LEARNING AND CONTAMINATION IN VIRTUAL WORLDS

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1. INTRODUCTION

The most recent advances of artificial life scientific research are opening up a new frontier: the creation of simulated life environments populated by *autonomous agents*. In these environments artificial beings can interact, reproduce and evolve [4, 6, 15], and can be seen as laboratories where to explore the emergence of social behaviors like competition, cooperation, relationships and communication [5, 7] . It is still not possible to approach a reasonable simulation of the incredible complexity of human or animal societies, but these environments can be used as a scientific or artistic tool to explore some basic aspects of the evolution [1, 2, 3, 9, 10, 11, 12, 13, 14].

The combination of these concepts with robotics technology or with immersive-interactive 3D environments (virtual reality) are changing quickly well known paradigms like *digital life*, *man-machine interface*, *virtual world*. The virtual world metaphor becomes interesting when the artificial beings can develop some form of learning, increasing their performances, adaptation, and developing the ability to exchange information with *human visitors*. In this sense the evolution enhances the creative power and meaningful of these environments, and human visitors experience an emotion of a shift from *a simplified simulation of the reality* to a *real immersion into an imaginary life*. We may think that these realization are the first sparks of a new form of life: simulated for the *soft-alife* thinkers, real for the *hard-alife* thinkers, or a simple imaginary vision for the artists.

The key aspect of artificial societies is the potential to develop an internal knowledge in the community. This knowledge can be expressed through the ability to modify their behavior, structure and relationships in order to better adapt to the environment. In this paper we refer to several experiments where a community of artificial individuals, equipped with a personal neural network, autonomously develop a behavior to recognize and search for the food to survive. We explore several mechanism of learning: through genetics, through competition, through communication.

Some reference experiments can be found in the pioneer works of K. Sims [11] and D. Terzopoulos [15]. They developed interesting models for evolving digital creatures. In those experiments, they fix a specific task (swimming in a marine environment or winning a duel for the food) and trained the individuals through genetics selection or optimisation functions. The goal was to obtain creatures for computer graphics applications. In our approach the target is different: create continuous learning mechanisms to achieve complex task in social context like the development of an common language. The basic difference in these experiments is that we do not fix a specific target to reach. There is only a general goal: to survive. The digital creatures should be able to derive all the living functions (search for the food, competition/co-operation, communication) directly as priorities or intermediate goals to reach a better adaptation in the environment under an evolutive pressure.

Subsequently the digital communities developed along these experiments have been connected to an interactive installation where communication with humans is possible. The result is an immersive environment where humans can teach and feed the artificial individuals through their movements and exchange sound messages. Finally we describe a dance performance where this installation was used in a theatre. The artificial individuals, appearing as different shapes in a 3D virtual environment, learn to play with the dancers in real time, searching for the food, escaping from dangerous substances... and interacting with people in the theatre.

Fig 1: Picture from "Relazioni Emergenti", Siggraph 2000, New Orleans. The people interact with the living filaments inducing the life germination in the zones they approach. (C) Plancton Art Studio.

2. THE ALIFE ENVIRONMENT

The alife environment is a three-dimensional space where the artificial individuals (or *autonomous agents*) can move around. During the single iteration (*life cycle*) the individuals move in the space, interact with other individuals, exchange information, and reproduce generating another individuals.

2.1 THE INDIVIDUAL MODEL

The data structure of the individual is composed by the *genotype* and *status*. The genotype includes behavioural parameters regarding specie, dynamics, reproduction, metabolism and interaction. These parameters do not change during the individual life. The *status* parameters include dynamics and life parameters, and the current values of the information coded in the individual artificial brain. For each individual, these parameters change during life. A basic variable of the status is the *energy*. The energy is a sort of probability of surviving for the individual. It is gained through the food eaten by the individual at each life cycle, and is needed to move and reproduce. Low energy values can cause the death of the individual. An individual can die also for fights against other individuals or for accidental or natural death: when the individual age is over the average expected life the probability of death increases with the age.

THE INDIVIDUAL BRAIN AND THE SENSORS

The central structures of the individual are the sensors and the brain. The brain is divided in several zones (see fig. 2) in order to cover different tasks. The sensors to have the goal to achieve information from the environment surrounding the individual position. The sensors are characterised by a *scope range* in terms of distance of sensibility. In particular the individual has a smell sensor to locate substances, a taste sensor to decide the reaction to a substance, a touch sensor to identify the direct contact with another individual, a hearing sensor to hear sound messages and a see sensor in order to locate the other individuals.

Any individual is endowed with a small artificial brain composed by a neural network. For each task like movement, direct (contact) interaction, eating, sound emission a branch (sub-net) of the network is provided. All the branches share the same inputs but have different weights.

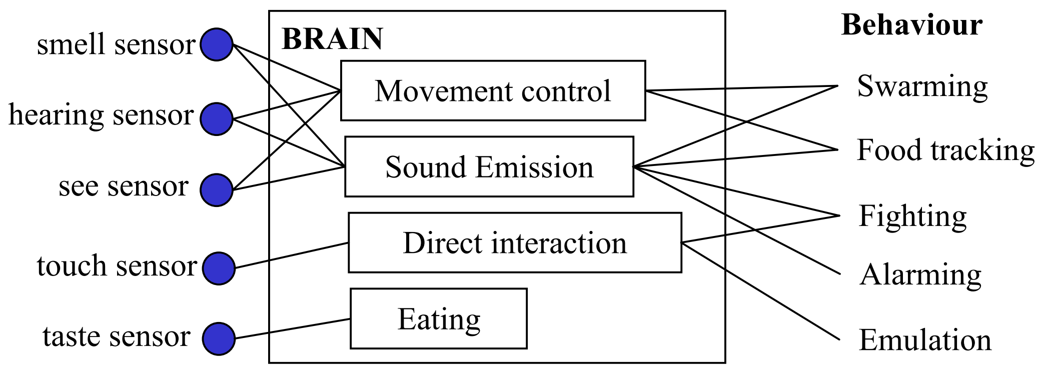

Fig 2: Sensors, artificial brain and behaviours of the individual

The most experimented task up to now has been the network for the movement. This sub-net is composed of four layers of neurons with several neurons in the input layer (4-12 depending by the active sensors), 4 neurons in two hidden layers and 1 neuron in the output layer (see fig. 3). The input layer is connected to information coming from the sensors. The output layer defines the change in the movement direction (curvature). Therefore, the agent movement is the result of the application of the network to the input information in order to decide the new movement direction.

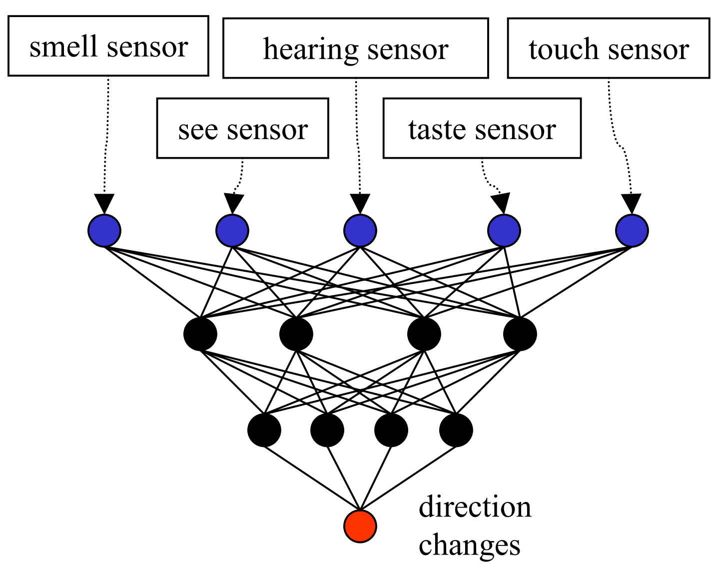

Fig 3: The individual artificial brain to control the movement

The data coming from the sensors and the previous state of the individual supply the neural network in order to decide the action to realise. Typical reactions are moving towards (or escape from) a substance or another individual or show indifference, or react to a specific message in the environment.

METABOLISM

The individual is characterised by a metabolism in terms of specific reaction to the different substances. When the individual enter in a cell with a substance, the individual can *eat* the substance activating its metabolism. Contemporary, the substance disappears from the environment.

Depending by the features of its metabolism, the individual identifies specific substances as *food or poison* or other useless substances. The food increases the individual energy; the poison decreases the energy and it could causes the death of the individual itself. The other substances don't produce any modification in the individual status. Finally when the individual eats, transforms the substance in another substance (ehm...) emitted in the environment.

REPRODUCTION AND MUTATIONS

The reproduction model is aploid: one parent-one child. A probabilistic model for self-reproduction is performed at every life cycle. The *fecundity* probabilistic parameter is recorded in the genotype. Reproduction can occur only if the individual has energy greater than a specific amount. In the reproduction, an amount of energy is transferred from the parent to the child.

In the reproduction, a probabilistic-random mutation occurs on the genetic parameters in relation to a *mutation average rate* and *mutation maximum intensity.* The application of the mutation mechanism on the genotype can change radically the individual behaviour increasing the possibilities of evolution of the whole population. In the reproduction, the status of the child individual is derived from the parent except for random mutations. In such a way the child will have a similar behaviour but with some little differences in respect to the parent.

Fig 4: Digital creatures living in the alife world

2.2 INTERACTION, COMMUNICATION AND COLLECTIVE BEHAVIOR

On the base of the structures described in the previous section, several kind of interaction and communication channels can be developed.

COMPETITION

When an individual try to enter in a cell with another individual an interaction occurs. Depending on their genetics, the individuals can apply several models of interaction: competition, co-operation and indifference. In case of competition they fight. That one featured with the higher energy wins and survive, the looser dies.

DIRECT COMMUNICATION: BEHAVIOUR EMULATION

In case of co-operation the individuals exchange information about the behaviour they have developed to survive that means the weights of the neural networks. The direct communication is activated when a meeting between two individuals occurs. During the communication each one of the two individuals modify the neural networks, weighting own information in relation to the energy balance of the two individuals. In few words, the behaviour could be synthesised by the sentence: "if you have a higher energy respect to me, it could be better for me try to partially emulate your behaviour". This mechanism of co-operation/emulation recalls a *reinforcement learning* mechanism and it represents a sort of translation of the genetic mutation in the cultural domain. In formulas:

$$W_{Ai} = W_{Bi} * \alpha + W_{Ai} * (1-\alpha)$$

Where W_{Ai} is the i-th weight of the network of the moving individual and W_{Bi} is the i-th weight of the network of the met individual; α is the emulation factor defined as:

$$\alpha = \alpha_{MAX} * (E_B - E_A) / (E_A + E_B)$$

Where E_B and E_A are the individual energies. The emulation mechanism is active only if the energy of the met individual (E_B) is higher than own energy (E_A). In this case α ranges between 0 (similar energies) and α_{MAX} (maximum relative difference, typically 0.5).

BIOCHEMICAL COMMUNICATION

This kind of interaction is much more indirect than the emulation mechanism. The individuals of the same specie share similar metabolic reaction to substances like food, poison, attraction and repulsion. During their movement, eating, escaping from danger, attraction towards the food they emit different substances in the environment. These substances have a limited lifetime and after a while disappear. The sensors allow the individuals to consider the presence of these substances in the environment and include this information in the decisional process performed by their artificial neural network.

Therefore the individual has the potentiality to establish, during a learning process, a connection between some substances and some survival needs like: markers of predatory or presence of food in the neighbourhood. Through the emulation behaviour, the mechanism of substance emissions/reactions, is shared by the most of the population. Hence a common dictionary emerges: that means a common list of associations between substance and meaning. This is the base for the development of a biochemical language.

SYMBOLIC COMMUNICATION

The third channel of communication is the emission of sound messages in environment that can be hear from any individual in the neighbourhood. This kind of communication is direct and it is the most difficult to develop in the artificial life environment. In the following we treat the sound messages but the discussion could be generalised on symbols instead of sounds. In particular a very basic symbol could be also a gesture or a body expression, perceived by the eye and recognised as a *symbol* in the brain.

The reason of the difficulties depends on the need to involve very complex learning and reasoning structures to manage the information flowing between the individuals. In order to explain the complexity of the problem we try to divide this goal in three different tasks:

1) To learn a correlation between a sound message and an event connected with the survival needs (food, danger, etc..).

2) To share this knowledge with the other individuals of the population to realise a common dictionary of message-meaning.

3) To elaborate the composition between symbols in order to generate other meanings and share this composition and meaning rules with the other individuals.

It should be clear that the third task requires a tremendous effort of research in order to produce an intelligence that has a complexity not very far from the human one. This goes out from our goals that are limited to the discussion of the two first tasks: the creation of a common symbol-meaning dictionary shared by the most of the population.

At this stage of development we don't have experimented a neural network able to manage the correlation between sounds and events but it seems very promising to do it using a mechanism of reinforcement learning which defines a sort of probability of synchronicity between sounds and events.

An individual, which has developed an ability to understand the environment message, is more able to find food and escape from danger. Therefore it can gain higher energy increasing the probability to survive. For this reason also for the symbolic communication, the same concept of the behaviour emulation of the higher energy individuals can be applied. In particular it can drive the population to share the same information in order to reach the second goal: the convergence of most of the creatures towards the same correlation list.

SWARMING

The last social mechanism we discuss in this section is the tendency of some kind of individuals to create groups that navigate together in the space. This mechanism is important not only as a way to navigate but as a way to maintain a constant contact of interaction inside a group and grow together in the learning process. Furthermore, this mechanism is important to increase the scope range to find some food and decrease the probability to be captured from predatory. In some sense the *swarming* phenomena creates a sort of dynamic niche of local evolution and it characterise *a micro-society*.

The swarming behaviour is possible using the sensor to perceive other individuals in the neighbourhood. This information is processed in order to compute the swarm baricentre and the distance of the individual from the baricentre.

In our experiment we fix two thresholds on the distance (large and small). If the distance is greater than the large distance or lower than the small distance, the swarming behaviour is not active. In the other cases the individual moves towards the swarm centre. The result is very interesting. There is not a preferred leader of the group and looking to the implemented model it should causes a quite chaotic behaviour. At the contrary the results show that the group seems to move quite coherently in some directions. Some individuals goes out from the group, some other merge into and the leader changes continuously but the whole group goes around coherently looking for the food.

Fig 5: The swarming effect. The creatures tend to navigate together changing continuously the leader. Some creature go out from group, some other go in.

Alternatively to this model we could include the swarm centre location in the input of the neural network for the dynamics. In this way the swarming mechanism could emerge of a strategy of survive instead of a pre-programmed behaviour.

3. LEARNING IN AN ALIFE WORLD

The very basic idea to include learning tasks in an alife environment is to connect learning to the survival goals. It means that we should realise an evolutive pressure pushing the individuals to learn. In this way, learning is not an option for the individuals but a survival need. In order to explain the application of the structures described in the previous sections, we have implemented some experiments described in the next paragraph.

3.1 LEARNING AS A NEED TO SURVIVE

In this experiment we put a number of individuals in the environment (typically 256) with the neural network initially filled with random numbers. In the environment we random distribute a fixed rate of food bits. Each bit occupies a single cell and it disappears after a fixed number of life cycles (lifetime, typically 10 cycles).

Than we setup a learning experiment that consists in the autonomous development of the ability of the individuals to recognise the presence of food in the neighbourhood, move toward the bit and eat the bit itself. To obtain this knowledge, the individuals have to evolve progressively their neural network in order to react to the input information in the best way to survive. We would to outline here that any explicit target for food search is a-priori implemented in the individual behaviour.

We have realised three different experiments corresponding three different mechanisms of learning illustrated in next paragraphs: a) direct competition, b) competition for the resources, c) emulation. The first two mechanisms regards the evolution through the genetics. The third mechanism regards a learning based on the communication.

In order to monitor the learning stage, we measure the food bits currently present in the environment. When the individuals are not expert in the food eating, this number is high. Food disappears for accidental eating (an individual passing randomically over a food cell) or for passed lifetime. When the individuals learn to eat, the food decreases rapidly due to intentional passing of the individuals over a food cell.

3.2 LEARNING THROUGH GENERATIONS: DIRECT COMPETITION

In this first experiment, the learning mechanism is based on the genetic evolution through the direct competition. The individuals don't change the network weights during their life but only through the genetic mutations in the reproduction.

The selection mechanism is based on a direct competition based on energy. When two individuals meet on the same cell, they fight. The individual with the higher value of energy, wins and survive while the looser dies.

For each individual, the energy level is the balance of the energy increased by the food and the one consumed in life cycle. An increase of the ability to eat food produces an increase of the energy and of the probability to win in the fights. All the other learning mechanism (communication and emulation) are switched off in this experiment.

In the plot of fig. 7 a diagram of the average food density in time is shown for all the three different learning strategies. Each time point corresponds to the average of 100 life cycles. At the beginning the food presence increases up to reach the maximum corresponding to the equilibrium between the food randomically consumed and the one periodically distributed. After the maximum, a slow decrease of the food presence is exhibited corresponding to the individual learning. Finally a saturation value is reached corresponding to the maximum ability that the individuals can reach trough this mechanism.

The increase of the ability to eat is clearly demonstrated looking to the alife animation. At the beginning the individuals move in a very chaotic pattern. During the learning process some individuals passing close a food bit. After some strange trajectories they succeed to reach the food. At the end, when a food bit compares in the environment, immediately many individuals converge towards the food. The one that has developed the best ability, succeeds to reach the food increasing its energy. The others don't eat and will be filtered out by some more able competitor.

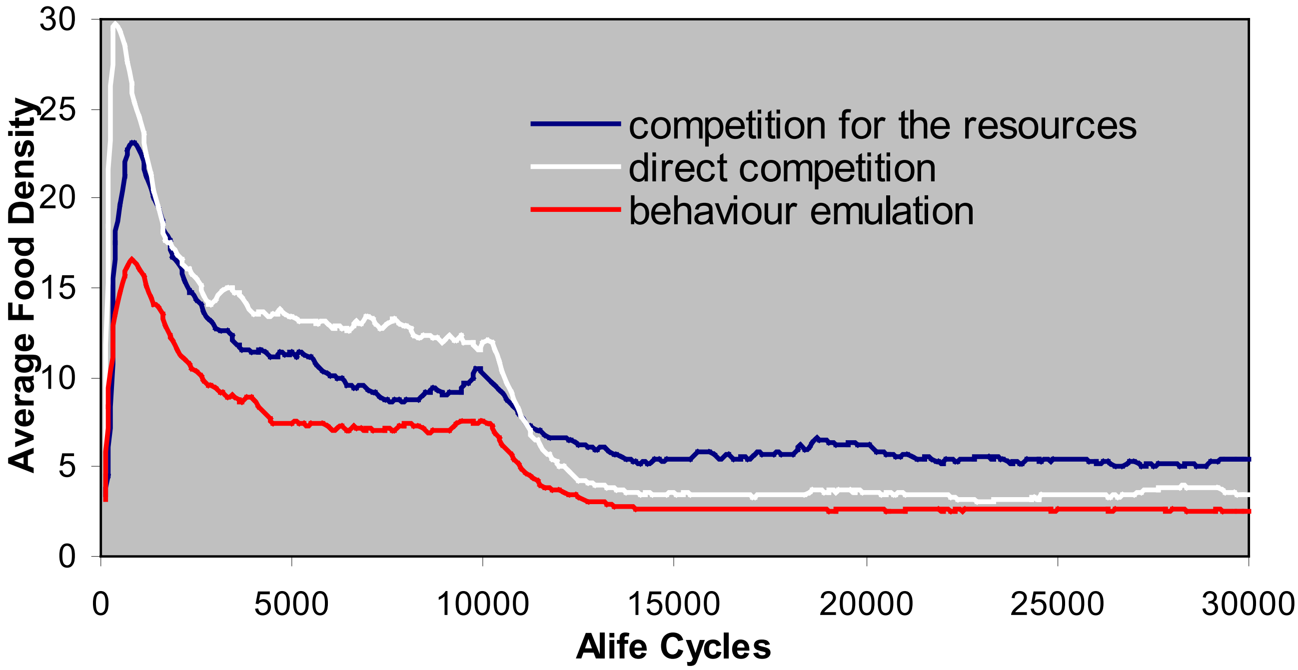

Fig 7: Comparison of the efficiency of the three different strategies of learning: direct competition, competition for the resources, behaviour emulation.

3.3 LEARNING THROUGH GENERATIONS: COMPETITION FOR THE RESOURCES

In the second experiment, the learning mechanism is based on the genetic evolution through the natural selection. Also in this case the individuals don't change the network weights during their life but only through the genetic mutations in the reproduction.

The situation is quite similar to the previous one but with two differences:
1) when two individuals meet, they ignore the meeting and have no interaction (no fights);
2) the energy consumed in life cycle is quite higher in respect to the previous case.

In this case the selection is not more based on the competition but the individuals are forced to eat in order to avoid the decrease of the energy under the survival threshold. In few words they compete for the resources instead to compete directly each other. The plot of fig. 7 shows a trend similar to the previous case, but the final value is lower. This means this mechanism is more efficient than the previous one.

This mechanisms of learning is quite different from the previous model one and it is more similar to the natural selection where the animals compete mostly for the resources in the context of complex network of co-evolution of a multitude of different species. In spite of these differences, the results exhibited by the experiment are similar and both mechanisms are very efficient in the production of intelligence through the evolution.

3.4 LEARNING THROUGH COMMUNICATION: BEHAVIOR EMULATION

The third mechanism we experimented is not based on evolution through genetic mutations but it regards the learning during the single individual life and it is connected to the communication mechanisms. In some sense it is much more related to the *cultural advancement* of the population: when two individuals meet they communicate exchanging their information about own developed behaviour. The learning mechanism is based on a partial emulation when an individual meets another individual with higher energy. The amount of the emulation depends on the energy differences (see par. 2.2 for details). The individuals do not die, but when the energy goes to zero, they are forced to apply small changes to their behaviour, that means small changes to the neural network weights.

As the previous case, the plot of fig. 7 shows the same trend, but comparing to the other cases, the values reached with this mechanism are lower and faster reached. This means that this mechanism is the most efficient in respect to the others. This comparison has only a reference value because of in the reality these mechanisms are contemporary present.

In this case the competition is similar to the stock market competition. When an individual becomes quite able to eat, increases its incoming of energy without any competitor. The other individuals try to emulate and learn from him. When the others reach its level and someone becomes better, the first individual starts to have an attenuation of the energy incoming and then a drastic energy reduction up to finish its energy. At this point it is forced to change its behaviour to come back to a positive energy incoming.

This form of learning is the most intriguing because of its feature of dynamics and *volatility*. In fact the produced knowledge is still a product of the whole society but it is moved dynamically between the various individuals. Although the knowledge is generated during the life of the individuals, it can be transmitted through the generations. In this sense is the one more similar to the *culture*.

3.5 SOME REMARKS ABOUT THE *CONSCIOUSNESS DILEMMA*

To have a visualisation of the ability reached autonomously by the digital creatures, in fig. 8 and fig. 9 we report two sequences of life with creatures passing close a food bit. In the first sequence the individuals are at the beginning of the training experiment. They exhibit indifference for the food. The second sequence is related to trained individuals. In this case is quite clear a strong finalisation of the creatures movement to catch the food.

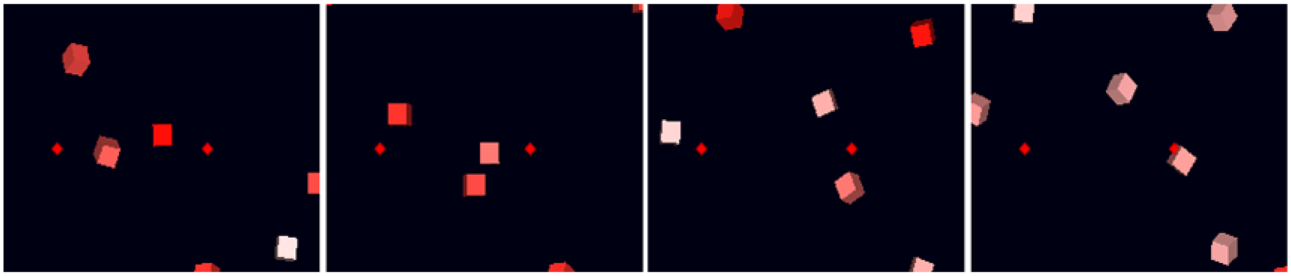

Fig. 8: The creatures at the beginning of the training experiment. They shows indifference in respect to the food.

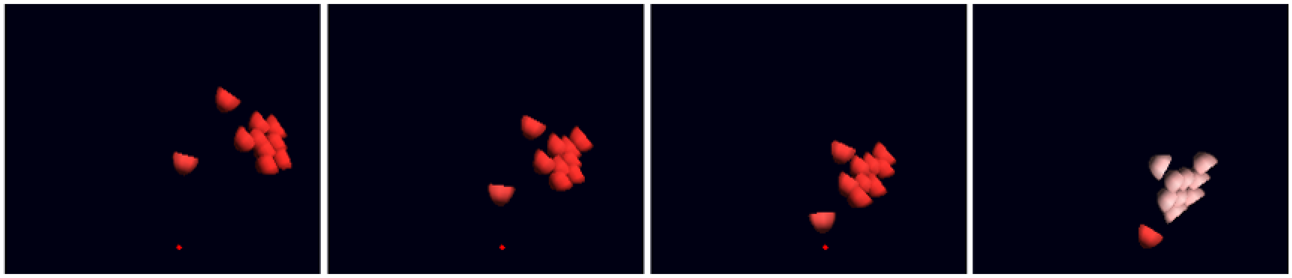

Fig. 9: The creatures after the training catching the food.

It should be noted that in the described mechanism the individuals achieve the ability to eat but they don't develop any form of *consciousness* of eating or *intentional direction* towards the specific target of eating . Simply they establish a relation between some behaviour (the weights of the neural networks) and the satisfaction of some survival needs (the fooding to increase the energy and to longer survive).

We could apply the same procedure to a higher communication level, like sound messages or the development of a language. Probably, we could allow the development of the complex behaviour relating it to an increase of adaptation. When the selection mechanism is extended to the competition between societies and groups also some behaviour like affect, love, parent care can be revisited as survival needs. In conclusion a very high level of *adaptive behaviour* and *intelligence* could be reached without any consciousness.

Now we are no more able to answer this question: what is really the consciousness ? Could it be developed in a digital being ? Are intelligence and culture possible without consciousness ?

4. HUMAN-ARTIFICIAL CONTAMINATION IN AN INTERACTIVE MEDIA CONTEXT

In the previous sections we have shown the realization of an artificial world where the creature can learn and exchange information in order to create the base for an autonomous language. So far all the world is confined in the digital domain. A real jump in the potential of these world is to establish a contact between this world and humans. The idea is not the human control of the world, but a sort of contamination or better a cross-fertilisation.

There are many approaches to establish this communication which corresponds different communication metaphors. In the following we describe the paradigm we selected among the many possible ones.

4.1 INTERACTIONS IN THE SHARED HYBRID ENVIRONMENT

The starting point is the place where the interactions occur. This place cannot be different from the environment. So we have to re-define the borders of the environment. In the installation, the image of the artificial world is projected on a 2D screen. The area for the human interaction consists in the area in front of the screen. To interact, a person has to enter in this area in order to produce modification in the artificial world. In such a way we have extended a dimension of the environment in the real world building an hybrid real-digital ecosystem.

In order to develop the interaction between real and artificial, we introduced for humans the possibility to emit substances and messages in the environment. This approach allows at least two of the types of communication mentioned in par. 2.2: the biochemical and symbolic (sound messages) communication. At this moment only the biochemical communication channel has been implemented.

The interaction area is observed by video-cameras acquired in the computer. A tracking program detects people presence in terms of change detection in the image. This information is mapped as substances emitted by the real people in the digital dimension of the environment. The metaphor is that a person releases substances when moves in the hybrid environment. This kind of relation it is enough to allow the people to play with the digital beings (see fig. 10).

In order to install a communication, people use the voice to decide what kind of substance emit in the environment. Spatial microphones record the sound and a sound processing algorithm translates the messages in a code. At this stage of development we classify the message in five classes identified with the five vocals a/e/i/o/u. More complex procedures could be created recognising other sound cues like intonation profile. Then we use this information to mark the type of substance released in the environment. When there are several species in the space, a specific substance can be an attraction for those creatures that recognise the substance as food. The other species can show a repellent or indifferent reaction depending on their metabolism. The result is that the people, through their voice, can attract or repel different creatures.

Fig 10: Playing with digital entities through a biochemical communication.

4.2 ALIFE AND DANCE: THE "AURORA DI VENERE" PERFORMANCE

The described installation was used on an alife-dance performance shown at the Theatre of the Palais de San Vincent (Italy), in March 2001. *Aurora di Venere* is presumably one of the first world live perfomance including alife interacting with the dancers. The performance (about 30 min.) included 8 dancers, 6 computers (SGI and PCs), 6 video-projectors and 8 sound amplifiers for 3D sound rendering around the theatre. Two video-projectors were focused on two on two large screens (12x8 m.) located at the background and at the front (semi-transparent) of the theatre's stand. The other 4 projectors covered the entire ceiling of the theatre that has a dome shape.

In the performance, the dancers interact with digital entities projected on the stand screens (see fig. 11). The performers dance in the middle of the screens, and they seem completely immersed inside the digital creature movements. The dancers play with the images of the artificial individuals which move following their own personality: they attract and repel the creatures through the *biochemical communication* mechanism explained before. The digital creatures were equipped with a neural network trained with the emulation behaviour to search for the food and reject the disliked substances.

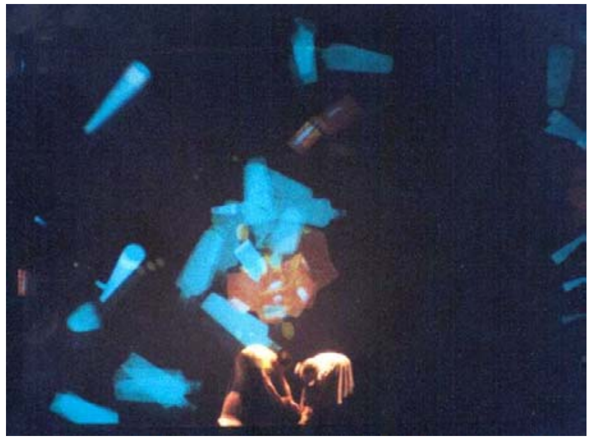

Fig 11: Pictures from the alife-dance performance "Aurora di Venere": the dancers play with the digital creatures projected over the background and over a semi-transparent screen of the theatre's stand.

During the performance the story grows in intensity when the artificial beings (fig. 12, 13) escape from the front screens invading the public and the theatre ceiling. They search for people movements and produce 3D sounds travelling in the theatre. At the end the whole internal pseudo-spherical surface of the theatre is invaded by digital beings.

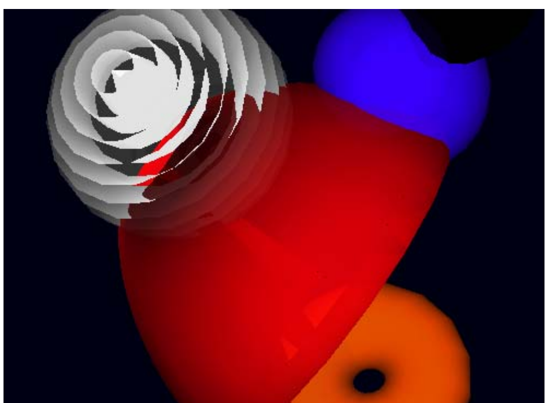

Fig 12: Digital plancton and dices: creatures for the "Aurora di Venere" alife-dance performance.

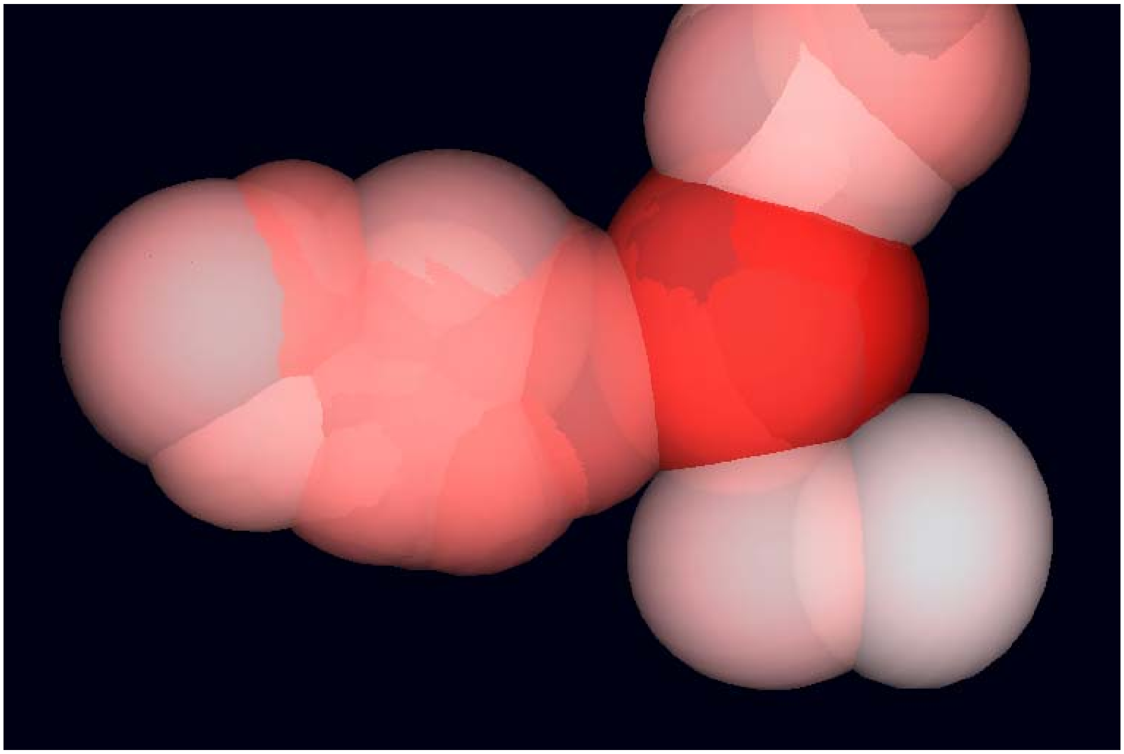

Fig 13: Cell-like creatures for the "Aurora di Venere" alife-dance performance.

CONCLUSIONS

We have explored several ways to build digital creatures living in an artificial world, able to learn from the sensorial experience and through genetics. Several paradigms of learning has been experimented successfully in order to achieve autonomously simple tasks like search for food. A basic platform for the development of an autonomous language has been introduced. This platform is limited to the emergence of a dictionary symbols-meanings shared by the digital population. These concepts have been applied in an interactive installation where real people can interact with the artificial creatures through a mechanism of substance emission-reception. This installation has been involved in an alife-dance performance in a theatre.

Rather than conclusions, this experience opens many questions about "what does digital life means ?" "Is it really possible to develop an autonomous culture in alife worlds ?" "Is it possible to have knowledge without consciousness ?", "how far this knowledge could go?". Maybe the only reasonable conclusion today is to raise these questions. Using imagination and art to find some answer.

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