Multi-Agent Systems

M2 SIAME

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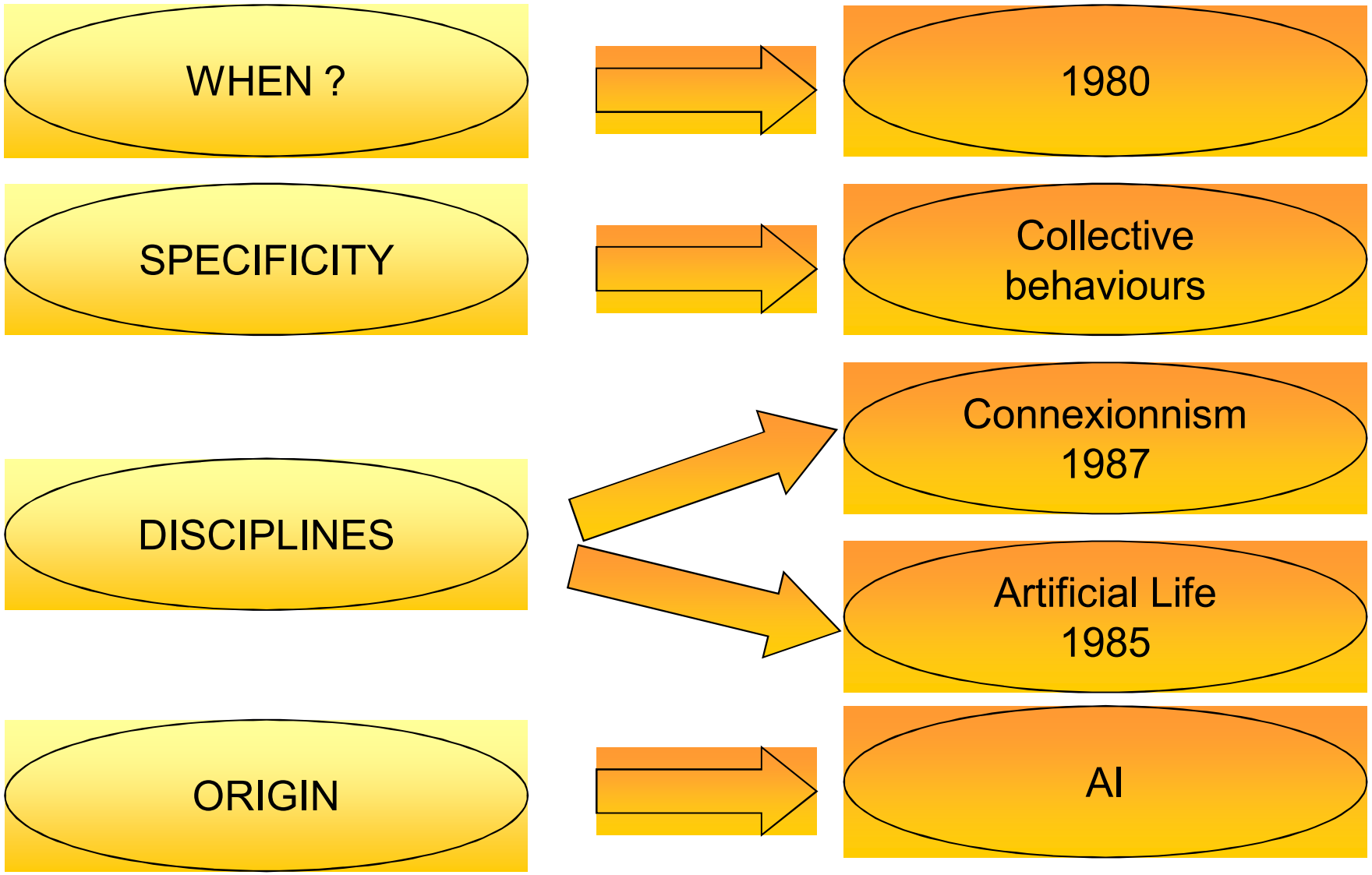
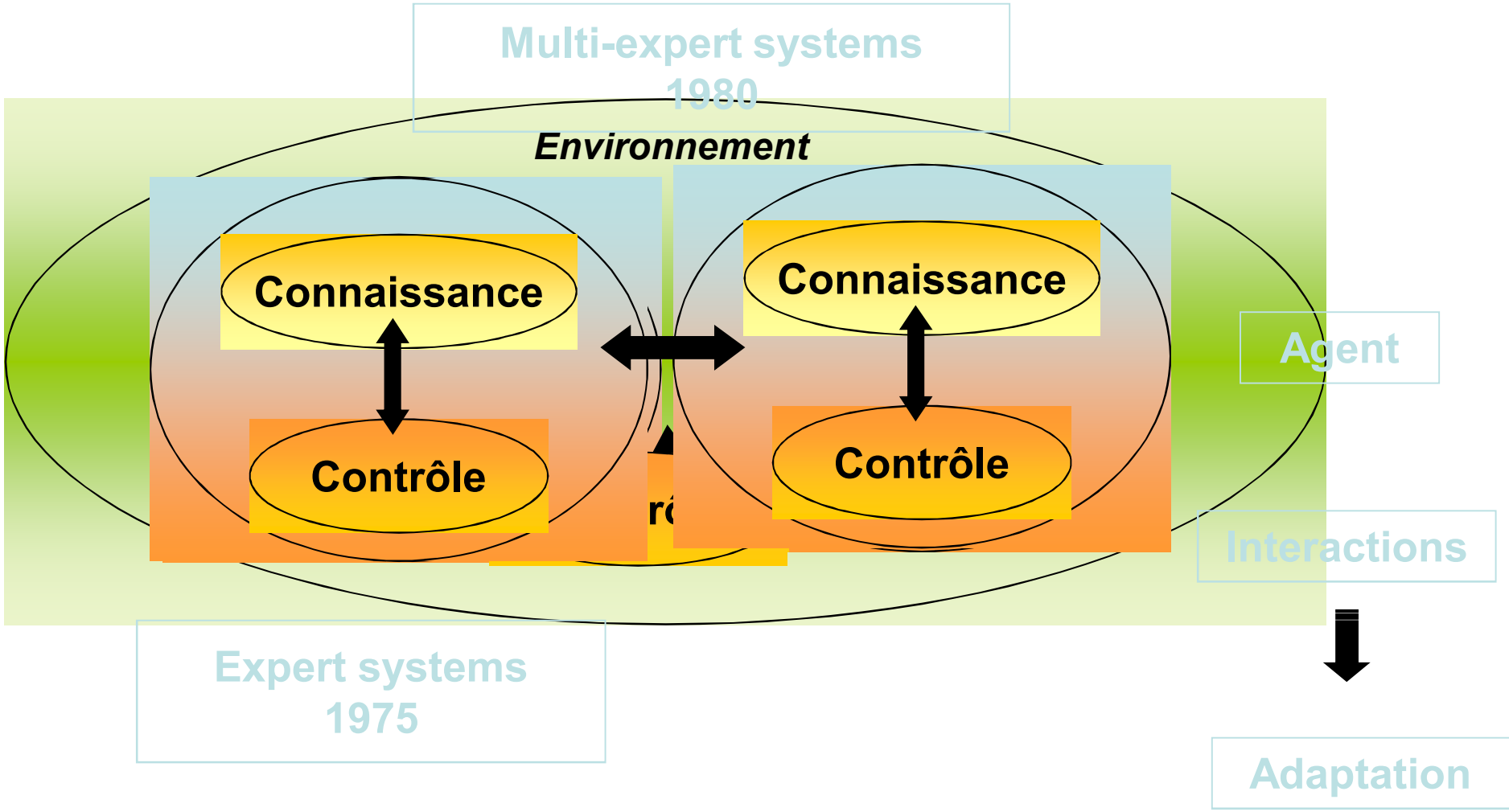

WHEN ?
1980
SPECIFICITY
Collective behaviours
DISCIPLINES
Connexionnism 1987
Artificial Life 1985
ORIGIN
AI

Why DAI - MAS ?



Domains with multiple knowldege => limits of these systems

Multi-Agent System

✓ Definition

» MAS [Ferber, 95]

- o A set of entities C plunged into an environment E
- o A set of agents A ⊆ C
- o A system of actions (operations) allowing agents to act in E
- o A system of communication between agents (messages sending , broadcast)
- o An O organization which structures all the agents and which defines the functions performed by the agents (notion of role and possibly of groups)
- o Possibly: a relation to the users U who act in this MAS via agents of interfaces U ⊆ A

» SMA [COLLINE, 06]

- o Macro system made up of autonomous agents who interact in a common environment (to solve a common task)

Multi-Agent System

- ✓ Characteristics
  - » Autonomy
    - o No global control
  - » Distribution
    - o The data are distributed in the agents and the environment
  - » Locality
    - o Every agent has a limited view
  - » Asynchronism
    - o The agents are asynchronous computation units
- ✓ Analysis
  - » MAS = Made up of an aggregate of autonomous software in interaction, called agents, and are characterized by
    - o A dynamic environment into which are plunged the agents
    - o Partial perceptions of their environment
    - o Restricted cognitive capacities

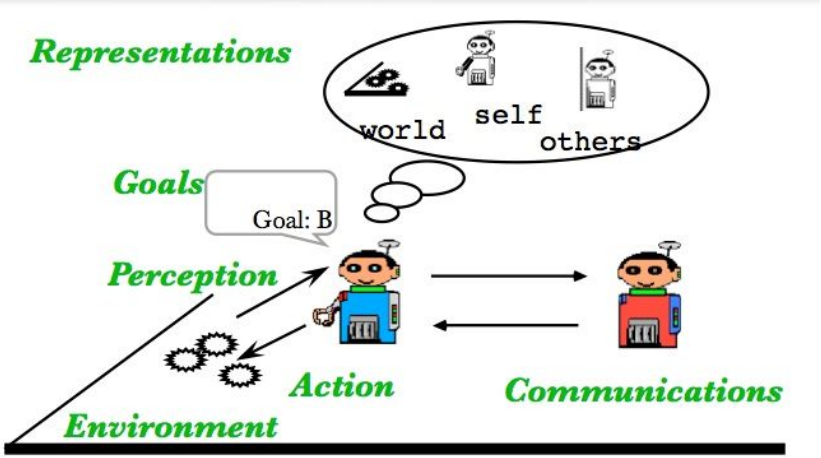
MAS

- ✓ Properties
  - » Open / Close
    - o The agents can enter / take out freely
  - » Homogeneous / heterogeneous
    - o The agents are built/ are not built on the same model
    - o Heterogeneousness
      Rather for cognitive agents and in small quantity
      Advantages to facilitate agents' integration not initially planned
    - o Homogeneity
      Rather for the agents reactive and in great quantities
  - » Advantages
    - o Can be reused
    - o Modularity
    - o Robustness
    - o Acquisition and simplified validation
    - o Incomplete specification

Agent - Definitions

- ✓ Agent [Ferber, 95]
  - Physical or virtual entity
  - Autonomous
  - Situated in an environment and capable of acting in an environment
  - Capable of communicating directly with the other agents
  - Having an individual objective / function of satisfaction
  - Having resources
  - Capable of perceiving (in a limited way) its environment
  - Having a partial representation of the environment
  - Having skills and offering services
  - Possibly capable of reproducing

    Behavior =
    - Satisfy its objectives
    - Consideration of the resources
    - and the skills
    - function of its perception
    - ,its representations
    - and the communications receiptes



Agent - Properties

[Jennings, 95]

- ✓ Reactive
  - » Maintain interactions with its environment
  - » Answer the changes of the environment to satisfy its purposes
- ✓ Pro-active (teleonomy)
  - » Behavior not only managed by the events
  - » Generate and reach purposes
  - » Take initiatives to satisfy its purposes
- ✓ Social capabilities
  - » Capacity to interact with the other agents via languages of communication to satisfy its purposes via it
    - o Cooperation: work together in team to reach a shared goal
    - o Coordination: manage the interdependences between activities
    - o Negotiation: capacity to reach agreements on questions of public interest

Agent – Properties

✓ Persistence and Adaptability

- » Persistent agent
  - o If an agent is proactive it is at first because it is provided with at least a goal for which it tries to satisfy in a persistent way as long as
    - – It thinks that it is still possible (logical pre condition)
    - – It possesses the resources to make it (physical precondition)

- » Adaptive agent
  - o In front of an environment perpetually changing (openness), an agent constantly has to modify the plan which it pursues to reach a goal
    - – Perceive and estimate the situation of its action
    - – Build representations in the course of functioning (learning)
    - – Elaborate dynamic plans which launch internal processes or on the contrary stop them

Agent – Properties

- ✓ Autonomy
  - » Autonomous agent
    - o Its existence is appropriate for it, independently of the existence of the others
    - o He can maintain its viability in dynamic environments, without outside control
    - o The internal decision-making on its behavior to be had is only a function of its perceptions, knowledge and representations of the world
  - » The agents can be dependent and autonomous

Agent - Typology

- ✓ **Reactive agents**
  - » Do not possess model of internal symbolic reasoning
  - » The execution of an agent is directly connected to its perceptions by a function reflex: stimulus, answer
  - » Absence of representation of the environment, the other agents, its capacities
  - » The past (history) as well as the future (actions plan) are not taken into account
    - o the executed actions depend on what it takes place in the present
  - » Not symbolic interactions mediatized or not via the environment or directly by mutual influence

Agent - Typology

- Role of the environment extremely important for the functioning of the system
  - Important topology
- Organizations of type ethology, emergent, …
- Example of basic cycle of a reactive agent
  - rules: rules condition / action; percepts: set of percepts

```
repeat
   state := interpret_input (percept);
   rule := match(state, rules);
   execute(rule[action]);
forever
```

  - Numerous works
  - Situated rules [Wavish, 90]
  - Subsumption [Brooks, 86]
  - Eco-solving [Ferber, 95]

Agent - Typology

✓ Cognitive Agents

- » Possess a model of internal symbolic reasoning
- » Explicit representations of the environment, the other agents, its capacities, …
- » Management of a history
- » Interaction with the others by sophisticated communications
- » Participation to social organizations
- » Example of basic cycle of a deliberative agent
  - o s : état, eq : queue of events

```
s := initialise();
repeat
   option := options_generator (eq, s);
   selected := deliberate (options, s);
   s := update_state (selected, s);
   execute(s);
   eq := get_new_events();
forever
```

Agent - Typology

✓ Reactive Agent

- » Biological metaphor (ants)
- » No symbolic model representing the environment
- » No explicit purpose, not (few) memory
- » Communication via the environment
- » Interaction by tracks put down in the environment (pheromones)
- » Behavior reflex (stimulus-answer)

✓ Cognitive Agent

- » Social metaphor / psychological (human beings)
- » Representation of the explicit knowledge on the other agents
- » Notion of purpose, memory
- » Direct communication by sending of messages
- » Interaction implemented by means of languages of interaction based on the theory of the speech acts
- » Deliberative behavior

Agent - Typology

✓ Reactive Agent

- » System with many agents (100)
- » (Biological) implicit organization
  - o Self-organisation
- » Bottom up design approach
- » Robustness
- » Experimental validation

✓ Cognitive Agent

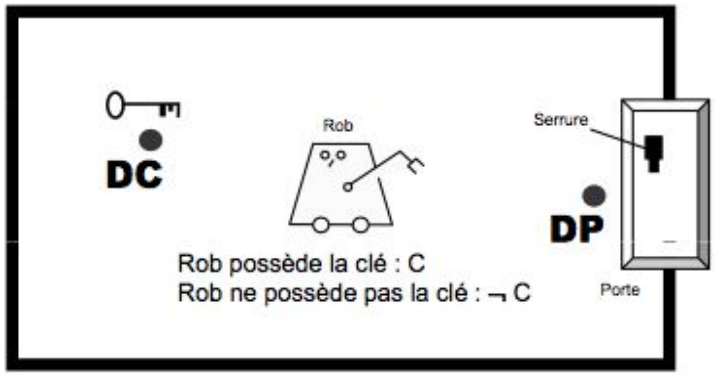
- » System with few agents (10)
- » Explicit organization (social)
  - o Allocation of tasks
  - o Resource sharing
  - o Protocols of interaction, coordination, negotiation
  - o Partial centralization
- » Top-down design approach(DPS)
- » Possibilities of formal validation

Agent: reactive / cognitive agent

✓ Exercice

- Proposer un algorithme réactif permettant de résoudre le problème ci-dessous puis un algorithme cognitif permettant de résoudre le même problème. Dans les deux cas, le robot "Rob" cherche à sortir d'une pièce (vous vous placerez dans un cadre général, c'est-à-dire que vous ne savez pas si la porte est ouverte, fermée, ou fermée à clef, vous ne connaissez pas la position de Rob et vous ne savez pas si Rob possède ou non la clé permettant d'ouvrir la porte)
- Dans la figure ci-dessous est répertorié l'ensemble des variables que Rob peut manipuler au cours de son raisonnement (DC, DP, …)
- L'ensemble des actions que Rob peut mettre en œuvre est
  - ALLER_A_DC, ALLER_A_DP, DEVEROUILLER, MARCHER_ALEATOIREMENT, OUVRIR, PRENDRE_CLE, SORTIR
- Vous utiliserez les actions cognitives lorsque vous construirez la solution cognitive et les actions réactives lorsque vous construirez la solution réactive

Problème :
« Rob le robot doit sortir de la pièce ».



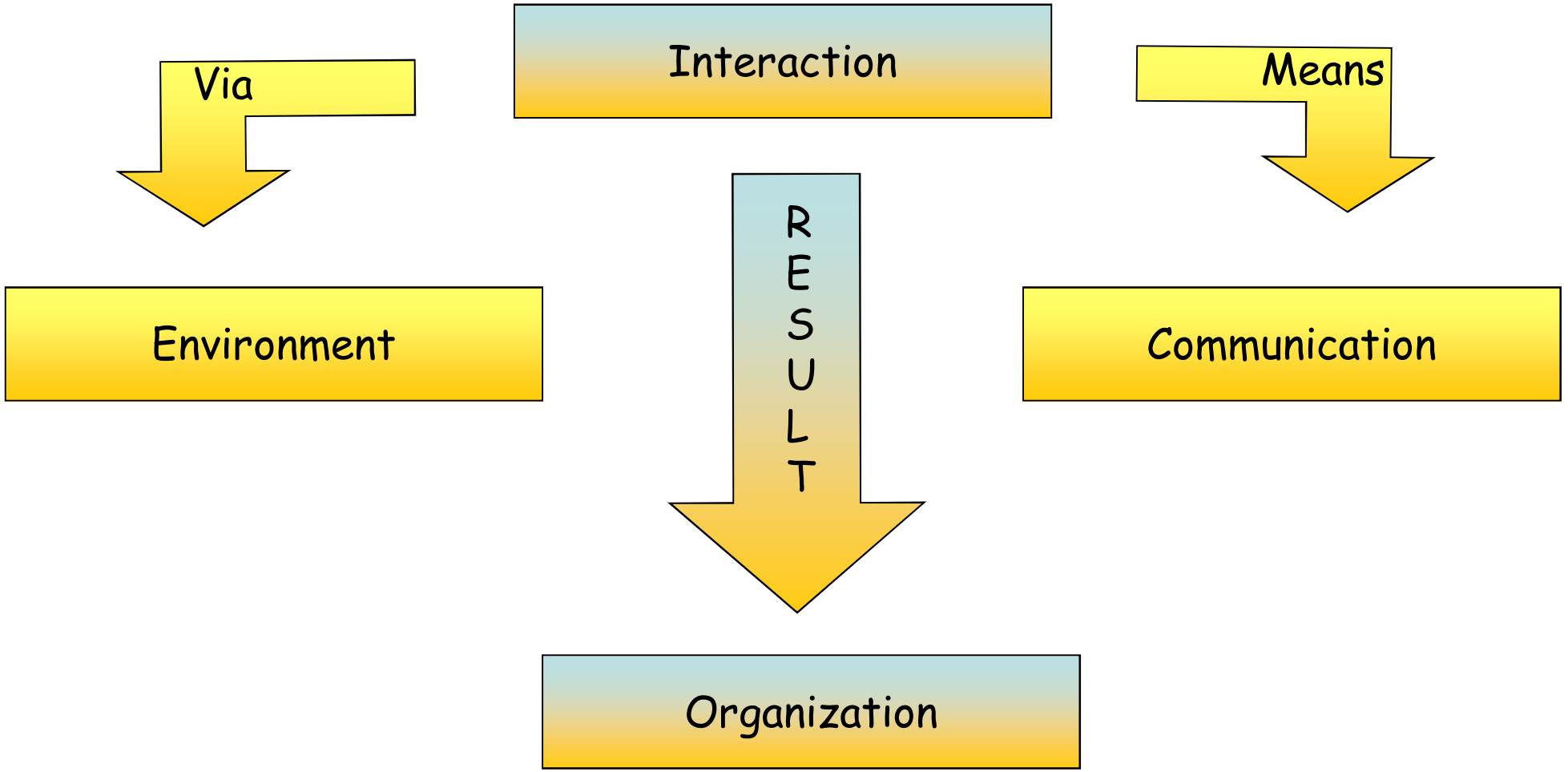
Interaction

- ✓ Definitions [Ferber, 95]
  - » Dynamic getting in touch of 2 or more agents through a set of reciprocal actions
  - » Interaction situation
    - o Set of behaviors resulting from the combination of agents that must act to achieve their objectives while taking into account the constraints coming from more or less limited resources and their individual skills

- ✓ Examples
  - » Building a house
  - » Robots carriers
  - » Pooling of expertise
  - » Cars moving

Interaction

- ✓ Central concept



Interaction

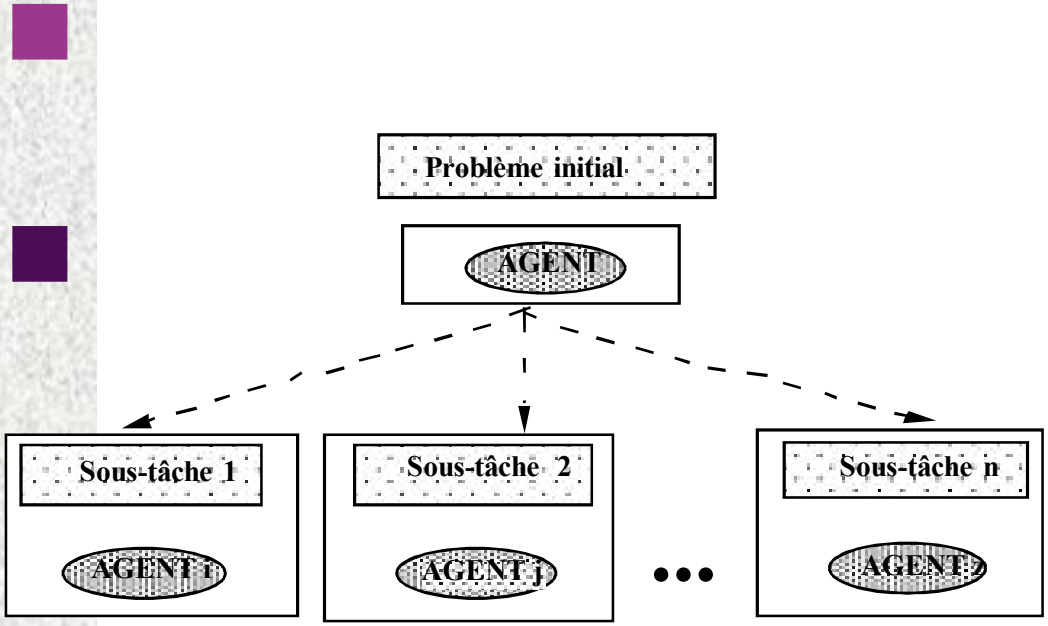
- ✓ Components and types of interactions
  - » Compatibles and incompatibles goals
    - o The goal of an agent A is incompatible with the goal of an agent B if agents A and B have respective purposes to achieve the conditions respectively described by p and q and p⇒¬q (satisfied(goal(A, p) ⇒¬satisfied(goal(B, q))
      - – Cooperation or indifference situation
        - > Consistent goals
      - – Antagonism situation
        - > Incompatible goals
  - » Resources
    - o All environmental and material elements that are useful to carry out a task
  - » Agents capabilities
    - o Can an agent make alone a task ?
    - o Does an agent need others to achieve its goal?

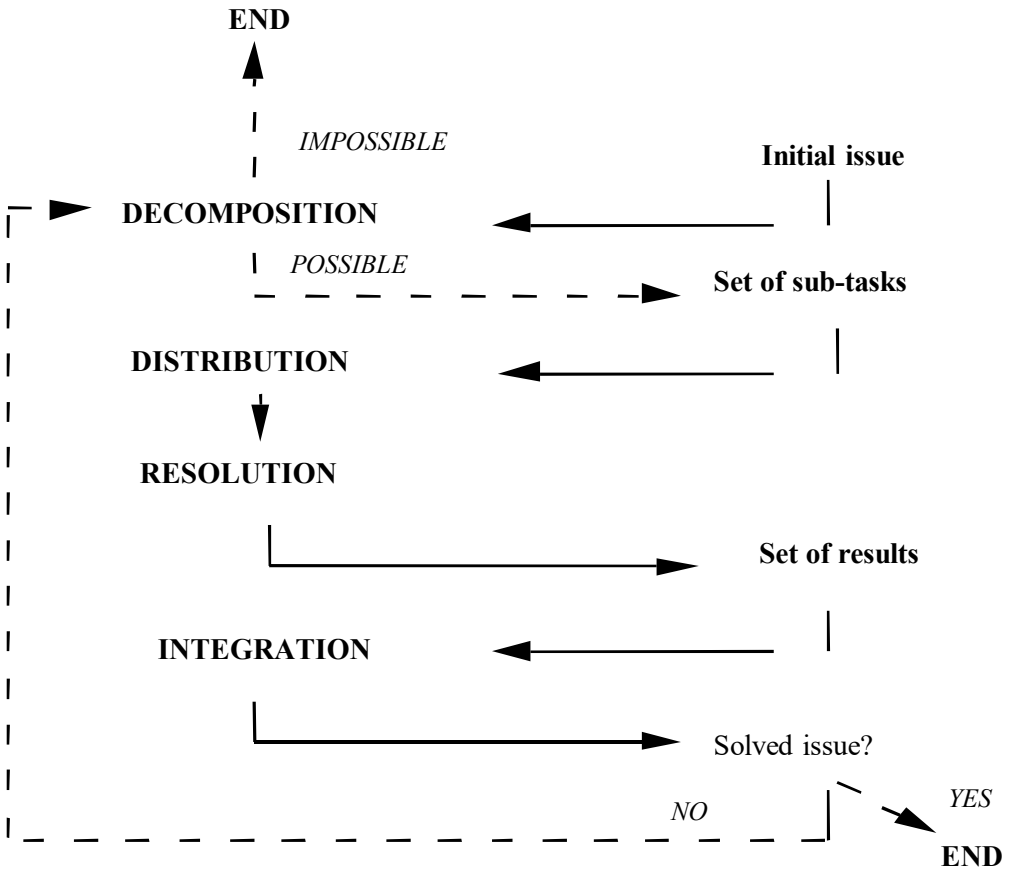
Interaction

Goals	Resources	Capabilities	Types of situation	Category
Compatible	Sufficient	Sufficient	Independence	Indifference
Compatible	Sufficient	Insufficient	Simple collaboration	Cooperation
Compatible	Insufficient	Sufficient	Congestion	
Compatible	Insufficient	Insufficient	Coordinated collaboration	
Incompatible	Sufficient	Sufficient	Individual pure competition	Antagonism
Incompatible	Sufficient	Insufficient	Collective pure competition	
Incompatible	Insufficient	Sufficient	Individual conflicts for resources	
Incompatible	Insufficient	Insufficient	Collective conflicts for resources	

Cooperation by tasks sharing

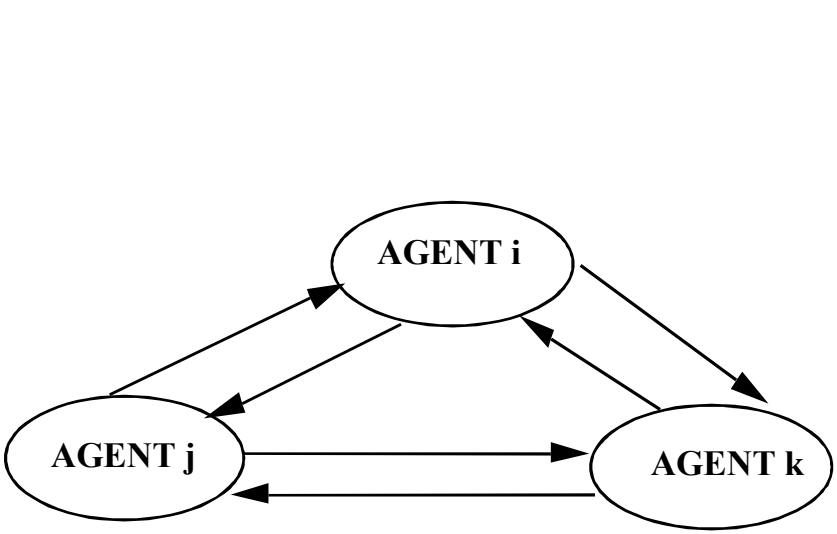
- ✓ Who do what and how according to goals and capabilities of agents as well as contextual constraints

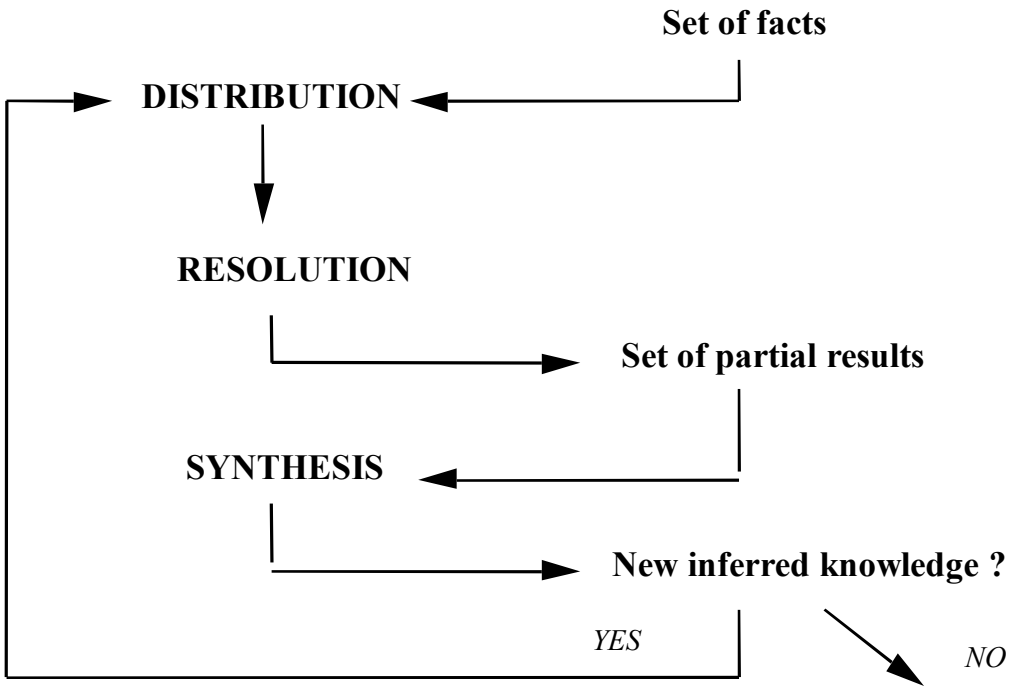




Cooperation by results sharing

- ✓ In order to increase confidence, the range of results





Correspondence synthesized image - real object [Smith, 81]

La communication

La communication

- La communication nécessite la connaissance
  - Langage de communication
  - Protocole de transport
  - Protocole d'interaction
- Que communiquer ?
  - Informations communes : croyances, intentions, tâches
  - Terminologie personnelle : réécriture ?
- Quand communiquer ?
- Avec qui communiquer ?
  - Accointances : compétences des autres et concepts partagés
- Protocole
  - Qui peut dire quoi et à quel destinataire

La communication

✓ Deux types de communication

1. Communication indirecte
   - Structure de données commune
     - Ex : tableau noir

2. Communication directe
   - Envoi de messages
     - Point à point
       - > Connaissance du destinataire du message

         (M1) A : B, Hello A connaît le destinataire
     - Diffusion totale
       - > Envoi simultané d'un message à tous les agents du système

         (M2) A : All, Hello A ne connaît pas le/les destinataire(s)

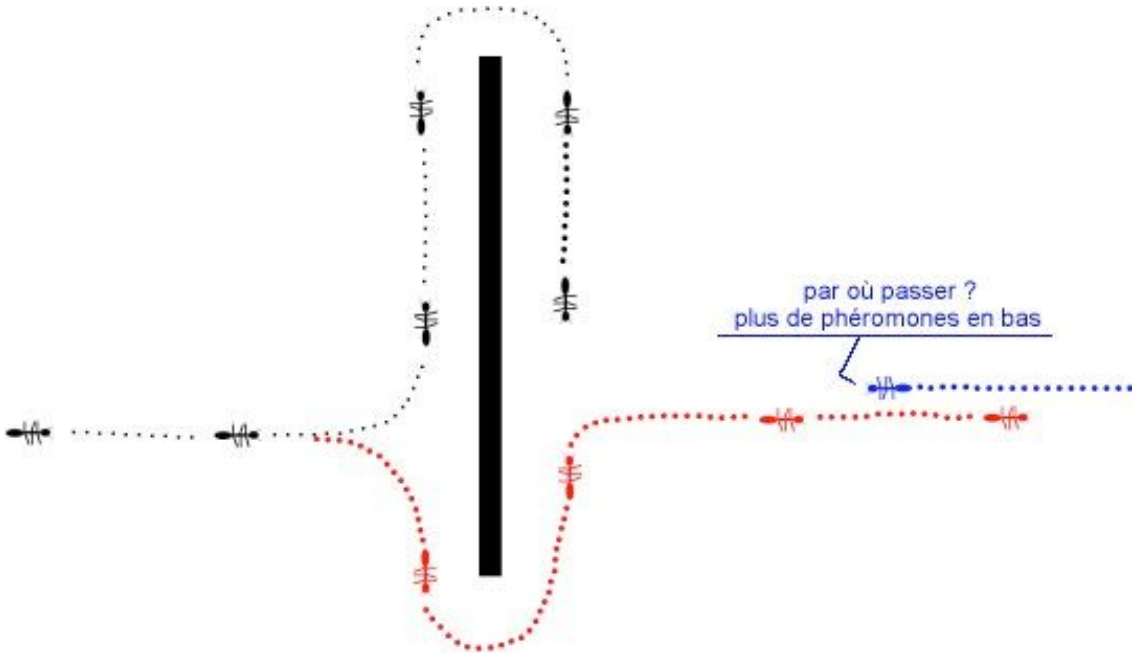
         (M2') A : {x | dist(A,X) < d}, Hello
     - Diffusion restreinte
       - > Envoi d'un message aux agents connus
     - Murmure
       - > Bouche à oreille
     - Relaxation [Lesser, 80]
       - > Envoi d'un message de proche en proche

La communication indirecte

- ✓ Tableau noir (Blackboard)
  - » Métaphore de la classe d'écoliers [Bachimont, 90]
  - » Agents = élèves; Problème = les pièces + la pièce initiale
    - o Les agents sont indépendants et ne réagissent qu'aux modifications du tableau. Ils participent quand des informations du tableau remplissent leur condition
  - » Pour organiser une communication sur plusieurs niveaux d'abstraction, le tableau peut être structuré en zones virtuelles, chaque zone est consultée par un groupe donné d'agents
    - o Un niveau d'abstraction représente la solution selon différents points de détails
  - » Modèle du tableau noir [Erman, 75], [Corkill, 86], [Engelmore, 88]

La communication indirecte

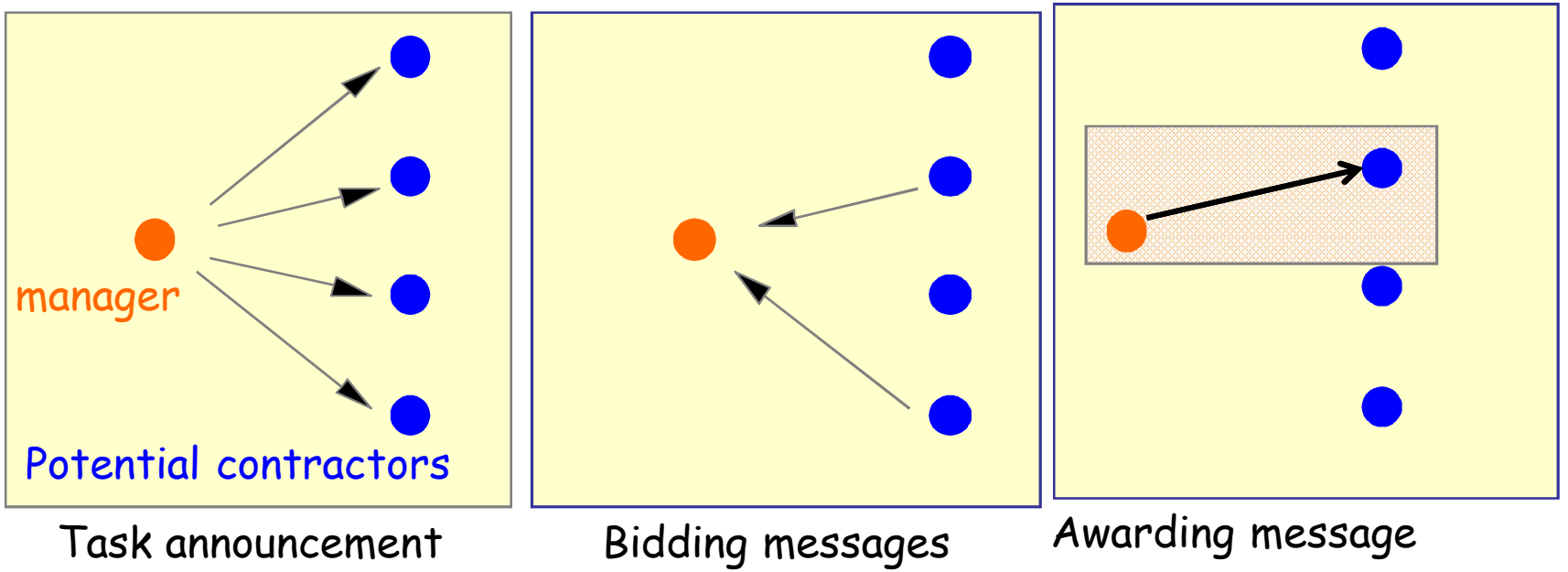
- Partage de l'environnement
  - Communication restreinte à un ensemble fini de signaux ayant des interprétations fixées
  - Transmission par modification de l'environnement
    - Fourmis : dépôt de phéromones
    - Surveillance de malades : capteurs



La communication directe

- Envoi de messages
  - Transmission par diffusion (broadcast)
    - Réseaux de contrats [Smith, 80]
  - Transmission directe
    - Modèle d'acteurs [Hewitt, 77]
    - Modèle des accointances
  - Transmission à un groupe (multicast)
  - Outils
    - ACL : Act Communication Language de FIPA [FIPA, 98]
    - KQML : Knowledge Query Manipulation Language [Finin, 93]
    - KIF : Knowledge Interchange Format [Genesereth, 92]

Contract CNET [Smith, 80]

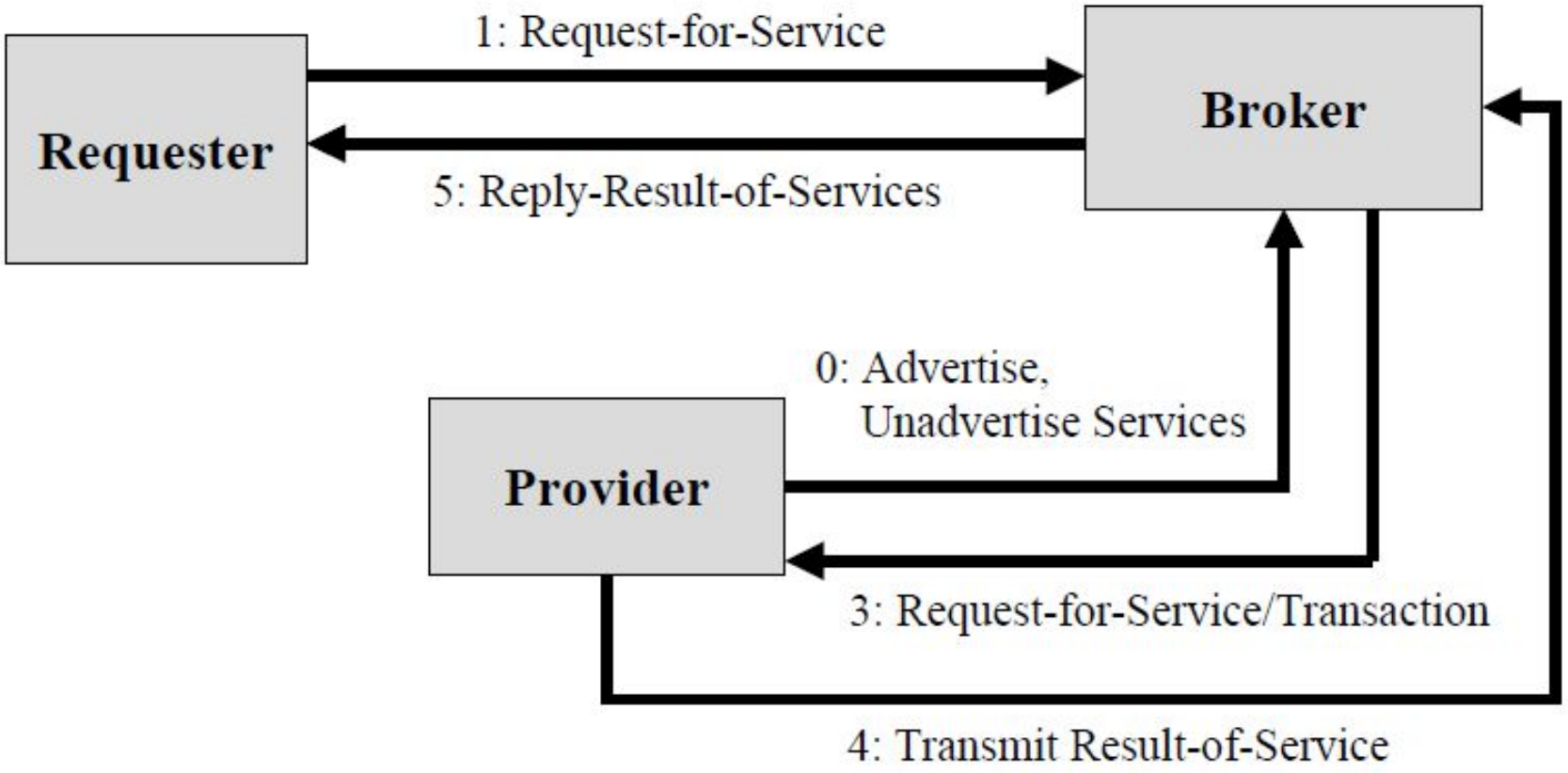


Envoi d'un appel d'offre au système (ciblé ou pas)

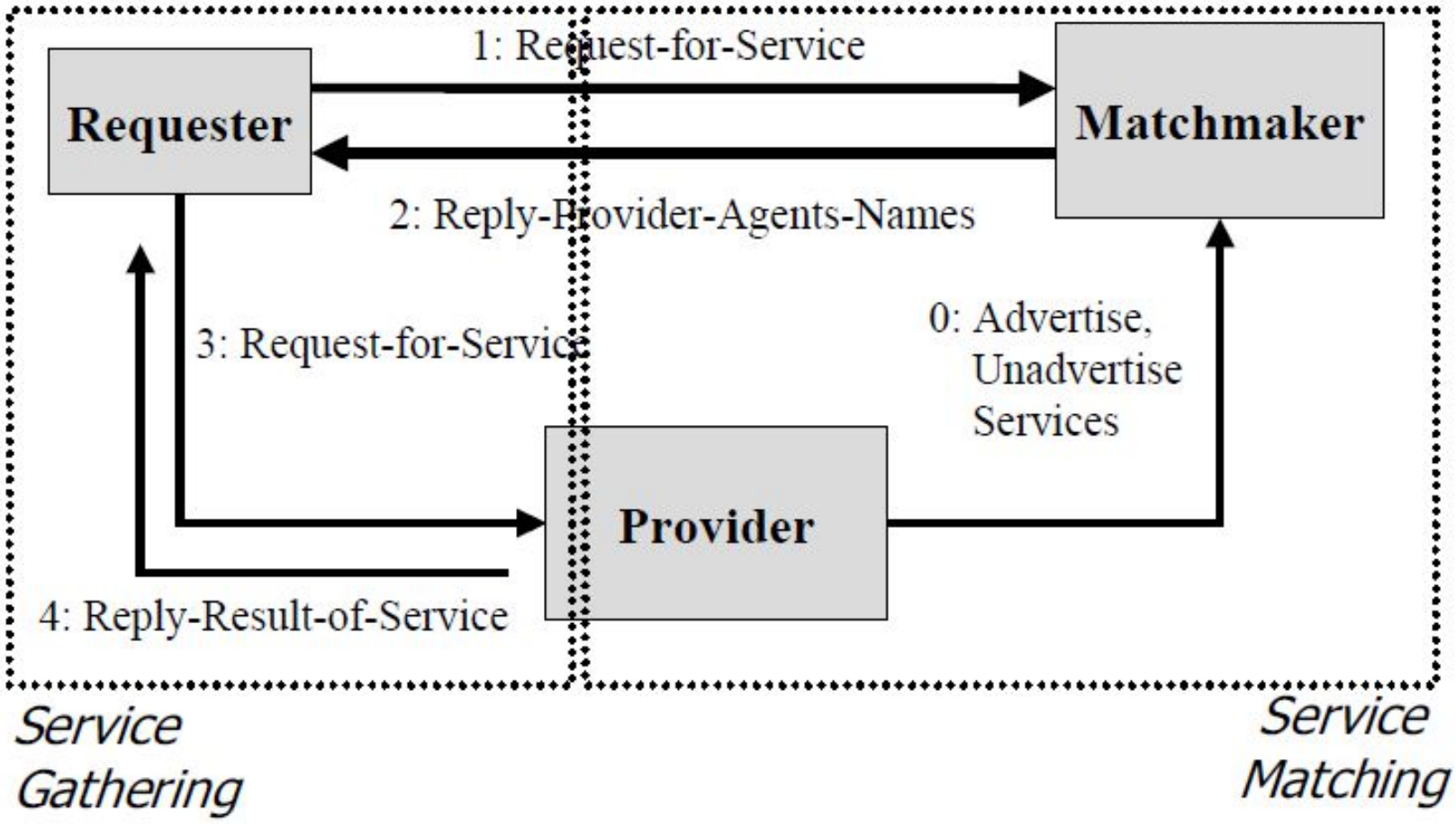
Les agents contactés évaluent l'annonce de tâche. S'ils sont intéressés ➔ envoi d'une offre au manager

Le manager sélectionne les agents les mieux placés en évaluant les réponses qu'il a reçues
Ces derniers assurent l'exécution de la tâche

Brokering [Klush, 01]

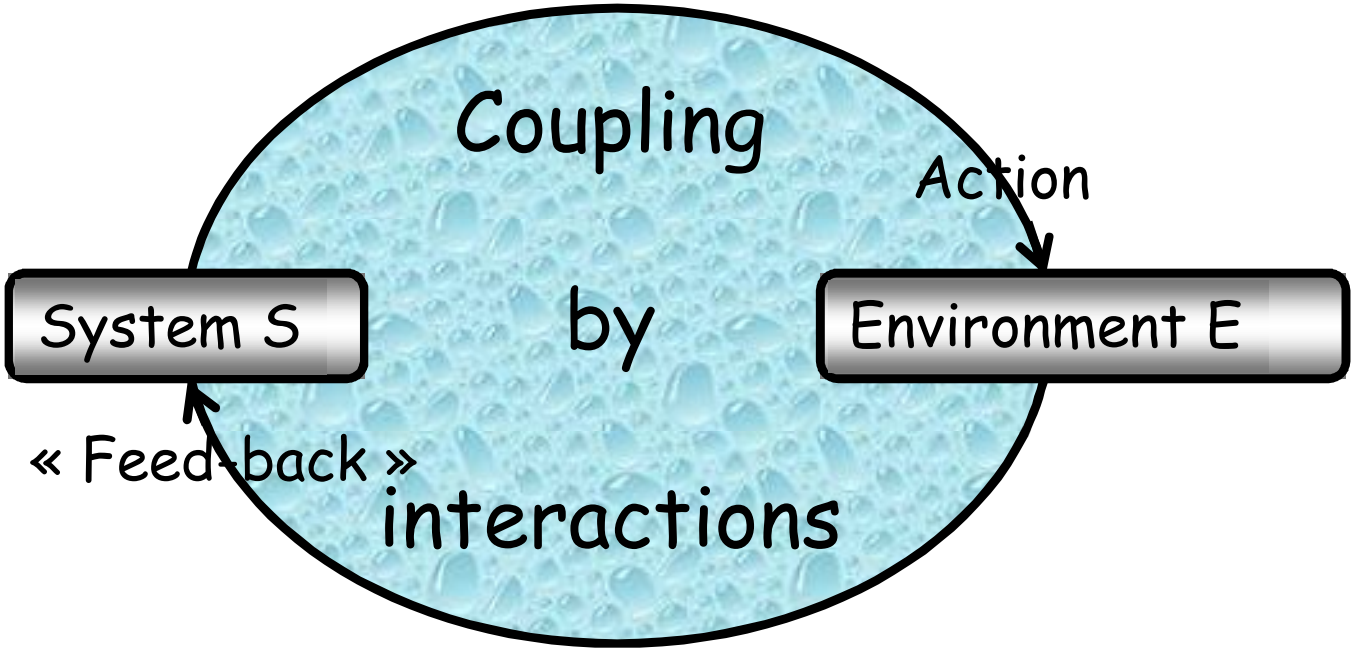


Matchmaking [Klusch, 01]

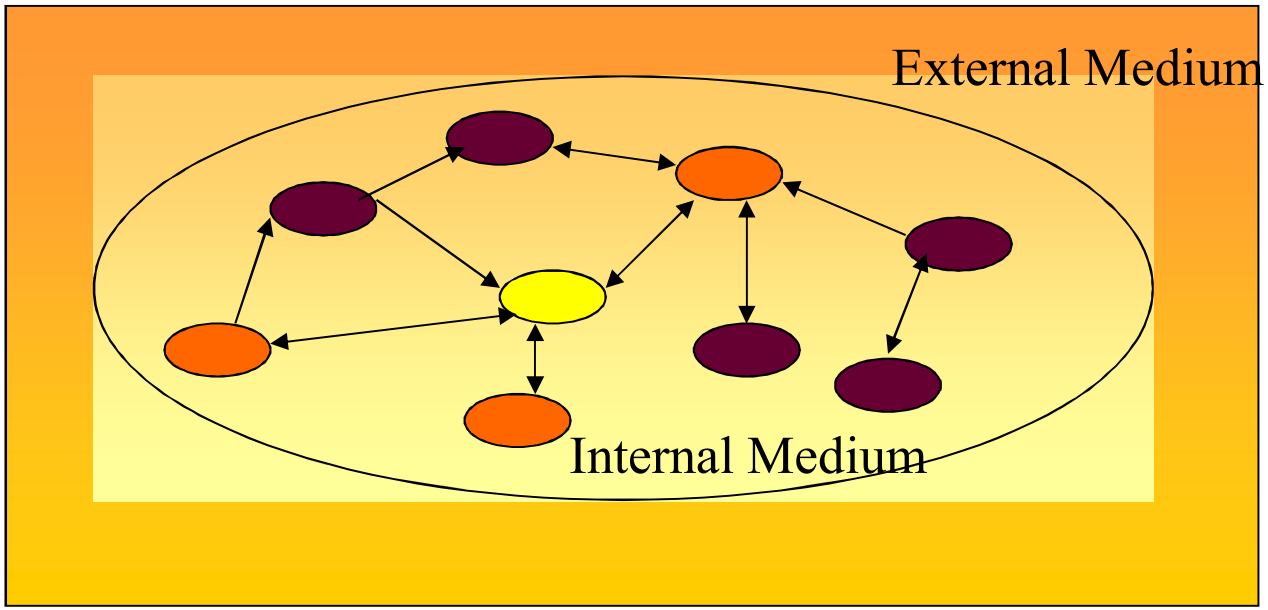


Environment

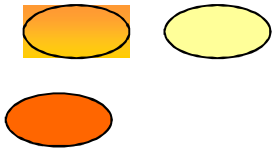
- Coupling system / environment
  - World W = system + environment
  - S system = Operation of distinction of an observer in the world
  - Environment of the system E = World (perceptible or not) – System



Environment



Physical
Social



- ✓ Environment: structure the SMA
  - » Supplies a shared space
  - » Endows the resources
  - » Is locally observable
  - » Is locally accessible
  - » Can define rules
  - » Can maintain dynamics

Properties [Russel, 95]

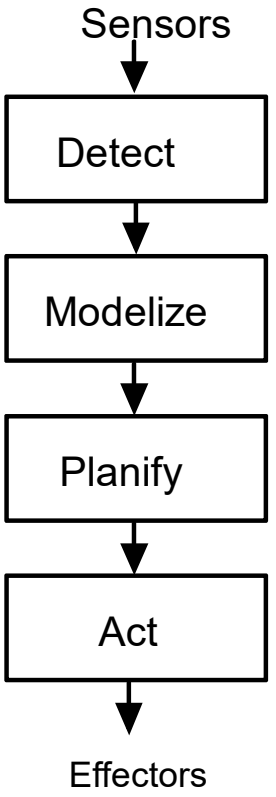
- Accessible/ inaccessible
  - The obtained information about the state of the environment can be complete, valid and up to date
- Determinist / Indeterminist
  - An action = a single effect
- Statics / Dynamics
  - Unchanged while the agent deliberates (except by the actions of the agent)
- Discrete / continuous
  - Finished number fixed by actions and by perceptions of the agent

Subsumption Architecture [Brooks, 1986]

- ✓ Incremental Construction

  Horizontal levels — Perceive → Act

  Vertical levels — Perceive → Planify → Act

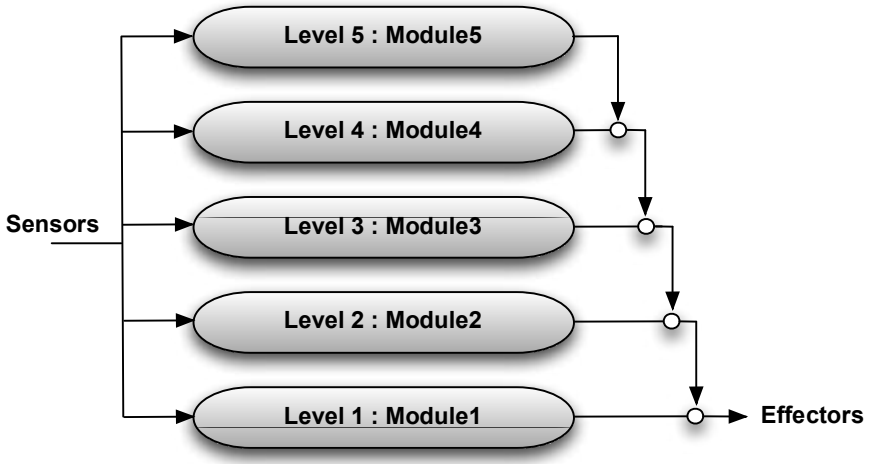


- ✓ Vertical division
  - » The superior layer is in direct contact with the sensors. It shapes the physical sizes measured to make them useful by a layer of modelling
  - » That this generates in its turn symbolic information, which allow to update an internal map of the world
  - » The layer of planning uses the information stored in this representation simplified by the world to decide on actions to be carried out
  - » The last layer is responsible for the execution of these actions(shares). It communicates then directly with the actuators of the robot
    - o Only the modules of entrance(entry) and exit(release) are in touch with the world, and the whole system works only if each of the modules worked correctly

Subsumption Architecture

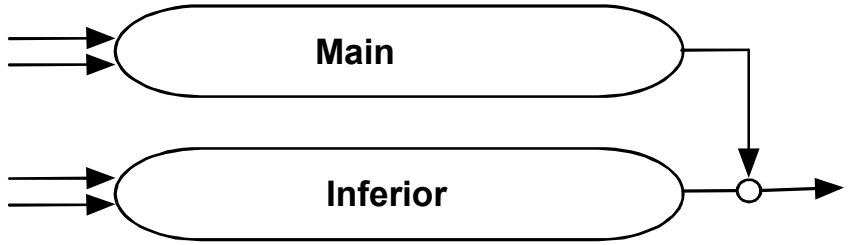
- Horizontal division
  - Every layer is in direct contact at once(at the same time) with the sensors and with the effectors of the robot
  - In architecture of subsumption
    - Every layer is in touch with inputs and outputs and can act on the system: every layer is a behavior
    - There is in principle neither internal representation of the world, nor system of planning
    - A robot based on such a model possesses reactive architecture of type " perception-Action "
    - Every layer generates answers according to the received stimuli
    - The answers of the superior layers subsume those of the lower layers

➔Architecture of subsumption



Subsumption Architecture

- 3 key ideas: intelligent behavior can be generated
  - without explicit representation (against the symbolic AI)
  - without explicit abstract reasoning (against the symbolic AI)
  - the intelligence is an emergent complex property of certain systems due to the **interactions**
- The decision-making of an agent is realized through a set of behavioral modules corresponding to the task to be realized
  - Behavior implemented under the shape of rules: Situation ➔ Action
- Modules realize their task in parallel
  - When 2 modules have a conflict (they produce contradictory results)
    - Only the information given by the main behavior is considered
  - If the lower module produces results while the main module does not work, its effect is taken into account; but if the main module also produces results, these last ones have priority on those given by the lower module



Subsumption Architecture

✓ Example

- » Objective
  - o Realize a collective of robots to investigate a remote planet. The purpose of these robots is to collect samples of ore MX on the ground. The location of these samples is unknown at first. Robots memorize the location of the base where from they come and where they have to return the collected ores. They have no map of the region to be investigated, on the other hand they know that this region contains unbridgeable obstacles. To simplify, we suppose that a robot possesses an energy allowing it to work infinitely.
  - o Define
    - – for a "solitary" robot
      - > rules or behavioral modules
      - > the hierarchy of subsumptions
    - – Same question for a set of cooperative robots