

Advanced Topics in Agent-Oriented Computing

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1 Trans-disciplinary Research

2 Activity Theory

- Background from Activity Theory
- Lessons Learned: From AT to MAS

3 Distributed Cognition

- Background from Distributed Cognition
- Lessons Learned: From Distributed Cognition to MAS

4 Psychology

- Background from Psychology
- Lessons Learned: From Psychology to MAS

5 Computer Supported Cooperative Work

- Background from CSCW
- Lessons Learned: From CSCW to MAS

6 (Cognitive) Anthropology & Ethology

- Background from (Cognitive) Anthropology & Ethology
- Lessons Learned: From (Cognitive) Anthropology & Ethology to MAS



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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 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



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Why X-Disciplinary Research?

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

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



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Activity Theory (AT)

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) [Vygotsky, 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 nowadays

- Re-discovered and widely applied in Computer Science and related fields in the last years [Nardi, 1996]
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- Brought to the MAS field by both Italian and Spanish groups
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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



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Artifacts in AT

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



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Role of Artifacts in AT

- Artifacts can be either *physical* or *cognitive*—or, they may have a twofold nature
 - example of physical artifacts are shelves, doors, phones, whiteboards, ...
 - example of cognitive artifacts are operating procedures, heuristics, scripts, languages, ...
 - examples of artifacts with a twofold nature (physical / cognitive) are operating manuals, computers, ...
- Artifacts 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



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Artifacts as Enablers and Constrainers of Activities

- As mediating tools, artifacts have both an *enabling* and a *constraining* function

enablers artifacts expand out possibilities to manipulate and transform different objects

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



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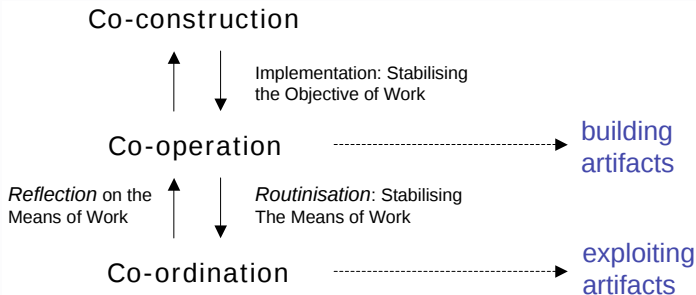


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Layers for Collaboration Activities in AT

- 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*

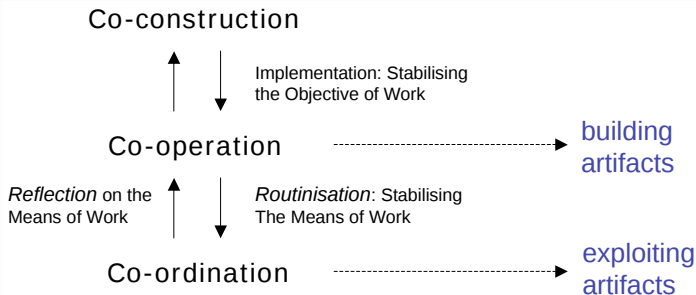
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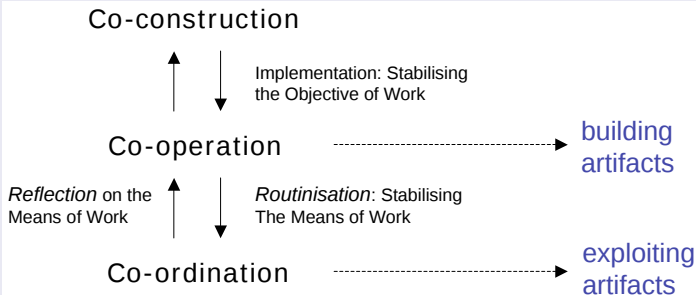
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Co-ordination in AT

- 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



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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 artifacts—are then the *object* of the co-operative activity, and its results as well



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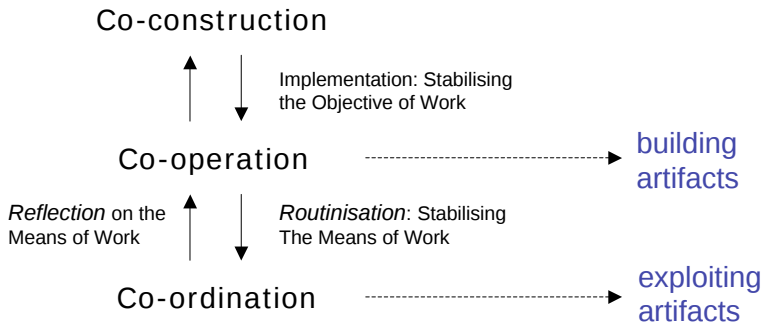
Co-construction in AT

- 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

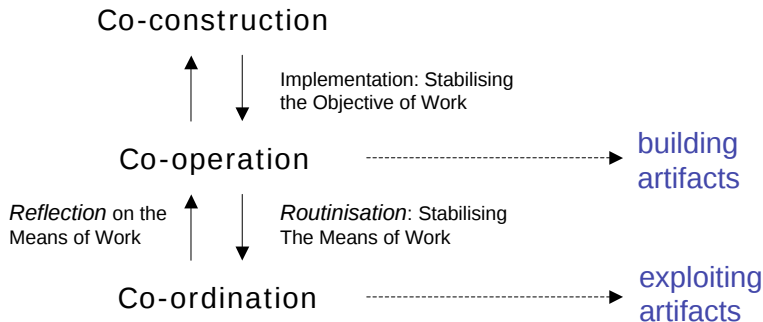


Collaborative activities in AT

- 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



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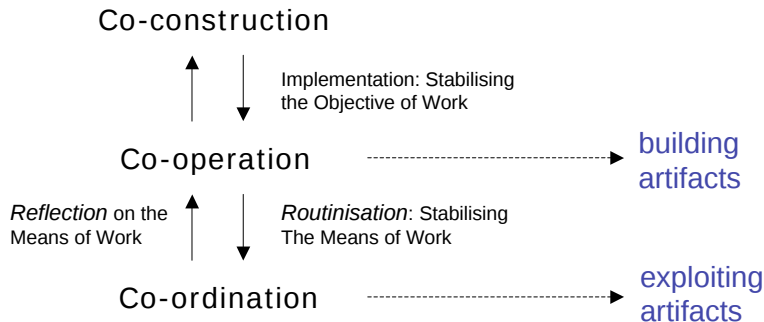


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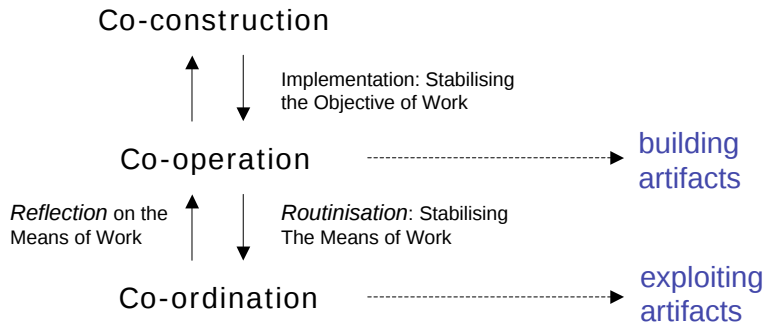


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Agents are not the Only Abstractions Needed

Basic Abstractions: Agents plus Artifacts

- 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]
- Artifacts, 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*
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Relevance of AT Research in MAS

Artifacts are essential—in MAS, too

- AT investigation is relevant in MAS since it points out that artifacts 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

Role of environment

- AT emphasises the fundamental role of the *environment* in the development of complex systems
- Also, AT suggests that artifacts are the essential tools [Weyns et al., 2007, Viroli et al., 2005]
 - the model of MAS evolution must be
 - designed so as to make it favourable to the development of artifacts
 - artifacts are essential



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“The environment of MAS is both the *medium* and the *arena* of the interaction between agents. The environment is the *medium* because it provides the *resources* and the *constraints* for the interaction. The environment is the *arena* because it is the *stage* where the interaction takes place.”



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“The environment of MAS is not only a place where agents interact, but also a place where artifacts are used to enhance their capabilities and to constrain their interactions.”



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Artifacts for collaboration and coordination

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



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Coordination artifacts & media

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- Examples include abstractions like tuple spaces, channels, blackboards, but also pheromone infrastructures, e-institutions, ...



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AT Layers for MAS Collaboration

Layers for MAS collaboration & coordination artifacts

- 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 artifacts—in particular, coordination artifacts
- The three layers are labelled as
 - *co-ordination*
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AT Layers for MAS in Detail

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



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Levels of Use of Artifacts

Co-ordination: both intelligent and non-intelligent agents could coordinate

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

Co-operation: intelligent agents could change artifacts to change MAS

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

Co-operation: MAS engineers could embody social intelligence in artifacts

In the same way, MAS engineers can use artifacts 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



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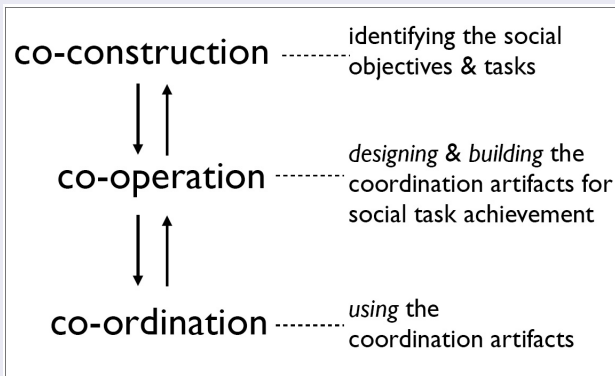
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AT Layers for MAS Collaboration: The Picture

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Outline

- 1 Trans-disciplinary Research
- 2 Activity Theory
 - Background from Activity Theory
 - Lessons Learned: From AT to MAS
- 3 Distributed Cognition
 - Background from Distributed Cognition
 - Lessons Learned: From Distributed Cognition to MAS
- 4 Psychology
 - Background from Psychology
 - Lessons Learned: From Psychology to MAS
- 5 Computer Supported Cooperative Work
 - Background from CSCW
 - Lessons Learned: From CSCW to MAS
- 6 (Cognitive) Anthropology & Ethology
 - Background from (Cognitive) Anthropology & Ethology
 - Lessons Learned: From (Cognitive) Anthropology & Ethology to MAS



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 *artifacts* in the *environment*



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Cognition is Distributed

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

It is partially in the material space of humans, but it is also embodied in artifacts of material form, and information of any sort distributed on the objects, tools and instruments that constitute the environment.



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Knowledge is partially in the material aspects of humans (e.g., memory) and partially in the material aspects of external forms and information (e.g., artifacts, documents, etc.). Knowledge is distributed on the physical level and represents the cognitive structure of the environment.



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Knowledge is partially in the material aspects of human activity, such as artifacts, tools, and information systems. Knowledge is also distributed among individuals, teams, and information systems. Knowledge is also distributed across time and space, and is represented in various ways, such as in memory, in documents, and in artifacts.



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Analysis of Distributed Cognition focuses on *distributed cognitive systems*

- People interact with external *cognitive artifacts* containing knowledge represented in some form
- Human *intelligent behaviour* results from the distributed interactions with other humans and with cognitive artifacts
- 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



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Cognitive Artifacts

Cognitive artifacts: a definition [Norman, 1991]

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

Cognitive artifacts 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 artifacts also modify the nature of the tasks to be performed



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Personal vs. System View

System view

Individuals plus artifacts altogether as a (functional) subsystems

- Understanding activities requires to consider (cognitive) actors and (cognitive) artifacts altogether
- Actions are sometimes mediated sometimes targeted to artifacts, and cannot be fully understood without them

Personal view

Individuals as subsystems affected by artifacts

- Practical reasoning is deeply affected by artifacts
- Individuals should change the way in which they represent actions, plan, deliberate and finally act



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Environment in Distributed Cognitive Systems

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 artifacts 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 out
- 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?



Environment in Distributed Cognitive Systems

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 artifacts 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

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- In distributed cognitive systems, the nature of the environment is critical and has a profound effect on the system's performance
- The environment can be seen as a complex system of constraints and resources that shape the system's behavior
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Work environment

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Environment in Distributed Cognitive Systems

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- In distributed cognitive systems, the nature of the environment (physical, social, cultural, cognitive) is a key factor in the design of the system
- The environment is a complex superposition of social, cultural, cognitive, and physical constraints
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- In distributed cognitive systems, the nature of the environment

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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



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The Function of Action in Distributed Cognitive Systems

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



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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

- Artifacts are essential parts of the MAS cognitive processes
- Cognitive artifacts encapsulate knowledge as explicitly represented



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Agent View vs. MAS View

Personal / agent view

- Once artifacts 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)+artifact(s) altogether



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(Cognitive) artifacts shape MAS environment

- Artifacts determine the structure of MAS environment
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- Structure of the environment, and knowledge it contains, affect the activities of agents within MAS



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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
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Outline

- 1 Trans-disciplinary Research
- 2 Activity Theory
 - Background from Activity Theory
 - Lessons Learned: From AT to MAS
- 3 Distributed Cognition
 - Background from Distributed Cognition
 - Lessons Learned: From Distributed Cognition to MAS
- 4 Psychology
 - Background from Psychology
 - Lessons Learned: From Psychology to MAS
- 5 Computer Supported Cooperative Work
 - Background from CSCW
 - Lessons Learned: From CSCW to MAS
- 6 (Cognitive) Anthropology & Ethology
 - Background from (Cognitive) Anthropology & Ethology
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Agents & Goals

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*

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



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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*
- *Artifacts* are such objects
 - they have a *function* associated
- Artifacts have no goals to achieve
 - they may have a *destination* associated
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On the Relation Between Agents & Artifacts

Use & use value [Conte and Castelfranchi, 1995]

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- Evaluating an artifact 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 artifact

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

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



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



On the Relation Between Agents & Artifacts

Use & use value [Conte and Castelfranchi, 1995]

- When facing an artifact, an agent may adopt different perspectives
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Articulating the Agents & Artifacts Relationship

How could an agent deal with an artifact?

- There are at least three different ways an agent can exploit an artifact

- 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 artifact, 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



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Goals in MAS

Agents have goals

strong agency Agents have explicitly-represented goals

weak agency Agents have implicitly-represented / encoded goals

Artifacts have functions

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



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Agents & Artifacts Interacting

Aspects of agent-artifact relationship

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

aware use because the agent is aware of the artifact's function

unaware use because the artifact's use is encoded in the agent by the programmer / designer

selection An agent can select an artifact 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 artifact to adapt its function to some required use-value goals and to its possible future destinations

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MAS Engineers Designing Agents

Basic choices to make in agent design

- Should an agent be aware of artifact's behaviour and structure, and of how to use them?
 - should an agent be able to reason and deliberate about artifact use?
- Should an agent be aware of artifact's function and possible uses?
- Should an agent be able to act over artifacts to modify them and adapt their function?
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Outline

- 1 Trans-disciplinary Research
- 2 Activity Theory
 - Background from Activity Theory
 - Lessons Learned: From AT to MAS
- 3 Distributed Cognition
 - Background from Distributed Cognition
 - Lessons Learned: From Distributed Cognition to MAS
- 4 Psychology
 - Background from Psychology
 - Lessons Learned: From Psychology to MAS
- 5 Computer Supported Cooperative Work
 - Background from CSCW
 - Lessons Learned: From CSCW to MAS
- 6 (Cognitive) Anthropology & Ethology
 - Background from (Cognitive) Anthropology & Ethology
 - Lessons Learned: From (Cognitive) Anthropology & Ethology to MAS



Computer Supported Cooperative Work (CSCW)

Basic issues in CSCW

- CSCW aims at automating human cooperative work through computational procedures
- However, two diverging strategies are currently emerging [Schmidt and Simone, 2000]

automation

flexibility

- 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*



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Automation vs. Flexibility: Key Issues in CSCW

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



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- They work more as *constrainers* rather than as *commanders*
- By giving structure to the common field of work, coordinative artifacts encapsulate those coordination responsibilities that are better to be *automatised* in order to achieve efficiency in cooperation
- In all, coordinative artifacts

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Automation of Collaboration Activities in MAS

Coordinative artifacts for automation of MAS collaboration

- *Coordinative artifacts* rule MAS collaboration, working more as constrainers rather than as commanders
- Coordinative artifacts structure MAS common field of work, as specialised abstractions automatising and making collaboration efficient
- As constrainers, coordinative artifacts define and govern the space of the admissible articulation of MAS collaboration activities
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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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 - Background from Activity Theory
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- 3 Distributed Cognition
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- 4 Psychology
 - Background from Psychology
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- 6 (Cognitive) Anthropology & Ethology
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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 and Arcos, 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
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- 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]



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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
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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



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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
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from: The notion of Agent Forging: a new theory of agent intelligence



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Building the Future of Agents: From Cognitive Psychology to Artificial Intelligence



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See [this slide](#) for a more detailed discussion of the *logocentric bias* in MAS research

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