

## MASTER WEB INTELLIGENCE

**Multi-Agent Systems****Organization**

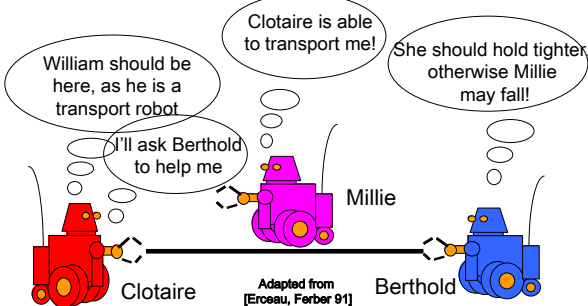
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adapted from  
[boissier-  
sichman  
Tutorial AAMAS 03]

**Outline**

- **Organization in MAS**
  - Motivations
  - Definitions
  - History
  - Dimensions
- Organizations with an Agent Centered Point of View
- Organizations with a System Centered Point of View
- Dynamic of Organizations
- Conclusion

**From an agent point of view****From an agent point of view (2)**

- Needs to insure a better integration of the agents in the system in order to better adapt themselves to eventual changes in the environment :
  - agents should explicitly represent and exploit (by using internal reasoning mechanisms) the other agents' capacities
- Delegation/Adoption of tasks/beliefs between the agents may produce coalitions, structures that need to be represented, exploited
- **Despite or Thanks to**
- Multiple limitations
  - Cognitive, Physical, Temporal, Institutional,
- Autonomy of the agents
  - agents act autonomously according to their goals, skills,
- Organizations the agents take part in (they should explicitly represent and exploit them)

## From a MAS point of view

- Needs to insure a global behavior at the MAS level
  - In terms of cooperation, collaboration, ...
  - To be sure that the global goals of the system or collective instance are achieved
  - A way to control the increasing number of agents
  - A trick to filter potential interactions

### Despite or Thanks to

- Multiple limitations
  - Cognitive, Physical, Temporal, Institutional,
- Autonomy of the agents
  - agents act autonomously according to their goals, skills,
- Delegation/Adoption of tasks between the agents that need to be controlled

## From applications point of view

- Current applications show an increase in
  - Number of agents,
  - Duration and repetitiveness of agent activities,
  - Heterogeneous of the agents, Number of designers of agents
  - Ability to act, to decide,
  - Action domains of agents, ...
- More and more applications require the integration of human communities and technological communities (ubiquitous and pervasive computing), building connected communities (ICities) in which agents act on behalf of users
  - Trust, security, ..., flexibility, adaptation

## Intuitive Notions of Organizations

- in everyday life, e.g. an office table, ...
- in ethology, e.g. an ant hill, ...
- in biology, e.g. a cell, ...
- in computer science, e.g. Software/hardware architecture, class diagram, design patterns, information system, ...
- in human society, e.g. a soccer team, a school, an enterprise, a government, ...

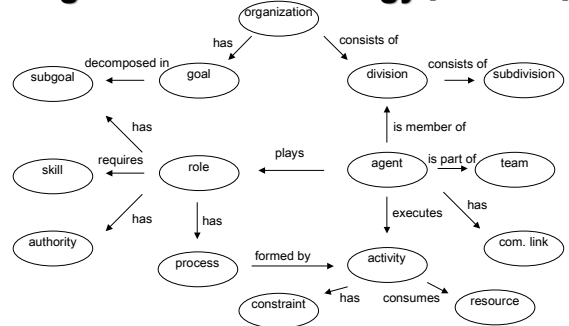
## What is an Organization ?

- Organizations are structured, patterned systems of activity, knowledge, culture, memory, history, and capabilities that are distinct from any single agent [Gasser 01]  
→ **Organizations are supra-individual phenomena**
- A decision and communication schema which is applied to a set of actors that together fulfill a set of tasks in order to satisfy goals while guarantying a global coherent state [Malone 87]  
→ **definition by the designer, or by actors, to achieve a purpose**
- An organisation is characterized by : a division of tasks, a distribution of roles, authority systems, communication systems, contribution-retribution systems [Bernoux 85]  
→ **pattern of predefined cooperation**
- An arrangement of relationships between components, which results into an entity, a system, that has unknown skills at the level of the individuals [Morin 77]  
→ **pattern of emergent cooperation**

## What is an Organization ?

- Organization is a supra-agent pattern of **emergent** cooperation or **predefined** cooperation of the agents in the system, that could be defined by the designer or by the agents themselves, for a purpose.
- Pattern of emergent/potential cooperation
  - Organizational entity, institution, social relations, commitments
- Pattern of predefined cooperation
  - Organizational structure, norms, ...

## Organizational Ontology [Fox et al. 98]



## Organization Typology [Baeijs 96]

- Centralised
  - Simple hierarchies : centralized decision,
  - multi-level hierarchies : decision on different levels
  - recursive structures : ...
- Decentralized
  - multiple hierarchies :
  - Market : contractual dimension
- Unstructured
  - Groups : shared goal, task division, heterarchical decision, several information exchanges
  - Teams : common environment in which agents interact,
  - SIG : interest sharing
  - Communities of practice : grouping of individuals in an independent manner of existing organizations

## Historical Remarks

- **70 → 90** : Beginnings
  - 77 : Area of Interest in Distributed Hearsay-II [Lesser 80]
  - 81 : An Organizational View on Distributed Systems [Fox 81]
  - 87 : DVMT [Corkill 83, Pattison 87]
  - 89 : MACE [Gasser 89], Roles [Werner 89]
- **90 → 00** : Maturation
  - Dependence Theory [Castelfranchi 92]
  - CASSIOPEE [Collinot 96], MARSO [MARCIA 97]
  - AGR [Ferber 98], TAEMS [Decker 96], TEAMS [Tambe 98]
  - Computational Organization Research [Carley 99]
- **00 → now** : Important dimension in MAS
  - MAAMAW 01
  - Workshops on Norms, Institutions, Organizations in ICMAS, AAI, AAMAS

## Multiple Inspiration Sources

- Mathematics, Computer science adapted from [Corkill 83], [Bouron 92], [Boissier 93], ... [Demazeau 02]
- Mechanics, Thermodynamics
  - Sigma [Baeijs 98], Friends [Van Aeken 99], ...
- Sociology
  - [Pattison 87], [Bond 90], [Gutknech 98], [Costa 96], [Hannoun 99], ...
- Social Psychology
  - [Sichman 95]
- Ethology
  - [Drogoul 93], ...
- ...

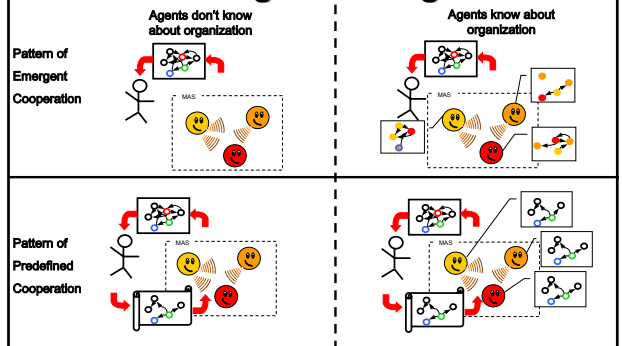
## Multiple Studies [Gasser 01]

- **Theoretical** : Abstract and general models of possibilities, limits, and mechanisms of organization ;
  - **Phenomenological** : Description/analysis/explanation of existing (human, biological, computational, physical, etc.) organizations ;
  - **Technological** : technologies for solving complex problems, for overcoming « individual » limitations (cognitive, physical, temporal, institutional, etc), and as efficiency optimization strategies
- **Computational Organization Research**

## Dimensions

- Organization is a complex notion :
  - Not only one **BUT** several views on organization
  - Not only one **BUT** several definitions
  - Not only one **BUT** several models
  - Not only one **BUT** several approaches
- This tutorial aims at proposing a comprehensive view
  - of this notion
  - of its use in Multi-Agent Systems as a programming model

## Who sees/designs the organization?



## Points of View on Organization

- Pattern of emergent cooperation
  - Agents initiate, define the organization
  - Models are mostly focused on the agent's behavior more or less seen as a social entity
  - ➔ **Agent Centered Point of View on Organizations**
- Pattern of predefined cooperation
  - Designer initiates, defines the organization
  - Models are mostly focused on the organization instead of the agents
  - ➔ **Organization Centered Point of View on Organizations**

## Who sees/designs the organization?

	Agents don't know about organization	Agents know about organization
Pattern of Emergent Cooperation	MANTA ...	Social Reasoning Mechanism Contract Net Protocol ...
Pattern of Predefined Cooperation	MASE GAIA MESSAGE ...	TAEMS STEAM MOISE+ AGR ...

Agent Centered Point of View

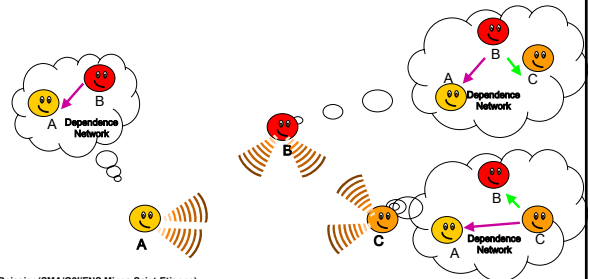
Organization Centered Point of View

## Outline

- Organization in MAS
- **Organizations with an Agent Centered Point of View**
  - Main Features
  - MANTA
  - Contract Net (CNET)
  - Dependence Based Coalitions (DBC)
- Organizations with a System Centered Point of View
- Dynamic of Organizations
- Conclusion

## Main features

« The social concepts are all focused on the **agents'** behavior seen as a social entity » [Lemaître 98]



## Main features (2)

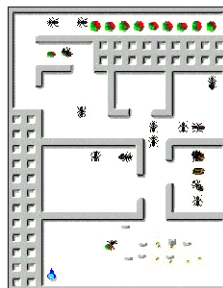
- No distinction between description of organization and description of agents
- Organization are inside the agents, no global representation
- Agents are dynamic, autonomous entities that evolve without any explicit constraint
  - on their behaviors
  - on their communications,

## Main features (3)

- Organizational concepts, pattern of cooperation are in the “**eye**” of the Agents,
- “Organization” may have a “Social” aim :
  - Joint Intentions [Levesque 90, Cohen 91]
  - Social Commitment [Singh 97, Castelfranchi 92]
  - Dependence networks [Castelfranchi, Sichman 95], Power relations [Castelfranchi 92]
  - Temporal dependencies (STARS) [Allouche 00]
  - Goal Dependencies (Eco-Problem Solving) [Ferber 89]
- Or a “Normative” aim :
  - Commitment – Conventions [Jennings 93, 95]
  - Obligations – Permissions [Dignum 96]

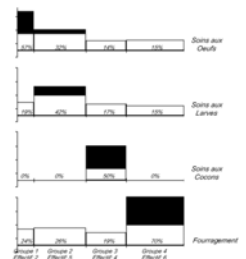
## MANTA

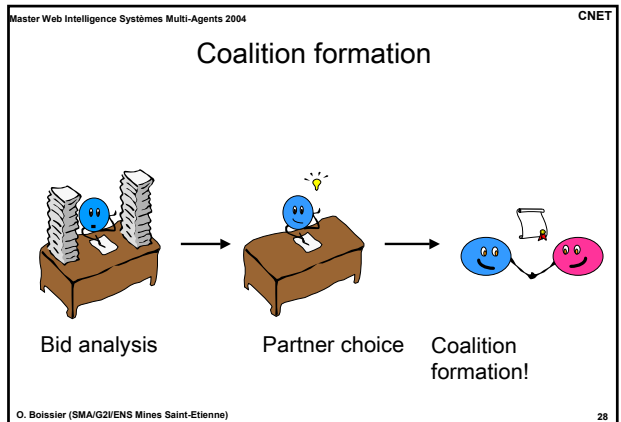
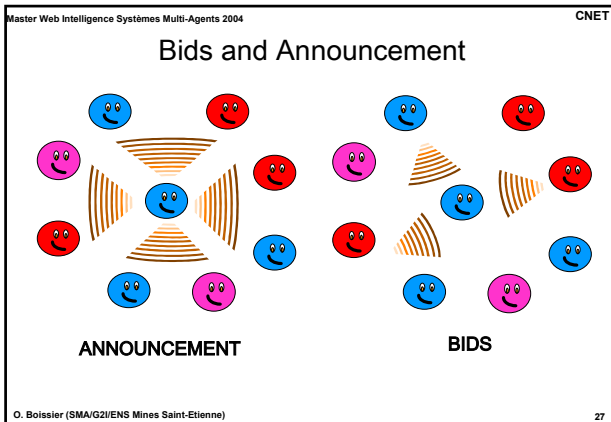
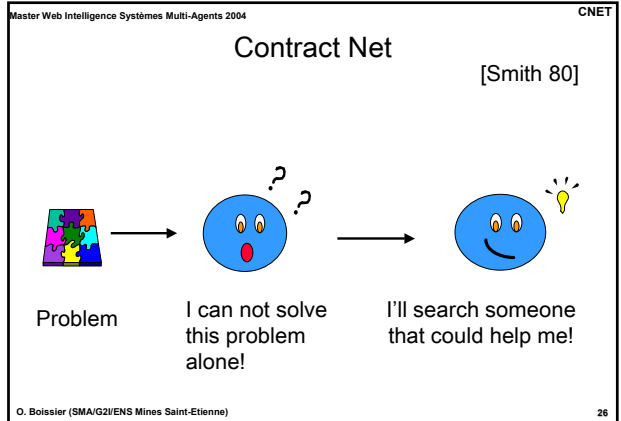
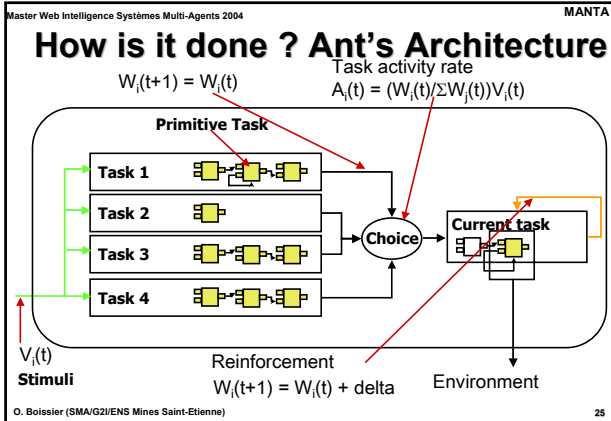
- MANTA [Drogoul 93]
  - (*Modeling an Ant hill Activity*)
  - Study of the emergence of work division within a primitive ant society
  - Emergence of several functional groups: feeders, egg nurses, larvae nurses



## Implicit Organization

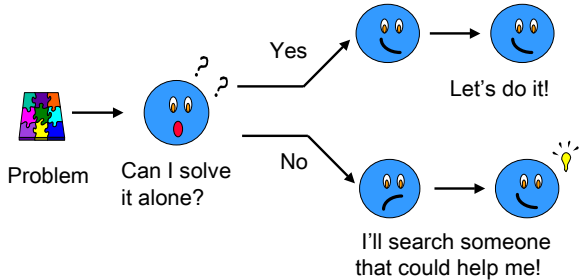
- Emergence of an organization observable throughout the labour specialization of the ants thanks to feedback mechanism and spatial dimension of the system



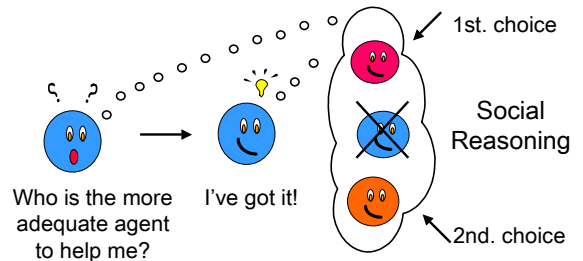


## Dependence Based Coalitions

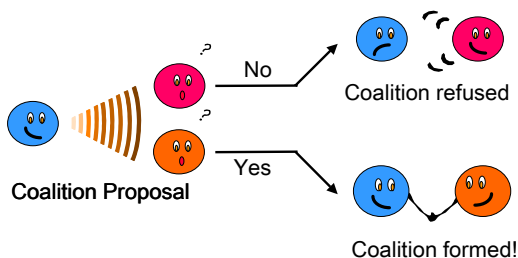
[Sichman 95, 98]



## Dependence Based Coalitions



## Dependence Based Coalitions



## Coalitions as Emergent Organizations

- Since the manager has sent the award (CN) or the partner has accepted to cooperate (DBC), a **mental notion** regarding the cooperation is built (commitment, joint commitment, etc.)
- This mental notion can be seen as an **organizational mental attitude**: an agent knows he is taking part in a group, to achieve a certain goal, by eventually using a certain plan, on behalf of another(s) agent(s)



## Dependence Based Coalitions

[Sichman 95]

- Class of problems where :
  - Huge networks of processing resources that are heterogenous, autonomous, distributed
  - Openness
  - Remote execution of services,
  - Composition of services,
- in which one should insure :
  - Interconnection and interoperability of its elements,
  - Adaptation of its elements to possible changes in the environment, due to the dynamic entry and exit of services,
  - Existence of an operational model which could allow these elements to cooperate, if they want to.

## Dependence Theory

- The emergence of social structures is an essential issue in MAS, both for:
  - problem solving purposes
  - simulation purposes
- Dependence Theory [Castelfranchi 92] [Sichman et al. 94] provides a nice framework to model such phenomena

## Dependence Theory

- Socially situated agents may depend on one another to achieve their *own* goals. In terms of the dependence theory, an agent  $ag_i$  **depends** on some other agent  $ag_j$  with regard to one of its goal  $g_k$ , when:
  1.  $ag_i$  is not autonomous with regard to  $g_k$ : it lacks at least one of the actions or resources necessary to achieve  $g_k$ , while
  2.  $ag_j$  has the missing action/resource

## Dependence Theory

- An agent  $ag_i$  *depends* on another agent  $ag_j$  for a given goal  $g_k$ , according to a set of plans  $P_{g_k}$  if she has  $g_k$  in her set of goals, she is not autonomous for  $g_k$  and there is a plan  $p_{g_k}$  in  $P_{g_k}$  that achieves  $g_k$  where at least one action used in this plan is in  $ag_j$ 's set of actions.
- An example of a basic **dependence relation** could be:  

$$basic\_dep(ag_1, ag_2, g_1, p_{111} = a_1(), a_2(), a_4(), a_2)$$

## Dependence Theory

- An agent  $ag_i$  **OR-depends** on a set of agents  $Ag_j$  when she holds a disjunction set of dependence relations upon any member  $ag_k$  of  $Ag_j$ . Any member of the set  $Ag_j$  is sufficient but unnecessary for  $ag_i$ 's goal. *OR-dependence mitigates social dependence.*
- An agent  $ag_i$  **AND-depends** on a set of agents  $Ag_j$  when she holds a conjunction set of dependence relations upon all members of  $Ag_j$ . All members of the set  $Ag_j$  are necessary for  $ag_i$ 's goal. *AND-dependence strengthens social dependence.*

## Social Reasoning Mechanism (1)

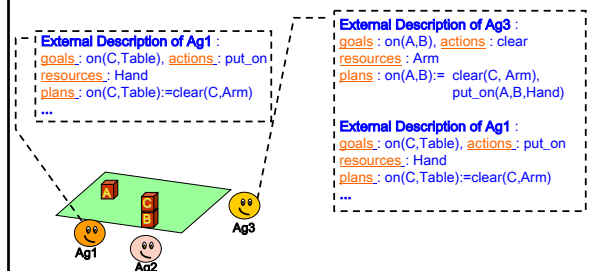
- Based on Dependence Theory [Castelfranchi 92]
- Explains why social interactions occur, based on agents' **complementarity**
- Each agents represents in a private **external description** his information about the others
  - goals, plans, actions and ressources

## Social Reasoning Mechanism (2)

- Explicit reasoning about the others (meta-level, domain independent)
- Belief revision about the others (in an open scenario, the representation of the others is never correct and complete)
- General Principles :
  - non-benevolence
  - Sincerity
  - self-knowledge
  - consistency

## Example of External Description

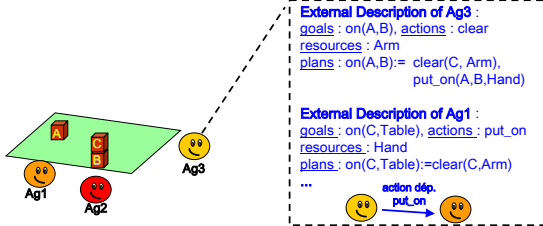
Input Sources : explicit communication, perception, built-in data during design time, inference



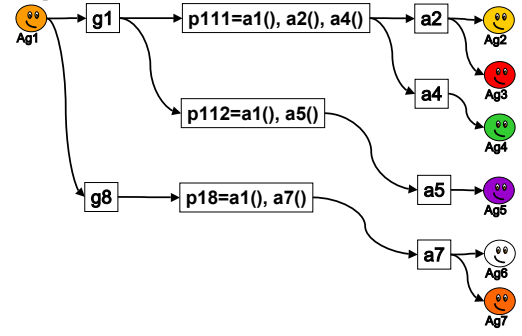
## Example of Dependence Relation

There exists a plan which achieves goal  $on(A,B)$ , thus  $Ag3$  is not a autonomous, for this plan, because it doesn't have action  $put\_on$ .

$basic\_dep(Ag_3, Ag_1, on(A,B),$   
 $on(A,B) := clear(C, Arm), put\_on(A,B, Hand),$   
 $put\_on(A,B, Hand))$



## Dependence Networks



## Social Reasoning

Given two agents  $i$  and  $j$ , the following situations may hold:

- **Independence**
- **Unilateral** Dependence (agent  $i$  depends on agent  $j$  for one of its goals  $g$ )
- **Bilateral** Dependence (agents  $i$  and  $j$  depend on each other for their goals  $g_1$  and  $g_2$ )
  - Mutual Dependence MD :  $g_1 = g_2$
  - Reciprocal Dependence RD :  $g_1 \neq g_2$

## Social Reasoning : Goal Situations

- A **goal situation** relates an agent to a goal :
  - **NG**( $i, g$ ) : the agent  $i$  does not have the goal  $g$
  - **NP**( $i, g$ ) : the agent  $i$  has the goal  $g$  but it does not have any plans to achieve it
  - **AUT**( $i, g$ ) : the agent  $i$  has the goal  $g$ , and at least a plan  $p$  makes it action-autonomous to achieve  $g$
  - **DEP**( $i, g$ ) : the agent  $i$  has the goal  $g$ , and every plan  $p$  to achieve  $g$  makes it action-dependent to achieve  $g$
- This notion is taken into account for goal, plan and partner (acceptance) choice.

## Social Reasoning : Dependence Situations

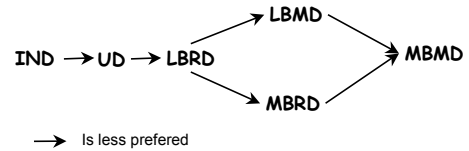
A **dependence situation** relates 2 agents and a goal :

- $IND(i,j,g) \equiv DEP(i,g) \wedge \neg dep\_on_a(i,j,g,i)$
- $LBMD(i,j,g) \equiv MD(i,j,g,i) \wedge \neg MD(i,j,g,j)$
- $MBMD(i,j,g) \equiv MD(i,j,g,i) \wedge MD(i,j,g,j)$
- $LBRD(i,j,g,g') \equiv RD(i,j,g,g',i) \wedge \neg RD(i,j,g,g',j)$
- $MBRD(i,j,g,g') \equiv RD(i,j,g,g',i) \wedge RD(i,j,g,g',j)$
- $UD(i,j,g) \equiv dep\_on_a(i,j,g,i) \wedge \neg \exists g' (is_g(j,g') \wedge dep\_on_a(j,i,g',i))$

→ This notion is taken into account for partner (proposal) choice

## Social Reasoning : Dependence Situations

- Possible ordering of the dependence situations to choose a partner :



## Social Reasoning : Goals and Plans

- A certain goal is **achievable** for an agent  $i$  if there is a plan whose all actions can be executed by at least one agent in the agency
- A certain plan is **feasible** for an agent  $i$  if all its actions can be executed by at least one agent in the agency
  - a goal is achievable if there is at least one feasible plan for it

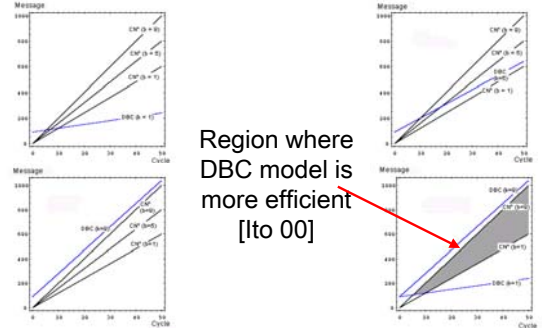
## Dependence Based Coalitions (1)

- An agent may use his dependence networks and other associated notions (goal and dependence situations) to try to form organizations when he can not achieve his goals by himself
- Whenever the agents reasons socially well, this technique is useful in the long term

## Dependence Based Coalitions (2)

- An agent first chooses a goal to achieve
  - its most important achievable goal
- Then, it chooses a plan to execute
  - Its less costly feasible plan for this goal
- According to its goal situation:
  - if he is AUT, he executes the plan alone
  - If he is DEP, he uses the dependence situations to choose a partner

## Comparison between CNet & DBC

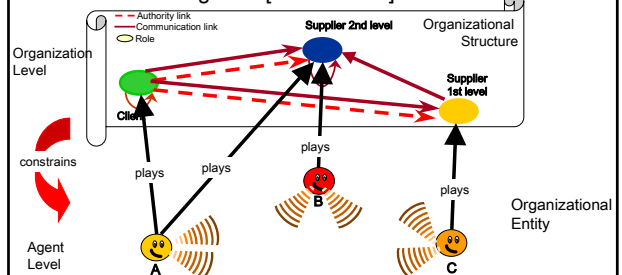


## Outline

- Organization in MAS
- Organizations with an Agent Centered Point of View
- **Organizations with a System Centered Point of View**
  - Main Features
  - AGR
  - STEAM
  - MOISE+
- Dynamic of Organizations
- Conclusion

## Main features (1)

« The leading concept is the **group** or the **organization** instead of the agent » [Lemaître 98]



## Main features (2)


- Make a clear distinction between description of organization and description of agents
  - Two levels : organization and agent
- Agents are dynamic, autonomous entities that evolve within organizations
  - Organizations constrain the behaviors of the agents
  - Organizations may be the result of the activities of agents

## Main Features (3)

- Organizational concepts and models used as an aid to the designer
  - Structural Model in several Methodologies
    - GAIA [Zambonelli 01], TROPOS [Bresciani 01], MESSAGE [Caire 01], MASE [DeLoach 02], AALADIN [Ferber 98], CASSIOPEE [Collinot 96], ...
- Agents “know” about organization which they belong to
  - What is the organization about ?
    - Fonctionnal (eg : TAEMS),
    - Structural (AGR),
    - Both and more (STEAM, MOISE+)
  - What is the link between Organization and Agent's Autonomy
    - Not a question (TAEMS, AGR, STEAM),
    - Explicit Normative Dimension (MOISE+)

## AGR

[Ferber, Gütknecht 98]

- **A**gent **R**ole
- Previously known as AALADIN
- Used within the  platform
- Agent
  - Active entity that plays roles within groups. An agent may have several roles and may belong to several groups.
- Group
  - Set of agents sharing common characteristics, i.e. context for a set of activities.
  - Two agents can't communicate with each other if they don't belong to the same group

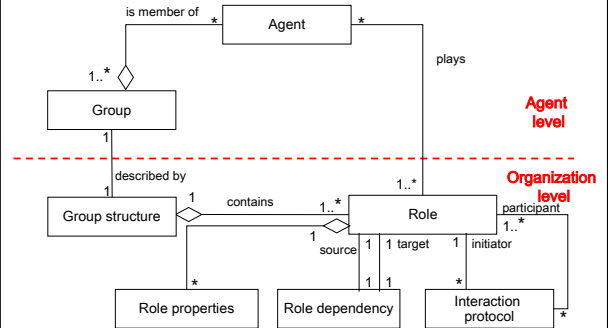
## Role

- Abstract representation of the status, position, function of an agent within a group.
- Roles are local to group
- Several agents can play the same role.
- A role is a description of an expected behavior of an agent
- A role describes constraints that agents playing that role should satisfy
- Roles are interrelated through interaction description and relation/dependencies between roles

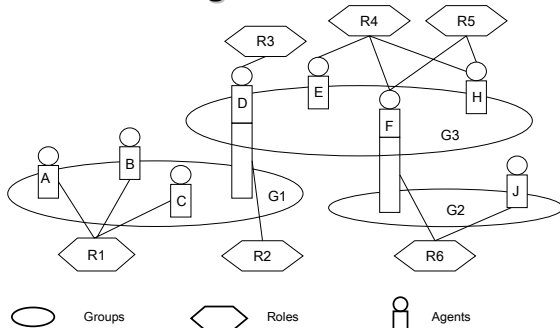
## Group and Organizational Structures

- Group Structure
  - Abstract definition of a group
  - Contains description of roles, relations between roles, interaction specification
  - Taxinomy of group structures
- Organizational Structure
  - Set of group structures and description of their relations

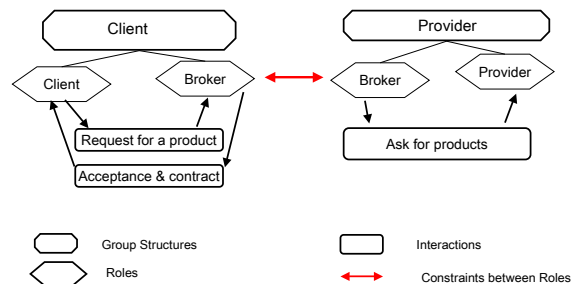
## Meta-model



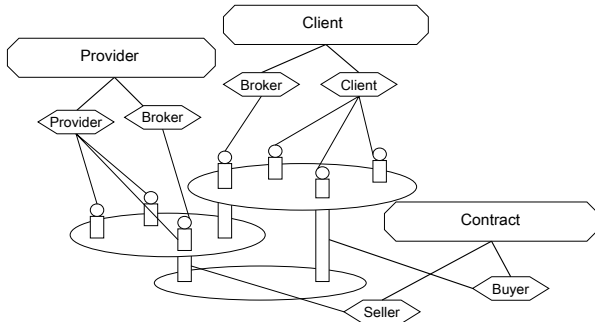
## Notations : Agent Level



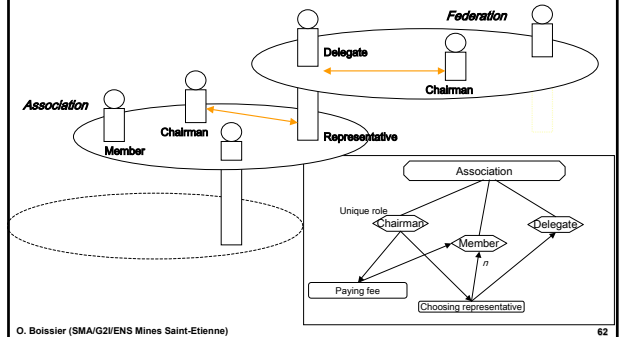
## Notations : Organizational level



## Example



## Hierarchies representation



## STEAM [Tambe 98]

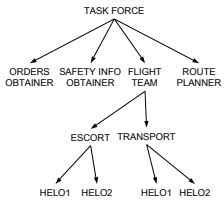
- **Shell for TEAMwork**
- General framework to enable agents to participate in teamwork.
  - Different applications: Attack, Transport, Robocup soccer
- Based on an enhanced SOAR architecture and 300 domain independent SOAR rules
- Principles :
  - Team synchronization
    - Establish joint intentions, Monitor team progress and repair, Individual may fail or succeed in own role
  - Reorganize if there is a critical role failure
  - Reassign critical roles based on joint intentions
  - Decision theoretic communication

## Main Components

- Based on: [Pynadath 99]
  - Joint intentions theory as building block for a team's mental attitude enabling flexible reasoning about coordination activities [Levesque 90, Jennings 95],
  - Shared Plans Theory: Hierarchical structure of joint intentions and individual intentions [Grosz 96, Rich 97]
- Teamwork knowledge consists of:
  - Coherence preserving rules requiring communication between team members to ensure coherent initiation and termination of team plans
  - Role-monitoring and repairing rules ensuring substitution of roles between team members
  - Decision-theoretic techniques to weigh communication costs and benefits to avoid excessive communication in the team.

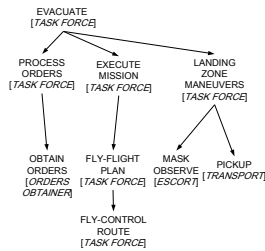


## TEAM SPECIFICATION



**Organization:** hierarchy of roles that may be filled by agents or groups of agents.

From [Tambe 00]



**Team Plan:**

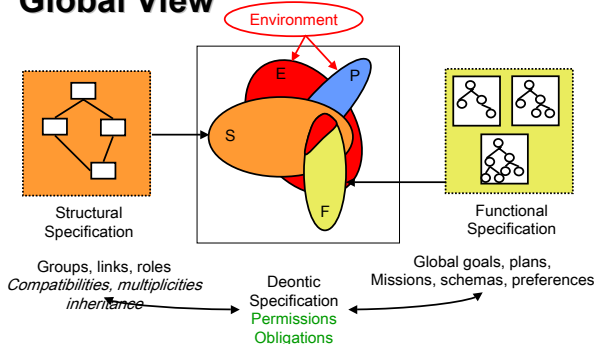
- initial conditions,
- term. cond. : achievability, irrelevance, unachievability
- team-level actions.

## MOISE+

[Hannoun 02, Hübner 03]

- **M**odel of **O**rganization for multi-agent **S**yst**E**ms.
- <http://www.lti.pcs.usp.br/moise>
- Distinguishes three main dimensions in the organization of a Multi-Agent System:
  - Structural specification
  - Functional Specification
  - Deontic Specification

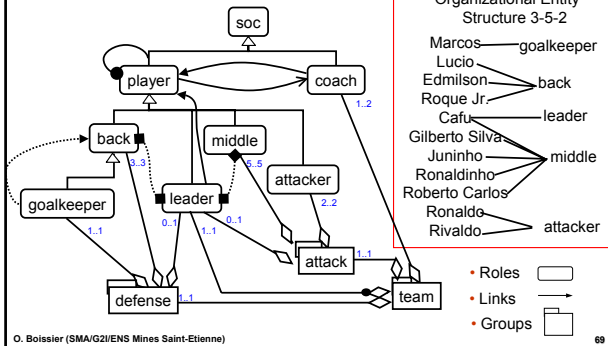
## Global View



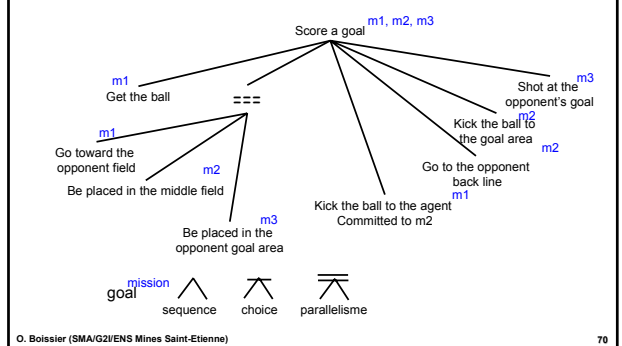
## Main Concepts

- **Role:** label which will be used to assign constraints on the behavior of agents playing it
- **Link:** relation between roles that directly constrain the agents in their interaction with the other agents playing the corresponding roles.
- **Group:** set of links, roles, compatibility relations.
- **Social Scheme:** goal decomposition tree where the root is the Scheme's goal, the subgoals are structured into missions.
- **Missions:** set of coherent goals that are to be assigned to roles.

## Structural Specification



## Functional Specification

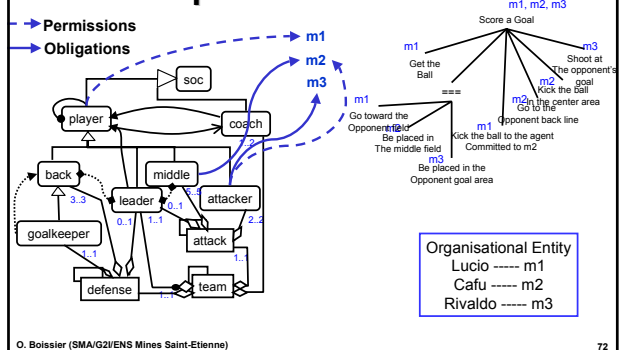


## Deontic Specification

- Explicit relation between the functional and structural specifications
  - Permissions and obligations to commit to missions in the context of a role
  - To make explicit the normative dimension of a role

Role	Deontic Relation	Mission	Temporal Constraint (cf. [carron 01])
Back	Permission	$m1$	In [0 30]
Middle	Obligation	$m2$	during [Attacker]
Attacker	Obligation	$m3$	Any

## Deontic Specification



## Outline

- ✓ Organization in MAS
- ✓ Organizations with a System Centered Point of View
- ✓ Organizations with an Agent Centered Point of View
- **Dynamic of Organizations**
- Conclusion

## Reorganization [Hübner 03]

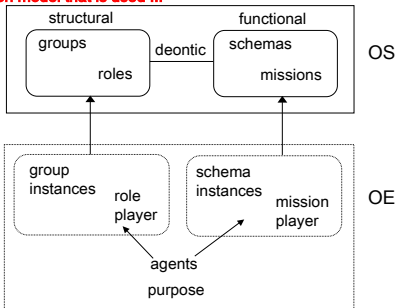
- Several aspects regarding a reorganization process
  - what is changed?
  - when the process is started?
  - who takes the initiative?
  - how the process is controlled?

## What is changed ?

Depends on the organization model that is used !!!

e.g. In MOISE+  
[Hübner 03]

- Org. Spec. Level
  - Deontic Spec.
    - Permissions,
    - Obligations
  - Func. Spec.
    - Schemas
    - Missions
  - Struct. Spec.
    - Roles, groups, links
- Org. Entity Level
  - Agents/roles
  - groups



## When is the process started?

- Static
  - process start is already predefined, already « designed » in the organizational specification
  - examples: [Stone 98] [Carron 01]
- Dynamic
  - reorganization happens as a consequence of the system functioning
  - If the system (agents) goal and/or performance is not adequate, the organization must be changed

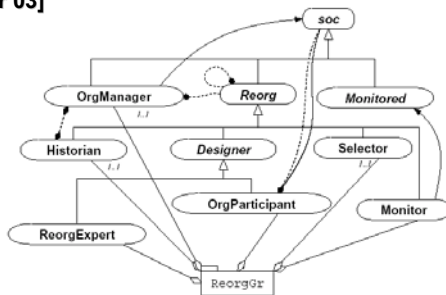
## Who takes the initiative?

- Endogenous
  - one agent (centralized) or many agents (decentralized) within the system
  - auto-organization (adaptation, learning)
- Exogenous
  - MAS user
  - example: [Malone 99]

## How is the process controlled?

- Controlled
  - the rules of the reorganization process are known in advance
  - examples:[Horling 01]
- Emergent
  - an agent takes the initiative by himself, despite the others
  - it can fail, if the others do not agree

## MOISE+ Reorganization Group [Hübner 03]



## MOISE+ Reorganization Schema [Hübner 03]



### Deontic relations:

$OrgManager \rightarrow obl(m_1)$   
 $Monitor \rightarrow obl(m_2)$   
 $ReorgExpert \rightarrow obl(m_4)$   
 $OrgParticipant \rightarrow pcr(m_5)$   
 $Selector \rightarrow pcr(m_6)$

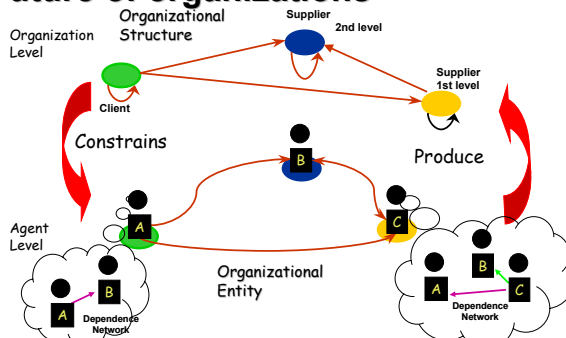
## Outline

- ✓ Organization in MAS
- ✓ Organizations with a System Centered Point of View
- ✓ Organizations with an Agent Centered Point of View
- ✓ Dynamic of Organizations
- **Conclusion**

## Conclusion

- Organization is a complex and rich dimension in MAS:
  - represented in different “eyes”: Designer – Observer – Agents
  - expressed with two points of view: Agent-Centered vs. Organization-Centered
  - using multiple models: e.g. Joint intentions, shared plans, dependence theory, ...
- Organization is built to fulfill different aims
  - To help the cooperation between the agents,
  - To control the cooperation between the agents.
    - Forgetting or not the autonomy of the agents
- Organizing is a complex process:
  - Static or dynamic
  - Bottom up or top down

## Future of organizations



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