Finding the Shortest Path Using ACO (Ant Colony Optimization) in the Metro of Madrid.

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ABSTRACT

Human beings, in this paper represented by Ants are always moving from place A to Place B. It is part of our nature, we need to move between points.

Because of this basic needs we have, it is also very important to us to find the "best way" path. In this paper I will describe an ant simulator created to help the madrid metro users (ants) to find the shortest path from Madrid Metro Station A to B. This work could be also easily adapted to others related problems like traveling by car from city A to B, flighting from country A to country B, etc.

Author Keywords

ACO (Ant Colony Optimization), Multi Agents, Metro Madrid, Finding the Shortest Path, Metaheuristic, Pheromones, Stigmergy.

1.- INTRODUCTION

Complex problems in nature are solved by organizing independent life units (agents) into societies, where each agent is capable of autonomous decision making. The problems that multi-agent systems can solve are most likely impossible for a monolithic system or a single agent.

For example, in this paper we will describe a real problem where people need to go from Madrid Metro Station A to B using the shortest path.

In this real example it is possible to see that our agents, represented in the software simulator as Ants, in real life by people, will start moving from different paths, but after the time goes by they will finally find the shortest path and all will do the same path.

2.-BASIC CONCEPTS

The metro of Madrid is composed of many lines and stations that connects the city.

Figure 1 - Real Madrid Metro Map [1]

It would take a lot of time to transport the real Madrid Metro Map to the software simulator, so I decided to transport only some of the stations (nodes) and connections (edges) to the software simulator as we can see in the figure below.

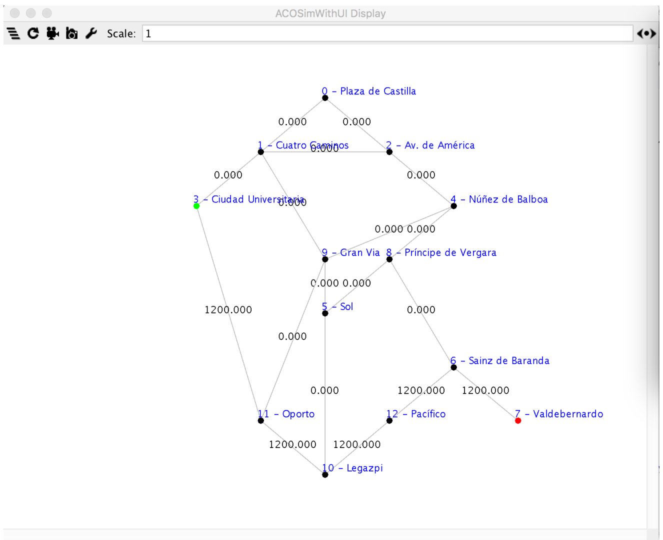

Figure 2 - Simulated Madrid Metro Map

The **Ant Colony Optimization** (ACO) **metaheuristic** is a versatile algorithmic optimization approach based on the observation of the behaviour of ants. As a result of numerous analyses, ACO has been applied to solving various combinatorial problems. The ant colony metaheuristic proves itself to be efficient in solving NP-hard problems, often generating the best solution in the shortest amount of time. However, not enough attention has been paid to ACO as a means of solving problems that have optimal solutions which can be found using other methods.

The shortest path problem is undoubtedly one of the aspects of great significance to navigation and telecommunications. It is used, amongst others, for determining the shortest route between two geographical locations, for routing in packet networks, and to balance and optimize network utilization. [2]

The basic idea of the ACO meta-heuristic is taken from the food searching behaviour of real ants. While walking, ants deposit pheromone, which marks the route taken as they move from a food source to their nest, and foragers follow such pheromone trails. The concentration of pheromone on a certain path is an indication of its usage. These pheromone trails are used as a simple indirect form of communication. The process of emerging global information from local actions through small, independent agents not communicating with each other is called Stigmergy [3].

Ants are creatures of limited intelligence, yet in nature they manage amazing feats such as building nests and finding food [4]. They do this through an organized collaborative behaviour that exploits the intelligence of the swarm of individuals in the ant colony [5]. The French entomologist, Pierre Paul Grasse investigated the social behaviour of insects and discovered that ants are capable to react to what he referred to as "significant stimuli", which are signals that activate a genetically encoded reaction. He observed that the effects of these reactions can act as new significant stimuli for both the insect that produced them and for the other insects in the colony. Grasse coined the term Stigmergy to describe this particular type of indirect communication in which the workers are stimulated by the performance they have achieved. Stigmergy is defined as a method of indirect communication in a self-organizing emergent system where its individual parts communicate with one another by modifying their local environment [6]. Ant colony optimization (ACO) is an optimization technique inspired by the exploratory behaviour of ants while finding food. Ants start from their nest and find different paths to the food. In this context, the local information available to the ant is the path that it took to the destination. However a single ant is not aware of the complete topology of the environment. Ants thus communicate with each other by depositing traces of pheromone as they walk along their path. Subsequent ants that arrive in search of food, base their decisions of which path to take on the pheromone traces left in that locality by the previous ants. This form of communication is indirect, i.e., one ant releases the pheromone information into the environment, and another ant senses that pheromone information from the environment just as Grasse had defined. As more ants travel over a particular path, the concentration of pheromone increases along that path. Pheromones along a path also gradually evaporate decreasing their concentration on that path. The pheromone acts significant stimuli since other ants are able to sense the pheromones deposited by each other, and they generally take the path of maximum pheromone concentration. This is how the ants progressively converge on a single optimum path between their nest and the food [7].

This behaviour of the ants can be used to find the shortest path in the Madrid Metro Map because every metro user (ant) will deposit the pheromone and will help the ants find the shortest route.

A metaheuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems. The use of metaheuristics has significantly increased the ability of finding very high quality solutions to hard, practically relevant combinatorial optimization problems in a reasonable time. A particularly successful metaheuristic is inspired by the behavior of real ants. Starting with Ant System, a number of algorithmic approaches based on the very same ideas were developed and applied with considerable success to a variety of combinatorial optimization problems from academic as well as from real-world applications.

MASON is a fast discrete-event multiagent simulation library core in Java, designed to be the foundation for large custom-purpose Java simulations, and also to provide more than enough functionality for many lightweight simulation needs. MASON contains both a model library and an optional suite of visualization tools in 2D and 3D. [8]

A multi-agent system is a set of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each individual agent.

Problem of the shortest path

For the directed graph G = (V,E) where V is the set of vertices and E is the set of edges we assign the cost aij to each of its edges (i, j) ∈ E (alternatively, this cost can be also called the length). For the resulting path (n1, n2, . . . , nk), its length can be expressed by For mula [9].

$$a_{ij} = \sum_{i=1}^{k-1} a_{n_i n_{i+1}} \qquad [9]$$

A path is called the shortest path if it has the shortest length from among all paths that begin and terminate in given vertices. The shortest path problem involves finding paths with shortest lengths between selected pairs of vertices. The initial vertex will be designated as s, while the end vertex as t.

A number of basic variants of the shortest path problem can be distinguished:

- Finding the shortest path between a pair of vertices.
- Finding the shortest paths with one initial vertex.
- Finding the shortest paths with one end vertex.
- Finding the shortest paths between all pairs of vertices.

This problem finds its application in a number of areas such as routing in telecommunications networks, dynamic programming, project management and as suggested in this paper to find the shortest path in the Madrid Metro Map.

3.- REAL CASES SIMULATIONS

A.- Going from Ciudad Universitaria Station to Valdebernardo Station

Using MASON [8] and the Java Source code shared by Prof. Nik Swoboda and Pepa Hernández, I was able to adapt the source code to apply to this problem of finding the shortest path between metro stations in Madrid . This project was called by the author as MAS (Metro Ants Simulator) and is available at github as a free and open source software. [10]

The first simulation is to use 3000 ants to find the shortest path from *Ciudad Universitaria* Station to *Valdebernardo* Station. As we can see in the figure below the parameters were set with 3000 ants, PheromoneMax = 10 and PheromoneMin = 1.7.

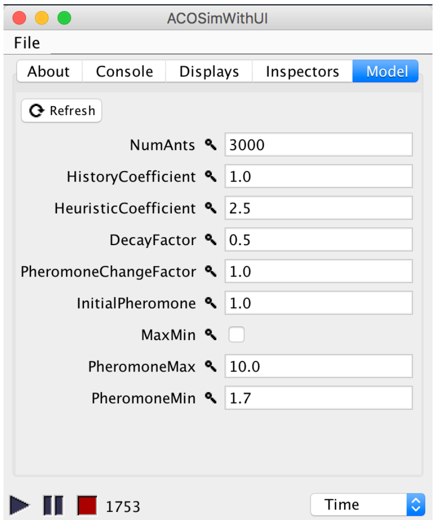

Figure 3 - ACO Simulator Parameters.

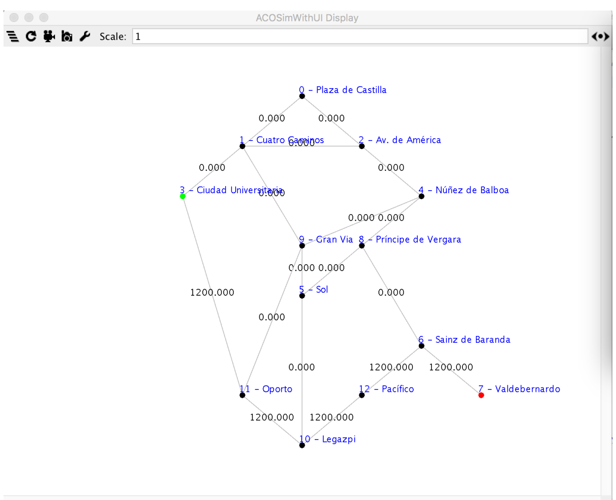

Figure 4 - ACO Simulator finding the shortest path from *Ciudad Universitaria* station to *Valdebernardo*.

To simulate with others stations, it is necessary to change the Start and End parameters in the code ACOSim.java.

setStart(nodes[3]);

setEnd(nodes[7]);

The results after executing the simulator and waiting for the ants find the shortest path will be as we can see in the image below.

Figure 5 - ACO Simulator results.

```
ACOSimWithUI [Java Application] /Library/Java/JavaVirtualMachines/jdk1.7.0_80.jdk/Contents/Home/bin/java (Jun 30, 2016, 6:37:30 PM)
----
Nodes visited:
  3 - Ciudad Universitaria 11 - Oporto 10 - Legazpi 12 - Pacifico 6 - Sainz de Baranda 7 - Valdebernardo
----
Nodes visited:
  3 - Ciudad Universitaria 11 - Oporto 10 - Legazpi 12 - Pacifico 6 - Sainz de Baranda 7 - Valdebernardo
----
```

The shortest path to go from *Ciudad Universitaria* metro station to *Valdebernardo* is to pass through *Oporto, Legazpi, Pacífico, Sainz de Baranda* and finally arrive in *Valdebernardo.*

It is very important to explain that this results are true based in the map created for this simulator, but it is not true in the real Madrid Metro Map.
As mentioned before, it will be necessary to update the simulator map with all the stations and lines in a future work to have the real result.

We did simulate during this study with different numbers of ants, PheromoneMax and PheromoneMin, and changing parameters changes the necessary time to find the shortest path.

B.- Adding obstacle, changing the stop time between stations and updating the scenario with real time data.

In a future work, the next phase will be to add obstacles along the stations, for example closing a stations because a repair or any problem. It will force the ants to find new ways to go.

Another possibility is to update in real time the stop time between stations and adapting the algorithm to find not only the shortest way but also the fastest way to go from different stations.

5.- CONCLUSION

When we think about metro services, it is hard to find ways to improve the user experience, but one suggestion will be to integrate the data with the number of trains circulating in a determine time and place and also the stop time in each stations.

Another researches have been using different sources of date to propose new models for finding the optimum route based on the integration of traffic data from different sources. Ant Colony Optimization is applied in this problem because the concept of this method (movement of ants in a network) is similar to urban road network and movements of cars.

Nowadays traffic data is obtained from multiple sources including GPS, Video Vehicle Detectors (VVD), Automatic Number Plate Recognition (ANPR), Floating Car Data (FCD), VANETs, etc. All such data can be used for route finding. [11]

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