# Agents and Artifacts: Multi-disciplinary Foundations

## Multiagent Systems LS

Sistemi Multiagente LS

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Ingegneria Due

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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. Sociology
   - Background from Sociology
   - Lessons Learned: From Sociology 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

# 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

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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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# Outline

# 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]
- 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
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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
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- By mediating *artifacts*
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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
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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

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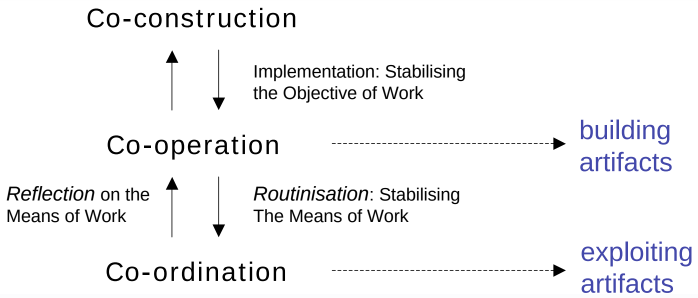
# Layers for Collaboration Activities in AT

- 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*

## AT Layers: The Picture



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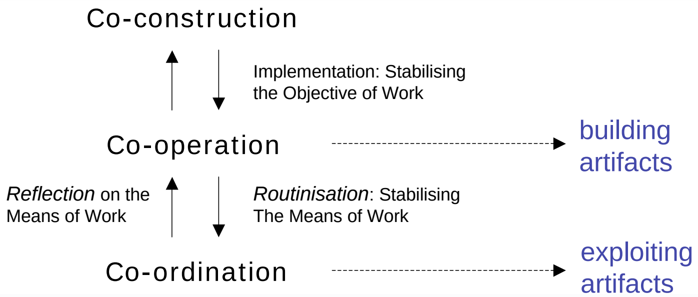

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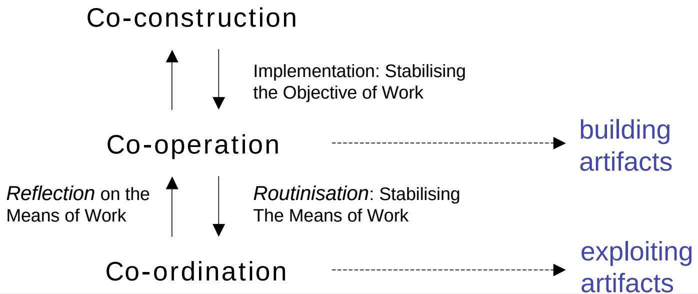

# Co-ordination in AT

- 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

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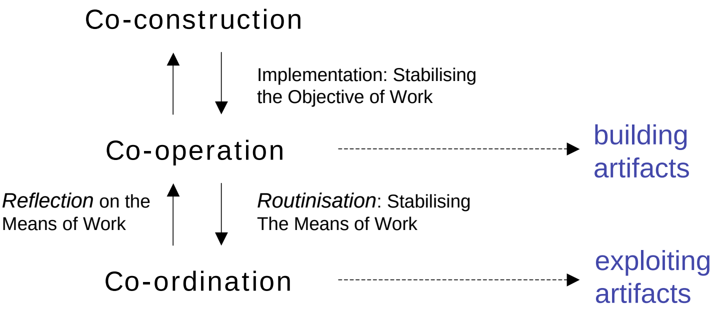
- Neither the object of work, nor the scripts are stable, and must be collectively constructed, i.e., *co*-constructed

# 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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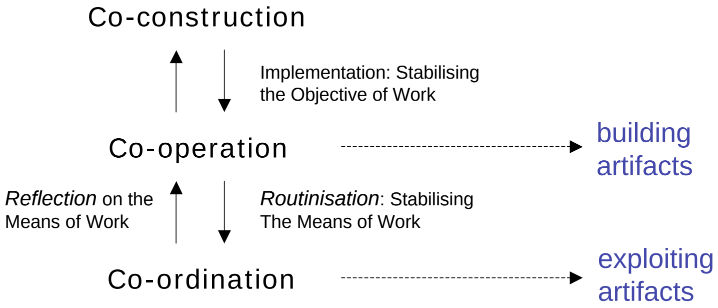


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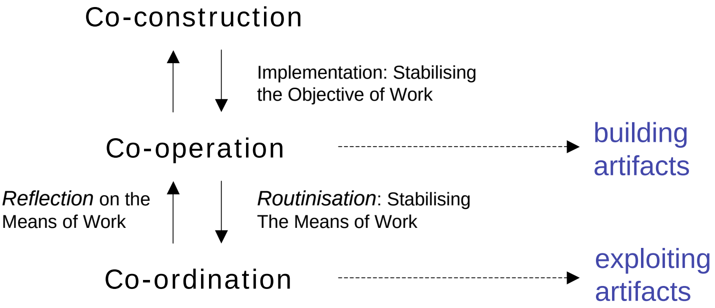


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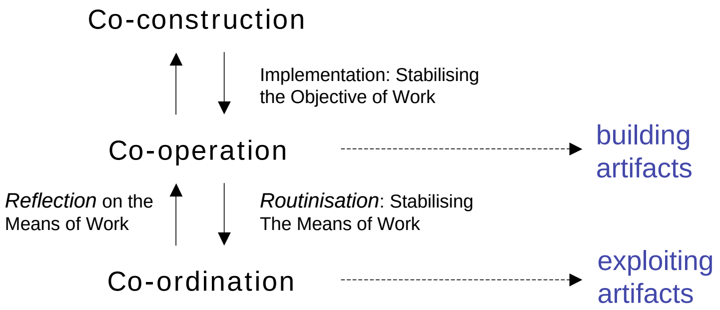


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# Outline

# 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*
    - in general, to improve agent ability to achieve their individual and social goals

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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
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# Coordination Artifacts

## 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

## Coordination artifacts & media

- Coordination artifacts represent a straightforward generalisation of the notion of coordination medium, as coming from fields like coordination models and languages and distributed AI
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- The three layers are labelled as
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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

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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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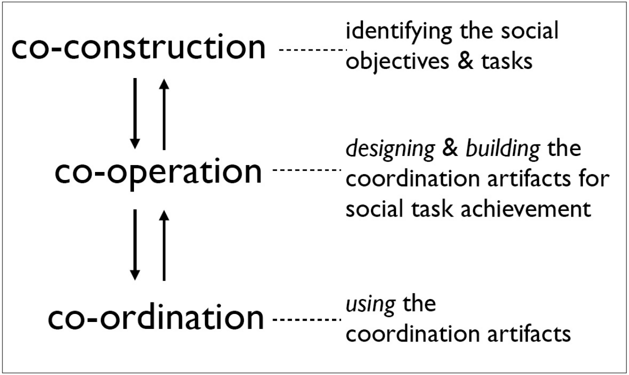

# Outline

# Distributed Cognition in Short

## Distributed Cognition. . . [Kirsh, 1999]

- . . . is a branch of cognitive sciences
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  - is *distributed* across individuals, tools and *artifacts* in the *environment*

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## Cognition transcends individuals

- Intelligent processes in human activity go beyond the boundaries of individual actors
- Knowledge is not confined within human minds
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## Knowledge representation transcends individuals

- Knowledge representation does not pertain individual humans only
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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
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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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*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.
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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 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?

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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
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  - 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
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## 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 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
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  - 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
  - a goal-governed system follows external goals by adjusting internal ones

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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
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# On the Relation Between Agents & Artifacts [Conte and Castelfranchi, 1995]

## Use & use value

- When facing an artifact, an agent may adopt different perspectives
- 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

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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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# Outline

# 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
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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?
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# Outline

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## 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

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- 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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# 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: stressing computational procedures to automate coordination of activities
  - flexibility: stressing the flexibility of computational procedures with respect to intelligent coordination by collaborating actors
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## 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
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- *Coordinative artifacts* are the rulers of collaboration
- They work more as *constrainers* rather than as *commanders*
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- In all, coordinative artifacts

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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
  - tool using vs. tool making distinction
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# 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
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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
- 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)

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## 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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# 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

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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. Sociology
   - Background from Sociology
   - Lessons Learned: From Sociology 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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# Agents and Artifacts: Multi-disciplinary Foundations

## Multiagent Systems LS

Sistemi Multiagente LS

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