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University of Ruse “Angel Kanchev”

MULTIAGENT SYSTEM WITH ARTIFICIAL INTELLIGENCE

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08,2022

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ARTIFICIAL INTELLIGENCE – Agent Oriented Approach

1. Definition
2. Characteristics
3. Rational Agent
4. Agents' Types
5. Environment

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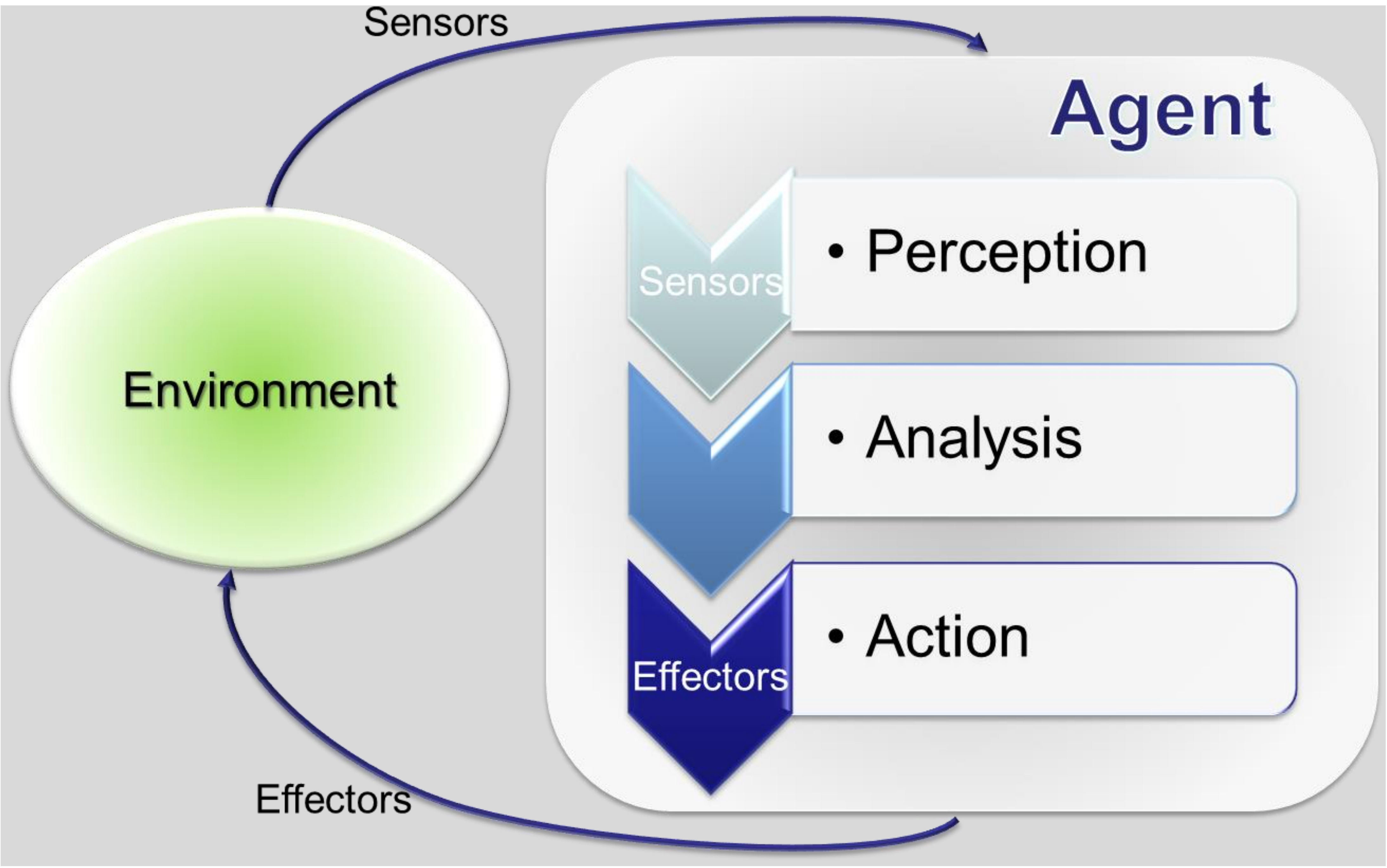
Definition

Intelligent Agent

Intelligent agent - any system that has the ability to perceive the environment through sensors, analyze what is perceived and perform actions in it through effectors

The prototype of on Agent is a Person:

- Person sensors – eyes, ears, skin, tongue, nose, neuromuscular system, etc.;
- Effectors – limbs, eyes, tongue, etc.;
- Perception: at the lowest level – electrical signals; after processing - visual objects, sounds ...
- Analyses – through the brain
- Actions - movement, running, carrying an object...



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Characteristics

Intelligent Agent

Autonomy: the property of the agent to determine its behavior based on accumulated experience (at the expense of built-in knowledge) and to act on its own initiative

Adaptability: ability of the agent to teach oneself in action to respond to changes in the environment and to adapt to those that are permanent to communicate with other agents through some sign system

Mobility: self-directed movement of an agent from one medium to another in a networked environment

Collaboration: working in multi-agent systems involving division of tasks, pooling of results and exchange of knowledge and experience

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Characteristics

Intelligent Agent

Rationality

A rational agent – actions to increase his chance of success

- Consistency of perceptions
- Embedded and acquired knowledge

Involves gathering information

A performance measure is needed to be able to assess such as:

- Default rate;
- Pass Level;
- Speed;
- Required resources...

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Intelligent Agent

An ideal rational agent - For any conceivable perceptual grouping, a rational agent must be able to select an activity that's anticipated to attain the most extreme result, given the prove given by the perceptual arrangement and anything is implanted within the agent's information

Rational action depends on:

- Performance Measure (Objectives)
- The sequence of perceptions
- Knowledge of the environment
- Possible actions

The ideal rational agent acts according to the function

Percept Sequence x World Knowledge → Action

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Intelligent Agent

The agent's program - a function realizing the transition from perceptions to actions. The body of the program is a cycle, with each step involving perception, selection, and action

Techniques: knowledge-based reasoning; statistical analysis; fuzzy logic; Neural Networks; evolutionary (genetic) programming, etc.

Architecture: the hardware on which the program works - a regular computer or a specialized device.

⇒ Agent = Architecture + Program

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Intelligent Agent

Table-driven agent:

- uses a perception / action table to determine its next action;
- are implemented through a lookup table.

The table looks for an optimal variant of a perception/action pair

Problems:

- the table can get very large (chess – 10^{120} states)
- no knowledge of the current state;
- are not adaptable when the environment changes;
- usually requires a lot of time for the designer to define (or train the agent)
- conditional returns to a previous state cannot be performed;
- … practically impossible

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Agents' Types

Intelligent Agent

Common reflex agent

- Uses derived rules of type condition - action
- It obeys rules
- Perceptions must be interpreted
- An example from the field of fire fighting:

  If (tank_is_empty) then return_to_refuge

Problems:

- still too large to generate and store;
- no current status knowledge;
- not adaptable to a changing environment (needs to change or adapt rules)
- cannot make conditional transfers to past states.

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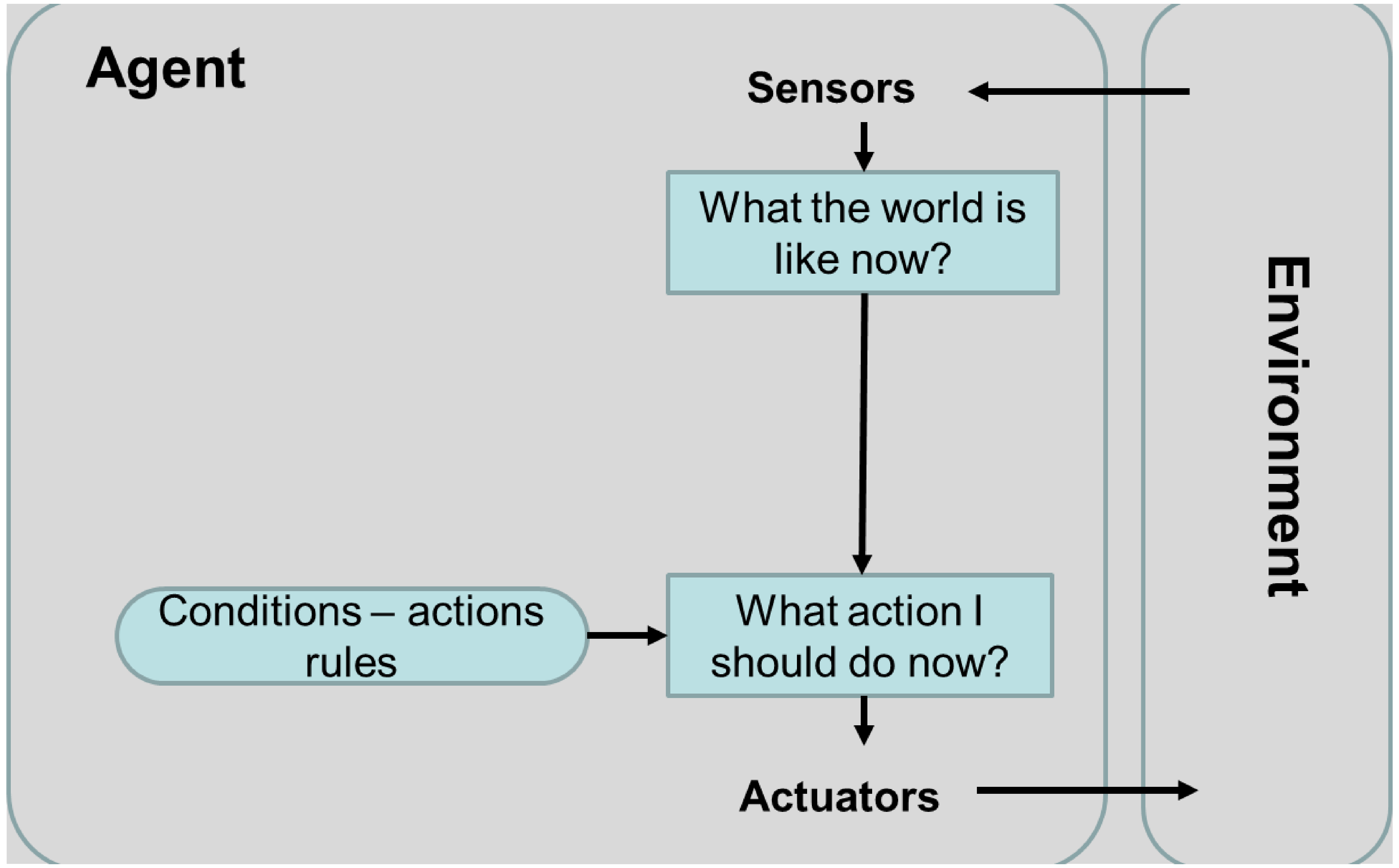
Agents' Types

Intelligent Agent

Schematic diagram of a simple reflex agent. We use rectangles to denote the current internal state of the agent's decision process, and ovals to represent the background information used in the process. (Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Fourth Edition. Pearson Education, 2020)



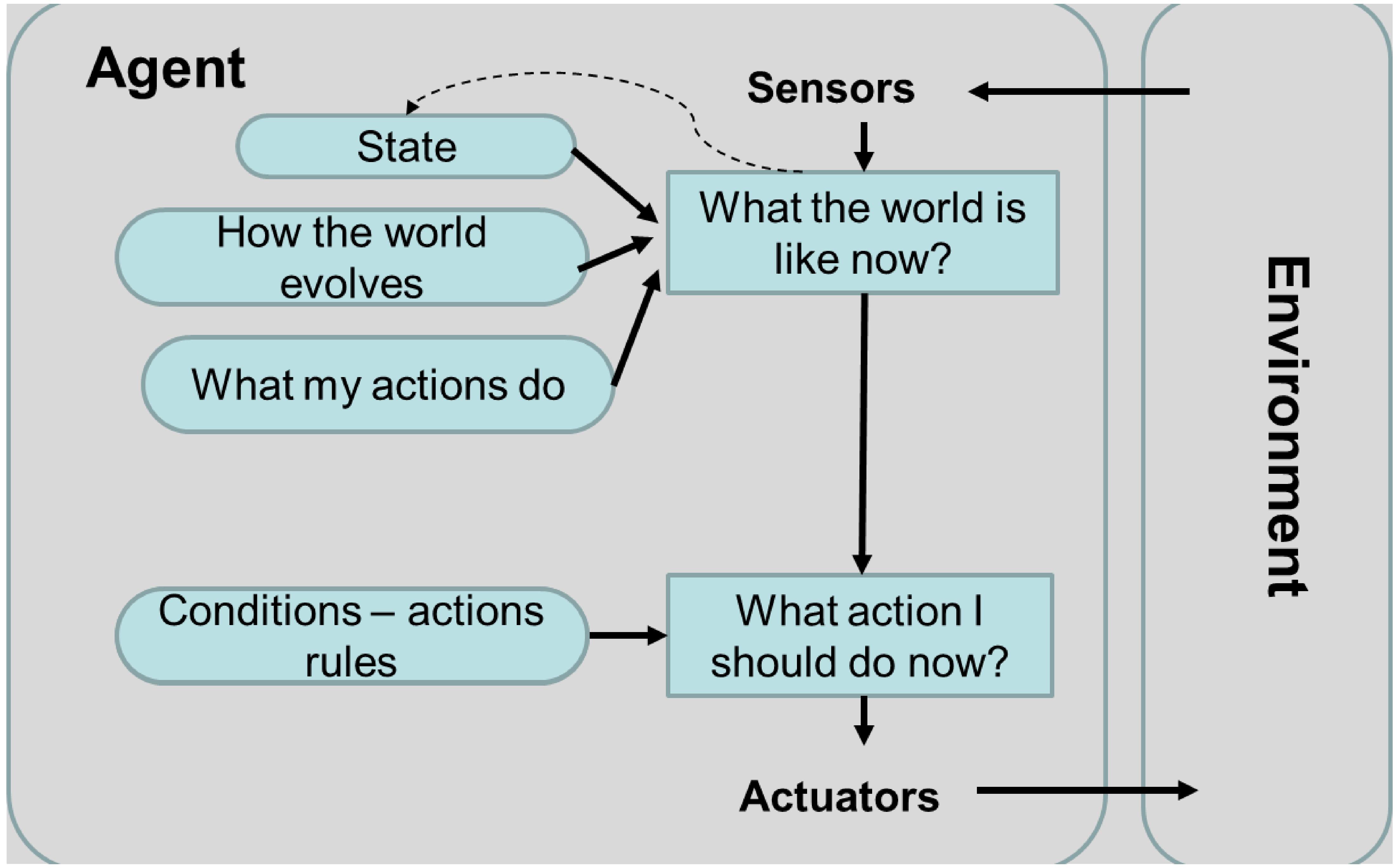
Agents' Types

Intelligent Agent

Model-based reflex agent:

- Updating the internal state representing the perceptual history
- Predicting consequences of actions given the state
- It needs the ability to represent a change in the environment

(Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Fourth Edition. Pearson Education, 2020)



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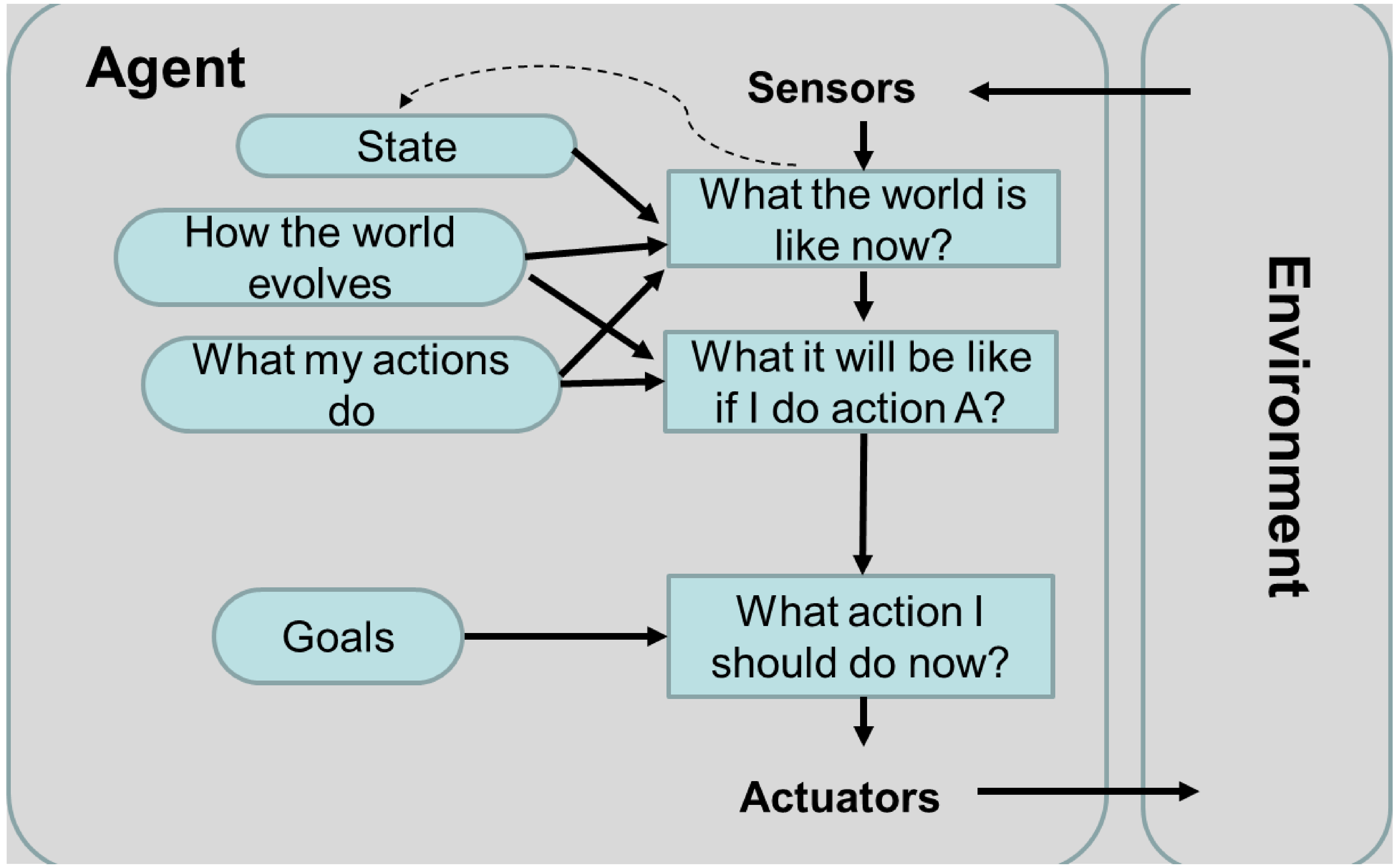
Intelligent Agent

Model-based, goal-based agent:

- A detailed presentation of the goal - as a desired situation
- Selecting the target with the highest expected applicability (highest chance of being useful)
- Actions are generated by planning to the selected target state
- Analysis of long sequences of possible actions before deciding whether the goal has been achieved (looking into the future, "what will happen if I do ...?")

(Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Fourth Edition. Pearson Education, 2020)



Agents' Types

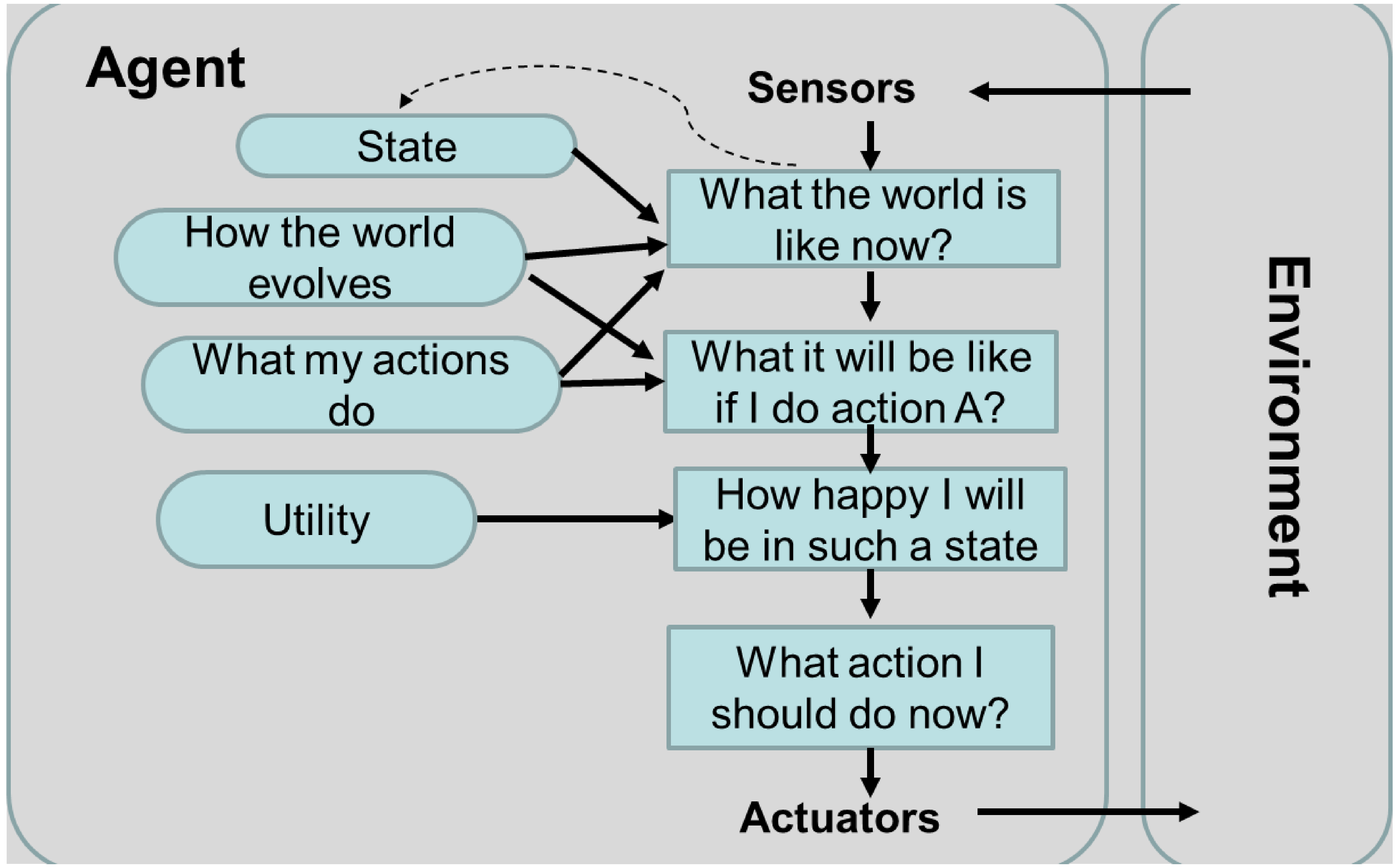
Intelligent Agent

Model-based, utility-based agent:

- How to determine the appropriate course of action given many alternatives
- Applicability function

  U: State → Real number

- measure of success from a given condition
- Allows decisions comparing choices between conflicting goals and choices between probability of success and goal importance (if achievement is uncertain).



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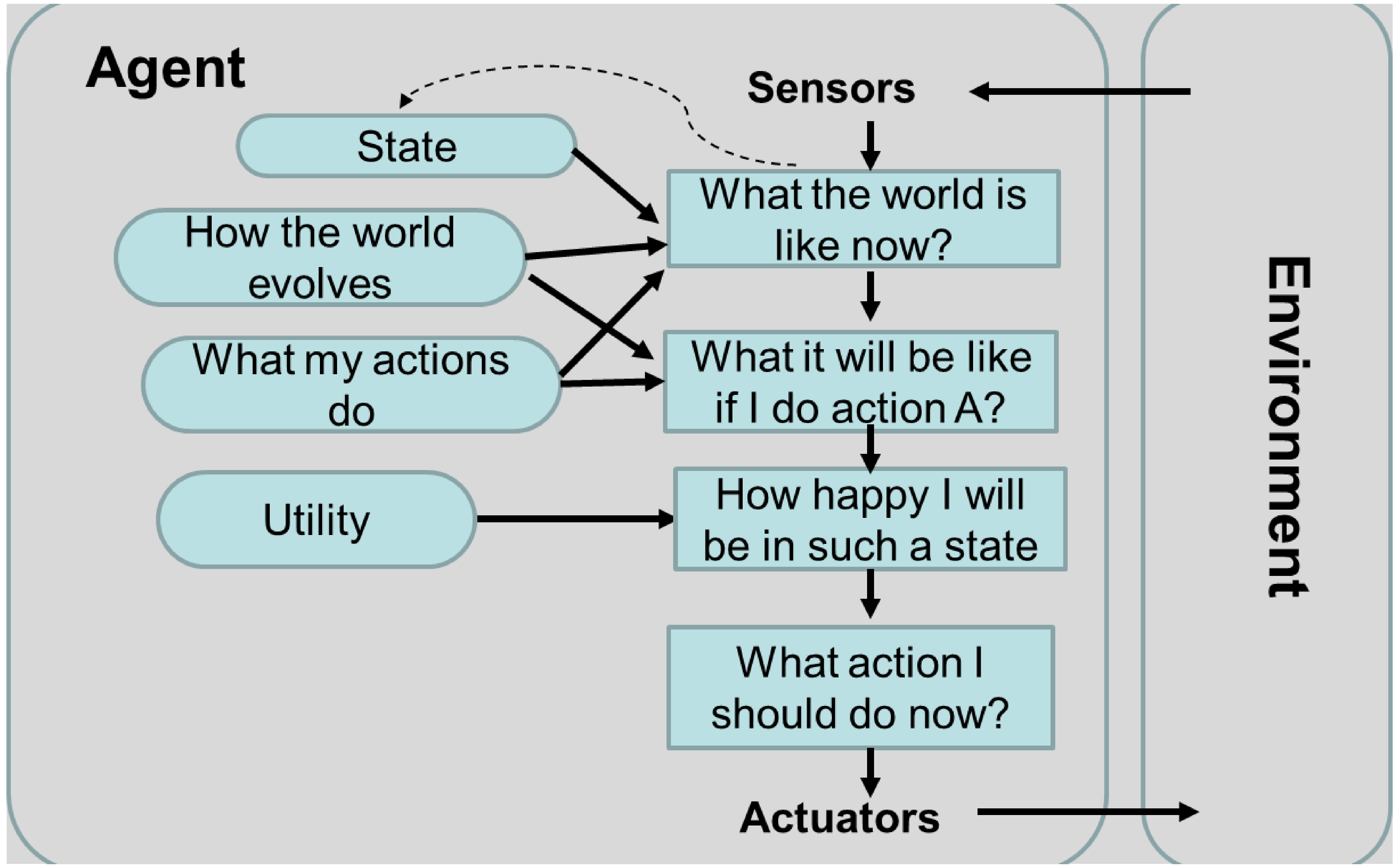
Agents' Types

Intelligent Agent

It uses a model of the world, along with a utility function that measures its preferences among states of the world. Then it chooses the action that leads to the best expected utility, where expected utility is computed by averaging over all possible outcome states, weighted by the probability of the outcome.

(Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Fourth Edition. Pearson Education, 2020)



Intelligent Agent

The type of the environment could be different, depending on the goal, situation etc.

The Environment's types are:

- ***Accessible / Inaccessible*** (fully observable or partially observable) - Are relevant aspects of the environment available to the sensors?

- ***Deterministic / stochastic*** - Is the next state of the environment completely determined by the current state and the chosen action? If only the actions of the other agents are non-deterministic (indeterminate), the environment is called strategic.

- ***Episodic / Resultant (subsequent)*** - Can the quality of an action be assessed in an episode (perception + action) or does future development matter for quality assessment?

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Intelligent Agent

- ***Static / dynamic*** - Can the environment change while the agent is deliberating? If the environment does not change, but the agent changes its performance over time, the environment is referred to as semi-dynamic.

- ***Discrete / continuous*** - Is the environment discrete (chess) or continuous (a robot moving around a room)?

- ***With / without intelligent opponents*** - they must have information about the strategic, game-theoretic aspects of the environment. In the engineering environments – without; in social and economic systems – with.

Intelligent Agent

Task	Accessible	Deterministic	Episodic	Static	Discrete	Agents
Image analysis	Fully	Deterministic	Episodic	Semi	Continuous	One
Parts lifting robot	Partially	Stochastic	Episodic	Dynamic	Continuous	One
Control in a refinery	Partially	Stochastic	Resultant	Dynamic	Continuous	One
Interactive English learning	Partially	Stochastic	Resultant	Dynamic	Discrete	Multi
Taxi driving (self driving car)	No	Stochastic	Resultant	Dynamic	Continuous	Multi

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LECTURE 5

Society of Agents

1. Society of Agents
2. Attributes of MAS
3. Coordination through Interaction
4. Task Decomposition and Assignment

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Society of Agents

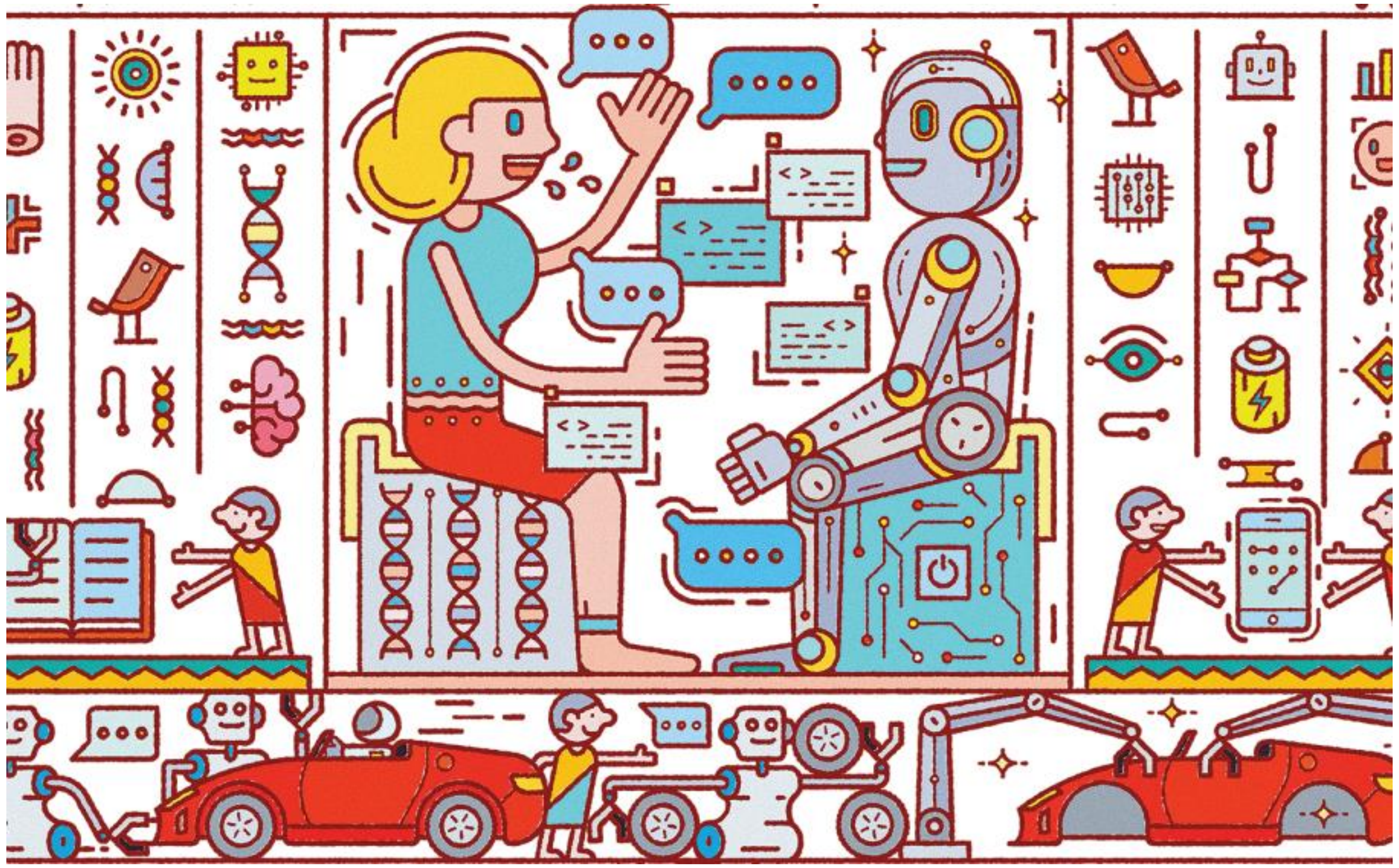
Normally AI focuses on one agent.

But, what happens when we have more than one agent:

– could they work together?

– will there be any problems?

All those questions are concerning the Society of agents.



H. James Wilson, Paul R. Daugherty, Collaborative Intelligence: Humans and AI Are Joining Forces (https://hbr.org/2018/07/collaborative-intelligence-humans-and-ai-are-joining-forces)

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Society of Agents

- What is an agent as part of society?
- It is an intelligent agent that has more characteristics such as:
  - Reactivity - the ability to respond to the environment changes in real time
  - Pro activeness - ability to take initiative for action to achieve goals, i.e. not to be guided by events, but to be able to choose the course of action himself
  - Social ability - opportunities for agents to interact (communicate, cooperate, cooperate) with each other as well as with humans using some kind of agent communication language

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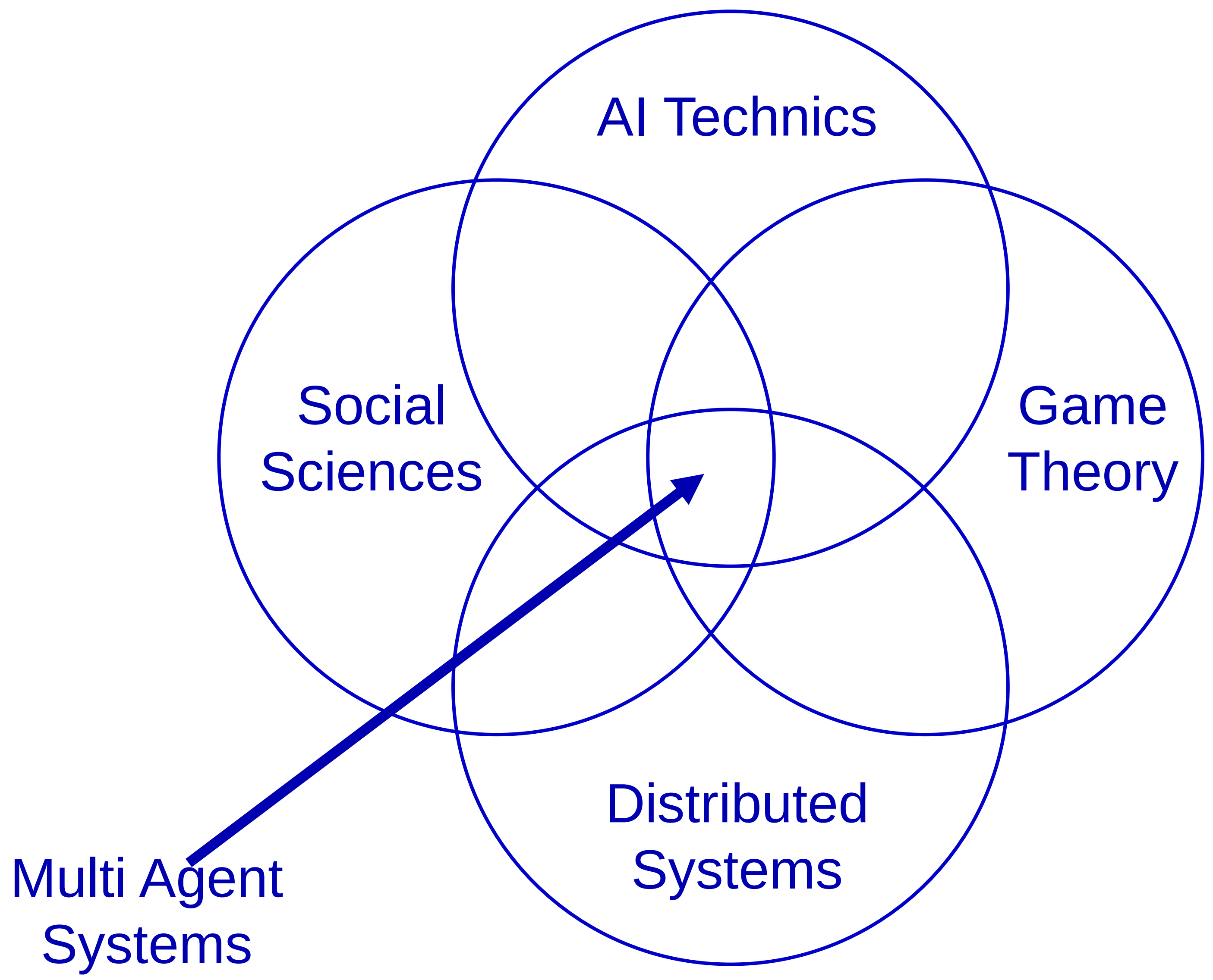
Society of Agents

- Do we have to solve all the problems of the AI itself (eg planning, communication, training...) before creating an agent??

➢ …In brief, although we use artificial intelligence techniques for agent design, it is not necessary to solve all problems before we have created an AI agent

- Classical AI does not consider the social aspects of agents. But in fact, these are very important aspects of intelligent activity in the real world



Attributes of MAS

	Attribute	Range
Agents	Number	From two upward
	Uniformity	Homogeneous / heterogeneous
	Goals	Contradictory / complementary
	Architecture	Reactive / deliberative
	Abilities (sensors etc.)	Simple / Advanced

From Huhns & Singh 1998, “Agents and multi-agent systems: Themes, approaches and challenges”

Attributes of MAS

	Attribute	Range
Interaction	Frequency	High / low
	Persistence	Short-term / Long-term
	Level	Signal level / Knowledge level
	Pattern	Decentralized / hierarchical
	Variability	Fixed / changeable
	Purpose	Competitive / cooperative

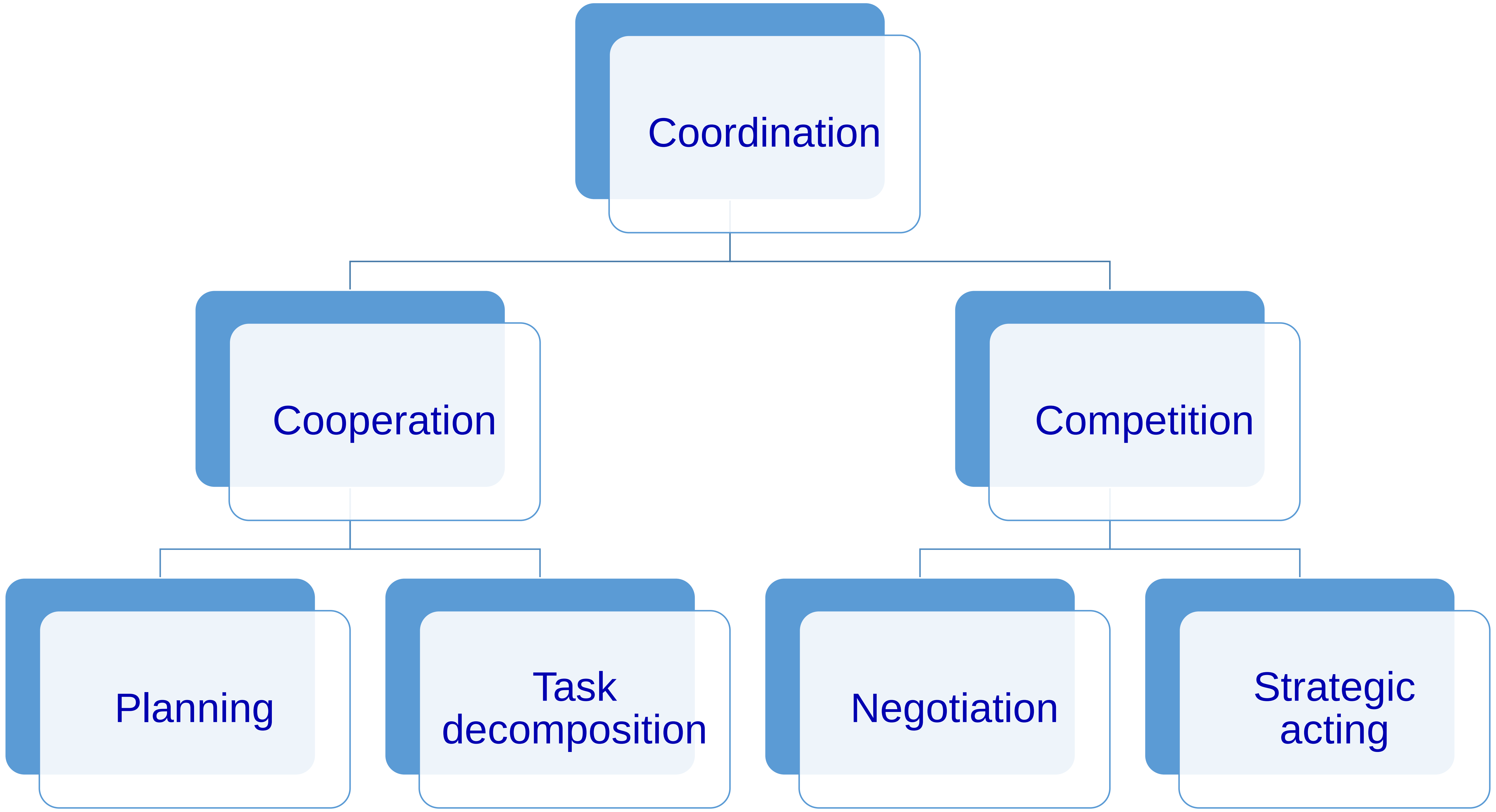
From Huhns & Singh 1998, “Agents and multi-agent systems: Themes, approaches and challenges”

Attributes of MAS

	Attribute	Range
Environment	Predictability	Foreseeable / unforeseeable
	Accessibility	Limited / unlimited
	Dynamics	Low / high
	Diversity	Poor / rich
	Availability of resources	Restricted / ample

From Huhns & Singh 1998, “Agents and multi-agent systems: Themes, approaches and challenges”

Coordination through Interaction



Coordination through Interaction

Benevolent agents (like team of fire brigades, robots exploring unknown terrain):

- The agent voluntarily helps other agents without being commanded to do so.
- The agent's benevolent actions are intended to benefit the society to which the agent belongs.
- The agent should not expect an immediate reward or benefit for its benevolent actions. If it did, then the agent is instrumental, not benevolent.
- The agent's benevolent action is taken while the agent is pursuing one of its own goals in such a way that it should neither prevent nor help the agent accomplish its goal.

- Agents are assumed to act truthfully
- Cooperative distributed problem solving: agents can be designed to help when ever asked
- Cooperation mechanisms are for example contract nets, and blackboard system

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Coordination through Interaction

Self-interested agents (from different organizations, Internet markets, computer games):

- Agent has its own description of the environment it uses and its actions are based on that description
- Agents assumed to work for their own benefit, possibly at expense of others
- Coordination by adequate mechanism design, e.g. Game theory, Auctions

- It does not mean that they want to harm other agents
- It does not mean that they only care about things that benefit them

Contract Nets

There are different roles in a net of agents.

The roles are not specified in advance, they are rather dynamic and can change during the execution of the task. For example, a contractor can further break the task into subtasks and assign them to other contractors!

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Contract Nets

Manager - An agent that wants a task to be solved is the manager

- announces a task (the task specification)
- receives and evaluates bids from potential contractors
- awards a contract to a suitable contractor
- receives and synthesizes the results

- Contractors - Agents able to solve the task are potential
  - receives task announcements
  - evaluates the capability to respond
  - responds with a bid or declines
  - perform task if the bid is accepted
  - report the results back

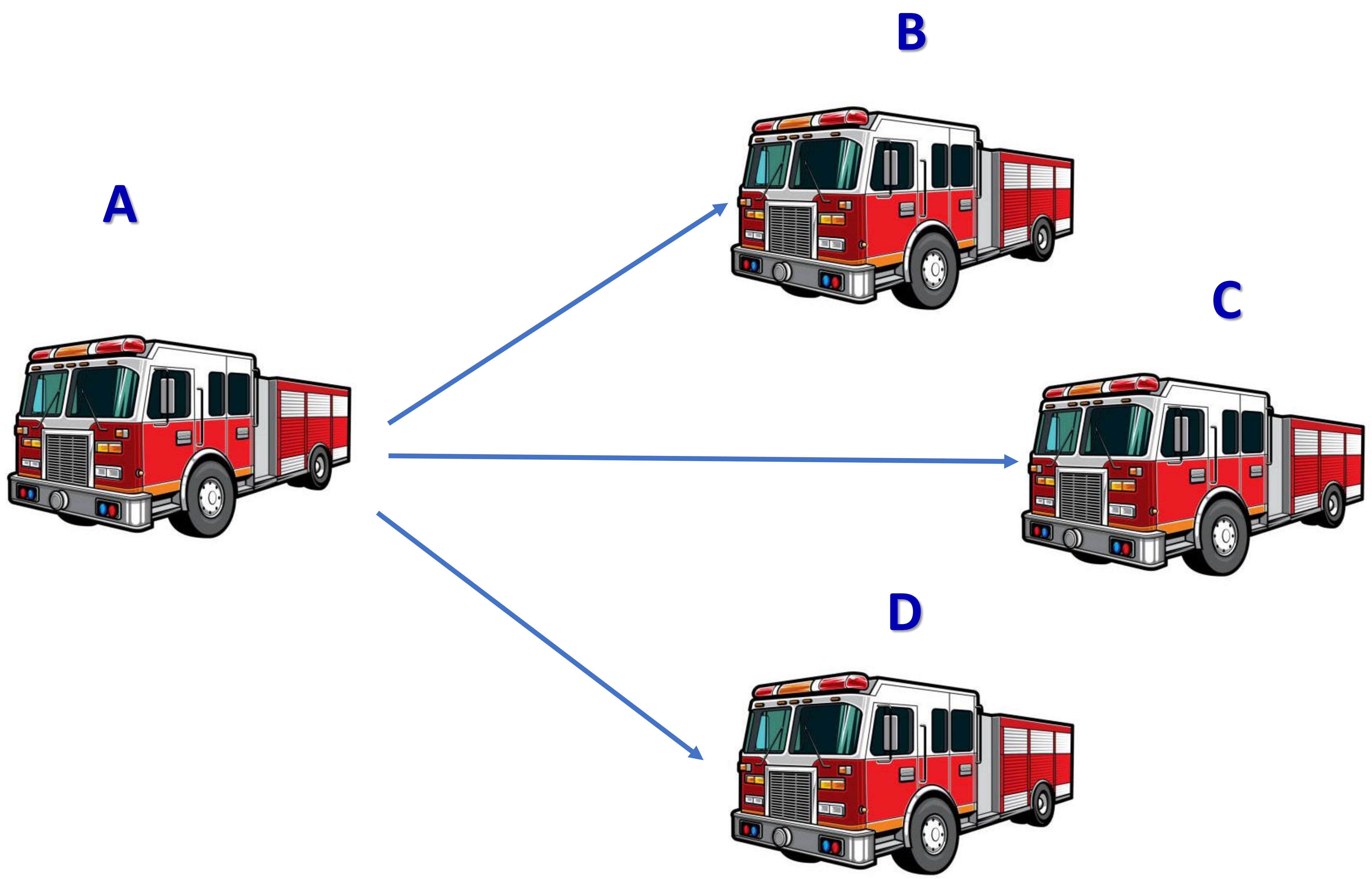
Task Decomposition and Assignment

Contract Nets

Fire Brigade Example

Fire brigade A needs help
to extinguish a building

Task specification:
- needed amount of water,
- the location of the fire,
- and a deadline



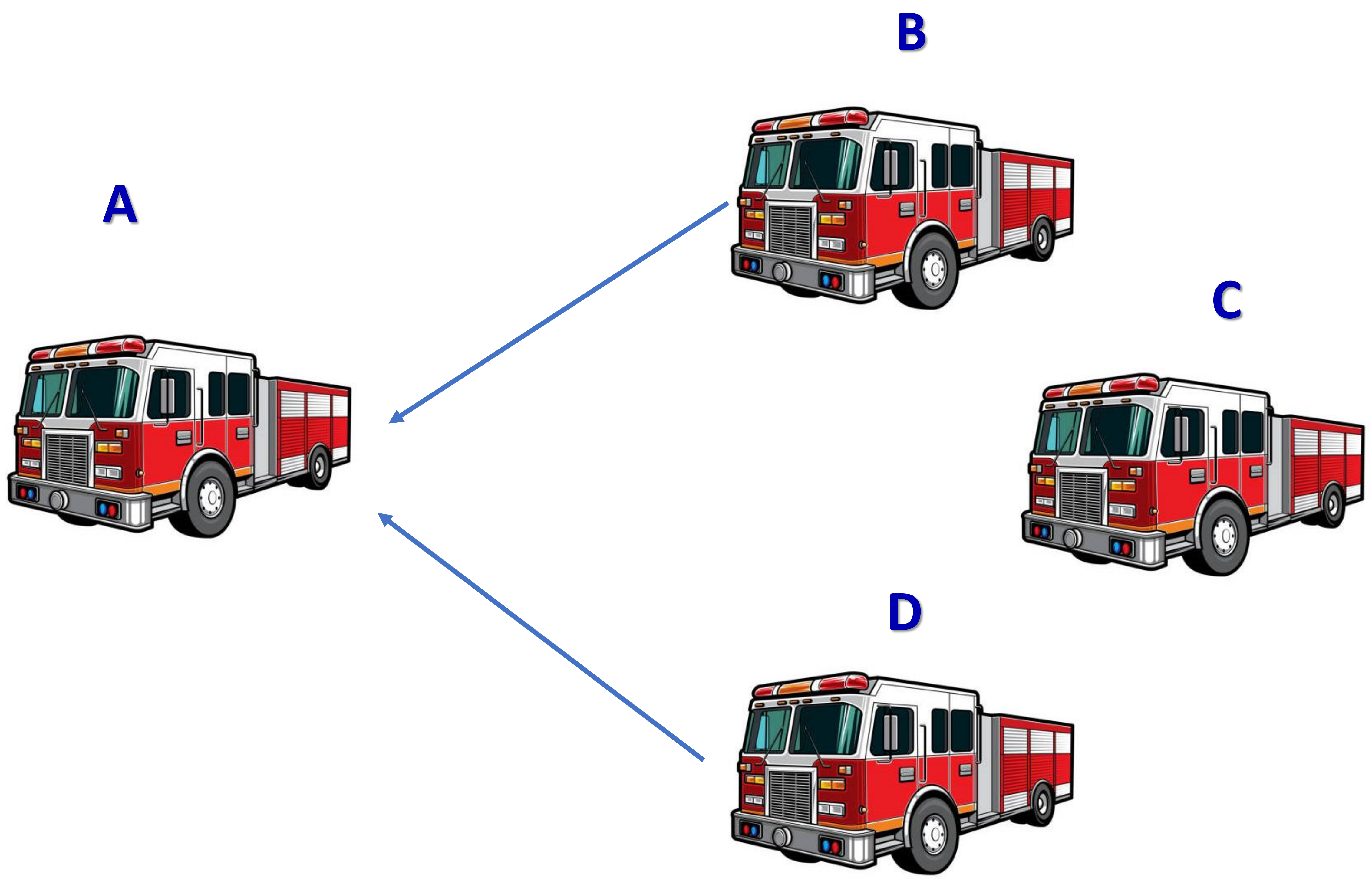
Task Decomposition and Assignment

Contract Nets

Fire Brigade Example

Agent B and D submit their bits

The bit contains estimated costs
for traveling to the location
and for refilling the tank



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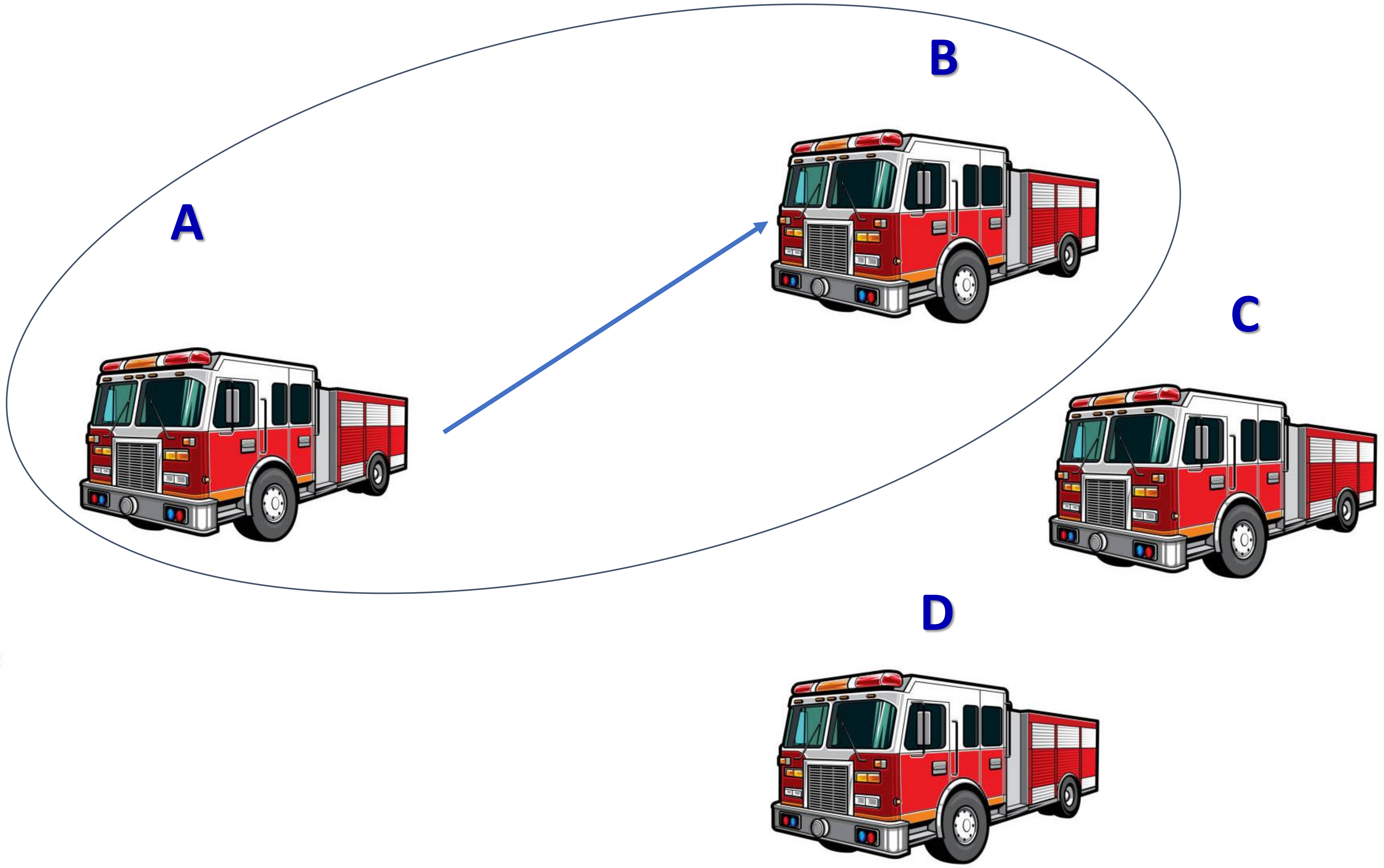
Contract Nets

Fire Brigade Example

The manager awards a contract

to the most appropriate agent

- For example, agent B, which is closer to the fire



The contractor sends back a report after finishing the task or further subdivides the task …

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Contract Nets

Limitations:

- Task allocation and problem detection and resolution can be non-trivial
- Communication overhead
- The selected contractor may not be the best choice, but a better candidate may be temporarily employed in the task allocation process

- Efficiency modifications
  - Focused addressing / direct contracts (e.g. team structure)
  - Agent send status message
    - ✓ eligible but busy
    - ✓ ineligible
    - ✓ uninterested
    - ✓ …

Blackboard Systems

- Data-driven approach to task assignment
  - ➢ A number of “experts” are sitting next to a blackboard
  - ➢ When one of the experts sees that she can contribute something, she writes this on the blackboard
  - ➢ This continues until the “solution” comes up on the blackboard
- Mainly used for distributed problem solving, e.g. speech recognition
- Requires a common interaction language
- Event-based activation
- Can have different levels of abstraction

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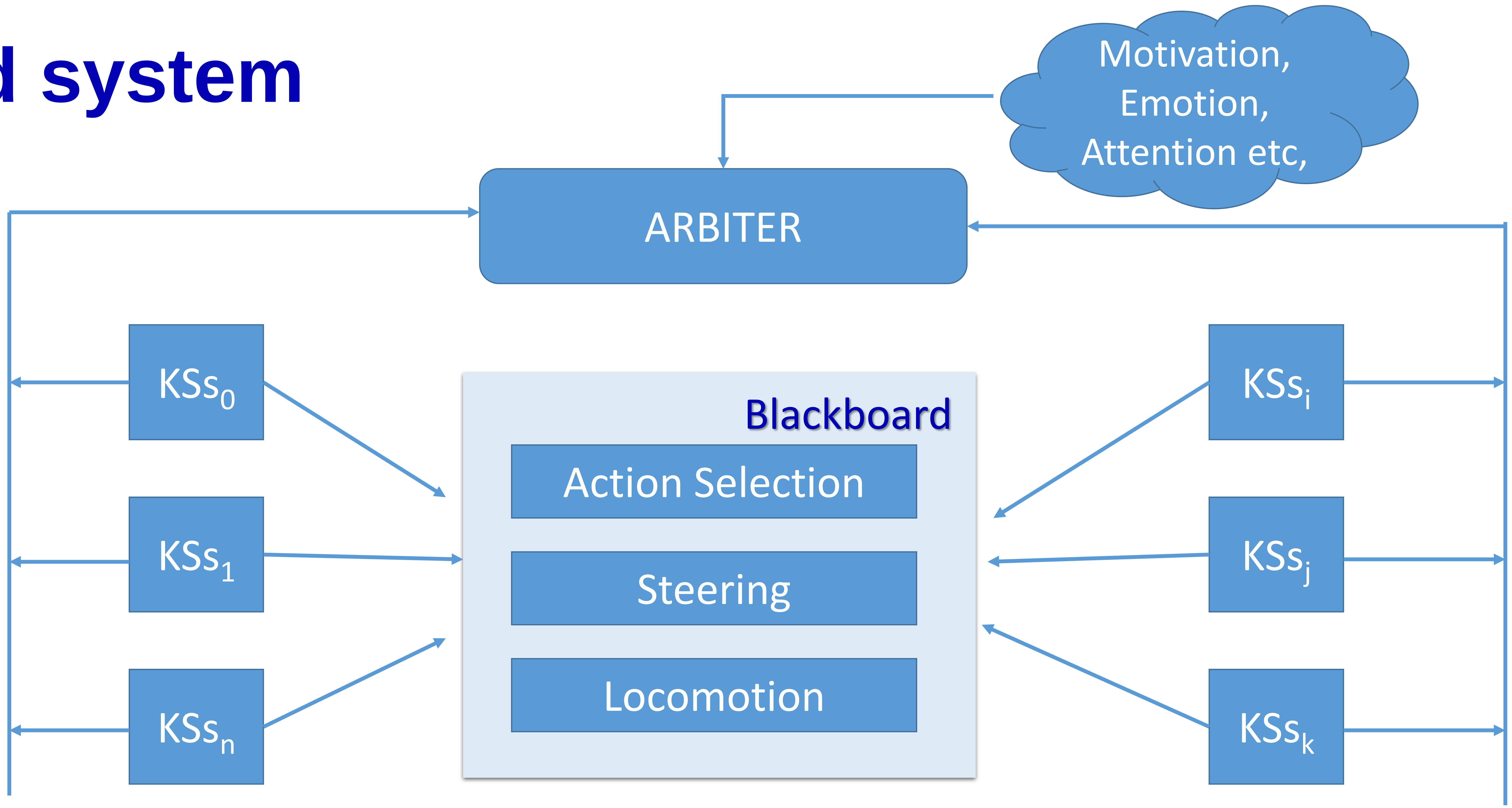
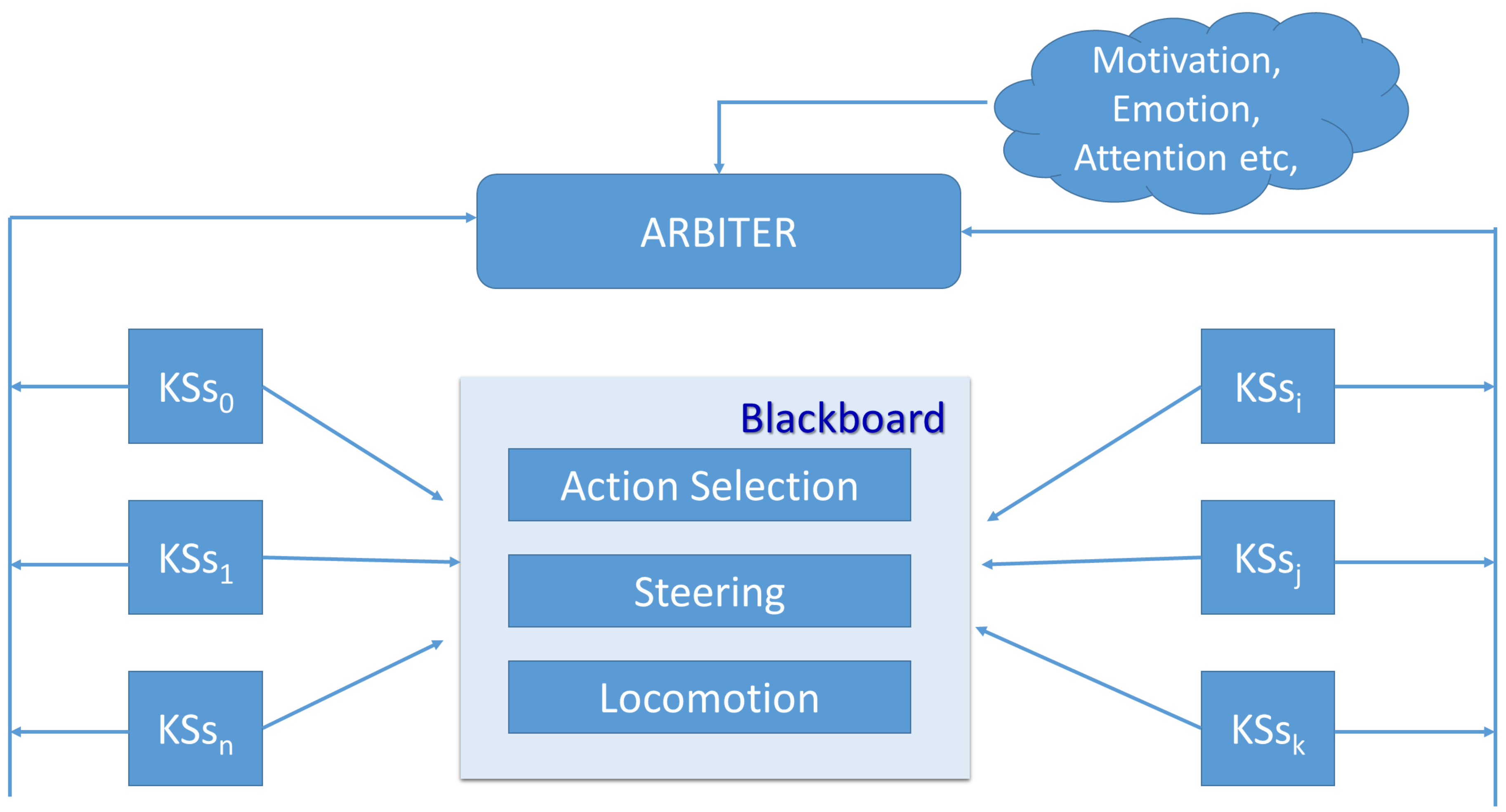
Task Decomposition and Assignment

Blackboard system



“Blackboard Architectures,” Steve Rabin, AI Game Programming Wisdom, pp. 333 - 344

Blackboard system



Arbiter
Selects "winning" KS for accessing blackboard. Mechanism can be reactive (data-driven) but also goal-driven, e.g. select KS with highest expected future outcome

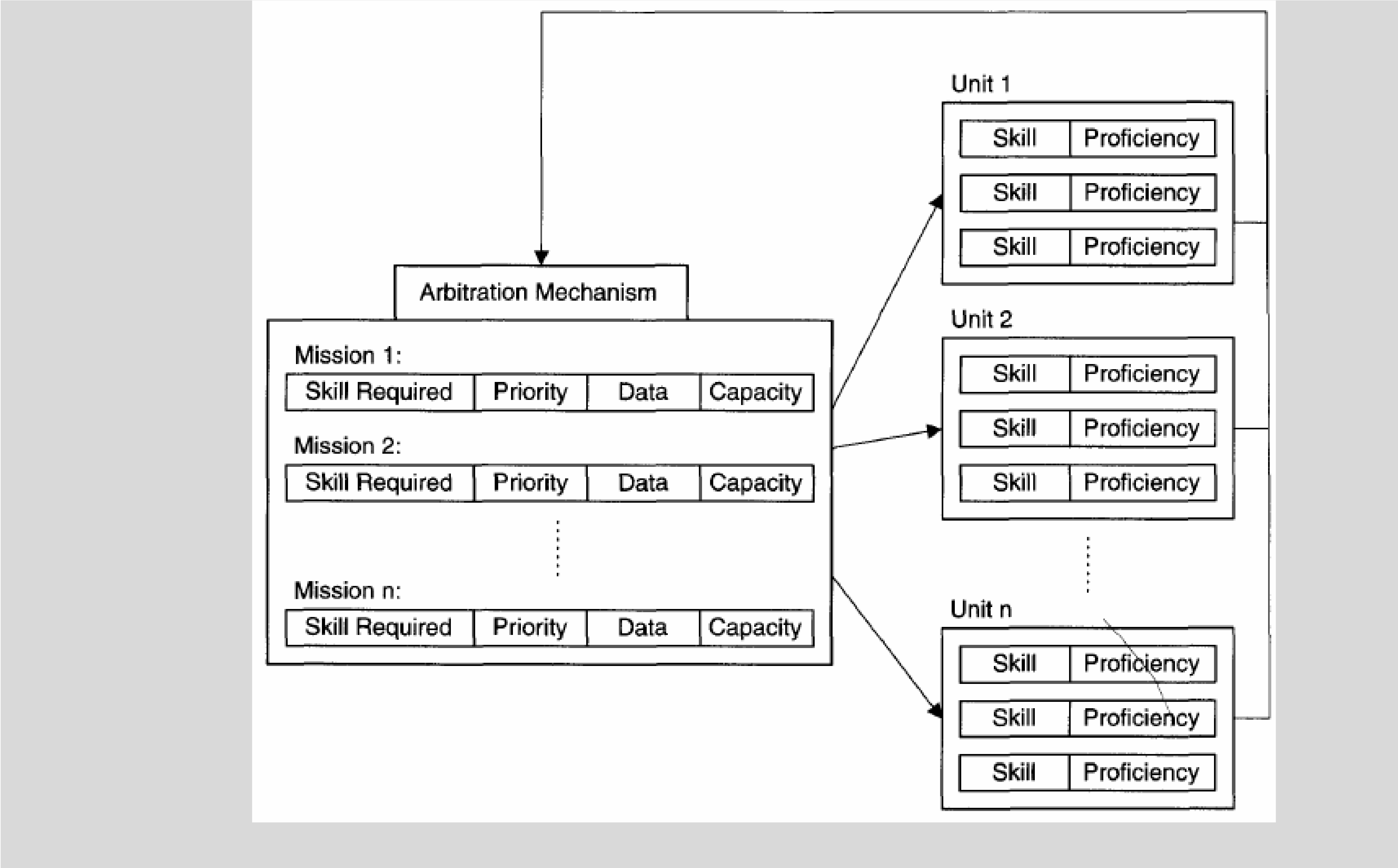
Knowledge sources (KSs)
A series of components that are able to operate on the blackboard

Blackboard
publicly read / writeable data structure (e.g. shared memory)

Blackboard System

Example: RTS game BBWar using the C4 blackboard architecture (MIT 2001)

- The KSs are individual units that have special skills that can be executed on demand
- The blackboard contents take the form of open missions
- Units from different levels of the hierarchy pay attention to different types of postings
  - ➢ Commanders look for ATTACK-CITY missions and create ATTACK- LOCATION missions
  - ➢ Soldiers look for ATTACK-LOCATION missions
  - ➢ …
- Implemented as a hash table mapping skill names to open missions



"Blackboard Architectures," Steve Rabin, AI Game Programming Wisdom, pp. 333 - 344

Blackboard System

Advantages:

- Simple mechanism for cooperation and coordination
- KSs do not need to know about other KSs they are cooperating with
- Postings can be overwritten by different systems, e.g. units can be replaced
- Can also be used for inter-agent communication

Disadvantages:

- Mainly suitable for agents executed on the same architecture

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Self-interested Agents

- What happens when agents are not benevolent?
  - Why should they report their capabilities truthfully?
  - Why should they actually complete contracted tasks?
- Cooperation works fine if we can design the entire system by ourselves
  - We can then try to maximize some performance measure and guarantee that all member of a team of agents work towards the common goal

- If agents work for different parties the common goal might not be the goal of the single agents
  - e.g., assume an arrival management system for airports with a number of different airlines or the Internet
- If an MAS becomes large and complex the overall goal is not evident (e.g. in an intelligent house)
  - It might be more robust to design agents as self-interested agents

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Self-interested Agents

- What is the self-interest of a competitive agent?
- She tries to maximize her expected utility!
- AI techniques are good for that, but …
- …here we have other agents that also act
- All agents know (to a certain extend) what their options are and what the payoff will be

➢ Strategic deliberation and decision making

   ➢ Choose the option that maximizes own payoff under the assumption that everybody also acts rationally

   ➢ Does not maximize social welfare but is robust

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Game Theory

- Game Theory is the field that analyzes strategic decision situations
  - economic settings
  - military contexts
  - social choices

- Usual assumption: All agents act rationally
  - Unfortunately, humans do not follow this pattern all the time
  - Often change their utility function on the way or simply do not maximize or do not assume that all others act rationally

- Nevertheless: For designing MAS it might just be the right theoretical framework because we can designour agents to act rationally.

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MULTIAGENT SYSTEM WITH ARTIFICIAL INTELLIGENCE

assoc. prof. Desislava Atanasova

08,2022

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LECTURE 3

Multiagent Systems Interactions

1. Agent Communication
2. Speech Acts
3. KQML and KIF
4. Ontologies

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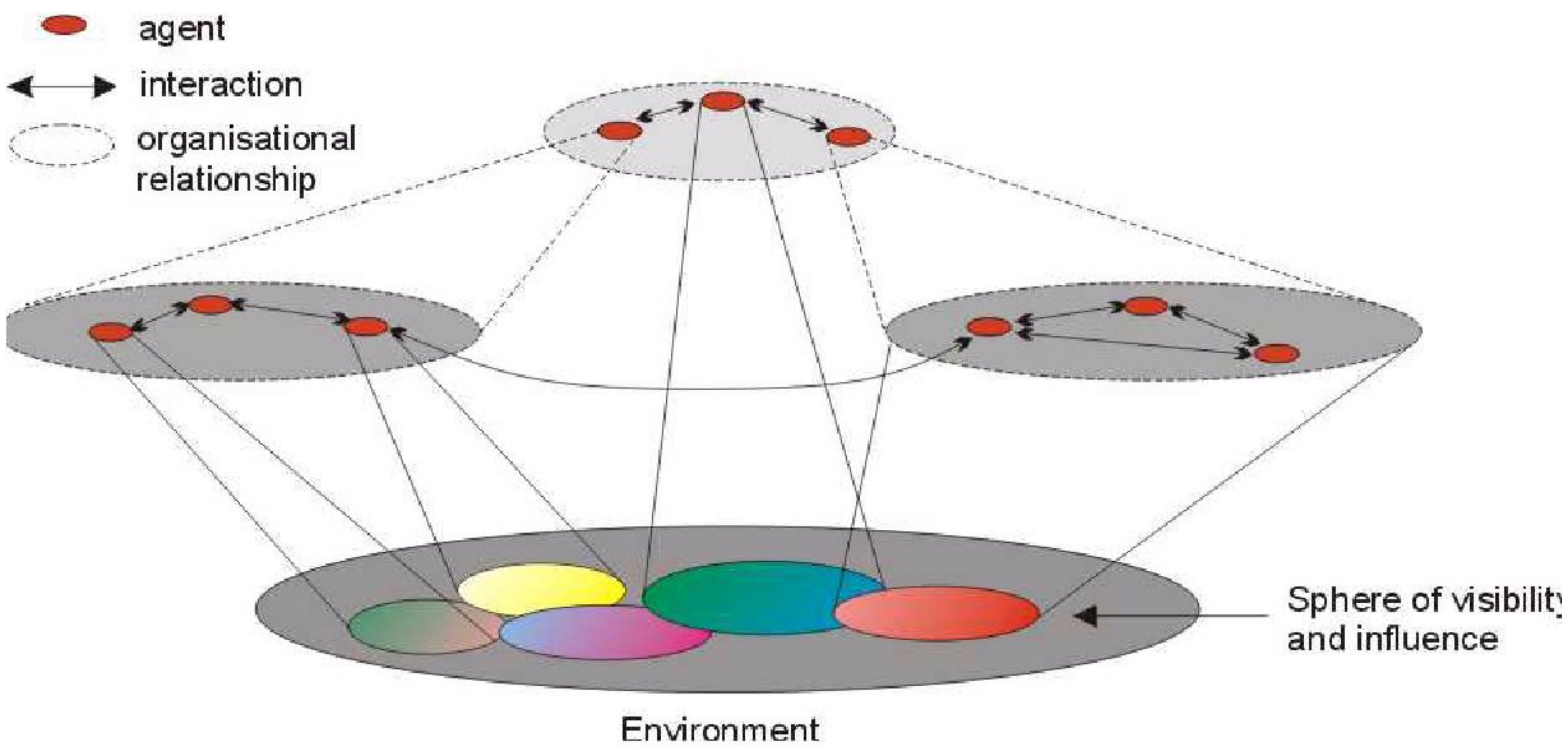
There's no such thing as a single agent system



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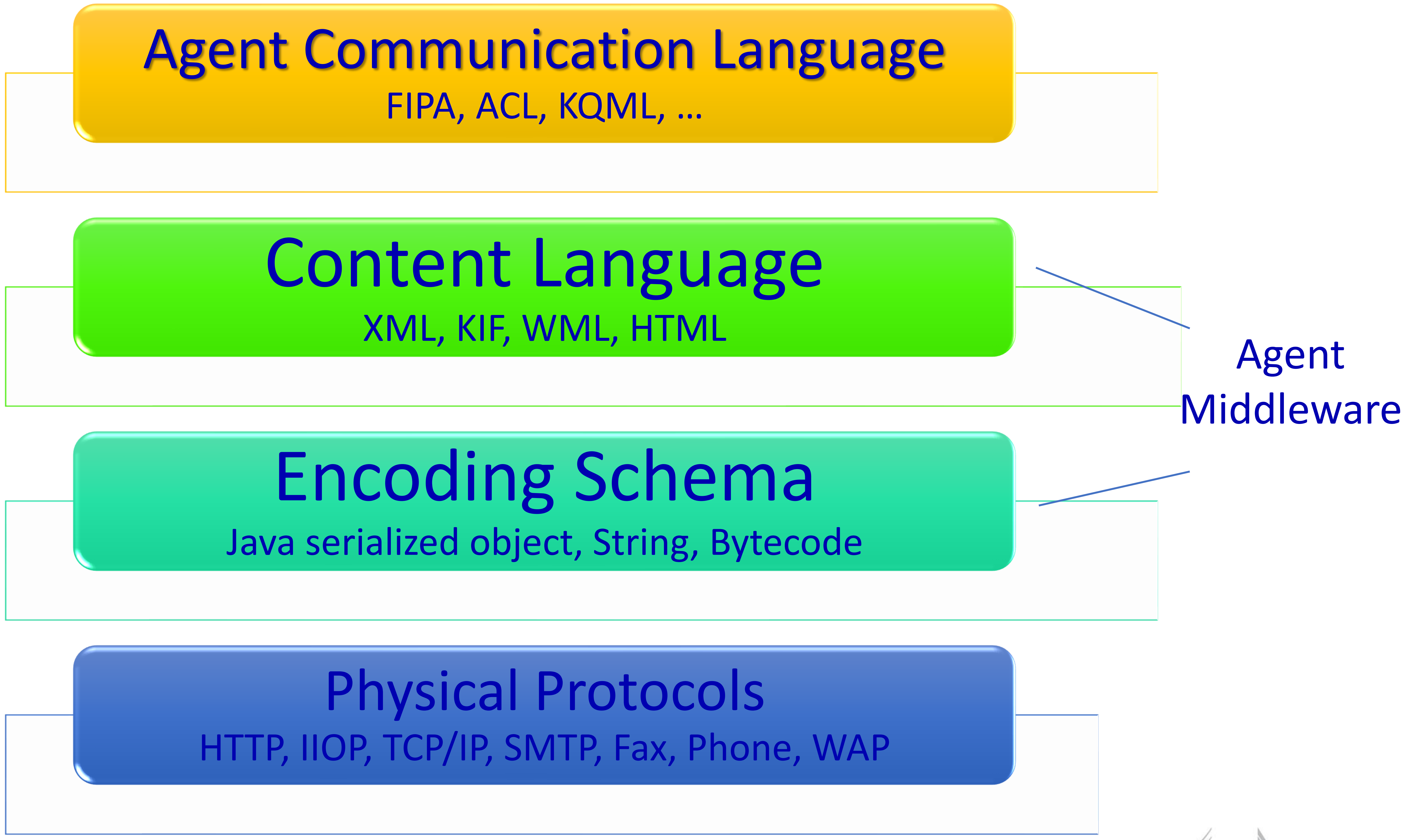
Agent Communication



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Agent Communication

In order to work together, agents need a means of communication with each other. They could be:

- communication:
  - speech acts; KQML & KIF; FIPA ACL
- ontologies:
  - the role of ontologies in communication
  - aligning ontologies
  - OWL

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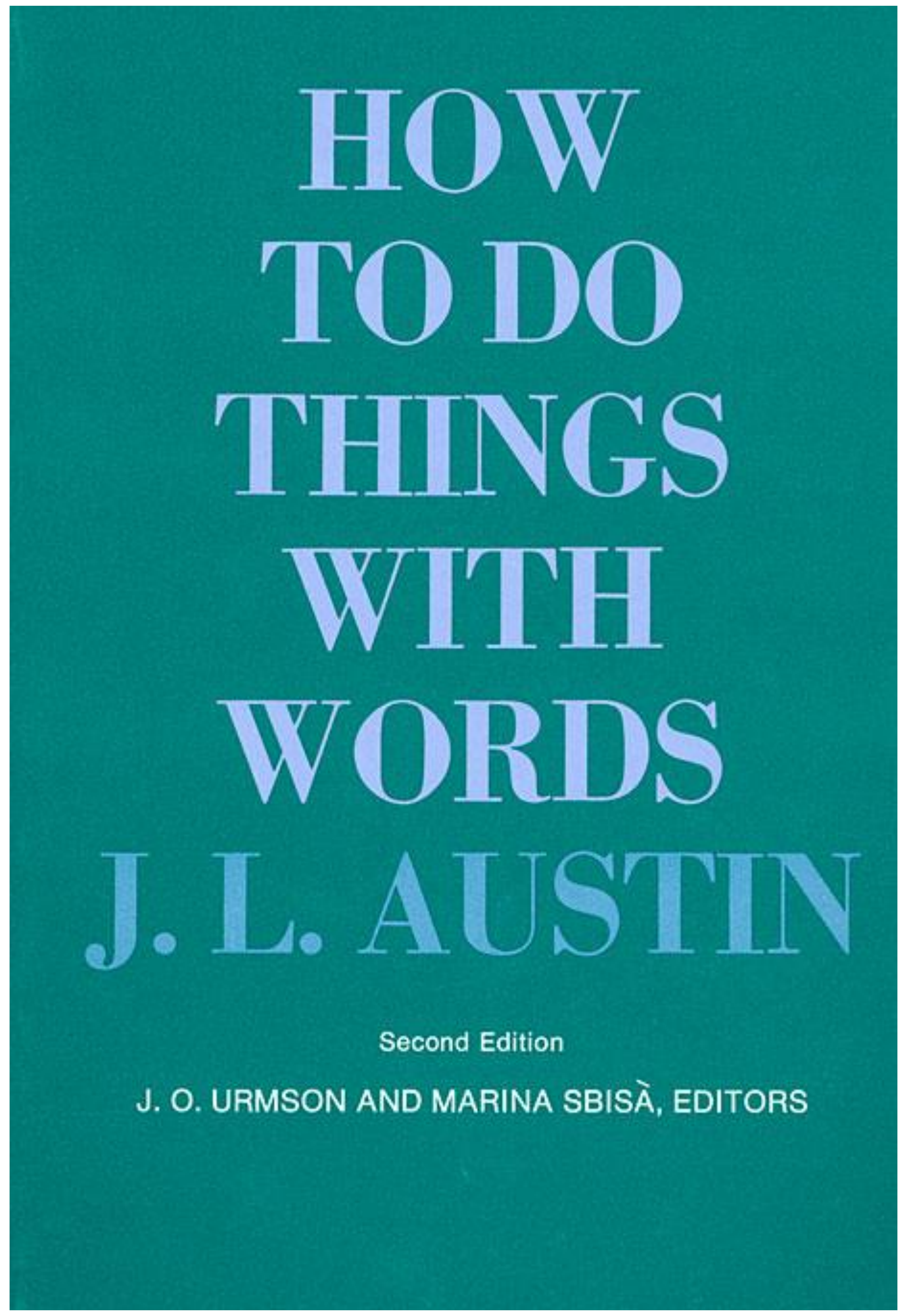
Agent Communication

- Austin's 1962 book "How to Do Things with Words" is where speech acts first appeared.
- Speech act theories, or theories of how language is used, are pragmatic theories of language - they make an effort to take into account how language is utilized by individuals on a daily basis to further their objectives and aims
- Speech act theory serves as the foundation for the majority of analyses of communication in (multi-)agent systems...undoubtedly because existing theories on how to model action can be directly related to the "activity" element.
- Austin observed that some statements resemble "physical" gestures.



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Speech Acts

- John R. Searle noted the following in his first published in 1969 book Speech Acts: An Essay in the Philosophy of Language:

➢ *representatives*:

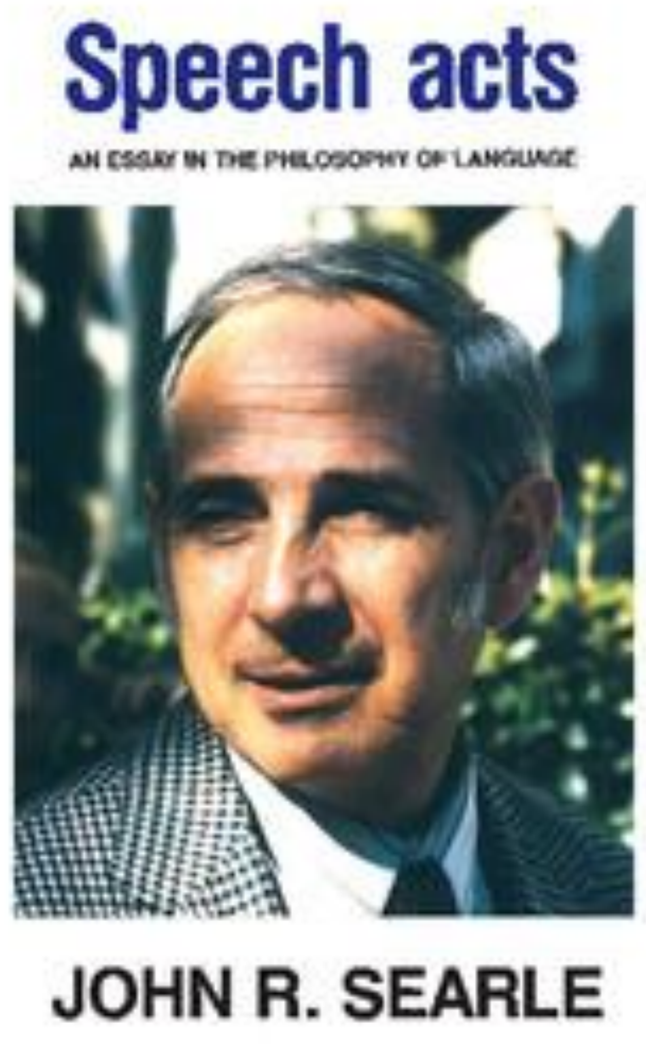
  ➢ such as informing, e.g., 'It is raining'

➢ *directives*:

  ➢ attempts to get the hearer to do something e.g., 'please make the tea'

➢ *commissives*:

  ➢ which commit the speaker to doing something, e.g., 'I promise to...'



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Speech Acts

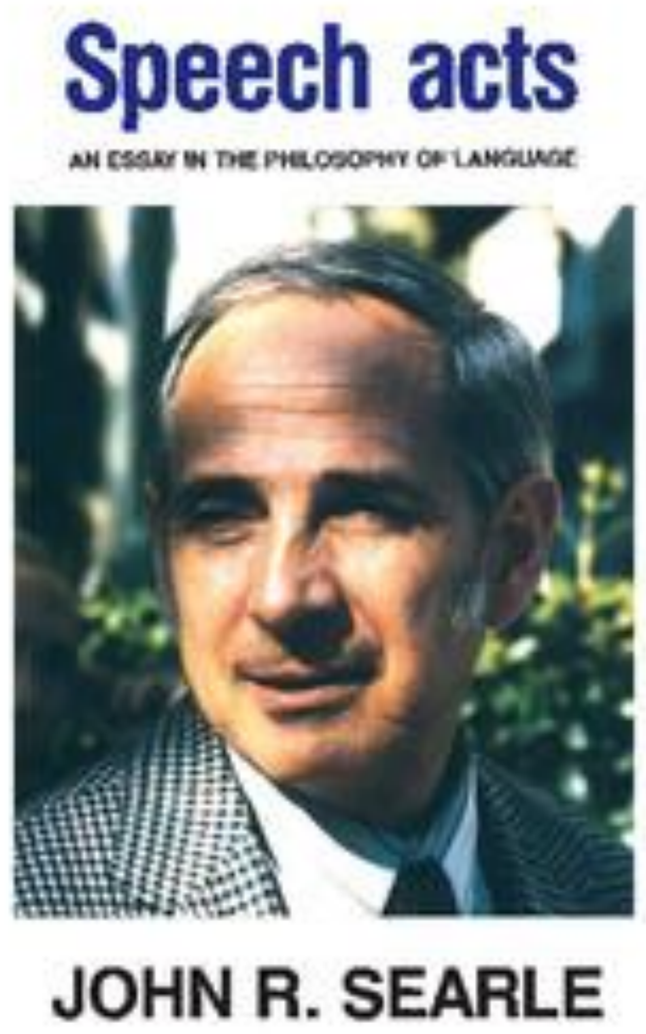
- John R. Searle noted the following in his first published in 1969 book Speech Acts: An Essay in the Philosophy of Language:

➢ *expressives*:

   ➢ whereby a speaker expresses a mental state, e.g., ‘thank you!’

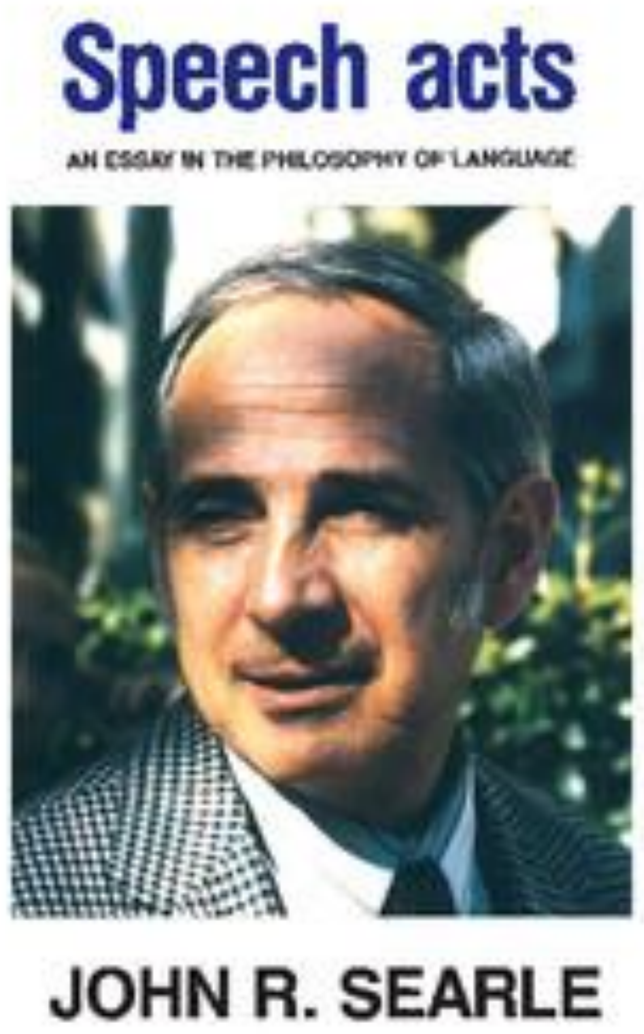
➢ *declarations*:

   ➢ such as declaring war or naming.



Speech Acts

- There is some disagreement over the appropriateness of this (or any!) categorization of speech activities.
- Generally speaking, a speech act can be divided into two parts:
- *a performative verb*:
    - e.g., request, inform, ask, …
- *propositional content*:
    - e.g. “the door is closed”, “the box is delivered”…



Speech Acts

- How is the semantics of speech acts defined?

- When is it appropriate to indicate that someone has made a request or informed you?

- Similar to STRIPS planner, Cohen and Perrault (1979) developed the semantics of speech acts using the precondition-delete-add list formalism of planning research.

- Remember that a speaker cannot, in most cases, compel a listener to adopt a particular mental state.

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KQML and KIF

- Agent communication languages (ACLs) - standard message exchange format

- Knowledge Query and Manipulation Language (KQML), well known ACL, developed by the DARPA-funded Knowledge Sharing Effort (KSE).
- It consists of two parts:
    - ➢ the message itself: the Knowledge Query and Manipulation Language (KQML);
    - ➢ the body of the message: the Knowledge interchange format (KIF)

KQML and KIF

- KQML is an ‘outer’ language, that defines various acceptable ‘communicative verbs’, or performatives.
- Example performatives:
  - ask-if (‘is it true that. . . ’)
  - perform (‘please perform the following action. . . ’)
  - tell (‘it is true that. . . ’)
  - reply (‘the answer is . . . ’)
- KIF is a language for expressing message content, or domain knowledge.
  - It can be used to writing down ontologies.
  - KIF is based on first-order logic.

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Ontologies

- Ontologies are designed for a variety of purposes, including knowledge representation, exchange, management, modeling, engineering, and education.

- The Air Force Institute of Technology has been studying the Multiagent Systems Engineering (MaSE) methodology recently. The goal of research is to create a reliable approach for creating multiagent systems. Multiagent system development is broken down into three steps by MaSE: analysis, design, and implementation. As seen in the graphic, MaSE originally had four steps in the design phase and three steps in the analysis phase.

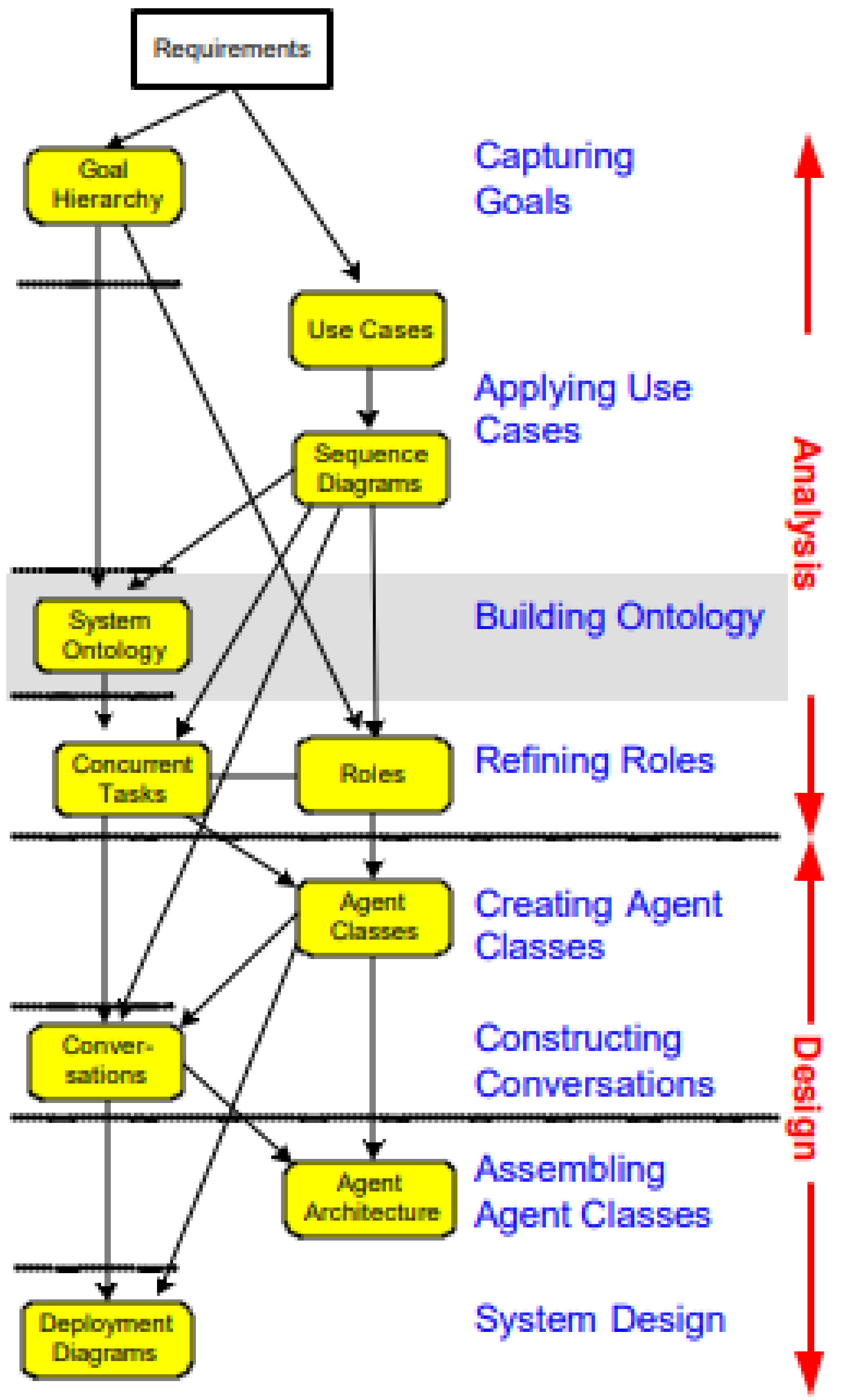


Fig. 1. Extended MaSE Phases, Steps and Models

Ontologies

- Ontologies generally come in varying levels of granularity.
  - Application ontology
  - Domain ontology
  - Upper ontology
- An ontology is less reusable the more specialized it is.

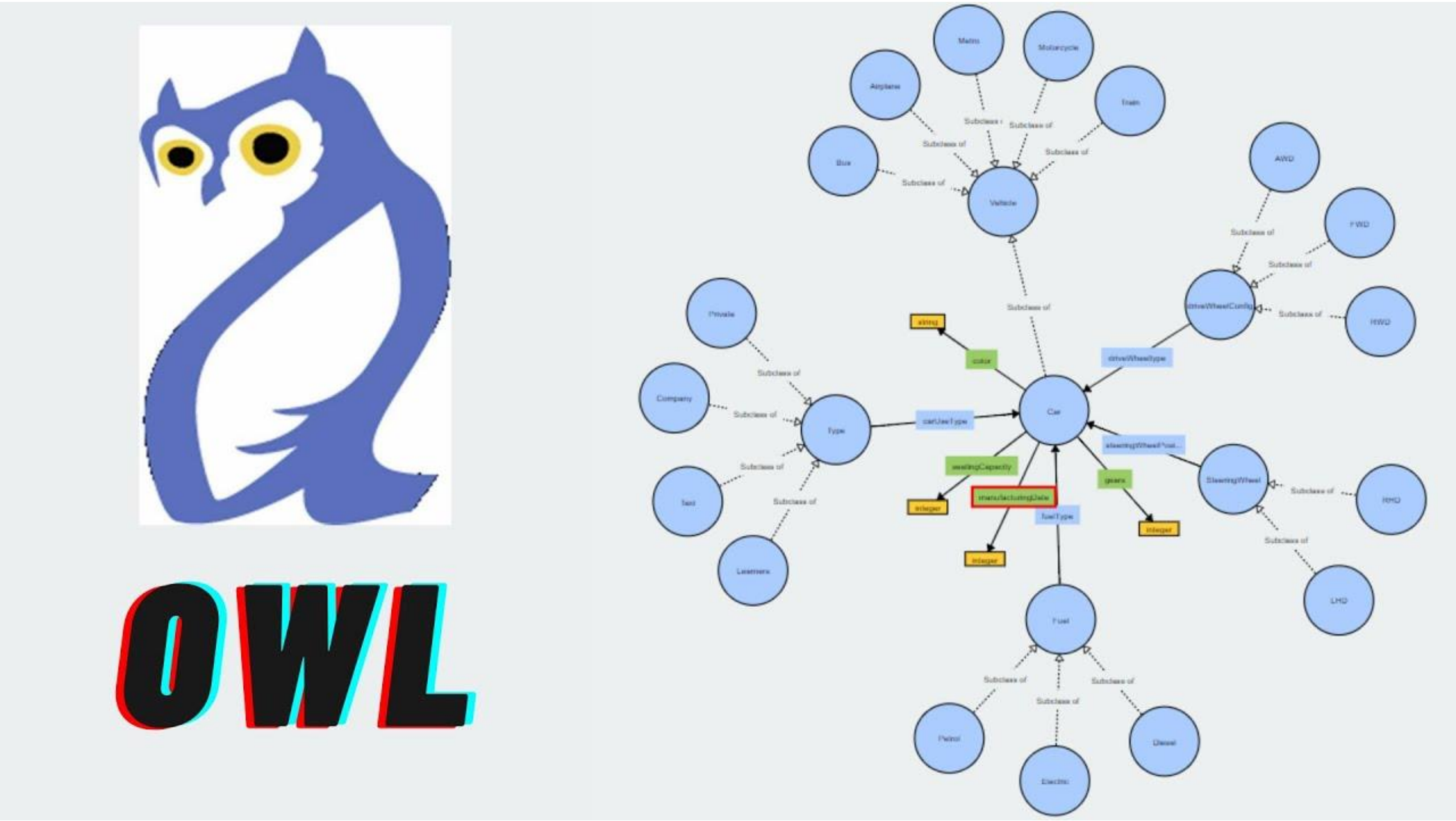
- Application and domain ontologies will typically overlap
  - Illustrated by the challenges of facilitating interoperability between similar ontologies.
  - Different knowledge systems can be integrated to form merged knowledge bases
- But in many instances, understanding is all that is required.!

Ontologies

- Given that various designers have varied contexts and requirements, modeling ontologies is a challenge.

- OWL - Web Ontology Language

➢ OWL is a language built on the semantic web and computational logic that is intended to represent complicated knowledge about objects and their relationships. Additionally, it offers thorough, reliable, and significant differences between classes, properties, and connections.



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LECTURE 4

Decisions and planning in solving distributed tasks

1. Negotiation
2. Negotiation Strategy
3. Multi-Agent Negotiations
4. Game theory in negotiation

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Negotiation

Negotiation - a dialogue between two or more people or parties to reach a desired outcome regarding one or more issues of conflict. It is an interaction between entities who aspire to agree on matters of mutual interest.

Distributed conflict resolution

Decision making

Proposal → accepted, refined, criticized, or refuted

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Negotiation

Negotiate – YES or NO?

- Professor George-J.-Siedel from the university of Michigan, conducted the following experiments:
- Ask the students to go the city, walk into retail stores, fast food restaurants, and try to negotiate a lower price despite a fixed price (not into a market)
- Results: 69% Successful in getting lower prices; 6% to 100% discount, with average 40%
- Total savings: 1580$

Negotiation

Types of negotiation:

- Distributive (also called Position-based)
- Integrative (also called interest-based)
- Mixed-motive negotiation

Distributive (also called Position-based)

- with them, only one side wins - the other loses
- also called competitive negotiations
- It is used to allocate limited resources
- Each side seeks to improve its position by maximizing its gain at the expense of the opponent's loss
- There is no possibility of winning agreements

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Negotiation

Integrative (also called interest-based)

- The parties are interacting.
- Negotiations in the non-zero sum case can focus on common interests without seeking profit, but on negotiating settlements
- the goal is to exchange relevant information that allows them to integrate their interests and find new ones
- opportunities for cooperation
- in this type, negotiators tend to choose compromises

Mixed-motive negotiation

- According to some authors, it does not exist - the negotiations are purely theoretical in one of the two extremes
- Any other type of negotiation can be located between these two extremes and can be described as mixed motive negotiation
- This type of negotiation occurs when: some negotiation points are better for both parties than others... and the potential for negotiation is to increase the total gain available to both parties
- Negotiators usually combine various compromises and concessions in order to reach an agreement

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Negotiation Strategy

- Negotiation tactic
- The parties must make offers that are consistent with their preferences.
- If they reject the other party's offer, they must make a counteroffer
- A negotiation strategy is an opportunity to generate subsequent offers
- The idea is for the negotiator to decide whether to accept and give in or offer a "counter-offer"

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Negotiation Strategy

Tradeoffs

- Many issues are being negotiated
- Each negotiator attempts to shift an issue in the opponent's perceived direction while at the same time shifting the other in their favor
- Each tries to find a joint, win-win solution

Concessions

- It is often the case that both parties or one of them agree to enter into such an agreement
- Pruitt defines the concession as:

«A change in the offer in the assumed direction of that of the other party's interests, which reduces the level of the sought-after benefit»

- Benefits of the concession:
  - Possibility to accelerate the agreement
  - Not allowing one negotiator to leave the negotiations
  - Encouraging the other negotiator to repeat the concession

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Negotiation Strategy

Limit

- A negotiator's ultimate position, the level of utility (or benefits) beyond which he or she is unwilling to concede
- Also called a stored value
- Any agreement lower than this value is considered worse than no agreement

Goal

- the value the negotiator is aiming for because it considered realistically achievable
- It can be taken as a preferred value

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Negotiation Strategy

Influence factor

- In practice, negotiation strategy is influenced by many various and complex factors, including:
    - previous experience of similar negotiations, gender, culture,
    - availability of alternatives, intermediaries, time pressure and reactions to the behavior of the adversary
- However, when it comes to negotiations between autonomous agents, only some of these factors are essential

Time pressure

- The desire of the parties is always to conclude the negotiations as quickly as possible
- The main reason is the costs that may result from ongoing negotiations, the need to obtain end result quickly, pressure from an impending deadline or fear of the opponent leaving the negotiations
- It usually incentivizes negotiators to make concessions more quickly
- Modeled well in MAS

Negotiation Strategy

Reactions to Opponent Behavior

- Basing one's negotiation behavior on that of one's opponent is a common strategy among both humans and autonomous agents
- We distinguish two main types of reactions:
  - Matching : or imitation, where if one party demands more, the other demands become bigger and vice versa. If one side makes important concessions, the other reacts with similar concessions (as in integrative negotiations)
  - Mismatching: concessions made by one side lead the opposing side to believe that the first negotiator is desperate to reach an agreement. This is also called tracking (used in distributive negotiations)

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Multi-Agent Negotiations

- It appeared more than three decades ago.
- Options are:
    - Agent-to-agent
    - Person-to-agent negotiations
- It develops based on the behavior of the person in negotiations
- Agents can outperform humans in the process of search for optimal solutions in negotiations with many issues

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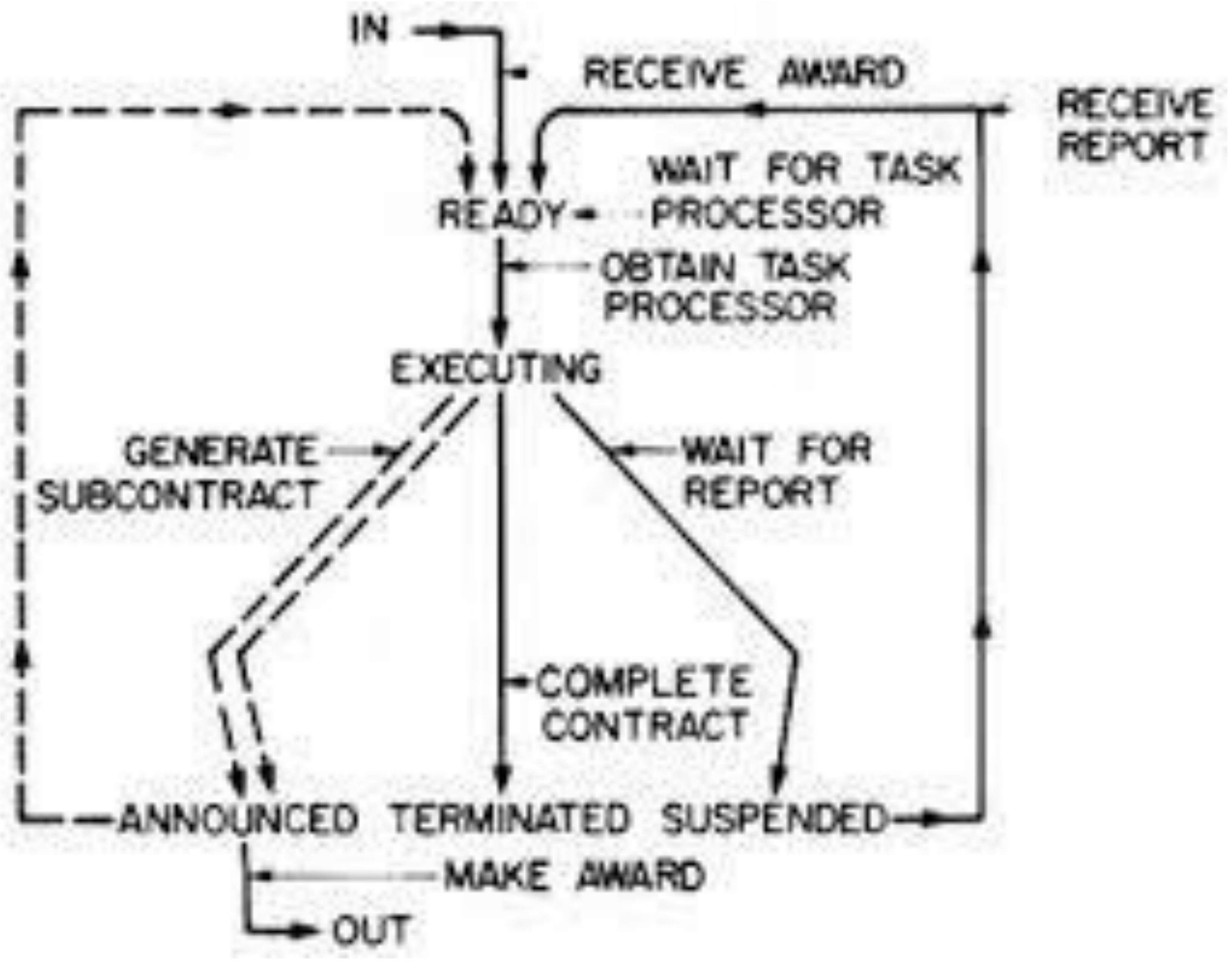
Negotiation Protocol

- A negotiation protocol is a set of rules that define the management of interactions between partners during a negotiation session (also called a thread)
- Covers:
  - Types of participants, including third parties (such as brokers)
  - Possible negotiation states: When the negotiation is suspended, ongoing, still open, etc
  - Events that can change negotiation states (e.g. offer accepted)
  - Valid actions by negotiators (eg offering a counter-offer, leaving the negotiation process, etc.)



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Negotiation Protocol

Alternate Offer Protocol

- Many different versions
- Complete and incomplete information
- Upon receiving an offer from the other party, the negotiator may:
    - To exit the negotiation session
    - To accept the offer
    - To offer a counter offer with or without a discount
- Can use deadline, limited time for offer, etc.
- The standard form of the Alternate Offer protocol can be enhanced to support specific application needs. For example, to support one-to-many negotiations

Monotonic Concession Protocol

- At the beginning of the negotiation session, negotiators are required to disclose information about their preferences on the main points of the negotiations:
    - E.g. I'm more interested in delivery time than price
- The offers proposed by each contractor must contain a sequence of discounts, i.e. each subsequent offer having less utility to the negotiator offering it than the previous one
- There is no option to hold a position

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Negotiation Protocol

One Step Negotiation Protocols

- It has only one round, where the two agents propose their variants of a deal, and they must accept it

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Negotiation Object

- The topic under discussion in the negotiation process or a set of issues on which agreement must be reached
- An object can be composed of a single issue or attribute (e.g. delivery time) or it can cover multiple issues (price, quality, delivery time, etc.)
- The agent makes an offer to the other negotiator when it assigns a value to each of the attributes describing the agreed characteristics of the object
- Whenever the negotiation process is about multiple issues, the negotiators have opportunities to make compromises, and then the importance of an issue can differ from the perspective of one side and the other.
- In some negotiation options, the parties may offer a complete package containing several offers.

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Agent Decision Model

- The negotiation protocol defines what is the set of possible actions that can be taken during a negotiation session.
- The agent's decision model allows him/her to:
    - To assess the value of the offer received by the opponent
    - To decide whether the tender submitted is acceptable
    - To determine what to do as the next step
- Using respectively
    - Utility function/preference relations
    - Condition of acceptance
    - Negotiation strategy

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Agent Decision Model

Utility Function

- A utility function is an idea borrowed from microeconomics that encodes an agent's preferences and quantifies his satisfaction
- It determines the utility that the given agent would have from receiving (or being offered) an offer
- If an agent is interested in several offers, his utility would probably be a weighted sum of the utility functions of all offers.

Preference relationships

- A logic that describes the possible alternatives
  - A+B: A and B are equally preferred by the agent
  - A>B: A is strictly preferred than B by the agent
  - A>=B: A is preferred than B by the agent
  - e.g. I prefer a blue car to a black car, blue and red are equally preferred
- Challenges:
  - These preferences should be complete, they should cover all the possible alternatives
  - Typically it is assumed that these preferences are transitive

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Agent Decision Model

Condition of acceptance

- In order to accept or reject an offer, an agent relies on its Aspiration Rate AR
- It reflects how much utility an agent expects to obtain at the negotiation cycle

Negotiation strategy

- Concession
  - The agent accepts to reduce its Aspiration Rate
  - Thus, it accepts offers with lower utility
- Several types
  - Time-based Concessions (TBC)
  - Behavior-based Concessions (BBC)
  - Resource-Based concession (RBC)

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LECTURE 5

Decisions in solving distributed tasks

1. Game theory in negotiation
2. Nash equilibrium
3. Prisoners' dilemma
4. Bargain
5. Voting
6. Auctions
7. Heuristic-based negotiation

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Negotiation

Part of negotiations are:

- language for communication
- negotiation protocol
- decision process by which an agent decides upon its position, concessions, criteria for agreement, etc.

Single party **or** multi-party negotiation: one to many or many to many

May incorporate a single shot message by each party or discussion with a few messages going back and forth

Negotiation techniques are:

- Game theoretic negotiation
- Heuristic-based negotiation
- Argument-based negotiation

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Evaluation

Criteria to evaluate negotiation protocols among self-interested agents

Agents are supposed to behave rationally

Rational behavior = an agent prefers a greater utility (payoff) over a smaller one

Payoff maximization: individual payoffs, group payoffs, or social welfare

Social welfare

- The sum of agents' utilities (payoffs) in a given solution.
- Measures the global good of the agents
- Problem: how to compare utilities

Pareto efficiency

- Measures global good, does not require utility comparison

Individual rationality (IR)

Stability

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Nash equilibrium

It is a game theory concept

- determines the optimal solution in a non-cooperative game in which each player lacks any incentive to change his/her initial strategy;
- a player does not gain anything from deviating from their initially chosen strategy, assuming the other players also keep their strategies unchanged.

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The Prisoner's Dilemma

- The title comes from Albert Tucker who, whereas instructing at Stanford College, brought the diversion to life. He told of two burglars captured by police close the scene of a burglary. The two were taken absent and set in several meet rooms. Each suspect was examined and told they must carefully select whether to confess and involve the other.
- Without confessions, the police seem as it were charge them with minor guns charges coming about in a one-year jail sentence. Ought to both burglars confess and involve the other, they would each serve 10 a long time behind bars. Be that as it may, in case one burglar confesses and ensnares the other, whereas the other doesn't, at that point the one who collaborated with police would go free whereas the assistant would serve 20 a long time in jail.

The Prisoner's Dilemma

- Two men are collectively charged with a crime and held in separate cells. They have no way of communicating with each other or making any kind of agreement. The two men are told that:
    - if one of them confesses to the crime and the other does not, the confessor will be freed, and the other will be jailed for three years;

  and

    - if both confess to the crime, then each will be jailed for two years.

Both prisoners know that if neither confesses, then they will each be jailed for one year.

Prisoner 1 (columns) / *Prisoner 2* (rows)

Prisoners	Don't confess	Confess
Don't confess	Win/Win	Lose Much / Win much
Confess	Win Much / Lose much	Lose/Lose

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The Prisoner's Dilemma

The 'standard' approach to this problem could be to put yourself in the place of a prisoner, and reason as follows.

- Suppose I cooperate. Then if **j** cooperates, we will both get a payoff of 3. But if **j** defects, then I will get a payoff of 0. So the best payoff I can be guaranteed to get if I cooperate is 0.
- Suppose I defect. Then if j cooperates, then I get a payoff of 5, whereas if j defects, then I will get a payoff of 2. So the best payoff I can be guaranteed to get if I defect is 2.

So, if I cooperate, the worst case is I will get a payoff of 0, whereas if I defect, the worst case is that I will get 2.

I would prefer a guaranteed payoff of 2 to a guaranteed payoff of 0, so I should defect.

Since the scenario is symmetric (i.e. both reason the same way), then the outcome that will emerge - if both agents reason 'rationally' - is that both agents will defect, giving them each a payoff off 2.

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Bargain

- In a transaction when the seller and the buyer value a product differently, a surplus is created. A bargaining solution is then a way in which buyers and sellers agree to divide the surplus.
- For Example: A – car 15000, B – car 25000
- Trade leads to the generation of a surplus that should not occur
- A negotiated settlement provides an acceptable way to divide the surplus between the two parties.

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Voting

- Truthful voters - Rank feasible social outcomes based on agents' individual ranking of those outcomes

- Social choice rule

- Binary protocols

- Pluralist protocols

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Auctions

- The auctioneer wants to sell an item at the highest possible payment and the bidders want to acquire the item at the lowest possible price
- A centralized protocol, includes one auctioneer and multiple bidders
- The auctioneer announces a good for sale. In some cases, the good may be a combination of other goods, or a good with multiple attributes
- The bidders make offers. This may be repeated for several times, depending on the auction type
- The auctioneer determines the winner

Auction characteristics:

- Simple protocols
- Centralized
- Allows collusion “behind the scenes”
- May favor the auctioneer

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Auctions

- Auction settings
  - Private value auctions: the value of a good to a bidder agent depends only on its private preferences. Assumed to be known exactly
  - Common value auctions: the good's value depends entirely on other agents' valuation
  - Correlated value auctions: the good's value depends on internal and external valuations

- Auction protocols

English (first-price open cry) auction - each bidder announces openly its bid; when no bidder is willing to raise anymore, the auction ends. The highest bidder wins the item at the price of its bid.

Strategy:

In private value auctions the dominant strategy is to always bid a small amount more than the current highest bid and stop when the private value is reached.

In correlated value auctions the bidder increases the price at a constant rate or at a rate it thinks appropriate

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Auctions

- Auction protocols

First-price sealed-bid auction - each bidder submits one bid without knowing the other's bids. The highest bidder wins the item and pays the amount of his bid.

Strategy:

No dominant strategy

Bid less than its true valuation but it is dependent on other agents bids which are not known

Dutch (descending) auction - the auctioneer continuously lowers the price until one of the bidders takes the item at the current price.

Strategy:

Strategically equivalent to the first-price sealed-bid auction

Efficient for real time

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Auctions

- Auction protocols

Vickery (second-price sealed-bid) auction - each bidder submits one bid without knowing the other's bids. The highest bid wins but at the price of the second highest bid

Strategy:

The bidder dominant strategy is to bid its true valuation

All-pay auctions - each participating bidder has to pay the amount of his bid (or some other amount) to the auctioneer

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Auctions

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Heuristic-based negotiation

- Creates a good rather than an optimal solution
- Heuristic-based negotiation:
    - Computational approximations of game theory techniques
    - Informal negotiation patterns
- There is no central intermediary
- Speeches are private between negotiating agents
- The protocol does not prescribe an optimal course of action
- A central concern: the agent's heuristic decision-making during negotiation

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Argumentation-based negotiation

- Arguments used to persuade the party to accept a negotiation proposal
- Different types of arguments
- Each argument type defines preconditions for its usage. If the preconditions are met, then the agent may use the argument.
- The agent needs a strategy to decide which argument to use
- Most of the times assumes a BDI model

Appeal to past promise - the negotiator *A* reminds agent *B* of a past promise regarding the NO, i.e., agent *B* has promised to the agent A to perform or offer NO in a previous negotiation.

Preconditions: *A* must check if a promise of NO (future reward) was received in the past in a successfully concluded negotiation.

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Argumentation-based negotiation

Promise of a future reward - the negotiator A promises to do a NO for the other agent A at a future time.

Preconditions: A must find one desire of agent B for a future time interval, if possible a desire which can be satisfied through an action (service) that A can perform while B can not

Appeal to self interest - the agent *A* believes that concluding the contract for NO is in the best interest of *B* and tries to persuade *B* of this fact.

Preconditions: *A* must find (or infer) one of *B* desires which is satisfied if *B* has NO or, alternatively, *A* must find another negotiation object NO' that is previously offered on the market and it believes NO is better than NO'.

Threat - the negotiator makes the threat of refusing doing/offering something to *B* or threatens that it will do something to contradict *B*'s desires.

Preconditions: *A* must find one of *B*'s desires directly fulfilled by a NO that *A* can offer or *A* must find an action that is contradictory to what it believes is one of *B*'s desires.

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University of Ruse “Angel Kanchev”

MULTIAGENT SYSTEM WITH ARTIFICIAL INTELLIGENCE

assoc. prof. Desislava Atanasova

08,2022

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LECTURE 6

Cooperative Agents. Competing agents

1. Cooperative Agents
2. Competitive Agents
3. Major Open Topics
4. Problem Domains and Applications

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Cooperative Agents

There are said to be two main categories of multi-agent cooperative learning approaches.

Team training - applies the search behavior of one learner to the entire team of agents. It is similar to traditional machine learning techniques, but may have scalability issues as team size increases. Team learning techniques can assign identical behavior to multiple team members in order to maintain scalability.

Concurrent Learning - Uses multiple concurrent learning processes. Adopts parallel learning approaches, typically using a learner for each team member, with the hope that this reduces the total space by designing it into N separate spaces.

This makes the environment non-stationary, which violates the premise of most traditional machine learning techniques. For this reason, concurrent learning requires new (or significantly modified versions of) machine learning methods

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Team Learning

- Types
- **Homogeneous**
  - The assumption that all agents have the same behavior drastically reduces the learning search space. Research in this area includes analyses of the performance of the homogeneous team discovered by the learning process, comparisons of different learning paradigms, or the increased power added by indirect and direct communication abilities.
  - Learning rules for cellular automata is an oft-overlooked paradigm for homogeneous team learning

- **Purely-heterogeneous**
  - In heterogeneous team learning, the team is composed of agents with different behaviors, with a single learner trying to improve the team as a whole. This approach allows for more diversity in the team at the cost of increasing the search space. The bulk of research in heterogeneous team learning has concerned itself with the requirement for or the emergence of specialists. The results of Luke and Spector shows that restricted breeding (preventing cross-breeding of behaviors for different specialists) works better than unrestricted breeding, which suggests that the specialization allowed by the heterogeneous team representation conflicts with the inter-agent genotype mixture allowed by the free interbreeding. However, the question is not fully answered.

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Team Learning

- **Hybrid Team Learning**
  - In hybrid team learning, the set of agents is split into several groups, with each agent belonging to exactly one group. All agents in a
  - group have the same behavior. One extreme (a single group), is equivalent to homogenous team learning, while the other extreme (one agent per group) is equivalent to heterogeneous team learning. Hybrid team learning thus permits the experimenter to achieve some of the advantages of each method.

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Concurrent Learning

- The foremost common elective to team learning in cooperative multi-agent frameworks is concurrent learning, where numerous learning forms endeavor to concurrently move forward parts of the group. Most regularly, each operator has it claim unique learning handle to adjust its behavior.
- Credit Assignment
- Dynamics of learning
- Modeling other agents

- **Credit Assignment**
  - When managing with different learners, one is confronted with the assignment of divvying up among them the remunerate gotten through their joint activities. The only arrangement is to part the group remunerate similarly among each of the learners, or in a larger sense, isolate the compensate such that at whatever point a learner's compensate increases (or diminishes), all learners' rewards increment (diminish). This credit assignment approach is as a rule named global reward.

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Concurrent Learning

- **Dynamics of learning**
  - When applying single-agent learning to stationary situations, the operator tests with distinctive behaviors until ideally finding a universally ideal behavior. In energetic situations, the specialist may at best attempt to keep up with the changes within the environment and always track the moving ideal behavior. Things are indeed more complicated in multi-agent frameworks, where the operators may adaptively alter each others' learning situations.
  - Fully Cooperative Scenarios
  - General Sum Games

- **Modeling other agents (teammate modeling)**
  - Learning about other agents in the environment so as to make good guesses of their expected behavior, and to act accordingly (to cooperate with them more effectively for example)
  - Direct communications
  - Indirect communications

Competitive Agents

- **Opponent Modeling**
  - In a few settings, modeling the rival can be vital to urge great comes about from the amusement. In such models, (approximations of) adversary inclinations are spoken to, which can shape the basis for genuine specialist procedure. Typically especially vital when trade-offs can be made between amusement results between diverse players and a few sort of Pareto-efficiency is included, e.g. as in multi-issue transactions. Rival models can be characterized for a single adversary or for a course (sort) of opponents

- **Market and Strategy Modeling**
  - In other settings, models of adversary inclinations are less significant, and parameters concerning the products around which the market diversion is played, or the total (mysterious) showcase behavior (decided by a considerable sum of reasonably mysterious operators) is of more significance. In case of the fundamental great, one may think of a great of which its valuation can be decided from cooperation in numerous recreations.

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Competitive Agents

- **Models of Application Settings**
- Application settings and models that go assist than the ordinary diversion theoretic stylizations are vital for this field. Advertise recreations are frequently considered related to more particular application models

- **Co-learning and Evaluation:**
- When applying versatile methods for competitive specialists in multiagent frameworks, the quality of an versatile procedure for an operator depends on the (versatile) techniques of other operators. Within the case that all operators utilize really versatile procedures as well, different shapes of colearning happens. Up to presently, such situations of different operators are still or maybe confined and basically address learning in agreeable frameworks and e.g. stochastic (general-sum) games

Major Open Topics

- **Scalability**
- Versatility is an issue for numerous learning strategies, but particularly for learning in multi-agent frameworks. The multidimensionality of the look space develops quickly with the number and complexity of operator behaviors, the number of operators included, and the measure of the organize of intelligent between them. In this way, the look space develops so quickly that it may not be conceivable to ponder the complete joint behavior of a huge, heterogeneous, profoundly communicating multiagent system.
- Effective learning in this complex space requires a few degree of give up: either by segregating the learned behavior between person operators, by decreasing the heterogeneity of operators, or by decreasing the complexity of the agents' capabilities. Procedures such as cross breed group preparing, behavior deterioration, or somewhat restricting the area of fortification give promising solutions in this course. It isn't however well portrayed beneath what imperatives and for which issue spaces these obliged strategies work well

Major Open Topics

- **Adaptive Dynamics and Nash Equilibria**
- Multi-agent frameworks are ordinarily energetic situations, with different learning specialists competing for assets and tasks. This dynamism presents a special challenge not regularly found in single-agent learning: as the operators learn, their adjustment to one another changes the world situation. How do operators learn in an environment where the goalposts are continually and adaptively being moved?
- As said some time recently, this co-adaptation of learners to one another leads to a infringement of a essential suspicion of most machine learning methods; for this reason, completely modern multi-agent learning calculations may be required to bargain with this issue. Usually exacerbated by credit task schemes, which whereas regularly vital, can change over an conventional agreeable situation into a general-sum or indeed (accidentally) competitive environment.

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Major Open Topics

- **Problem Decomposition**

- The state space of a expansive, joint multi-agent errand can be overpowering. An self-evident way to handle this can be to utilize domain knowledge to rearrange the state space, regularly by giving a littler set of more “powerful” activities customized for the problem domain. For illustration, Mataric applies Q learning to choose from hand-coded responsive behaviors such as dodge, head-home, look or scatter for robot scavenging assignments. An elective has been to decrease complexity by heuristically breaking down the issue, and hence the joint behavior, into partitioned, less difficult behaviors for the specialists to memorize.

- Such deterioration may be done at different levels (breaking down group behaviors into sub-behaviors for each specialist; breaking down an agents’ behavior into sub-behaviors; etc.), and the behaviors may be learned independently, iteratively (each depending on the prior one), or in a bottom-up design (learning basic behaviors, at that point gathering into “complex” behaviors)

Problem Domains and Applications

- **Embodied Agents**
- The taken a toll of robots has diminished altogether, making it doable to buy and utilize a few (tens, hundreds, or indeed thousands of) robots for a assortment of assignments. This drop in fetched has impelled investigate in multi-agent agreeable robotics. Additionally, computer equipment is cheap sufficient that what cannot be performed with genuine robots can presently be exhausted reenactment; in spite of the fact that the mechanical technology community still emphatically energizes approval of comes about on genuine robots

- Predator-Prey Pursuit
- Foraging
- Box Pushing
- Box Pushing
- Keep-Away Soccer
- Cooperative Navigation
- Cooperative Target Observation
- Herding

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Problem Domains and Applications

- **Game-Theoretic Environments**
- Many multi-agent systems may be cast in game-theoretic terms; essentially as strategy games consisting of matrices of payoffs for each agent based on their joint actions. In addition to game-theoretic analysis of multi-agent systems, some common problem domains are also taken from game theory.

- Coordination Games
- Social Dilemmas

Problem Domains and Applications

- **Real-World Applications**
- Numerous of the depicted issue spaces are coordination, arranging, and constraint-satisfaction issues requiring real-time, conveyed choice making. Since the applications are regularly exceptionally complex and profoundly dispersed, learning techniques have seldom been connected to them, and so they are displayed here fundamentally as case challenge issues for multi-agent learning.

- Distributed Vehicle Monitoring
- Air Traffic Control
- Network Management and Routing
- Electricity Distribution Management
- Distributed Medical Care
- Supply Chains
- Hierarchical Multi-Agent Systems Problems
- Models of Social Interaction
- Meeting Scheduling

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LECTURE 10

Multiagent Systems Coalitions

Forming Coalitions

Coalitional games model scenarios where agents can benefit by cooperating. Sandholm (et. al., 1999) identified the following stages:

Coalitional Structure Generation
Deciding in principle who will work together. It asks the basic question:
Which coalition should I join?
The result: partitions agents into disjoint coalitions. The overall partition is a coalition structure.

Solving the optimization problem of each coalition
Deciding how to work together, and how to solve the "joint problem" of a coalition. It also involves finding how to maximise the utility of the coalition itself, and typically involves joint planning etc.

Dividing the benefits
Deciding "who gets what" in the payoff. Coalition members cannot ignore each other's preferences, because members can defect:
...if you try to give me a bad payoff, I can always walk away...
We might want to consider issues such as fairness of the distribution.

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Characteristic Function Games

The objective is to connect a coalition that the agent cannot question to - this includes also calculating the characteristic function for different games.

Each coalition has its own payoff value, defined by the function

$\mathbf{v}(C) = k$ then the coalition will get the payoff k if they cooperate

on some task

Sandholm (1999) proposed:

- If the game is **superadditive**:
  - if $\mathbf{v}(U) + \mathbf{v}(U) < \mathbf{v}(U \cup V)$
  - The coalition that maximises social welfare is the Grand Coalition
- If the game is **subadditive**:
  - if $\mathbf{v}(U) + \mathbf{v}(U) > \mathbf{v}(U \cup V)$
  - The coalitions that maximis social welfare are singletons
- However as some games are neither subadditive or superadditive:
  - the characteristic function value calculations need to be determined for each of the possible coalitions!
  - This is exponentially complex

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Characteristic Function Games

- Accepting that we know the characteristic work and the payoff vector, what consolidation ought to an agent join?
- An outcome x for a coalition C in game ⟨Ag, **ν**⟩ is a vector of payoffs to members of C, such
- that x = ⟨x1, . . . , xk⟩ which represents an efficient distribution of payoff to members of Ag
- Where “efficient” means:
- Example: if **ν**({1, 2}) = 15, then possible outcomes are: ⟨15,0⟩, ⟨14,1⟩, ⟨13,2⟩ … ⟨1,14⟩, ⟨0,15⟩
- Thus, the agent should only join a coalition C which is:
  - *Feasible*: the coalition C really could obtain some payoff than an agent could not object to; and
  - *Efficient*: all of the payoff is allocated

Characteristic Function Games

- In any case, there may be numerous coalitions
- Each contains a diverse characteristic function
- Operators lean toward coalitions that are as beneficial as possible
- Hence a consolidation will as it were shape in the event that all the individuals lean toward to be in it
- I.e. they don’t imperfection to a more ideal fusion

- Therefore:
  - “which consolidation ought to I join?” can be decreased to “is the amalgamation stable?”
    - Is it levelheaded for all individuals of fusion C to remain with C, or seem they advantage by abandoning from it?
    - There's no point in me joining a amalgamation with you, unless you need to create one with me, and bad habit versa

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Stability

- The concept of stability can be reduced to the concept of the core.
  - Stability is a necessary but not sufficient condition for coalition formation
  - i.e. unstable coalitions will never form, but stable coalitions are not guaranteed to form
- The core of a coalitional game is the set of feasible payoff distributions to coalition members that no sub-coalition can reasonably object to
  - Intuitively, a coalition C objects to an outcome if there is some other outcome that makes all of them strictly better off
- The idea is that an outcome will not happen if someone objects to it!
  - i.e. if the core is empty, then no coalition could form

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Sharing the Benefits of Cooperation

The Shapley value is best known attempt to define how to divide benefits of cooperation fairly.

- It does this by taking into account how much an agent contributes.
- The Shapley value of agent i is the average amount that i is expected to contribute to a coalition.
- The Shapley value is one that satisfies the axioms opposite!

Symmetry
Agents that make the same contribution should get the same payoff, i.e. the amount an agent gets should only depend on their contribution.

Dummy Player
These are agents that never have any synergy with any coalition, and thus only get what they can earn on their own.

Additivity
If two games are combined, the value an agent gets should be the sum of the values it gets in the individual games.

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Shapley Axioms: Symmetry

- Agents that make the same contribution should get the same payoff
- The amount an agent gets should only depend on their contribution
- Agents i and j are interchangeable if their marginal contribution are the same for each coalition
- The symmetry axiom states:
- If i and j are interchangeable, then their Shapley value is equal

Shapley Axioms: Dummy Player

- Agents that never have any synergy with any coalition, and thus only get what they can earn on their own.
- An agent is a dummy player if he/she only adds to a coalition what it could get on its own

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Shapley Axioms: Additivity

- If two games are combined, the value an agent gets should be the sum of the values it gets in the individual games
- I.e. an agent doesn't gain or loose by playing more than once

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Shapley value

- Recall that we stated:
- The Shapley value for an agent is based on the marginal contribution of that agent to a coalition (for all permutations of coalitions)
- The marginal contribution can be dependent on the order in which an agent joins a coalition
- This is because an agent may have a larger contribution if it is the first to join, than if it is the last!
- For example, if Ag = {1,2,3} then the set of all possible orderings, is given as {(1,2,3), (1,3,2), (2,1,3), (2,3,1), (3,1,2), (3,2,1)

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Representing Coalitional Games

- It is important for an agent to know if the core of a coalition is non-empty
- Problem: a naive, obvious representation of a coalitional game is exponential in the size of Ag.
- Now such a representation is:
  - utterly infeasible in practice; and
  - so large that it renders comparisons to this input size meaningless
- An n-player game consists of 2n-1 coalitions
  - e.g. a 100-player game would require 1.2 x 1030 lines

% Representation of a Simple
% Characteristic Function Game

% List of Agents
1,2,3
% Characteristic Function
1 = 5
2 = 5
3 = 5
1,2 = 10
1,3 = 10
2,3 = 10
1,2,3 = 25

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