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Simulation of Online Communities Using MAS Social and Spatial Organisations

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Abstract**—**Online Communities are an example of socially-aware, self-organising, complex adaptive computing systems. The multi-agent systems (MAS) paradigm coordinated by self-organisation mechanisms has been used as an effective way for the simulation and modeling of such systems. In this paper, we propose a model for simulating an online health community using a situated multi-agent system approach, governed by the co-evolution of the social and spatial organisations of the agents.

Keywords**—**multi-agent systems, organizations, online communities.

I. INTRODUCTION

THE evolution of today's computing systems and their open and dynamic environments require approaches that can deal in an effective way with their increasing complexity. These systems exhibit self-organised, adaptive behaviours similar to complex adaptive systems (CAS): they are composed of many interacting parts, giving rise to emergent patterns of behaviour. The behaviour is said to be emergent because at the macroscopic level, the system exhibits new complex properties that are not found at the local level of the different components. CAS self-organise and adapt to changes in the environment without central control or rules governing their behaviours. In such systems, order can emerge through the process of self-organisation [1], [2]. Multi-agent systems (MAS) coordinated by self-organisation and emergence mechanisms have been used [3] for the development of such systems, and the role of the environment has been increasingly taken into consideration, as the environment is considered a first class entity in building MAS [4].

In order to engineer systems capable of "adequate" adaptation to their environment, we propose a coupling between the system and its environment [5]:

-A structural coupling expressed in the co-evolution of the structure of the system and its environment

-A behavioural coupling expressed in the co-evolution of the behaviour of the system and its environment

-The retroactive effect of one coupling on the other; the changes that occur in the system's structure and behaviour during the environment's evolution are correlated.

We propose to use situated MASs [6] to build computing systems aware of, or embodied in their environment. The design of the situated MAS must address the following:

-The structural coupling represented by the spatial organisation of the MAS.

-The behavioural coupling represented by the social organisation of the MAS.

-The co-evolution of both organisations through the MAS dynamics.

Online communities are a good example of self-organised, complex adaptive systems. Simulating an online community gives us a better understanding of its evolution, predicting the contribution behaviours of its members and therefore allows us to determine the key factors for its success especially in increasing the community members' participation rate.

The remainder of the paper is organised as follows: in section two, we give a brief overview of related work. In section three, we present a model of social organisation and spatial organisation of the agents. In section four, we apply this model to the simulation of an online community, based on the co-evolution of the social and spatial organizations, and we conclude in section five.

II. RELATED WORK

A. Organisations in MAS

In recent years, the notion of organisation and the related concepts were applied to model MASs. Ferber proposed the AGR model [7] where agents, groups, and roles are the primitive concepts. Agents play roles within groups. The MaSE (Multi-agent Systems Engineering) [8] approach was extended to include organisational concepts such as goals, roles, agents' capabilities and assignment of roles. Odell et al. [9] have used extended UML to propose a metamodel for agents, groups and roles based on agents' capabilities and their current activities. The OMNI framework [10] takes into consideration three dimensions of an organisation: norms, structural relations and contextual relations. In this paper, we propose to extend this existing work on social organisation of a MAS, by adding a spatial dimension and taking into consideration the physical environment in which agents act

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and interact.

B. Stigmergy

Stigmergy is a concept introduced by the French biologist Grassé [12]. He studied the behaviour of termites during the construction of their nests and noticed that the behaviour of workers during the construction process is influenced by the structure of the constructions themselves. This mechanism is a powerful principle of cooperation in insect societies. It has been observed in many insects such as wasps, bees and ants. It is based on the use of the environment as a medium of inscription of past behaviours' effects and their ability to influence the future ones. More generally, this mechanism shows how simple systems can produce a wide range of more complex coordinated behaviours, simply by exploiting the influence of the environment. It allows the self-structuring of the environment through the agents' activity; the state of the environment and the current repartition of agents in the environment determine their respective future evolutions [13].

III. Social and Spatial Organisations of the Agents

In our proposed model, the system is viewed as an artificial ecosystem populated by agents in which the environment is in the centre of the implementation. Agents interact with each other and co-evolve in a shared environment. We assign to the environment two levels: a physical level represented by a spatial organisation and a conceptual level represented by a social organisation as follows (Fig. 1):

The physical environment is represented by a network or a graph. Agents are situated in the different nodes of the graph called locations. These locations form the organisational positions that agents can occupy at the physical level of the environment. Edges of the graph represent pathways between different locations. The perceptions/actions of these agents are situated in the physical environment. A set of nodes or locations forms a place. Places are to be defined based on a neighbourhood relationship between the nodes depending on the graph topology. Places form the organisational units of the spatial organisation. As the network topology is highly dynamic, the places are also dynamic and keep changing over time. The relation between the topology of the system and the spatial organisation is autopoetic.

The social organisation of the system is the social structure in which agents can act and interact with each other. Agents are organised in groups (organisational units) and play different roles (organisational positions) in each group. Roles in the system define the behaviours that agents exhibit as part of that role [14]. The agents' perceptions depend on the position of the agents in the place, and the actions depend on the roles they can play. Agents' indirect communication and coordination are achieved through the use of the stigmergy mechanism and more particularly, through the diffusion, propagation and evaporation of a specific digital pheromone. This digital pheromone is viewed as a spatial structure for coding the control and meta-control information.

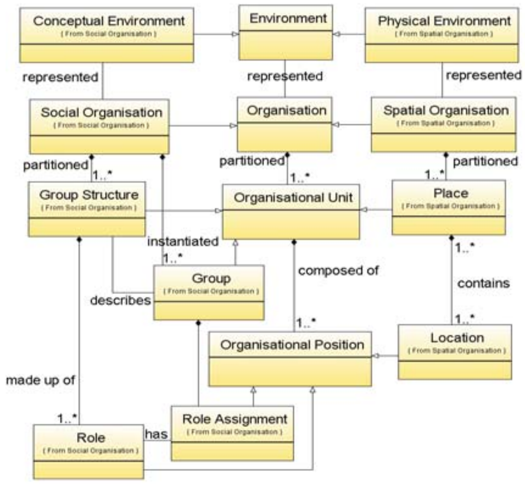

Fig. 1 UML class diagram that represents the agents' organisations

A. Social Organisation

In this section we present a description of the social organisation (Fig. 2):

Agents: Agents are the active, mobile, and interacting entities in a system. They have a spatial position, and they play at least one social role. They control their own execution and can move from one position to another. Agents have the capacity to change the spatial and social environment they are in.

Roles: Roles are the smallest components of the social organisation. They define the set of behaviours that a given agent playing a particular role can perform. An agent starts with assigned roles and can dynamically change its roles as the system evolves.

Groups: Groups form the organisational units of the social organisation. A group is a set of agents assigned roles that are related according to some common purpose or by a pattern of interactions. Groups serve as a way of partitioning the social environment into distinguishable units.

Group Structures: Group structures describe which set of roles are members of a group [7]. Each group is described by a group structure.

Role Assignments: Role assignments relate agents to roles in a group. While roles can exist in a group as part of its structure as described by the group's group structure, the role may not be played by any agent. We refer to roles that are actually played by agents as role assignments [14].

Action: Actions are the set of capabilities that agents can realize as part of their agent behaviour. Actions are provided to agents through the social roles they play and these actions affect the local environment of the agents. Agents' interactions and behaviours in the system are expressed through the actions that they employ in their environment. When an agent actually plays a role and the actions are realized, the agent is said to be assigned that role. The clustering of roles into group structures form the structural definition of the social organisation, while the actual groups that are created and the role assignments that agents play form the concrete definition.

Multiplicity Constraint: A multiplicity constraint describes a relationship between a role and its group. It describes how many agents can play the role in question for the group.

Dependency Constraint: The dependency constraint describes how a potential role assignment for a role depends on the existence of an actual role assignment for a different role.

Correspondence Constraint: The correspondence constraint describes how an agent playing a given role in a group will automatically play a corresponding role.

These constraints are treated as meta constraints that help describe and structure the social environment [7]. They define the structural rules governing the social environment.

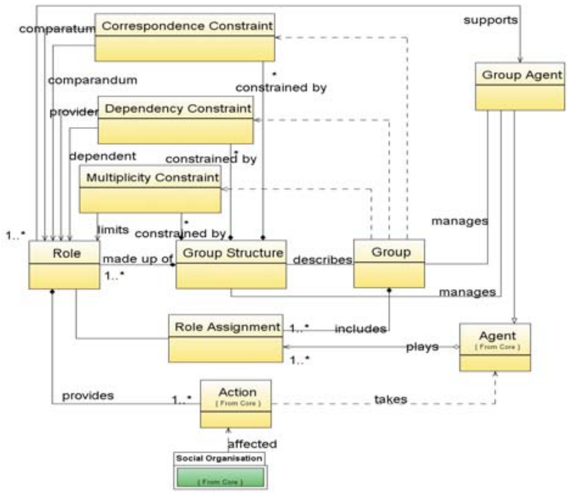

Fig. 2 Social organisation

B. Spatial organisation

The spatial organisation (Fig. 3) is comprised of the following components:

Location: Locations are the smallest components of the spatial organisation. They define the spatial positions that agents are situated in. As the system evolves, agents are able to add new locations to the spatial organisation, and existing ones can be removed.

Place: Places partition the spatial organisation into distinguishable units. A place is a collection of locations that are spatially close to each other or clustered based on a neighbourhood relationship. Places can be predefined by the designer, and new ones can emerge as the system evolves.

Path: Paths relate locations to each other. They form the arcs of the spatial graph linking different nodes.

Both locations and places form an integral part of the spatial organisation. Locations help provide the conditions under which agents exist [15] while places organise locations into units and partition the system at the physical level. Agents can be positioned at one location at a time, but they can be situated in multiple places simultaneously when the places overlap with the agent's location.

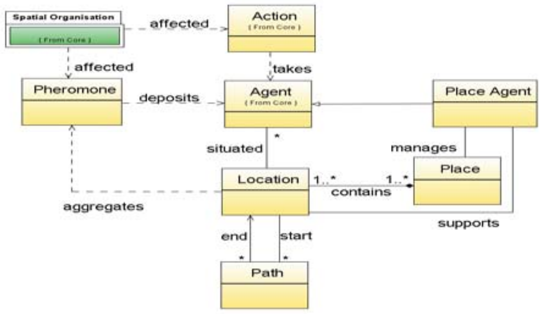

Fig. 3 Spatial organisation

In addition to providing an organisational structure to the physical environment, places give it flexibility and scalability. Places are managed by place agents [16]. These specialized agents provide the local services and resources to other agents situated in each place. When an agent in a given place requires access to data sources, the request for this service goes through and is provided by the place's place agent [17]. By dividing the overall physical environment into smaller self-organising units, places divide the set of processes that define and change the environment's states and distribute the agent load in the environment. Thus, there is no need to have a large, single, complex entity executing the environment processes, especially for systems with a largely diverse and heterogeneous physical environment, where such lack of partitioning overwhelms the processing capabilities of the environment and plateaus performance and growth [15]. Because of this division of the physical environment and its heterogeneous make up, agent behaviour in the system can vary depending on the agent's spatial position.

The effect of the interactions between the different agents is materialized in the environment and can be expressed by the use of a spatial structure in the form of a digital pheromone. This structure is composed of the following fields [18]:

–Label: identifies the nature of the information;

–Intensity: expresses the degree of pertinence of the information;

–Diffusion rate: expresses the distance to which information is spread in the environment;

-Evaporation rate: expresses the persistence rate of information in the environment.

C. Co-evolution of the social and the spatial organisations

An agent's behaviour and the role it will play are greatly affected by its position in the spatial organisation. Its position is also affected by its actions and the roles it plays in the social organisation and by the different activities in the environment (pheromone presence etc.). The coupling between the spatial and social organisations is retroactive and is expressed in the graph topology. The co-evolution of both spatial and social organisations is achieved through the stigmergy mechanism, which allows the self-structuring of the environment through the agents' activities (Fig. 4).

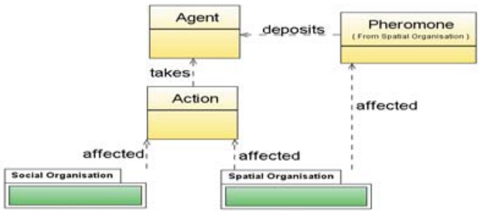

Fig. 4 Co-evolution of the social and spatial organisations

IV. Example of online communities

To illustrate the proposed approach, we apply it to the example of simulating the evolution of an online community. An online community is a community of people that communicate and interact socially using the Internet as the medium of communication [19]. Online communities are composed of people from different groups who participate in a common social environment. Examples of online communities vary from e-mail distribution lists, to blogs, to chat rooms and even to instant messaging.

Online communities are growing at a tremendous rate. Despite their vibrancy, a large number of them fail, with the participation dropping to zero. In order to better understand how they grow, evolve and function in a mature state, their simulation may give us ways to predict their growth and hopefully we will be able to determine the factors that motivate participants' contributions.

In this example, we will focus on online communities whose members communicate through postings on a web site. Online communities exhibit behaviours similar to a self-organised complex adaptive system. Agents in online communities represent the users belonging to the community and users who are browsing through its contents. The community we will explore is an online health support community [20].

A. *Spatial organisation of the health online community*

The different web pages of the online community are the physical medium in which agents interact. These pages or locations include a home page, a page for database articles, a membership sign-up page, forum postings pages, etc. An agent can be situated in any of these locations. The links between pages form the paths connecting the different locations together in the neighbourhood relationships. The degree or strength of this neighbourhood relationship is based on the closeness of the web pages to one another. Pages with high content similarity exhibit stronger neighbourhood ties and have a shorter distance to each other than pages that are contextually different. The clustering that results is represented in the system as places, where each place corresponds to a topic.

The spatial environment consists of places, locations, paths, and pheromones. Locations have content, which can be about one or more topics. There is one main topic, and there may be additional topics, provided that they are related to the main topic. Each topic in the location has a proportion that indicates which percentage of the location is on that topic. In addition, each topic has a relevancy value that indicates how relevant the information or opinion on that topic is. The higher the percent, the more relevant it is. Every location also has a location type

Paths connect two locations and are bi-directional. They provide agents with a means of navigating among the locations within the community. Each path has a distance that indicates how closely related two locations are in terms of their content. The shorter the distance, the more closely related the locations are. Distance is calculated based on how many topics the two locations have in common compared to the total number of topics at the two locations. In addition, the relevancy and proportion of topics common to both locations are also compared. The fewer non common topics there are and the more similar the common topics are in terms of proportion and relevancy, the shorter the distance. Places are used to group locations with similar content, and each place has one topic that it is about.

Pheromones are part of the spatial environment, and they are used by agents for indirect communication. An agent drops a pheromone at a location after creating it to alert other agents. Pheromones have a pheromone type or label consisting of topics and a proportion for each topic that indicates how much of the pheromone is on the topic. In addition, each pheromone has an evaporation rate, intensity, and diffusion rate.

-*Evaporation rate* ($1-\rho_j$): expresses the persistence rate of information at a location i in the environment. The lower its value, the longer is the influence of the spread information:

$$\rho_j = |N_{ij}| / |N_i| \tag{1}$$

N_{ij} is the set of neighbours of location i addressing topic j and N is the set of all neighbours of location i.

-*Diffusion rate*: is calculated based upon the distance to neighbouring locations that have the same topic j at the location i where the pheromone was dropped. The higher its value the greater the scope of the information is in the environment.

$$\lambda = \sum_{j \in T} p_j \left(\frac{|N_{ij}|}{N} \right) \tag{2}$$

Where T is the set of topics, p is the proportion of the topic in the location.

-Intensity I(d,t): expresses the pertinence of the information. how relevant the topic is, and it is based upon the percentage of the neighbours at the location where the pheromone was dropped that have the same topic. This formula calculates the level of pheromone at a given distance d from the original deposit at time t.

$$I(d,t) = I_0 \rho_j^{\,t} (\lambda)^{-d/\lambda} \tag{3}$$

ρ_j represents the persistence rate, ($1-\rho_j$) the evaporation rate, I_0 the initial intensity, λ the diffusion rate.

B. Social organisation of the health online community

Agents that belong to the online health community can play the following roles [20]:

-Moderator: Oversees the operations within the online community

-Help Seeker: Expresses insecurity, asks for data, facts, opinions, values

-Information Seeker: Asks for data and facts

-Information Giver: Provides data and facts

-Opinion Seeker

-Opinion Giver

-Group Founder: Establishes new groups within the community

An agent may be assigned to one or more roles. When an agent arrives at a location, it checks if the topic it is interested in is at the location. If the topic is not at the location, the agent moves to another location. Otherwise, the agent will perform one or more actions. The action an agent performs will depend on what role it is active in and its current location.

Agents can perform a number of different actions:

-Move from one location to another location

-Perceive the content (topics) of its current location

-Update its knowledge using the content of its current location

-Perceive the paths (direction to neighbouring locations) of its current location

-Perceive the pheromones of the current location, including pheromones spread from neighbouring locations

-Deposit pheromones

-Assign itself to a new role.

-Change the role it is active in

-Create locations, places

-Create new communities

The most important actions performed by agents are updating knowledge, moving to a new location, creating a location, and becoming assigned to a role.

-Updating knowledge: An agent keeps track of its knowledge on each topic. The agent has a maximum capacity of knowledge. When an agent updates its knowledge, the amount of knowledge it gains for each topic depends on the percentage of the topic at the location and its relevancy.

-Moving to a new location: The agent follows pheromones to find locations that have the topic the agent is interested in. It checks the pheromones at its current location. If there are no pheromones with the topic the agent is interested in, then the agent will choose a neighbouring location to move to.

-Creating a location: When an agent creates a new location, it must set the location type, the neighbour of the location, the topics of the location, and the location's place. The location type will be determined by the action the agent is taking as part of the role it is currently active in. The main topic of the location is the topic the agent is interested in. Additional topics may be added, as long as each topic in the location is related to at least one other topic in the location, and the agent has acquired knowledge of the topic. The relevancy of each topic in the location will be set based upon a combination of how much knowledge the agent has of that topic as a percentage of its knowledge capacity and how closely related the topic is to the other topics in the location. If the topic of the place where the agent is currently at is the same as the main topic of the new location, then the new location will be added to that place. Otherwise, the agent will have to decide whether to create a new place for the location. Finally, the agent will move to the new location and drop a pheromone there to alert other agents of the new location

-Role assignment: If the agent is aware of a role, it can be assigned to the role if it meets a set of predefined requirements. Once the agent is assigned to the new role, it can perform actions associated with that role.

C. Simulation and Results

The computer simulation program was developed in Java. The simulation was run several times using 151 agents, and the results were fairly consistent every time with only minor variations.

Simulation results show consistently that the number of agents assigned to the Information Giver role increases each time. The other roles assignments did not increase in the same frequency as the Information Giver and that is a result of a design limitations.

We tested the number of new locations and places created. The results show that the number of each type of location increased. In addition, new places are created and there is a place for each topic of the online health community. A closer examination of the data, however, shows that for places with a small number of locations, a very high percentage of locations in the place have a main topic that is the same as the place topic. In order to determine how well locations are grouped together we examined the neighbours of a location and calculate the percentage of neighbouring locations where the main topic is the same as the main topic of the location. A high percentage indicates that locations with the same main topics are located closer together. For almost every location, all the neighbours of the location have the same main topic as the location.

Another measure was the study of the dependency between the social organisation and the spatial organisation and, more particularly, between roles and locations in order to show the degree of coupling between the two organisations. A chi-square test was performed on the counts of location types created by agents active in a certain role. A contingency table was built to calculate the expected frequencies for each intersection of role and location type. The test shows that there exists a dependency between the type of location created and the active role of the agent that created the location.

V. Conclusion

Multi-agent systems are widely used for the simulation and modeling of complex systems. In this paper, we integrate a spatial dimension to the MAS. We argue that the coupling between the system and its environment should be taken into consideration. At the physical level, as the multi-agent system is structurally represented by the spatial deployment of the agents in the physical environment, the structural coupling is expressed through the spatial organisation with respect to the environment. At the conceptual level, the behavioural coupling is represented in the MAS by the social organisation and its coupling to the spatial organisation. From the multi-agent perspective, the issue is the necessity to study the relation between the spatial organization and the social organization and their retroactive effects.

We have proposed an approach for developing complex self-organised systems from a MAS perspective, where the coupling between the social organisation and the spatial organisation of the agents is at the center of the model. Agents use the stigmergy mechanism for their indirect communication by depositing digital pheromones. This allows the self-structuring of the environment. We applied the model to the example of simulating the evolution of an online community. Results did show that the social and spatial organisations are not independent in their evolution. We are currently implementing this model to other web applications that exhibit complex adaptive systems behaviours to test the consistency of the results.

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