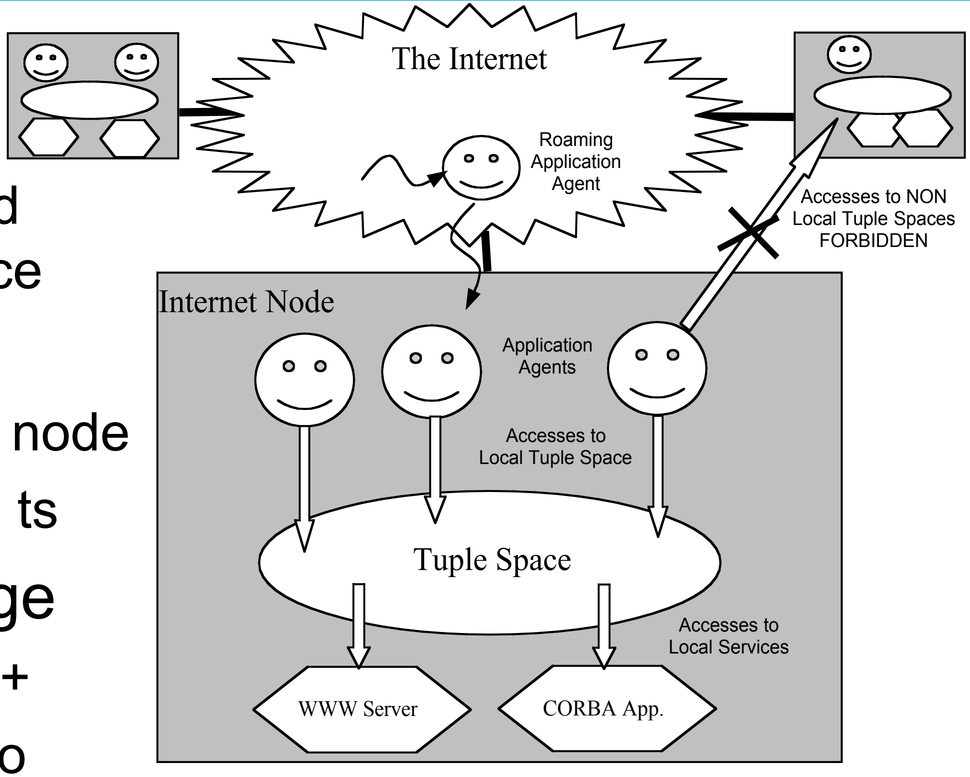
MARS: Mobile Agent Reactive Spaces

- University of Modena, ITALY
- Ported on different agent systems (*Aglets*, *Java2Go*, *SOMA*)
- One tuple space on each node
- Linda-like access to local resources
- Meta-level tuple space for programming tuple space behavior



MARS Features

- Coordinables
  - Java Agents
  - Everything is accessed via the local tuple space
- Coordination media
  - a tuple space on each node
  - implicit access to local ts
- Coordination Language
  - JavaSpaces interface +
  - `readAll`, `takeAll`, to access all matching tuples
- Coordination Laws
  - fully programmable in Java



MARS: Coordination Laws

- Meta-tuples to associate reaction to access events (meta-matching)

  `(Ag-Id, Tuple, OpType, ReactObj)`

- Access the base-level tuple space triggers pattern-matching in the meta-level to look for reactions to execute
- *`ReactObj`*: Java object with a single method (the reaction itself)
- Example

  `(ag@mo.it, null, read, O1)`

  triggers the reaction method of object `O1` when the agent `ag@mo.it` performs a `read` operation

MARS: Security Model

- ACLs on tuples
- Agents associated to *roles*
- *Examples:*
  - reader role: can only read tuples
  - write role: can write and extract tuples
  - manager: can install/deinstall reactions
- Agent-installed reactions
  - affects only those agents of the same applications
- Problem
  - garbage collection of reactions

Case Study in MARS

- Inter-agent coordination
  - automatic binding to the local tuple space
  - the agent can check or being notified for tuples left by other agents to signal a previous visit
  - reactions can monitor agent activities, or collect garbage
- Accessing to the resources on a node
  - associatively retrieve references to HTML files
  - reactions can deal with heterogeneity (e.g. HTM instead of HTML files), deny access to files already accessed by another agent (solving inter-agent coordination)
- Problems
  - garbage collection of reactions

MARS: Sample Code

```
// tuple definition as in JavaSpaces
class FileEntry extends AbstractEntry
{ public String PathName;  public String Extension;
  public Date ModificationTime; public File ActualFile;
  public FileEntry(String name, String extension, Date modificationTime, File file)
  {               PathName = name; Extension = extension;
                  ModificationTime = modificationTime; ActualFile = file;      }   }
….
FileEntry FilePattern = new FileEntry(null, “html”, null, null);
// creation of the template tuple, as in JavaSpaces
Vector HTMLFiles = LocalSpace.readAll(FilePattern, null, NO_WAIT);
// access to the local tuple space. The reference is automatically initialised as the agent
arrives on that node
// returns all matching FileEntry tuple, if any
if (!HTMLFiles.isEmpty())               // if some matching tuples are found
                  { for (int i = 0; i < HTMLFiles.size(); i++)    // for each matching tuple
                  {               FileEntry Hfile = (FileEntry)HTMLFiles.elementAt(i);                //
       Hfile: tuple representing a  single file
                                        if (this.SearchKeyword(keyword, Hfile.ActualFile))
                                                     ……
```

MARS: Examples of Reactions

```
// can be associated to readAll operations on FileEntry templates with HTML extension
//via the meta-level tuple:   (HTML2HTM_instance, (null, “html”, null, null), readAll, null)

class HTML2HTM implements Reactivity
{
public Entry[ ] reaction(Space s, Entry Fe, Operation Op, Identity Id)
// no match already occurred if the site has only htm files
{ Fe.Extension = “htm”;                       // modifies the extension of the required files
  return s.readAll(Fe, null, NO_WAIT);        // read FileEntry tuples with HTM extension
}}
```

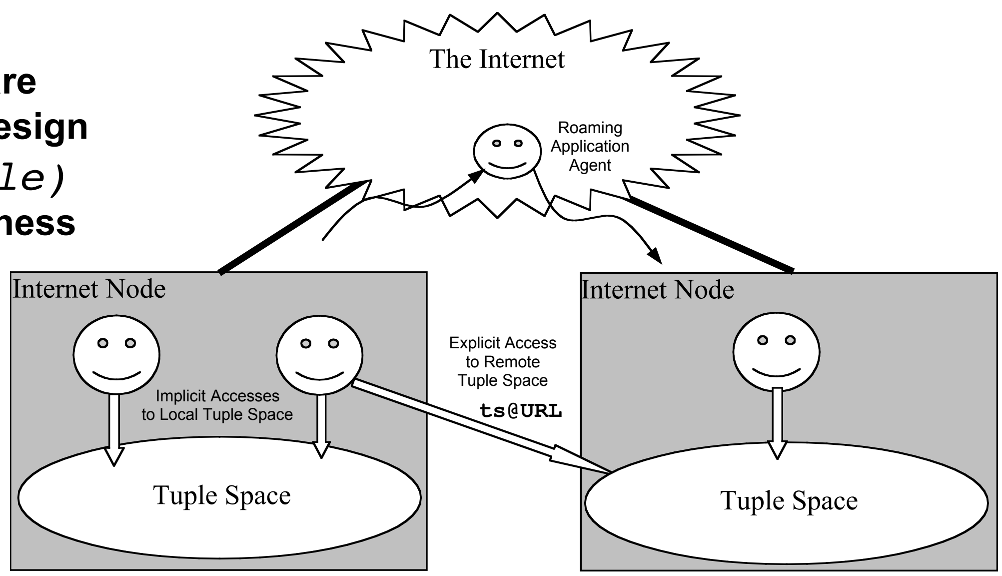
```
// can be associated to take operations via: (TransformTakeObj, null, take, null)

class TransformTake implements Reactivity
{
public Entry reaction(Space s, Entry Fe, Operation Op, Identity Id)
{ if(matched(Fe)) { // if a match has been produced
            if (Id.equals(manager)) // check for the identify of the agent performing the operation
                        return s.take(Fe, null, NO_WAIT);// the tuple is deleted from the spac
            else  {SecurityRegister.add(“takeAll”, Fe, Id);   // log the access
                        return Fe }  // the tuple is returned but it not extracted
else return null;          }            // no match has been produced   }}
```

TuCSoN

- University of Bologna, ITALY
- Implemented in form of a variant model (LuCe)
  - pure Java
  - currently converging to TuCSoN
  - along with coordination technology for a specialised development framework
- Partially formalised
  - ReSpecT tuple centres
  - coordination language
- TuCSoN
  - **Tu**ple **C**entres **S**pread **o**ver **N**etworks
- Multiple local tuple centres as Internet services
  - supporting both network-aware and -unaware coordinables

The TuCSoN Coordination Model

- Multiple Tuple **Centres** in a local coordination space
  - TuCSoN nodes
- Multiple coordination spaces
  - The TuCSoN coordination space: twofold interpretation
    - One global –
    - Multiple local –
  - Local vs. remote interaction
    - *tc?op(tuple)*
      - **network-unaware**
      - **adaptivity by design**
    - *tc@node?op(tuple)*
      - **network-awareness**
- Coordination as an Internet Service



TuCSoN Coordinables and Languages

- Coordinables
  - conceptually, any agent accomplishing the coordination language
  - pragmatically, C, C++, Java, Prolog agents
    - heterogeneity addressed from the very beginning
- Coordination language
  - Linda-like
    - out, in, rd, inp, rdp
- Communication language
  - based on first-order logic
    - uninterpreted symbols
  - logic tuples
    - tuple centres as theories of the communication

TuCSoN Coordination Media

- Tuple centres
- The idea
  - standard tuple space interface
    - **data-driven coordination *(to the agent's perception)***
  - programmable behaviour in response to standard communication events
    - **control-driven coordination *(transparently to agents)***
  - information perception vs. representation
    - **tuple space: ≡**
    - **tuple centre: ≠**
- Programmable behaviour specification
  - through reactions to communication events
  - ReSpecT

ReSpecT

- **Re**action **Spec**ification **T**uples
- First-order Logic Tuples
  - `map(OpName,Event),react(OpName,ReactBody)`
  - `reaction(Operation,ReactBody)`
  - FOL tuples for both communication and coordination
- Tuple Centre composed by
  - Tuple space
  - Specification space
- Execution model
  - reactions as transactions
  - communication events *plus* triggered reactions perceived atomically at the agent level
- Uniform specification protocol
  - `outSpec/1, inSpec/1, rdSpec/1, …`

ReSpecT: Main Predicates

Tuple centre's state access and modification	
`out_(Tuple )`	Succeeds, by putting tuple `Tuple` into the tuple centre
`rd_r(Tuple )`	Succeeds, if a tuple `T` matching `Tuple` is found in the tuple centre, by unifying `T` with `Tuple`; fails otherwise
`in_r(Tuple )`	Succeeds, if a tuple `T` matching `Tuple` is found in the tuple centre, by unifying `T` with `Tuple` and removing `T` from the tuple centre; fails otherwise
`no_r(Tuple )`	Succeeds, if no tuple matching `Tuple` is found in the tuple centre; fails otherwise
Communication event's information access	
`current_tuple(Tuple )`	Succeeds, if `Tuple` matches the tuple involved by the current communication event
`current_agent(Agent)`	Succeeds, if `Agent` matches the identifier of the agent which triggered the current communication event
`current_op(Operation)`	Succeeds, if `Operation` matches the operation which produced the current communication event
`current_tc(Name)`	Succeeds, if `Name` matches the identifier of the tuple centre performing the computation
`Pre`	Succeeds in the pre phase of any operation
`Post`	Succeeds in the post phase of any operation
`Success`	Succeeds in the pre phase of any operation, and in the post phase of any successful operation
`Failure`	Succeeds in the post-phase of any failed operation

TuCSoN: Coordination Laws

- Coordination laws
  - Any computable law into the coordination medium
  - Global rules into global abstraction
    - Coordination policies
    - Mediation services / Ontologies
    - Enforced/refined security policies
  - Global intelligence for a MAS
    - Emerging behaviour
- Coordination laws as (meta-level) tuples
  - Spreading the intelligence of a MAS
  - Self-modifiable MAS

Case Study in TuCSoN

- Access to local resources and inter-agent coordination similar to MARS
- In addition:
  - The agent can access a site from remote (without having to move there) to check if the site has been already visited
  - By using absolute names, the application works even if agents are not mobile
  - The logic model for both tuples and reactions can facilitate the access and the intelligent" analysis of large information sources
- Problems:
  - explicit management of tuple space URLs
  - untyped data

TuCSoN: Reaction Examples

```
% makes a rd of an in on page/3 tuples

reaction(in(page(_,_,_)), ( post,
            current_tuple(page(Name,FileName,Ext)),
            out_r(page(Name,FileName,Ext))
)).
```

```
% safe update of page/3 tuples

reaction(out(update(PageName,OldFileName,NewFileName,OldExt,NewExt)), (
            in_r(update(PageName,OldFileName,NewFileName,OldExt,NewExt)),
            in_r(page(PageName,OldFileName,OldExt)),
            out_r(page(PageName,NewFileName,NewExt))
)).
```

Summarizing: Our Ideal Scenario

- Coordinables
  - all entities must find a place in the coordination architecture –> PageSpace
- Coordination Media
  - location-dependent identification and access to tuple space:
    - MARS, TuCSoN for Internet nodes
    - Lime for mobile users and devices
- Coordination Language
  - Standard interface (JavaSpaces?)
  - Multiple models for tuple spaces: OO (MARS, PageSpace), logic (TuCSoN), DB-oriented (T Spaces)
- Coordination Laws
  - fully programmable (MARS, TuCSoN)

Open Issues

- Security issues
  - Internet asks for secure coordination models
- Economic issue
  - if the Internet will become a global market
- Software engineering tools
  - patterns for Internet-agent composition
- Standardization
  - Java? XML?

Coordination and Security

- Two facets of the same problems
  - Handling security means ruling interactions
  - Coordination means ruling interactions
- Cryptography is simply an enabling mechanism
- Security policies must impose rules on interactions and make them harmless
- A coordination model can help in
  - monitoring of interactions through the coordination media
  - checking for authorisation
  - denying/enabling access to a coordination media
  - denying/enabling access to specific information in a coordination media

Economic Models

- Internet resources no longer for free
  - tragedy of the commons
  - E-commerce of intangible goods
- Models and tools needed for
  - resource control
  - micro-payment
- What about coordination?
  - economic transactions imply interactions
  - can a coordination model support them?
  - what a market-oriented coordination model should be?

Coordination Patterns

- Patterns as high-level abstraction for composition
  - rules for component composition and interaction
- Internet-agent patterns
  - mobility patterns: one-hop, looping, itinerant
  - interaction patterns: master-workers, contract-net, agent trees…
- Problems
  - patterns cannot abstract from the communication infrastructure
    - what kinds of interaction mechanisms are available?
    - what will patterns be if (programmable) tuple spaces are available?

XML Tuple Spaces

- Is Java the right choice for Agents?
  - heavy-weight
  - agent are not self-contained
  - requires programming skills
- XML agents
  - light-weight
  - self-contained
  - require (little more than) document-preparation skills
- XML Interactions?
  - Tuple space models based on XML
  - tuples as XML documents OR
  - XML documents as tuples?

Conclusions

- Advantages of coordination models and architectures for Internet applications:
  - to facilitate an engineered approach to Internet application development
  - to leads to a simple and secure application design
- Several open issues and, of course:
  - need for unifying models and reference architectures
  - need for real-world applications

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