Ontological modelling of Natural Categories-based Agents: an Ant Colony

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ABSTRACT
Nowadays, the study of multiagent systems is a significant and promising research area, since they are considered useful for simulating the behaviour of real systems. On the other hand, ontologies are considered the best manner for representing reusable and shareable knowledge. In this work, we make use of ontologies for modelling the multiagent system. In particular, top-level ontological categories are used for modelling the concepts of the domain. The application domain is an ant colony, and some results of this research are shown in the paper.

Keywords
Multiagent Systems, Ontologies, Social Systems

1. Introduction
Nowadays, both Agent and Multiagent Systems (MAS) fields constitute an important research and development area in an increasing number of Universities, Research Institutes and, from the last decade, in the industria. In consequence, these ideas are applicable into multiple domains. Furthermore, many definitions of what an agent and an MAS are, each being valid for a certain aplication domain but no one better or more correct than the others, have been given [19]. Moreover, MAS are considered a positive manner for modelling and simulating real systems [10]. In this work, the concepts of agent and MAS are going to be applied in the domain of artificial societies' systems that simulate the behaviour of a specific type of natural society (i.e., ants).

Modelling agents for simulating artificial social systems has frequently been performed by means of simple agents, and some interesting results have been drawn from it [7]. However, such approaches impose strong constraints to the emergent social behaviour, reducing the possibilities of analysing and obtaining conclusions related to more complex societies as the human one is. A similar fact happens with the traditional attempts made by the Artificial Intelligence (AI) community in order to incorporate rational behaviour to the agents by applying techniques such as logical rule sets or representational theory inside the MAS architecture. Actually, it has usually been necessary to simplify the problem due to the complexity provoked by the application of such techniques from a computational point of view [1; 2].

A more modern phenomenon in the representational theory field can be found in the usage of ontologies for sustaining the agent's knowledge [4]. The term ontology has a philosophical origin since it comes from the Aristotle's attempt to make a classification of the things in the world. In the AI field, many definitions have been given to the term ontology, although the most accepted one is that given in [14], where it is defined as "a formal, explicit specification of a shared conceptualisation". Moreover, ontologies provide potential terms for describing our knowledge about the domain [4].

The main advantage of using ontologies for representing the existing knowledge is that they allow for sharing and reuse of bodies of knowledge in a computational form [6]. The knowledge included in an ontology can be shared because this knowledge uses to be consensual, that is, it has been accepted by a group not by a single individual [24]. Ontologies have also been used for building knowledge bases in different fields [12]. In the ontological engineering research area there are two main approaches for building ontologies:

(a) Collaborative ontological development: Due to the significance of the ontologies for supporting the representation of knowledge in CSCW tools, the importance of collaborative ontological engineering is increasing as it can be observed from the number of such a class of tools that have appeared lately ([6]; [8]). These systems are domain ontologies-oriented.

b) Generic ontologies construction: Some attempts for creating large scale, generic ontologies that fix a series of concepts according to some general classification criteria have been made. From this first classification of concepts, ontologies for specific domains can be developed. The advantage of this type of ontologies radixes in the resolution of compatibility problems that appear when trying to unify ontologies designed according to different high-level concepts. The project Cyc's goal [5] was to create an ontology of this type and used three classification basic criteria:

(1) Represented things versus internal things.

(2) Individuals versus collections.

(3) Tangible versus intengible versus both.

In [20], some problems with the CYC ontology are raised: (1) the category Thing has no properties of its own; (2) things cannot be represented on its own machine; (3) collections are treated as intangible; (4) Process is under Individual Object but

Tangible Object is under Process, etc. Thus, the top-level ontology designed by Sowa attempts to overcome those problems [21]. This particular ontology has been used as a reference for our work.

As a counterpoint to the current state of the research and development in the area, some metamodels have appeared with the aim of solving the problems related to the traditional Artificial Intelligence approaches. The author in [13] defines an agent, but the novelty of this definition is that it gives reasons that support the unnecessity of keeping a partial representation of the environment. In [16], the author states that the intelligence could emerge from the interaction between agents with differentiated functionalities. More recently, Goldspink addresses topics such as the incorporation of the complex systems theory and the autopoiesis to solve those problems, emphasizing in this way his job's intentionality, which has become a new research direction to be used as the starting point for further developments that concretizes the metamodel and that can prove its utility for studying social systems.

The application domain chosen is an ant colony which is an application domain in which the indivudual level is not the most important but the group level, because the ants together form a coherent whole and maintain themselves as a group whereas individuals have no or little self-interest [23]. Then, the MAS modelled in this work corresponds to an ant colony.

The structure of this paper is as follows. The methodology used for developing this work is described in Section 2. Section 3 describes the coordination process in multiagent systems. In Section 4, the scenario in which the model is applied is described. Section 5 reflects the results obtained by applying the methodology in a concrete application domain. Finally, some conclusions and final remarks are put forward in Section 6.

2. Methodology

Given the current state of the art in the ontological agents' modelling it seems logic that if we maintain the classical trends in the development of new projects, we should find the same computational complexity problems. The relative novelty in the development of ontological agents is a good reason to continue to exploit techniques for simulating natural social systems by means of artificial societies. The purpose then is to obtain conclusions about their benefits and to reach social systems closer and closer to human systems, which is the most important goal of this discipline.

Our work consisted in creating an artificial social system in an ants colony context. In this section, the following aspects are presented: (1) the ontology; (2) the definition of agent; (3) the social laws for coordinating the MAS; and (4) the application scenario, the colony of *Nothomyrmecia macrops* ants.

2.1 The top-level ontology

A model is ontological when it explicitly makes use of ontologies. In principle, the ontology is the key element for allowing the agents defined with this model to interpret the incoming information, so that the agents can perform their tasks (e.g., planning, goals identification, etc) once such (incoming) information is represented in a useful way.

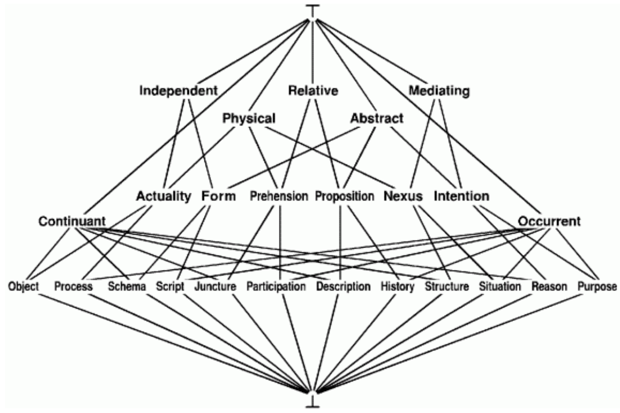

Figure 1: Lattice of top-level categories

The Sowa's top-level categories [21] have been taken as a reference for designing the agent's ontology. This author defines three classification criteria for formalising the ontology:

(a) It distinguishes among abstract and physical concepts according to the spatial-temporal location. For example, an abstract entity is the proper information, independently from the physical medium it is captured from. The same information can be included in a tape, a newspaper, etc, although it is always the same information independently from its location in time and place. On the other hand, a physical entity is defined as having both a spatial and a temporal location. Other attempts for defining physical entities, such as the energy or the mass would imply the exhaustive study of physical theories.

(b) According to the dependence degree with respect to other entities, an entity can be either independent, relative, or mediator. The existence of an independent entity does not depend on being related to other entities. However, a relative entity can only exist if it is related to other entities. Finally, a mediator entity establishes a relationship between two entitites.

(c) According to the temporal stability of its identity, an entity can be either continuous or occurrent. An entity is continuous when its identity is recognizable during a non-empty temporal interval. An entity is occurrent when it cannot be associated to a concrete temporal interval (e.g., the human being's life).

If we combine these distinctions, 12 concepts are formed, namely: Object, Process, Schema, Script, Juncture, Participation, Description, History, Structure, Situation, Reason, and Purpose. Figure 1 shows the lattice defined by the previous distinctions and the concepts derived from them.

2.2 A natural categories-based agent

We use in this work the definition of agent given in [21]: an agent is an animate entity capable of performing tasks with a specific purpose.

An animated entity is one that has soul or anima (from the Greek word psyche). Aristotle defined the psyche as the principle a living entity is determined by, but in his efforts for classifying all the existing things, he also defined the processes an animated entity should meet, namely: nutrition, perception, desire, locomotion, imaginery and thought. In this work, the agents of the artificial society will be assumed to possess the capabilities described in the following lines.

2.2.1 Nutrition

Nutrition could be defined as the "Purpose"[1] objective established for the agent with the intention of keep maintaining or improving their existence. This implies that the agent must have knowledge of its own existence and be aware of the fact that it is independent, actual, and continuous, that is, an object "Object" according to Sowa's top-level categories. Furthermore, it must be capable of measuring how good it feels in order to know its capability to survive.

It is said that an agent is capable of performing the nutrition process when:

1) it knows about its own existence; and

2) it knows its health condition; and

3) it has defined objetives in order to be always in his best health condition.

2.2.2 Perception

Perception consists in receiving information from the environment. The agent must know its environment as an entity separated from itself, and it must periodically receive information through its input channels "Juncture".

It is said that an agent is capable of performing the perception task when:

1) it knows about the existence of its environment; and

2) it has a set of input channels that connect the environment to the agent; and

3) it is capable of cataloguing the information from the environment in one of the concepts defined in the agent's ontology.

2.2.3 Desire

By its definition, an agent wants to meet its objectives in order to reach a specific state, which has been considered to be better than the current one. The agent's state can be understood as its current situation "Situation", which would be comprised of all the instances interpreted in the last x time stamp units.

It is said that an agent is capable of performing the desire process when it has defined a series of actions to decide which states are better than others.

2.2.4 Locomotion

Locomotion is defined as the capability an entity has to move in its environment in both temporal and spatial dimensions. It is said that an agent is capable of performing the locomotion process when:

1) it knows that it has determined spatial and temporal locations; and

2) it is capable of modifying its location voluntarilly.

2.2.5 Thought

Thought consists in identifying the relevant aspects of the current situation and deducing the goals to achieve from those relevant aspects. Moreover, the agent will elaborate a (more or less general) plan to achieve each particular objective, or the subset of objectives chosen.

2.3 The agent's control

The following types of control modules have been designed for the agent:

2.3.1 Knowledge acquisition

The sensors of the agent receive information from the environment and compare this information with the current agent's state to identify the significant changes produced in the environment. That new information is interpreted by making use of the ontology and the (new) concepts underlying the current situation.

The agent has a memory where the most relevant situations and concepts are stored. The current situation progressively forgets concepts and these concepts are included into the agent's memory. These concepts will gradually loose importance if they are not reinforced and they will be finally forgotten.

2.3.2 Monitoring for identifying objectives

The agent evaluates the current situation and new objectives are generated to improve that situation. Moreover, these objectives stand as a part of the current situation. This module can also discard current objectives or modify some parameters of such objectives.

2.3.3 Planning and control

Plans are developed attending to the strategies defined for each objective. Then, the decision of which action or actions to perform at each moment is made. Each new situation implies the revision of the plan and deciding again the action to perform.

2.4 The ontological framework

An existing ontological tool, called ONTOIN, has been used for the construction of the ontologies presented in this work because this tool allows for editing inconsistency-free ontologies in a graphical, friendly manner [8;9]. The ontological schema included in this tool can be described as follows. In ONTOIN, an ontology is comprised of a set of concepts, each having a set of attributes. Each attribute has a range of possible values. An attribute can be either specific to that concept or inherited from another concept of the same ontology. Here is where the relationships appear in this ontological model, and a relationship always involves the participation of two concepts.

So far, ONTOIN allows for defining taxonomic (is a class of) and mereological (is a part of) relations, although this tool is currently being expanded to cover a wider range of relations, such as topology, causality, influence, etc. Returning to the nature of the attributes, if an attribute A from a concept C1 is inherited from a different concept C2 then there exists a taxonomic relation between C1 and C2, written IS-A (C1, C2). Moreover, in this model attribute (multiple) inheritance is permitted for taxonomic organisations.

On the one hand, taxonomic relations are assumed to hold all irreflexivity, asymmetry and transitivity. On the other hand, mereological relations are assumed to hold irreflexivity, asymmetry and non-transitivity. The axiomatic ontological component is also taken into account in ONTOIN since different types of axioms can be represented in this ontological model: (1)

[1] See [21] for further information about Top-Level Categories

Internal structure-based axioms, that is, axioms that result from the relation 'concept has attribute'; and (2) *other axioms*, derived from some properties concerning relationships between concepts for taxonomic and mereological organisations.

The ONTOIN tool does not only is useful for editing ontologies but it can also be used for integrating different ontologies specified with the edition facility. The integration framework used in the ONTOIN tool is adapted from the one presented in [9]. For this work, only the editing facility has been used since our goal was to build the ontologies that represent the different agents involved in the MAS.

3. Coordination in the MultiAgent System

A basic aspect in the development of a MAS is to coordinate all the agents. The principle of rationality can be described as follows: "if an agent has knowledge that one of its actions will lead to one of its goals, then the agent will select the action" [17]. In order to apply it to an MAS, it must be redefined in order to refer to the overall system. This is described by the social level hypothesis: "There exists a computer level immediately above the knowledge level, which is concerned with the inherently social aspects of the MAS" [15].

There exist different approaches for modelling the social aspect of the agents. For instance, in [3] the author models explicitly social actions and in [18] new categories of social agents are presented.

The design of social laws for artificial social systems is a good approximation between a totally centralized approach and a totally distributed one.

In an artificial social system, each agent must decide according to its current state and to the state of its accessible environment. In a distributed approach whatever conflict between agents would imply to establish a negotiation process between the involved agents. Social laws impose constraints to the agents' activities so that conflicts are avoided and they ensure that the agents are capable of achieving their objectives and the society can meet its global objective.

Designing social laws is a quite complex task, so it would be very helpful to have a metric for measuring the goodness of a particular social law in comparison to other laws. In [11], several criteria that have been considered useful are defined, namely: minimal social laws criteria, and simple social laws criteria.

3.1 Minimal social law

Each agent has both a series of objectives to achieve and a series of strategies to accomplish those objectives. Besides, objectives at a social level have been defined, and these objectives must be met at every moment in order to ensure the survival of the society.

A social law is useful when it guarantees the achievement of the objectives at a social level and allows each individual agent to achieve their individual goals in one manner at least.

Thus, a social law is minimal when it is useful and it permits the agents to be as free as possible, that is, there is not another useful social law that offers the agents more alternatives to achieve their objectives.

3.2 Simple social law

The simplicity criterion for social laws consists in creating useful social laws that allow the agents to make their own decisions by taking the least possible number of information captured from the environment into account.

A social law imposes a series of contraints over the actions an agent must take under determined circumstances. A useful social law is said to be simpler than another useful social law when it is easier for the agent to know whether an action can be done than with the other law. By using simple social laws, the agents are less dependent on their sensors and allow the agents to develop simpler strategies.

3.3 The formalization of the system

The following definitions establish the formal framework for the concepts of the study of the agent's model used in this work.

3.3.1 The environment

The environment can be defined as a set of tuples <location, cell> with a specific topological structure. This structure is determined by the connectivity of the cells. Let us now formalize the concepts location and cell:

Location: It is a bidimensional vector (x,y) that defines the cell position in the environment. Two cells are said to be connected (i.e, adjacents), when the arithmetic difference between any component of their location vectors is equal to 1.

Cell: It is a tuple <attributes, objects>. Attributes are the physical properties of the environment, such as temperature, pressure, etc. On the other hand, the objects are the independent entities placed in that particular cell.

3.3.2 Objectives, strategies, and actions

The objective of an agent is a tuple <expression, strategy> where:

Expression: It is a function $f: S \rightarrow Z$, where S stands the agent's states and Z is the set of positive and negative numbers. Thus, given the current situation $s \in S$, f(s) is the completion degree of the objective. The objective intends to reach a state in which f(s) is maximized.

Strategy: It can be defined recursively as follows:

- ❑ A function $g: E \times S \rightarrow P(A)$, where E stands for the environment state, S stands for the agent state, and P(A) stands for the power set of actions that can be performed.
- ❑ A sequence of goals.

An action defined on the environment (or on the agent) is a function $h: E \rightarrow E$ (or $h': A \rightarrow P(A)$), where E stands for the environment state (converserly A stands for the agent states). Therefore, an agent can perform actions either on the environment or on other agents.

It can be said that there does not exist defined strategies for achieving social goals because it is the set of all the agents' strategies, which allows for the achievement of the expression.

3.3.3 The social laws

In order to establish the social laws, an initial hypothesis must be formulated. Our initial hypothesis is this: "with the defined strategies, the social goals can be achieved. Moreover, each individual agent can also achieve its own goals with those strategies".

A social law is a subset of strategies which cannot be modified by any agent individually. A social law is useful while the initial hypothesis is valid. A social law is minimal if there is not a smaller subset of strategies that conforms a useful social law. A social law is simple when the strategies that are permitted for the agent uses the least possible information for establishing the possible actions to be performed.

Furthermore, the social laws are incorporated into the ontological model as axioms of the domain, that is, they must always hold in order to ensure the consistency and correct evolution of the MAS. This guarantees that the social laws are held and the agents' interactions are constrained by these social laws or axioms of their ontological model.

3.3.4 The multiagent system

The multiagent system is a tuple <E, L_i, IC, A, S, O_i, O_s>, where:

- E stands for the sequence of tuples <environment_state, time stamp>
- L_i: It is the sequence of tuples <ant_state, time stamp>
- IC represents the set of initial conditions for both environment and the set of agents.
- A is the set of actions that can be performed by an agent on the environment and on other agents.
- S stands for the set of strategies defined for the system.
- O_i represents the set of goals defined for each agent.
- O_s is the set of social goals.

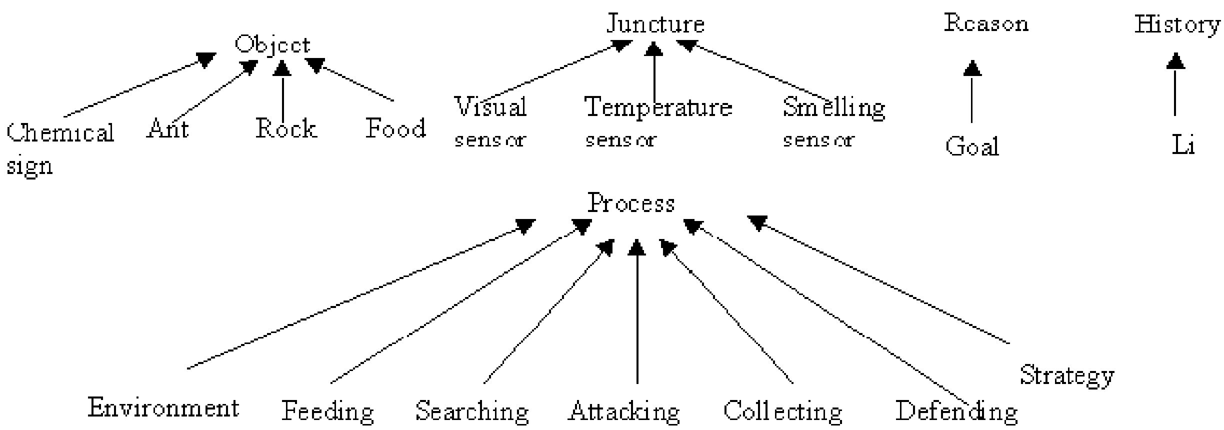

Figure 2. The natural categories for some of the most significant element of the MAS

4. The scenario: A colony of Nothomyrmecia macrops ants[2]

Nothomyrmecia macrops is one of the most known and ancient ant species. It is believed that it is one of the first species and it is characterized by having a very simple social organization.

There are three types of adult ants, namely: the queen ant, the worker ant, and the soldier ant. Each ant type provides certain funcionality to the society:

(1) Queen ant: the survival of the specie depends on the queen ant because it is responsible for the reproduction of the specie.

(2) Worker ant: they are in charge of collecting food, taking care of the eggs and keeping the maggotss in good temperature and feeding condition.

(3) Soldier ant: they are in charge of defending the colony from the attack of enemies.

The eggs, which are put by the queen ant, are moved by the worker ants to a place with an appropriate temperature. The maggotss, which must be fed by the workers until they become adult, come from these eggs.

These ants have a unique chemical sign used to identify them, and this characteristic permits other ants to identify whether they belong to the same specie and the type of ant it belongs to. Furthermore, they have the capability of leaving other chemical signs in order to indicate the path to an area with food or to an enemy. They have antennas on the head that can be used for communicating with other each other (i.e, communicating the existence of enemies, asking for help, etc).

5. Results

In this section, the model obtained from the problem description is introduced. First, the ontology used by each individual ant is described. Then, the different agent's control modules are exposed, and finally the social laws that coordinate the

[2] Characteristics from other species have also been included because they were considered to be interesting for studying the social system

multiagent system are presented. Figure 2 shows the categorisation for some of the most significant elements of the multiagent system according to Sowa's natural categories.

5.1 The multiagent system

The model formalized in subsection 3.3.4 is particularized now for the application domain chosen in this work. All the relevant aspects are intuitively described in the following lines:

- Specifying the cell attributes that are part of the environment: temperature and smelling.
- Defining the different classes of objects that can be found in a cell: an ant, food, or a rock.
- Specifying the state of the agent in terms of its smelling, health, current strategies, and sensors value.
- Defining the actions that can be performed on the environment: move (direction); eat; grasp(object); leave(object); put an egg; leave sign.
- Defining the actions that can be performed on another agent: touch (movement).
- Defining the strategies: going to the ant hill; searching for food inside the ant hill; searching for an empty cell; going outside the ant hill; searching for food out of the ant hill; carrying food to the ant hill; following a sign; searching for a maggott; warning another ant; take a maggott to a good place.
- Defining the objectives of each agent: feeding itself; searching for food inside the ant hill; staying at the ant hill; the survival of the specie; searching for an empty cell; collecting food; searching for food out of the ant hill; feeding maggotts; keeping maggotts safe; asking for help; finding a new task to perform.
- Defining the social objective: keeping the queen alive.

5.2 The ontology

The main elements of the ontology modelled are the environment and the objects that can exist in it, the senses of an ant, its objectives, its strategies for achieving its goals, and the primitive actions that can make on the environment.

5.2.1 The environment and its objects

The environment is formed by a set of cells in a rectangular structure. Each cell is one of the locations in two dimensions, and each cell has a determined temperature and has a specific smelling, which can be a mixture of different primitive smellings. A cell can contain at a particular moment an ant, food, or an obstacle (e.g., a rock).

An ant can be either adult or not, and it can be considered by other ants as friend or enemy, attending to the specie it belongs to. An adult ant, according to its social role can be queen, worker, or soldier. The ant's condition is formed by its health, its safety sensation, and its stack of goals to achieve. The food is an object with a concrete energetic value. The rocks are a physical obstacle that the ants must avoid. A part of the ontological modelling of the objects that exists in this application domain can be found in Figure 3. There, the ontology is edited by using the ONTOIN tool mentioned in subsection 2.4.

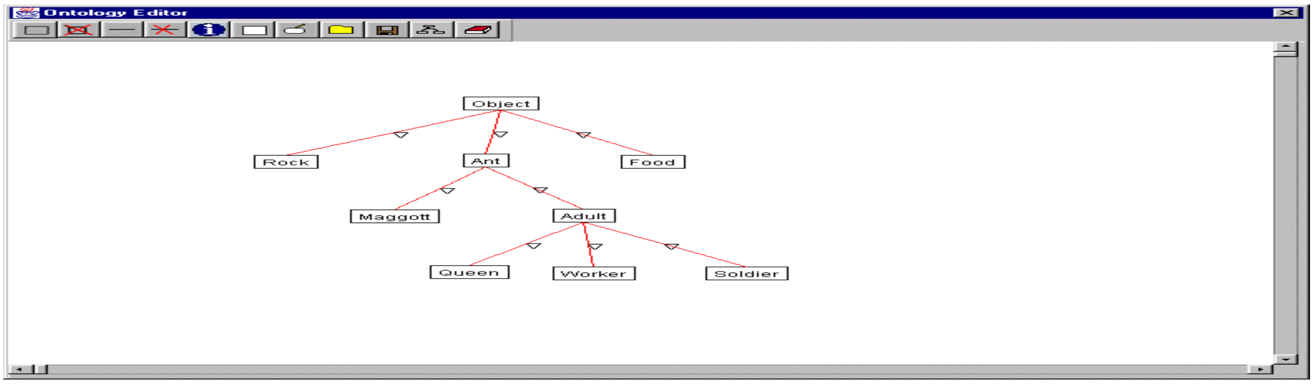

Figure 3. Editing the ontology with the ONTOIN tool

5.2.2 The ant's senses

The ant has three sensors used for obtaining information from the environment. These three sensors are:

(1) Chemical sensor: it is used for identifying smellings in a determined radius. The ants give off a unique smelling through which they can communicate to other ants the specie they belong to, the type of ant, and even the exact ant; it acts as an identification card. This can be useful for the same ant to know, for instance, the path it has used by following the sign it previously left. Moreover, they are able to leave on purpose other chemical signs attending to the task they perform so that it is possible to indicate the path to an area with food or to an enemy.

(2) Visual sensor: the sight is one of their less developed senses so that its scope is shorter than that obtained with the smelling. Despite this fact, it can be useful for detecting the other ants' head movements. These head movements have a meaning and they are useful to tell another ant about the need of help for attacking an enemy, collecting food or for other different tasks.

(3) Temperature sensor: it is used as a reference when they look for places with appropriate temperatures to leave the food, the eggs or the maggotss.

5.2.3 The objectives, the strategies and the actions

The objective of every ant is to maintain its level of energy and security into an acceptable (pre-defined) range of values. The strategy for keeping the nutritional level is based on detecting when its health condition has reached certain threshold and if so, proceed to search for new food. Concerning the secutrity issue, the ant can take shelter in the ant hill or asking other ants for help; otherwise it will fight.

The queen ant’s objective is the survival of the specie. Its strategy consists in putting eggs periodically whenever she has a good health condition.

The worker ants have two social objectives: (1) collecting food; and (2) taking care of the maggots. In order to collect the food, they can go out and searching for food or they can try to follow the sign of another worker ant which pursues the same goal. Then, the food will be stored in the ant hill, particularly, in areas with appropriate temperature for its conservation. For taking care of the maggotts, some worker ants will feed them. They can also be in charge of moving the eggs and the maggotts to areas with the most appropriate temperature. Normally, an idle worker ant will wander in the ant hill until finding a new task to perform, or it will go out of the ant hill and search for food.

The soldier ant’s goal is to keep the colony safe against enemies.The strategy for achieving it consists in staying close to the ants it must defend. The degree of security an ant has depends on two factors: (a) the number of soldier ants that ant has around it; and (b) the number of enemies that can be detected by both ants (i.e. the worker and the soldier one).

In the current design, the starting point is an ant colony which has no intention of conquering other ant hills. However, the possibility of the appearence of enemies from other ant species has been reflected in the model. Then, an ant from the other species, which belongs to the environment, will have as its objective to attack every ant from the rest of species. When attacking, an ant can bite, and the soldier ants can also segregate a harmful acid.

The primitive actions an ant can perform over the environment are: (1) moving in whatever direction; (2) eating food; (3) biting another ant; (4) grasping an object; (5) leaving an object; (6) segregating acid; (7) putting an egg; (8) moving the head; and (9) leaving a chemical sign.

5.2.4 Contribution for modelling the MAS

In this subsection, we explain the contribution of the ontology for modelling the MAS through the exposition of an example. Let us suppose that we have a worker ant which has to collect food. Then, the ant has two possibilities: a) going out and searching for food by itself; b) going out and follow the chemical sign of another ant which pursues the same goal. Each agent is provided with an ontology which specifies all the actions it can perform and all its static knowledge about the world. For instance, this is a summary of the processes a worker ant has in its ontology defined: go_to(place), search(object), collect(object), smell(object), store(object, place). Therefore, when a worker ant is at the ant hill and wants to search for food by itself, the sequence of actions can be roughly described as follows: (1) go_to (out_of_ant_hill); (2) search (food) (it can imply to move to the place where the 'food' is); (3) collect (food); (4) go_to (ant_hill); (5) search (safe_place); and (6) store (food, safe_place) (it can imply to move to the 'safe_place').

On the other hand, if the worker ant wants to follow another ant's chemical sign, the actions sequence would be the following one: (1) go_to (out_of_ant_hill); (2) smell (chemical_sign); (3) go_to (place_indicated_chemical_sign); (4) collect (food); (5) go_to (ant_hill); (6) search (safe_place); (7) store (food, safe_place).

All these processes belong to the ontology and must obey the social laws defined for the MAS and reflected into the ontology as axioms. Each ant possesses an ontology which is all the static knowledge the agent has about the MAS it belongs to. Each ant's ontology depends on its role, although ants with the same role have the same ontology since the can perform the same processes and they have the same goals. However, all the ontologies are based on a global MAS ontology which contains the overall functionality of the system and is (partially) reused for generating the particular ontologies for each type of ant.

6. Conclusions

In this work a multiagent system has been presented that attempts to partially simulate an ant colony. One of the currently most significant tools for representing knowledge, the ontologies, has been used for modelling the agents' internal structure, so that our model can take advantage of the main benefits of the ontological representation, namely knowledge reusability and shareability. All the agents share the same vocabulary since their particular ontologies come from a common, global one so that they can directly share information and distinctions. In this way, the groups of agents do not need to develop a common lexicon as it is needed in other approaches (see [22]).

The ontologies used for modelling the agents are based on the top-level categories established in [21] so that every single entity that exists in the agent's world must belong to one of the twelve basic categories. Indeed, as it can be observed in Figure 2, the concepts that appear in our application domain correspond to natural categories defined in the quoted work.

In particular, in the Artificial Society modelled here agents are assumed to possess a set of capabilities that guarantee their ‘animated’ character. These are nutrition, perception, locomotion, desire and thought. In order to make these capabilities operative by the agents, various types of control modules have been implemented. Such modules allow the agents to perform knowledge acquisition, to monitor their situations for identifying objectives and to perform planning and control as such. The complexity of such control modules will depend on the complexity of the application domain since the manner in which nutrition, perception, locomotion, desire and thought are implemented differs from an application domain to another. Furthermore, different domains might require different 'psyches'.

An ontological framework that allows to build both inconsistency-free taxonomies and partonomies has been utilised for modelling ants’ communications. The concepts for the resulting ontologies are all grounded on the above mentioned natural categories, and include for each ant its conceptualisation about all the environment (and the objects it contains), its senses, its objectives, its strategies and the actions to be taken.

To end, we have also described the social laws that must govern the MAS designed in our work. The organizational rules used in [25] can be considered similar to the social laws here used because they indicate the safety properties of the organization.

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8. References

[1] Brooks R.A. (1991a).'Intelligence without representation', Artificial Intelligence, No 47, p.p. 139-159.

[2] Brooks R.A. (1991b). 'Intelligence without reason', Proceedings of the Twelfth International Joint Conference of Artificial Intelligence, Darling Harbour, Sydney, Australia 24-30 August, Morgan Kaufmann, p.p. 569-595.

[3] Castelfranchi, C. (1998): Modelling social actions for AI agents. Artificial Intelligence 103: 157-182.

[4] Chandrasekaran, B., Josephson, J.R., & Benjamins, V.R. (1999): What are ontlogies, and why do we need them. IEEE Intelligent Systems, 20-26.

[5] Cyc Proyect, The. http://www.cyc.com/cyc-2-1/cover.html

[6] Duineveld, A.J., Stoter, R., Weiden. M.R., Kenepa, B., & Benjamins, V.R. (1999): WonderTools? A comparative study of ontological engineering tools. International Journal of Human-Computer Studies 52:1111-1133.

[7] Epstein J.M. & Axtell R. (1996): Growing Artificial Societies, MIT Press, Cam.

[8] Fernández-Breis, J.T. & Martínez-Béjar, R. (2000a): A web-based framework for integrating knowledge. Expert Systems With Applications 18(4): 315-330.

[9] Fernández-Breis, J.T. & Martínez-Béjar, R. (2000b): A cooperative tool for facilitating Knowledge Management. Industrial Knowledge Management: A micro-level approach: 123-138.

[10] Fernández-Breis, J.T., Paniagua-Arís, E., & Martín-Rubio, F. (2000): Analysis of Multi Agent Systems for representing human organisations (in Spanish). SEID'2000, Orense, Spain.

[11] Fitoussi D. & Tennenholtz M. (2000): Choosing social laws for multi-agent systems: Minimality and simplicity. Artificial Intelligence 119: 61-101.

[12] Fridman Noy N. & Hafner C.D. 2000. Ontological foundations for experimental science knowledge bases. College of Computer Science. Northeastern University. Boston, Massachusetts, USA.

[13] Goldspink C. (2000): Modelling social systems as complex: Towards a social simulation meta-model. http://www.soc.surrey.ac.uk/JASSS/3/2/1.html

[14] Gruber, T.R. (1993): A translation approach to portable ontology specifications. Knowledge Acquisition Journal 5:199-220.

[15] Jennings, N.R., & Campos, J.R. (1997): Towards a social level characterisation of socially responsible agents. IEEE Proceedings on Software Engineering 144(1).

[16] Minsky M. (1987): The Society of Mind, Picador, London.

[17] Newell, A. (1982): The knowledge level. Artificial Intelligence 18:82-127.

[18] Paniagua-Arís, E., Martínez-Béjar, R., Palma-Méndez, J.T., & Martín-Rubio, Fernando (2000): Towards a Teleo-Social Agent Category. Third International Conference on Knowledge-Based Intelligent Information Engineering Systems, Adelaide, Australia.

[19] Software Agents: An Overview. British Telecommunications. http://www.labs.bt.com/projects/agents/publish/papers/review1.htm

[20] Sowa, J.F. (1995): Top-level ontological categories. International Journal of Human-Computer Studies 43:669-685.

[21] Sowa, J.F. (2000): Knowledge Representation. Logical, Philosophical and Computational Foundations. Brooks-Cole.

[22] Steels, L (1997): Constructing and Sharing Perceptual Distinctions. Coupling of meaning creation and naming games in software experiments. In: van Someren, M. and G. Widmer (eds.) (1997) Proceedings of the European Conference on Machine Learning. Springer-Verlag, Berlin.

[23] Steels, L. (1995): When are robots intelligent autonomous agents? Journal of Robotics and Autonomous Systems. 15 (1995) 3-9

[24] Studer, R., Benjamins, V.R., & Fensel, D. (1998): Knowledge engineering, principles and methods. Data and Knowledge Engineering 25:161-197.

[25] Zambonelli, F., Jennings, N.R., Wooldridge, M. (2001). Organisational rules as an Abstraction for the Analysis and Design of Multi-Agent Systems. International Journal of Software Engineering and Knowledge Engineering (to appear)