Multiagent System

Overview

Flavien Balbo

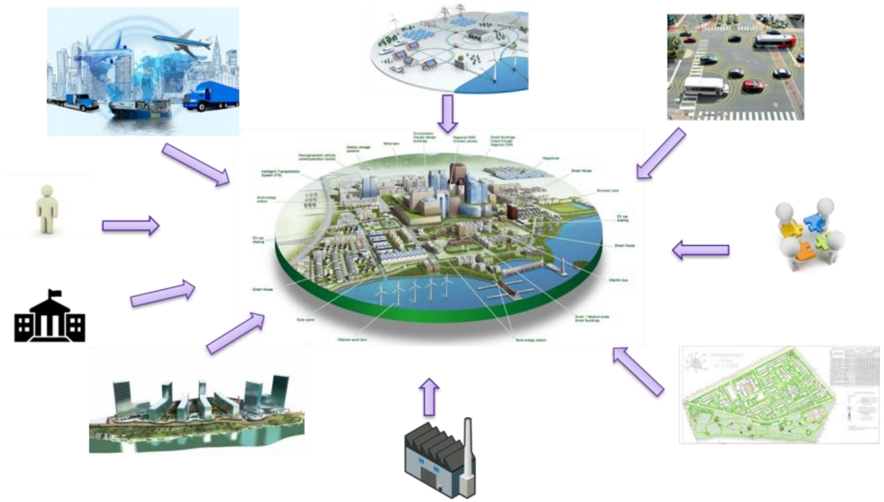
Source

- http://www.csc.liv.ac.uk/~mjw/pubs/imas/distrib/pdf-slides/lect01.pdf
- Multiagent Systems, A Modern Approach to Distributed Artificial Intelligence Edited by Gerhard Weiss, MIT Press.
- https://www.emse.fr/~boissier/enseignement/mas.html
- M. Wooldridge: An Introduction to MultiAgent Systems
- Weyns, D., Omicini, A., et Odell, J. Environment as a first-class abstraction in multi-agent systems. Autonomous Agents and Multi-Agent Systems, 14(1) :5, 2007. Special Issue on Environments for Multi-agent Systems.
- Morin, E. La methode. Tome 1. La nature de la nature. Editions du Seuil, Paris, 1977.
- Jacques Ferber, Multi-agent systems - an introduction to distributed artificial intelligence. Addison-Wesley-Longman 1999, pp. I-XVIII, 1-509
- E. Werner, Cooperating agents: A unified theory of communication and social structure, In L. Gasser and M. Huhns, editors, Distributed Artificial Intelligence Volume II, pages 3-36, Pitman Publishing: London and Morgan Kaufmann, San Mateo, CA, 1989.

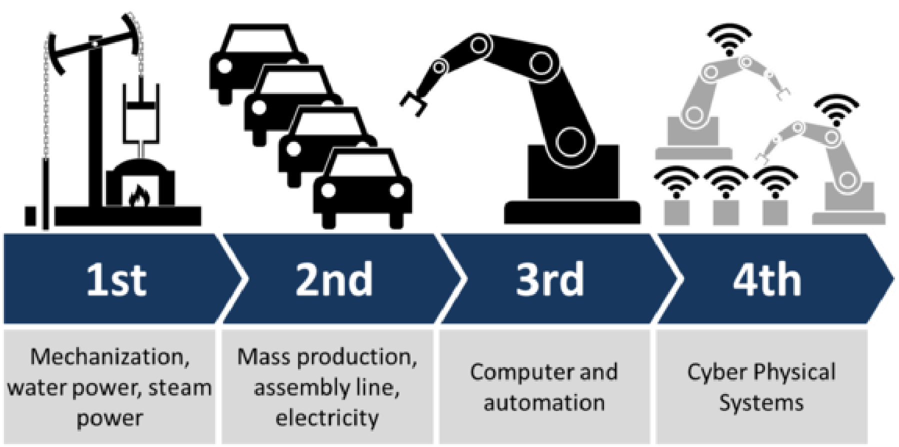
Motivation

- **New systems**

Smart cities



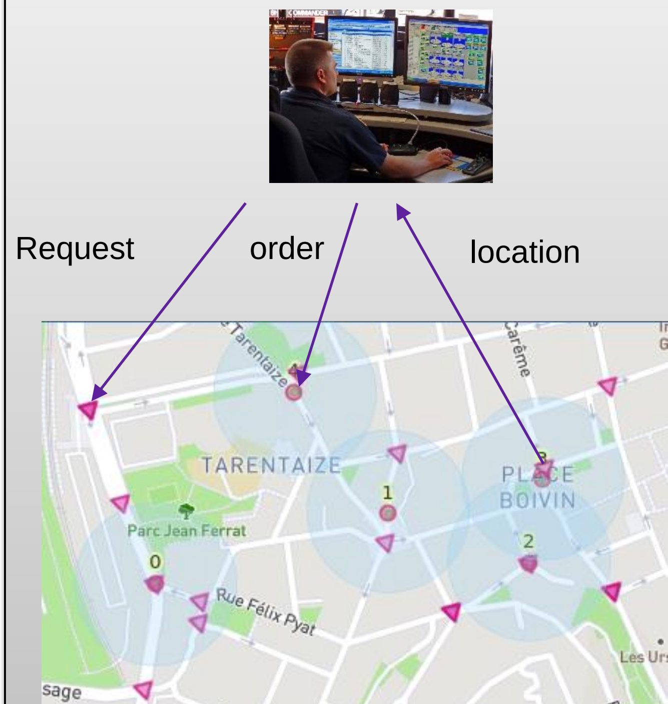
Industry 4.0



➡ What are the features of a solution in these environnements?

➡ Is a centralized paradigm adapted to these environnements?

Motivation



management of a Taxis' fleet

- **Focus: deployment of an autonomous taxi (AV) fleet in a smart city**
- **Hypothesis**
  - Autonomous vehicle: they can drive and choose their path autonomously
  - Passenger request: appear and disappear randomly in the city
  - Transportation traffic: autonomous vehicles drive among "classical" vehicles
- **Objective**
  - Create an online on-demand transportation service with this new type of vehicle
  - How to allocate (optimally?) requests to AV?

Motivation

Which issues are related to a solution in these systems?

security

efficiency

privacy

complexity

Robustness

…

What means these issues for the On-demand service?

- Security: it must be attack-proofed
- Efficiency: allocation process must be efficient (waiting time of the passenger, length of the vehicle trip, …
- Privacy: information about traveler or vehicles must remain private
- Complexity: the service must scale with the number of requests
- Robustness: the service must be ensured despite communication troubles, vehicle troubles, …

Is a centralized solution adapted?

- Security: mainly one node, the central
- Efficiency: optimal algorithm exist but the central is a bottleneck (processing and communication)
- Privacy: all information have to be centralized
- Complexity: the problem is NP-complete
- Robustness: the central shut down, the service ends. The central is a bottleneck for communication

Motivation

- What are the features of these new systems?

Dynamic

Open

Multi-scale space / time

Distributed

Decentralized

More or less observable

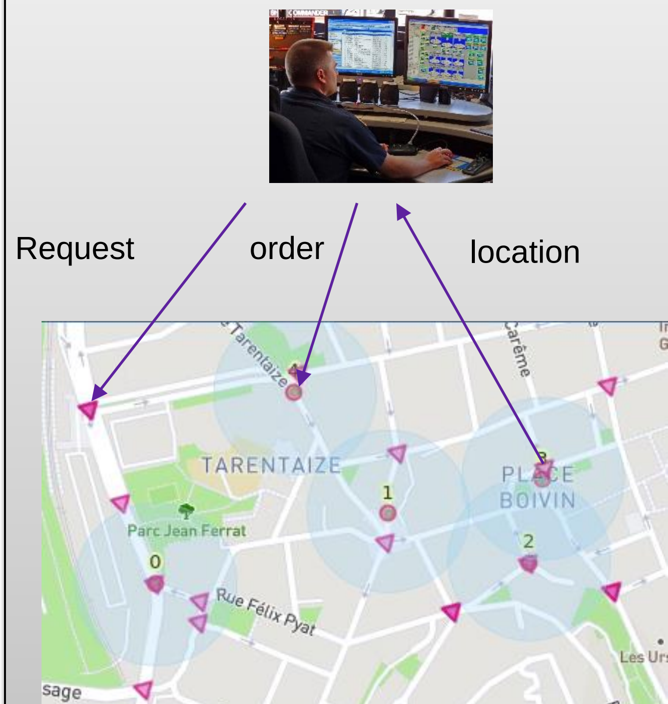
Unpredictable

- What means these features for the On-demand service?
  - Dynamic: traffic evolve independently of the AV, requests of travelers are dynamic too.
  - Open: AV may be added/removed from the fleet
  - Multi-scale: management may be at the scale of the city, the district
  - Distributed: information about requests/AV may be centralized or not
  - Decentralized: different types of decision (operational, tactic, strategic)
  - Observability: is the AVs' state known or not
  - Unpredictable: transportation traffic is with difficulty predictable

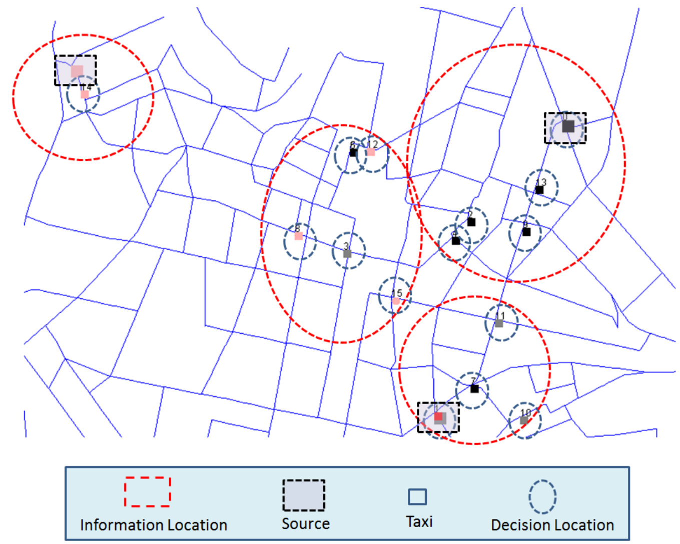
- Is a centralized solution adapted?
  - Dynamic: the central must be up-to-date about the state of the system.
  - Open: the central must be up-to-date about the state of the system.
  - Multi-scale: one system for several scales
  - Distributed: Information have to be collected
  - Decentralized: decisions are taken by a dispatcher
  - Observability: is the positions of the AV states have to be collected
  - Unpredictable: transportation traffic is with difficulty predictable

Multi-Agent

Motivation



Centralized management of a Taxis’ fleet



Decentralized management of a Taxis’ fleet

Motivation

Dynamic | Open | Multi-scale space / time | Decentralized | Distributed | More or less observable | Unpredictable

- **Which properties for the components of a decentralized solution?**

Embedded | Autonomous | Goal oriented | Proactive | Rational | Reactive

- **What means these features for the On-demand service?**
  - Embedded: AV perceives the other vehicles, the infrastructure
  - Autonomous: AV takes decision without control
  - Goal-Oriented: AV has (at least) one objective, go to its destination. It may be more complex.
  - Proactive: AV may anticipate the traffic evolution
  - Rational: AV chooses the best itinerary according to its information about traffic
  - Reactive: AV adapts the vehicle operation (acceleration, brake,…) according to the movements of the other close vehicles.

Motivation

Dynamic | Open | Multi-scale space / time | Decentralized | Distributed | More or less observable | Unpredictable

- **Which relations between the entities of the solution?**

Coordination | Interaction | Organization

- **What means these relations for the On-demand service?**
  - Coordination: avoiding the same request is allocated to (at least) two AV
  - Interaction: the decision of one vehicle influences the others (allocation, direction)
  - Organization: the allocation process of each vehicle may be rules by a predefined organization.

Motivation

- **In « conclusion »**
  - An “old” paradigm (after 1970) for actual challenges
  - Numerous new systems have complex characteristics: dynamic, open, distributed, …
  - Numerous new systems are complex: the behavior of the system results of the interaction between its components.
  - Solutions to these systems may be:
    - Based on a centralized approach: A gap between the characteristics of the system and the constraints of the approach.
    - Based on a decentralized approach: Better adapted but raise new challenges like the coordination of autonomous entities.

Outline

- **Introduction**
  - ***Motivation***: from a technological point of view
  - ***Domain overview***: problematic, application domain
- **Agent & multiagent**
  - Agent: autonomous entity
  - Multiagent: interacting autonomous entities
- **Multiagent system components**
  - **A**gents
  - **E**nvironment
  - **I**nteraction
  - **O**rganization
- **Conclusion**

Motivation

Technological evolution

- Design of increasingly interconnected systems: Internet, wifi, bluetooth
- Computing and transmission power increase,
- Information (size, complexity, modality) become available
- Resources (distributed, heterogeneous, shared)

⇒ *Computing may be portrayed as a process of interaction*

Need for intelligence

- The complexity of automated tasks is increasing,
- The complexity of systems should be addressed through a more abstract paradigm,
- Natural mechanism of delegation: Computers always do more for us,
- Natural humanization mechanism: a different relationship to the computer (programmer and user).

⇒ *Need to build computer systems that can act effectively on our behalf*

⇒ *Computer systems should be able to act independently and in a way that represents our best interests while interacting with other humans or systems*

Motivation

- **Programming evolution**
  - Machine code,
  - Assembly language,
  - Independent programming language,
  - Procedures and functions,
  - Objects,
- **To**
  - Agent: autonomous, rational,…
  - Multi-agent system: coordination, interaction,…

⇒ *systems to represent our best interests, implies systems that can cooperate and reach agreements (or even compete) with other systems that have different interests (much as we do with other people)*

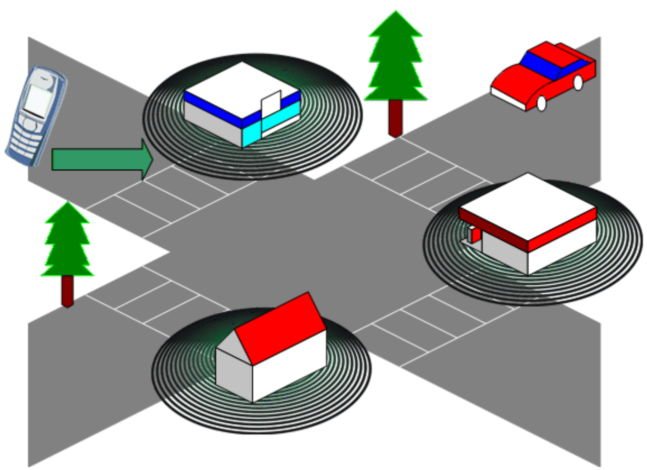
⇒ *Modification of our conception of a system: it is not more a one-piece entity that computes the solution BUT a set of entities that are in interaction to compute the solution.*

Introduction

Motivation

Designing decentralized solution

- **Delegation:** clients and sellers are agents
- **Interaction :** a negociation process between agents



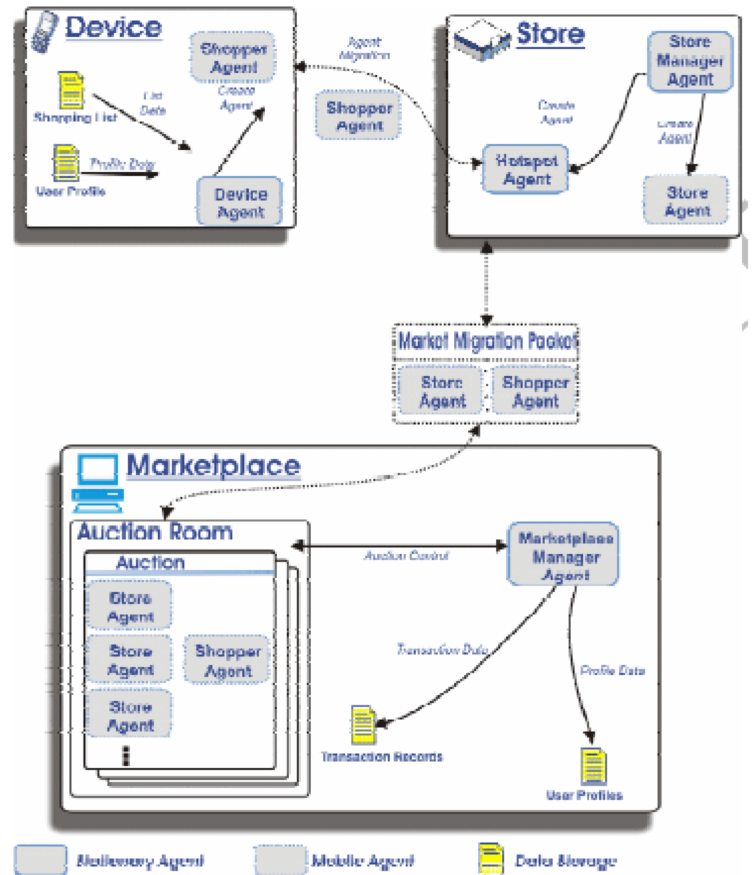


Figure 12. Overview Architecture of Easishop

Keegan, S. O'Hare, G.M.P. & O'Grady, M.J., EasiShop: Ambient Intelligence Assists Everyday Shopping, Journal of Information Sciences Elsevier Press, Vol 178, No. 3 pp 588-611, 2008. Elsevier.

Motivation

Simulation: Understanding complex systems

- **Delegation:** agents simulate human decision
- **Interaction:** Traffic is a combinaison of influence between vehicles

- $\mathcal{A}$ the set of agents (simulated drivers); and
- $\mathcal{E}$ the environment and $I_{\mathcal{E}}^{a_i}$ the set of all information perceived by an agent $a_i \in \mathcal{A}$.

A mental representation M_{a_i} of an agent a_i is a triplet (A, R, D) in which:

- $A = \{a_1, a_2, ..., a_n\}$ is the subset of all agents perceived by a_i;
- $R = \{r_1, r_2, ..., r_k\}$, where each r_i is a binary relation expressing an interaction between two agents of A; and
- $D = \{dom(a_1), dom(a_2), ..., dom(a_n)\}$ defines the domain of each agent in A.

A. Donniec, R. Mandiau, S. Piechowiak, A behavioral multi-agent model for road traffic simulation in Engineering Applications of Artificial Intelligence, 21, pp. 1443-1454, 2008

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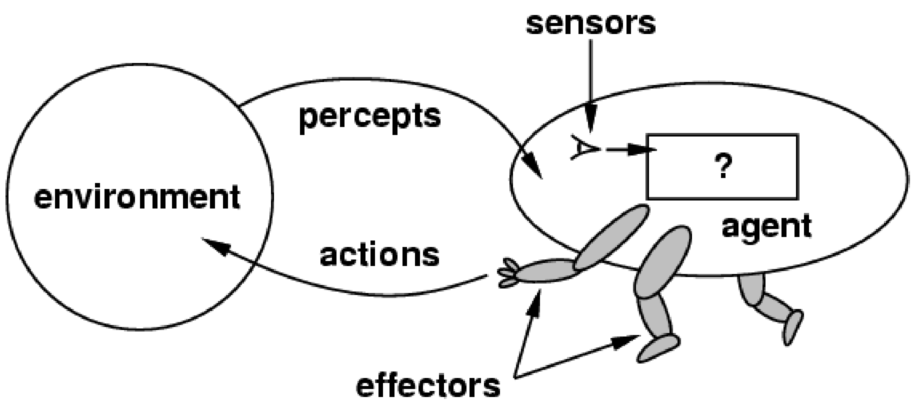
  - **I**nteraction
  - **O**rganization
- **Discussion**

Agent

- **An agent is an entity, which is**
  - *Autonomous*: it decides on his actions to satisfy its goals
  - *Adaptive*: it considers his environment in its decision process
  - *Rational*: it chooses the best alternative (maximize a performance indicator) according to its knowledge.
  - *Social*: it can communicate for coordination purpose



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Agent

Definition

- ***Autonomous***: AV takes decision without control (driving, planning)
- **Adaptive**
  – Pro-active: AV may anticipate the traffic evolution
  – Reactive: AV adapts the vehicle operation (acceleration, brake,…) according to the movements of the other close vehicles.
- **Rational**: AV choose the best action according to its information
- **Social**: AV communicates using a communicative network

Agent versus Objet

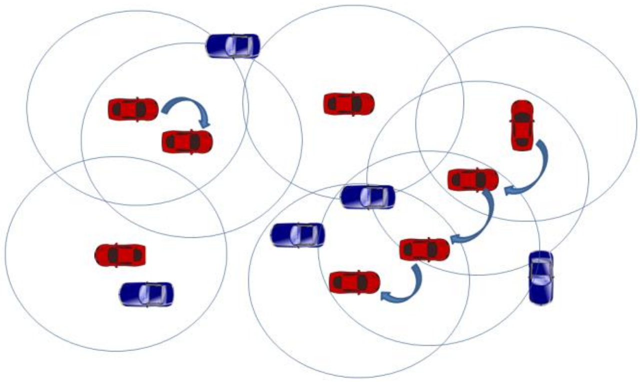
- **An object is passive, it only comes back to life when it receives a message.**
- **An object encapsulates its state and its behavior, but not the choice of its actions => an object is an *obedient agent.***
- **An object represents a level of abstraction too fine for the behavior.**
- **A method is a mechanism too primitive to describe an interaction.**
- **Only "is one" and "is composed of" organizations are available.**

Agent versus Objet

- An agent has control over its behavior WHEN an object has control only over its state.
- An object o1 can only make calls to known functions on o2
- An a1 agent can ask an a2 agent to do something that it does not necessarily know: delegation, learning, planning ...
- An object does it for nothing BUT an agent does it because he wants to or if he is "paid".

Definition

- **Multi-agent system is one that consists of a number of agents which interact with one another. In the most general case, agents will be acting on behalf of users with different goals and motivations. To interact successfully, they will require the ability to cooperate, coordinate and negotiate with each other, much as people do" (Wooldridge 1997)**



Multi-Agent system

Modeling

- **Vowel approach [Demazeau 95]**
  - Agent
    - Sources: Artificial Intelligence, Object, Robotics ...
    - Definition of the active entities of the system: internal architecture, knowledge representation, ...
  - Environment
    - Source: Simulation, Physics, GIS, ...
    - Definition of the common element shared by the agents (perception, action, environment dynamics, ...).
  - Interaction
    - Sources: language acts, conversation.
    - Definition of the elements structuring the interactions (communication language, interaction protocol, ...).
  - Organization
    - Source: Sociology, Social Psychology, CSCW
    - Definition of the elements to structure, constrain the agents (organizational structure, laws, norms, ...)

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- **Conclusion**

Agent taxonomy

A common principle, several modeling

- **Reactive Agent**

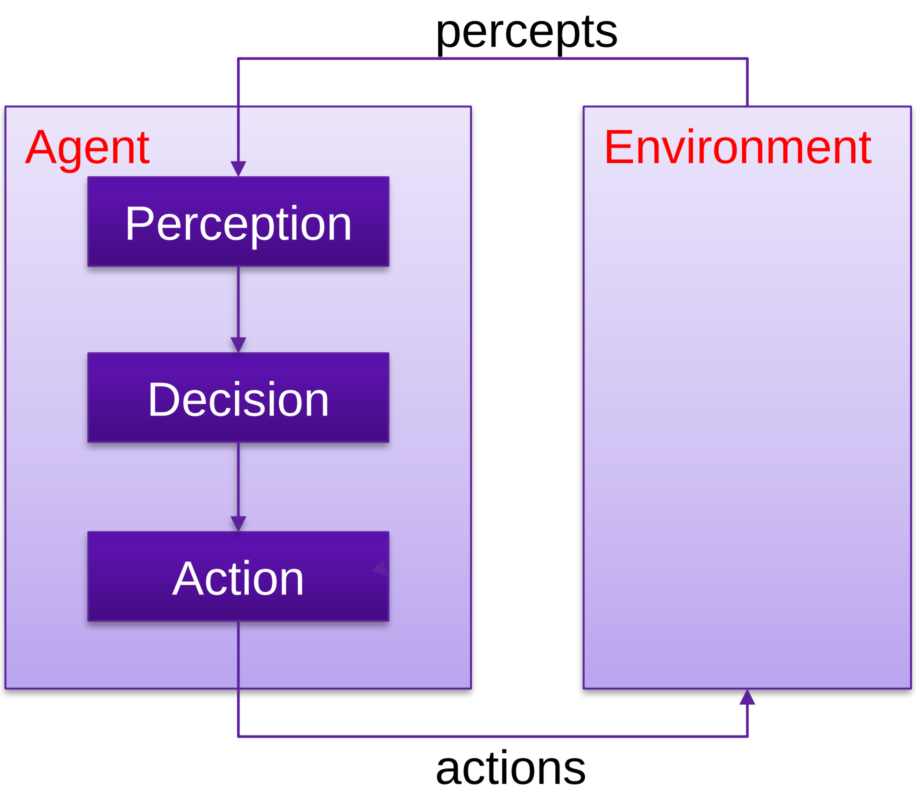
Agent reacts to its percepts following a reflex process

- *Perception*

  What the world is like now?
- *Decision*

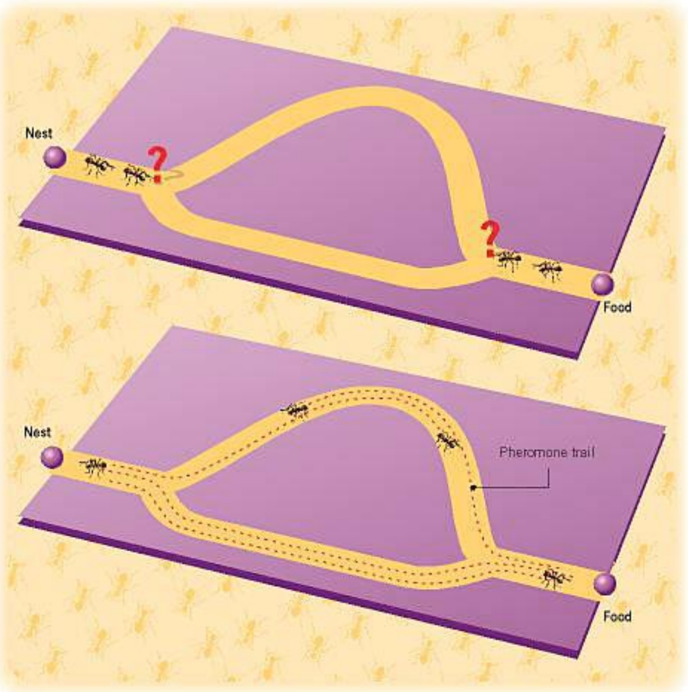
  Condition-Action rules
- *Action*

  What action I should do now?



Characteristics

- **no explicit representation of the environment**
- **no memory of its history, nor any explicit goal**
- **stimulus-response behaviour**
- **“organic" mode of organization**
- **large number of agents (>100), homogeneous to fine grain**
- **The structure of the system emerges from behaviors and not from a will of organization.**
- **Inspiration**
  - Social insects : ants, termites, bees ...
  - Eco-systems
  - Phytosociology: plant community



An individual behavior, a collective result

Discussion

- **Benefits**
  - Simplicity of modeling
  - Economic
  - Simplicity of development
  - Robust
  - Elegance
- **Boundaries**
  - Agents without environment modeling must be able to access sufficient information from their local environment.
  - Decisions based on a local environment not taking into account other information.
  - Difficult to make learning reactive agents.
  - Difficult to develop agents with multiple behaviors, as the dynamics of interactions become too complex.

Agent taxonomy

A common principle, several modeling

- **Cognitive Agent**

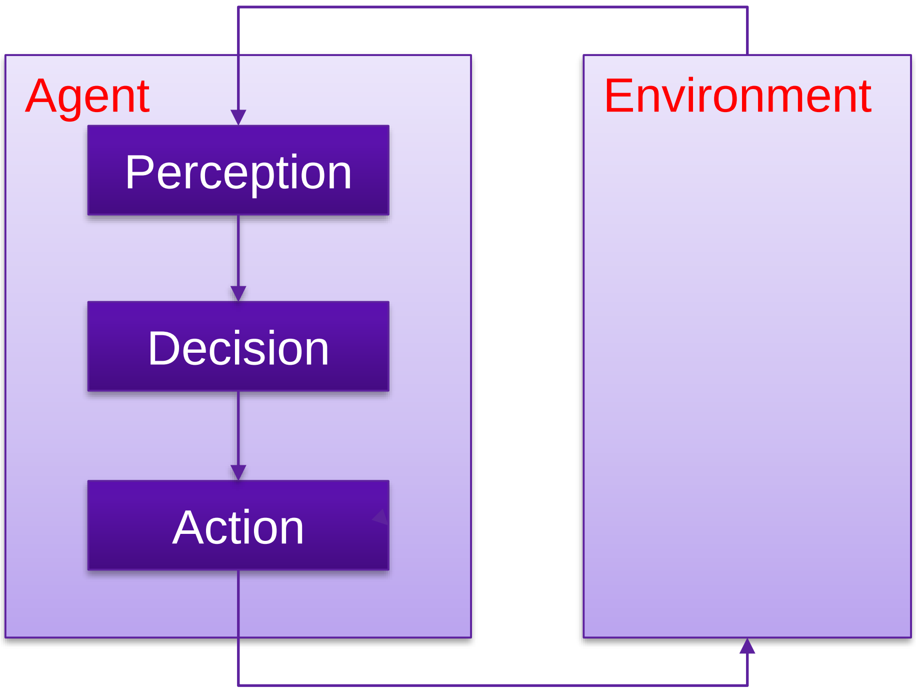
Agent acts following a reasoning process

- *Perception*

  What the world is like now?
- *Decision*

  Reasoning process based on an objective function or a goal
- *Action*

  What action I should do now?



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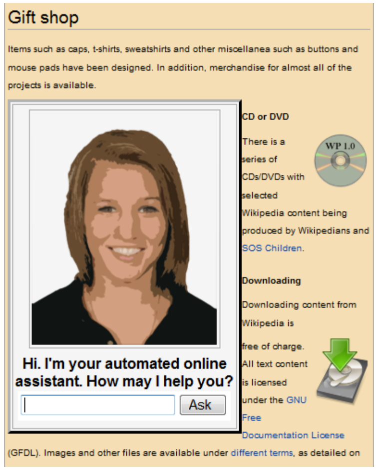
Cognitive Agent

Characteristics

- **Explicit representation of the environment and other agents**
- **Can take into account its past and has an explicit goal - "social" mode of organization (planning, commitment)**
- **Small number of agents, heterogeneous to coarse-grained**
- **Relationships between agents are established based on the collaboration necessary to solve the problem.**



Chatbox (Wikipedia)

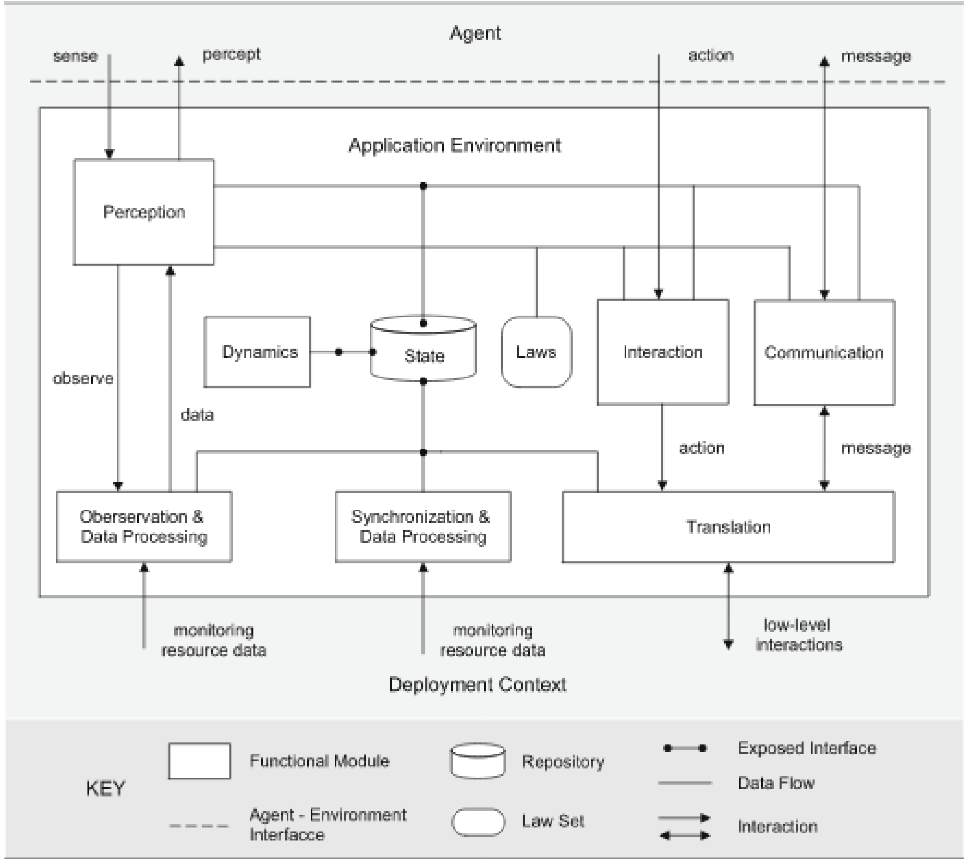
Characteristics

- **[Weyns 07]: Environment**
  - provides the conditions for agents to exist,
  - mediates interactions between agents and gives access to resources.
- **[Weyns 05] The environment must**
  - Structuring
    - The environment allows the MAS to be structured both physically and socially, and supports communications.
  - Support and lifecycle management
    - The environment is in charge of the maintenance of resources and agents, as well as their dynamics.

Functional Architecture

- **The environment must :**
  - Provide observability
    The environment provides the representation structures, resources and bodies of agents.
  - Provision of accessibility
    The environment manages the accessibility of structures and resources.
  - SMA regulation
    The environment controls access to structures and resources, and maintains access laws.
  - Provide Ontology
    The environment provides a common ontology that can be consulted by agents.

The environment is a first-order abstraction [Weyns 2007]



Definition

General [Morin 77]

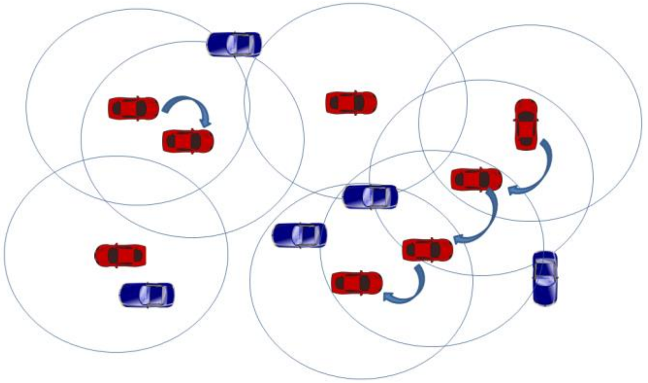
- Interactions are reciprocal actions modifying the behavior or nature of elements, bodies, objects, phenomena in presence or influence.

Multi-Agent [Ferber 95]

- Dynamic linking of two or more agents through reciprocal actions.

Objective

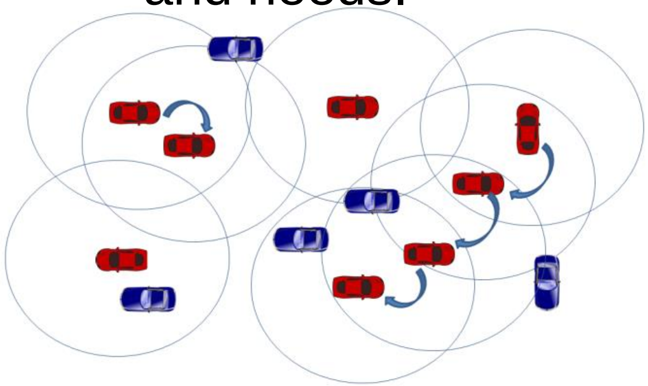
- Reach the goal of the system thanks to the cooperation, coordination, negotiation between the autonomous entities



Autonomous Vehicles interact through
1) Their perceptions of others
2) Their communications

Definition

- **Four ways of interacting between agents [Werner89] :**
  - *No communication*: agents do not communicate, either they interact by perception of the environment or they can achieve their goal without external help.
  - *Sending signals*: agents synchronize by sending coded messages.
  - *Sending plans*: the transfer of information concerns the agents' tasks and beliefs.
  - *Sending messages*: this mode of communication, the most used in the SMA community, allows agents to exchange their intentions and needs.



No communication: the positions, movements, turn signal

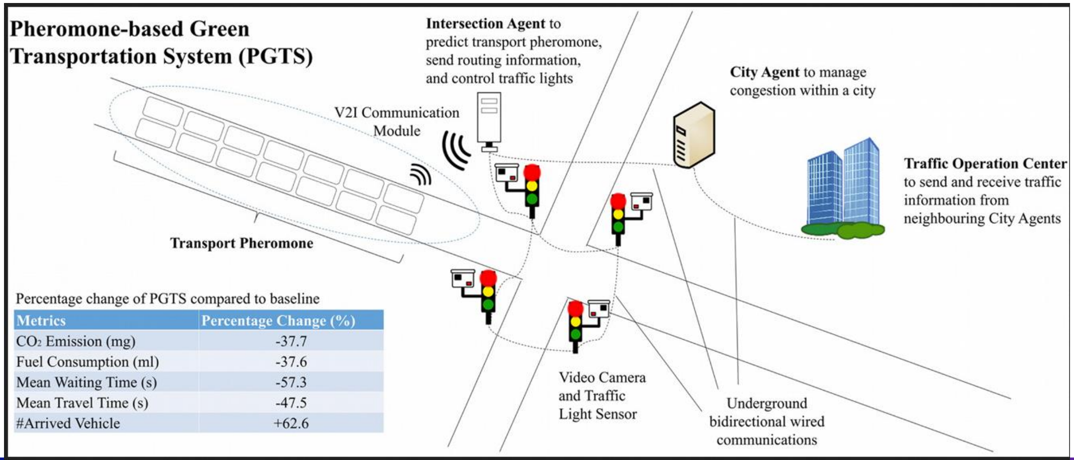
Sending signal: beep the horn

Sending plans: send its direction at a junction

Sending messages: share its intention to overtake

Indirecte interaction

- **Principle**
  - A logical environment facilitates information exchange.
- **Receiver-directed interaction**
- **Modality**
  - Stigmergy: information is based on an environment modification (pheromones put/perceive by ants
  - Shared space (BlackBoard, tuples space): a space where information is shared by agents



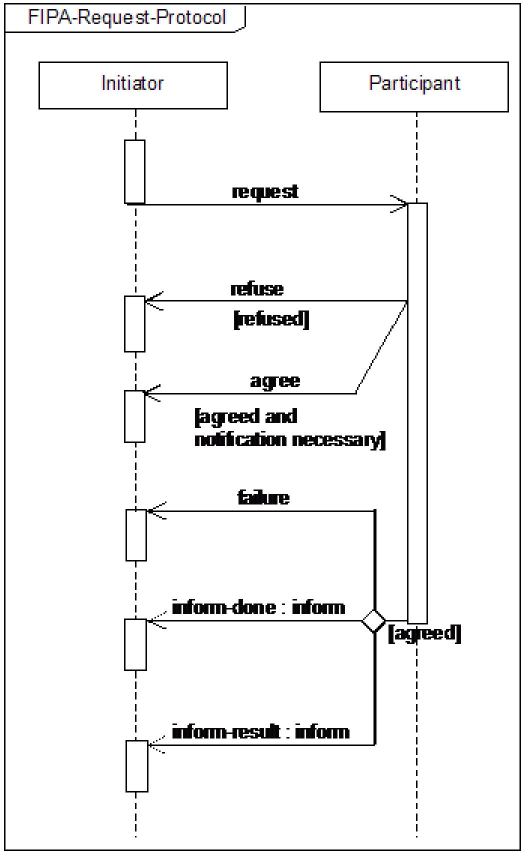
Metrics	Percentage Change (%)
CO_2 Emission (mg)	-37.7
Fuel Consumption (ml)	-37.6
Mean Waiting Time (s)	-57.3
Mean Travel Time (s)	-47.5
#Arrived Vehicle	+62.6

"traffic congestions are predicted based on the transport pheromone intensity of the target and adjacent upstream roads "

Soon, K. L., Lim, J. M. Y., & Parthiban, R. (2019). Coordinated Traffic Light Control in Cooperative Green Vehicle Routing for Pheromone-based Multi-Agent Systems. *Applied Soft Computing*, *81*, 105486.

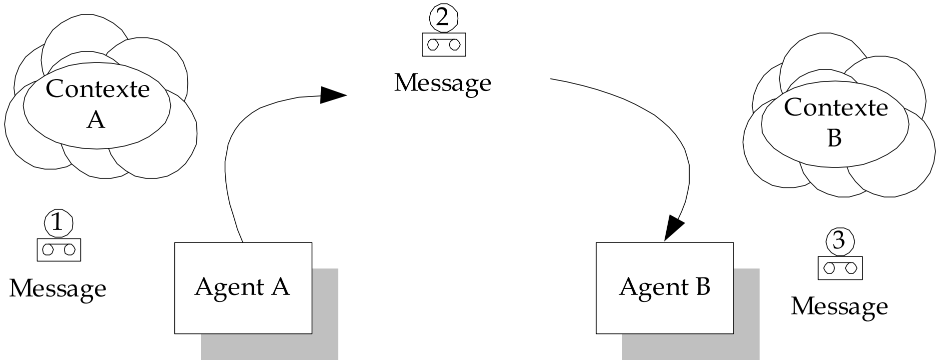
Directe interaction

- **Classic addressed communication approach: a sender sends a message to a receiver located by its address.**
- **Interaction directed by the sender**
- **Modalities**
  - Point-to-point, broadcast, restricted broadcast.



Communication

[Shannon 48] Problematic



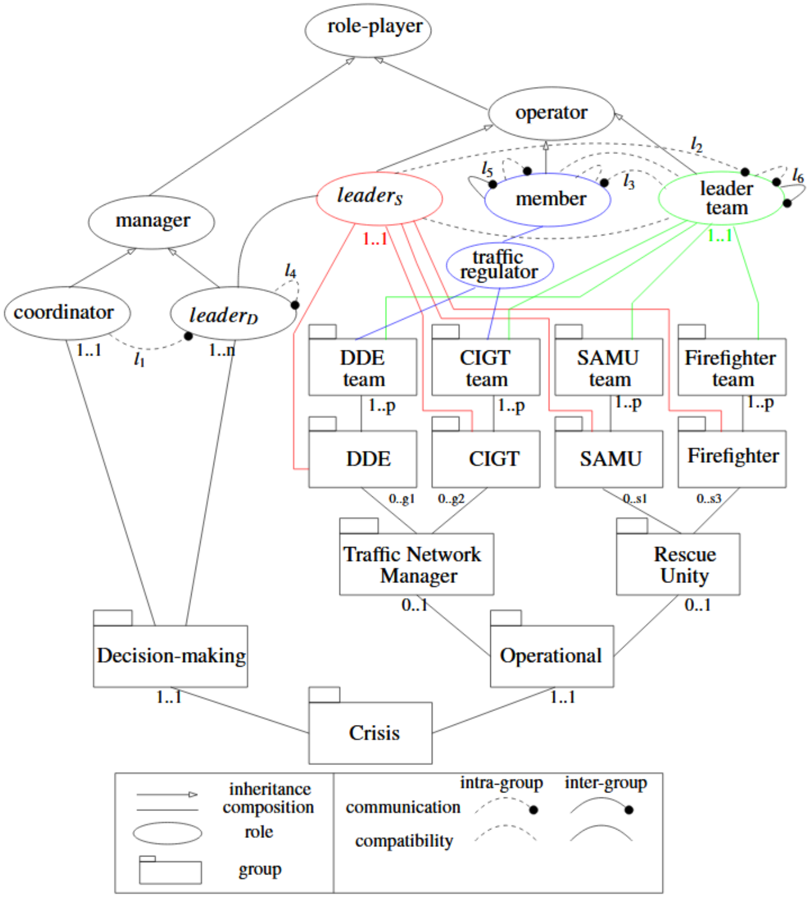
Communication is the voluntary exchange of information caused by the production and perception of symbols from a shared system of conventional symbols [Russel et Norvig 03]

That means

- A common language (syntax)
- A common interpretation (semantic, protocol)
- A common communication canal

Definition

- Organisation is a supra-individual phenomenon.
- Defined by the designer or actors in order to accomplish a goal.
- Predefined framework of cooperation
- Pattern of emergent cooperation



Boissier, O., Balbo, F., & Badeig, F. Controlling multi-party interaction within normative multi-agent organizations. *COIN'10 in Agent Systems* (pp. 357-376). Springer, Berlin, Heidelberg.

Discussion

- ***Agent Design***

How to design autonomous agents capable of successfully performing the tasks that have been delegated to them.

- ***Multi-agent design***

How to design agents capable of interacting (cooperation, coordination, negotiation) with other agents in order to successfully perform the tasks delegated to them, especially when the agents' interests/goals are antagonistic.

Discussion

- **Difficult to manage reactive and proactive behaviour**
  - Either the agent never achieves his goal because he keeps changing strategy when the environment changes.
  - Or the agent undertakes tasks that cannot be done (because the environment has changed).
- **Difficult to predict the behavior of the system.**
  - Objectives decided at execution.
  - Contextual actions.
- **Emergence of group behavior**
  - not explainable only with the behavior of individuals (interactions must be taken into account).

Dial a ride problem (DARP) with a fleet of autonomous taxis

What is the best allocation of taxis to traveler requests?

- **Hypothesis on the vehicles**
  - Fixed number of vehicles
  - No centralized decision process: each vehicle decides of which traveler request, it wants to satisfy

- **Hypothesis on the traveler requests**
  - No information on their location
  - A lifespan

Which multi-agent solution?

Exercice

- Based on the AEIO approach, propose formal multiagent models for this problem in two cases
  - MAS is based on reactive agents (DARPR (DARP Reactive model)) ;
  - MAS is based on cognitive agents (DARPC (DARP Cognitive model)).

- For simplification purpose:
  - Vehicles move in an Euclidian space;
  - Vehicle cannot satisfy simultaneously several requests (i.e. several client like in carpooling)

- At minima (you can propose other questions), answer to these questions for DARPR and DARPC model.
  - Agents: what are agents and their behaviors?

    => basic behavior and decision process
  - Environment: What are its properties?

    => what belongs to the environment? what is perceptible? What is modifiable?
  - Interaction: How agents influence behaviors of other?

    => Which information is useful and how / when the information is exchanged? There is indirect interaction?
  - Organization: What rules the behavior of agents?

    => Agents have permissions, obligations, …?