Modelling Interactions Between Autonomous Agents

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Abstract

In the framework of designing programming environments based on the paradigm of autonomous agent systems, we conceived an interaction model based on the notions of charge and force.

In a multi-agent system, an agent is defined as an autonomous entity composed of an agent's kernel and charges forming an envelope around this kernel. An agent perceives the other agents exclusively through sensors attached to his charges. Therefore all the dynamics of the system is governed by charges.

The introduced interaction model supports two kinds of dynamics: an internal dynamics obtained by changing the charges inside an agent, and an external dynamics obtained by the agents movements through the environment. These dynamics enable the agents to vary jointly the forces acting on them and the forces they generate.

Because the high level semantics of the charges is not fixed by the model, the model may be used as well for modelling high level interactions, like psychological relations, as for modelling low level interactions, like elementary interactions used in artificial life.

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1. INTRODUCTION

In the framework of designing programming environments based on the paradigm of autonomo agent systems, we conceived an interaction model based on the notions of charge and force, startir from the idea that attraction and repulsion, the essential basis of physical, chemical or biologic systems, are more elementary notions than communication. Under this hypothesis, we pretend th these notions are more suited to formalize autonomous behaviours than other notions, which a straightaway too much cognitive.

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The goal of this paper is to justify and to describe this interaction model and to show its expressi power and importance for the research domain of multi-agent systems. The first section discusses tl conceptual differences between interaction and communication. The second section introduc previous attempts in modelling interaction. The third one is a formal presentation of our model charges. In the forth section, we evaluate the expressive power of the model and we give son perspectives. In the conclusion, we recapitulate the introduced notions and their interest for mul agent systems.

2. COMMUNICATION VERSUS INTERACTION

In this section, we justify our interest in pure interactive models instead of communicative models f multi-agent systems (cf. [Ludwig, 1994]). First, we introduce interaction and communication befo connecting them through a metaphor.

We define **interaction** as a dual action between agents, with an emitting action and a perceivir action. The **emitting action** of an interaction is an action performed by a certain agent. An action defined as a phenomenon, whose effects can be observed. The **perceiving action** of an interaction done by one or more agents. Therefore modelling interactions between agents can afford black b properties of agents: it is an external and incomplete description of exchanges (cf. [Courant et a 1994]).

One usual way to see interaction, is to assume that the only actions accessible to agents are actions v the environment and consequently that the only contact agents can have occur through tl environment. Therefore, the environment is responsible for the **perceivability** of actions.

Due to the perceivability criterion upon which lies the existence of interactions, it is obvious that tl interaction between agents is grounded on the properties of the medium in which the agents evolv Therefore a model of interaction may be given by a global law related to a given environment. Such model can be of physical, chemical or biological nature (see also [Brooks et al., 1993]).

Communication is defined as a relation between concepts belonging to different agents (cf. figure 1 The concept to be communicated is said to be the **emitted concept** and the concept, that the receivir agent builds up by communication, is said to be the **received concept**. A concept, belonging to certain agent, depends on his knowledge base and on his abstraction capabilities. Communication therefore a complex activity which depends on the agents' individual features and the possibility agents to be in contact, i.e. to interact. Therefore modelling communication between agents requir the total transparency of agents (white box): it leads to an internal and complete description exchanges.

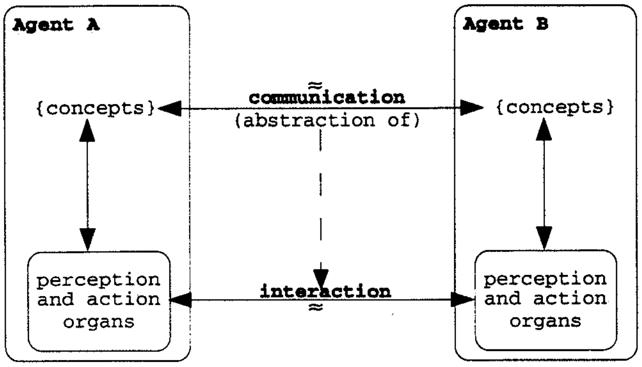


Figure 1. Interaction and communication connected through a metaphor

In order to communicate a given concept, called emitted concept, an agent A has to choose some actions. This choice is a dependency relation (action choice relation) inside the agent A, depending on his individual knowledge and abstraction capabilities. This relation is not observable from the outside. The relation between the action and the perception done by an agent B is an interaction enabled by the perceivability hypothesis of the environment. The relation between the perception and the deduced concept, called received concept, is a dependency relation, depending on the individual knowledge and abstraction capabilities of the agent B. In real systems, this relation is not observable from the outside.

As shown in the figure 1, communication is then a relation between concepts, and is defined as the composition of the action choice relation, the interaction and the abstraction relation. This schema represents a metaphor (cf. [Hobbs, 1992]), in which a concept from one context, i.e. agent, is in relation with another concept of another agent.

Because interaction is in general only a similarity relation between the action and the perception, communication is also only a similarity relation between the emitted and the received concept. If the two dependency relations are replaced by one determining relation, and if the interaction becomes an identity relation, then communication becomes an identity relation between concepts, too.

It should be outlined that in general only the interaction relation can be observed from outside the agents. The two dependency relations are proper to the respective agents and the communication relation, between concepts belonging to different agents, is obtained by the metaphor.

These reflections show that a great interest should be brought to interaction instead of communication, because interaction is more elementary and the only one that is observable.

3. PREVIOUS ATTEMPTS IN MODELLING INTERACTION

In the context of problem solving, robotics and distributed artificial intelligence in general, various models have been proposed for interaction.

The first model for interaction uses **accointances** (cf. [Agha, 1986]). Accointances may be seen as transparent sensory and actuator ports. They enable agents to sense and to act on the outside world without any knowledge about the coexisting agents. A natural way to realize, for example, the producer-consumer problem is to use accointances. Neither the producer needs knowledge about any consumer, nor the consumer needs any knowledge about a producer. The only thing the producer is interested in, is to produce certain entities and to get rid of them. The consumer is only interested in these entities and don't need to know who produced them.

An other model is based on **crumbs** and the pheromone model in biology. All interactions between individuals of a "crumb" system is based on the fact that some agents emit crumbs and that other agents collect these crumbs (cf. [Hußmann, 1992]). This exchange of crumbs enable agents to mark paths, for example.

A third model is the **propagational** model, represented by gradient fields and above all by potential fields (cf. [Payton, 1990]). Potential fields are widely spread in robotics (cf. [Krogh, 1984], [Clark et al., 1991]) for path planning and obstacle avoidance. This method assigns (electrostatic) charges to goals and obstacles. A total field is then generated by the superposition of all elementary fields. I Arkin and Clark's systems, potential fields called schemas, are used to represent perceive information (obstacles) or elements of local planning (stay on path, go in one direction, go to goal etc.). The superposition of such schemas enables the robot to build up a representation of the world i which he is moving.

The main problem of this approach is that a robot can be trapped in a local minimum and he can't ge out anymore. This problem arises from the fact that no charge is attached to the robot and that th fields are static, because they only depend on local parameters of the charged entities. Potential field associated to the world are only used as a heuristic information. In [Clark et al., 1991], the solutio proposed to avoid local minima is to determine, for a given environment, the different adjustab parameters (see also section 4.3).

Potential fields can also be used for a pure reactive modelling of autonomous agents. The applicatio domain of potential fields, seen as an interaction model, becomes then much greater and richer.

4. INTERACTION MODEL BASED ON CHARGES AND FORCES

Now, we present a more general model based on the idea to use potential fields and induced forces fo interaction. This will not only enable us to avoid local minima in a robot application, but also t enlarge the application field of the notion of charge.

The model refers to a multi-agent system with **situated** agents: we suppose that **charged** agent evolve in an **environment** defined as a vector space, with adequate distance measure.

A **charge** is a typed attribute attached to agents. We call **virtual charge** the residual effect, produce in a certain point, by a real charge.

A **force** is the effect caused by a charged agent on another agent charged with the same type o charge. It specifies in this way the interaction between agents and is represented by a vector.

The following sections will now present the model in detail. We start with the notion of charge typ and then we illustrate the model through an example.

4.1. CHARGE TYPE

Formally, a charge type is defined by the following attributes:

- a domain of intensities;
- a set of manipulators;
- an interaction protocol;
- a propagation function;
- a force function;
- a composition function.

4.1.1. Domain of intensities

The domain of intensities of a charge type is defined by:

- a sign;
- a domain of absolute values.

Basically the sign is bivalent {+,-}. The null intensity inactivates the charge and must therefore b contained in the domain of absolute values.

4.1.2. Set of manipulators

A manipulator is defined as a function of (domain of intensities) Æ (domain of intensities) and allow the local evolution of a charge. The internal dynamics of charges inside an agent are thereby realize by the manipulators. The set of manipulators may contain for example, the assignment which is th most general manipulator, the incrementation or the decrementation with fixed or relative offset, the null-setting in order to inactivate a charge.

4.1.3. Interaction protocol

The interaction protocol of a charge type defines the relation between charged agents, depending on the signs of the present charges. For charges with bivalent signs, two basic models can be cited:

- the **classification** protocol: charges with identical signs attract each other and charges with different signs repel each other;
- the **coupling** protocol: charges with different signs attract each other and charges with identical signs repel each other.

Note that the terms of classification and coupling, denoting the two interaction protocols, are justified by the effects they produce on simple multi-agent systems, ruled by a single type of charge, with equal and invariant intensities. A system, ruled by the first interaction protocol, produces two groups of agents, one charged positively and the other negatively. This generates a polarization of the environment. A system of agents, acting according to the second protocol, will produce couples of agents.

4.1.4. Propagation function

The propagation function specifies a virtual charge, which represents the potential field associated to a charge. The virtual charge VC in a point p2 is the result of the propagation of the real charge C situated in a point p1 different from p2. It is defined as VC = P(C, p1, p2), where P(C, p1, p2) is the propagation function.

4.1.5. Force function

The notion of force represents the interaction between agents. The force function defines the intensity of the force acting on an agent, with charge C located in a certain point, when a virtual charge VC is induced by another agent. This function F(C, VC) depends on the charge of the agent and on the virtual charge. It respects the border conditions F(0,_)=0, F(_,0)=0. These conditions are natural as the force expresses the interaction between agents (if the agent is not charged, or if the environment contains no other charged agent, there can be no interaction). The force vector lies on a line depending on the two points, where the charged agents are located. Its origin is the point where the considered agent is located and its orientation is specified by the interaction model. We call elementary force the representation of one interaction between a couple of agents.

4.1.6. Composition function

The total force, perceivable by a given agent, represents the interaction between all the other agents and himself. The composition function specifies, for a given agent, the resultant of several elementary forces (for example, the vectorial sum), called total force.

4.2. IMPLEMENTATION

In this section, we describe how the model can work in the context of multi-agent systems.

The model of interactions based on charges and forces has already been embedded in an agent specification language. Different specification modules are used in order to specify the environment, the charge types, the agents kernels and the system, binding an environment, the specified types of charges and the different agents. Agents are seen as being composed of an envelope structure, the charges, and an internal structure, the kernel. All agents belonging to the given system evolve inside the specified environment.

The figure 2 shows a procedural interpretation of the interaction model in a multi-agent system. The charges are part of the agent structure. Sensors inform a charged agent about his situation vis-à-vis the rest of the world by giving him the intensity and the orientation of the present total force vector. The force calculation process uses the propagation function and the notion of virtual charge to propagate real charges. The elementary force is then calculated by using the interaction model and the force function. The total force, perceivable by the agent, is generated through the composition of all the elementary forces. Figure 2 details the force calculation process attached to a given agent A.

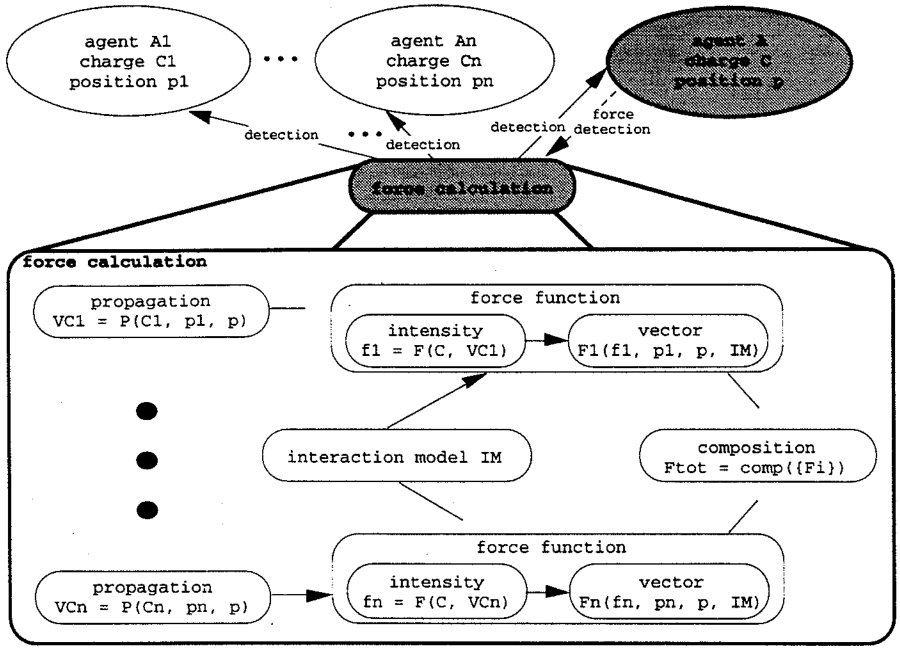


Figure 2. Procedural interpretation of the model

4.3. ILLUSTRATION

Now, we present the interest of the model through an example. We show that our model is capable catch the notion of schemas for obstacle avoidance, introduced by Clark and Arkin (cf. [Clark et a 1991]). We also show that our model allows to remedy the problem of local minima encountered wi potential fields.

The model used to avoid obstacles defined in [Clark et al., 1991] is to define potential fields arou obstacles with fixed and implicit charges. The intensity of such a field is adjustable by changing gain factor. The influence zone is a disk of adjustable diameter. For a given situation, the field is sta and independent of the robot.

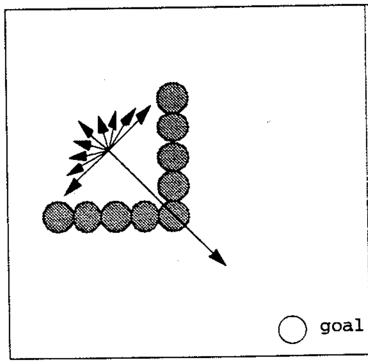
In our model, the obstacles and the robot will be loaded with charges that have a bivalent sign and t interaction protocol is the coupling protocol. Both obstacles and robots are charged positively, order to have a repellent interaction between robots and obstacles. The intensity of virtual charges defined in the same way as the field intensity of Clark's potential field (attenuation).

Robots and the goal have a second type of charge in common. This type of charge has a bivalent si and obeys the coupling protocol. Robots are charged positively and the goal is charged negatively order to generate an attraction between the robots and the goal. The intensity of virtual charges constant.

The major difference between Clark's field and our model is that we can specify the interacti between the robot and the obstacles by using a force function, which depends on the charge of t robot and the present virtual charges. The robot can change the intensity of his own charge and by t way change the forces acting on him.

In [Clark et al., 1991], the robot has to adjust, for a given environment, the gain and the sphere influence in order not to be trapped by a local minimum (cf. figure 3 and [Clark et al., 1991] for mc details). These values are ad hoc for this environment, but they are not necessarily well suited neith for another one, nor for a dynamic environment.

On the other hand, our model accepts explicit dynamic charges. Hence to get out of a local minimu a robot only needs to have a control level that detects if he has been trapped and consequently he c adapt his charge (cf. figure 4). This adaptation will increase the repellent property of the obstac against the attractive property of the goal. Therefore this method allows the robot to move correc even in dynamically changing environments.



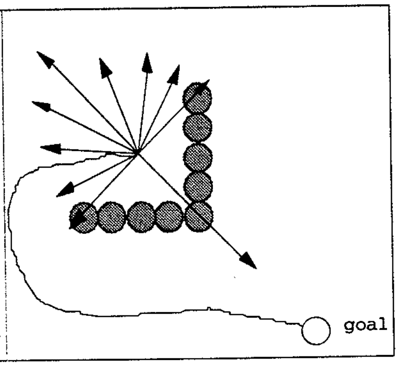


Figure 3. Canyon problem **Figure 4.** Robot is getting out

Figure 5 shows how obstacle avoidance may be achieved in the case of an environment with one goal in the centre, 12 immobile obstacles (cercles) and 10 mobile robots. Some special points of this simulation may be outlined. The robot starting from the upper left corner enters a canyon and after a certain time he is getting out by himself. The second point to note is that all the robots are mutual dynamic obstacles for each other as long as they have not yet reached the goal.

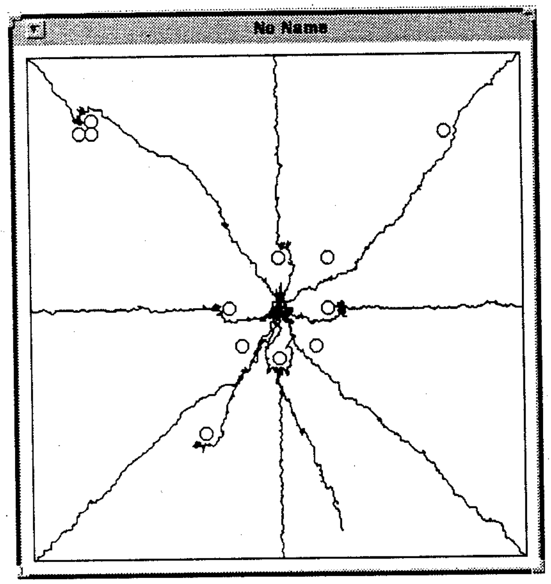


Figure 5. Ten mobile robots reaching a common goal

5. EVALUATION

In this section, we first analyse the expressive power of our interaction model and second we give some general perspectives for improving it.

5.1. EXPRESSIVE POWER

First we show some features of the expressive power through some attributes of the model and second we discuss more general aspects of the expressive power.

5.1.1. Expressive power through the attributes of the model

First we analyse some aspects of the propagation function which is part of the model. We defi virtual charges as follows: VC = C * PF, where VC is the virtual charge, C is the real charge and PF the propagation factor. In the case where virtual charges are underlying to an attenuation, PF loo like the representation of figure 6. Most physical charges underly such an attenuation, as for examp gravity or electrostatic charges. The propagation factor can also be of quite different shapes, as f example in figure 7, where virtual charges only exist in some regions around the central real charg This enables to model a selective and limited perceptibility in certain directions (North, East, We South).

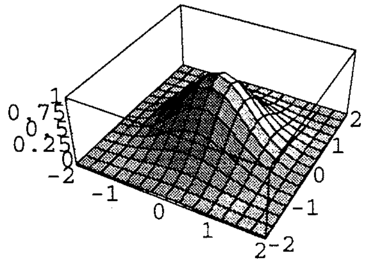


Figure 6. Attenuation factor

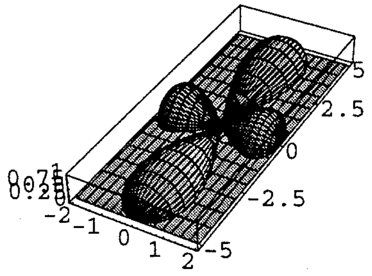


Figure 7. Propagation factor depending on relative positions

The second aspect of the expressive power of the model to be outlined is the orientation of the fo vector. We call a force vector to be **centred,** if it lies on the line between the two agents (cf. figure Its origin is the point where the considered agent is located and its direction is given by the interacti model. Most forces in physics may be modelled in this way.

Figure 8. Centred force vector

A **decentred** force vector is defined as follows. Let A1 and A2 be two charged agents, the line D perpendicular to the line {A1, A2}. D is splitting the plane in two half-planes, the attractive one a the repulsive one (cf. figure 9). A decentred force vector acting on A2 has its origin in P2 and extremity is either in the attractive half-plane or in the repulsive half-plane, according to t interaction model. This is for instance a mean to induce force fields structured as spirals.

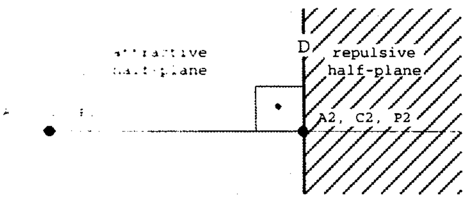


Figure 9. Decentred force vector

5.1.2. General aspects of the expressive power

The presented model has been defined to keep a great generality and a good expressive power. T kinds of dynamics, allowing agents to vary jointly the forces acting on them and the forces th generate, are supported by the model. These dynamics take root in the definition of virtual charg (potential field), via the propagation function. The first dynamics is internal to the charges. It allo to fit even non movable agents with adaptive capabilities: without moving, an agent adapts himself a certain situation, defined as a constellation of forces by changing his own charges. The second c is based on the agent's ability to move in the environment. This kind of dynamics is, for examp governing the fleeing behaviour of a pray in presence of a predator.

Because the high-level semantics of the charges is not fixed by the model, this opens up the field modelling a wide range of applications. The model may be used as well for modelling high level interactions, like psychological relations, as for modelling low level interactions, like elementary interactions used in artificial life and for the problem of obstacle avoidance in robotics.

5.2. PERSPECTIVES

The interaction model should be seen as a starting point to develop various interaction models. The importance of interaction versus communication is quite obvious, if we see interaction as a global law through out the environment and communication as a more abstract concept depending on local features of the involved agents, i.e. their abstraction capabilities.

Bertil Malmberg (cf. [Langage, 1968], page 57) describes the difference between speech and language in the following way: *Speech is a physical phenomenon. The act of speaking is devided in three phases: the production of a sequence of sounds, the transmission of this sequence via sound waves and the reception of the sound waves by a sensor. Language is an abstract phenomenon.*

In respect of this definition, we can consider speech, as it is described by Malmberg, as an interaction. The production of a sequence of sounds is done using the actuator vocal system, the transmission is done by the environment under the hypothesis that perceivability is guaranteed (no vacuum) and the reception is done using an acoustic sensor (ears).

In psychology (cf. [Psychologie, 1987], page 109 - 118), the behaviourist approach started with the hypothesis that the reason for animals not to speak, is perhaps a lack of adequate stimulations. This leads to some non concluding experiences of trying to make monkeys learn human spoken language. But other experiences of making monkeys learn a language based on graphical signs, were quite successful. A similar experience in machine language acquisition is described in [Feldman et al., 1990].

Brooks in [Brooks et al., 1993] also takes in account philosophical arguments based on the central hypothesis, that thought and language are grounded in physical patterns generated in our sensory and motor system as we interact with the world.

These different arguments should make us reconsider the construction of multi-agent systems. Starting from the richness of local features and interaction, our goal is to fill in the gap between low level behaviours and high level behaviours, like linguistic capabilities and cognition. To do this, we propose to build complex interaction models, starting with the interaction model based on charges and forces. For example, the model can be enriched in different ways:

- Inspired from physics, we can integrate the notion of spin, the main interaction types governing particles and attach dynamic behaviours to charges: oscillating behaviours may be used for dissipative structures modelling.
- Inspired from molecular biology, we can build various biosensors and allow the formation of complex structures resulting from elementary molecular and atomic interactions. This will lead us to enrich our model of multi-agent systems by dynamic types of agents and charges.

The agent's kernel may also be enriched by more sophisticated interfaces with the charge envelope, allowing, for example, to interpret variations of force intensities or allowing a kind of agent's consciousness about his own charges. This can be achieved by a generalization of the notion of charges, as basic constituents of the whole agent structure including both the envelope and the kernel. This will lead to a recurrent modelling of agents, which is a fundamental requirement to catch emergence phenomena.

An other perspective, supported by a more general analysis we have made on autonomy, is to model by charges the concepts of actualization and potentialization, which ground the antagonistic dynamics of natural systems (cf. [Lupasco, 1987]). This antagonistic dynamics can be obtained by encapsulating subsystems governed by the coupling protocol.

6. CONCLUSION

We proposed a model in which agents are viewed as charged entities and in which all the dynamics of a multi-agent system is governed by charges. An agent perceives the other agents exclusively through sensors attached to his charges, which can be seen as forming an envelope around an agent's kernel.

The notion of charges and forces has been defined as generally as possible. At this moment, th support two kinds of dynamics: an internal dynamics, by changing the charges inside an agent, and external dynamics, by the agent movements in the environment. In both cases the autonomy of t agents is seen as the capability of taking local decisions.

The model enables typed charges and the possibility of multiple-charged agents. So the dynamics the agents obeys the concurrent action of the charges. The definition of global criteria for t management of the charges belongs to the agent's kernel. The hedonistic policy for example, allo an agent to define priorities, depending on his internal state, his strategies, his objectives...Th hedonistic point of view is appropriated for modelling certain problems where the solution coinci with a stable state of the system. The search for satisfaction is the will to reach a certain constellati of forces. The satisfaction measure is a function of the detected forces and the strategy tries maximise this satisfaction, by the different dynamic features of the model.

The model is open for experimentations able to contribute both to distributed problem solving a artificial life. Because the high-level semantics of the charges is not fixed, the model opens up t field for numerous modellings yet to be made in the domain of systems of autonomous agents. T model based on charges and forces covers the whole of range of interactions from high lev interactions, as psychological relations, to low level interactions like the elementary ones used artificial life. Charges are able to catch phenomena like action coordination and competition, whi can be observed in social systems. Typed charges constitute a common language between agen surely a primitive one, but nevertheless with a great expressive power.

The integration of our model of charges in a prototype of agent description language is presently progress.

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