Objective versus Subjective Coordination in the Engineering of Agent Systems

Andrea Omicini

DEIS

Università di Bologna

Sascha Ossowski

AI Group

Univ. Rey Juan Carlos, Madrid

Objective vs. Subjective Coordination ...

Outline:

1. Introduction
2. Coordination: Overview
3. Subjective vs. Objective Coordination
4. Coordination and AOSE
5. Vision

Why Coordination?

- *Interaction* as an Independent Dimension in Today's (Computer-based) Systems
  - non-trivial systems are multi-part & dynamic
  - coordination as managing interaction

- *Sociality* as a Fundamental Issue in Multi-Agent Systems
  - social abstraction is perhaps more powerful than MAS
    - organisational viewpoint on systems
  - social laws as coordination laws

Why Agents and SE?

- Out of the Academia
  - models, technologies, and methodologies for the engineering of multiagent systems
  - SE for MAS

- Agents as the Next Big Thing in SE
  - agent-oriented abstractions to tackle complexity of today's system engineering
  - MAS for SE

Why Coordination and AOSE?

- Engineering the Interaction Space
  - interaction as an independent dimension for the engineering of non-trivial systems
  - need for specific abstractions, model, technologies, and methodologies

- Engineering Agent Societies
  - societies as first-class entities
  - models, technologies, and methodologies for the engineering of agent societies

Objective vs. Subjective Coordination ...

Outline:

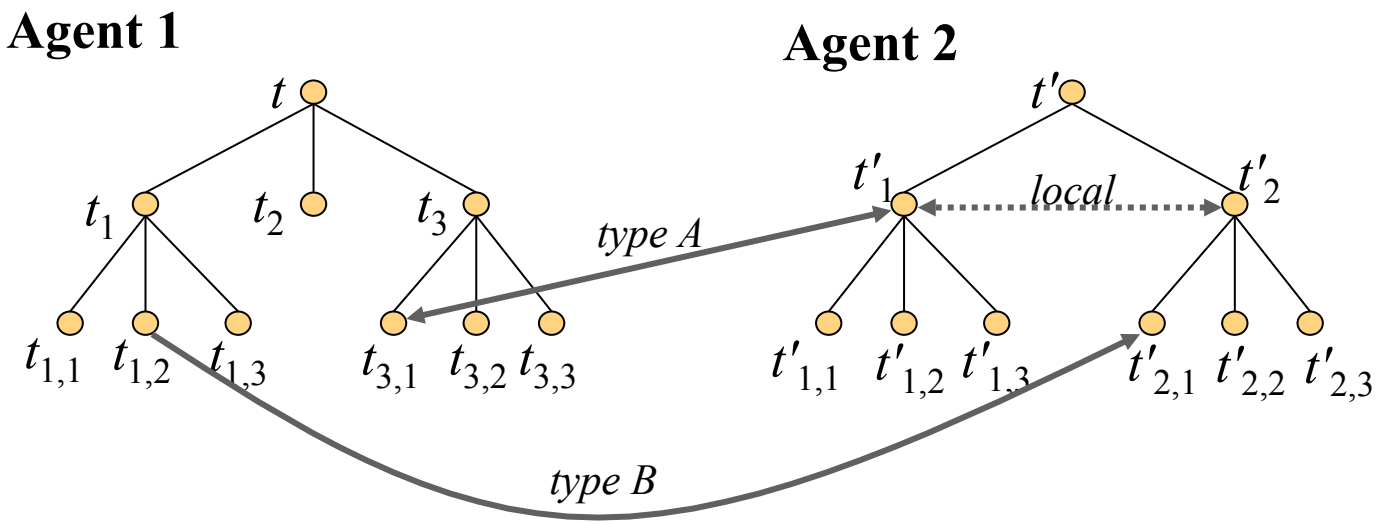
1. Introduction
2. Coordination: Overview
3. Subjective vs. Objective Coordination
4. Coordination and AOSE
5. Vision

What is Coordination?

- Everybody knows, nobody agrees
  - "This is not *coordination*"
- Robotics, Software Engineering, Multi-Agent Systems, Programming Languages, …
- Social Sciences, Economy, Biology, …

Coordination: Definition 1

Coordination: management of dependencies (Malone & Crowston)



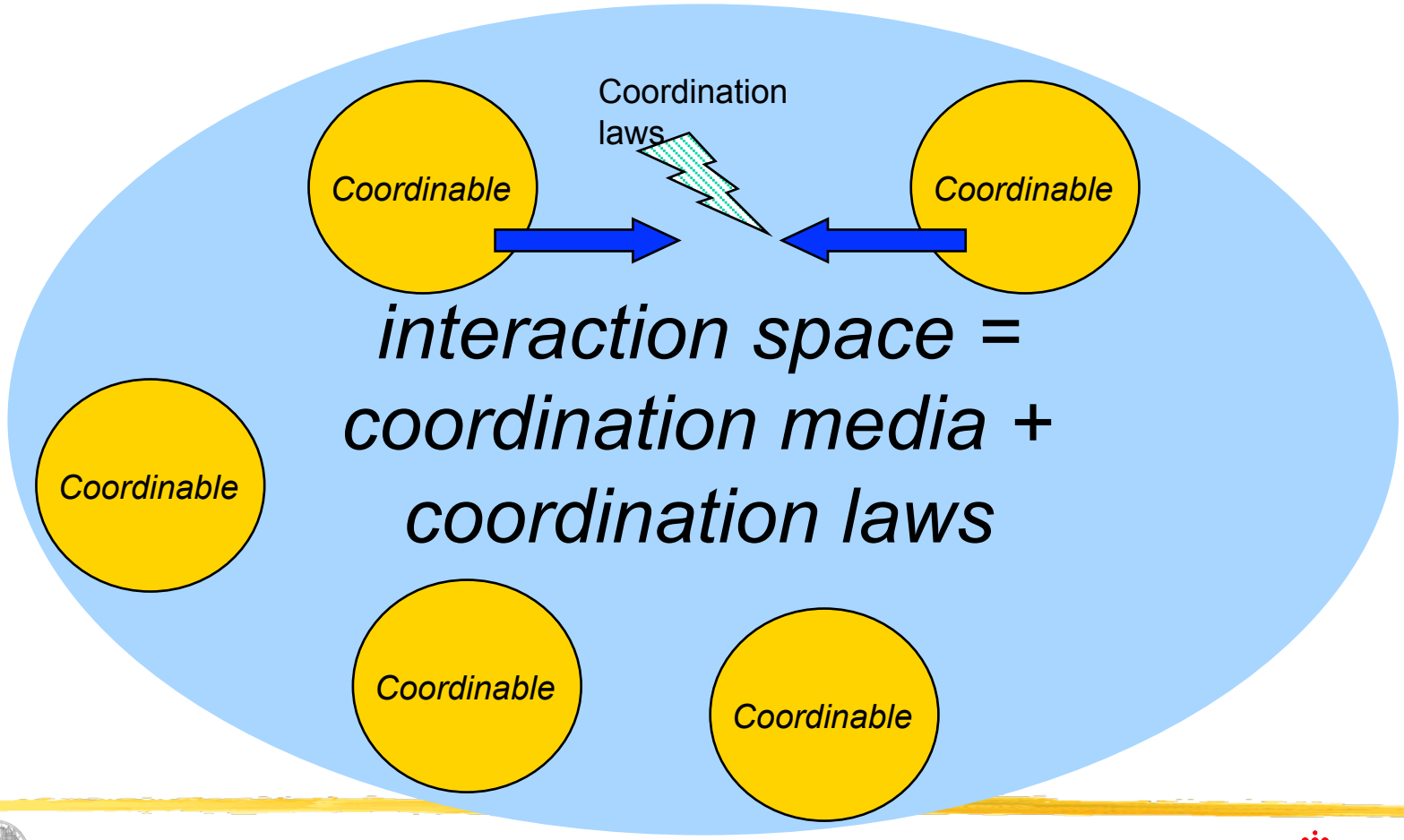
Coordination: Definition 1

- Ontology:
  - "coordinables":
    - agents / processes
  - objects of coordination:
    - tasks/ goals/ activities/...
  - taxonomy of dependencies:
    - shared resources, producer/consumer etc.
  - set of coordination actions / primitives / transactions:
    - synchronisation, resource selection etc.
    - `out, in, rd`

- Coordination process:
  - dependency **detection**: which dependencies are present
  - management **decision**: which coordination actions/primitives to apply
  - these tasks usually guide complex agent interactions....

Coordination: Definition 2

Coordination: constraining interaction (Wegner)



Coordination: More Definitions

- "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)
- "The integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal" (B. Singh)
- "Co-ordination is a way of adapting to the environment" (von Martial)

A layered Model of Coordination

Application layer: engineer for desired properties / functionalities

- *Coordination mechanisms*
- Coordination laws, norms, conventions, etc.

Framework layer: middleware

- Coordination languages: protocol languages (COOL etc.)
- Coordination media: tuple-based (TuCSoN etc.)

Infrastructure layer: enabling technologies

- Communication infrastructure
- Computing platforms

Coordination Mechanisms

Open vs. Closed:

- In closed environments, many assumptions are possible
  - coordination algorithms, efficiency issues
- In open environments, most assumptions are unlikely
  - open coordination services, security issues

Controlled vs. Uncontrolled:

- design-time controlled:
  - behaviour of all agents in the system is known at design time
- run-time controlled:
  - dynamically supervised coordination
- uncontrolled:
  - unexpected (frequencies of) behaviours are possible

Coordination Mechanisms

Direct vs. Mediated:

- mediated coordination mechanisms rely on a distinguished coordinator agent or coordination medium
- in direct mechanisms coordination “emerges” from peer-to-peer interaction

Coupled vs. Uncoupled (Tolksdorf, ESAW'00):

- Coupled coordination mechanisms are based on assumptions on some (other) agent's behaviour
- Uncoupled mechanisms impose no assumptions on agent behaviour

Quantitative vs. Qualitative:

- measure success of coordination in a qualitative fashion (utility etc.)
- quantitative stance on coordination dependencies

Coordination Mechanisms: Design Issues

Designer's interest in Coordination

Micro-level design

- given an *open* environment with multiple agents
- built *one* additional agent with desired characteristics

Macro-level design

- build *systems* of multiple agents with desired characteristics

open environment

- uncontrolled agents
- enforcement of coordination laws

closed environment

- controlled agents
- problem-solving systems

Objective vs. Subjective Coordination ...

Outline:

1. Introduction
2. Coordination: Overview
3. Subjective vs. Objective Coordination
4. Coordination and AOSE
5. Vision

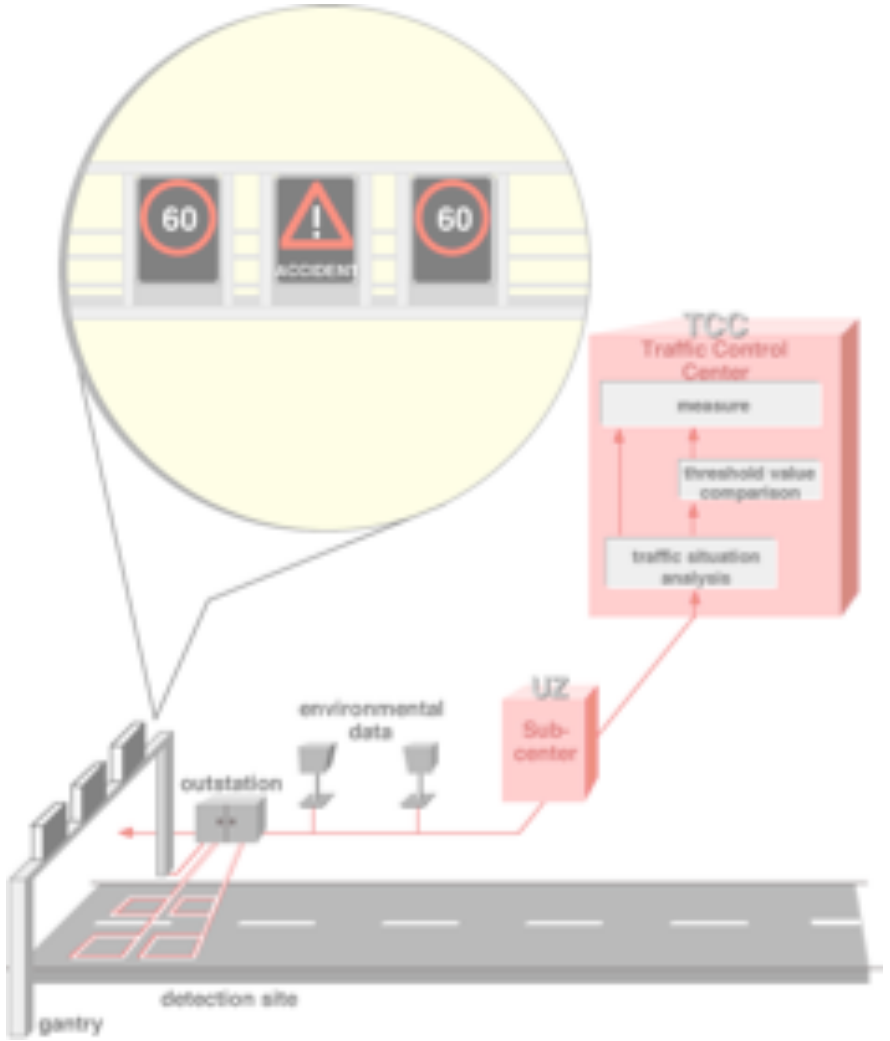
Objective vs. Subjective Coordination

Objective vs. subjective coordination (Schumacher, LNAI 2039)

- A coordination mechanism can be analysed from different perspectives:
  - Subjective perspective
    - *coordination from inside agents*
    - handling interaction from the individual agent's viewpoint
  - Objective perspective
    - *coordination from outside agents*
    - handling interaction from the infrastructure's viewpoint
- We argue that both perspectives need to be taken into account when designing a coordination mechanism

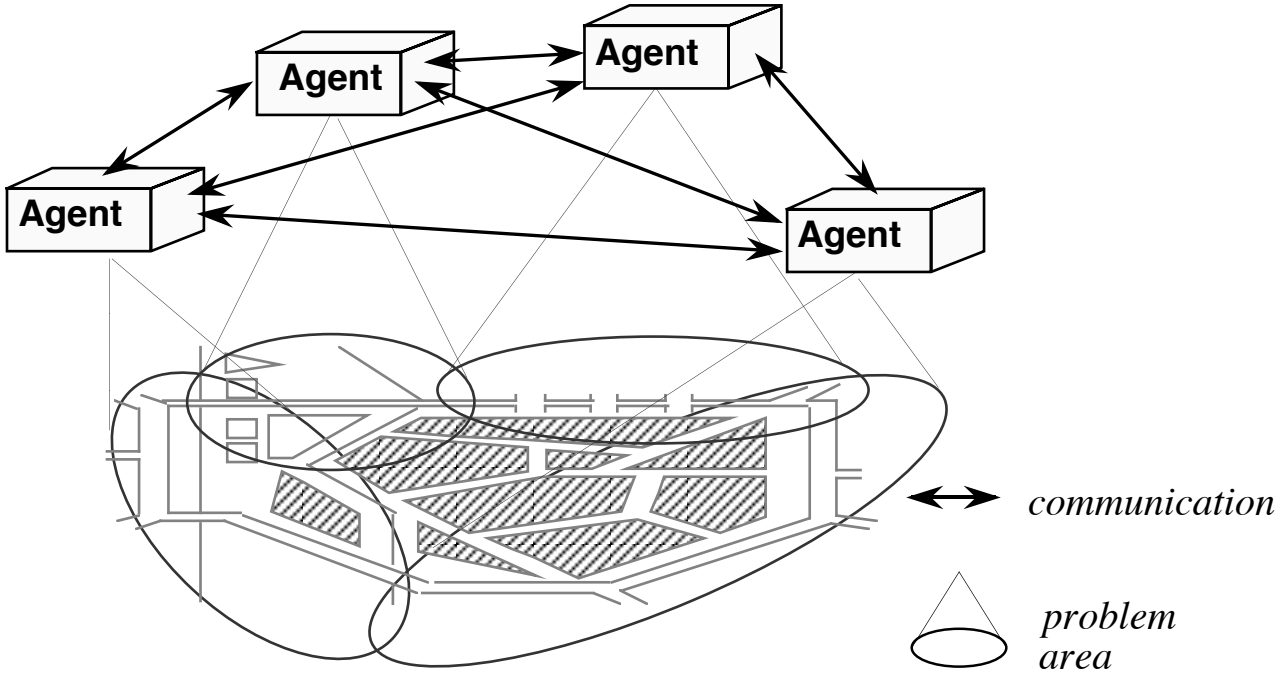
Objective vs. Subjective Coordination: An Example

- Domain:
  - urban road network
- Global goal:
  - assure **smooth flow of traffic**
- Actions:
  - traffic-sensitive proposals for **signal plans**



Objective vs. Subjective Coordination: An Example

- Intelligent traffic management agents:
  - each agent is responsible for one *problem area*
  - *knowledge-based* generation of alternative local signal plans
  - each agent ranks local signal plans w.r.t their *local* effects
  - co-ordination to cope with *interrelations* between local signal plans



Objective vs. Subjective Coordination: An Example

- Subjective perspective:
  - how to minimise negative impacts in the *local* problem area?
  - model self-interested behaviour

- Objective perspective:
  - how to minimise negative impacts equally among *all* problem areas?
  - objective biasing: design and tune social norms

- "*Structural cooperation*" (Ossowski, LNAI 1535):
  - coordination mechanism for closed environments that integrates both perspectives

Subjective perspective: Plan relations

- *Individual* context:
  - choose the individual plans $\pi_i,...\pi_j$ that minimises ***local*** problems in an area

- *Social* context:
  - *multiplan* μ: simultaneous execution of individual plans $\pi_i,...\pi_j$
  - Interrelation respecting executability of a plan(*exec*)
  - Interrelation respecting the outcome of a plan (*res*)

- Plan relations:

$$indifferent_x(\pi,\mu) \quad \int \; \big(exec(\pi,s) \mid exec(\pi\circ\mu,s) \mid res(\pi\circ\mu,s) = res(\pi,s)\big)$$
$$\int \; \big(\downarrow exec(\pi,s) \mid \downarrow exec(\pi\circ\mu,s)\big)$$
$$interferent_x(\pi,\mu) \quad \int \; exec(\pi,s) \mid exec(\pi\circ\mu,s) \mid res(\pi\circ\mu,s) \;?\; res(\pi,s)$$
$$complementary_x(\pi,\mu) \quad \int \; \downarrow exec(\pi,s) \mid exec(\pi\circ\mu,s)$$
$$inconsistent_x(\pi,\mu) \quad \int \; exec(\pi,s) \mid \downarrow exec(\pi\circ\mu,s)$$

Subjective perspective: Social dependencies

- *Dependence relations* among agents :

$$prevents_x(\alpha,\pi,\gamma,\mu) \quad \lceil \quad prep_x(\alpha,\pi) \mid prep_x(\gamma,\mu) \mid inconsistent_x(\pi,\mu)$$

$$enables_x(\alpha,\pi,\gamma,\mu) \quad \lceil \quad prep_x(\alpha,\pi) \mid prep_x(\gamma,\mu) \mid complementary_x(\pi,\mu)$$

$$hinders_x(\alpha,\pi,\gamma,\mu) \quad \lceil \quad prep_x(\alpha,\pi) \mid prep_x(\gamma,\mu) \mid interferent_x(\pi,\mu) \mid res(\pi \circ \mu, s) \prec_\alpha res(\pi, s)$$

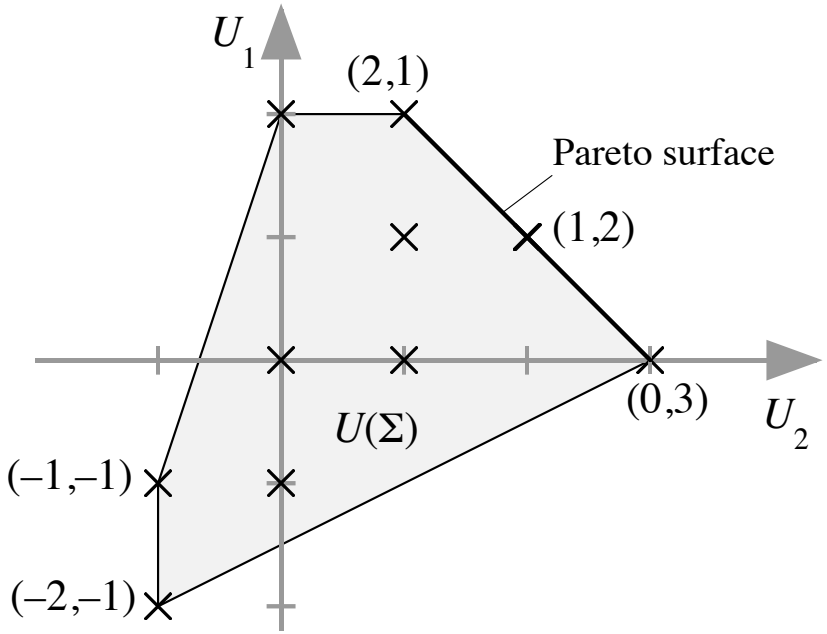
$$favours_x(\alpha,\pi,\gamma,\mu) \quad \lceil \quad prep_x(\alpha,\pi) \mid prep_x(\gamma,\mu) \mid interferent_x(\pi,\mu) \mid res(\pi, s) \prec_\alpha res(\pi \circ \mu, s)$$

- Normative *context*:
  - preparedness (*prep*): capability + absence of prohibitions

$$prep_x(\gamma,\mu) \lceil can(\gamma,\mu) \mid \text{not } forbidden_x(\gamma,\mu)$$

Qualitative to quantitative mapping

- Modelling *cooperation*:
  - *Utility vector* of a multiplan: reduction of distance to ideal states of each agent
  - *Mixed multiplan*: probability distribution over a set of legally enactable multiplans
  - *Expected utility* of a mixed multiplan: weighed sum of utilities of the component plans
  - *Feasible region S*: all reachable utility vectors



Qualitative to quantitative mapping

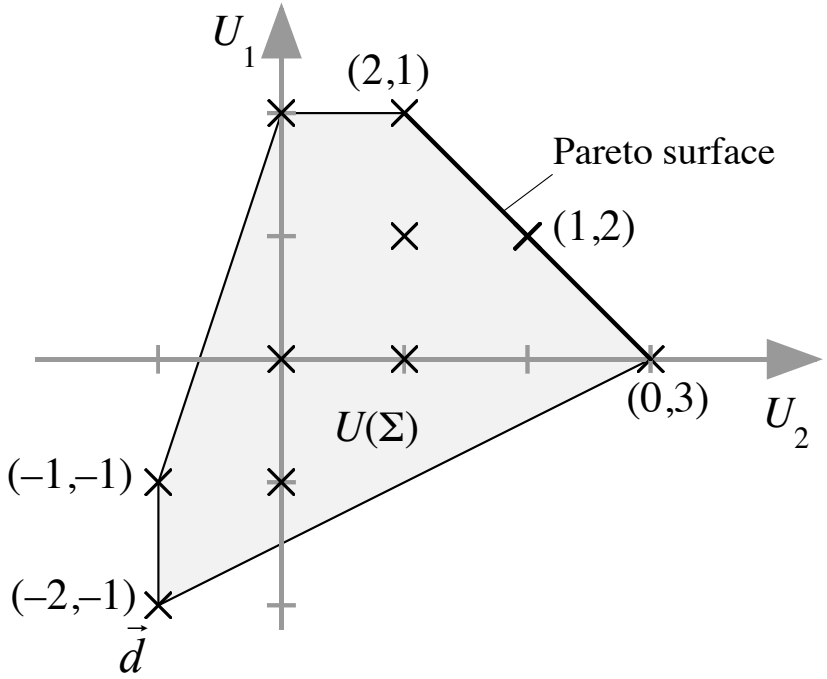
- Modelling *conflict*:
  - conflict utility: best local choice given that all acquaintances jointly try to harm the agent
  - *disagreement point* $\vec{d}$

- *Bargaining scenario* $(S, \vec{d})$:

  feasible region

  \+

  disagreement point



Objective perspective: outcome of coordination

- Desirable *properties* of a *solution* $\vec{\varphi}$ to the bargaining scenario $(S, \vec{d})$:
  - Individual rationality: $\vec{d} \le \vec{\varphi}$
  - Pareto-optimality: $\downarrow \exists \vec{x} \lfloor S, \vec{x} \; ? \; \vec{\varphi}.$ $\vec{\varphi} \le \vec{x}$
  - Symmetry: *same bargaining position*. $\varphi_i = \varphi_j$
  - Scale Invariance: φ_λ *solution to* $(\lambda S, \lambda \vec{d})$. $\lambda\vec{\varphi} = \vec{\varphi}_\lambda$
  - Contraction Independence:
    $S' \mid \; S, \vec{d} \lfloor \; S', \vec{\varphi}'$ *solution to* $(S', \vec{d})$. $\vec{\varphi} \lfloor \; S \; ? \;\; \vec{\varphi}' = \vec{\varphi}$

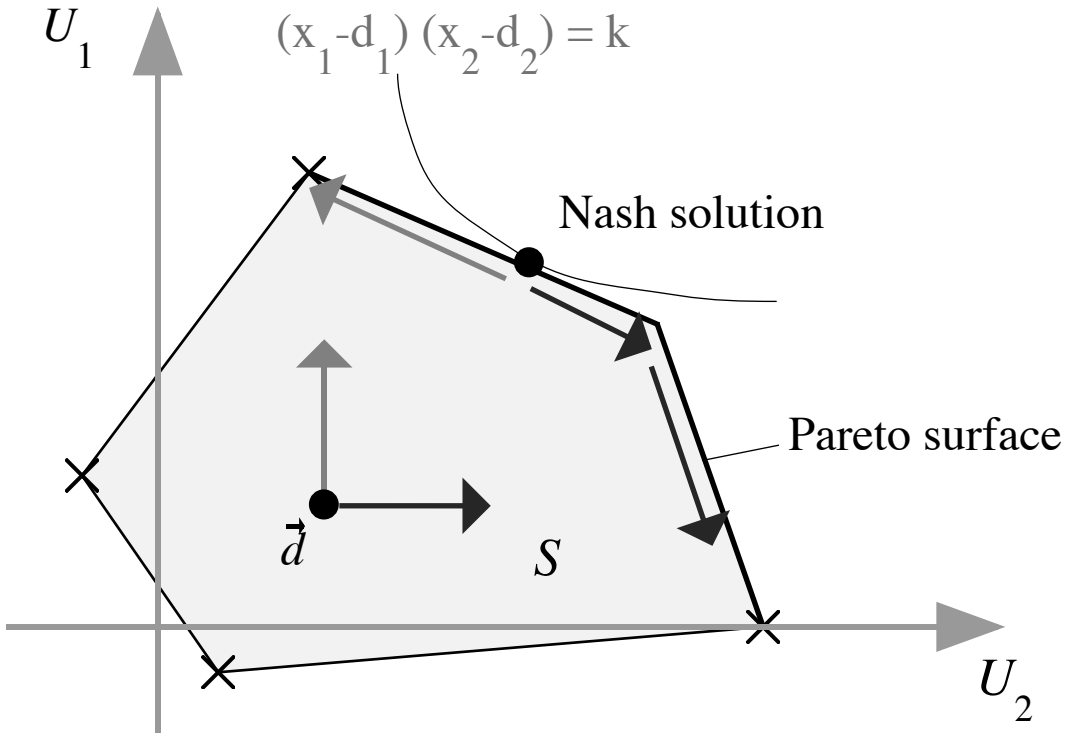
- **Theorem** (due to Nash):

  The only vector $\vec{\varphi}$ that complies with the above axioms maximises the function

$$N(\vec{x}) = \prod_{i=1}^{n} (x_i - d_i)$$

Objective perspective: biasing the outcome

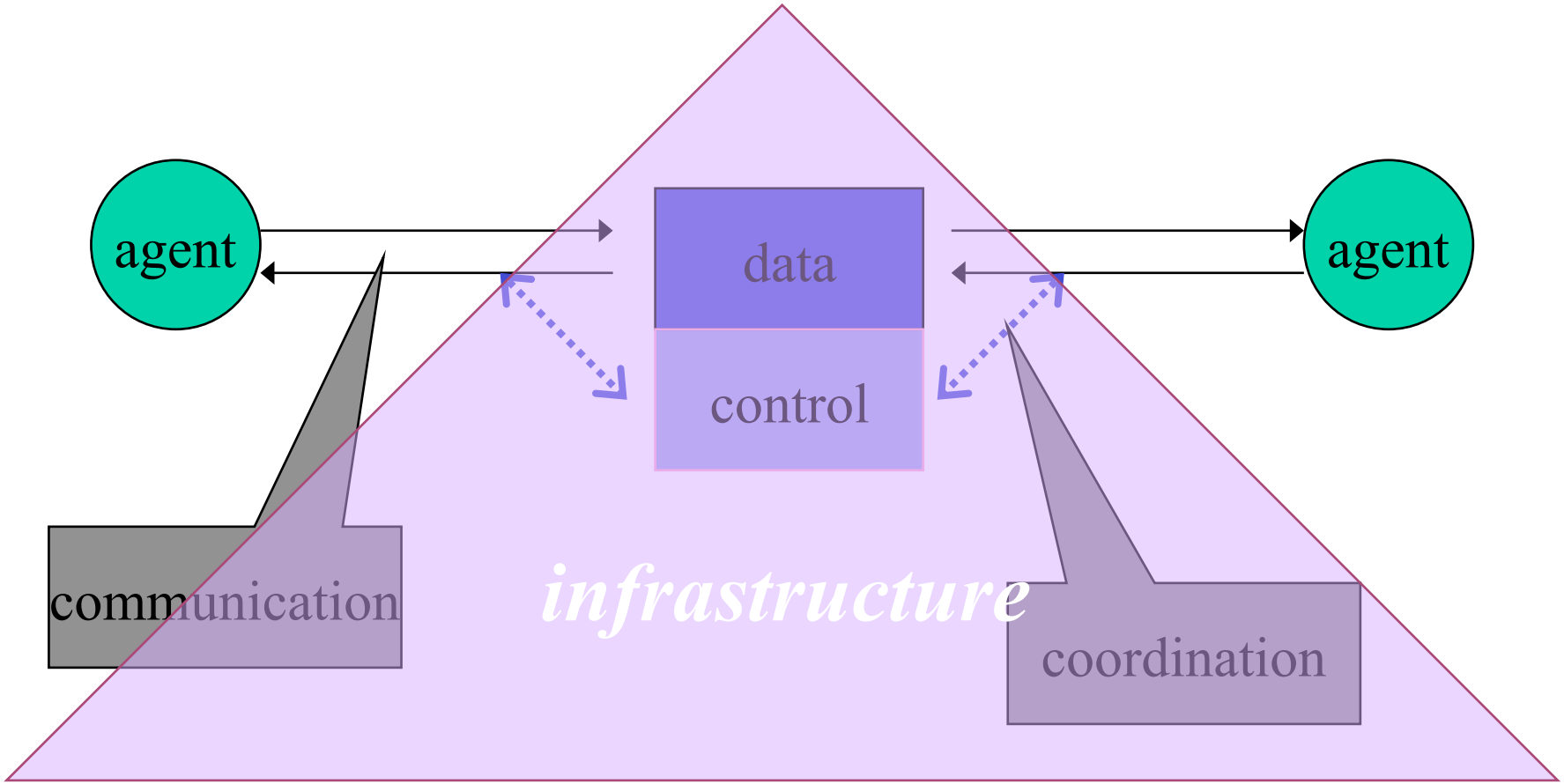
Disagreement Point Monotonicity:



Embodying Objective coordination

- *Ad hoc* implementations:
  - adapt agent architectures/ programmes
  - DCSP algorithms, . . .
- Coordination *middleware*:
  - specialised abstractions:
    - mediators, directory services, ontologies
  - general coordination abstractions:
    - tuple centres, manifolds, blobs
- Coordination as a *service*:
  - coordination abstractions as run-times
  - encapsulating coordination laws/ social laws/ social norms
  - open environments: agents free choose to use a service (and its laws...)

Objective Coordination as a (Run-time) Service



Coordination as a Service: An Example

- Workflow Management in Virtual Enterprises
- Issues
  - technology / infrastructure heterogeneity
  - knowledge source heterogeneity
  - business process heterogeneity
  - new specific VE processes
- You need
  - infrastructure
  - mediation
  - dynamic workflow management
    - workflow as a service
  - workflow rules as coordination rules
    - coordination media as workflow engines
    - encapsulating workflows into run-time services

Objective vs. Subjective Coordination ...

Outline:

1. Introduction
2. Coordination: Overview
3. Subjective vs. Objective Coordination
4. Coordination and AOSE
5. Vision

Engineering the (Agent) Interaction Space

- Need for specific high-level abstractions and powerful mechanisms
  - to support the analysis, design and development of multiagent systems as far as *interaction* is concerned
  - Suggesting/supporting methodologies for the construction of open, distributed, heterogeneous, and mobile systems
  - Intrinsically providing systems with features of flexibility, security, support for heterogeneity, intelligence, …

Roles vs. Organizations

- In a multiagent system, agents must be enabled to inter-operate to fulfil their role in the system
- Globally, the interactions between the different roles have to follow specific rules for the overall organization to work correctly and efficiently

Individual vs. Social Tasks

- agents, as individuals, must be enabled to sense and affect their environment and the other agents living in that environment to survive and reach their own goals (*individual task*)
- the whole society, can't be left in anarchy, as it serves a more general – *supra-agent* – goals (*social task*).

Task-driven MAS Design

- Individual & Social Tasks
  - driving the design
- *Delegation of Responsibility*
  - agents (and societies) encapsulate control
- Impact on the Design
  - individual tasks ⇨ design of single agents
  - social tasks ⇨ design of
    - agent interaction protocols
    - agent interaction rules

Modelling Agent Societies

- Society = individuals + social rules
- Social laws rule behaviours and interactions
- Social law as coordination laws
- Agent society =

  agents + coordination abstractions

Designing Agent Societies

- Defining social task(s)
- Designing
  - social / individual roles
  - interaction protocols
  - social laws
- Choosing the suitable coordination
  - mechanism
  - model
  - pattern
- Designing society upon/around coordination
  - laws
  - invariant
  - media

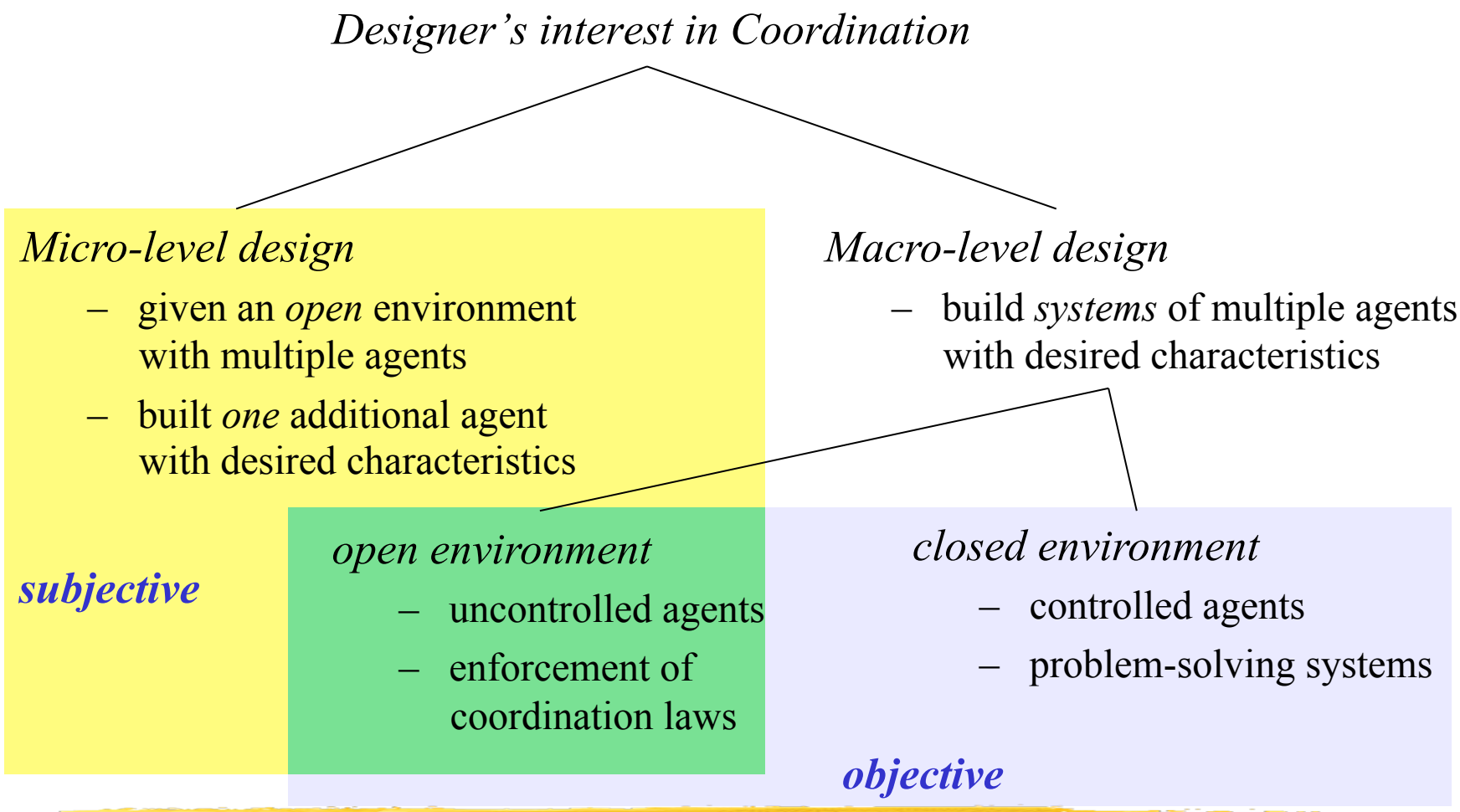
Developing Agent Societies

- Coordination technology
  - infrastructures, run-times
  - coordination as a service
- Coordination-specific IDE
  - monitoring / inspecting the interaction space
  - need for tools mapping abstractions into manageable metaphors

Society Design & Development: An Example

- Designing WF Participants as Agents
- Designing WFs as Agent Societies
- Designing WF Engines as Coordination Media
  - embodying WF rules as coordination rules
- Example: Using Tuple Centres as WF Engines
  - prescriptive / objective coordination approach
  - generative communication
    - inspectability of interactions
  - "generative coordination"
    - explicit representation of WF rules
    - inspectability of laws
    - incremental / dynamic modification
  - subjective issues
  - coordination technology / IDE

Subjective/Objective Coordination in Design

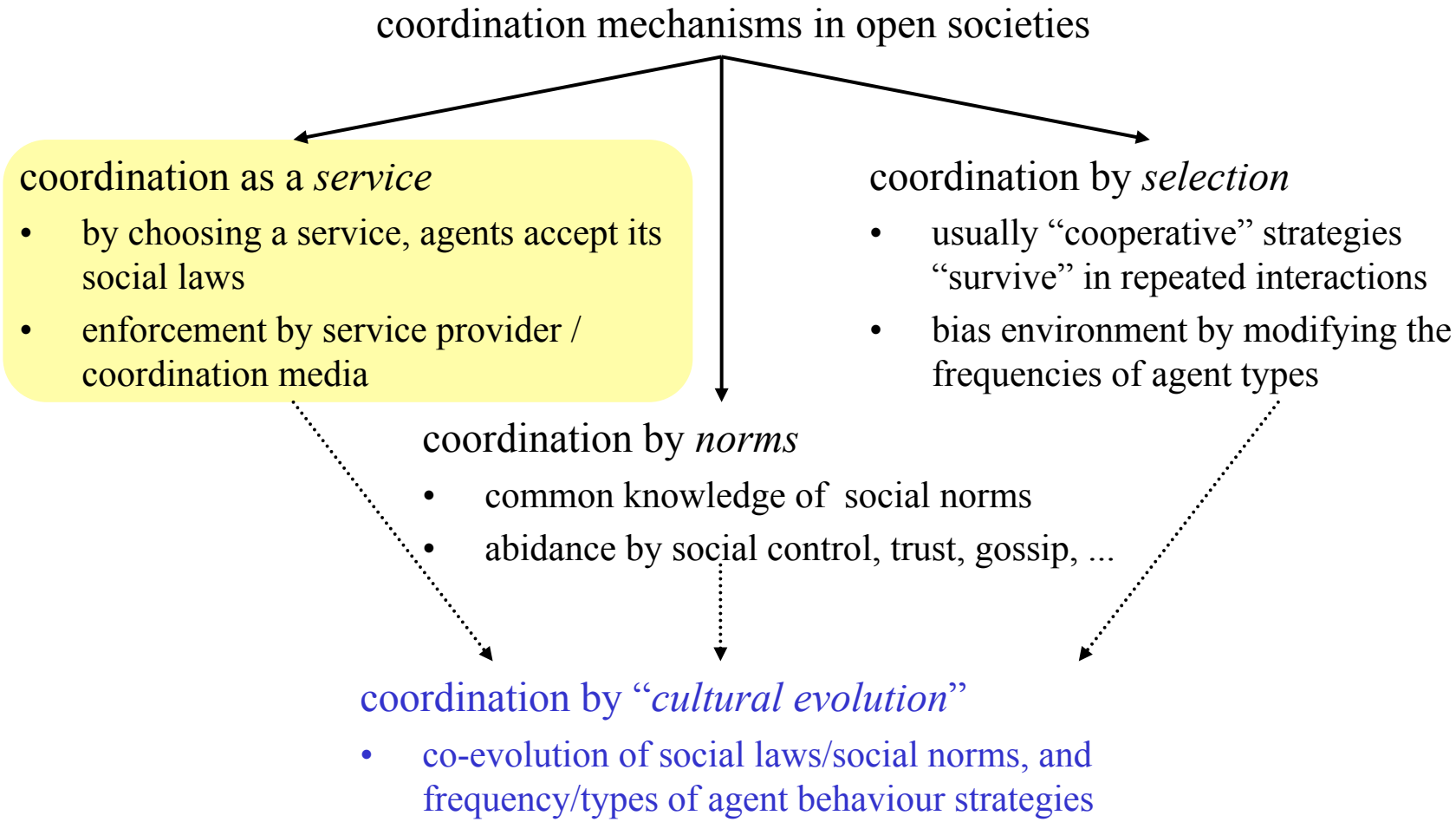


Objective vs. Subjective Coordination ...

Outline:

1. Introduction
2. Coordination: Overview
3. Subjective vs. Objective Coordination
4. Coordination and AOSE
5. Vision

Where do we go?



Bounded Coordination Context

- *control room* metaphor
- "forget about the agent"
- coordination laws: bounded interaction
  - *lights* and *screens* (for bounded inputs)
  - *buttons* and *microphones* (for bounded outputs)
- reversing the OO notion of interface
  - meta-level description of the boundaries
  - protocols for negotiating / paying for boundaries?

Design of social laws

- *Description* of social laws:
  - description language
  - enactment
- Global *effect* of social laws:
  - How to predict the influence of social laws to agent behaviour?
    - if social laws are too restrictive, agents won't choose the corresponding coordination service
    - if they are weak, it is not always clear in which direction they will bias the global system behaviour
  - mechanism design, libraries of social laws, . . .

Objective versus Subjective Coordination in the Engineering of Agent Systems

Andrea Omicini

DEIS

Università di Bologna

Sascha Ossowski

AI Group

Univ. Rey Juan Carlos, Madrid