Infrastructures & MAS

Sistemi intelligenti distribuiti LS

Prof. Andrea Omicini

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Outline

- *on the notion of (MAS) infrastructure*
- enabling vs. governing infrastructures
- a model for MAS infrastructure
- trends, experiences & open issues in MAS

Infrastructure as a key notion…

- for complex systems in general
  - not only for computational systems
  - but also in the context of organisational, political, economical and social sciences
- it has a general acceptation…
  - so, better to start from it

General definitions (i)

- (1) the underlying foundation or basic framework (as of a system or organisation); (2) the permanent installations required for military purposes; (3) the system of public works of a country, state, or region; also: the resources (as personnel, buildings, or equipment) required for an activity;

General definitions (ii)

- (4) the basic systems and services, such as transport and power supplies, that a country or organisation uses in order to work effectively
- (5) the basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons.

So, an infrastructure…

- is (part of) the environment that provides basic resources and critical services to complex systems (such as organisations, communities, societies, countries) living on top of it
- an infrastructure is persistent
  - once installed, an infrastructure typically survives the many systems it supports.
- remark the key role of infrastructures
  - their services typically cover critical system issues, and provide features that individual system components could not afford to provide or obtain elsewhere

MAS Infrastructure

- sources of complexity in a MAS…
  - components
    - agents
  - component interplay
    - agent societies
    - agent environment
- … a key role for infrastructure for MASs

MAS definitions (i)

- … a technical and social substrate that stabilises and rapidly enables instrumental (domain-centric, intentional) activity in a given domain... (solving) typical, costly, commonly accepted community (technical) problems in a systematic and appropriate ways
- infrastructure as a social, enabling support for providing MAS with cheap & systematic solutions to shared problems

MAS definitions (ii)

- Agents in a MAS are expected to coordinate by exchanging services and information, to be able to follow complex negotiation protocols, to agree on commitments and to perform other socially complex operations. We define the infrastructure of a MAS as the set of services, conventions, and knowledge that support such complex interactions.
- infrastructure as a support for complex agent (social) interplay, expressed in terms of services, convention and knowledge

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Infrastructure & environment

- infrastructures model the agent environment from a twofold viewpoint
- the agents' viewpoint
  - ideally, agents access the environment through expressive runtime abstractions, possibly provided as services by the infrastructure
- the engineers' viewpoint
  - infrastructures as the most suitable place where to embed elements of control (constraints, coordination laws, norms) for open, unpredictable systems

Keeping abstractions alive

- MAS engineering process as a continuum
  - from design down to development and deployment
- abstractions used at design time should not disappear
  - otherwise, practises for complex systems such as incremental design & development, runtime verification, and on-line engineering, are doomed to fail
- design abstractions should instead be provided at runtime by suitable infrastructures
  - along with suitable tools

Infrastructures & methodologies

- being sorts of invariants, so much impacting over MAS engineering, infrastructures implicitly promote ad hoc methodologies
  - or, viceversa, methodologies tend to suggest / shape the "form" of the infrastructure
- it is not by chance that MAS infrastructures are today often first choice with respect to AOSE methods
  - see the JADE case

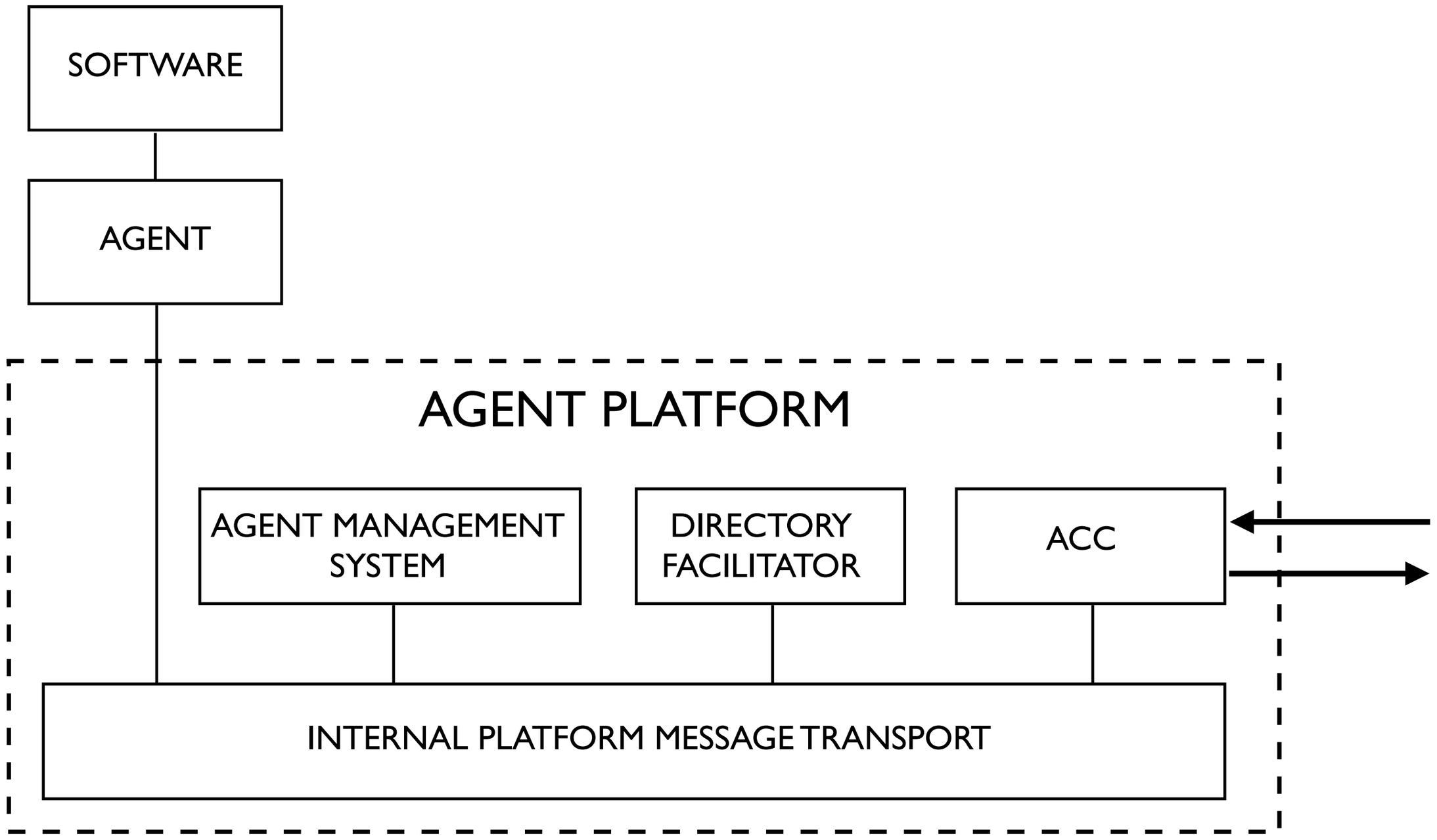
Interaction

- an infrastructure model
  - defines the component (observable) model
  - shapes the space of component interaction
- at their basic level
  - infrastructure are enabling component's interaction
    - providing abstractions and technologies to make it possible interaction among components

Examples: JADE & RETSINA

- JADE & RETSINA satisfy the necessary pre-conditions to allow agents to live, co-exist and interact within a MAS
  - through services as agent communication, inter-operation, security, naming, location, etc.
- enabling infrastructures define the space of (agent) interaction
  - first of all, by making such a space exist

JADE / FIPA reference model



RETSINA functional levels

RETSINA MAS INFRASTRUCTURE

MAS INTEROPERATION SERVICES	RETSINA-OOA Interoperator
CAPABILITY TO AGENT MAPPING SERVICES	Matchmaker
NAME TO LOCATION MAPPING SERVICES	ANS
SECURITY SERVICES	Certificate Authority Cryptographic Service
PERFORMANCE SERVICES	Failure Monitoring
MAS MANAGEMENT SERVICES	Logger Activity Visualiser Launcher
ACL INFRASTRUCTURE	Public Ontology Protocol Servers
COMMUNICATION INFRASTRUCTURE	Discovery Message Transfer

INDIVIDUAL AGENT INFRASTRUCTURE IN RETSINA

CAPABILITY TO AGENT MAPPING	Matchmaker Module
NAME TO LOCATION MAPPING	ANS Module
SECURITY SERVICES	Security Modele Public/private keys
PERFORMANCE SERVICES	Self Monitoring Cloning
MAS MANAGEMENT SERVICES	Logging and Visualisation Components
ACL INFRASTRUCTURE	ACL Parser Private Ontology Protocol Engine
COMMUNICATION MODULES	Discovery Component RETSINA Communicator

OPERATING ENVIRONMENT

Machines, OS, Network
Multicast, Trasport Layer (TCP/IP, Wireless, Infrared, SSL)

Enabling is not enough

- not only enabling infrastructures
  - E-Institutions (Noriega, Sierra), Logic-based-institutions (Vasconcelos), and the likes
  - TEAMCORE (Tambe et al.)
- in fact, enabling is not enough
  - what if we need to enforce some behaviour / interaction pattern / interaction history?
- in general, how can engineers super-impose laws that rule the behaviour of a multiplicity of autonomous agents
  - either as individuals and as a group?

Governing MAS interaction

- through the infrastructure – why?
  - "third party" with respect to agents
  - conceptually, the natural locus for MAS laws & norms
- one infrastructure, many MASs
  - economy of scale
- one model, many issues
  - conceptual integrity
- abstractions + tools => methodology
  - covering the whole engineering process
- environment invariant
  - to face complexity

Governing infrastructures

- a governing infrastructure
  - provides expressive, flexible and comprehensive abstractions to model and shape the space of component interaction
- examples
  - e-Institutions
  - coordination as a service (Viroli & Omicini)
  - RBAC infrastructure (Sandhu et al.)
- the same trend from enabling to governing infrastructures also emerges in fields other than MAS
  - CSCW (Schmidt & Simone)
  - workflow management

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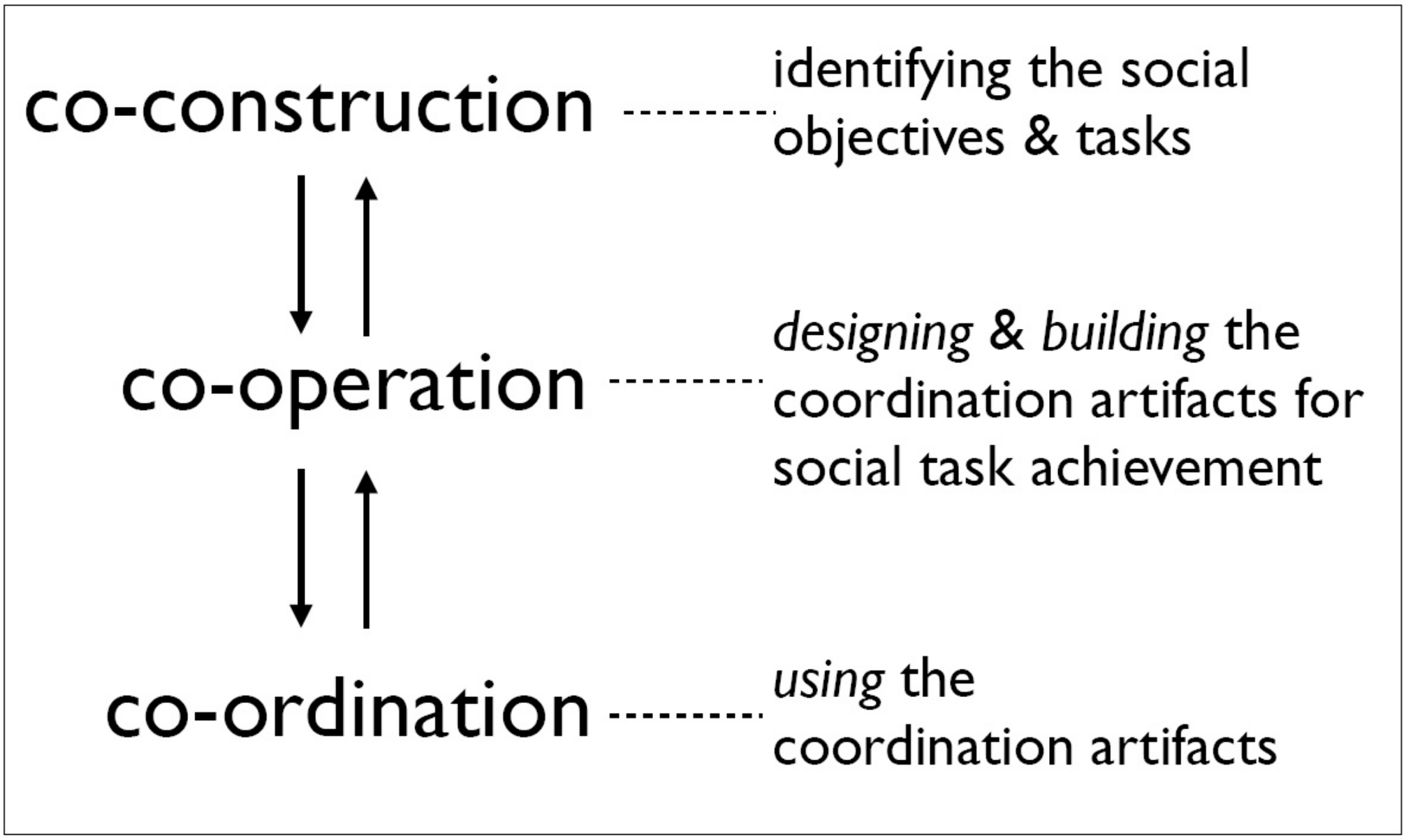
Activity Theory

- a social psychological theory about the dynamics in collective human work activity (from 1920 to Leontjev 1978, Vygotskij 1978)
- focus on human activities
- notion of artefact central to AT
  - mediator for any interaction in human activities
  - either physical
    - phone, cards, sheets, …
  - or cognitive
    - operating procedures, heuristics, language, …
- activities are performed through artefacts

Artefacts

- an artefact embodies a set of social practise
  - its design reflects a history of aims and uses
- as a mediating tool, an artefact has both an enabling and a constraining function
  - it expands the capabilities to manipulate and transform objects, and to interact in general
  - its very structure and possible behaviour impose a model and a practise

Collaborative activities in AT



Viewpoints over MAS infrastructure

- agent's viewpoint
  - artefacts can be used (co-ordination) in the day-by-day activity to achieve "normal" goals
  - artefacts can be designed and built (co-operation) in order to allow / improve goal achievement, or to adaptively respond to change
- engineer's viewpoint
  - artefacts are designed, developed and deployed to enable / constrain autonomous agent behaviours, and govern agent interaction (at the co-ordination level)
  - artefacts can be re-designed and modified at runtime to improve system's behaviour, or to respond to change (at the co-operation level)

AT as a model for MAS infrastructure

- infrastructures should provide MAS with artefacts to enable collaborative activities
  - and possibly allow for the three levels of co-ordination, co-operation, co-construction
- at the co-ordination level
  - enabling / governing agent interaction through artefacts
  - providing engineers with the abstractions
    - to drive the engineering process
- at the co-operation level
  - providing agents & engineers with the tools
    - to achieve the required level of observation over MAS interaction
    - to re-engineer artefacts at runtime

Desirable artefact's features

- inspectability
  - for both human & agents
- efficiency / specificity
  - specialised in the interaction management
- predictability
  - toward formal verification in complex systems
- malleability
  - to be forged dynamically
  - toward adaptability and self-organisation
- NOTES
  - all the above become requirements for MAS infrastructures
  - all the above also means that artefacts are not agents

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- *trends, experiences & open issues in MAS*

Experiences (tags)

- TuCSoN
- ReSpecT
- tuProlog
- SODA
- CArtAgO

TuCSoN
(i)

- Tuple centres
  - programmable coordination media
  - multiple & distributed
  - global vs. local name space
- Tuple centre = Tuple space + Specification space
  - behaviour specification as specification tuples
  - capturing / governing agent interaction via tuple centre

ReSpecT

- a logic language for the specification of the behaviour of tuple centres
- each ReSpecT rule is a FOL fact with a simple syntax
  - and a given a formal semantics
- each ReSpecT specification is a simple FOL theory
  - that defines the behaviour of the tuple centres it belongs to
    - where it is physically stored
  - inspectable / modifiable at run time

TuCSoN
(ii)

- Agent Coordination Context (ACC)
  - conceptual boundary between each agent and its environment
  - organisational / security abstraction provided by an infrastructure
  - negotiated by each agent when entering an organisation / MAS
- An ACC models / constrains
  - every interaction between the agent and the environment
- An ACC represents
  - the agent from the MAS viewpoint

tuProlog

- a Java-based Prolog, featuring
  - minimality
  - dynamic configurability
  - full-fledged Java-Prolog integration
- Both from theoretical and pragmatical motivations
  - we were not able to build our infrastructures from the existing Prolog systems
  - even though we had quite a deep experience

SODA

- A Methodology for Agent-Oriented Software Engineering
  - Societies in Open Distributed Agent spaces
- Based on
  - agents
  - society
  - environment
- as its basic bricks
- Under development
  - Ambra Molesini is the main person there

CArtAgO

- Common "Artefacts for Agents" Open infrastructure
  - a generic agent infrastructure based on artefacts
- Development started NOW
  - on an international basis
    - Tokio, Paris, Wien, Zurich are the main contractors
    - Cesena is the project leader

Open Source Projects

- TuCSoN
  - http://tucson.sourceforge.net
- tuProlog
  - http://tuprolog.sourceforge.net
- Luckily,
  - several users around the world
  - and now, finally, several students / forthcoming PhD working on them
    - you all included :)

So, . . .

- . . . trends????

Conceptual integrity (i)

- many traditionally separate issues concerning the management of agent interaction have led to different models, technologies & infrastructures
  - organisation, coordination, security, …
- toward a uniform conceptual framework for agent interaction issues
  - leading to general-purpose MAS infrastructures covering the whole range of problems
  - providing expressive abstractions to capture organisation, coordination, security, etc. altogether
    - essential in the engineering of complex systems

Conceptual integrity (ii)

- examples
  - roles everywhere (RBAC, Sandhu)
  - coordination & security (Bryce & Cremonini)
  - coordination & organisation (ACC + TuCSoN, Omicini & Ricci)

Conceptual integrity (experiences)

- Coordination & Security
  - tuple centres in TuCSoN
    - several simple, global policies can be represented & enacted by properly programming the coordination media
    - ReSpecT specification
- Coordination & Topology
  - topology as a form of spatial organisation
  - HiMAT infrastructure over TuCSoN (Cremonini)
    - special tuple centres for representing the agent environment
- Organisation, Coordination & Security
  - ACC + tuple centres in TuCSoN
    - roles & permissions to access tuple centres
    - coordination primitives as ACC allowed operations

Seamlessness

- supporting paradigm shifts
  - that hugely affects technologies and systems
- three dimensions (Rimassa 2003)
  - programming paradigm
  - development process
  - economical environment
- a suitably-designed infrastructure can address all of the three
  - and be the critical force behind a paradigm revolution
- example
  - JADE development

Seamlessness (experiences)

- Separation between coordination & computation
  - algorithmic vs. interactive computation (Wegner & Goldin)
  - TuCSoN infrastructure for governing interaction
    - independent of the component model
    - from interacting objects / processes to agents
- TuCSoN agent technology built over object technology
  - and mapping objects into the agent world
  - tuProlog Java / Prolog integration
- Physical actions as the model for agent/ environment interaction
  - to coherently represent objects & resources in the agent world (Cioffi 2004)

Vertical integration

- infrastructures upon infrastructures
  - fuzzy boundaries between telecommunication networks and software infrastructures
- examples
  - the Internet as the most striking one
    - born as horizontal integration
    - used for vertical integration, as a basic enabling layer for interoperability
  - even Java (both as a VM and as a platform)
  - .NET (?)

Vertical integration (experiences)

- TuCSoN
  - over Java
  - over Internet
- Ok, we also tried TuCSoN over .NET

Horizontal integration

- for legacy, but not only for legacy
- goal
  - allow for MAS integration through infrastructure integration
- this has also to deal with seamlessness
  - mostly for development & economy

Horiz. integration (experiences)

- TuCSoN is being interfaced with most technologies around
  - FTP, HTTP, mail, …
  - Web Services
- Work in progress Whitestein / Cesena
  - JADE + TuCSoN horizontal integration
    - a JADE agent can use a TuCSoN tuple centre in a FIPA-compliant way, and interact with a TuCSoN agent that know nothing of JADE / FIPA
  - agent & infrastructure model defined
  - first prototype already working

Social knowledge

- where to put what is "generally known to all the agents of a MAS"? Or, most of them. Or, what should be known to all of them
  - knowledge repositories, criminal records, social trust & reputation, …
- how to enable / promote the production of new knowledge?
  - social inference, abductive social reasoning, …
- … all instrumented as infrastructure services

Social knowledge (experiences)

- … this should be known to SOCS people
- ALIAS & followers (Torroni et al.)
  - social abduction
  - now implemented over TuCSoN tuple centres
    - some tuProlog somewhere?
- Work on trust & reputation
  - social reputation
    - tuple centres as “live” repositories for reputation

Supporting intelligence (i)

- supporting heterogeneity sometimes means supporting the less capable components
  - if I cannot assume intelligence of components, my infrastructure will not ask components to be intelligent
- but the point here is to provide heterogeneous services to heterogeneous components
  - to be used by any component at its level of capabilities
- intelligence of cognitive agents should not be assumed by the infrastructure, but cognitive agents should be put in condition to work at their best by the infrastructure
  - for instance, an object will simply use a tuple space as an artefact (co-ordination), a cognitive agent will possibly reason about the interaction state and behave accordingly

Supporting intelligence (ii)

- examples
  - Semantic Web
    - Web for cognitive agents
  - institutions as agents (Boella & van der Torre)
    - intentional stance to interpret institutions

Supporting intelligence (experiences)

- inspectable (& malleable) coordination media (ReSpecT, Denti & Omicini 2001)
  - cognitive agents can inspect coordination media to improve / adapt their own performance
    - state & laws of the coordination
  - cognitive agents can change coordination media to improve / adapt the global system performance
    - on-line self-engineering

Social intelligence

- natural systems exhibit forms of intelligence that can not be associated with individuals
  - swarms, ant colonies, …
- correspondingly, in principle agents are not the only possible source of intelligence in a MAS
  - "collective" intelligence is possible in computational systems too, and in MAS in particular
- the point here is how to design social intelligence
  - that may also be rephrased as how to embed social intelligence within infrastructures
  - for instance, a well-designed norm could promote intelligent MAS behaviour more or less independently from individual agent intelligence (and attitude and goals)

Social intelligence (experiences)

- Agent societies
  - organised around coordination media
  - embodying social norms and rules as coordination laws
- Experiences with tuple centres as social "cores"
  - and norms & rules repositories
- Laws are
  - explicitly represented
  - enacted by their representation
  - inspectable
  - "understandable"
    - given their formal semantics
  - modifiable

Self-organisation (exploited)

- Complex MAS scenarios like pervasive & ubiquitous computing, and to critical systems as well, call for adaptability and robustness
  - self-organising techniques adopted within the infrastructure to provide robust and adaptable services (Thompson 2003, Brueckner 2003)
  - typically, in the network layers (MANET)

Self-organisation (promoted)

- stigmergy (Hadeli 2003), swarm intelligence (Menezes 2003), field-based coordination (Mamei 2003)
  - models of self-organisation based on a MAS infrastructure that enables / promotes forms of self-organisation
- BIC (Behavioral Implicit Communication, Castelfranchi 2003)
  - generalise stigmergy to cognitive agents
  - observability and traceability of agent behaviours through the environment

Self-organisation (experiences)

- Joint work with Cristiano Castelfranchi
- Abstractions to support BIC & cognitive stigmergy
  - to promote forms of self-organisation based on stigmergy & cognitive agents
- Abstractions
  - provided by the infrastructure
  - featuring traceability and observability of agent actions
    - and support for agent awareness

Laws, norms & institutions (i)

- Joint project(s) with Giovanni Sartor
- Law in human society
  - defined and enforced by well-structured infrastructure
  - the metaphors directly apply to agents
- Problems
  - how to express laws & norms for agent societies?
    - is it again declarative vs. operational?
  - how to connect law specification and enactment?
    - can the same abstractions do both?
  - how to connect the law of humans with the law of agents?
    - e.g., agricultural systems & EU ever-changing rules

Laws, norms & institutions (ii)

- Examples in MAS literature
  - e-institutions (Noriega, Sierra et al.)
  - logic-based institutions (Vasconcelos)
  - work by Boella & Van der Torre

Laws, norms & institutions (experiences)

- ACC with CCS in TuCSoN (Ricci, Viroli)
- laws expressed in a CCS-like form
  - not only simple permissions, but also protocols
- laws are
  - explicitly represented in the ACC
  - specification ≡ enactment
  - inspectable by agent
  - supporting practical reasoning
    - reasoning about actions available / admissible

Legal implications

- system boundaries blurred
  - who know what is one system?
  - … let apart from MAS
- infrastructures introduce new stakeholders
  - new powers, new responsibilities…
- infrastructures have features and behaviours that are independent by any application/system running on them
  - but that can be affected by them in many complex ways
- (sw/hw) infrastructures incorporate (human) norms…
  - to be codified, embedded, enforced, maintained…
- big gray areas, some black holes…
  - a lot of things to understand, a lot of work to do

Applications

- almost any advanced application scenario is infrastructure-dependent
  - pervasive / ubiquitous computing, home care, advanced manufacturing systems, …
- … but the point here is that new infrastructures often open new application scenarios
  - think of IPv6: every square inch on the earth could have its own distinguishing IP…

Applications (experiences)

- Projects on
  - e-learning
  - logistics
  - computer & law
- Work on
  - workflow management
  - virtual enterprises / organisations
  - bioinformatics

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- *conclusions* (ok, I cheated)

Conclusions

- Infrastructures are already the foundations of many critical systems of today
- Ever growing complexity of systems due to
  - social demand
  - social impact
  - technology push
  - market impulse
- will mandate for money and research on infrastructure research & implementation
- Those who will have infrastructures in their hands…
  - be a stakeholder