Breedbot: An Edutainment Robotics System to Link Digital and Real World

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Abstract. The paper describes Breedbot an edutainment software and hardware system that could be used to evolve autonomous agents in digital (software) world and to transfer the evolved minds in physical agents (robots). The system is based on a wide variety of Artificial Life techniques (Artificial Neural Networks, Genetic Algorithms, User Guided Evolutionary Design and Evolutionary Robotics). An user without any computer programming skill can determine the robot behaviour. Breedbot was used as a didactic tool in teaching Evolutionary Biology and as a futuristic toy by several Science Centers. The digital side of Breedbot is downloadable from www.isl.unina.it/breedbot.

Keywords: Edutainment, User Guided Evolutionary Design, Evolutionary Robotics.

1 Introduction

Nowadays, new-generation robots are widely used in Edutainment. There is a niche market that is fed by big and small industries which produce and sell didactic robotics kits. Between the many products available, a good example of this category are the Lego MindStorm kit (http://mindstorms.lego.com/) that is conceived mainly for schools and the small robot Surveyor (http://www.surveyor.com/) that is oriented to university and research center. Together with these kits, there are some robots that can be imagined as artificial pet companions: famous examples of this product line are Furby robots produced by Tiger Electronics (http://www.hasbro.com/furby/) and Paro (http://paro.jp/english/), a robot that is used also for cognitive rehabilitation. The main part of these robots presents an hardware structure that is sometimes very complex (formed by sensory apparatus with cameras, infrared sensors and ultra-sounds etc; by actuators as wheels, tracks, mechanical limbs and by powerful on-board computers), but this complexity is not counterbalanced on the behavioral side, as the behaviours they show, on the contrary, are quite rudimentary. Substantially we can observe in present edutainment robots a remarkable distance between their "bodies"

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sophistication (hardware) and poverty of their "minds" (Artificial Intelligence software underlying behaviors production).

The growth of this niche sector depends just on the individuation of methodologies and approaches that can reduce the gap between bodies and minds. In this work we describe a prototype made by us by which we try to apply Artificial Life techniques to robotics for Edutainment. In particular, it seems to us very promising to use the physical robot as a bridge between digital worlds created by Artificial Life and physical environments in which we and, obviously, the robots act. As it is known Artificial Life [3] is a discipline that tries to simulate in a digital world (software) the functional and structural features of biological systems. This discipline uses various techniques, models and methodologies such as Genetic Algorithms, Evolutionary Computation, Artificial Neural Networks, etc. that, in this framework, that is to say the A-life approach to technology, are used to build up digital objects by breeding, training or evolving them. Many applications are proposed in the context of User Guided Evolutionary Design [1] where a breeding digital environment allows users to "evolve" novel artificial objects. The mechanism is simple: on a computer screen a set of variants of the object users are seeking to evolve is proposed between which users can choose a subset of variants. The system then produces a new set of variants. The selection/production process proceeds until users have obtained the desired objects. There are applications in the field of evolution of artistic images [12], training human face profiles for crime investigations, objects design for furniture firms, etc. Most of those systems produce software images for static objects (cfr. for artistic images Artificial Painter [4], [8]). Moreover, within the broader field of Artificial Life, researchers are developing models and techniques to evolve actual robots [7].Our system, Breedbot, is built up by integrating the above cited A-life-like methodologies in order to permit children to evolve interesting mobile robots behaviors in an digital environment that can then be downloaded and tested on real robots. We attempted to try to avoid any form of "information processing methodology" (i.e.: programming) for children using hi-tech (i.e.: robots). This way the A-life techniques that are used are, to a certain extent, invisible for children who use it. Breedbot simulates the evolution of populations of digital agents (simulated robots) with elementary navigational capabilities. Based on Artificial Life and Evolutionary Robotics techniques, the digital environments allows the user to select agents with efficient sensory-motor behavior. This is done through a user- guided genetic algorithm (UGGA) that permits to select robots that are controlled by a neural network (i.e.: the model of the brain of an artificial pet). For the user- guided genetic algorithm the basic idea consists in showing the ongoing process (robots behaviors) on a computer screen (digital environment) and allowing the user to judge the robots actions, as a teacher or a breeder does in everyday life. In the following sections, 2 and 3, we describe the Breedbot system in detail. In section 4 we present some preliminary applications while section 5 is devoted to identify Breedbot limits and future directions for its improvement.

2 Breedbot: An Environment for Breeding Robots

Breedbot is an integrated hardware/software system that allows users with no technical or computer experience to breed a small population of robots. We will now describe Breedbot hardware and software in detail.

2.1 Breedbot's Hardware

Breedbot is shown in Fig.1a. It is built using motors, infra-red sensors, bricks and an on-board computer from the Lego Mindstorms kit. It is rectangular in shape. Its base measures 16*15 cm and it is 10 cm high. To move, it uses two large drive wheels, each controlled by its own small electric motor. Two wheels provide stability. All the wheels are fixed so there is no steering mechanism. The on-board computer (a Lego Mindstorms RCX) and the electric power supply are located on top of the motors. The sensor system - three Mindsensor infrared sensors - is placed above the on-board computer. The first sensor is mounted half way along the robot's short side and points in its direction of motion. The other two are fixed half way along the long sides. Each sensor produces a signal with a strength inversely proportional to its distance from an obstacle. The sensors can detect obstacles up to a maximum range of 15 cm.

2.2 Breedbot's Software

On software side, Breedbot uses a digital environment to simulate a process of artificial evolution that allows users with no technical or computer experience to breed a small population of robots. At the beginning of each simulation, the computer screen shows a first generation of robots in action. After a certain time, some of the robots are selected to produce offspring. Users can let the system select the "best robots" or make the decision themselves. If the system makes the decision, it rates the robots by their ability to explore the environment, and selects those with the highest scores. Human users, on the other hand, simply choose the robots they think have performed best. Once the selection procedure is over, the system creates clones of the selected robots. During this process it introduces random mutations into their control systems. The robots created in this way constitute a new generation. This selection/cloning/mutation cycle can be iterated until the "breeder" finds a particularly capable robot. At this point the brain of the simulated robot can be uploaded to a real robot and the user can see how it performs in the real world. Figure 1a shows a robot which has just received a "brain" developed with Breedbot. Figure 2 show's Breedbot's graphical interface.

On the left side there are the 9 robots while they explore a rectangular arena with walls. On the right side there is a display that indicates the current generation, radio buttons to choose between human and machine selection, STOP and RESET buttons and a graph, updated after each generation, that shows the mean fitness obtained in the exploration task along generations. The left hand side of the screen displays the behavior of the nine simulated robots in the arena,

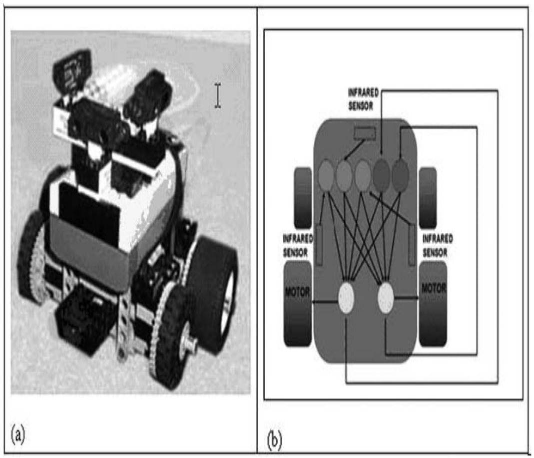

Fig. 1. 1a. A picture of the robot built with the Lego Mindstorms kit. 1b. A schematic representation of the robot and of its control system.

which is surrounded by walls. The right hand side provides information about the state of the system (the number of the current generation, a graph showing changes in the mean fitness of the population) along with a number of commands allowing the user to stop the system and to choose between human and artificial selection. The pull-down menu in the top left corner contains system utilities (to change the geometry of the environment, save configurations etc.).

Breedbot is designed to be easy to use for breeders of small robots. Breeders can use the system's graphical interface, to organize their own experiments in artificial evolution and if they want, they can select the individuals which will be allowed to reproduce. They can stop the program at any time, choose what they consider to be a well-adapted robot, and use the infrared port to upload its control system (its Artificial Neural Network) to a real Lego MindStorms robot (see Figure 3).

3 Artificial Life Techniques in Breedbot

Up to now, we have described the system without considering what is going on "inside", an aspect that is not directly perceivable by users. In this section we will open this black box to describe the Artificial Life techniques that are employed in the system.

The on-board computer on the hardware side and the Breedbot simulator on the software side, implement an Artificial Neural Network that is the system that controls the robot. The network, a simple perceptron, receives sensory stimuli from the infra-red sensors, processes the data and activates the robot's motors. The system's neural architecture consists of a layer of input neurons and a layer of output neurons (see Figure 1b). The input neurons receive stimuli from the

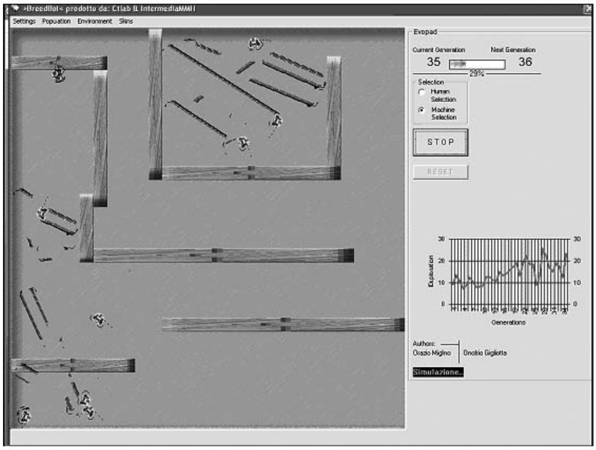

Fig. 2. A snapshot representing the Graphical Interface of Breedbot software

sensors and transmit these signals, through one-directional links (”connections”) to the output neurons. Each connection is associated with a transfer value (its ”weight”). This way, the signal arriving to the output neurons is filtered by the weights of the connections from neurons in the input layer. The input layer is made up of three sensor neurons, two proprioceptor neurons and two bias neurons. Each infrared sensor is associated with a single sensor neuron which receives its signal and activates the rest of the network. The two proprioceptor neurons have recurrent connections from the motor neurons (see Figure 1b). Thus the state of these neurons at time t+1 reflects the state of the motor neurons at time t. Finally, the bias neurons are always ”on” (they always have an activation of 1). These neurons, which do not receive any kind of signal from the external environment, play an essential role, ensuring that the robot is always able to move, even when receives no input from the sensors. The output layer consists of two motor neurons: these neurons determine the robot’s behavior at any given moment. Each motor neuron controls an electric motor. Its output is regulated by a threshold activation function. If the sum of the inputs to the neuron is equal to or higher than the threshold the neuron produces an output of ”1”. For values below the threshold, the output is 0. When a motor receives a ”1” it turns clockwise for 2 seconds. When it receives a ”0” it does nothing. In this way, the robot has three possible behaviors: it can move forward for 3 cm (when both motors are on); it can turn 10 degrees to the left (when the right motor is on and the left motor is off); it can turn 10 degrees to the right (when the right motor is off and the left motor is on). The software simulator replicates the physical characteristics of the robot and the training arena. Using the simulator we can conduct artificial evolution experiments with a population of 9 simulated robots. This aspect is based on Genetic Algorithms and Evolutionary Robotics. In terms of size, sensors, motors, and neural architecture, each individual in the population is identical to all the others. Only the weights of

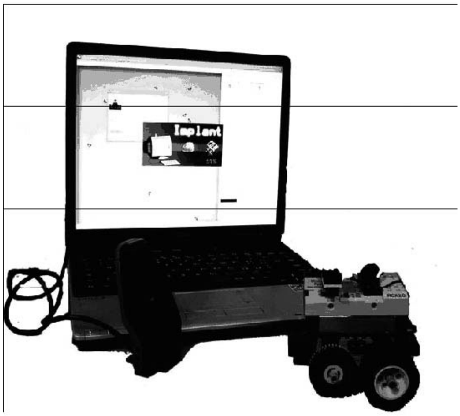

Fig. 3. The transfer of the control system (an Artificial Neural Network) from the Digital Environment to the real Lego MindStorms robot, through the infrared port

the connections in their control systems distinguish them. These are stored in their "genotypes". When breeding begins (the first generation of robots), the weights of the connections are extracted randomly from a uniform distribution in the range -1 - 1. For a certain time, the robots are allowed to move freely. Then the "breeder" (either the system or a human being) selects three robots for reproduction. Each robot's genotype (the values of its connections) is cloned three times, producing three offspring. But the clones are not perfect. During the copying process 3 per cent of the weights "mutate". The choice of which weights modify and the new value of the modified weight are random.

4 Preliminary Breedbot Application

The preliminary application of Breedbot has regarded two main spheres, both concerning Edutainment. First of all Breedbot has been used in various spreading exhibition in Italy, such as the Festival of Science in Genoa and in Rome or Futuro Remoto in Naples. In these demonstrations, Breedbot has been used by many children that could use both the software and the hardware of Breedbot prototype. Just relying on qualitative observations, we noticed that the joint use of the digital content and the physical robot led a better understanding of the themes that were meant to introduce.

For this reason we have run a pilot experimentation [6] in a school to verify if using software and hardware together could produce better results in learning. It is, in fact, well-known that computer simulation can be a powerful teaching tool, because they allow the learner to manipulate the most important variables involved in a process and observe what are the results [5], [10], [13]. It is not very much investigated if the use of simulation (digital content) and robots can enhance learning. So we compared two groups of students: in the first one the students interact with a traditional multimedia hypertext (the control group), while in the other one the students could also manipulate the Breedbot prototype. These groups were formed by 22 Italian high school students (average age = 14.5 years) both attending a Biology Course. The questionnaire that was used to evaluate the students was developed together with biology teachers in order to measure the students competence in basic concepts of evolutionary biology. The questionnaire has 14 items with 4 different answers, of which only one is correct.

The following graph shows the preliminary results regarding Breedbot application in this context. The results of this pilot study indicated that the use of

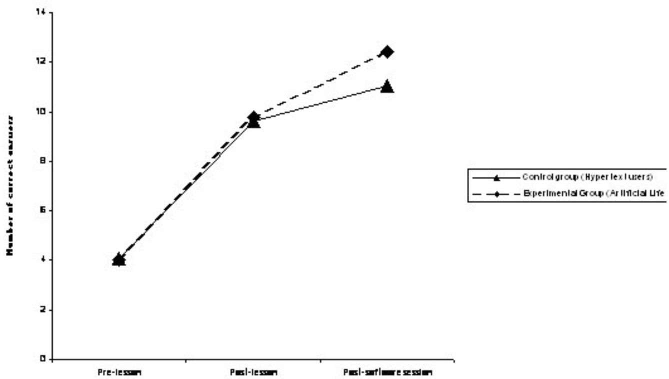

Fig. 4. The graphs show the average performance of the control group (solid line) and the experimental group (dotted line) across time. The subjects were tested on a questionnaire regarding evolutionary theory before a standard lesson, after the lesson, and once again after using either a hypertext tool (control group) or the artificial life tool Breedbot (experimental group).

Breedbot system, both software and hardware, improves learning (in the present case about a curricular subject such as Biology).

5 Conclusions and Future Directions

The preliminary results presented above suggest that the use of an integrated software-hardware system as Breedbot can be very useful in Edutainment. What we would like to stress is that its use allows to focus on the gap-link between digital and real world. As the process runs in simulation and can be transferred in reality, it makes it possible for users to ask about the limits and potentials both in simulation and in reality.

This is, of course, just a suggestion: the issue will be faced up in more detail in the next investigating efforts. Another issue we aim at tackling regards the extension of the Breedbot system. We now intend to improve the system to handle with different robots. In particular it will be particularly interesting to try the system with the Surveyor robot (www.surveyor.com) that is quite different in size and shape and is provided with different actuators. The robot built with Lego Mindstorms Kit has two wheels, while Surveyor is a crawler, that means that it has tracks to move. This modifies completely the robot interaction with the external environment, thus underlying, once again, the importance of transferring digital agents in real world.

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