USD

Odense
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MAS Course 1

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SCHEDULE OF THE COURSE + EXAMINATION

MAS 01	04 Aug.	Introduction, Methodology, Agents,
MAS 02	05 Aug.	
MAS 03	06 Aug.	
MAS 04	09 Aug.	
MAS 05	10 Aug.	
MAS 06	11 Aug.	

attendance ; handouts ; individual work
[Ferber 95] [HERMES 01] [OFTA 04]

MAS Examination — 13 Aug. — Written Control

INTRODUCTION

What is an Agent ?

External Definition : a **real** or **virtual** entity that evolves in an **environment**, that is able to **perceive** this environment, that is able to **act** in this environment, that is able to **communicate** with other agents, and that **exhibits** an **autonomous** behaviour

---> autonomous agents, robots

---> the autonomy principle

The Autonomy Principle [Müller 95]

Natural Autonomy

Autonomy of a system as an organisation of processes able to maintain itself

Artificial Autonomy

Autonomy as the capability to exploit the actual circumstances to serve its purpose

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Internal Definition : a **real** or **virtual** entity that **encompasses** some **local control** in some of its **perception** , **communication** , **knowledge acquisition** , **reasoning** , **decision** , **execution**, **action** processes.

---> the delegation principle

---> mobile objects, personal assistants

The Delegation Principle [Demazeau 90]

Weak Delegation

KNOWLEDGE (complementary descriptions, ...)

Medium Delegation

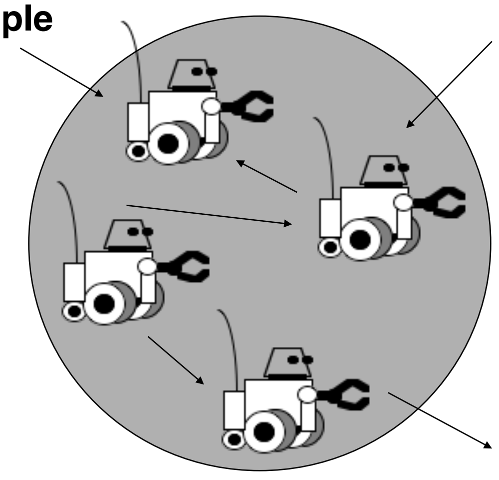
POSSIBLE SOLUTIONS or PLANS (agreement on a common solution, ...)

Strong Delegation

CHOICES or GOALS (requesting someone to do something, ...)

What is a Multi-Agent System ?

A set of possibly organized agents which interact in a common environment
---> the distribution principle



MAS main interests :

---> To extend classical mono-agent AI models and tools (A-centered)

---> To study specific multi-agent models and tools (MAS-centered)

Agents and Multi-Agent Systems

External Definition : a **real** or **virtual** entity that evolves in an **environment**, that is able to **perceive** this environment, that is able to **act** in this environment, that is able to **communicate** with other agents, and that **exhibits** an **autonomous** behaviour

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---> the delegation principle

But there is no agent without any MAS !

MAS Micro and Macro Issues

Micro issues (Agent oriented)

- how do we design and build an agent that is capable of acting autonomously
- are oriented towards mental and environmental issues
- are typical of agent theories (Cohen & Levesque, Rao & Georgeff, Shoham, Singh, Wooldridge & Jennings, ...)

Macro issues (MAS oriented)

- how do we get a society of agents to cooperate effectively?
- are oriented towards interactions and organisations issues
- are typical of multi-agent theories (Durfee, Ferber, Gasser, Hewitt, Lesser...)

How to bridge between Micro and Macro Issues

Agents Environments Interactions Organisations

Agents
- internal architectures of the processing entities

Environment
- domain-dependent elements for structuring external interactions between entities

Interactions
- elements for structuring internal interactions between entities

Organisations
- elements for structuring sets of entities within the MAS

Multi-Agent System, Emergence, Recursion

The Declarative Principle

MAS = A + E + I + O

The Functional Principle

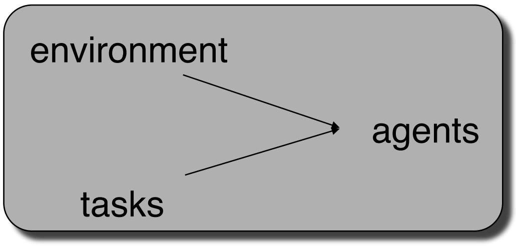
Function(MAS) = ∑ Function(entities)
+ Emergence Function

The Recursive Principle

entity = basic entity | MAS

Distributed Problem Solving

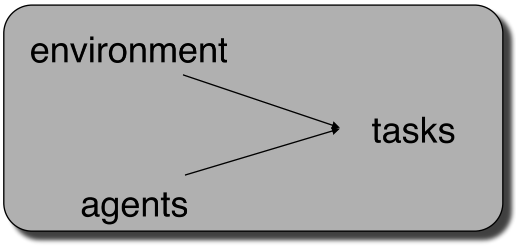
global conceptual model
global problem
global success criteria
division of :
- knowledge
- resources
- control
- authority



focus on the collaborative resolution of global problems by a set of distributive entities
- society goals directed
- input : tasks, environment
- output : model of the distributed entities
- schema to solve the tasks

Decentralized System Simulation

local conceptual models
local problems
local success criteria
division of :
- knowledge
- resources
- control
- authority



focus on the coordinated activities of a set of agents evolving in a multi-agent world
- agent goals directed
- input : agents, environment
- output : tasks which can be solved
- schema to solve the tasks

Historical Roots

Hearsay II (1973)
- blackboard architecture

Actors (1973)
- language to describe complex control structures

Beings (1975) Society of Mind (1978)
- common agent structures

Contract Net (1982)
- decentralized hierarchical control

DVMT (1984)
- distributed interpretation, organisation

Reactive Robots (1986)
- subsumption architecture

Mace (1987)
- multi-agent environment

MAS Characteristics

Natural decomposition of action, perception, or control, sharing of resource, environment, ...

No constraint about the heterogeneity of agents

Agents are perceived as being autonomous entities behaving rationally

No constraint about the grain of the agent model

Need for 3 or more coordinating agents or environments : interactions, organization, ...

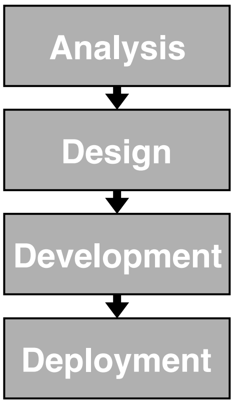
METHODOLOGY

VOWELS : Domains and Problems

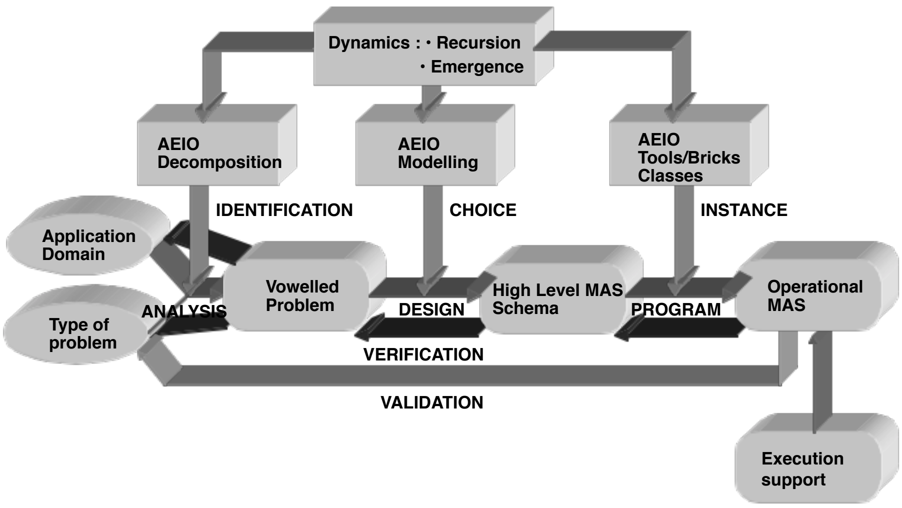
Computer-Aided	Design
Computer	Vision
Decision	Support
Electronic	Commerce
Entreprise	Modelling
Manufacturing	Systems
Natural Language	Processing
Network	Monitoring
Office and Home	Automation
Robotics	Control
Societies	Simulation
Spatial Data	Handling
Telecommunication	Routing
Traffic	Management

MAS Methodology

Methodology
= Approach + Model + Tools + Problem + Domain
= Analysis + Design + Development + Deployment



VOWELS : General Approach



VOWELS : Vowels Oriented Programming

We defend an instance of Multi-Agent Oriented Programming, the VOWELS framework which consists :

- 1/ to express the problem to solve independently of the domain
- 2/ to "vowellify" the problem in terms of A E I O U, ...
- 3/ to choose understood frames of A, E, I, O, U, dynamics, and recursion
- 4/ to leave VOWELS "emergence engine" complete the missing bricks by itself and build the appropriate MAS...
- 5/ ... to be deployed as self on a distributed settling...
- 6/ ... to be settled and used interactively

MAS methods vs. Components methods (start)

Components Methods meaning...
- Components meaning JavaBeans, MS-COM, ...

Characteristics of the Components Methodology
- continuity Approach / Modelling / Implementation
- fixed Data Interaction Model between components
- no organisation nor group primitives
- components are built first, and then their dynamics

Characteristics of the MAS Methodology
- no full continuity Approach / Modelling / Implementation
- free Data interaction Model [Demazeau 95], ...
- organisation and group primitives [Occello 97], ...
- entry point of the design is not unique nor imposed [Demazeau 97], ... even it often corresponds to agents

MAS methods vs. Components methods (end)

Some common features between the methods

- introspection, persistence, mobility of basic entities
- event-driven communication between entities
- entities design and integration into applications

Characteristics of the Components Methodology

- customisation of entities at design time only
- existing de facto standards towards interoperability
- application independent reusable interoperable entities

Characteristics of the MAS Methodology

- possible dynamic allocation of roles during run time
- efforts to standardisation through the FIPA foundation
- still frequently application dependent entities

Agent Unified Modeling Language (AUML)

AUML is part of a standardization effort done by FIPA under the auspices of IEEE *http://www.auml.org*
To create new diagrams and stereotypes for specific agent concepts when UML is not enough.

AUML extends UML with :

- Agent class diagram
- Interaction diagrams : AUML Interaction diagrams frequently used to model communication between agents
- Organization diagram

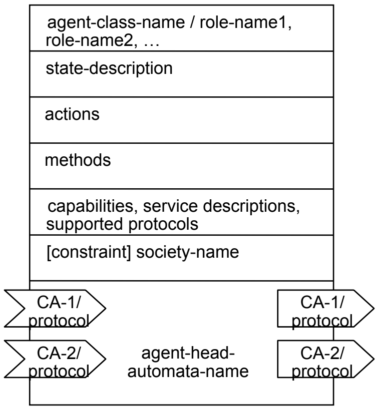
Work in progress :

- Few diagrams
- No tool
- No validation algorithm
- Based on semi-formal semantics of UML: space for ambiguity

Agent UML Agent Diagram

UML Class diagram with some additions:

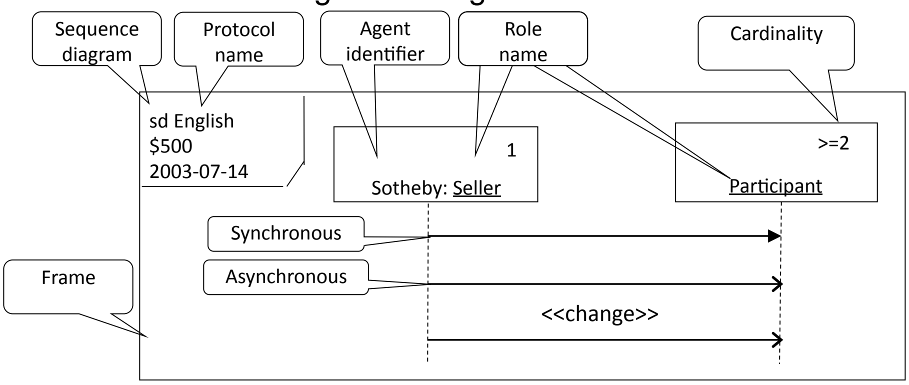
- New compartments to specify services, capabilities, incoming and outgoing messages
- Agent behavior on receiving and sending messages
- Agent role and group



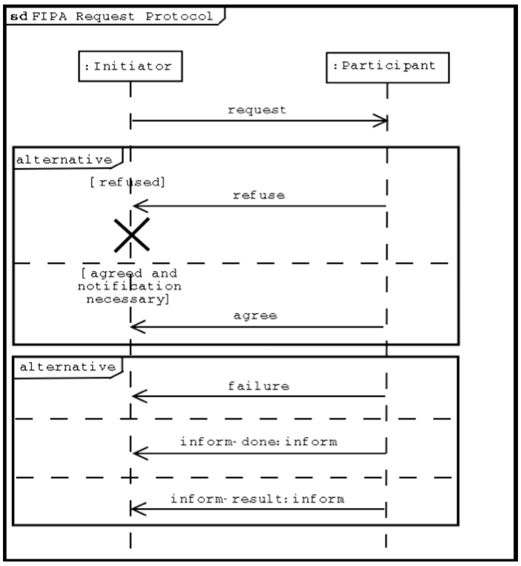
Agent UML Interaction diagram (1)

UML 2.0 Interaction diagram with some additions:

- Agent role and group are added
- Cardinality on message sending
- Blocking and non-blocking constraints
- Actions on message receiving



Agent UML Interaction diagram (2)



ANALYSIS

Extrinsic Decomposition [Alvares 96]

Characteristics

- each agent is able to solve the whole problem
- the use of many agents in parallel speeds up the problem solving
- it is a purely physical (spatial or temporal) decomposition of the work between the agents

Examples

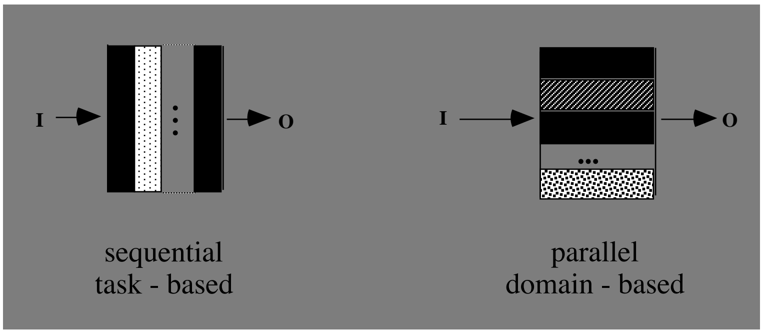
- there is an examination to be prepared by several professors. Each one wil be responsible to prepare a given number of questions (spatial)
- each professor will work for a given time (temporal)

Intrinsic Decomposition [Alvares 96]

The decomposition is based on a specialization

Two possible ways

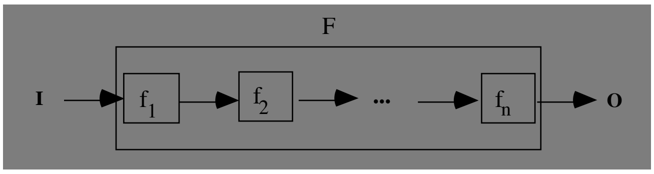
- to solve the problem partially for any case
- to solve the problem entirely for some cases



Sequential or Task-based [Alvares 96]

Exemple: to prepare an examination subject, we can divide the work in three subproblems

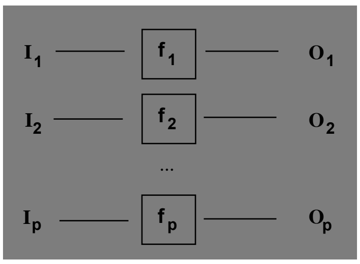
- to determine the number of questions by topic
- to really conceive each question
- to revise the questions



**$F(I) \text{---> } O : f_n R...R f_2 R f_1(I) \text{---> } O$,
where R is a temporal relation between the functions, and can be "precedes" or "succeeds"**

Parallel or Domain-based [Alvares 96]

Example: to prepare an examination subject, we can imagine some domain division like by type of question (to fill in, discursive, multiple choice, ...) or by subject (topic)



$I = I_1 \cup I_2 \cup ... \cup I_m$, $O = O_1 \cup O_2 \cup ... \cup O_n$, $f_i(I_i) \text{---> } O_i$

Comparative Properties [Alvares 96]

	extrinsic	sequential task-bsd	parallel domain-bsd
ag's competence and behaviour	same	different	different
allowance of parallelism	yes	no	yes
allowance of ag's simplification	no	yes	yes
type of decomposition	quantitative	qualitative	qualitative
communication between agents	minimal	maximal	minimal

Using many criteria (1) [Alvares 96]

The criteria are not mutually exclusive, we can combine them

At every level, the decomposition criteria are exclusive

Example: to prepare an examination subject

- Determine the number of questions and the respective value by topic (sequential)
- There will be people to prepare questions about topic t1 and people to prepare questions about topic t2 (parallel)
- In topic t1, there will be discursive and simple choice questions (parallel).
- There will be people to revise all questions (sequential)
- Each question will be revised for technical aspects and for linguistic aspects (parallel)

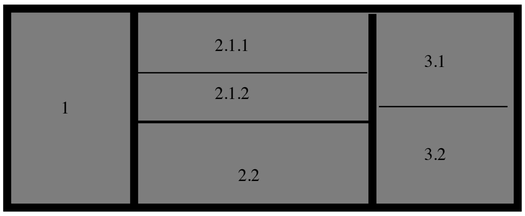
Using many criteria (2) [Alvares 96]

The problem is decomposed into :
- 1 determine topics 2 prepare questions 3 revise questions

The subproblem 2 is decomposed into
- 2.1 topic t1 2.2 topic t2.

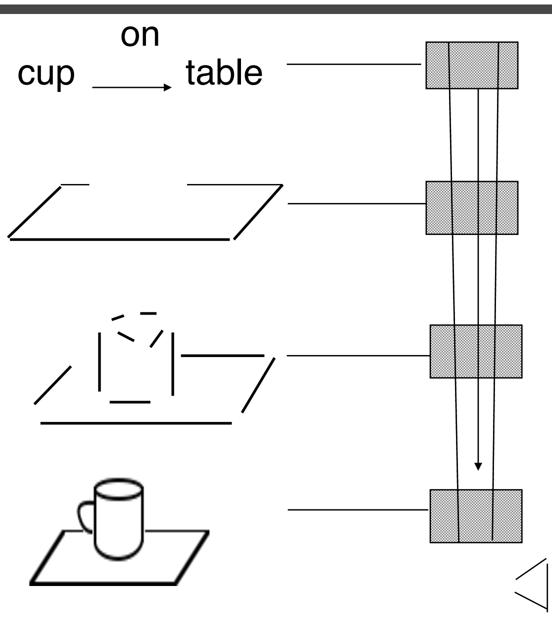
The subproblem 2.1 is decomposed into
- 2.1.1 discursive questions 2.1.2 simple choice questions.

The subproblem 3 is decomposed into
- 3.1 technical review; 3.2 linguistic review.



DESIGN

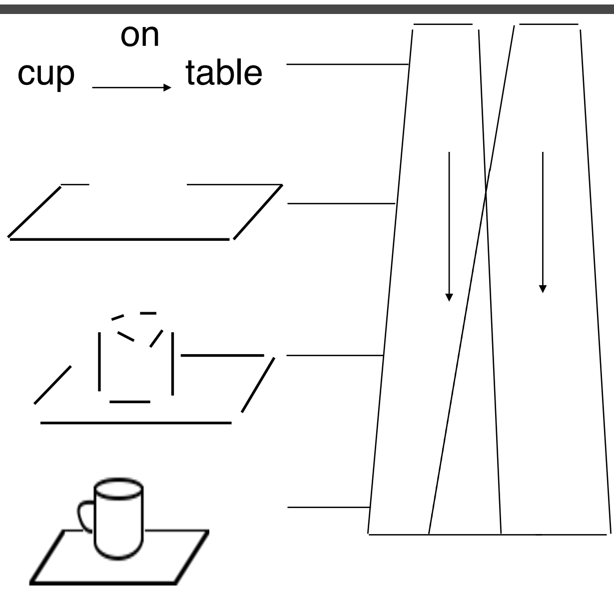
Decomposition by Location [Crowley 89]



spatio-temporal regions (dx,dy,dz,dt)

VAP system

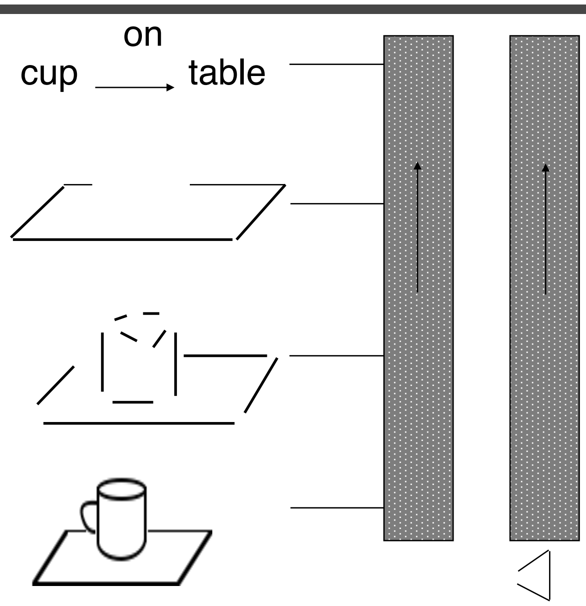
Decomposition by Output [Draper 83]



object models (cup, table)

SCHEMA system

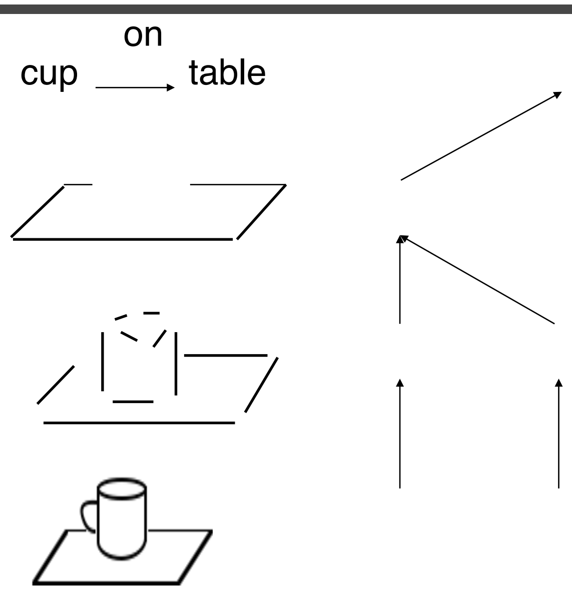
Decomposition by Tasks [Aloimonos 90]



primitive tasks (tracking, scanning, ...)

MEDUSA system

Decomposition by Input [Demazeau 86]



features (contours, highlights, ...)

SATURNE system

Decomposition by Abstraction [Demazeau 86]

	scene	scene	interpretation
3D model	object	feature grouping	recognized objects
2,5D model	scene features	scene description	scene elements
primal sketch	image features	image description	image elements
images	images	images	raw data
[Marr]	[Demazeau]	[Crowley]	[Neuman]

SATURNE : Vertical foci of attention

explicitely designed
cf. characteristics

contours

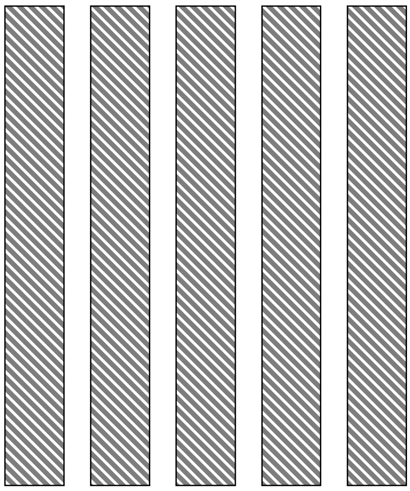
highlights

range data

stereo vision

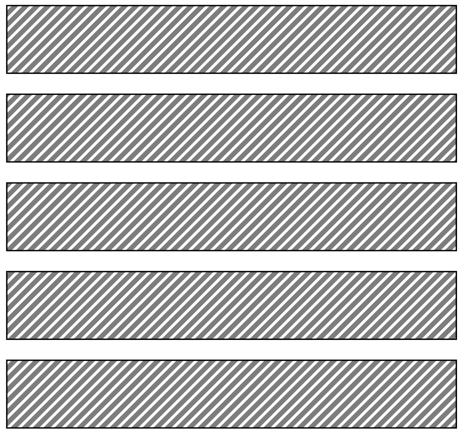
regions

...



SATURNE : Horizontal levels of representation

abstraction	scene
cf. representation	object
+	scene features
decentration	image features
cf. referential	images



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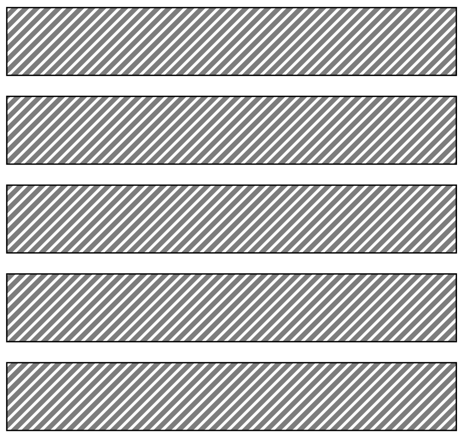
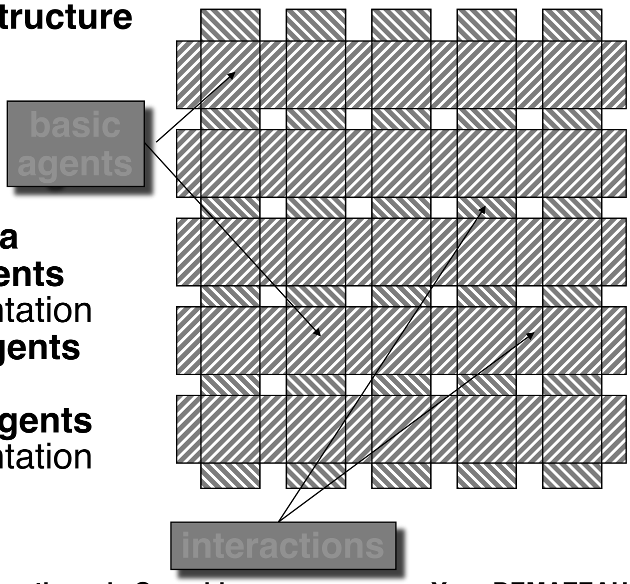


SATURNE : Agents and Society of Agents

organisational structure
horizontal links
vertical links

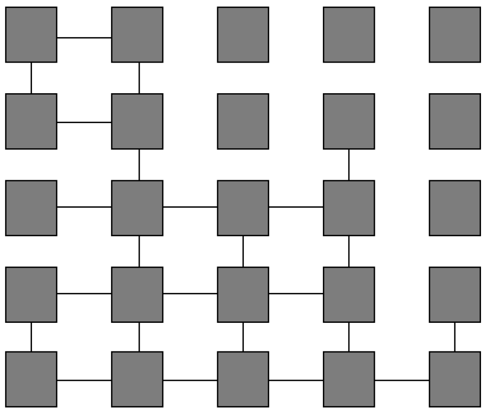


interaction media
between foci agents
levels of representation
between level agents
foci of attention
between basic agents
levels of representation
x foci of attention

SATURNE Behaviour : Scene Understanding

input
image
(environment)
basic agents

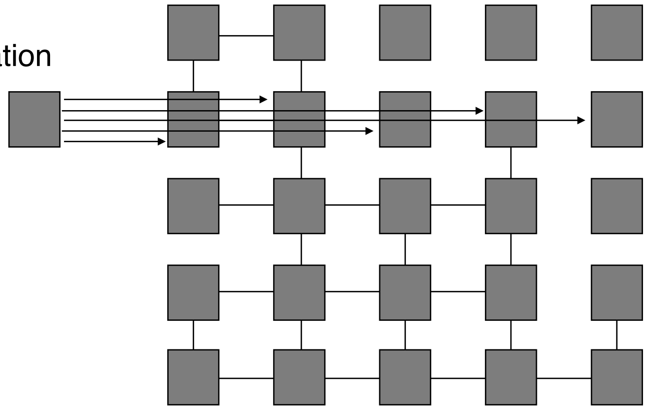
output
scene understanding
(global goals)



data driven
no explicit goal
no centralised representation
information exchange towards local coherence

decentralized system simulation

SATURNE Behaviour : Recognition Localisation



input
recognition, localisation
(global goals)
image
(environment)

output
basic agents

goal directed
explicit goal
purposive, centralised representation
information exchange towards global coherence

distributed problem solving

The COHIA (or KR x KP) Approach

Structuring the knowledge representation
- criteria : abstraction and decentration
- horizontal decoupling levels of representation
- vertical first-hand **interactions** : perception

Structuring the knowledge processing
- criteria : foci on space, time, features, models, tasks
- vertical decoupling into foci of attention
- horizontal second-hand **interactions** : communication

Identifying the basic entities of the system
- definition : intersection of level-agents & focus-agents
- choices : **agents**, **organisation**, **environment** models

Identifying the behaviour of the system
- System simulation : driven by the nature of the agents
- Problem solving : guided by the goals of the society

How MAS Methodology is specific ?

= Approach + Model + Tools + Problem + Domain
= Analysis + Design + Development + Deployment

It provides a new analysis and design approach

...

AGENTS

Secondary classification : Cognitive vs. Reactive

Function(MAS) = ∑ Function(A) + Collective Function

The Cognitive Side	**The Reactive Side**
few heterogeneous	many homogeneous
coarse-grained	fine-grained
cognitive agents	reactive agent
explicit goals	implicit goals
decoupling agents	coupling agents
sequential processes	parallel processes
symbolic approaches	subsymbolic approaches
focusing on representation	focusing on behaviour

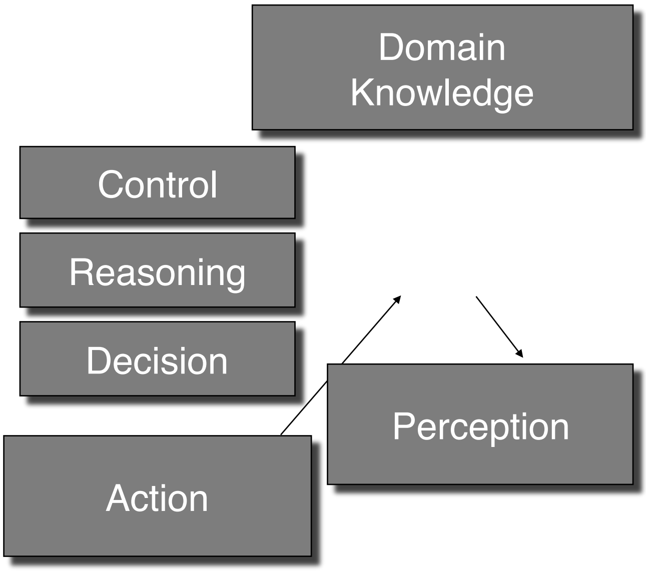
Integration

MAGMA

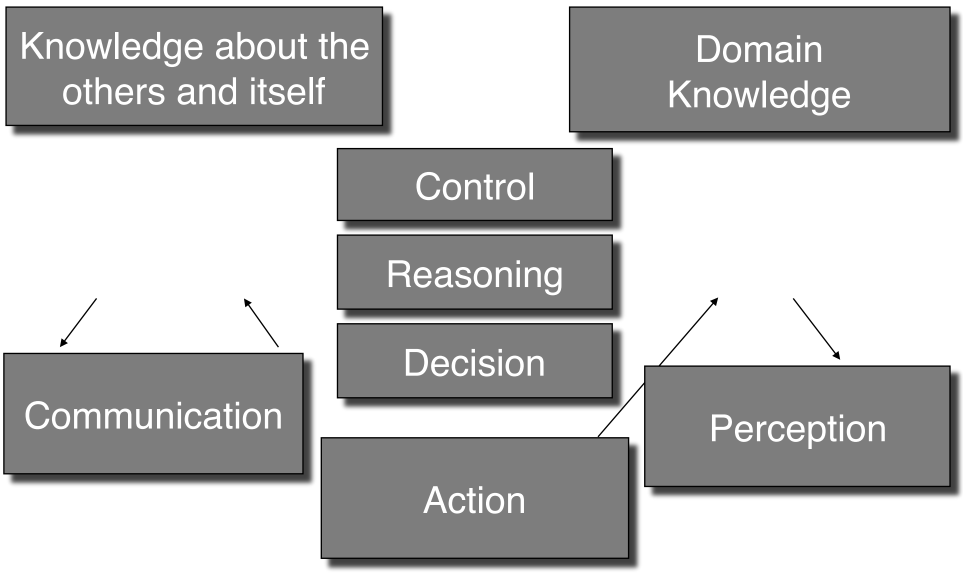
Classes of Cognitive Agents [Erceau 91]

organized agents	multiple perspectives social laws, rules
negociating agents	negociated conflict resolution
intentional agents	intentions, engagements, partial plans
cooperative agents	mutual representations, task allocation,
communicating modules	communication protocols
processes, actors	communication primitives

Cognitive AI Architectures



Cognitive Agent Architectures



Mutual Representations

dynamic societies
---> mutual representations of agents

- **who knows what :** the information available
- **who knows how to do what :** the competences
- **who performs what :** the tasks being performed
- **who intends what :** the intentions, the goals
- **who is committed in what :** the committments

how to represent this knowledge ?
how to update this knowledge ?

[Ferber 95]

BDI Agent Architectures

The behavior is driven by mental attitudes such as intentions, beliefs, goals, fears, etc.

The three main mental attitudes are beliefs, desires (goals), and intentions :

Intentions are persistent goals imposing an agent to act. Persistent goals are goals that are dropped only if they have already been achieved or if they are believed to be not reachable.

Beliefs, Desires, and intentions have lead to the major cogntivie agent class of architectures : the BDI architectures

The Inadequacy of Standard Logics

The need to have theories telling about what an agent believes in

There is an impossibility to use a standard classical logics (monotonic, universal, atemporal)

- from
  - ✓ V.Hugo=Writer(NotreDame)
  - ✓ Believe(Jean,Writer(NotreDame) = Writer(Misérables))

- you deduce
  - ✓ Believe(Jean, V.Hugo=Writer(Misérables))

There is a need to develop and use other logics

Logics of Knowledge and Beliefs

Logical theories about beliefs based on modal logic
Knowledge and Beliefs
- K(A, father (John, Peter))
- B(A, father (John, Peter))

Semantics of these logics is generally based on possible world semantics
Sentential Logics
- B(X,f) is true if and only if f is true for the theory associated to the agent X
- Lack of semantical referential

Possible World Logics
- B(X,f) is true if and only if f is true ine every world reachable by the agent X
- Implies omniscience

A standard modal logic for beliefs

Distribution axiom

Bel(a, (p ⇒ q)) ⇒ Bel(a, p ⇒ Bel(a,q)) (K)
Bel(a, p) ∧ Bel(a, (p ⇒ q)) ⇒ Bel(a, q))

Non contradictory principle

Bel(a,p) ⇒ ¬Bel(a, ¬p) (D)

Positive and negative introspection

Bel(a,p) ⇒ Bel(a,Bel(a, p)) (4)
¬Bel(a,p) ⇒ Bel(a,¬Bel(a, p)) (5)

Intentionality at the agent level

Distinction between

- intending an action
- intending to perform an action in some future (intention defined as a persistent goal to perform in the future)

To intend to perform an action assumes that

- X believes that A is possible
- X does not believe that he will not perform A (he is committing itself to perform A)
- X believes that, if some conditions are fullfilled, it will perform A
- X does not try to fully realise the consequences of A

Formalizing goals and intentions

Formal theories of intentions do exist, they usually associate the intentional states of the agents to their actions and consequences

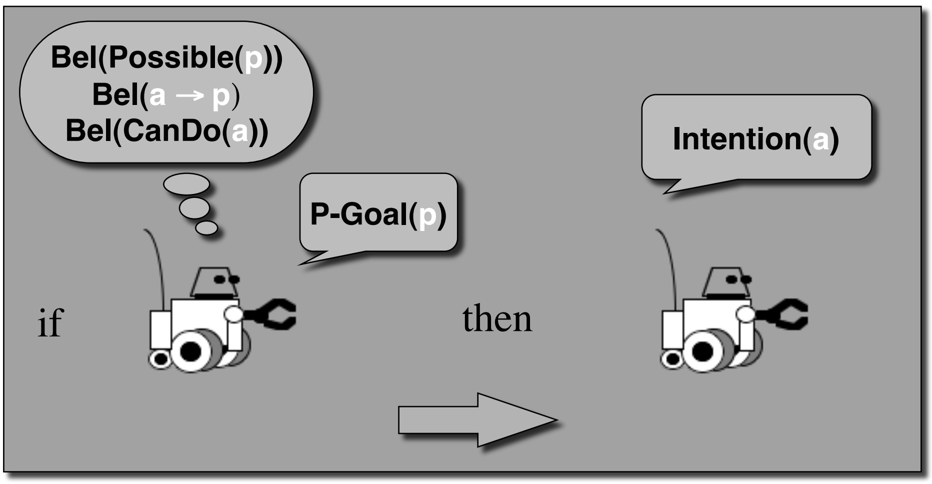
Ex: Cohen et levesque:

- Agent a has a persistent goal if he has the goal that p be true later, if he believes that p is not true now and if he believes that it will be true someday or it will always be false.
- Goal-p(a,p) = Goal(a,Later(p)) $\wedge$ Bel(a, $\neg$p) $\wedge$ ((Bel(a,p) $\vee$ Bel(a,Always($\neg$p)) -> $\neg$Goal(a,Later(p)))

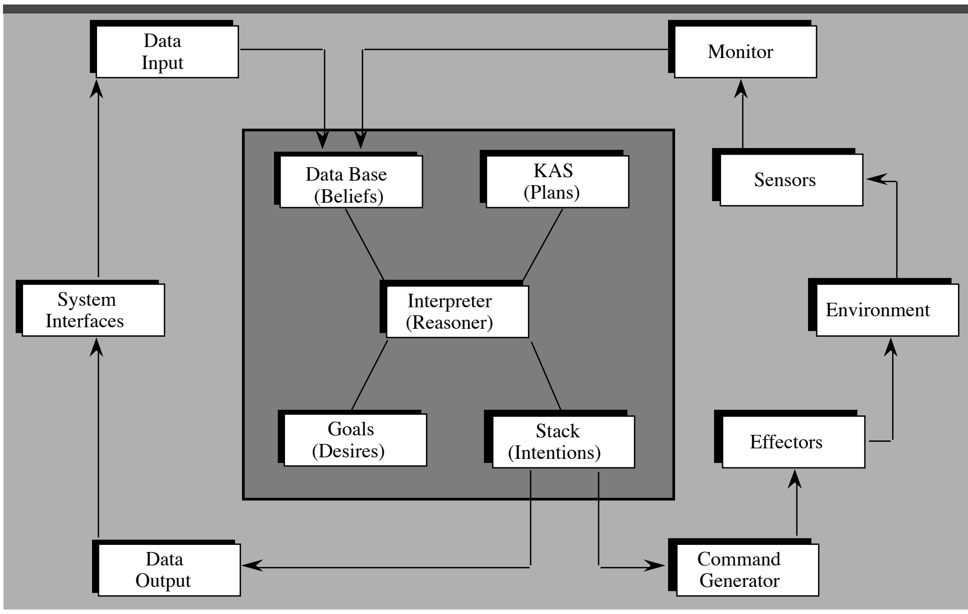
Some problems

- what happens if the action has been performed by another agent?
- what happens when an agent has several intentions ?
- when does an agent resign with some intention ?
- ...

General intention based behaviour [Ferber 95]



(BDI) Agent Architecture : Georgeff 85



Architectures based on cognitive agents

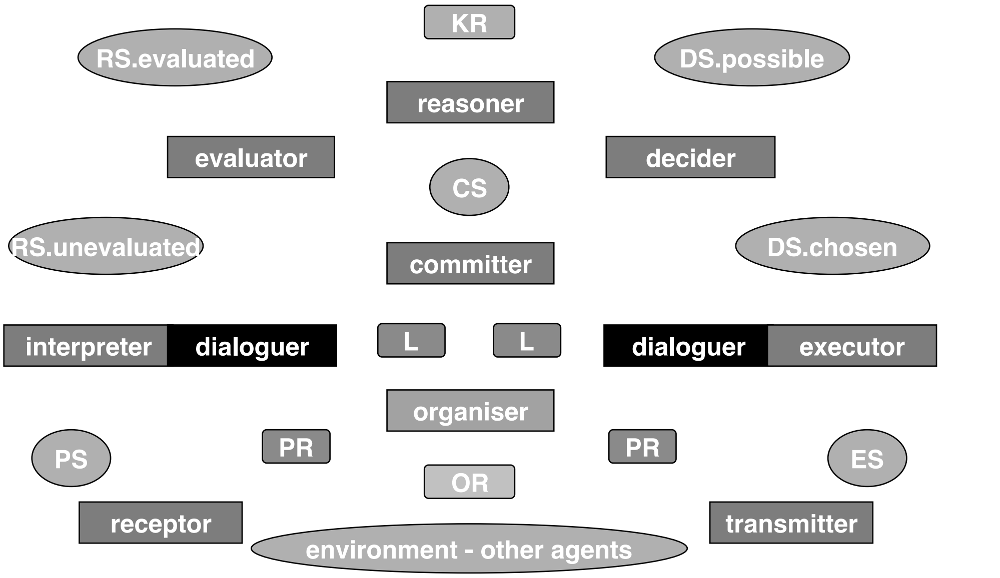
Small systems based on implementation of theories

- Agent-0 (Y. Shoham 90)
- Placa (M. Thomas 93)
- Concurrent MetaM (M. Fisher & M. Wooldridge)
- ...

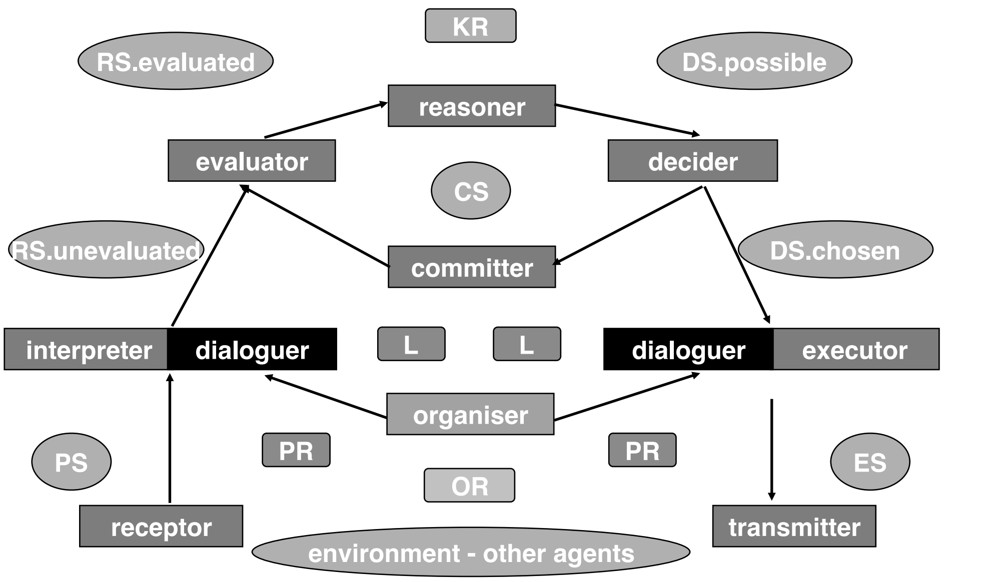
More elaborate systems:

- Mages (T. Bouron & J. Ferber 91)
- Grate (N. Jennings 93) and Archon (90)
- ASIC (O. Boissier 93)
- Interrap (J. Müller 95)
- ...

Agent Architecture : Boissier 93 [Hermes 01]



Boissier's agent : control flow



Boissier's agent : data flow