Multiagent Systems (SMA-UPC)

4. Multiagent Systems Design
Part 1:
Agent-Oriented Software Engineering Methodologies. The GAIA methodology.

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Multiagent Systems (SMA-UPC)

Introduction (to Agent Methodologies)

- **Software Engineering**
- **Agent-Oriented Software Engineering**
- **Software Methodologies**
- **Agent-Oriented Methodologies**

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Software Engineering
Status of Software Engineering in the New Millennium

- Current tendency to make *software functionalities* and *business cases* coincide - stimulated by the Internet era and reinforced by the DOTCOM economy
  - Leads to *linking software construction* and *business dynamics* more closely than ever
- In industry there is a need for swiftly-developed, complex software projects that are both *research-like* and *mission-critical*
  - Software development must no longer be thought of as *oriented toward a product* ***BUT*** it is an ongoing process *which continually delivers value* (continuous evolution)
- Software crisis
  - Hardware costs were decreasing while software costs were increasing.

Software Engineering
Abstractions

- Software deals with *"abstract" entities*, having a real-world counterpart
  - Numbers, dates, names, persons, documents, ...
- In what term shall we model them in software?
  - Data, functions, objects, agents, …
  - I.e., what are the abstractions that we have to use to model software?
- May depend on available technologies

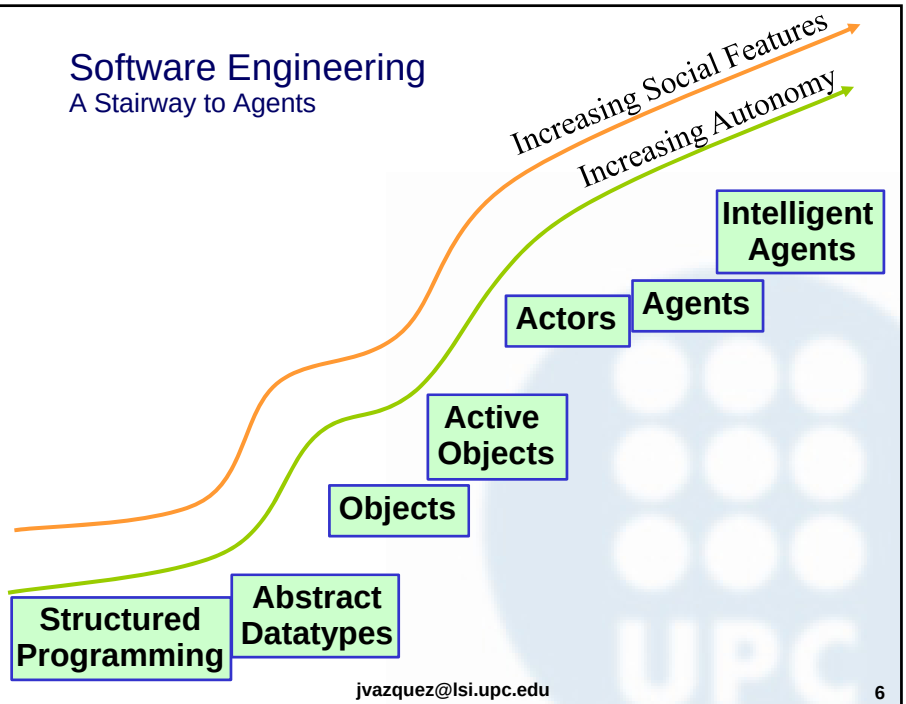
Software Engineering
Towards Agent-Oriented Software Engineering

"Objects are far from perfect, but are the only game in town"
-- Grady Booch

- Maybe the agent community would like to reply...

- A lot of research work has been done to define what an agent and a MAS are, how they compare to object-oriented concepts and which their distinguishing features are
- AO paradigm *subsumes* the concepts supported by the previous programming paradigms, and in particular by the object-oriented programming
  - Tries to *raise the abstraction level*
  - Software agents are undoubtedly more than a promising approach to *complex software development*

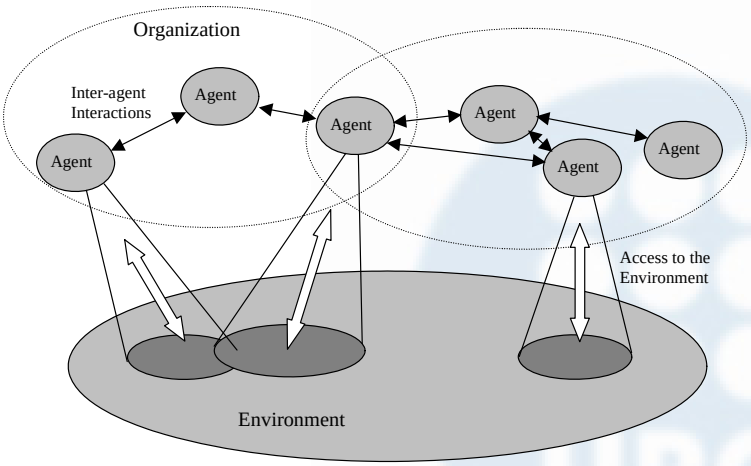
Software Engineering
A Stairway to Agents



Agent-Oriented Software Engineering
Abstractions

- The development of a multiagent system should fruitfully exploit higher level abstractions
  - Agents, autonomous entities, independent loci of control, situated in an environment, interacting with each others
  - Environment, the world of entities and resources agents perceive, control, consume or exploit.
  - Roles and interactions: identify functionalities, activities, responsibilities and interaction patterns.
  - Organizational Rules, which can be constraints on roles and interactions, or relations between roles, between protocols, and between roles and protocols (open/close systems)
  - Organizational Structures and Patterns: Identify the topology of interaction patterns and the control regime of activities (efficiency, robustness, degree of openness)

Agent-Oriented Software Engineering
Characterisation of a MAS



Agent-Oriented Software Engineering
Agent-Oriented Computing

- There has been some debate
  - On what an agent is, and what could be appropriately called an agent
- Two main viewpoints in agent development
  - The (strong) artificial intelligence viewpoint
    - A multi-agent system is a society of individual (AI software agents) that interact by exchanging knowledge and by negotiating with each other to achieve either their own interest or some global goal
  - The (weak) software engineering viewpoint
    - A multi-agent system is a software systems made up of multiple independent and encapsulated loci of control (i.e., the agents) interacting with each other in the context of a specific application

Agent-Oriented Software Engineering
Software Engineering Viewpoint on AO Computing

- The Second is useful because
  - It focuses on the characteristics of agents that have impact on software development
    - Concurrency, interaction, multiple loci of control
    - Intelligence can be seen as a peculiar form of control independence; conversations as a peculiar form of interaction
  - It is more general:
    - Several software systems, even if never conceived as agents-based one, can be indeed characterized in terms of weak multi-agent systems

Agent-Oriented Software Engineering
Key Characteristics of Agents

- Basic characteristics (SE Viewpoint)
  - Autonomy & Proactivity (*delegation of responsibility)*
  - Situatedness
  - Interactivity (*communication,* collaborative or competitive interactions)
- Additional characteristics (SE Viewpoint)
  - Openness (need of standards; need of proper infrastructures supporting the interoperations)
  - Learning & Adaptative Capabilities (Improving the effectiveness of its actions; adapting their behaviour to changing situations)

Agent-Oriented Software Engineering
There is more to Agent-Oriented Software Engineering

- AOSE is not only for “agent systems.”
  - Most of today’s software systems have characteristics that are very similar to those of agent and multiagent systems
- AOSE is suitable for a wide class of scenarios and applications

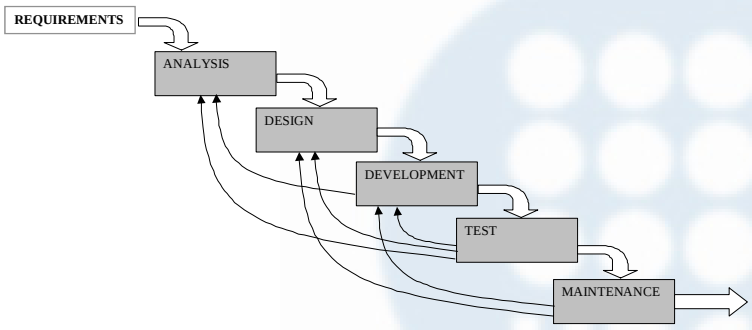
Agent-based computing, and the abstractions it uses, represent a new and general-purpose software engineering paradigm

Software Methodologies

- A methodology for software development…
  - is intended to *discipline the development*
  - defines the abstractions to use to model software
    - Data-oriented, flow-oriented, object-oriented, …
    - Defines the mindset of the methodology
  - disciplines the software process
    - What to produce and when
    - Which artefacts to produce
- Def: a software methodology is the set of guidelines for covering the whole lifecycle of system development both technically and managerially
  - full lifecycle process
  - comprehensive set of concepts and models
  - full set of techniques (rules, guidelines, heuristics)
  - fully delineated set of deliverables
  - modelling language
  - set of metrics
  - quality assurance
  - coding (and other) standards
  - reuse advice
  - guidelines for project management

Software Methodologies
The Classical "Cascade" Process

- The phases of software development:
  - Independent of programming paradigm;
  - Methodologies are *typically organized around this classical process*
    - Inputs, outputs, internal activities of "phases"



Software Methodologies
Tools

- Notation tools
  - To represent the outcome of the software development phases
    - Diagrams, equations, figures, …
- Formal models
  - To prove properties of software prior to development
    - Lambda calculus, Petri-nets, Z, ….
- CASE tools
  - To facilitate activities: rapid prototyping, code generators, …

Agent-Oriented Methodologies

- There is need for agent-oriented methodologies
  - Centred around specific *agent-oriented abstractions*
  - The adoption of OO methodologies would produce mismatches
    - Classes, objects, client-servers: little to do with agents
- Each methodology may introduce further abstractions
  - Around which to model software and to organize the software process
    - E.g., roles, organizations, responsibilities, belief, desire and intentions, …
  - Not directly translating into concrete entities of the software system
    - E.g. the concept of role is an aspect of an agent, not an agent

Agent-Oriented Methodologies
Agent-Based Analysis

- **Analysis** aims to understand, at least
  - What are the main actors interacting with the system
  - How the system interacts with these actors
  - What the system is supposed to do
- The system is a closed entity and we do not look into it to avoid anticipating design issues and decisions
- *In AO, we associate agents with the entities of the scenarios we are analyzing*
- Then, we associate accordingly
  - Roles, responsibilities and capabilities
  - Interaction patterns between agents
- This provides a neutral view of the problem.
- Methodologies such as Tropos and GAIA, do not use the word agent to identify analysis-phase entities

Agent-Oriented Methodologies
Agent-Based Design

- **Design** aims to engineer, at least
  - What are the main components interacting within the system
  - What are the responsibilities and the capabilities of each component in the system
  - How the components interact to implement the system, i.e., the architecture of the system
- *In AO, we associate agents with the components we use to build the system*
- Then, we associate accordingly
  - Roles, responsibilities and capabilities
  - Interaction patterns between agents
- Differently from analysis: we need to choose on which agents to use and how they interact

Agent-Oriented Methodologies

Relevant Agent-Oriented Methodologies

- Several methodologies and approaches for designing MASs exist in literature. In general they tackle different aspects of the MAS and in some cases they are quite complementary:
  - **GAIA**
    - Encourages a developer to think of building agent-based systems as a process of *organisational design.*
  - **TROPOS**
    - It is founded on the concepts of *goal-based requirements* adopted from the i* and GRL (Goal-oriented Requirements Language). Its distinguishing feature is the emphasis on *requirements analysis*
  - **Prometeus**
    - It focuses mainly on the *internal agent architecture*; it is basically a methodology for designing BDI agent systems
  - **ADELFE**
    - It is a methodology for the development of *adaptive* multiagent systems
  - **MESSAGE**
    - It covers most of the fundamental aspects of the MAS development, focusing mainly on analysis and high-level design. The main objective was to combine the best features of the pre-existing approaches, but … the result was a complex and farraginous methodology.
  - **PASSI**
    - It is a step-by-step requirement-to-code methodology. Integrates design models and concepts from both object oriented software engineering and artificial intelligence approaches

The GAIA Methodology

- **GAIA v.1**
- **GAIA v.2**

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GAIA Methodology

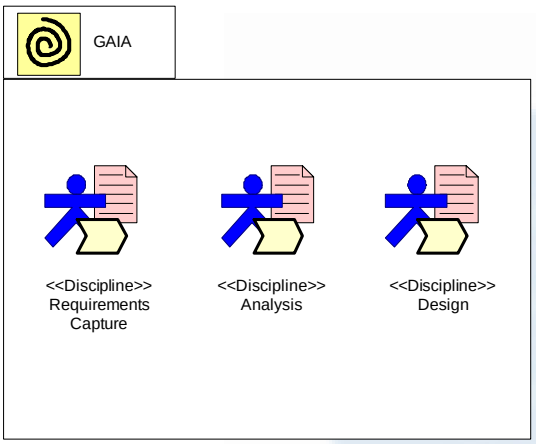
- Gaia is appropriate for the development of systems with the following main characteristics:
  - Gaia is not intended for systems that admit the possibility of true conflict.
  - Gaia makes no assumptions about the delivery platform;
  - The organisation structure of the system is static, in that inter-agent relationships do not change at run-time.
  - The abilities of agents and the services they provide are static, in that they do not change at run-time.
  - The overall system contains a comparatively small number of different agent types (less than 100).

GAIA Methodology
Case Study

Auction agent

1. The *configurator*: a GUI component, enables the user to control and monitor the agent's activity
2. The *parser*: translates retrieved information into an internal structure
3. The *bidder*: submits bids according to buying strategy. Implements two stages, bid and confirmation
4. The *manager*: controls the agent's activity, monitors the auction site, activates the parser, determines the next bid, activates the bidder and terminates the agent's purchasing activity

GAIA Methodology
Disciplines

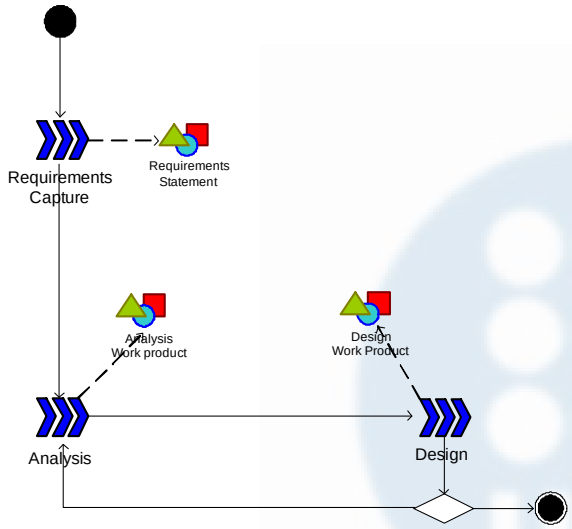


GAIA Methodology
Disciplines

- Requirements capture phase are considered *independent of the paradigm used* for analysis and design
  - For this reason Gaia does not deal with the requirements capture phase
- The analysis phase consists of the following models:
  - Role definition (permissions, responsibilities and protocols)
  - Interaction model (used for protocol description)
- The design phase consists of the following models:
  - Agent model
  - Service model (input, output, pre and post condition)
  - Acquaintance model

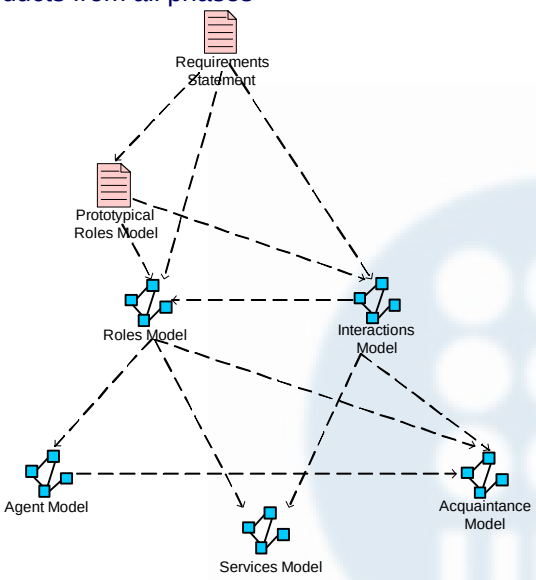
GAIA Methodology

Disciplines (Process Description)

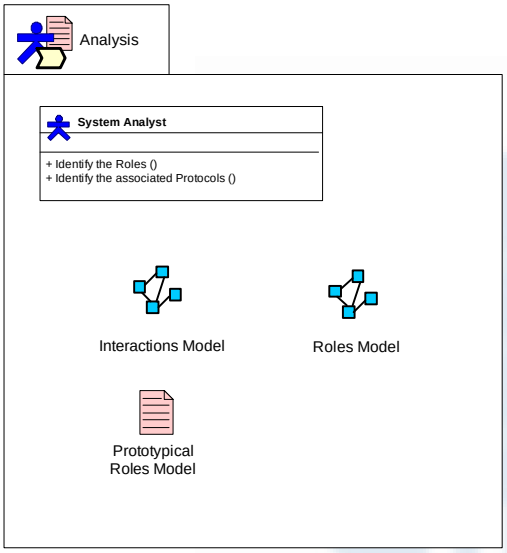


GAIA Methodology

Work Products from all phases



GAIA Methodology
Analysis Phase



GAIA Methodology
Analysis Phase: Role Model

Role Schema:	*name of role*
Description	*short English description of the role*
Protocols and Activities	*protocols and activities in which the role plays a part*
Permissions	*"rights" associated with the role*
Responsibilities	
Liveness	*liveness responsibilities*
Safety	*safety responsibilities*

- Template for role schemata

- Protocols, state the interactions of the role with other roles. In addition state the internal activities of the role
- Permissions, state what resources may be used to carry out the role and what resource constraints the role's executor is subject to
- Responsibilities. determine the functionality of the role. This functionality is expressed in terms of safety and liveness properties

GAIA Methodology
Analysis Phase: Role Model

Role Schema: Manager (MA)

Description:
Controls the auction agent activities

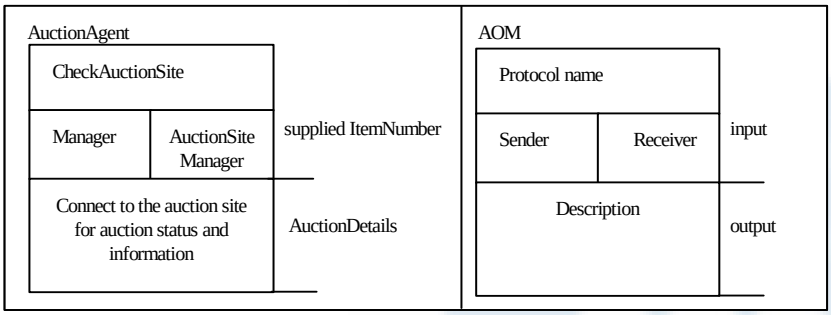
Protocol and Activities:
CheckAuctionSite , ActivateParser ,CheckForBid , Bid

Permission:
reads supplied ItemNumber // the item number in the auction site
AuctionDetails // the auction information

Responsibilities:
Liveness:
Manager = (CheckAuctionSite .ActivateParser .CheckForBid)$^{+}$[Bid]
Saftey:
true

- The Manager role scheme

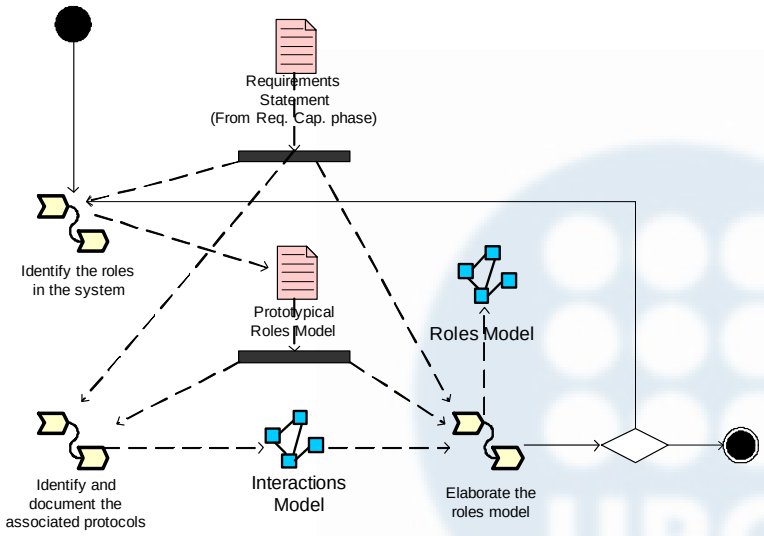
GAIA Methodology
Analysis Phase: Interaction Model



- The Interaction Model of the CheckAuctionSite protocol

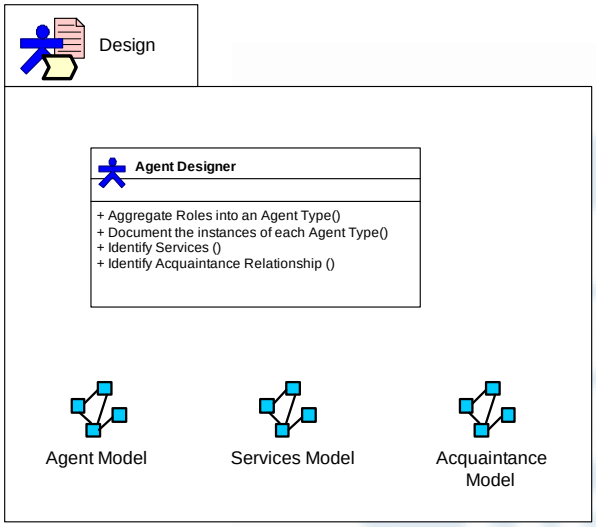
GAIA Methodology

Analysis Phase (Process Description)

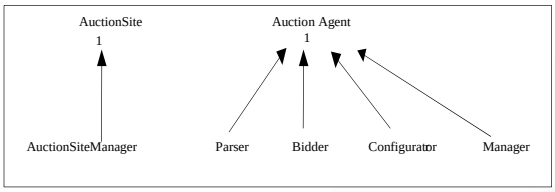


GAIA Methodology

Design Phase



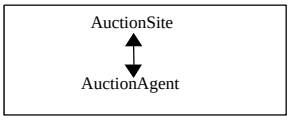
GAIA Methodology
Design Phase: Models



- The Agent Model

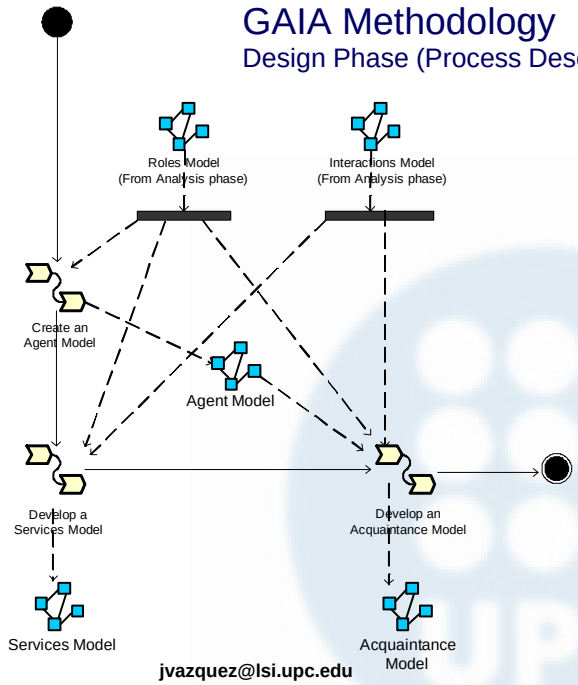
Service	Input	Output	Pre-condition	Post-condition
Get auction details	ItemNumber	AuctionDetails	true	true
Validate user	User	Exists	true	(exists=true) ∨ (exists=false)
Bid	User, ItemNumber, Price	Success	user exists	(success=true) ∨ (success=false)

- The Service Model



- The Acquaintance Model

GAIA Methodology
Design Phase (Process Description)



GAIA v.2

- First version of GAIA
  - Designed to handle *small-scale*, *closed* agent-based systems
  - Modelled agents, roles, interactions
  - Missed in modelling explicitly the social aspects of a MAS
- GAIA v.2: Official extension of GAIA
  - Thought for *open* agent systems
  - Significantly extends the range of applications to which Gaia can be applied
  - Focused on the *social organization* of the system
- Two further abstractions
  - Organizational rules
  - Organizational structures

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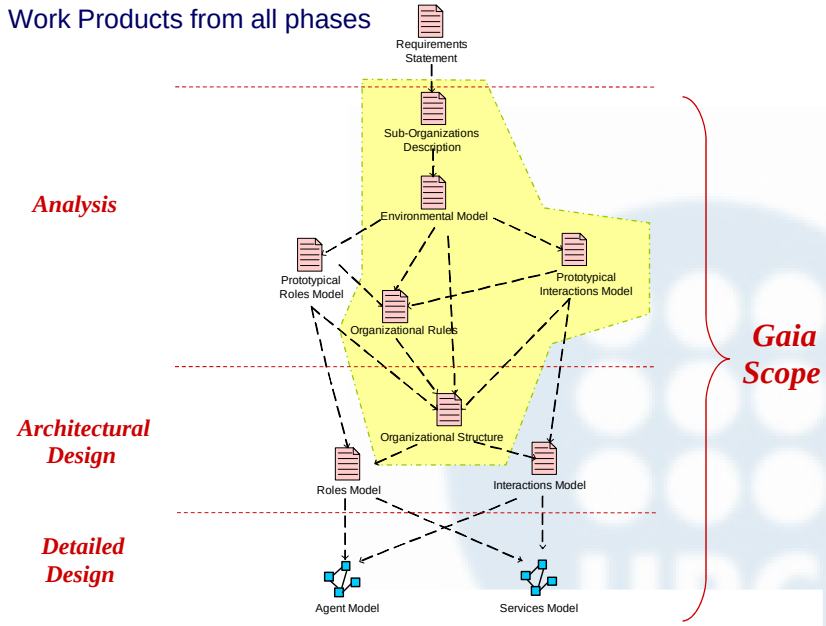
GAIA v.2

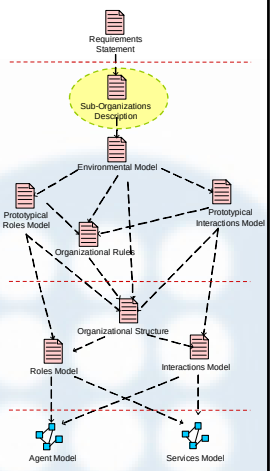
Work Products from all phases



GAIA v.2 Analysis

Sub-Organizations Description

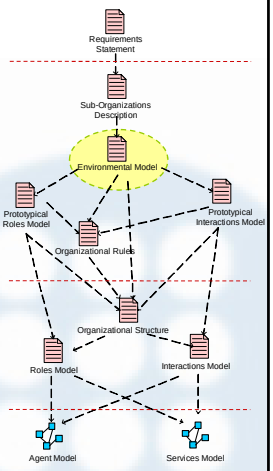
- Identify sub-organizations based on
  - the requirements or their presence in the application structure
  - subgoals that need to be achieved
  - limited interaction with other parts
  - required skills that are not needed in other parts



GAIA v.2 Analysis

Environmental Model

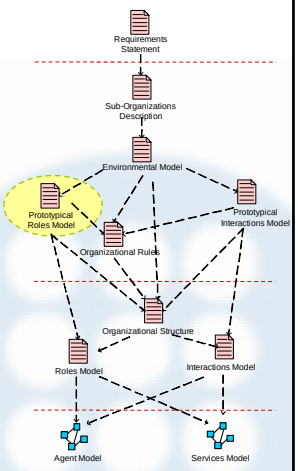
- Identify resources
  - a list of abstract computational resources, e.g. variables, tuples
  - the nature of the environment can be distributed
  - Relations between resources
  - The dynamics of the environment



GAIA v.2 Analysis

Preliminary Role Model

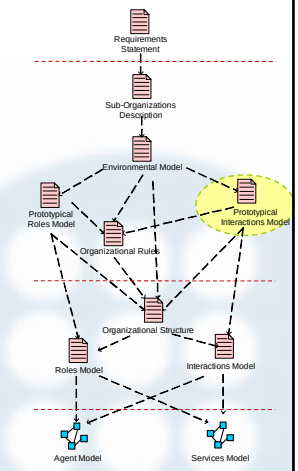
- Identify roles
  - Identify *Basic skills* (partial roles)
  - Basic skills can be turned to complete roles if all other roles are known
  - The complete set of roles are known when the organization structure is known.
  - Basic skills
    - Permission: resource access and the amount of access (when mismatch redefine environment or add new roles)
    - Responsibility: expected behaviours (liveness and safety properties)



GAIA v.2 Analysis

Preliminary Interaction Model

- Identify interactions
  - Relations and dependencies between roles
  - Interactions are described as abstract protocols
    - Protocol Name, e.g. assign task
    - Initiator, the role starting the interaction
    - Partner, the role to interact with
    - Input, information used by initiator
    - Outputs, information provided by partner
    - Description, the purpose of the protocol and its activities



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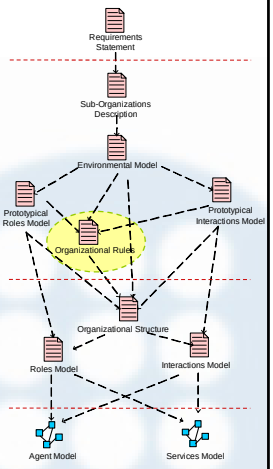
GAIA v.2 Analysis
Organizational Rules

- Identify Organizational Rules
  - Organizational rules are defined as
    - constraints on roles and protocols,
    - constraint and relations between roles,
    - constraint and relations between protocols,
    - constraint and relations between roles and protocols
  - Organizational rules are considered as *responsibilities* of the organization as a whole



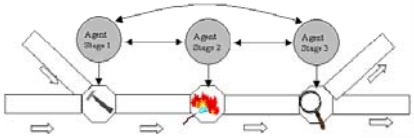
GAIA v.2 Architectural design
Organizational Rules

- Two kinds of Organizational rules
  - Liveness rules, e.g. a role can be played by an entity after it has played another role
  - Safety rules, e.g. two roles can never be played by the same entity
- Due to their similar nature, organizational rules can be expressed by making use of the same formalism adopted for specifying liveness and safety rules for roles
- Eg:
  - In the manufacturing pipeline, the correct management of the pipeline requires each of the stage roles to be played only once. This can be expressed by the safety rule:

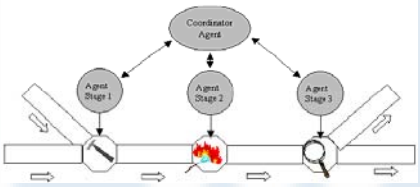
$$R = (STAGE[1], STAGE[2], \ldots, STAGE[N])$$

GAIA v.2 Architectural design
Organizational Structure

- In GAIA v.1 the role model may define the organizational structure in an implicit way. The structure of a MAS is more appropriately derived from the explicit choice of an appropriate organizational structure
  - Organizational structures viewed as first-class abstractions



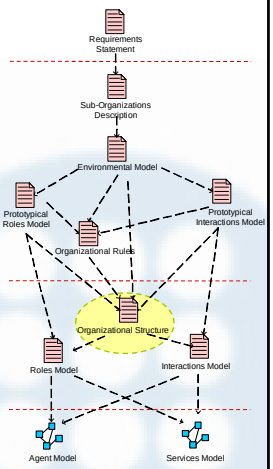
- Manufacturing pipeline: collective of peers organization



- Manufacturing pipeline: hierarchical organization

GAIA v.2 Architectural design
Organizational Structure

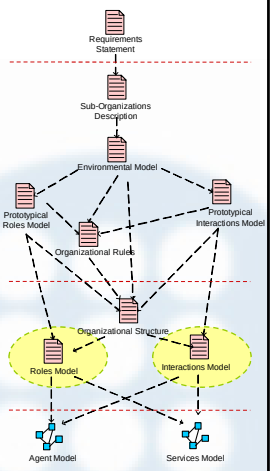
- Organizational structure
  - Topology of Organization: Peers, (Multi-level) Hierarchy, composite
  - Control Regime: Work Partitioning, Work Specialization, Market-based Models
- Decision Parameters for Organizational Structure
  - Computation and coordination complexity
  - (influence of) Organizational Rules
  - Structure of Real-World Organization
  - Simplicity
- Organizational Patterns
  - Catalogue of organizational structures



GAIA v.2 Architectural design

Role Model & Interaction Model

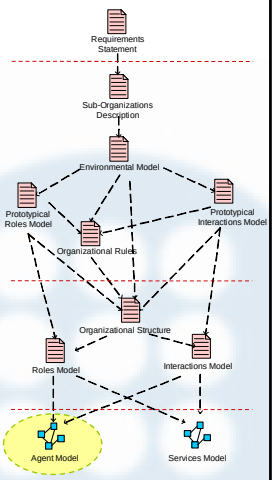
- Complete role models and interaction models
  - Based on decided *organizational topology*
    - Define all activities in which a role is involved (incl. Liveness and Safety)
    - Define organizational roles (not from analysis phase)
  - Based on decided *control regime*
    - Complete the definition of the protocols (e.g. which roles are involved)
    - Define organizational protocols (adoption of organizational structure)



GAIA v.2 Detailed design

Agents Model

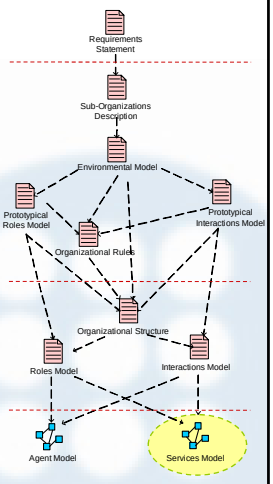
- Define agents model
  - An agent is a computational entity that *can play a set of roles*
    - Which agent classes should be defined to play specific roles?
    - How many instances of each agent class have to be instantiated?
  - Trade-off
    - Coherence of agent classes
    - Efficiency of agent classes
    - Similarity to real-world organization



GAIA v.2 Detailed design

Services Model

- Define services model
  - Identify the services associated with each agent class
  - Services are derived from protocols, activities, responsibilities, permissions
  - Properties of services
    - Input/output (derived from protocols)
    - Pre- and post-conditions (safety and organizational rules)



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