

Trends in MAS Infrastructures

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Outline

- **on the notion of (MAS) infrastructure**
- enabling vs. governing infrastructures
- a model for MAS infrastructure
- trends & 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 acceptance...
 - so, better to start from it

General definitions

(i)

(Merriam-Webster) (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)

(Cambridge) (4) the basic systems and services, such as transport and power supplies, that a country or organisation uses in order to work effectively

(The American Heritage) (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

(2) an infrastructure is *persistent*

- once installed, an infrastructure typically survives the many systems it supports.

(4),(5) 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)

(Gasser) *... 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)

- (Sycara) 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
- and should instead be provided by suitable infrastructures at runtime
 - 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

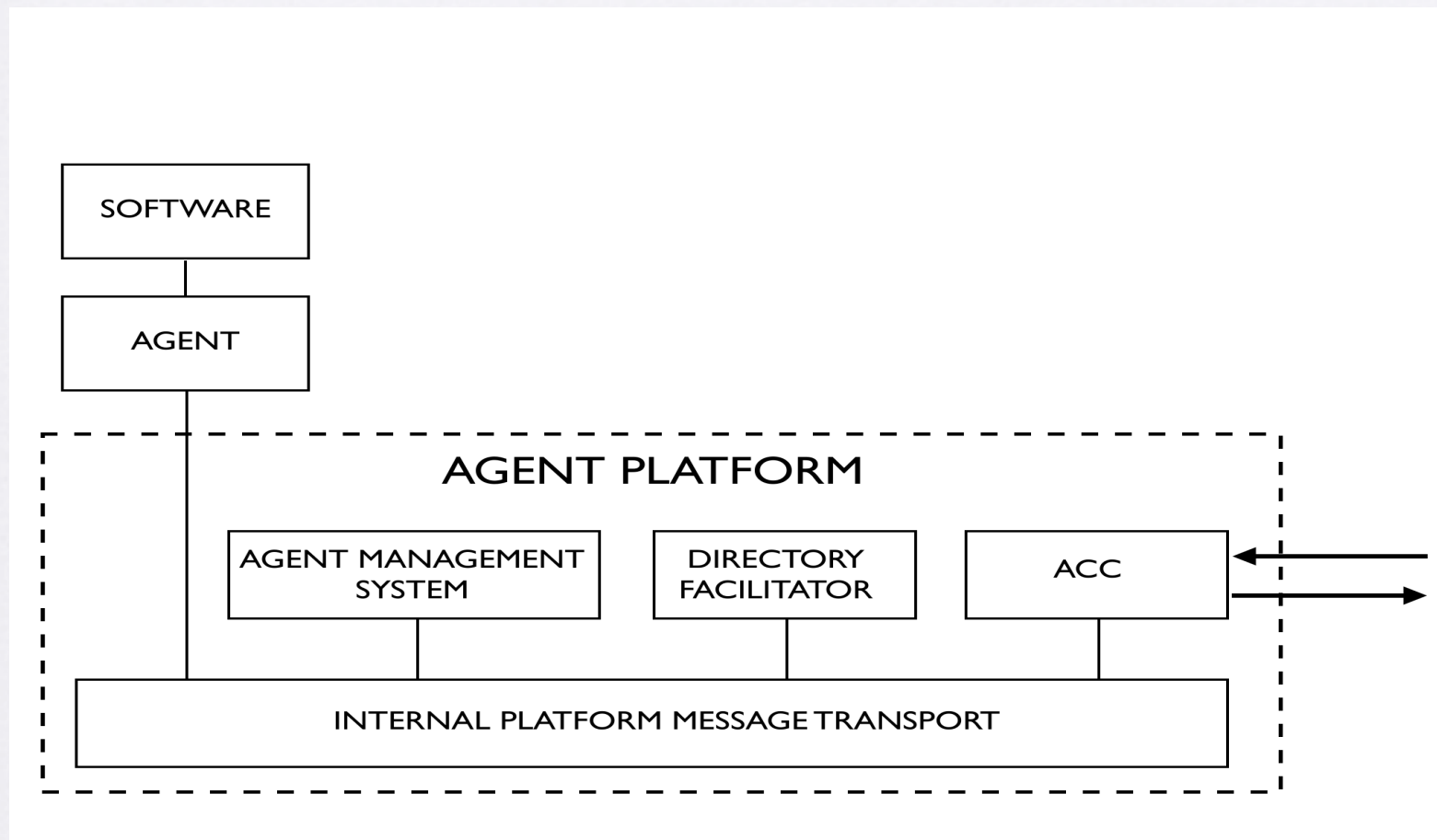
- an infrastructure model
 - defines the component's (observable) model
 - shapes the space of component's interaction
- at their basic level
 - infrastructure are *enabling* component's interaction
 - providing abstractions and technologies to make it possible interaction among components

Examples:

JADE & RETSINA

- JADE & RETSINA satisfy the necessary pre-conditions for agents living, 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 it 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
OPERATING ENVIRONMENT	
Machines, OS, Network Multicast, Transport Layer (TCP/IP, Wireless, Infrared, SSL)	

INDIVIDUAL AGENT INFRASTRUCTURE IN RETSINA

CAPABILITY TO AGENT MAPPING	Matchmaker Module
NAME TO LOCATION MAPPING	ANS Module
SECURITY SERVICES	Security Models 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	
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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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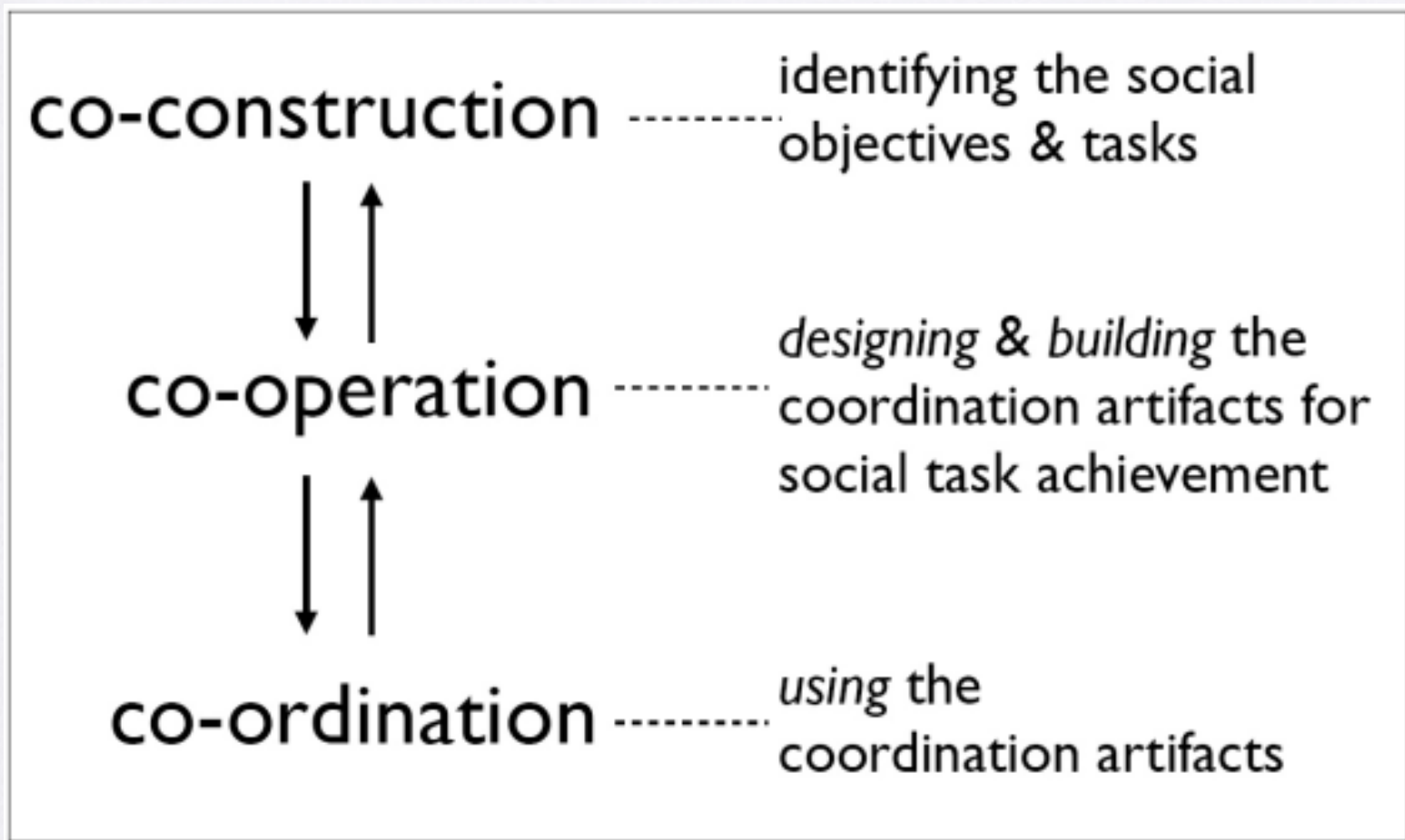
Activity Theory

- 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 *artifact* 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 artifacts

Artifacts

- an artifact embodies a set of social practise
 - its design reflects a history of aims and uses
- as a mediating tool, an artifact 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
 - artifacts can be used (co-ordination) in the day-by-day activity to achieve “normal” goals
 - artifacts can be designed and built (co-operation) in order to allow / improve goal achievement, or to adaptively respond to change
- engineer's viewpoint
 - artifacts are designed, developed and deployed to enable / constrain autonomous agent behaviours, and govern agent interaction (at the co-ordination level)
 - artifacts 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 artifacts 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 artifacts
 - 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

Desirable artifact'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

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Laws, norms & institutions (i)

- quite obvious here...
 - law in human society is 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
 - ACC with CCS in TuCSoN (Ricci, Viroli)

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)

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

Vertical integration

- infrastructures over 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 (?)

Horizontal integration

- for legacy, but not only for legacy
- goal: allow for MAS integration through infrastructure integration
- example
 - work in progress Whitestein / Cesena (JADE + TuCSoN)
 - 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

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

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 artifact (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
 - inspectable (& malleable) coordination media (ReSpecT, Denti & Omicini 2001)
 - cognitive agents can inspect & possibly change coordination abstractions to improve / adapt their own or the global system performance

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)

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
 - more on this in the next talk :)

Applications

- almost any advanced application scenario is infrastructure-dependent
 - e-learning, logistics, health care, home care, cybernetics, advanced manufacturing systems, virtual enterprises / organisations ...
- ... 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...

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...

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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...