NTNU

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Artificial intelligence

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Swarm intelligence

Exercises - part 1

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1 Introduction

A **system** is defined as a set of abstract, technological or living organizations cooperating on a common purpose. More formally, a system can be described using the following (set) notation:

$$S = \{B, S(s)\}$$

that means that a system S is formed by several subsystems $S(s)$ and that there exist some relations between the subsystems, indicated by B. A system is complex when it has more than two subsystems. In particular, a complex system can be represented as:

$$S = \{B, \{A, L\}\}$$

where A represents a set of agents and L represents a set of landscapes (the environments in which the agents operate). B, in this context, represents the relationships between the agents and the landscapes, modelled as a network.

An **agent system model** is a model where the agents, the landscapes and the network that models the relationship between agents and landscapes are defined, as described in the definition of complex system. For instance, the agents could be robots, the environment could be a labyrinth and the relationships network could be the set of interactions between the robots and the labyrinth.

An **agent**, therefore, can be defined in different ways. For instance, they can be seen as goal seeking objects (for instance robots looking for an exit from the labyrinth or ants looking for food). In case agents are described in the context of a more complex system, instead, they can be seen as system elements. Another possibility is to see agents as consumer (for instance, a car consumes fuel) and producers (that car moves as a consequence of fuel consumption). A **landscape** can be defined as the environment in which the agents are and operate. Agents can usually interact with the environment (for instance, a robot in a maze might have some sensors to see the location of the walls). A **network** can be modeled as a graph, and a network that evolves over time can be defined as a temporal graph. In this context, a network encodes the relations between the agents and the landscapes.

A **swam** is a group of independent agents that cooperate in order to reach a goal or to perform some actions. For instance, a swarm of birds consists of many birds that think independently but that are also able to remain compact and to perform actions as a group. The same phenomena has been observed in other situations (for instance, for bees and ants, but also for human beings that want to take the best decision on a certain topic).

Swarm intelligence is the intelligent behaviour resulting from the interaction of several agents belonging to a swarm. Those agents behave as described in the previous paragraph. Even if the behaviour of a single agent is not particularly intelligent, the behaviour of the entire swarm can be more intelligent than the one of an individual.

Let's consider an **agent-based system model for an industrial fish farm**. In this context, it is possible to study the problem from different perspectives. For instance, it could be possible to study the system from a business point of view, by considering the different stages of the production. However, I assume the question is referred to the fish behaviour. This means that the agents are fish, therefore they are able to move in a three dimensional space and to change their velocity. Moreover, it is possible to assume that there exist a sort of communication in the fish school, so that they can perform movements and actions in a coordinated way. The landscape, therefore, would be the tank in which the fish are. It is possible to consider, for example, that some food is introduced in the tank, that it is possible to introduce new fish or to remove some fish. In this model there would be only one type of agent, that is a fish. It would be possible to introduce several kinds of fish, with different behaviours, and to model them as different agents.

It is also possible to identify, in this context, the model purpose end ethics. Considering the perspective of a fish, the purpose could be to eat the food provided from the external environment, to follow the other fish in the school, and if we assume that the fish realizes it is in a fish farm, to escape when someone tries to catch it.

Some typical rules for learning can be related to a reward system: the knowledge of a fish improves when examples and consequences are provided. For instance, if a fish sees that all the other fish group together, it will probably learn to do the same. I think, therefore, that reinforcement learning could be a good learning method. Some other rules could include, for instance, trying to reach the food in the fastest time to have more of it.

2 Producer-consumer agents

A **producer-consumer agent** is an agent that consumes some resources to produce other resources. For instance, if we consider a panda as an agent, it will consume bamboo in order to move and to remain alive. If we consider a car, that can be modeled as an agent, it consumes fuel to move its wheels and go forward. A producer-consumer agent, therefore, can represent anything that, given some resources, outputs something, obtained after having elaborated the input resources. This transformation can usually be modeled using a mathematical function, such as the logistic function. Changes in this function allow the producer-consumer agent to adapt and to customize the production/consumption capacity in the context of a landscape.

A producer-consumer agent can be seen as a system, and it is also part of a subsystem, in which there can be other agents and the environment. If the agent, for instance, consumes too many resources, then there won't be any resource left for the future. In this case it is possible to describe the behaviour of the agent using a time-dependent representation (for instance by using differential equations, that can be discretized) and to use a PID controller to maintain the overall system stable.

In order to maintain a stable production through time, it is possible to perform an optimization on the mathematical function that describes the behaviour of the system. In order to optimize the value of its production, the same function has to be optimized by considering the output value and not, as in the previous case, the production stability.

3 Goal agents

A movable goal-oriented agent is an agent that is able to move in a landscape towards a goal. In a graphical context, where the environment can be represented by a tridimensional euclidean space, such an agent can be the model of a bird that flies towards a point (for instance, the top of a tree), that is its goal. Considering again the fish farming example, the fish can be considered as movable goal-oriented agents because they move towards the food, that is the goal. In general, the landscape is not necessarily a tridimensional euclidean space, since it can be a multidimensional space whose meaning is not geometrical, but the idea behind this kind of agent is the same.

This kind of agent can control its speed for instance by increasing it when the goal is far away and by decreasing it when the goal is closer, in order to be more precise when it comes to "hit" the goal. As for the direction, this is problem-dependent. In case the agent knows the location of the goal and the configuration of the environment, it is possible to perform a search in the space (similarly to the search in a labyrinth), while if there are some parts of the environment that are unknown to the agent, it needs to use heuristics and to make assumptions to determine the correct orientation in the space.

If there exist multiple targets, it is possible to select the best target on the basis of an estimate of the "value" of the target and of the resources used to reach it. In practice, it is necessary to have a model that, given a target, is able to return a value that indicates the desirability of the target. For instance, if the model says that the best agent is the closest, then the agent will move towards the closest agent, but if the positions change through time, it has to check the desirability of each target for each iteration.