Chapter VI
Artificial Mind

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ABSTRACT

The advances of artificial intelligence (AI) have renewed the interest in the mind-body problem, the ancient philosophical debate on the nature of mind and its relationship with the brain. The new version of the mind-body problem concerns the relationship between computational complexity and self-aware thought. The traditional controversy between strong and weak AI will not be settled until we are able in the future to build a robot so evolved to give us the possibility to verify its perceptions, its qualitative sensations, and its introspective thoughts. However, an alternative way can be followed: The progresses of micro-, nano-, and biotechnologies allow us to create the first bionic creatures, composed of biological cells connected to electronic devices. Creating an artificial brain with a biological structure could allow verifying if it possesses peculiar properties with respect to an electronic one, comparing them at the same level of complexity.

INTRODUCTION

The attempt to understand the nature of mind goes back to the time of the Greek philosophers. In modern times, the behavioral movement concentrated on the external behavior, excluding the importance of the internal mental processes. Only in the last decades the cognitive sciences and the artificial intelligence (AI) research attracted attention on mental processes, reviving the interest in the nature of intelligence and reflexive thought.

The development of computer technology opened a new research method by means of computer simulations of functions typical of the human brain.

After the enthusiasm of the first times, when many prototypes were developed, the successes of AI research faded in the ’80s due to the difficulty to move the AI algorithms in the complexity of the real world.

However, although the wide, excessively expensive and ambitious AI systems that concentrated on specific problems were once renounced, in the last decade, swift developments have produced many applications in robotics and several useful algorithms applied to all kinds of fields, where the complexity of the problems is greater and traditional algorithms cannot reach significant results.

Nonetheless, the solutions proposed for the problem of the nature of mind remain debatable.

The development of AI created a diatribe between the supporters of the so-called strong and weak AI. Following weak AI, the computer is just a powerful tool that allows us to verify hypotheses and to implement useful functionalities, but it will never have the features of a human mind.

Following strong AI, the computer can be considered a real mind that in the future, endowed with evolved programs, will possess all the features of the mind and cognitive states.

This unsolved diatribe changed over time into a dispute between materialists and nonmaterialists. The purpose is not anymore to decide if the technology will succeed in developing robots with an intelligence similar to the human one (we understood that this is a very far goal but that we will reach it for all practical purposes), but to understand the very nature of mind and its relationship with the brain.

This problem is seen today not only as a philosophical but also as a scientific goal, whose application to AI development will be an important consequence.

BACKGROUND

Weak AI vs. Strong AI

One of the most famous and sharp criticisms of strong AI is John Searle's work (1980) and its "Chinese room" thought experiment. An English man is closed in a room. He does not understand Chinese. He receives a sheet containing a story and some questions on the story written in Chinese, and a set of rules to draw Chinese symbols in reply to the questions. The man follows the rules and answers the questions.

The rules correspond to a computer program. The man corresponds to a computer that processes the program specified by means of formal rules. The man can become so clever that his answers are indistinguishable from those of a Chinese man.

Strong AI maintains that the computer understands the story, but the man in the room does not understand the story at all. He does not know the meaning of the Chinese symbols. Many objections have been raised by Searle's conclusion about this thought experiment, and Searle always rejected them with extremely smart considerations.

However, it is clear that the English man accomplishes in the room only a careful but stupid copying task from a lookup table and does not perform a learning algorithm such as those AI (and all the more reason for the human mind) is able to accomplish.

The man in the room could try to understand the connection between the lookup table items and the story, and finally he could learn Chinese. The same could be accomplished by a machine using, for example, an artificial neural network or other symbolic knowledge representation techniques. Thus, it seems that the progresses of AI succeed without difficulties in giving a computer the ability to understand the connections between information, and to memorize and learn them.

Douglas Hofstadter (1979; see also Hofstadter & Dennett, 1981), one of the most convincing and famous strong-AI supporters, maintains that a growing complexity of the computer processes, including the interaction between different cognitive levels, could lead a machine not only to the ability of understanding and learning, but also to the emergence of the ability of self-reflection that is the basis of consciousness.

Hofstadter hypothesizes that consciousness rises from the closure of a tangled loop between the high (symbolic) level and low (neurophysiological) level, bounded to each other by a chain of causalities. The most central and complex symbol of the high level is the one we call *I*. This closed loop allows the representational system to perceive its own state inside a set of concepts.

Currently, many AI programs already possess the ability to know their own structures and react to variations of these structures, exhibiting a rudimental kind of control of the self. In conclusion, Hofstadter affirms that the mind can be reproduced inside a computer because it can be simulated by a program, thus it does not reside in the biological structure of the brain.

The "Hard Problem"

The above considerations seem to lead to the assertion that a computer could in the future present all the features of a human mind, including consciousness. However, the problem is not so easily solved.

Following David Chalmers (Chalmers, 1995, 1997), to be able to develop an intelligent machine that is aware, understands, learns, and possesses a control of its own self as a human being does is not equivalent to state that this machine possesses a mind in the subjective and qualitative sense that we experience.

He coined the term "hard problem" to indicate the problem to understand the origin of the subjective and qualitative component of the mind experience differently from "easy problems," that is, the problems that concern the integration between internal mental states and sensorial perceptions, selective attention, emotional behavior, and so forth. These problems should in principle be solved in the future by means of the neurophysiological research and the computer science approach.

In the future, a computer could also be able to reproduce faithfully the human thought in a third-person fashion, but nothing indicates that the computer would have a first-person experience of what it is elaborating.

As an example, Minsky's emotion machine (Minsky, 2006) could soon reproduce many typically human functionalities, like emotions and the idea of self, but there is no reason to think that the computer would experience emotions and the sense of self in the same subjective way as we do.

The hard problem is not a problem about how functions are performed, but the problem to understand why the performance of the functions is associated with conscious experience.

We are not able to explain why, for instance, when the brain processes a specific wavelength of light, we have the experience of a specific color (the "blueness" of blue).

Consciousness and Laws of Nature

Chalmers does not deny that the biological structure of the brain is heavily implied in the onset of the phenomenon of consciousness, but he affirms that the connection between conscious processes and their neural correlates are not obvious. However, both Chalmers and Searle (1980) believe that the difference between man and machine could be connected with the specific properties of the brain physiology. The exact reproduction of the neural physiology, even with a different chemistry, could lead to reproduce also the experiential properties of consciousness.

Another way to face the problem, as Chalmers suggests, is to admit that consciousness is an irreducible phenomenon, that is, an a priori property of nature. In this way, consciousness would obey laws similar to the other fundamental physical laws like gravity or electromagnetism.

The key observation is that not all the entities in science are explained in terms of more primitive physical entities. For instance, space-time, mass, and charge are considered fundamental entities of the universe because they are not reducible to something easier.

In the case of consciousness, the goal would be to affirm that the brain state B produces the conscious state C due to the fundamental law X. We could come to a theory of everything that includes the laws of consciousness inside the set of the laws of nature.

A possibility to include consciousness in the laws of nature has been opened by quantum mechanics, in whose fundamentals the role of the observer is extremely critical. Several idealistic or interactionist theories are still competing with the traditional Copenhagen interpretation: Erwin Schrödinger (1956) first approached the Oriental monism in the frame of quantum mechanics, putting the accent of the indissolubility between the physical event and observer's mind. After him, J. Archibald Wheeler (1983), Eugene Wigner (1961, 1972), and in more recent times Josephson and Pallikari-Viras (1991) and Henry Stapp (1993) maintained quantum theories where consciousness is crucial in the objectivity of physical reality.

In particular, Stapp (1993) proposes an interpretation where consciousness, intended as an a priori phenomenon, is the cause of the wave function collapse. On the other hand, Chalmers' hypothesis is that a way to include consciousness in the frame of the laws of nature is to develop a theory of everything based on the concept of information, hypothesizing that information has two aspects: a physical one and an experiential one. Systems with equal structural organization include equal information. This idea is compatible with Wheeler's (1983) theory that information is a fundamental concept of physics. The laws of physics could be re-coined in informational terms, satisfying the congruence between physical and psychophysical structures.

Although the role of the observer in quantum mechanics remains an extremely controversial issue, in the last few years several quantum mind theories have been developed (Hagan, Hameroff, & Tuszynski, 2002; Matsuno, 1999; Tuszynski, Trpisova, Sept, & Sataric, 1997) that intend to connect the biophysical properties of the brain to quantum physics. The most authoritative is the Penrose-Hameroff theory (Hameroff & Penrose, 1996; Penrose, 1994), which hypothesizes that in microtubules, cellular structures inside the neuron, quantum reductions take place associated with simple consciousness events. Microtubules possess the physical properties suitable to obey quantum laws, thus they could play a fundamental role in the phenomenon of consciousness.

THE MIND-BODY PROBLEM IN THE 21ST CENTURY

Both the hypothesis that intelligence and self-awareness could spring from the complexity of the brain, or an artificial structure perfectly homologous to the brain, and the parallel hypothesis that consciousness is an a priori entity of nature and could be connected to the fundamentals of quantum physics are at the moment indemonstrable. However, thanks to the progresses of electronics and of computer technology, we can start to build the bases of an empirical proof of these theories.

During the past decade, several laboratories in the world carried out experiments on direct interfacing between electronics and biological neurons in order to support neurophysiological research, but also to pioneer future hybrid human-electronic devices, bionic robotics, biological computation, and bioelectronic prostheses (Akin, Najafi, Smoke, & Bradley, 1994; Canepari, Bove, Mueda, Cappello, & Kawana, 1997; Egert et al., 2002; Maher, Pine, Wright, & Tai, 1999; Potter, 2001). Progress in this research field is quick and continuous.

During the early '90s, Fromherz's group (Max Planck Institute of Biochemistry) first pioneered the silicon-neuron interface. The group keeps developing sophisticated techniques to optimize this kind of junction (Fromherz, 2002; Fromherz, Muller, & Weis, 1993; Fromherz, Offenh*äusser, Vetter, & Weis,* 1991; Fromherz & Schaden, 1994).

Many other experiments have been carried out with different aims: Garcia, Calabrese, DeWeerth, and Ditto (2003) and Lindner and Ditto (1996) at Georgia Tech tried to obtain simple computations from a hybrid electronic leech creature. As the neurons do not behave as "on-off" elements, it has been necessary to send them signals and interpret the neural output using the chaos theory.

In 2000, a team of the Northwestern University of Chicago, University of Illinois, and University of Genoa (Reger, Fleming, Sanguineti, Alford, & Mussa-Ivaldi, 2000) developed a hybrid creature consisting of lamprey neurons connected to a robot. In front of light stimuli, the creature behaves in different ways: follows light, avoids it, and moves in circle.

In 2002, De Marse, Wagenaar, and Potter at Georgia Tech created a hybrid creature made of a few thousand living neurons from a rat cortex placed on a special glass Petri dish instrumented with an array of 60 microelectrodes, also able to learn from its environment.

In 2003, Duke University's group (Carmena et al., 2003) succeeded in connecting 320 microelectrodes to monkey cells in the brain, allowing them to directly translate the electrical signals into computer instructions and to move a robotic arm. In 2005, the SISSA group (Ruaro, Bonifazi, & Torre, 2005) experimented with the possibility to use neurons on MEAs (microelectrode arrays) as "neurocomputers" able to filter digital images.

Despite these astonishing results, neurophysiological research is far from understanding in detail the learning mechanism of the brain and fails to interpret the cognitive meaning of the signals coming from the neurons.

Our group, the Living Networks Lab, since 2002 has carried out experiments on networks of biological human neurons directly connected to MEAs (Figure 1).

A Bionic Brain

The neurons, adhering directly to an MEA support, are stimulated by means of simulated perceptions in the form of digital patterns, and the output signals are analyzed. In previous experiments, we verified that the neurons reply selectively to different patterns and show similar reactions in front of the presentation of identical or similar patterns (Pizzi, Fantasia, Gelain, Rossetti, & Vescovi, 2004a; Pizzi, 2006).

On the basis of these results, we developed a bionic creature able to decode the signals coming

Figure 1. MEA support and magnification of neural stem cells adhering on the MEA

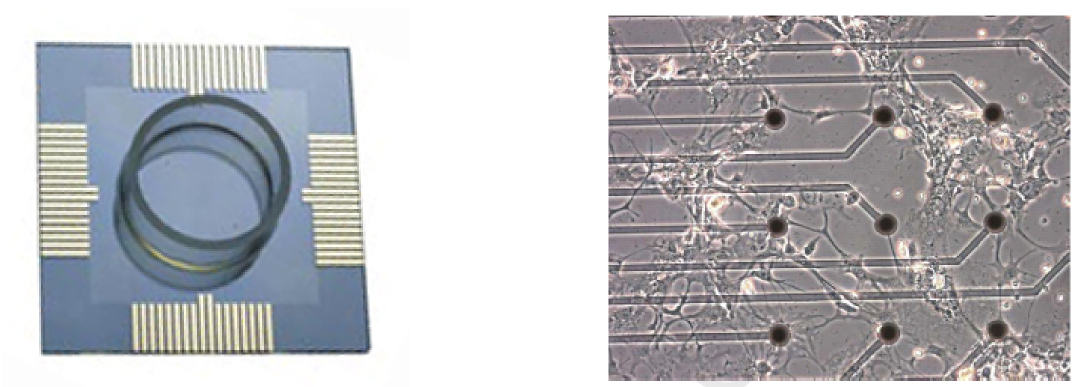
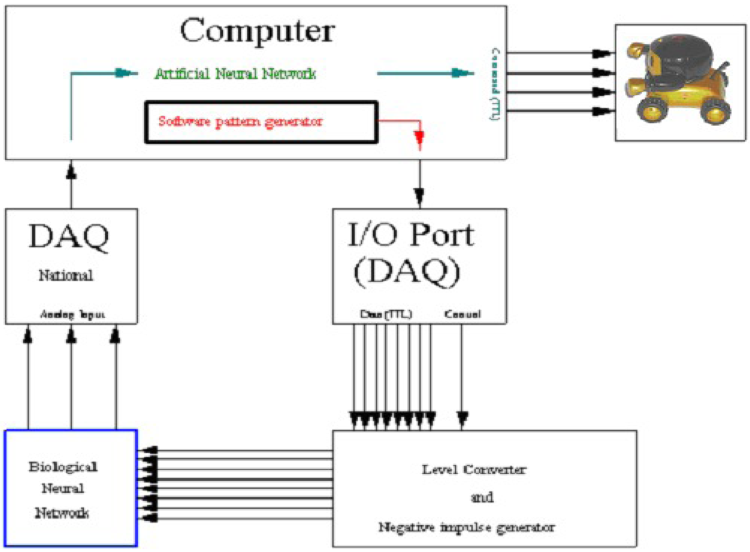


Figure 2. Block diagram of the hardware

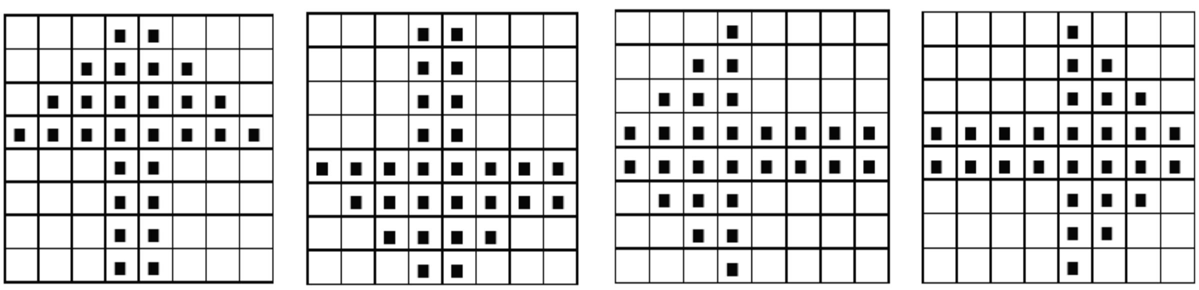


from a network of neurons stimulated by digital patterns. The whole hybrid system is shown in Figure 2.

We arranged on the MEA eight input channels picked from eight electrodes, on which living cells were attached. The cells were cultured on the connection sites of the MEA and were connected to each other as in the case of a Hopfield (1980) artificial neural network.

The first phase of the experiment consisted of stimulating the neurons with a set of simulated perceptions in the form of four digital patterns (Figure 3).

Figure 3. The four patterns: forward, backward, left, right



The stimulation occurs with a 100 mV positive voltage followed by a brief -100 mV depolarization pulse. The stimulation frequency is 433 Hz, and the sampling rate is 10 kHz.

Each pattern is constituted by a matrix of 8x8 bits. Every bit lasts 300 ms. The cells are stimulated 2.4 seconds for each pattern. Each stimulation is followed by a 1-second pause and is repeated 10 times for each pattern in order to allow the neurons to learn.

Once the training phase was finished, a testing phase was carried out. During this phase, we sent to the neurons several stimulations corresponding to one of the four patterns in a random order.

The reactions of the neurons have been sent to an artificial neural network that classified the answers on the basis of the neural reactions recorded after the training phase. The model of the artificial neural network, a novel architecture called ITSOM (Inductive Tracing Self Organizing Map; Pizzi, de Curtis, & Dickson, 2002), was developed considering that a self-organizing architecture was necessary as we had no set of known outputs to train with.

In the described experiment, we tested the hybrid system with 25 random patterns. The evaluation of the proposed model presents an accuracy of 80.11% and a precision of 90.50%. These results (Table 1) allow us to consider the effectiveness of our hybrid classifier quite satisfactorily.

This research shows a way to deeply analyze the behavior of networks of neurons and to decode their signals in reply to simulated perceptions. After an adequate increase of the number of electrode connections, the system should be able to receive real perceptions from suitable sensors and to react to them.

Our challenge consists of studying in detail the behavior of networks of neurons and of verifying if this bionic system, after a suitable increase of complexity, will allow the emergence of behaviors typical of a human mind in an artificial structure with features homologous to the brain structure.

Possible Quantum Processes in Cultured Neurons

Another research line of our group concerns the search for possible quantum processes inside the neurons. Our system is constituted by networks of human neural stem cells cultured on a set of MEAs. We verified that weak electromagnetic stimulations are able to produce action potentials in networks of neurons under extremely strict conditions of optical and electrical shielding.

The first results showed very high values of cross-correlation and frequency coherence during electromagnetic pulses (Pizzi, Fantasia, Gelain, Rossetti, & Vescovi, 2004b); these results encouraged us to continue the experimentations.

During the last 3 years, we prepared and carried out several other experiments, improving both the hardware detection and controlling system and the shielding techniques. We also took the maximum care in preparing the experimental

Table 1. Performance of the hybrid classifier

	Pattern F	Pattern B	Pattern L	Pattern R	Total
Sensitivity	100%	45.45%	75%	100%	80.11%
Specificity	94.44%	100%	83.33%	84.21%	90.50%

protocols devoted to exclude possible biases and alternative hypotheses.

All the experiments confirm the presence of spikes in neurons under tested conditions of optical and electrical shielding. On the basis of the experimental findings and the bench tests, it is possible to state that the spikes appearing in the neural signals simultaneously with the electromagnetic pulses are not due to interference.

The reactivity of neurons to the electromagnetic pulses could be due to the presence of microtubules in their cellular structure. The microtubules, formed by wrapped tubulin molecules, are structurally similar to carbon nanotubes. Actually, the structures are empty cylinders; the diameter of a microtubule is around 20 nm and its length is around some micron, whereas a carbon nanotube's dimensions can be similar to or less than those of the microtubule. Interesting optical, electrical, and quantum properties of carbon nanotubes are known (Andrews & Bradshaw, 2005; Gao, Cagin, & Goddard, 1998; Katura, 1999; Lovett, Reina, Nazir, Kothari, & Briggs, 2003; Wang et al., 2005). It is also known that both microtubules and nanotubes behave as oscillators (Marx & Mandelkow, 1994; Sept, Limbach, Bolterauer, & Tuszynski, 1999), and this could make them superreactive receivers able to amplify the signal.

The reported experimental findings need further exploration and confirmation. Nevertheless, they constitute an attempt to investigate on possible quantum processes in the brain: Experimental proofs are necessary to yield a validation of the quantum mind theories and to try to find an empirical solution of the mind-body problem.

FUTURE TRENDS

These preliminary results encourage us to continue our research with more and more complex experiments. As regards the research on possible quantum processes in neurons, many other experiments will be needed that must be confirmed by analogous experiments carried out by other groups. On the other hand, several theoretical physicists and cognitive scientists are developing new theories on the ontological implications of quantum physics and in particular on the theme of the quantum mind.

As regards our experiments on learning in the bionic brain, better performance can be reached in the future with a better tuning of the artificial neural network that decodes the neural signals. During an off-line experiment, we already tested a new procedure able to reach better performance. In the future, it will be possible to test the system with a higher number of electrodes and endow it with sensors that allow real perceptions instead of the simulated ones. Our goal is to create a bionic creature that reacts autonomously to environmental stimulations, and to improve the complexity of its neural networks.

Only the growth in complexity of the system could give rise to nonstereotyped behaviors, and make possible new answers to the problem of the relationship between mind, brain, and machines. On the other side, several scientists are implementing complex software systems able to emulate functionalities of the human brain. Also in this case, only a sharp increase of complexity of these intelligent systems can yield some indications on the real possibility to simulate the most evolved features of the human mind. Currently, several intelligent systems are able to exhibit performance similar or better than human ones, but this performance does not concern the sphere of emotions and self-awareness, and they are only partially able to perceive and learn autonomously from the environment and to improve their abilities over time.

Although the way toward the development of an artificial mind is still quite long, certainly AI is taking many important technological contributions in all the fields of our lives, by means of software embedded in instrumentations and computers, and of more and more evolved robots that facilitate many tasks in the past only pertinent to humans: from health to industry to domestic life.

In the particular case of our Living Networks Lab, we hope that the by-products of our research activity could be useful to deepen neurophysiological knowledge, test the possibility of biological computation, and develop bionic prostheses useful to people who suffer from neurological damage.

CONCLUSION

The success of the cognitive sciences, of AI, and of the neurosciences removed the problem of the nature of the mind and consciousness from the category of the philosophical problems and put it at the center of the attention of science.

The lack of ultimate answers on this issue is in part due to the poor complexity of the current artificial systems in comparison with the complexity of the brain, making it impossible to compare artificial and human performance and features. Therefore, a huge amount of work is still to be done, but some important courses have been drawn out, both in the field of the development of the software simulation of intelligent behavior, and in the field of the development of bionic systems that reproduce the neurophysiological structure of the brain.

Also, theoretical physics has still to yield an ultimate answer on its fundamentals in order to clarify the role of the person in the objective reality in such a way as to shed light on the nature of consciousness.

Despite the difficulty of the problems that neurosciences, informatics, and physics have to solve in this frame, the quantity of scientific material related to the issue of consciousness and to the implementation of AI hardware and software systems has grown exponentially during the last few years. This trend will certainly contribute to consider the birth of a real artificial mind and the solution of the mystery of consciousness as not so far and not so impossible events.

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