HUMAN-ARTIFICIAL ECOSYSTEMS:

SEARCHING FOR A LANGUAGE

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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 to explore the emergence of social behaviors like competition, cooperation, relationships and communication [3, 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 tools to explore some basic aspects of the evolution [1, 2, 3, 9, 11, 12, 13, 14, 15, 16].

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 the 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 and relationships creating structures and complexity in the society. In this paper we refer to several experiments where a community of artificial individuals, equipped with a personal neural network, autonomously develop a common set of symbol-meaning associations. Furthermore we illustrate the state of the art of development of the *E-Sparks* project. Goal of the project is the realization of a symbolic interactive installation where artificial beings can communicate with the humans. In this installation the creature progressively develop the ability to learn and classify the words pronounced by the humans and diffuse in the community up to the emergence of a common and autonomous vocabulary.

2. THE SOCIAL LEARNING AND THE PARTIAL EMULATION MODEL

In our approach, the basic concept is to create a continuous learning mechanisms to achieve complex task in social context. The aspect of social learning is crucial to organize the individual learning and give to the society the ability to grow in a rich cultural progression. The social way to the development of knowledge and intelligence is much more powerful and it requires the definition of a mechanism to exchange information between the individuals.

2.1 The partial emulation model

In [3] we have introduced a simple and basic model in order to organize the individual learning in the social context: the *partial emulation model*. In this approach the behaviour and its success degree is viewed as a knowledge level reached by the individuals.

In order to go in little detail of the model we define better the problem. Let suppose a society of artificial individuals (*autonomous agents*). Each individual continuously try to increase the degree of success of own behaviour trough a own path of trails, successes and flops (*individual learning*). Now let suppose that two individuals have a meeting. Each one of the two individuals have a specific behavioural configuration. The problem is: which is a good model in order to take advantage by the interaction in terms of exchange of information or evolve the behaviour of the interacting individuals.

The most simple model we can imagine could be synthesized by the following sentence:

- *if you are more successful than me I adopt your behaviour -.*

Unfortunately this model has two very important lacks:

1. In most of the cases is very difficult decide if the other is *better than me*. In general this is a result through a series life cycles and meetings.
2. None new behaviour is produced in the society by the way of the interaction.

Using this model, in some case, the final result of the social learning could be worst than the best individual learning.

The partial emulation model is a slight extension of this model. It could be synthesised by the following sentence:

- *it is generally convenient for me, try to partially emulate your behaviour –*

We tested very good results of this model in learning problems (food tracking in [3]). A complete theoretical justification of this model is not simple. It important take into consideration several aspects:

- A general trend to clusterize the behaviours around the most successful behavioural centroids.
- A dynamic equilibrium between the *individual learning* which promote new behaviours and the emulation which promote the concentration of the resources around few evolution lines.

In terms of the degree of success, this model produces results which are much better than a similar society with none interaction models.

A basic explanation is that the *adaptation* is a mechanism which promote the synchrony between the following two events:

- the *existence* of a specific behaviour
- a *high success degree* associated to that behaviour.

This means that we have a high probability that the modified behaviour after the partial emulation is better than the original behaviour. In this sense the partial emulation model is a synchronic model promoted by the adaptation.

By a mathematical point of view the partial emulation model can be applied in different way depending by the contest.

In [3] we applied this model in order to develop in a society the ability to understand that the tracking of food bits is a good strategy to survive. In that case each individual was equipped with a neural network controlling the movement. The input of the networks were the previous movement status and the signals from sensors for substances in the neighborhoods of the individuals. The *behaviour* is represented by the weights of the neural network.

When two individuals had a meeting they modify their weights by a factor ? :

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

Where W_{Ai} is the i-th weight of the network of the first individual and W_{Bi} is the i-th weight of the network of the other individual; ? is the emulation factor.

An interesting aspect of the social learning is the feature of dynamics and *volatility* of the knowledge. The produced knowledge is 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 individual, it can be transmitted through the generations.

2.2 The development of an autonomous language

The next experiment we have set up is the development of an autonomous primitive language in the artificial society as a self-organising process of symbol-meaning relations shared by the community. Our intention is not to modelling the language of real animal or human communities, but we refer to a completely imaginary artificial society. These societies could be regulated by mechanisms much simpler and probably different from the biological ones. Furthermore, with the term *primitive language* we refer to the sharing process in the community of a symbol-meaning dictionary. In principle the term *symbol* is general and it can assumes different meaning depending by the context (a gesture, a body expression, a phoneme, a sound, a sign).

The development of an autonomous language is a very complex task. In order to achieve concrete results we have to distinguish several stages of development. In the following scheme we try to divide the problem in two different stages of development. These stages describe only one of several possible ways for the formation of a shared dictionary.

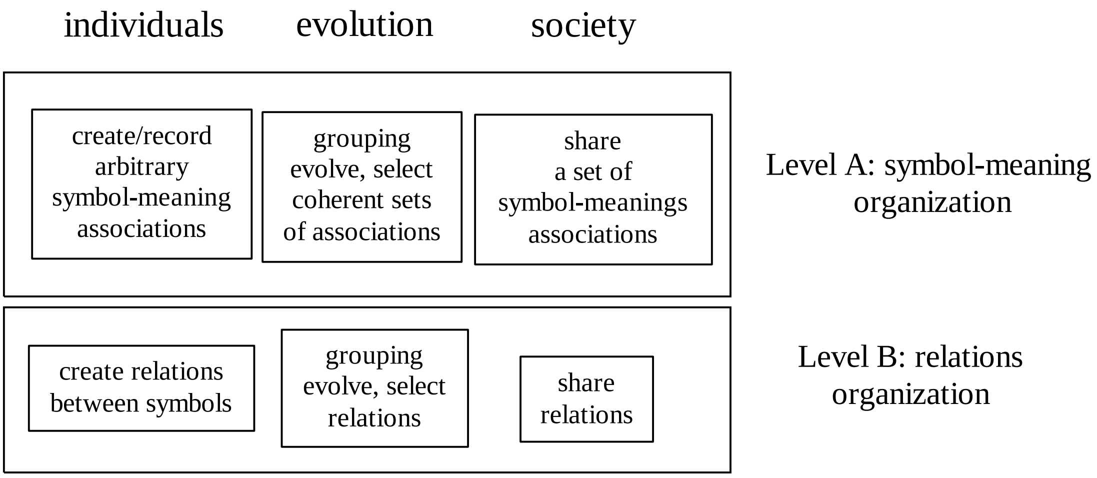

Fig. 1: Processes for the development of an autonomous language in artificial societies

In the left column of scheme of fig. 1 we represent the processes operating at the individual level, in the central column the processes involved during the evolution through the social communication and in the right column that ones operating at society level. The processes involved in the level A consists in the autonomous creation of a basic set of symbol-meaning associations shared by the community. In this process the symbols are progressively created by the individuals; grouped, evolved and selected through the social communication. At the society level a set of shared symbols-meaning association progressively emerges.

The processes involved in the level B are referred to the emergence of relations between symbols at individual and society levels. This level could be seen as the beginning of symbol composition in order to pass to a higher level of language development.

At the current level of the research reflected in this paper, we take into consideration only the processes involved in the level A. We have realized two experiments to explore these processes. The first experiment consists in a study of the symbol-meaning organization in the society using the partial emulation model. The second experiment is a prototype for human-artificial exchange for an interactive installation where the artificial creatures can assume words from speaking human visitors and activate the sharing process in the community.

Both the experiments are based on the same model for the artificial world. This model is described in the following paragraph.

3. THE EMERGENCE OF A SHARED SET OF SYMBOLS IN THE COMMUNITY

The artificial life (*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 interacting with other individuals exchanging information. A population of 512 individuals has been considered.

The individual is composed by the *genotype* and the *artificial brain*. The *genotype* is composed by parameters which does not change during the individual life, like dynamics and interaction parameters. The brain includes the current values of the information coded in the weights of an artificial neural network controlling the communication and a memory zone where the known symbols are recorded. The memory is divided in cells. Any cell represent a meaning and the content of the cell represents the symbol currently associated to that meaning. For simplicity, the symbols are treated as *words* described by two normalised parameters (x and y) and the memory is fixed on only 4 words. Therefore any cell of the memory contains two floating numbers between 0 and 1. A scheme of the neural network and the memory archive is reported in fig. 2.

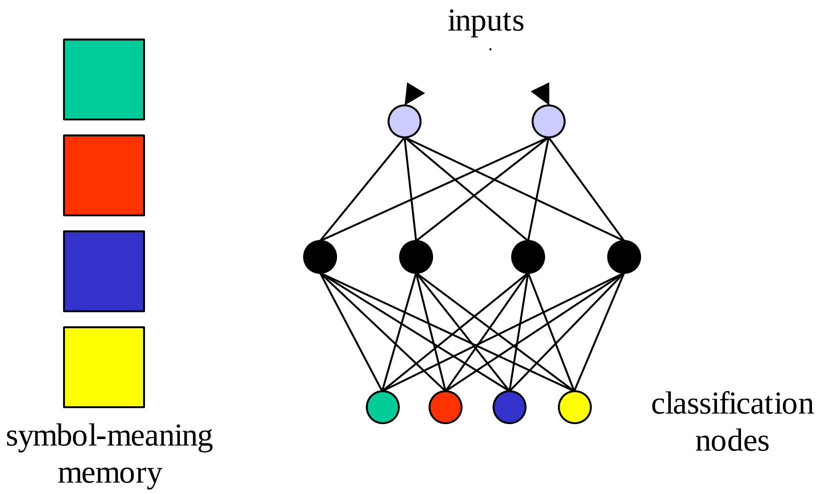

Fig 2: The network for symbol classification into meanings

The network has the goal to classify the input words in one of the four meanings. This is obtained considering the result of the classification as the highest value of the output nodes. The individual continuously try to classify their own words using the network. In some case the result is correct, in other case the result is wrong. A global efficiency is computed. The errors are due to two possible reasons:

1. the neural network is not still well trained to classify all the words
2. the own set of symbols are ambiguous. This means there are too similar symbols for different meanings.

In case 1, the efficiency can improve during the learning phase. In case 2, the efficiency could remain very low. In this sense the efficiency of the network is a measure of the level of learning of the individual but also of the ability of the individual to develop a coherent and clear set of symbols. The individuals continuously try to modify the network weights in order to achieve a better performance (*self-training mechanism*). This kind of self-learning is individual.

When a meeting between an individual A and another individual B occurs, a communication event is generated. Each one of the two individuals chooses randomically a cell of own memory and communicates to the other individual the word contained in that cell and related meaning.
In the meeting, the partial emulation model is applied in two directions:

?? partial emulation of the weights of the neural network

?? partial emulation of the own word corresponding to the same meaning of the input word.

The emulation factor is very low (5 %). The emulation is applied only to the individual at low network efficiency and only if the difference between own word and the input word is below a specific threshold.

This model represents a premium to the individuals which are able to develop a good classification system and a good symbol set. It is fundamental to outline that the premium is intended for the set of symbols and not for the single symbol. In some sense this model is an implementation of the criteria of the *survival of the clearest* enunciated by Pinker in the evolutionary theory of the language [10].

The results are illustrated in the plot and the images of fig. 3. These images represent the two coordinates that describe the word (*x* and *y*). The colour of the symbol represents the meaning. At the beginning (time=cycle 300), both words and meaning are very scattered. During the evolution some clusters emerge (time=cycle 8000).

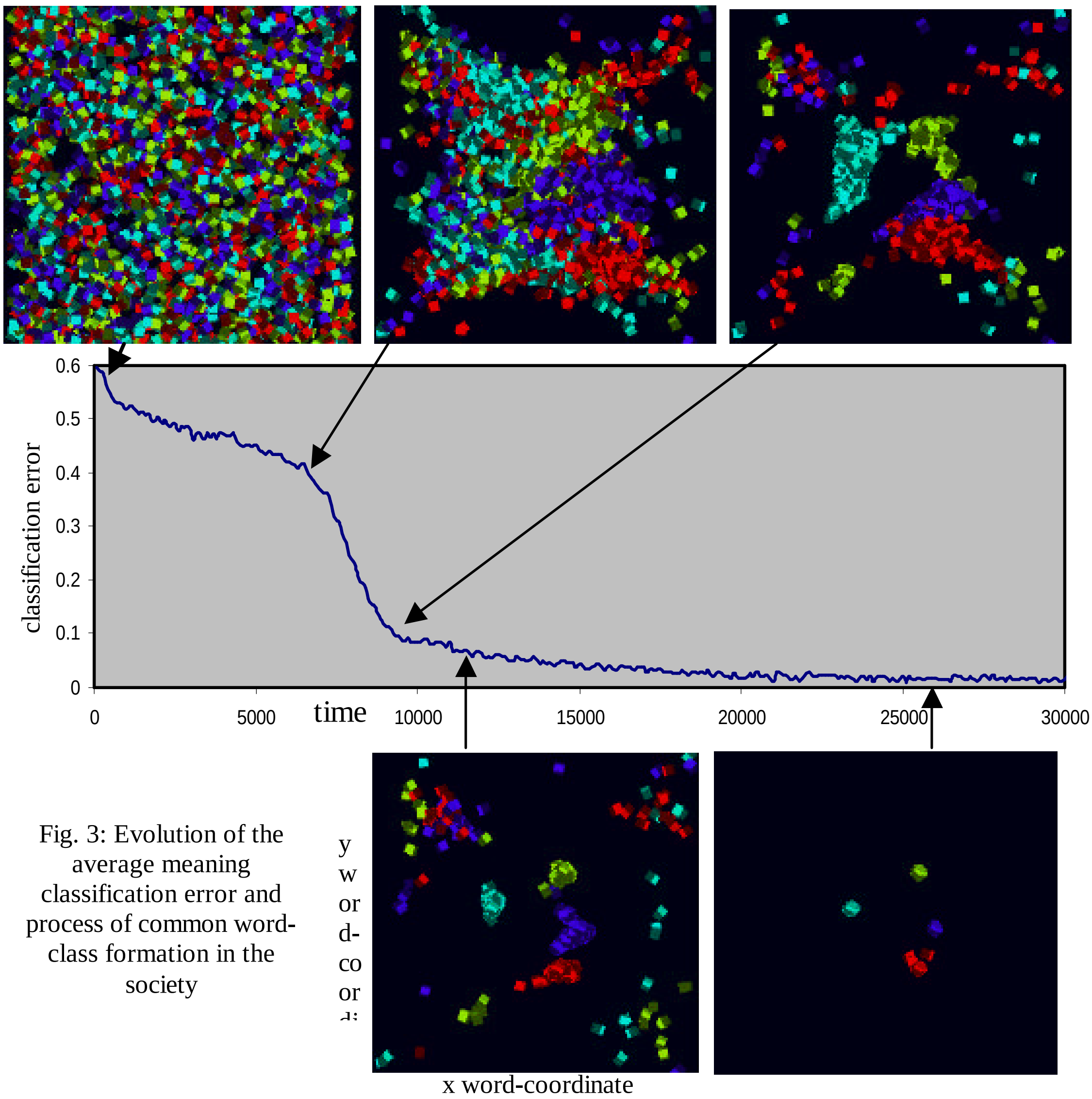

Fig. 3: Evolution of the average meaning classification error and process of common word-class formation in the society

These clusters are due to group of individuals which use a similar word to identify a similar meaning. This effect if pushed up by the formation of groups of individuals in the physical space. These micro-societies create niches of evolution and the communication level is very high. In fig. 4 an example of grouping in the physical space is illustrated.

This effect produces the creation of local dialects (see image corresponding to the cycle 11000 of fig. 3). The dialects tend to disappears when the communication between different groups occur.

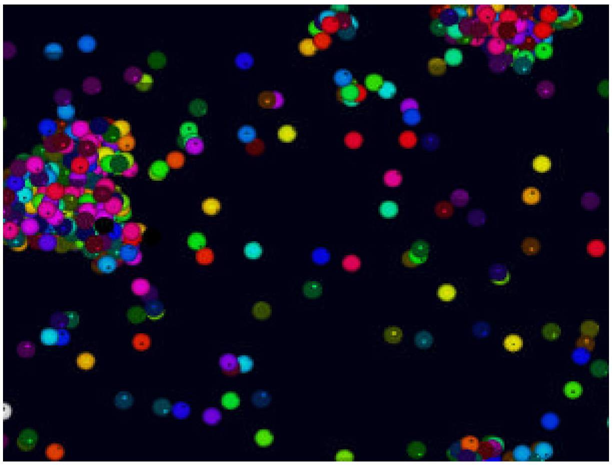

Fig. 4: formation of individual groups in the physical space

Through the partial emulation mechanism, the individuals involved in these group tend to share the same set of symbol-meaning associations. The convergence on a specific set is driven by that individuals who are more able to develop a set with good differences between the symbols and good ability to correctly classify the symbols with own neural network.

Is very interesting to note the strong increase in the average classification ability of the individuals when the first clustering structures occur (see fig. 3). Under clustering condition the neural networks become less confused by the noise introduced by the scattering; the partial emulation starts to help the individual learning and the classification starts to work. At the end, when a common well defined 4-clusters set is established, the classification problem becomes more simple and the classification error reaches the minimum values.

The error is computed as the fraction of wrong classifications of own words. A 1.0 value means a wrong classification for all the words in the memory cells. A 0.0 value means a completely correct classification. The value reported in the plot of fig. 3 is averaged over the whole population. At the end of the evolution, the average classification error is 0.03. This means that about only 12 individuals over 100 do wrong in the classification of one word over four.

4. SPEAKING WITH HUMANS IN THE HYBRID ECOSYSTEM

In the previous sections we have shown the realization of an artificial world where the creatures 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 cross-fertilisation of elementary words. Following this direction, the digital communities developed along these experiments have been connected to an interactive installation where communication with humans is possible. This is an immersive environment where humans and artificial individuals can exchange sound messages.

The first step has been the creation of the interaction mechanism. The artificial individuals, appear as solid shapes in a 3D virtual environment projected over a 2D screen. The area for the human interaction consists in the area in front of the screen. In such a way we have extended a dimension of the environment in the real world building an hybrid real-digital ecosystem. The interaction area is observed by a video-camera acquired in the computer. A tracking program detects the people presence in terms of change detection in the image. This information is mapped as substances admitted by the real people in the digital environment. The metaphor is that a person releases substances when moves in the hybrid environment. The creatures attracted by these substances come towards the people and the communication starts (see fig. 5).

Fig. 5: Interaction human-artificial in the hybrid environment. On the left, playing with creatures in the “E-Sparks” first installation prototype. On the right, the alife-dance performance "Aurora di Venere" (Theatre of Palais of San Vincent, Italy). The dancers play with the digital creatures projected over a semi-transparent screen of the theatre's stand.

The second step regarding the speaking communication is still in progress. This step can be divided in two problems: a) the word speaking-receiving facility for human-creature exchange and b) the connection between the social context discussed in the previous paragraph and the interactive installation. In this paper we refer to first of the two problems.

In order to allow the communication, we installed spatial microphones in the installation. The voice signal is sent to the creature approached for communication. When a visitor speak in the environment, the creature apply a series of reactions as illustrated in the scheme of fig. 6.

1. Wait for voice signal. When the energy of signal go over a minimum threshold the word capturing reaction is activated.
2. When the energy of the signal go under a minimum threshold the capturing reaction is deactivated and a word is insulated form the context and supplied to the analysis chain.
3. The word is converted in parameters. These parameters describe the sequence of 20 milliseconds blocks of the raw signal. Each block is described by 14 parameters computed trough an auto-regressive algorithm. Typically, a whole word is described by 500-1000 parameters depending by the duration in time.
4. The input word is classified in one of the words currently present in the memory cells (vocabulary). At the current state of art, the euclidean distance from any word is computed and the word corresponding to the minimum distance is selected. In next step the neural network will be introduced in substitution of the deterministic rule. The criteria of the continuous self-learning over the words in own vocabulary is going to be used (as that one illustrated in the previous paragraph).

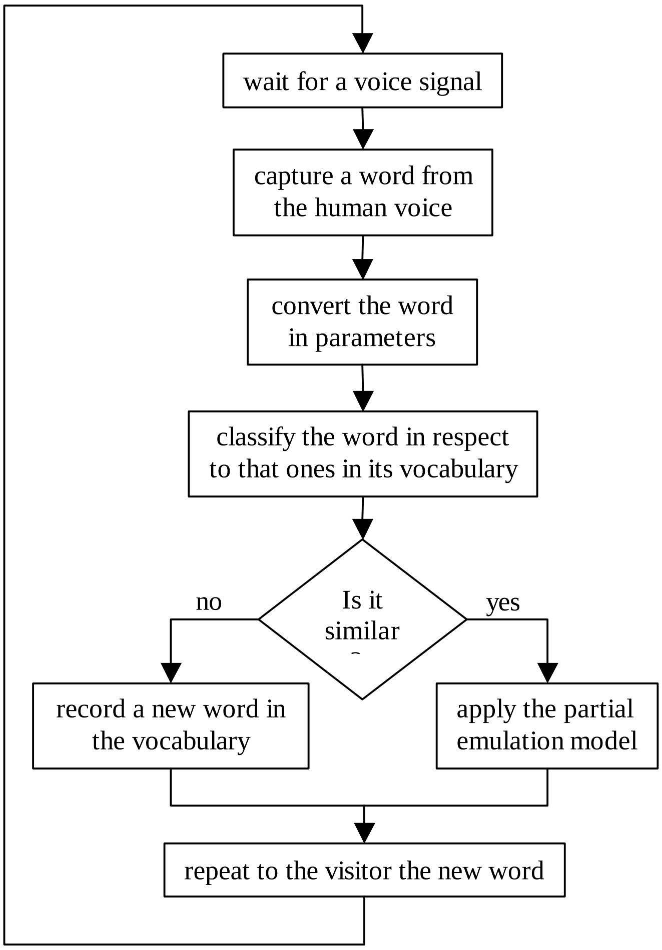

Fig. 6: the creature interaction with the visitor

5. If the minimum distance is under a specific threshold, the corresponding word is recognised as *similar* to one *known* word. In this case, the partial emulation model is applied: any parameter of the recognised word is lightly moved towards the corresponding parameter of the input word following a very low emulation factor (typically 0.05).
6. Otherwise, if the minimum distance is over the threshold, the input word is recognised as a *new word* and recorded in the vocabulary if it is not full already.
7. The emulated word or the new word is synthesized in a new raw signal that is sent to the speakers.
8. Finally the creature is waiting for a new voice signal.
9. After a while the connection is deactivated and the creature is free to go around and applying exactly the same procedure when another creature is met.

In this way, the words admitted from the visitor are diffused in the society during the next communication phase. In the diffusion, the words are distorted in relation to the words already known by the creatures. If the visitor repeat several time the same word, he pushes the creatures toward an exact learning of that word. Otherwise, he can wait and to observe the influence of own interaction on the creature language.

In order to point out the “speaking procedure” a one-to-one experiment has been prepared. In the experiment, a person speaks directly with a creature (see fig. 7).

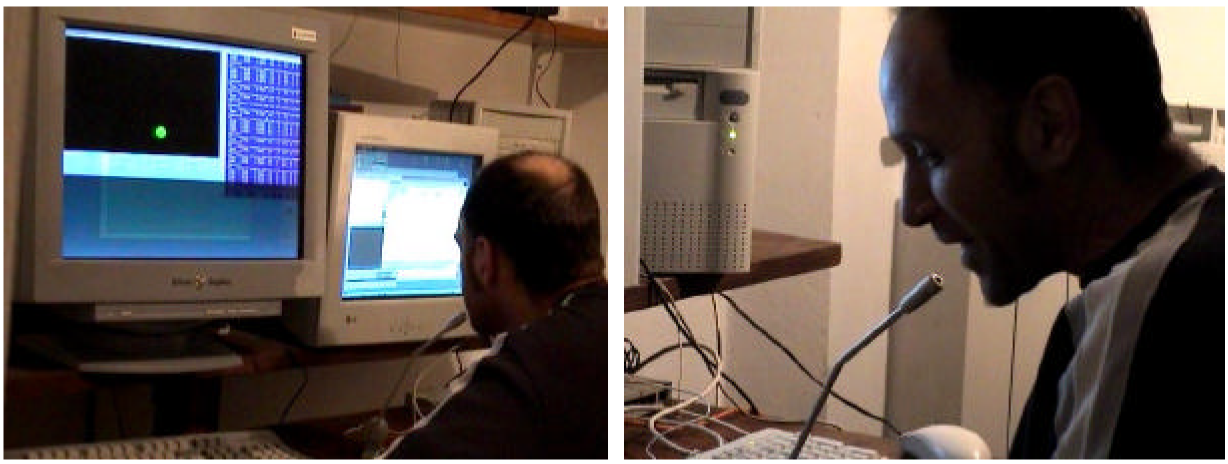

Fig 7: Piero speaking with a simple spherical creature

The result is very interesting. For the first learning phase the creature repeats almost the word pronounced by the human speaker. When its vocabulary is quite full, the reaction of the creature is quite surprising, especially when the speaker repeat several time the same new word. Firstly a strange answer is given and than the creature try to progressively distort a known word towards the word repeated by the speaker.

This exercise allow to the speaker the possibility to drive a game with ambiguities and projection of meanings in such a way that the creature seems much more smart that really it is. It exactly this transfer of the visitor in the metaphor of the *real digital life* that we are interested to realize in the *E-Sparks* project: create a theatrical representation of an imaginary life founded on the same evolutionary mechanisms that are at the base of our evolution.

CONCLUSIONS

Rather than conclusions, this experience opens many questions like:
what does digital life will mean in our next future ?
is it really possible to develop an autonomous culture in artificial worlds ?
how far this knowledge could go ?
is it possible to found the base of the language formation on an evolutionary context ?
could be it possible interpret psyche, affect, consciousness on the same evolutionary base ?

Maybe the only reasonable conclusion today is to raise these questions. Using imagination and art to hypothesize some answers.

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