

# Agents & Artefacts: Definitions & Conceptual Framework

Distributed Systems  
Sistemi Distribuiti

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Academic Year 2013/2014

- 1 Agents & the A&A Meta-model
- 2 On the Notion of Artefact in the A&A Meta-model
- 3 MAS Engineering with A&A Artefacts
- 4 A&A Artefacts for Cognitive Agents
- 5 On the Notion of MAS in the A&A Meta-model



# Outline

- 1 Agents & the A&A Meta-model
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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

- 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 \_\_\_\_\_ 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

### 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 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 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)

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**genus** artefacts are computational entities

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## Artefacts are 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 network, 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 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

**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 II

### 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



# Cognitive Artefacts

## Definition (A&A Cognitive Artefact)

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

**genus** cognitive artefacts are artefacts

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

## Rational exploitation of (cognitive) 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*

# Cognitive Artefacts: Usage Interface

## Agents, artefacts & operations

- 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 acceptance of the term



# Cognitive 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

# Cognitive Artefacts: Operating Instructions II

## Operating Instructions

- 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

# Cognitive 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

## Cognitive 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 in a MAS

- MAS are made of agents & artefacts
- Two fundamental entities give rise 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, ...

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