Framing Coordination

From Transdisciplinary Models
to Infrastructures and Tools for MAS Engineering

Multiagent Systems LS
Sistemi Multiagente LS

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1 Motivations
   - MAS, Complexity & Coordination
   - (Too) Many (Un-coordinated) Viewpoints over Coordination
   - The Technology Galore

2 The Whole Mess of Coordination
   - Surveys
   - Coordination Approaches
   - Outside AI / CS / SE

3 The Coordination Sieve

4 Framing Coordination with the Sieve

5 Final Remarks
Motivations

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MAS & Complex Systems I

MAS as complex systems

Agents as sources of complexity

- **Autonomy**  Unpredictable behaviour
- **Sociality**  Non-compositional behaviours

**Situatedness**  Unpredictable interaction with the environment

Multi-Agent Systems (MAS) as sources of complexity

- Multiplicity of interacting components
- Global vs. local structure and behaviour
MAS & Complex Systems II

MAS for complex systems

MAS as tools for
- Modelling complex systems
- Engineering complex system
## What is a Complex System? I

### Modelling complex systems
- Complexity sometimes related to non-formalisability
- “Perceived complexity”
  - if it allows for a simple explanation, it is not complex
  - an informal notion if there is one... but of some use

### Building complex systems
- Complexity undermines conceptual integrity in principle
  - no way few abstractions can be used to design a complex system
- Disclaimer: complexity should not be confused with emergent behaviours
What is a Complex System? II

Sources of complexity

- Multiplicity of heterogeneous components
- Unpredictable behaviours of both components and environment interaction
Motivations

MAS, Complexity & Coordination

Complexity & Coordination

Making components work together effectively and fruitfully

- focus on interaction and its management
- beyond communication, interoperability, conversations
- beyond the reductionist vision, toward holistic, systemic vision
  - no way to govern large system based on individual / peer interactions
- there is something beyond the sum of the individual parts
  - that of course comes out when parts are put together
An Example

- You are asked to re-organise the life of a small town (10,000 inhabitants) where a new railway and a new station will be installed, in place of the old local hospital and several private buildings. You have not only to prepare the new hospital, private buildings and infrastructure, but also re-use the old station and railway, prepare new houses, organise the transition, and the life of all the people involved during the 2-years of time it will take.

- Just at the beginning of your work, one of your collaborators comes and tells you: “No problems!!! All the people in the town speak the same language, and perfectly understand each other! Our problems are over, we can safely rest.”

- Question: How would you react?
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Different Viewpoints I

Computer Scientists vs. Engineers

MAS are for

- modelling complex systems
- engineering complex systems

Coordination as modelling / engineering interaction

- models, theories, technologies
- methodologies, best practices, tools
Different Viewpoints II

Complexity & Engineering

Engineers are troubled by complexity
- complexity as a source of richness or problems?
- e.g., enabling vs. protecting
  - open vs. closed systems
  - security as a form of coordination

What about
- autonomy (of components / agents)
- openness (of societies)
- unpredictability (of the environment)

Are they problems to solve, or potential sources of solutions?
Different Viewpoints III

Agent’s vs. Designer’s Viewpoint

- Each agent coordinates
  - trying to understand its best path toward its own goals
  - interacting with other agents and the environment
  - according its own goals, desire, intentions, beliefs, knowledge, capabilities

- Each designer coordinates agents and the whole system
  - trying to make it behaves globally as required
  - based on / despite of agent’s autonomous behaviour
  - according to his/her knowledge / understanding of both agent’s and system’s behaviour

- Coordination as either
  - an agent activity / an activity over agents

- Agents as either
  - coordinating / coordinated entities
Design-time vs. Run-time System Organisation

- Everything is defined statically at design time & fixed once and for all vs.
- Everything is defined at run-time & dynamically modifiable
- And all the places in between...

Again, in some sense

- Closed vs. Open Systems
- Fully controlled vs. Self-organising systems
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“Qualities” of Coordination

- Identifying main dimensions and properties
  - expressiveness
  - scalability
  - correctness
  - formal representation / verification
  - effectiveness
  - efficiency
    - in performance & representation
  - qualitative and quantitative measurability
  - maintainability

- (Different) relevance to scientists and engineers
  - have led to different approaches in technologies, too
Pervasiveness of Coordination

- **Contexts**
  - Interoperability
  - Communication
  - Cooperation
  - Coordination
  - Negotiation
  - Integration
  - Orchestration
  - ...

- **Research areas**
  - OK, we cannot even try listing them, really
  - so many
  - even (particularly?) out of the AI/CS/SE triangle

- **Different / overlapping / confusing definitions**
Huge number of technologies proposed
- to make system components work together etc.

Heterogeneous contexts & diverse abstraction/technology levels

Examples of coordination-related technologies
- integrating and coordinating services: Jini, OSGi, Java Spaces, TSpaces, GigaSpaces, ...
- specifying and enacting workflow: WfMC architecture, Workflow Languages—XPDL, BPML, ...
- supporting groupware
- composing and orchestrating Web Services: Orchestration servers, Orchestration Languages—BPEL4WS, ...
- integrating wireless technologies: BlueTooth, ZeroConf,...
Example: Wireless technologies

Integrating & Coordinating Autonomous Wireless Devices

- **Bluetooth (IEEE 802.15.1)**
  - simple coordination capabilities in the basic radio technology
    - master / slaves
    - piconet / scatternet
    - gateways
    - automatic discovery & configuration of peer devices

- **ZeroConf (Rendezvous)**
  - service-oriented coordination protocol
  - upon different radio / connection technologies
    - Ethernet, WiFi, Bluetooth, ...
  - transparent & automatic discovery of user services
Example: Service-Oriented Architectures

- Pervasive computing contexts
  - Intelligent / smart home
- Specifications and platforms
  - OSGi
  - Jini
- Coordination technologies
  - JavaSpaces
  - TSpaces
  - GigaSpaces
Example: Distributed Workflow Management

Automating the Specification and Enactment of Business Processes

- Coordination of distributed independent and heterogeneous tasks cooperating in the same workflow
  - coordinating humans and machines in socio-technical systems

- Workflow architectures
  - workflow specification and enactment services
  - workflow engines

- Workflow Specification languages
  - XPDL
  - BPML
  - ...

- Virtual Enterprises / Organisations
Example: Component Integration & Coordination

Shift from the Individual Components to the their “Containers”

- Coordination of distributed independent and heterogeneous tasks cooperating in the same workflow
  - ...that glue components offering services which eventually manage component interactions (i.e. coordination services)
  - Transactions, concurrency, persistence, ...
- Infrastructure view

- Application Servers
  - CORBA components
  - Enterprise Java beans
  - .NET components
Example: Web Services Orchestration

Shift from the Individual Web Services to Composition of Web Services

- ...though enactment services (engines) that glue multiple individual services in the same orchestration (workflow)
- Choreography/Orchestration servers
  - specification and enactment
- Choreography/Orchestration languages
  - BPEL4WS, WSCI, ...
Remark

The (coordination) technology galore...

- ... poses more issues than the mere technology one
  - "govern" technologies are not governable?
- every technology / infrastructure / tool
  - embodies / reifies a model
  - support / promotes a methodology or a practice
  - either explicitly or implicitly
- i.e., they affect the whole spectrum of engineering

Answers at the technology level are typically

- specification and enactment

Choreography/Orchestration languages

- very focused & specialised
  - easy to recognise similar issues everywhere
  - with similar answers
  - but developed separately & independently

Very exciting, not very intelligent
Lots of heterogeneous models to face the whole mess of coordination…

• … even several heterogeneous surveys

Lots of individual good results but…

• typically, few points of contact between two different surveys
• people tend to take religious standpoints
  • or, they tended – now they mostly prefer to forget about the whole matter
Several Definitions...

Coordination is the process by which an agent reasons about its local actions and the (anticipated) actions of others to try and ensure the community acts in a coherent manner [Jennings and Wooldridge, 1998]

Coordination as management of dependencies between independent activities [Malone and Crowston, 1994]

[Coordination as the activity that] involves the selection, ordering and communication of the results of agent activities so that an agent works effectively in a group setting [Lesser, 1998a]

Co-ordination is a process in which agents engage in order to ensure a community of individual agents acts in a coherent manner [Nwana et al., 1997]

[Coordination as] a way of adapting to the environment [von Martial, 1992]
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Several Surveys & Books...

**Surveys**

- “DAI Approaches to Coordination” [Gasser, 1992]
- “Models and Technologies for the Coordination of Internet Agents: A Survey” [Papadopoulos, 2001]
- “Models of Coordination” [Tolksdorf, 2000]
- “Co-ordination in Software Agent Systems” [Nwana et al., 1996]
- “Coordination Models: A Guided Tour” [Busi et al., 2001]
- “Reusable Patterns for Agent Coordination” [Deugo et al., 2001]
- ...

**Books**

- “Co-ordination in Artificial Agent Societies” [Ossowski, 1999]
- “Coordination of Internet Agents” [Omicini et al., 2001]
- ...

Omicini & Ricci (Università di Bologna)
Coordination Everywhere... 


Coordination spread in several chapters

- Huns and Stephens’ section on coordination
  - Coordination as a ‘subsection’ of communication (2.2 Agent Communication, 2.2.1 Coordination)
- Durfee’s chapter of Distributed Problem Solving and Planning
  - Related to distributed planning and execution
- Singh’s chapter on formal methods in DAI
  - Coordination section
- Agha’s chapter on Concurrent Programming
  - Section on coordination in agents’ ensemble
- Ellis’s chapter of CSCW and Groupware
  - Section(s) on coordination
Coordination from DAI... [Durfee, 1993]

**General view**

- AI and Social / Organisational Sciences are inextricably related
  - coordination in a MAS as fundamental to intelligence
  - *individual* and *collective* intelligence
- Coordination as a distributed search problem
  - search space as a common representation for organisation, plans & schedules
  - global shared plan / organisation foundation for strong interdisciplinarity
Coordination: supporting / promoting agent activities as a collective

- scheduling, detection, learning, ... 
- moving from individual to social viewpoint
  - Organisation
    - roles & responsibilities
    - limiting required info and deliberation scope
  - Architectural concepts
    - support for communication is not enough (KQML)
- Focus on infrastructures
  - support for articulated agent interaction
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Coordination Approaches Galore

- Approaches rooted in Distributed Artificial Intelligence (DAI)
- Approaches coming from Software Engineering contexts
  - more focus on infrastructure support to coordination
- Approaches using Economics Metaphors
- Approaches founded on Social Control and Institutions
- Approaches based on Coordination Media & Languages
- Coordination through the Environment
  - swarming & stigmergy coordination
- ...
Coordination as Distributed Problem Solving

- Coordination as managing tasks / interdependencies [Decker, 2002]
  - PGP, GPGP [Lesser, 2002]
  - TÆMS (Task Analysis and Environment Modeling System) [Decker, 1996]

- Formal / complex model
  - actions & task, non-local effects, task structures
  - global planning / scheduling
  - coordination mechanisms as (formal) algorithms

- Task structures for
  - reason about coordination
  - communicate about coordination
Founding Coordination on Commitments and Conventions

- “Foundation of Coordination” [Jennings, 1993]
- Same DAI-vision
  - Coordination as distributed goal search problem
- Basic bricks
  - (joint) commitments & (social) conventions
  - local reasoning
- Frameworks & Technologies
  - GRATE* system/technology [Jennings, 1995]
    - teamwork
  - ADEPT architecture [Jennings et al., 1998]
    - business process management
ACL-based Approaches

- Coordination just upon communication [Cost et al., 2001]
  - Patterns of communications

- Interaction protocols, conversations
  - Individual viewpoint over coordination
  - Conversations “out of agents”

- Some assumptions
  - intelligent, homogeneous agents
  - high-level communication language (KQML, FIPA)
  - closed societies, low cardinality
  - marginal role of the environment
  - communication / coordination between peers / pairs

- Approaches
  - COOL (COOrdination Language)
Coordination Services

  - specified declaratively
  - based on temporal logics
  - for open systems based on opaque agents
Team-Oriented Coordination

- **TEAMCORE** [Pynadath and Tambe, 2003, Tambe, 1997]
  - coordination out of agents
    - “proxies” for legacy, “stupid” agents
    - focus on the infrastructure
    - as both enabling and promoting coordination
  - team-oriented programming
    - for developers
    - specification of team organisation hierarchy in terms of role & groups
    - specification of the hierarchy of reactive team plans
    - assignment of agents to plans
Middle-Agents

- Coordination as intermediation [Sycara and Klusch, 2001]
  - performed by specialised (Middle-)Agents
  - between service providers and requesters (agents)
- Service-oriented view
  - brokering in open environment
- Mediation services
  - as coordination services
    - processing agent capabilities and service descriptions
    - enabling semantic interoperation between agents and systems
    - management of data and knowledge
    - enacting distributed query processing and transactions
- Toward Team-oriented coordination [Giampapa and Sycara, 2002]
  - Coordination as a team problem solving, à la Tambe
  - RETSINA + TAEMS/GPGP
Market-Oriented Coordination [Wellman, 1993]

- Based on metaphors from economics science
  - “Market-Oriented Programming” [Wellman, 1995]
  - decentralised control [Ygge and Akkermans, 1999]
  - Contract Net Protocol
  - Computational Ecologies (Hubermann and Hoggs)

- Heterogeneous agents
  - not necessarily intelligent ones
  - open societies, high cardinality
  - environment in terms of resources
Coordination through Social Laws
[Shoham and Tennenholtz, 1995]

- Coordination as a restriction over agent activity
  - allowing them to reach their own goals
  - avoiding interferences
  - constraining interactions
  - “social laws”

- Social law as built into action representation
  - rather than epiphenomenal
  - implemented as architectural system properties
  - designed off-line
  - explicitly represented (run-time)

- The problem of open societies
Coordination and Institutions [Dignum and Dignum, 2001]

- Organisation
  - social order
  - global behaviour emerging from individual interactions
    - how to make individual goals coexist with global ones
- Coordination frameworks to cope with duality
  - rules and infrastructures
- Norms and Institutions
  - to cope with the challenge of social order in open societies
  - explicitly represented and embodied out of agents
  - in general Institutions make it possible to
    - specify the co-ordination structure that is used
    - describe exchange mechanisms of the agent society
    - determine interaction and communication forms in the agent society
    - facilitate the agent’s perception of the aims and norms of an agent society
    - enforce the organisational aims of the agent society
Coordination as a Service

TuCSoN coordination model/infrastructure
[Omicini and Zambonelli, 1999]

- Tuple Centres [Omicini and Denti, 2001]
  - general purpose customisable coordination services
    - programmable logic tuple spaces
    - generative communication
    - ReSpecT language for coordination specification
    - enacting/enforcing coordination laws & constraints
  - spread over the TuCSoN nodes
    - network awareness
    - agent mobility

- Agent Coordination Contexts [Omicini, 2002]
  - enabling and ruling agent access/use of the services
  - organisation & security issues

- Orthogonal to the agent model/platform
  - TuCSoN & friends
Coordination through the Environment: Stigmergy Coordination

- Coordination enabled and mediated by the environment [Parunak et al., 2001]
  - environment as a shared space for indirect communication
    - coordination through the environment
  - support for open & heterogeneous agent societies
  - overcomes the problems and limitations of individual viewpoint and knowledge
  - it intrinsically embeds domain constraints

- No need for direct symbolic communication among agents

- Prescriptive

- e.g., Pheromone-based model of coordination
  - Measuring coordination [Parunak and Brueckner, 2001]
Swarming Intelligence

- Distributed problem-solving devices inspired by collective behaviour of social insect colonies and other animal societies [Bonabeau et al., 1999]
  - From natural systems
    - global robust intelligent behaviour
    - with simple & non-intelligent individuals
    - intelligence in the interaction / coordination — among agents, and with the environment

- Self-organisation by local interactions

- Stigmergy as a subset
Field-based coordination

- Computational fields as coordinators [Mamei and Zambonelli, 2006]
  - Co-fields
- A unifying approach for space-based, stigmergy, and field-based coordination
  - TOTA [Mamei and Zambonelli, 2004]
  - infrastructure tuples for fields, individual tuples for agents
  - tuple propagation, diffusion and decay
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Remarks (I)

Coordination is neither an AI nor a CS problem

- It concerns complex systems
  - where both *complexity* and *system* are notions whose nature and definition vary according to the field of interest
- There are branches of science that work on complex systems since long before we (AI, CS, SE, MAS, whatever) did
  - They are to some extent *more science* than we are
  - They have results
Theory of Coordination

Coordination Theory [Malone and Crowston, 1994]

- coordination as managing dependencies among activities
- dependencies among tasks
- different sorts of dependencies
- coordination processes to manage them
  - Shared Resources
  - Task Assignment
  - Producer / Consumer
- Many different sort of systems and organisations can be modelled as such
Activity Theory (AT) [Vygotskii, 1978]

Theory about the development/dynamics of collective human work [Nardi, 1996]

- Social/Psychological focus on human activities
  - objects and objectives
  - collaboration activities and actions
- Focus on activities and artifacts that always mediate human activities
  - Both physical and psychological nature
    - cultural means, tools, signs mediating the relationship between human agent and objects of environment
- Explicit account for contexts and situated interaction
- Particular focus on social artifacts, mediating social activities [Bardram, 1998]
CSCW & Workflow Management

- Coordination and articulation as main issues  
  [Schmidt and Simone, 1996, Schmidt and Bannon, 1992]  
  - complex society/organisation context
- Gap between flexibility and automatism/structure  
  [Schmidt and Simone, 2000, Dayal et al., 2001]  
  - Hot discussion: Suchman vs. Winograd & co.
    - automated mechanisms / coordinators — Winograd & Flores, Workflow Management Approach,...
    - situated action —Suchman and classic CSCW
- CSCW toward more coordination support from infrastructure
- WfMS toward more flexibility for unpredictable events
The Lack of a Unitary View causes
  Weak scientific debate
    Separated clusters of coordination scientists
    Fragmented results
  Feeble spreading of relevant results
    Law impact on other communities — that may even need them?
    Sporadic trans-disciplinarity
    People re-invent the wheel — Microsoft Orchestration???
  No transfer to industry
    Unmarketable concepts and technologies
    Unremarkable impact, in the end

But: is it a *Unitary View* what we really need?
Remarks (III)

- Complexity involves multiplicity & requires multiple views
  - forgetting about finding THE view
  - multiplicity as an intrinsic property of complex systems
- Looking for a common frame, a structure, a sieve where the multiple views
  1. could be located, discussed, and compared in some of their parts
  2. could benefit one each other — beyond inter-disciplinarity, toward trans-disciplinarity
- Understanding and bridging coordination gaps
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Mind the gap! Towards a unified view of CSCW.


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