Artefacts for Agents: Function and Use in MAS

Autonomous Systems
Sistemi Autonomi

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Academic Year 2017/2018

1. Artefacts: Multi-disciplinary Foundations
2. Agents & Artefacts: Definitions & Conceptual Framework

Next in Line...

1 Artefacts: Multi-disciplinary Foundations

2 Agents & Artefacts: Definitions & Conceptual Framework

Focus on...

1. Artefacts: Multi-disciplinary Foundations
   - Premises
   - Activity Theory
   - Distributed Cognition
   - Sociology
   - Computer Supported Cooperative Work
   - (Cognitive) Anthropology & Ethology
2. Agents & Artefacts: Definitions & Conceptual Framework
   - Agents & the A&A Meta-model
   - On the Notion of Artefact in A&A
   - MAS Engineering with A&A Artefacts
   - A&A Artefacts for Cognitive Agents
   - On the Notion of MAS in the A&A Meta-model

Multi-, Inter- Trans-Disciplinary Research

From multi- to trans-disciplinary research

- multi-disciplinary research means that multiple areas are involved in the same research activity—results are drawn from and concern different fields
- inter-disciplinary research means that models, methods and techniques are brought from one area to a different one—results mainly concern the latter area
- trans-disciplinary research means that models, methods and techniques are first brought from one area to a new one; then, once are suitably extended and generalised, results are brought back to the original area

Why X-Disciplinary Research? I

Convergence of scientific research

- complexity of systems (observed, modelled, constructed) is characterising more or less all of the human knowledge
- the same patterns in observable phenomena, system structure & behaviour, scientific models, methods, and techniques, occur repeatedly in many heterogeneous research fields

Why X-Disciplinary Research? II

Convergence towards MAS

- complexity of computational systems today matches complexity of biological, social, economical, organisational, . . . , systems
- results from other areas dealing with complex systems may be useful / important / essential for computational systems & MAS in particular
- results from computational systems & MAS are already changing the way in which scientific activity is conducted in every other areas

Questions to be Answered I

We already learned something...

- ... about the reasons behind the agent abstraction,
- as well as some of its features

However, before a complete and precise definition could be given, some issues have to be clarified

Questions to be Answered II

We have to understand...

- ...if agents are the next thing after objects, what happens to objects, then? What about the paradigm shift?
- ...as object-oriented systems are made of interacting objects, are multiagent systems made of interacting agents—only?
- ...if societies and environment are essential to agent-oriented systems, how should they be handled in MAS modelling and engineering?
- ...if agents have to act, which are the objects of their acting?

Finally, we would like to taste...

- ...the flavour of X-disciplinary research

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Activity Theory (AT) I

Origins of (cultural-historical) Activity Theory

- born in the context of Soviet Psychology
- rooted in the dialectic materialism by Marx & Engels
- mostly by the work by Lev Vygotsky (1926-62) [Vygotskiĭ, 1978]
- broadly speaking, AT is a very general framework for conceptualising human activities – how people learn, how society evolves – based on the concept of human *activity* as the fundamental unit of analysis

Activity Theory (AT) II

Activity Theory nowadays

- re-discovered and widely applied in Computer Science and related fields in the last years [Nardi, 1996]
- mostly in fields like Computer Supported Cooperative Work (CSCW) and Human Computer Interaction (HCI)
- brought to the MAS field by both Italian and Spanish groups
  - e.g., [Ricci et al., 2003]

Human Activity in AT

Main focus of AT

- AT focuses on *human activities*
- within a *social / organisational context*
- as separated by their respective (physical and ideal) *objects*

Collaborative activities in AT

- cooperation is understood as a *collaborative* activity
- a collaborative activity has *one objective*
- a collaborative activity is *distributed* onto *several actors*, who participate to the activity
- explicit norms and rules regulate the relationships among individual participants' work

Mediated Interaction in AT

Every human activity...

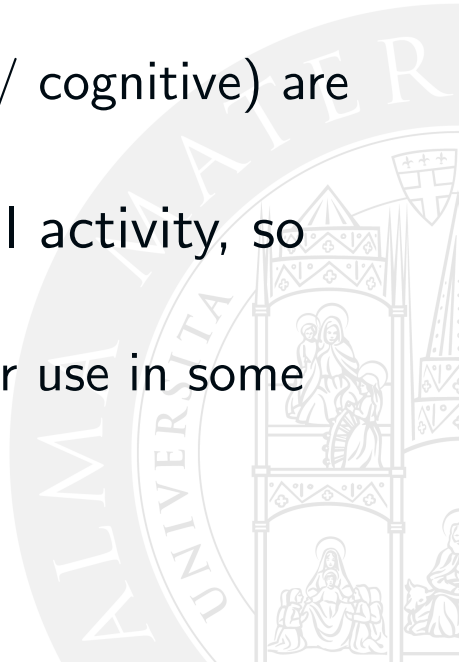
- ...is found to be mediated...
- ...by mediating artefacts...
- ...of heterogeneous nature, either physical or psychological
  - operating procedures, heuristics, scripts, languages, ...

Artefacts in AT

- artefacts are the tools that mediate actions and social interactions
  - artefacts mediate between individual participants and their environment
  - artefacts embody the portion of the environment that can be designed and controlled to support participants' activities
- as an observable part of the environment, artefacts can be monitored along with the development of the activities
  - to evaluate overall system performance and
  - to keep track of system history

Role of Artefacts in AT

- artefacts can be either physical or cognitive—or, they may have a twofold nature
  - example of physical artefacts are shelves, doors, phones, whiteboards, ...
  - example of cognitive artefacts are operating procedures, heuristics, scripts, languages, ...
  - examples of artefacts with a twofold nature (physical / cognitive) are operating manuals, computers, ...
- artefacts are both a means but also a product of social activity, so they embody a set of social practise
  - their design and structure reflect a history of particular use in some given social / organisational context



Artefacts as Enablers and Constrainers of Activities

- as mediating tools, artefacts have both an *enabling* and a *constraining* function

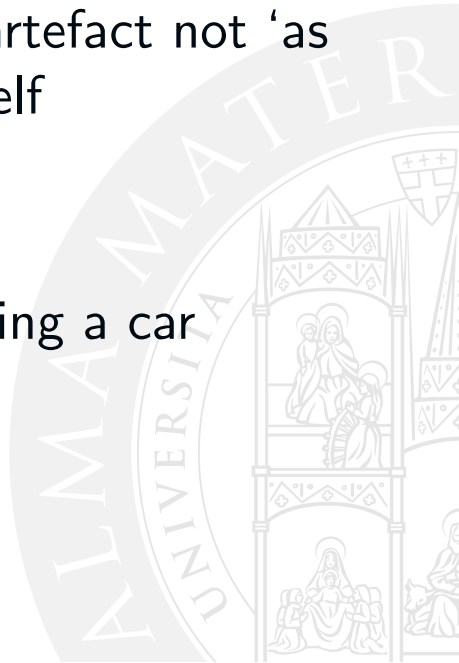
enablers: artefacts expand out possibilities to manipulate and transform different objects

constrainers: the object is perceived and manipulated through the artefact not 'as such' but within the limitations set by the artefact itself

- a simple example: a driving wheel

enabler: enables me to change direction while driving a car

constrainer: allows me only one way to change direction while driving a car

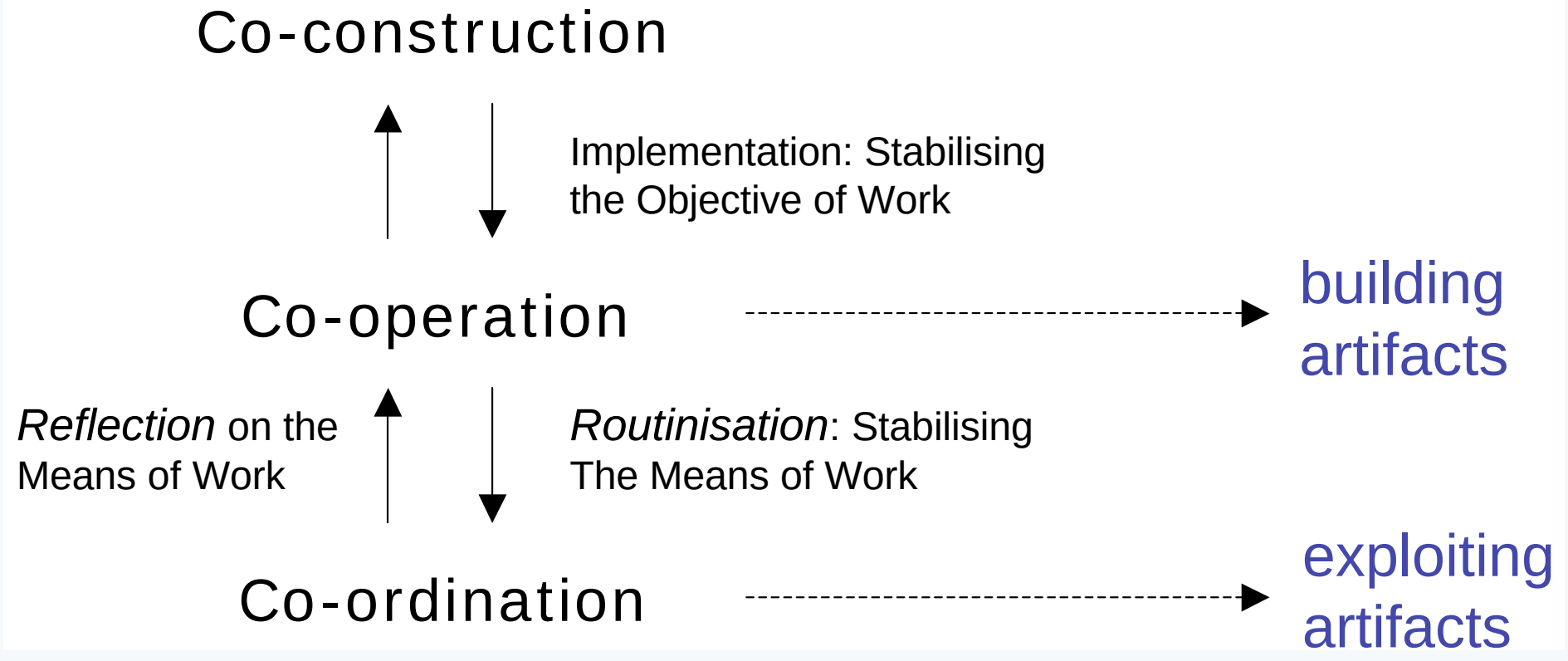


Layers for Collaboration Activities in AT I

- AT identifies a three-layered structure for social (collaborative) activities [Bardram, 1998, Engeström et al., 1997]
- the three layers are labelled as
  - co-ordinated
  - co-operative
  - co-constructive

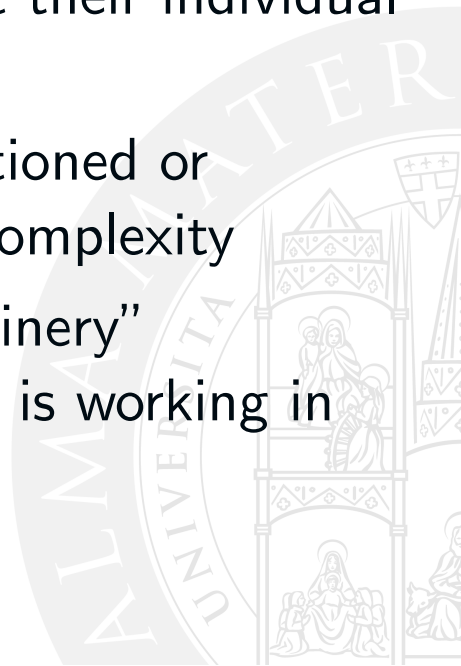
Layers for Collaboration Activities in AT II

AT Layers: The Picture



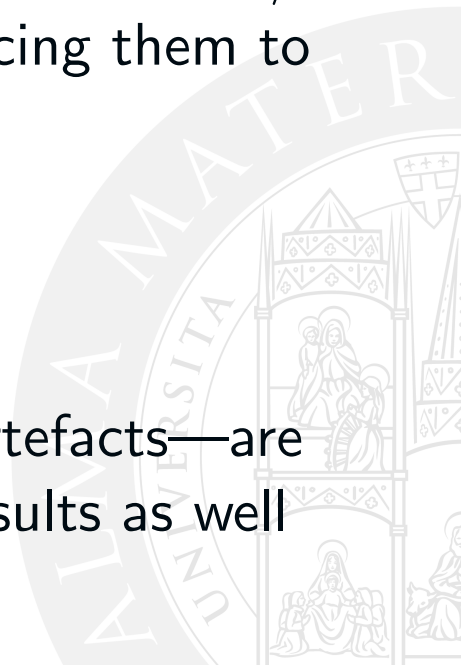
Co-ordination in AT

- the *co-ordinated* aspect of work captures the *normal* and routine *flow of interaction*
- participants follow their *scripted roles*, each focusing on the successful performance of their actions, implicitly or explicitly assigned to them
- participants share and act upon a common object, but their individual actions are only externally related to each other
- *scripts* coordinating participants' actions are not questioned or discussed, neither known and understood in all their complexity
- participants act as "wheels in the organisational machinery" [Kuutti, 1991], and co-ordination ensures that an activity is working in harmony with surrounding activities



Co-operation in AT

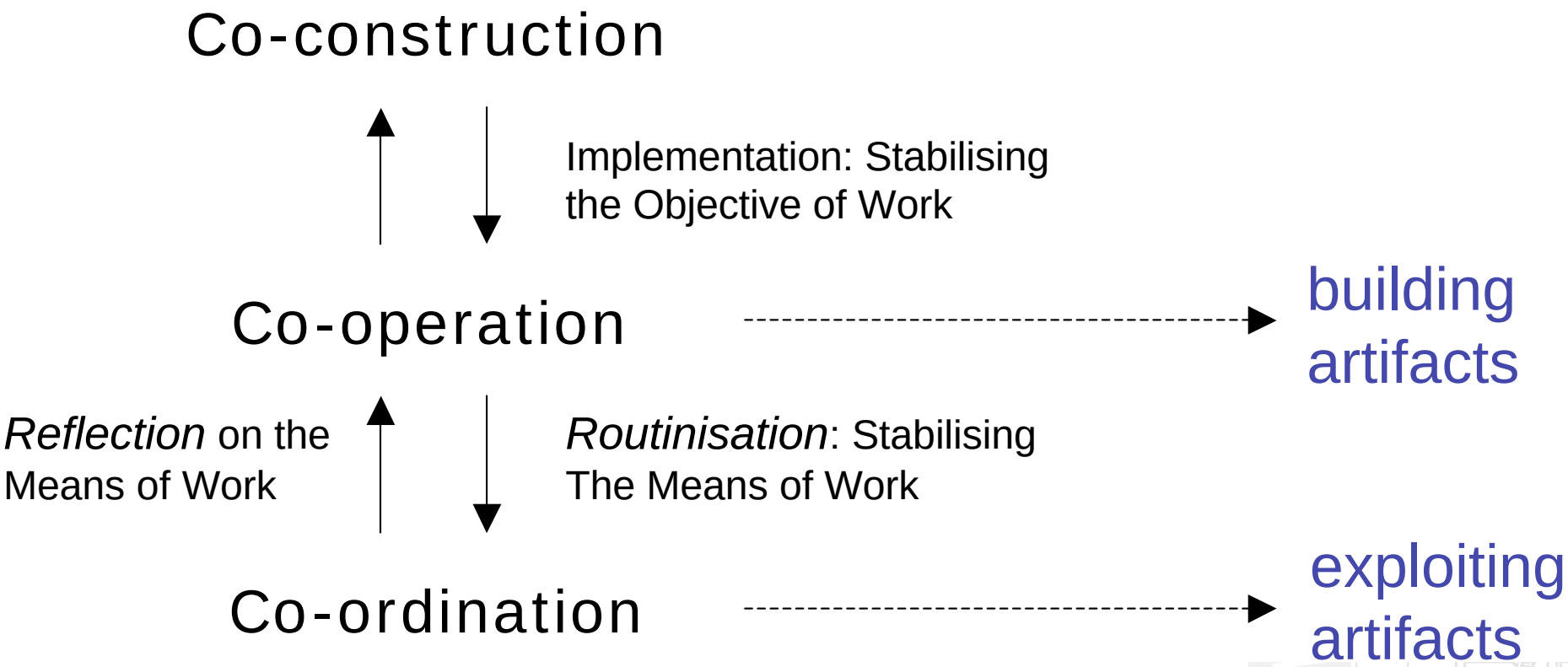
- the *co-operative* aspect of work concerns the mode of interactions in which actors focus on a common object, thus *share* the *objective* of the activity
- here, actors do not have actions or roles explicitly assigned to them
- with regard to the common object, each actor has to balance his/her own actions with other agent actions, possibly influencing them to achieve the common task
- at the co-operation level
  - the object of the activity is stable and agreed upon
  - the means for realising the activity is not yet defined
- the means for realising a collaborative activity—the artefacts—are then the *object* of the co-operative activity, and its results as well



Co-construction in AT

- the *co-constructive* aspect of work concerns interactions in which actors focus on re-conceptualising their own organisation and interaction in relation to their shared objects
- neither the object of work, nor the scripts are stable, and must be collectively constructed, i.e., *co*-constructed

AT Layers: Summing Up I



AT Layers: Summing Up II

Collaborative activities in AT

- a collaborative activity is not to be seen in general at one single level
- co-ordination, co-operation, and co-construction are instead to be interpreted as *analytical* distinctions of the same collaborative activity, concurring in different times and modes to its development

Agents are not the Only Abstractions Needed

Basic Abstractions: Agents plus Artefacts

- adopting AT as a conceptual framework for MAS social activities has led to recognise that *agents are not the only basic abstractions* to model and build MAS [Ricci et al., 2003]
- artefacts, too, are necessary [Ricci et al., 2006]
  - to enable and constrain agent actions
  - to mediate agent interactions with other agents and with the environment
  - to model and shape MAS *environment*
  - in general, to improve agent ability to achieve their individual and social goals

Relevance of AT Research in MAS I

Artefacts are essential—in MAS, too

- AT investigation is relevant in MAS since it points out that artefacts are essential to enable and govern agent actions and interactions within a MAS
  - by enhancing agent capabilities to act
  - by constraining both individual and social activities in a MAS

Relevance of AT Research in MAS II

Role of environment

- AT emphasises the fundamental role of the *environment* in the development of complex systems
- also, AT suggests that artefacts are the essential tools
  [Weyns et al., 2007, Viroli et al., 2005]
  - to model MAS environment
  - to shape it so as to make it favourable to the development of collaborative activities

Coordination Artefacts I

Artefacts for collaboration and coordination

- coordination artefacts are artefacts used in the context of collaborative activities, mediating the interaction among actors involved in the same social context [Ricci et al., 2003]
- coordination artefacts can be either embodied or disembodied, referring to respectively physically or cognitive/psychological artefacts
- coordination artefacts are social artefacts shared by agents in a MAS, which are meant to enable and govern the interaction among agents, and between agents and their environment

Coordination Artefacts II

Coordination artefacts & media

- coordination artefacts represent a straightforward generalisation of the notion of coordination medium, as coming from fields like coordination models and languages and distributed AI
- examples include abstractions like tuple spaces, channels, blackboards, but also pheromone infrastructures, e-institutions, ...

AT Layers for MAS Collaboration

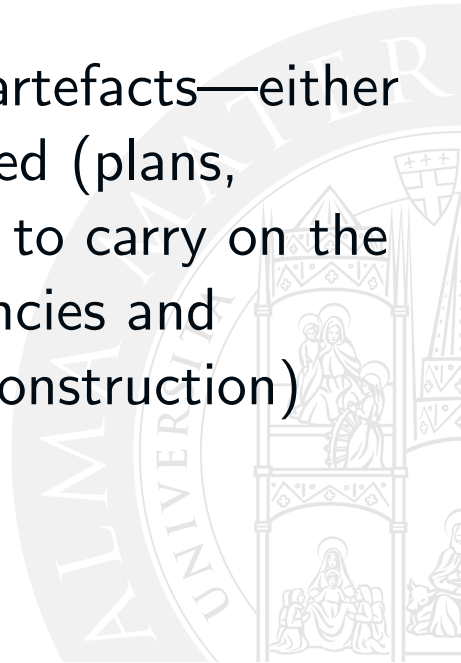
Layers for MAS collaboration & coordination artefacts

- the three levels identified by AT for social activities can be re-interpreted in the MAS context in terms of the relationship between agents and artefacts—in particular, coordination artefacts
- the three layers are labelled as
  - *co-ordination*
  - *co-operation*
  - *co-construction*

AT Layers for MAS in Detail I

co-construction — agents understand and reason about the (social) objectives (goals) of the MAS, and build up a model of the social tasks required to achieve them—this also involves identifying interdependencies and interactions to be faced and managed

co-operation — agents design and build the coordination artefacts—either embodied (coordination media) or disembodied (plans, interaction protocols, etc.)—which are useful to carry on the social tasks and to manage the interdependencies and interactions devised out at the previous (co-construction) stage



AT Layers for MAS in Detail II

co-ordination — agents use the coordination artefacts: then, the activities meant at managing interdependencies and interactions—either designed a-priori or planned at the co-operation stage—are enforced/automated

Levels of Use of Artefacts I

Co-ordination

both intelligent and non-intelligent agents could coordinate

Any agent (either intelligent or not) can simply exploit artefacts to achieve its own goals by simply taking artefacts as they are, and use them

Levels of Use of Artefacts II

Co-operation

intelligent agents could change artefacts to change MAS

Intelligent agents could possibly reason about the nature of the artefacts as well as on the level of achievement of their goals, and take the chance to change or adapt the artefacts, or even to create new ones whenever useful and possible as the result of either an individual or a social activity

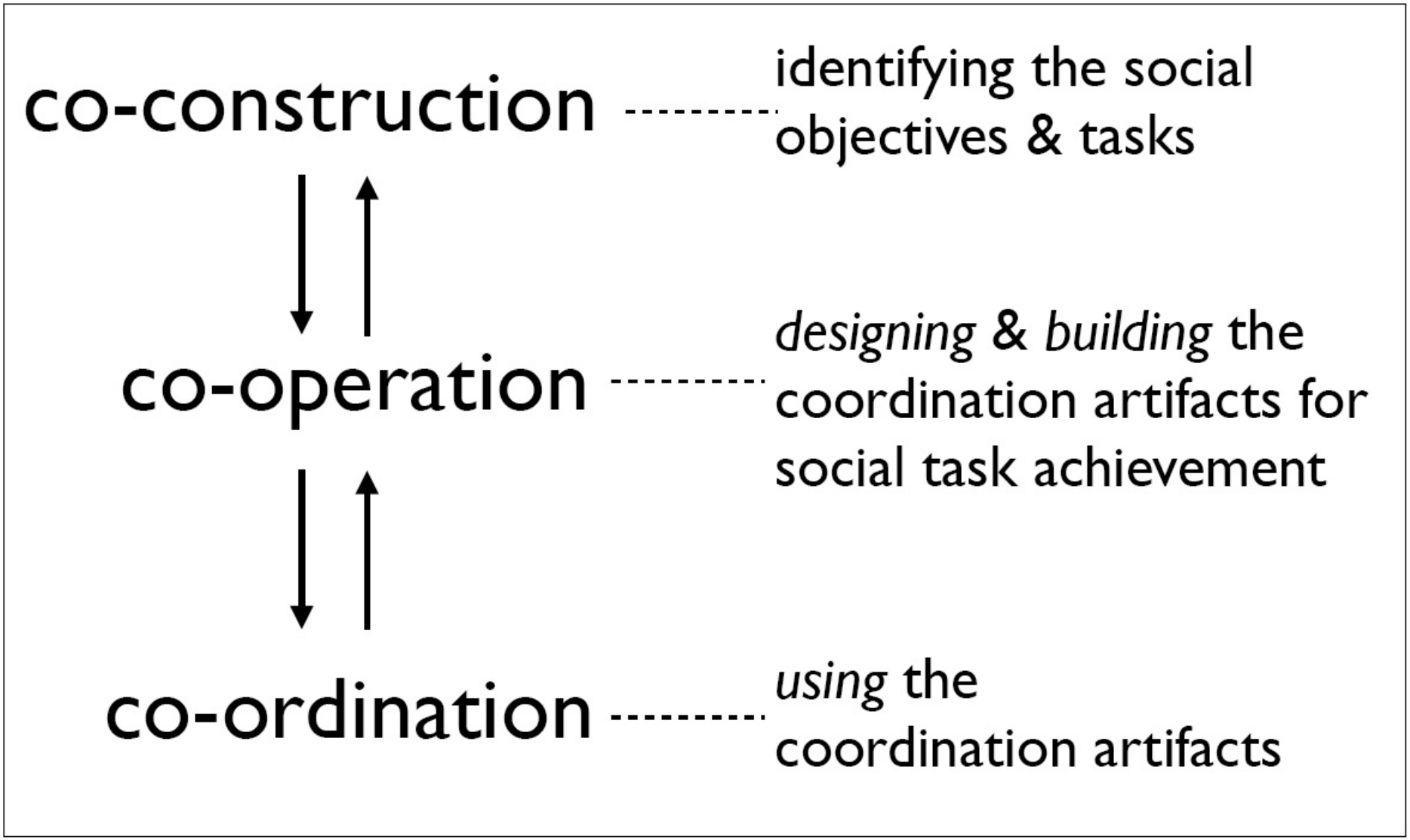
Levels of Use of Artefacts III

Co-operation

MAS engineers could embody social intelligence in artefacts

In the same way, MAS engineers can use artefacts to embody the "social intelligence" that actually characterises the systemic/synergistic (as opposed to compositional) vision of MAS [Ciancarini et al., 2000], but also to observe, control, and possibly change MAS social behaviour

AT Layers for MAS Collaboration: The Picture



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Distributed Cognition in Short

Distributed cognition... [Kirsh, 1999]

- ...is a branch of cognitive sciences
- which proposes that *human cognition* and *knowledge representation*
  - rather than solely confined within individuals
  - is *distributed* across individuals, tools and *artefacts* in the *environment*

Cognition is Distributed I

Cognition transcends individuals

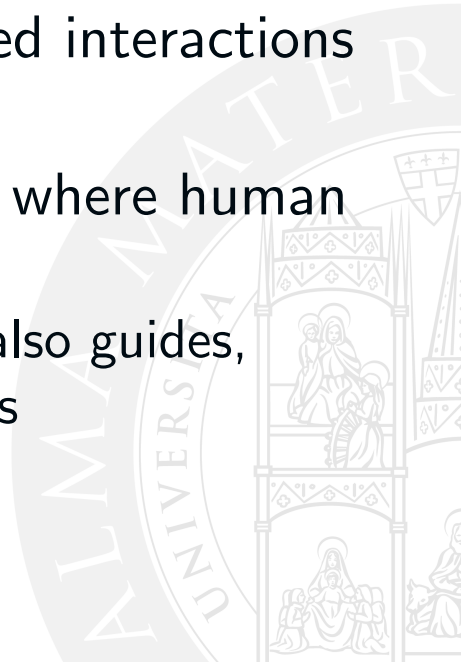
- intelligent processes in human activity go beyond the boundaries of individual actors
- knowledge is not confined within human minds
- cognition transcends individual cognition

Knowledge representation transcends individuals

- knowledge representation does not pertain individual humans only
- representation is distributed
  - partially in the mental spaces of humans
  - as external representations of memories, facts, and information of any sort distributed on the objects, tools and instruments that constitute the environment

Distributed Cognitive Systems

- analysis of distributed cognition focuses on *distributed cognitive systems*
- people interact with external cognitive artefacts containing knowledge represented in some form
- human *intelligent behaviour* results from the distributed interactions with other humans and with cognitive artefacts
- in the overall, this defines and determines the context where human activities are *situated*
  - that is, the physical, cultural and social context that also guides, constrains and partially determines intelligent activities



Cognitive Artefacts

Cognitive artefacts: a definition [Norman, 1992]

those artificial devices that maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance

Cognitive artefacts are. . .

- . . . a product of human design and work
- . . . aimed at aiding or enhancing our cognitive abilities
  - like post-its, calendars, agendas, computers, etc.
- . . . not mere amplifiers of our cognitive abilities
  - cognitive artefacts also modify the nature of the tasks to be performed

Personal vs. System View

System view

Individuals plus artefacts altogether as a (functional) subsystems

- understanding activities requires to consider (cognitive) actors and (cognitive) artefacts altogether
- actions are sometimes mediated sometimes targeted to artefacts, and cannot be fully understood without them

Personal view

Individuals as subsystems affected by artefacts

- practical reasoning is deeply affected by artefacts
- individuals should change the way in which they represent actions, plan, deliberate and finally act

Environment in Distributed Cognitive Systems I

Environment has a key role in distributed cognitive systems

- in distributed cognitive systems, the nature of the environment
  - on the one hand, depends on the artefacts and tools that shape it
  - on the other hand, determines the efficiency and effectiveness of the work and activities of the actors that are immersed in it

Work environment

- how do we define a working environment for individuals and organisations?
  - it mostly depends on the tasks that have to be carried on inside
- real work environments are a complex superposition of social, cultural, cognitive, and physical constraints
- how should the environment be understood as a complex analytical construct when the goal is environment design?

Coordination in Distributed Cognitive Systems

Observing real world activities

- an effective environment for a successful activity is a shifting coalition of resources and constraints
  - some physical, some social, some cultural, some computational
  - involving both internal and external computational resources
- activity is successful whenever such a coalition is suitably coordinated
  - lack of coordination means failure of activity
- coordination is then essential, and concerns activities, resources and constraints
  - at both the individual and the social level

The Function of Action in Distributed Cognitive Systems I

What is the purpose of an activity?

- a dominant assumption is that the point of activity is to change the environment in a way that (presumably) leads to goal satisfaction
- many action however do not make sense under this assumption
  - most communication actions, but not only them
  - for instance, people undertake actions to save attention, memory and computation; people recruit external elements to reduce their own cognitive effort by distributing computational load
  - this make sense if people is situated
- as a result, environment design should not merely be aimed at helping people to achieve their goals
  - it should also be designed to make other actions easy
  - such as epistemic, complementary, coordinative actions

Cognition outside Agents

- cognition & knowledge representation do not belong to agents only
  - objects & tools in the environment may participate to the cognitive processes
  - structure of MAS environment may explicitly represent knowledge
- cognition & knowledge representation are distributed in the environment
  - artefacts are essential parts of the MAS cognitive processes
  - cognitive artefacts encapsulate knowledge as explicitly represented

Agent View vs. MAS View

Personal / agent view

- once artefacts are exploited, they change the way in which agents act and reason about action

System / MAS view

- in order to understand and possibly evaluate agent (social) action within a MAS, one should consider agent(s)+artefact(s) altogether

MAS Environment is Structured

(Cognitive) artefacts shape MAS environment

- artefacts determine the structure of MAS environment
- knowledge is distributed in the environment, and encapsulated within cognitive artefacts
- structure of the environment, and knowledge it contains, affect the activities of agents within MAS

MAS Action & Coordination

MAS coordination depends on environment structure

- environment structure changes the nature of agent action
- environment structure affects agent mutual interaction
- environment structure modifies the way agents coordinate in a MAS
- environment structure should be designed to
  - help agent actions to achieve their goals
  - help epistemic, complementary, coordinative agent actions easier / effective

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Agents & Goals I

Cognitive interpretation of (social) action [Conte and Castelfranchi, 1995]

- agents in a society can be generally conceived as either *goal-governed* or *goal-oriented* entities
  - goal-governed entities refer to the strong notion of agency, i.e. agents with some forms of cognitive capabilities, which make it possible to explicitly represent their goals, driving the selection of agent actions
  - goal-oriented entities refer to the weak notion of agency, i.e. agents whose behaviour is directly designed and programmed to achieve some goal, which is not explicitly represented
- in both cases, agent goals are *internal*

Agents & Goals II

External goals

- *external goals* refer to goals that typically belong of the social context or *environment* where the agents are situated
- external goals are sorts of regulatory states which condition agent behaviour
  - a goal-governed system follows external goals by adjusting internal ones

Entities without Goals

Not every entity involved in (social) actions has a goal

- within a society, there are entities that are explicitly designed to provide a *function*
- *artefacts* are such objects
  - they have a function associated
- artefacts have no goals to achieve
  - they may have a *destination* associated
    - a *destination* is external goal attached to an artefact by an agent, in the act of using it
  - destination is then associated to the *use* of an artefact
    - destination is related but not identical to function: an artefact can be used according to a destination that differs from its designed function

On the Relation Between Agents & Artefacts

Use & use value [Conte and Castelfranchi, 1995]

- when facing an artefact, an agent may adopt different perspectives
- evaluating an artefact for use, to select it among many others, and then to use it, to achieve agent's own goals, are two different matters
- different sorts of external goals are associated by an agent to an artefact

use value the *use-value* goal, according to which the artefact should allow user agents to achieve their objective—this drives the agent *selection* of the artefact

use the *use* goal, which directly corresponds to the agent internal goal—this guides the actual *usage* of the artefact

Articulating the Agents & Artefacts Relationship

How could an agent deal with an artefact?

- there are at least three different ways an agent can exploit an artefact

use by merely using it, according to its function, and associating it to a destination

selection by selecting it for future use, according to its function, its possible future destinations, and the agent's goals and plans

construction & manipulation by adapting & changing an existing artefact, or by creating a new one for future use, thus designing its function, according to its possible future destinations, and the agent's goals and plans

Goals in MAS

Agents have goals

strong agency Agents have explicitly-represented goals

weak agency Agents have implicitly-represented / encoded goals

Artefacts have functions

- artefacts have no internal goals
- artefacts have a pre-designed function
- an artefact is associated with an external goal (its destination) by agents in the act of using it

Agents & Artefacts Interacting I

Aspects of agent-artefact relationship

use an agent can use an artefact, according to its use goal, associating it with a destination

- **aware use** because the agent is aware of the artefact's function
- **unaware use** because the artefact's use is encoded in the agent by the programmer / designer

selection an agent can select an artefact for future use, according to its use-value goal, reasoning about its possible future destinations and use goals

construction / manipulation an agent can modify an artefact to adapt its function to some required use-value goals and to its possible future destinations

- or, an agent can create *ex-novo* a new artefact with an agent-designed function according to some required use-value goals and to its possible future destinations

MAS Engineers Designing Agents

Basic choices to make in agent design

- should an agent be aware of artefact's behaviour and structure, and of how to use them?
  - should an agent be able to reason and deliberate about artefact use?
- should an agent be aware of artefact's function and possible uses?
- should an agent be able to act over artefacts to modify them and adapt their function?
  - should an agent be able to create *ad hoc* artefacts *ex novo*?
- should a MAS engineer be able to act over artefacts to modify them and adapt their function, or, to create new artefacts, *at run-time*?

MAS Engineers Designing Artefacts

Basic issues in artefact design

- how should an artefact be made in order to be ready for agent's use?
  - either aware, or unaware
  - possibly, within an open system
- how should an artefact be made in order to be ready for agent's evaluation and selection?
- how should an artefact be made in order to be ready for agent's modification and adaptation?
- how should MAS environment be structured in order to allow artefact run-time creation and modification?
  - by agents and MAS engineers?

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Computer Supported Cooperative Work (CSCW)

Basic issues in CSCW

- CSCW aims at automating human cooperative work through computational procedures
- however, two diverging strategies were observed emerging
  [Schmidt and Simone, 2000]

  automation stressing computational procedures to automate coordination of activities

  flexibility stressing the flexibility of computational procedures with respect to intelligent coordination by collaborating actors
- the former approach emphasises coordination by the computational entities ruling collaboration, the latter coordination by intelligent collaboration entities
- main problem: the two strategies *diverge*, they should instead *converge*

Automation vs. Flexibility: Key Issues in CSCW I

Mutual awareness for flexibility

- *mutual awareness* means that the actors of a collaboration activity affect and mutually perceive the other actor's activities through the shared workspace
- the so-called *common field of work* can reveal / conceal portions of the collaboration activities to the participants
- mutual awareness is then the basis for opportunistic, *ad hoc* alignment and improvisation, which ensure *flexibility* to collaborative activities

Automation vs. Flexibility: Key Issues in CSCW II

Coordinative artefacts for automation

- coordinative artefacts are the rulers of collaboration
- they work more as *constrainers* rather than as *commanders*
- by giving structure to the common field of work, coordinative artefacts encapsulate those coordination responsibilities that are better to be *automatised* in order to achieve efficiency in cooperation
- in all, coordinative artefacts

  work as constrainers they define and govern the space of the admissible articulation of activities

  work *not* as commanders they do not impose a pre-defined course of actions that could cause unnecessary rigidity and reduce the required flexibility

Automation of Collaboration Activities in MAS

Coordinative artefacts for automation of MAS collaboration

- *coordinative artefacts* rule MAS collaboration, working more as constrainers rather than as commanders
- coordinative artefacts structure MAS common field of work, as specialised abstractions automatising and making collaboration efficient
- as constrainers, coordinative artefacts define and govern the space of the admissible articulation of MAS collaboration activities
- on the other hand, they do not impose a pre-defined course of actions, promoting flexibility of intelligent agent coordination, and respecting agent autonomy

Flexibility of Collaboration Activities in MAS

Mutual awareness for flexibility of MAS collaboration

- shared MAS environment should be structured as the MAS *common field of work* to allow agents to mutually perceive each other's activities (*mutual awareness*)
- MAS common field of work can reveal / conceal portions of MAS collaboration activities to the agents
- mutual awareness promotes opportunistic alignment and improvisation of agent activities, and ensure *flexibility* to MAS collaboration

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   - On the Notion of Artefact in A&A
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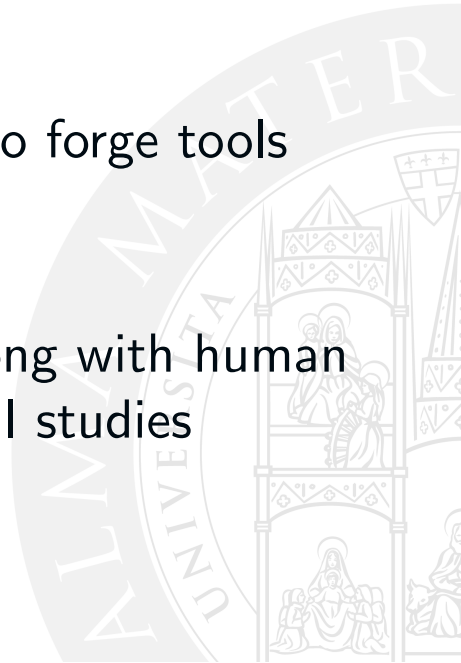
Anthropology: The Logocentric Philosophical Bias

- human capacity of language as the main sign of intelligence?
  - Western anthropology has long dwelt on such a point
  - the relation between language, use of tools, and evolution of intelligence has long been neglected [Hewes, 1993]
- human capacity of developing and using tools as a fundamental sign of intelligence
  - humans forge & use tools
  - the first characterisation of *Homo Abilis* is its ability to forge tools
    - tool using vs. tool making distinction
  - this is a clear sign of intelligence
  - evidence of co-evolution of language and tools use along with human intelligence is overwhelming in modern anthropological studies [Gibson and Ingold, 1993]



Ethology: Tools, Animals, and the Tooling Test

Use of tools is not an exclusive feature of humans

- beavers build dams, bees construct perfect hexagonal cells, many birds live in self-made nests, ...
- ethologists commonly measure intelligence of animals by making them face problems that require the use of tools to be solved—e.g., [Povinelli, 2000]
- a sort of tool-equivalent of the Turing test has been proposed by philosopher Ronald Endicott, which was aimed at evaluating intelligence in terms of the ability to exploit tools
  - the so-called "Tooling Test for Intelligence" [Wood et al., 2005]

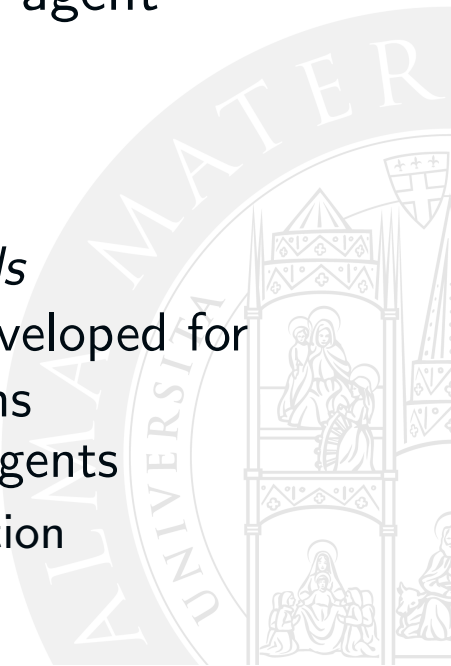
Anthropology from Theologists: Tools & Self-Awareness

Use of tools reveals awareness of self [Martelet, 1998]

- when using a tool, a creature shows it is able to distinguish and identify itself from the world around
- the use of a tool *reveals awareness* of self, and of the environment as well
  - whenever a tool is built with a goal, it is stored for further / repeated use, it is used for building new tools, etc.
- tools are at the same time the first and the most distinctive *expression of human intelligence*, along with language
- they are the most powerful amplifiers of the (both individual and social) *human ability to affect the environment*—to survive environment change, first, and to change the environment for the human purposes, then

The Logocentric Philosophical Bias in MAS

- agent capacity of language as the main sign of agent intelligence?
  - research on MAS still dwells on the *logocentric bias*
  - intelligent *use of tools by agents* is typically neglected
    - as a stunning example, FIPA (Foundation for Intelligent Physical Agents) just ignore pragmatic / physical agent actions, and only focuses on agent communication actions
- agent ability of developing and using tools as a sign of agent intelligence
  - a notion of *tool* for agents is needed
  - agents should be *able to use tools*
  - intelligent agents should be *able to forge & adapt tools*
  - a theory of physical / pragmatical action should be developed for agents, as refined as the one for communication actions
  - such a theory should focus on tool use / creation by agents
    - the notion of *Agens Faber* goes along this very direction [Omicini et al., 2006]



Tools, Agents, and the Tooling Test

Use of tools should be a feature for agents in a MAS

- MAS researchers should be able to measure intelligence of agents by making them face problems that require the use of tools to be solved
- a sort of tool-equivalent of the Turing test for agents using tools should be defined, aimed at evaluating agent intelligence in terms of the ability to exploit tools
  - a sort of "Tooling Test for Agent Intelligence"
- agent intelligence should then be measured by both the agent ability to communicate and by agent ability to use tools
  - the two abilities should be somehow strictly related, and "co-evolve" in some sense—a common theory of agent action could be of use here

Next in Line...

1 Artefacts: Multi-disciplinary Foundations

2 Agents & Artefacts: Definitions & Conceptual Framework

Focus on...

1. Artefacts: Multi-disciplinary Foundations
   - Premises
   - Activity Theory
   - Distributed Cognition
   - Sociology
   - Computer Supported Cooperative Work
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2. Agents & Artefacts: Definitions & Conceptual Framework
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The A&A Meta-model

A&A: A conceptual framework for MAS modelling & engineering

Based on the conceptual foundations discussed in the previous block of slides, the A&A meta-model is a conceptual framework characterised in terms of three basic abstractions [Omicini et al., 2008]:

agents represent pro-active components of the systems, encapsulating the autonomous execution of some kind of activities inside some sort of environment

artefacts represent passive components of the systems such as resources and media that are intentionally constructed, shared, manipulated and used by agents to support their activities, either cooperatively or competitively

workspaces are the conceptual containers of agents and artefacts, useful for defining the topology for the environment and providing a way to define a notion of locality

Reminder: Agents in the A&A Meta-model

Definition (A&A Agent)

An A&A agent is an *autonomous computational entity*

genus agents are computational entities

differentia agents are autonomous, in that they encapsulate control along with a criterion to govern it

A&A agents are *autonomous*

- from autonomy, many other features stem
  - autonomous agents *are* interactive, social, proactive, and situated;
  - they *might* have goals or tasks, or be reactive, intelligent, mobile
  - they live within MAS, and *interact* with other agents through *communication actions*, and with the environment with *pragmatical actions*

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Artefacts in the A&A Meta-model

Definition (A&A Artefact)

An A&A artefact is a *computational entity* aimed at the *use* by A&A agents

genus artefacts are computational entities

differentia artefacts are aimed to be used by agents

Artefacts are *to be used* by agents

- from use, many other features stem
  - which are either essential or desirable, but need not to be used as definitory ones

Artefacts have a Function I

Artefacts are designed for use

- being *aimed at* the agent's *use*, artefacts are *designed* to serve some purpose
  - and built as such
- when designed, they are then associated by design to their *function*
- artefact function does not necessarily determine the actual use of the artefact by an agent
  - however, it incorporates the *aim* of the artefact designer, envisioning the artefact as potentially serving agent's purposes

Artefacts have a Function II

Artefacts are transparent & predictable

transparency in order to be used by agents, artefact function should be available to / understood by agents

predictability in order to promote agent's use, artefact behaviour should be predictable

Artefacts are not Autonomous

Artefacts are designed to serve

- artefacts are designed to *serve* some agent's purpose
  - not to follow their own path of action
- an artefact has an embodied function, made repeatedly and predictably available to agents
- an artefact is a tool in the "hands" of agents
  - it does not need to be self-governed, it just has to be "governed" by agents when they use it

Artefacts are (Computationally) Reactive

Artefacts are *reactive* in terms of control

- artefacts behave in response to agent use
  - the behaviour of an artefact just needs to emerge when it is used by an agent
- in terms of control, an artefact just needs to be *reactive*
  - or, to behave as it were
- what about reaction to change?
  - should artefacts be reactive to environment change?

Artefacts have Operations and Interfaces

Agents use artefact operations

- in order to be used, artefacts should make *operations* available to agents
- operations change an artefact's state, make it behave and produce the desired effects on the environment
- either explicitly or implicitly, an artefact exhibits its *interface* to agents, as the collection of the operations made available

Artefacts are Situated

Artefacts & Agent Actions

- being used, artefacts are the primary target / means of agent's action
  - action is what makes agents strictly coupled with the environment
- artefact's function is expressed in terms of change to the environment
  - what the artefact actually *does* when used
- artefact's model, structure & behaviour are *expressed* in terms of agent's actions and *environment*
  - artefacts are *situated*

Artefacts are reactive to change

- along the same line used for agents, artefacts are then supposedly *reactive to change*
  - since they are structurally reactive in computational terms, this comes for free—unlike (proactive) agents

Artefacts Are Not Agents

Agents vs. artefacts

- agents are autonomous, artefacts are not
- agents encapsulate control, artefacts do not
- agents are proactive, artefacts are not
- agents are opaque, artefacts are transparent
- artefacts are predictable, agents are not
- agents may have a goal / task, artefacts do not
- artefacts have a function, agents have not
- agents use artefacts, but cannot use agents
- agents speak with agents, but cannot speak with artefacts
- agents are designed to govern, artefacts are designed to serve

Artefacts in the A&A Meta-model

Definition (A&A Artefact)

An A&A artefact is a *computational entity* aimed at the *use* by A&A agents

genus artefacts are computational entities

differentia artefacts are aimed to be used by agents

Artefacts are *to be used* by agents

- from use, many other features stem
  - artefacts have a function, are computationally reactive, are situated and reactive to change, are not autonomous, are transparent and predictable, have operations and interface for agent's use
  - artefacts are not agents

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Artefacts & Environment I

Artefacts as mediators

- artefacts mediate between agents and the environment
- artefacts embody the portion of the environment that can be designed and controlled to support MAS activities

Artefacts as representatives of MAS environment

- as an observable & controllable part of the environment, artefacts can be monitored along with the development of MAS activities
  - to evaluate overall MAS performance
  - to keep track of MAS history
  - to influence MAS behaviour and evolution

Artefacts & Environment II

Artefacts for environment design

- artefacts are the essential tools
  - for modelling MAS environment
  - to shape MAS environment so as to make it favourable to the development of MAS social activities

Artefacts as Enablers and Constrainers of MAS Activities

- as mediating tools, artefacts have both an *enabling* and a *constraining* function

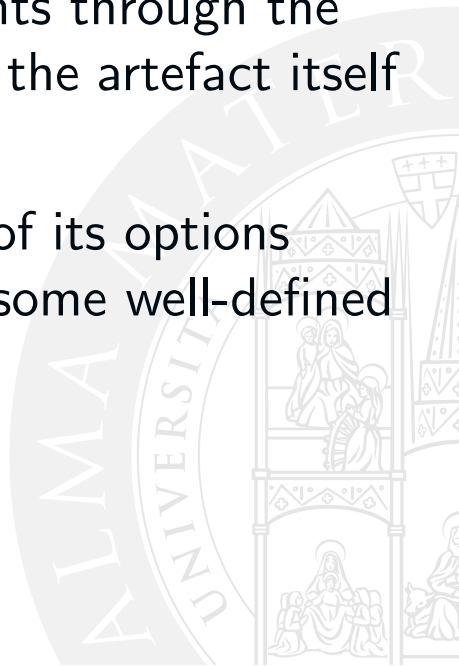
enablers: artefacts expand out agent's ability to manipulate and transform different objects

constrainers: the environment is perceived and manipulated by agents through the artefact not 'as such' but within the limitations set by the artefact itself

- a simple example: an agent-oriented printer driver

enabler: enables agents to use a printer, along with a number of its options

constrainer: limits in general agent interaction with the printer to some well-defined interaction patterns



Desirable Features of A&A Artefacts

How do we like artefacts?

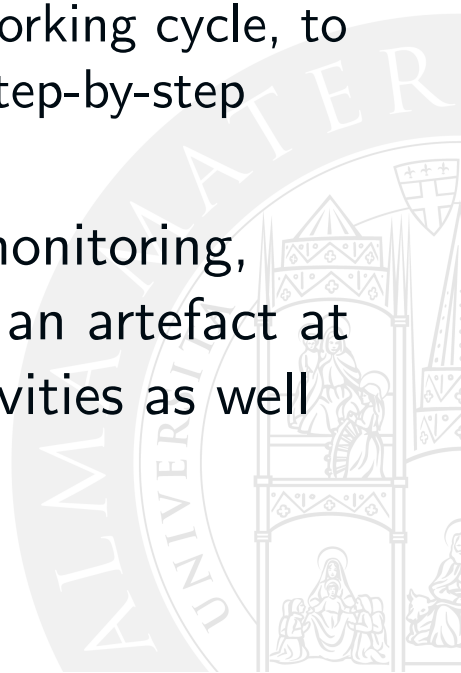
- artefacts could exhibit a number of relevant features, which would in principle enhance MAS engineers / agents ability to use them for their own purposes [Omicini et al., 2006]
  - *inspectability*
  - *controllability*
  - *malleability / forgeability*
  - *predictability*
  - *formalisability*
  - *linkability*
  - *distribution*

A&A Artefacts: Inspectability

- the state of an artefact, its content (whatever this means in a specific artefact), its operations, interface and function might be all or partially available to agents through inspectability
- whereas in closed MASs this information could be hard-coded in the agent—the artefact engineer develops the agents as well—, in open MASs third-party agents should be able to dynamically join a society and get aware at run-time of the necessary information about the available artefacts
- also, artefacts are often in charge of critical MAS behaviour [Omicini et al., 2004a]: being able to inspect a part or the whole of an artefact features and state is likely to be a fundamental capability in order to understand and govern the dynamics and behaviour of a MAS

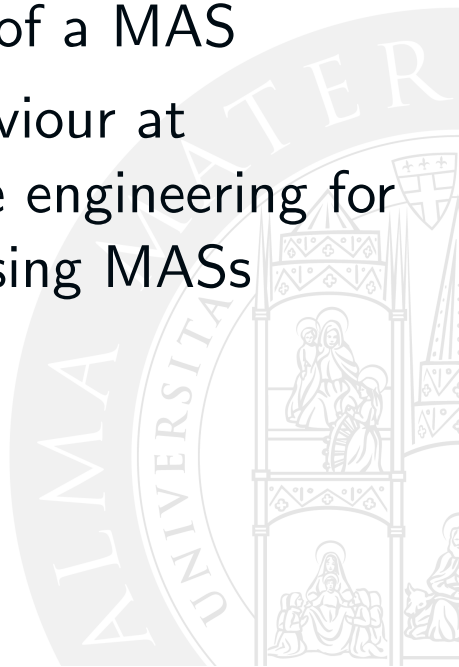
A&A Artefacts: Controllability

- controllability is an obvious extension of the inspectability property
- the operational behaviour of an artefact should then not be merely inspectable, but also *controllable* so as to allow MAS engineers (or even intelligent agents) to monitor its proper functioning
  - it should be possible to stop and restart an artefact working cycle, to trace its inner activity, and to observe and control a step-by-step execution
- in principle, this would largely improve the ability of monitoring, analysing and debugging the operational behaviour of an artefact at execution time, and of the associated MAS social activities as well



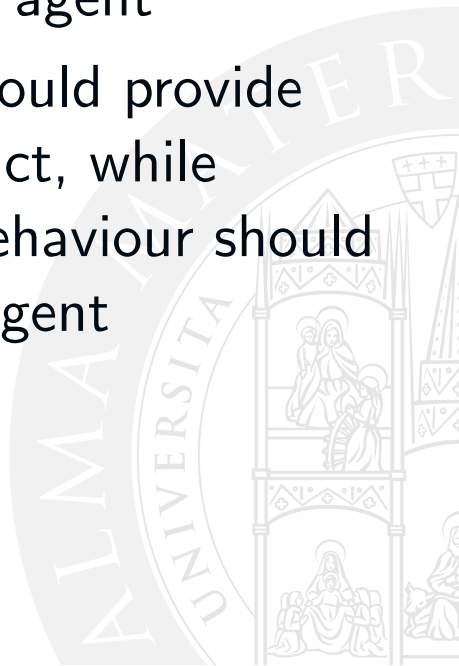
A&A Artefacts: Malleability

- also related to inspectability, malleability (also called *forgeability*) is a key-feature in dynamic MAS scenarios, when the behaviour of artefacts could require to be modified dynamically in order to adapt to the changing needs or mutable external conditions of a MAS
- malleability, as the ability to change the artefact behaviour at execution time, is seemingly a crucial aspect in on-line engineering for MASs, and also a perspective key-issue for self-organising MASs



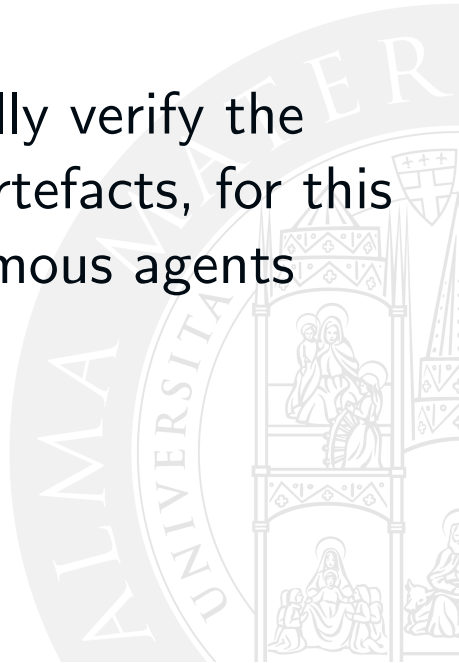
A&A Artefacts: Predictability

- differently from agents—which as autonomous entities have the freedom of behaving erratically, e.g. neglecting messages—, artefact operations, interface and function description can be used as the stable basis for a contract between an artefact and an agent
- in particular, the description of the artefact function could provide precise details of the outcomes of exploiting the artefact, while description of the artefact operations, interface and behaviour should make the behaviour of an artefact predictable for an agent



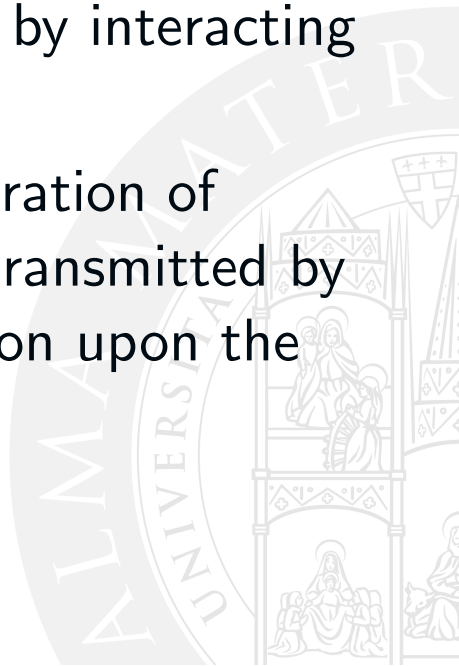
A&A Artefacts: Formalisability

- the predictability feature can be easily related with formalisability
- due to the precise characterisation that can be given to an artefact behaviour, until reaching e.g. a full operational semantics model—for instance, as developed for coordination artefacts in [Omicini et al., 2004b]—it might be feasible to automatically verify the properties and behaviour of the services provided by artefacts, for this is intrinsically easier than services provided by autonomous agents



A&A Artefacts: Linkability

- artefacts can be used encapsulate and model reusable services in a MAS
- to scale up with complexity of an environment, it might be interesting to compose artefacts, e.g. to build a service incrementally on top of another, by making a new artefact realising its service by interacting with an existing artefact
- to this end, artefacts should be able to invoke the operation of another artefact: the reply to that invocation will be transmitted by the receiver through the invocation of another operation upon the caller



A&A Artefacts: Distribution

- differently from an agent, which is typically seen as a point-like abstraction conceptually located to a single node of the newtwork, artefacts can also be distributed
- in particular, a single artefact can in principle be used to model a distributed service, accessible from more nodes of the net
- using linkability, a distributed artefact can then be conceived and implemented as a composition of linked, possibly non-distributed artefacts—or viceversa, a number of linked artefacts, scattered through a number of different physical locations could be altogether seen as a single distributed artefact
- altogether, distribution and linkability promote the *layering* of artefact engineering—as sketched in [Molesini et al., 2006]

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Levels of Use of Artefacts *(reprise)* I

Co-ordination

both intelligent and non-intelligent agents could coordinate

Any agent (either intelligent or not) could simply exploit artefacts to achieve its own goals by simply taking artefacts as they are, and use them

Levels of Use of Artefacts *(reprise)* II

Co-operation

intelligent agents could change artefacts to change MAS

Intelligent agents could possibly reason about the nature of the artefacts as well as on the level of achievement of their goals, and take the chance to change or adapt the artefacts, or even to create new ones whenever useful and possible as the result of either an individual or a social activity

Levels of Use of Artefacts *(reprise)* III

Co-operation

MAS engineers could embody social intelligence in artefacts

In the same way, MAS engineers can use artefacts to embody the "social intelligence" that actually characterises the systemic/synergistic (as opposed to compositional) vision of MAS , but also to observe, control, and possibly change MAS social behaviour [Ciancarini et al., 2000]

Agents & Artefacts Interacting

Aspects of agent-artefact relationship

use an agent can use an artefact, according to its use goal, associating it with a destination

- **aware use** because the agent is aware of the artefact's function
- **unaware use** because the artefact's use is encoded in the agent by the programmer / designer

selection an agent can select an artefact for future use, according to its use-value goal, reasoning about its possible future destinations and use goals

construction / manipulation An agent can modify an artefact to adapt its function to some required use-value goals and to its possible future destinations

- or, an agent can create *ex-novo* a new artefact with an agent-designed function according to some required use-value goals and to its possible future destinations

Cognitional Artefacts

Definition (A&A Cognitional Artefact)

An A&A cognitional artefact is an artefact *aimed* at the *cognitive use* by agents

genus cognitional artefacts are artefacts

differentia cognitional artefacts are aimed to be used in a cognitive way by agents

Rational exploitation of (cognitional) artefacts by cognitive agents

- in order to allow for its rational exploitation by intelligent agents, an A&A artefact possibly exposes
  - a *usage interface*
  - *operating instructions*
  - a *function description*

Cognitional Artefacts: Usage Interface

- one of the core differences between artefacts and agents is the concept of *operation*
- an operation is the means by which an artefact provides agents with a service or function
- an agent executes an action over an artefact by invoking an artefact operation
- execution possibly terminates with an *operation completion*, typically representing the outcome of the invocation, which the agent comes to be aware of in terms of *perception*

usage interface the set of operations provided by an artefact defines what is called its *usage interface*

- which (intentionally) resembles interfaces of services, components or objects—in the object-oriented acceptation of the term

Cognitional Artefacts: Operating Instructions I

Artefact's manuals for intelligent agents

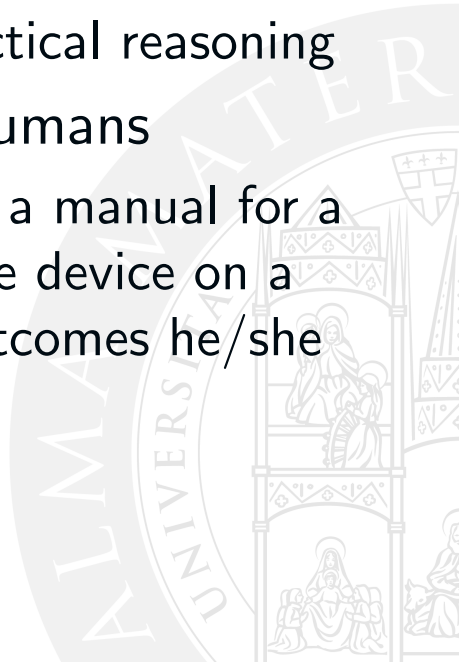
- operations cannot be invoked in any order
- artefact's state & behaviour, along with the effects of agent's actions on the environment via the artefact, depend on the execution order of operations

operating instructions *operating instructions* are a description of the procedure an agent has to follow to meaningfully interact with an artefact over time

- which should of course be coupled with usage interface

Cognitional Artefacts: Operating Instructions II

- operating instructions are a description of the possible *usage protocols*, i.e. sequences of operations that can be invoked on the artefact, in order to exploit its function
- besides a syntactic information, they can also embed some sort of semantic information for rational agents
  - rational agents can use such information for their practical reasoning
- artefacts are conceptually similar to devices used by humans
  - operation instructions play for agents a role similar to a manual for a human—which a human reads to know how to use the device on a step-by-step basis, and depending on the expected outcomes he/she needs to achieve



Cognitional Artefacts: Function Description I

Agents, artefacts & function

- agents should be provided with a description of the functionality provided by the artefact
  - which agents essentially use for artefact selection

function description artefacts could then be equipped with a *function description* (or, a *service description*), (formally) describing the function / service that the artefact is designed to provide agents with

- differently from operating instructions, which describes *how* to exploit an artefact, function description describes *what* to obtain from an artefact

Cognitional Artefacts: Function Description II

An example

When modelling a sensor wrapper as an artefact, we may easily think of the operations for sensor activation and inspection as described via usage interface and operations instructions, while the information about the sensory function itself being conveyed through function description of the sensor wrapper

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MAS in the A&A Meta-model

Definition (A&A MAS)

An A&A MAS is a *computational systems* made of agents and artefacts

genus MAS is computational system

differentia its basic components are agents and artefacts

A constructive definition

- based on the previous definitions
- also based on on the (primitive) notion of system as well

A&A MAS are Situated

MAS & situatedness

- MAS are made of agents & artefacts
- both agents & artefacts are situated computational entities
- as an obvious consequence, MAS are *situated computational systems*

MAS & environment

- a MAS is always immersed within an environment
- a MAS cannot be conceived / modelled / designed in a separate way with respect to its environment

A&A MAS have a Behaviour

MAS & activity

- MAS are made of agents & artefacts
- agents are pro-active, artefacts are reactive
- agents are autonomous entities, artefacts have functions

→ in the overall, a MAS has a behaviour that results from the interaction of autonomous, self-governing entities (agents) and reactive, functional entities (artefacts)

MAS Interaction in the A&A Meta-model I

Admissible interactions *within* a MAS

- MAS are made of agents & artefacts
- two fundamental entities give raise to four different sorts of admissible interactions

communication agents speak with agents
operation agents use artefacts
composition artefacts link with artefacts
presentation artefacts manifest to agents

MAS Interaction in the A&A Meta-model II

MAS interactions with the environment

- defining a system is to define a boundary—the same holds for a MAS, of course
- interactions occur within and without the boundaries
  - MAS interaction with the environment
- depending on the desired level of abstraction, we may attribute environment interactions to either individual agents & artefacts, or to the MAS as a whole

Delimiting a MAS

MAS boundaries

- our definition allows us to understand whether a computational system is a MAS
- it mostly define the class of the MAS in the A&A meta-model

What is an open system?

- how can we determine / recognise the boundaries of an open MAS?
- on the engineering side, how can we design an open MAS?
  - what should we actually design when designing a MAS?
  - what should anyway account for / account not?

Essence of a Single MAS

MAS characteristic

- to define one single MAS, we need a characterising criterion
- the very notion of system means there is a coherent way to interpret the overall set of components as a whole, and to determine whether a given component belongs to a given MAS
- characterising a single MAS then means firstly to define a criterion according to which an agent / an artefact could be said either to belong or not to a given MAS
  - hopefully in a univocal way
  - possibly dynamically depending on a number of parameters, like time, state of components, state of MAS, state of the environment, ...

1. Artefacts: Multi-disciplinary Foundations
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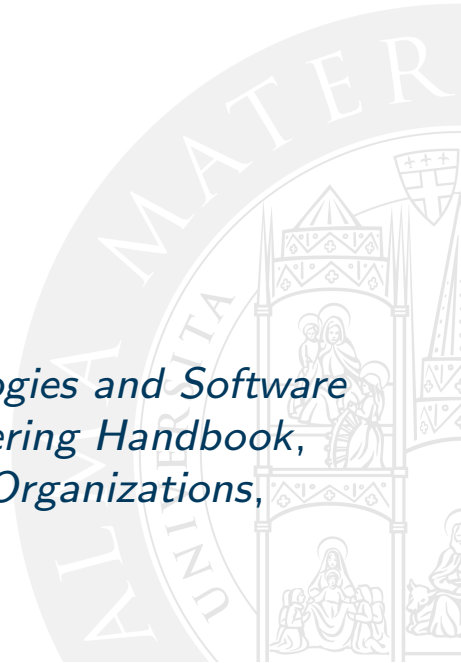

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Academic Year 2017/2018