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Distributed Artificial Intelligence

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1. Introduction

The evolution of multicore processors and computer networks combined with the recognition that much human problem solving and activity involves groups of people led to the development of a new research field: the Distributed Artificial Intelligence. Hence, it is a field that merges Artificial Intelligence with Distributed Computing. In 1988, one of the definitions for Distributed Artificial Intelligence was the following:

"Distributed Artificial Intelligence (DAI) is the subfield of AI concerned with coordinated, concurrent action and problem solving" [1].

The DAI research field originated more specific fields: Parallel Artificial Intelligence (PAI), Distributed Problem Solving (DPS) and Multi-Agent Systems (MAS).

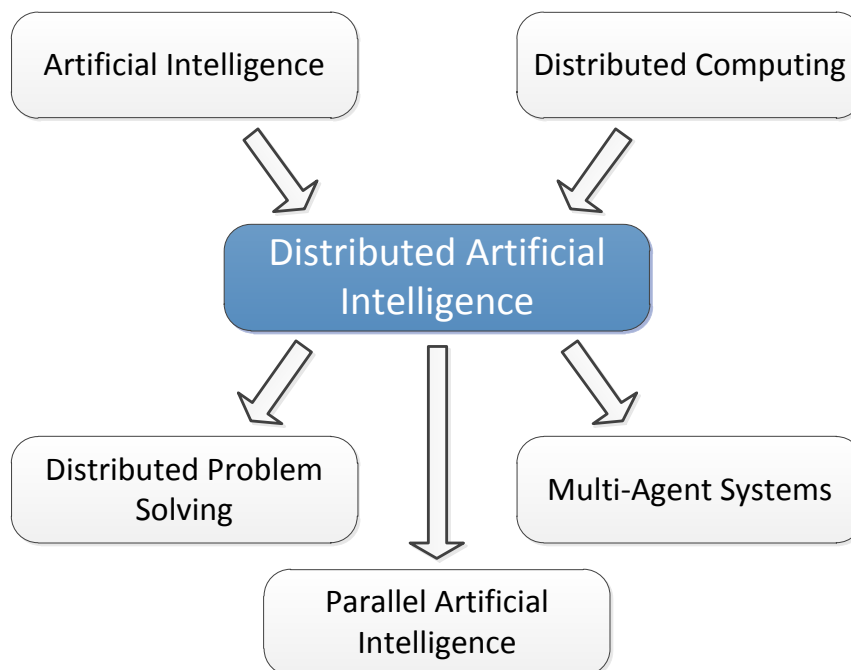


Figure 1 - Distributed A. I. context

Parallel computing enables AI researchers to handle significantly larger amounts of data in real time, which changes the way that AI systems can be built, which in turn makes memory-based reasoning and neural-network-based vision systems become practical. Parallel computing provides a platform to model and build intelligent systems by simulating the (massively parallel) processes that occur in nature, originating the Parallel Artificial Intelligence research field. This research field will not be considered in this document because it is more focused in system performance than system architecture.

The bounds of Distributed Problem Solving (DPS) and Multi-Agent Systems (MAS) are not well defined. Both are composed by a group of entities that interact. One may consider that in a DPS system, all the entities work together with a common interest of solving a well-defined problem, unlike the entities of a MAS that may have diverging interests.

"Multi-agent systems are those systems that include multiple autonomous entities with either diverging information or diverging interests, or both." [5]

The differences between DPS and MAS and some possible points of view to distinguish these research fields are addressed in the chapter 3.

Also, this document presents the main characteristics and considerations about Distributed Artificial Intelligence in chapter 2.

2. Distributed Artificial Intelligence

Although this is a computer science research field, it is quite interdisciplinary and the material is in general fairly abstract [5].

2.1. Motivation for Distributing Intelligence

The reasons for distributing AI systems include both the reasons for distributing a traditional system and the advantages of a DAI system. Some of those reasons are:

- **Adaptability** – With distributed systems is possible to achieve alternative perspectives on emerging situations.
- **Cooperation** – Cooperative systems are capable of solving larger problems than individual systems and with an improved efficiency.
- **Context specialization** – If each part has a well-defined context it would be better for purposes of control, extensibility and comprehensibility.
- **Cost** – Normally, multiple low cost computers are better than a centralized intelligent system with high cost and with sensors associated to it.
- **Parallel development** – A DAI system can be separated into parts that are developed separately by experts in each knowledge domain.
- **Efficiency** – If well synchronized, parallel tasks are faster to compute than sequential tasks.
- **Extensibility** – New parts can be developed and easily integrated with the DAI system.
- **Reliability** – The most important parts of the system may be redundant. There can be similar agents in different locations.
- **Quality of results** – The results may be crossed and combined, achieving better results than with a non-distributed system.

2.2. Distribution Distances

When talking about DAI systems, non-experts in the area often associate this theme to systems composed only by spatially disperse components. However, a DAI system may be defined by many types of distances, not only spatial but also temporal, logical or semantic, for example.

The **spatial distance** is present in a system disperse through spatially distributed locations, and on different and therefore distributed hardware. It can possess spatially distributed inputs (eg. sensors), inference motors, knowledge-bases and outputs (eg. actuators).

The **temporal distance** defines a DAI system in terms of costs of information that is (not) present at a given time. Some knowledge may not be available at a given time, because it has not yet been produced or derived [1]. The knowledge can be fixed or deduced through time in systems with learning capacities. In real-time systems, waiting for temporal coordination can reach high costs.

The **logical distance** is defined as the logical dependency between items of knowledge (i.e., the need to rely upon intermediary deductive processes or supporting facts to make some new knowledge accessible) is a basis for distribution or aggregation [1].

The **semantic distance** between incompatible knowledge and representations is a barrier that may need translation processes in some cases. Some intermediary agents may be present.

2.3. Considerations for Designing a DAI System

In the design of a Distributed Artificial Intelligent system it is important to take into concern the correct division of the problem through the agents and the communication between them.

Firstly, it is necessary to correctly formulate, describe, decompose, and allocate problems and synthesize results among a group of intelligent agents [1]. **If it is a system focused in the resolution of a problem (Distributed Problem Solving), then it is important to separate the problem into smaller ones and distribute those smaller problems through the agents.** This way, a single agent is focused in a smaller area, acting as an "expert" in solving its tasks.

Intelligent agents with great capability of solving a problem together are not really useful if they do not communicate in the same language or if they do not know how to interact with each other. In all DAI systems it is necessary to define communication languages and protocols. But this is not enough, the agents need to know what and when to communicate with each other, assuming sometimes social interactions similar to humans but in a more limited way. These interactions have to be carefully designed to prevent harmful interactions between the agents. So, it is necessary coordination! An individual agent needs to represent and reason about the actions, plans and knowledge of other agents in order to coordinate with them.

Finally, it is necessary to recognize and reconcile different viewpoints of each agent and even combine them to achieve a result (if it is intended to have one).

The considerations referred in this section may not be applicable to all DAI systems and some systems may be designed taking into concern these issues, so they can be self-adaptable to different environments or problems.

2.4. Distributed Learning

In general, single agent learning involves improving the performance or increasing the knowledge of a single agent [2]. An agent with improved performance or increased knowledge solves past problems with better efficiency or quality. Improved performance may be reached by rearranging the knowledge-base or by modifying the way that knowledge is used to solve a problem. Increased knowledge may be acquired with experience from past problems or by facts manually inserted in the knowledge-base.

Similarly to single agent learning, distributed learning also involves improving the performance or increasing the knowledge. However, it is related to a group of agents and not to a single isolated agent. It is important to be aware that improving the performance of a single agent does not necessarily means that the global performance of the group will improve. To improve the global performance it is necessary that single agents adapt to each other.

Distributed learning also includes increasing communication knowledge. An increase in communication knowledge can lead to an increase in performance by allowing the agents to communicate in a more efficient manner [3]. One of the improvements that can be made is the task assignment to the agents. If an agent knows what tasks the other agents can perform, it will highly improve communication effectiveness because the agent will not wrongly communicate with another agent that can't perform the current task.

2.5. Distributed Decision Making

The decision making process in a DAI system can be performed in a centralized unit that acquires the results of individual agents or can be distributed. In the first approach, the central unit must tell each agent what tasks it has to perform, but in the last approach each agent is "responsible" for its own decisions. The main advantages of such a decentralized approach over a centralized one are efficiency, due to the asynchronous computation, and robustness, in the sense that the functionality of the whole system does not rely on a single agent [5].

3. DPS Systems and MAS Comparison

Historically, a DPS system was defined as a system that is developed with emphasis on the problem, and how to get multiple agents to work together to solve it in a coherent, robust, and efficient manner [4].

However, not all systems composed by agents could be considered DPS systems. The example of economic agents or a system composed by agents that simulate a soccer game are not DPS systems at all. In this kind of systems, the single agents have their own interests and they might cooperate or compete, agree or disagree, etc. Almost all kind of social interactions may exist in this context. So, a new research field called "Multi-Agent Systems" arose.

However, the term "Multi-Agent System" was overused and abused along the time. Everything that has a group of both complex and/or simple agents has been considered a MAS. Considering this, DPS can be a subset of MAS.

Another view is that a system can be a DPS and benefit from a substrate of MAS. While a normal DPS system measures the results of the global system, it can be developed measuring the results of individual agents and optimizing them to achieve a better resolution for the global problem.

Also, it is possible to assume that DPS and MAS are complementary research agendas and that a system can be a DPS system or a MAS depending on how it is experimented with. If the agents are fixed and the environment is variable (or by other means: the problem), then it is a DPS system. If the environment is fixed and the agents are variable, then it is a MAS system [4].

4. References

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