A Fuzzy Artificial World: Zamin II

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Abstract. Zamin has previously been introduced as a fast and expandable artificial world for cognitive studies. Zamin's organisms have a simple case based reasoning decision making and unsupervised learning system. In this paper, we improve Zamin organisms' CBR brains to Fuzzy CBR brains and conclude the new brain system helps in evolution of more complex behavior and more successful life.

1 Introduction

In [1] *Zamin*[1] is introduced as a fast and expandable artificial life model based on ERL [2] and a more suitable model for cognitive A-Life studies in compare with known models like Echo [3], LEE [4] and Tierra [5].

Zamin creatures (which are called *Aryos*[2]) must compete for food, escape from predators and reproduce to keep up their species. Aryos choose their actions using a simple case based reasoning algorithm and are trained during their life time using case based learning. They are also subject to evolution during the lifetime of their species.

As shown in [1], Aryos are quite successful in development of several simple, but sufficient, strategies for living inside Zamin environment. But due to the simplicity of the evolved strategies, Aryos can not resist harsher environmental state like less food, more energy suffrages, more predators, etc.

In this paper, we'll improve Aryos' brains to fuzzy brains to increase the computational power and in turn, complexity of Aryos' living strategies. The paper is comprised of 4 sections:

The first one describes Zamin and its inhabitants.
Second section deals with the fuzzification of Zamin creatures.
At the third section, some results from Fuzzy Zamin runs will be presented.
And the last section presents the conclusion and further works.

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[1] Zamin means 'Earth' in Persian. It is also the abbreviation of *'Zoological Agents for Modification and Improvement of Neo-creatures'*.

[2] Aryo is a Persian name taken from Aryobarzan, a warlord living 2500 years ago.

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2 Zamin I in a Nutshell

Zamin environment consists of a simple lattice and three types of inhabitants: The Aryos which are mobile and learner organisms and are the main subject of our study; the *Sentinels* which are another mobile organisms, but their behavior is hard-coded and they are just aimed to kill the Aryos; and the *plants* which are the green energy resource of the Aryos.

2.1 Zamin Environment

Zamin environment is a simple spherical lattice (if an organism keeps moving in one direction, it will reach its source position again). Each cell of this environment can at most include one Aryo or Sentinel (Thus, once a cell is occupied by an organism, no other organism can move there). Energy is fed into this environment by the plants which are created by a constant growth-rate, but also have a maximum total, to assume a dependency on another limited resource.

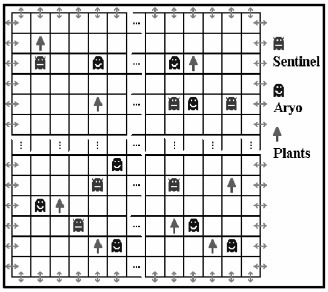

Fig. 1. The Environment

2.2 Aryos' Body and Life Cycle

The main creatures of this environment are the Aryos. Each Aryo has an internal energy state which is increased if it eats a plant or the flesh of a dead organism, and decreased, as it is attacked by other creatures. The energy level is also decreased by a constant usage factor and must be kept above a certain limit to prevent death. Once an Aryo is dead, its body remains for some period in the cell where it is dead. During this period, the body can be eaten by other organisms to gain energy.

Each Aryo can reproduce (asexually) once its energy level exceeds a threshold. After the reproduction, a certain amount of parent's energy is given to the child.

The same as almost all zoological organisms we know, Aryos' also have a face (which is called their direction). They receive inputs from that direction and can move only towards that. This direction property can be one of the four North, South, East, and West main directions.

2.3 Aryos' Genetic Code and Evolution

Many of the Aryo properties are not constant and are specified by a data structure which is called the *Genetic Code* or *Genome*. When an Aryo is born, the parent Genome is mutated by a predefined factor and passed to the infant. Then the infant is initialized using this code. Following the Mendel theory [6], an Aryo's genome remains unchanged during the life time of the organism. It can be mutated only during its passing to the infant.

The existence of this genome, the possibility of mutations on it, and the competitions between Aryos in finding energy resources and escaping enemies, composes an evolution based on natural selection [6]. Thus we can expect long evolutionary trends and organisms' performance increment during the long running time. [6]

As Aryos' reproduction is asexual, no combination operator is used.

2.4 Aryos' Action Choices

At each time step, each Aryo can choose an action. This action can be a choice of a move to one of the three cells in-front of the current cell or a changing of direction, reproduction, attacking to the organism in-front, eating or nothing at all.

As stated in 2.1, each Aryo has a *current direction*. As seen in Fig. 2, the Aryo can always choose to move to one the three cells in front, which are the cell directly in-front and the ones on its right and left sides. The organism can also choose to turn left or right to change its direction. A choice of movement to a cell which is occupied by another organism will result in discarding the action and an energy decrement penalty for the organism that has chosen the wrong action. Aryos also have an internal *tiredness* property. Tiredness is increased by moving or attacking and decreased by other action choices. Once an Aryo has reached its maximum tiredness, it can not move any more and a choice of move will again result in wrong-action energy penalty. The tiredness limit has a gene in Aryos' genome. A high value of this gene will result in higher tiredness limit, but as a side effect, results in more energy decrement by moving.

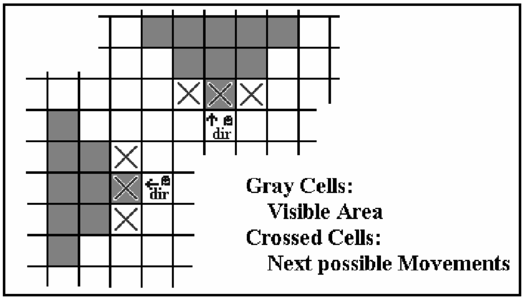

Fig. 2. Direction: Movements and Sensory Inputs

'Eating' is another action choice for an Aryo. Once there is a plant or a flesh in the cell where Aryo is, it can choose *Eat* command to eat it and increase its energy. As stated in [1], to increase the chance of evolution of specialized species and in turn species competitions, there is a gene in Aryos' genome called *'Carnivorousness'* which specifies what percent of a plant or flesh's energy is absorbed by the organism. An organism with a high value carnivorousness gene can get all the energy in a flesh, but a little from a plant, and reverse for an Aryo with low carnivorousness.

'Attacking' is another action choice. Once there is another organism (Aryo or Sentinel) in-front, Aryo can choose to attack it. Attacking will result in decre-

ment of a specific amount of energy from the organism which is being attacked. Choosing attack when there is no other organism in front will result in wrong-action energy penalty.

'Reproduction' or *'Splitting'* is the last action choice. Once an Aryo has more energy than a specific limit (this limit is specified in its genome), it can reproduce and create a child. The infant would be initialized using a genome similar to its parent's genome but with a few mutations. Some percent of the parent energy is also given to the infant. This amount is also specified in the genome.

An organism can also choose not to do anything at each time step.

2.5 Aryos' Sensory Inputs

Each Aryo has two types of sensory input sources. The first is its internal state which is composed of its energy level, its last change of energy level, its age and some flags specifying what it has done as its last action. The external sensory inputs specify the type and some properties of the most near object in their view point. These properties vary depending on the type of the object in-front. For a plant, only distance, relative angle and plant energy is given as sensory input, but for another Aryo or Sentinel, its energy level, carnivorousness, age, tiredness, etc. are given.

2.6 Aryos' Pleasure System

To guide Aryo's unsupervised learning system, each Aryo has an internal pleasure system which specifies how favorable its current state is. If the pleasure level is positive, it means that organism is pleased with its current state while a negative pleasure level means it is in pain. The absolute value of pleasure measure states the severity of organism's pleasure or pain.

The pleasure system uses a case based reasoning method. Each case is in the form of a pair (S, P) or (*State, Pleasure*) and says if current sensory input is S, then organism pleasure is P. We call each of theses cases a rule. Whenever there is a need of computation of pleasure, the current sensory inputs are compared with all pleasure rules S parts, and then, a weighted average of their P parts with weights relative to the similarity of the S parts to sensory inputs is computed as current pleasure level.

Pleasure rules remain unchanged during the life time of an Aryo and are initiated by the genome it receives. Thus, they only change by evolution.

2.7 Aryos' Decision Making

Another set of cases compose Aryos' decision making system. Each case (also called a "decision rule") is in the form of a triple (S, A, P) or (*state, action, pleasure*) which states that "in an experience where the sensory inputs have been S, action A was chosen and it has resulted in pleasure level P". At each action choice, sensory inputs are compared with the S parts of all action rules. Then the case which its similarity multiplied by its P part is the bigger is selected. At last, its A part is chosen as the action to perform.

2.8 Aryos' Learning

Once an action is selected and applied, pleasure is computed and its value is combined with the P part of the triple which has chosen the action.

2.9 Sentinels

Sentinels are quite similar to the Aryos. They have only two major differences: First, their behavior is hard-coded and they have no learning and genome. They have just one goal which is to search for the Aryos and killing them. Second, they gain energy by attacking to Aryos and do not eat anything.

3 Zamin II: Fuzzified Zamin I

In [1], we compared *Zamin I* with some other A-Life models from the view point of a research on evolution of complex behavior. We concluded that Zamin is a better choice than Artificial Chemistry (e.g. see [7]), Cellular Automata (e.g. see [8]), or Assembly Code models (e.g. see [5]) because it starts from a much more complex organisms base and therefore does not take time for evolution of primitive capabilities. It is also more suitable than models like Echo and LEE because it is less abstract than such models and provides easier comparisons with real world organisms for the experimenter.

Zamin I was successful in presenting some basic strategies for self organizing creatures, and overcame ERL creatures in average and maximum life time. But the resulting strategies were very simple and this simplicity was due to their simple decision making system. This section explains the changes we made to Zamin I creatures to alter their crisp reasoning system to a fuzzy one in order to overcome the inability of developing more complex behaviors. We have also made some refinements to the environment to facilitate the evolution of different species and in turn, competitions between species and arm races [6].

The CBR method used in *Zamin I* was quite crisp, and therefore, generalization and encapsulation of similar cases or states was impossible (e.g., an Aryo needed to have different rules to follow and eat food when it had different energy levels). To overcome this problem, we promoted the Aryos' brain system to Fuzzy CBR. In this model, all the *State* parts in pleasure and action rules are replaced by fuzzy rules, as follows:

3.1 Pleasure Rules

Each pleasure rule is again in the form of (S, P) pairs but this time the S part is specified with fuzzy sets. (See Fig. 3). In the previous model, S was a set of state values, for example it could say that "Energy Level is ..., Delta Energy Level is ..., Last Action is ..., Object in front is ..., etc." but in fuzzy model, it is in the form of: "Energy Level belongs to fuzzy set ..., Delta Energy Level belongs to fuzzy set ..., etc.".

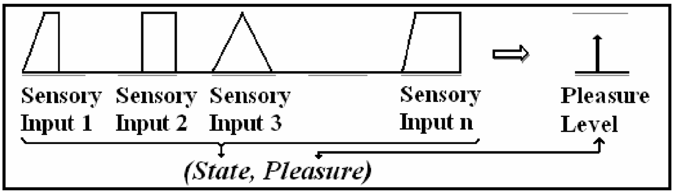

Fig. 3. General View of a Fuzzy Pleasure Rule

3.2 Pleasure Computation

The computation of pleasure has also changed as follows: After the current state is fed into each pleasure rule, each sensory input's value is put in its fuzzy set and fuzzy set outcomes are computed (as in Fig. 4). Then, the minimum value of the fuzzy set results is regarded as the rule activation value. Rules whose activation value is below a specific threshold are cut off at this level and not used in this step (This threshold has a gene). Then the final result of each rule is computed by multiplying the activation value to the pleasure value (the P part of the rule). Several methods were implemented for combining the rule results and each method has a gene specifying its likelihood of being used.

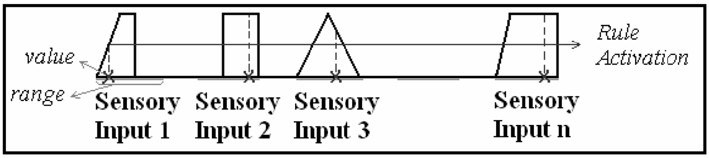

Fig. 4. Computation of Rule Activation

3.3 Decision Rules

The same as pleasure rules, decision rules are promoted to fuzzy, so that their S parts are described using fuzzy sets. Here again, a minimum limit for rule activation and several combination methods are used and each have a gene in genome.

3.4 Limited Fuzzy Sets

We have used a trapezoid shape for each fuzzy set, and therefore we need 4 points (genes) to specify each fuzzy membership set (Fig. 5). This makes the entire genetic space for rules very vast and in turn slows down the evolution (see more discussion in [1]). To overcome this problem, we have added a gene which limits the number of fuzzy membership sets to some predefined number namely low, middle, high, proportional, not proportional, zero, none-zero and effect-less. This gene is called *Fuzzy-Bounding-Gene.*

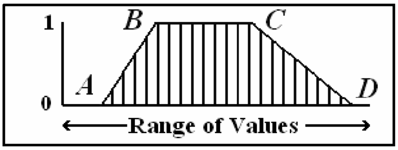

Fig. 5. Computation of Rule Activation

3.5 Learning

After each choice of action and applying the results, learning procedure is applied as in Fig. 6.[3]

3.6 Learning Gene

To have a measure of usefulness of learning for Aryos, there exist a gene which sets on or off the learning mechanism. When learning is active, more energy is spent in each time step but in return, every experience is passed to learning module.

3.7 Precision

To add the possibility of uncertain behavior, a precision gene is added which decides how fuzzy will the organism computations be. The higher its value, the more imprecise the brain processes will go on.

4 Fuzzy Zamin Results

Comparing with *Zamin* results, the average Aryo age is increased from about 170 to about 740 time units and the maximum age is increased from around 1800 to around 12000. These values indicate that Aryos have been quite successful in adopting their fuzzy brains.

Aryos in Zamin II can also tolerate much harsher environment. They can resist in environments in which the penalties for wrong actions are about 5 times more than the value at the beginning of simulation and the number of plants is half.

Fuzzy Zamin creatures are very much dependant on their learning system. All long life species have a learning gene which grants learning in all creatures of species population and disabling the learning system results in immediate extinction of the population.

In 95% of Zamin II runs, the *Fuzzy-Bounding-Gene* has a value which states that the creatures just use the 8 predefined sets. This complies with the common recommendation in fuzzy control design which states: *'Start with few membership functions.'*

[3] The absolute value of pleasure values are compared, because the most severe cases must be memorized.

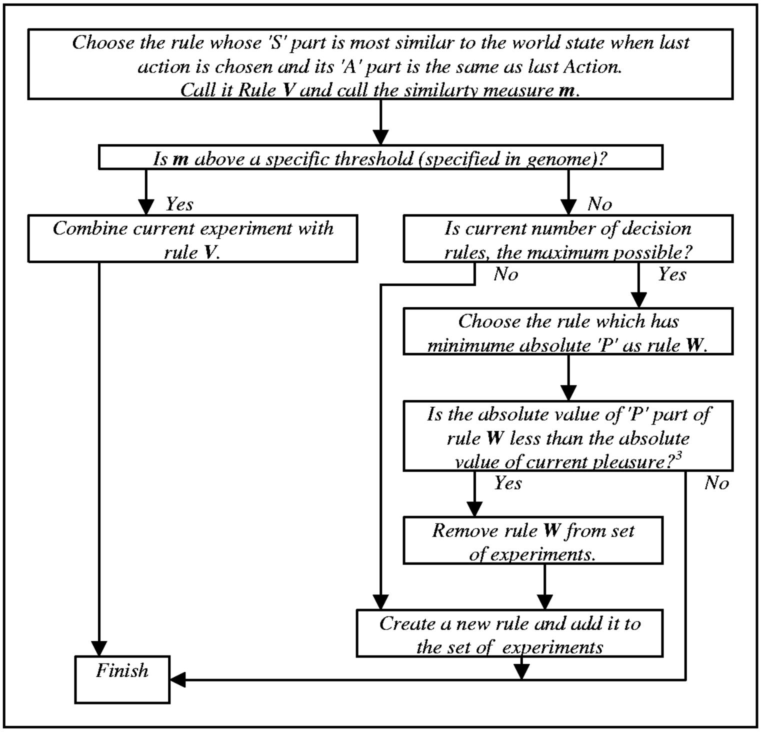

Fig. 6. The learning algorithm.

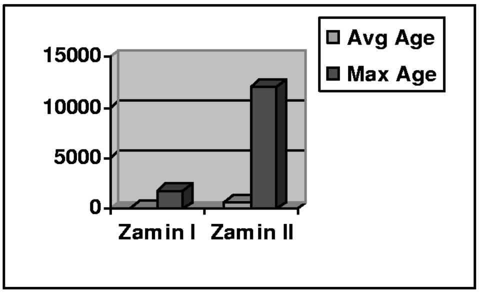

Fig. 7. Age comparison between Zamin I and II

5 Conclusion and Further Works

Zamin I, was a fast and expandable alife model, suitable for cognitive studies. Zamin creatures (called Aryos) develop their lifetime strategies by using a simple Case Based Reasoning brain and are trained both by evolution in long term and Case Based Learning in short term. *Zamin I* inhabitants develop simple strategies for their living inside *Zamin* but are not able to expand these strategies to more complex ones or resist harder environmental states.

In this paper, we promoted the simple CBR brains to Fuzzy CBR brains by changing all state variables from crisp values to fuzzy values and adding imprecise computation choice.

We showed that the average life time of the organisms and their resistance against environmental pressures has increased. Also it was shown that Aryos have well accepted their learning system and have chosen it. The evolution of several specialized living strategies also states our success in facilitating the evolution of more complex behaviors.

In the next step of this research, we are trying to extend the brain system to a 3 layer fuzzy model in which, the world state is first translated into some internal image and then used to make decisions. This is supposed to be helpful in studying the evolution of communication.

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