Mental Representation by Electric Neural Nets

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1 Introduction

For many years, the philosophers and psychologists wondered how living creatures represent the world in their mind. By becoming acquainted with mental representations, it is possible to simulate, to artificially create the structure that comes into being in the living creature's mind, representing the world. Owning to this, our systems can be equipped with some kind of biological intelligence that enables fundamental mental action–reaction behavior. This can be really important in robot control, where the complex program structures used so far can be replaced with a more efficient, possibly more hardware-based solution (with neural networks implemented in integrated circuit) which presumably provides finer, more conscious control.

The paper is divided into two parts. The first part discusses the biological background, the formation and the relations of the mental representation and cognitive science. In the second part an artificial neural network based model is introduced based on the experiments done on the paradise fish (*Macropodus opercularis*), the different algorithms, hardware and software implementations are presented.

2 Mental representations and the cognitive map

One of the main goals of cognitive science is to find out how the information is mapped in the mind (mental representation) [1]. A generally accepted classification of the different representations can be seen on Fig. 1.

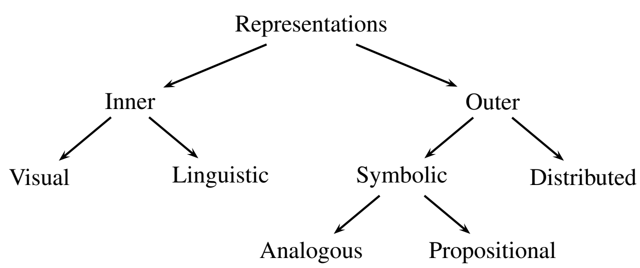

Figure 1: Classification of the representations after Eysenck and Keane

John 118	Michael 119	Jude 120	Helen 121
	Corridor		
Mark 125	Paul 124	Ingrid 123	Empty 122

Figure 2: Sketch of the working place

John stays in Room 118.	Mark stays in Room 125.
Michael stays in Room 119.	Paul stays in Room 124.
Jude stays in Room 120.	Ingrid stays in Room 123.
Helen stays in Room 121.	Room 122 is empty.

Figure 3: Description of the working place

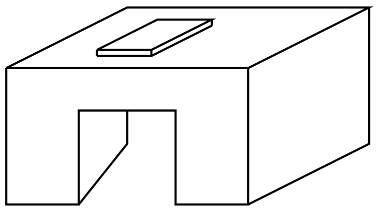

Figure 4: The book is on the table

The representation is such a notation, sign, that shows or describes something. In order to illustrate the visual and linguistic form of the representation [2] give the following example. Suppose that a plan has to be worked out to place people in different rooms. A possible solution for the problem is to draw a sketch containing the corridors, the rooms and the people working in them (Fig. 2). The description seen on Fig. 3 contains mainly the same information. The common in the two representations is that both enlighten the information only from a certain aspect, point of view.

Certainly, the sketch represents the real world much better than the linguistic representation, eg. the sketch also contains the arrangement of the rooms. That is why the visual representation can be considered analogous, because its structure follows that of the real world.

So, the visual and linguistic representations in many aspects are different. These differences, after [3, 4], are summarized as follows (see Fig. 4):

1. The linguistic representation is composed of symbols whose smallest part that still has a meaning is given (one-third of the letter B does not have any independent meaning). The visual representation does not have a smallest

unit, it is arbitrarily divisible.

2. In the linguistic representation symbols stand in the place of things that are represented by words. In the visual representation there is not always a distinct symbol for the thing it represents. Thus, eg. there is not a symbol for the relation that exists between the book and the table. The picture implicitly contains the relation "something is on something else".

3. Pictures have no grammar in the sense that the combinational rules of a language use the fact that different kinds of symbols exist in the language (eg. noun, verb).

The above mentioned differences characterize the inner representation, too.

3 The usage of cognitive map during learning

Regarding cognitive psychology, the key of learning is the ability of living organisms to mentally represent certain aspects of the world, ie. to map these aspects, and to perform operations on the mental representations. The representations can be eg. the maps about the surroundings of the living being. The operations done on the representation can be a kind of nothing venture, nothing win processes during that the living creature tries certain possibilities in mind. The operations can also constitute a multi-level strategy during which the living being makes certain steps for the sake of the next steps. An early representative of the learning in cognitive approach, Tolman, researched how a rat finds the way in a labyrinth [5]. In his opinion, the running rat in the labyrinth does not learn the series of left and right turns, it rather creates a cognitive map, the mental representation of the ground-plan of the labyrinth. Newer researches also prove the existence of the cognitive map. For the researches the scientists used such a labyrinth that consists of a central room and eight identical corridors opening radially from the central room. In each test of the experiment, the researchers placed some food at the end of all the corridors. After 20 tests in average, the rats solved the problem in such a way that they practically never returned to the previously visited corridors. The rats solved the exercises at the same efficiency when the possibility of using the sense of smell was eliminated by using a material with an intensive fragrance which oppressed the smell of food. One of the most remarkable results of the research was that the rats did not solve the exercise according to a strategy (eg. visited the corridors clockwise or anticlockwise), but they randomly selected the next corridor. This means that the rats did not learn any fix series of responses. The results more likely show that the rats constructed the inner representation of the labyrinth which contains the spatial relations of the corridors, and during the tests they mentally "tick" the already visited corridors [6, 7].

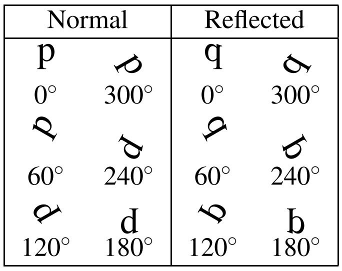

Figure 5: Rotated letters

Mental rotation and image scanning

Consensus has that imagination as an analog representation. Therefore, in order to understand the nature of the mental representations it is worth to recall two famous series of experiments that mainly researched the structure of the imagination. These experiments tried to answer such questions as how the image is stored in the mind, or what kind of operations we can do with these representations, etc. In the first series of experiments, the mental rotation was researched. During the experiments participants had to do dynamic transformations on visual images. In the other series of experiments, they scanned pictures on an imaginary map.

Mental rotation

In the series of experiments that studied the mental rotation, different imagined objects were examined [8, 9, 10]. Eg. Cooper and Shepard showed different alphanumerical signs to the participants in normal and reflected form (Fig. 5). They had to decide whether the form used in the tests were the normal or reflected form of the standard form. Generally, the following was established: the more the test forms were rotated compared to the standard form, the more time the participants needed to make the decision. The test series were done with different forms such as numbers, letters, etc. This fact confirms the universal validity of the results. Based on the experiments, it seems that the virtual images are placed similarly to the real objects in the mental space, namely in such a way that the physical objects are placed in the physical space. The mental objects are moved or rotated the same way as the physical objects. It also has to be mentioned that as the test objects become more and more complex, the participants have more and more difficulty to make right decisions about whether the rotated test objects are the standard objects or not.

Image scanning

During another series of experiments which also examines the nature of the mental objects the participants have to mentally scan an imaginary map [11]. During the tests the participants usually receive a fictitious map of an island. This map represents different orientation points marked with an ‘X’ (eg. a tree, a house, a lake etc.). In the first part of the experiment, the participants have to memorize the map until they can exactly reproduce the map in drawing. In the important part of the experiment, the participants get the names of different orientation points and an exercise that they imagine the objects on the map and focus on them. Five seconds later, another object is named. That time, the participants get the instruction that they scan the way between the first and second object in such a way that they imagine a flying black point. As the objects on the map are not at the same distance to each other, it can be determined how the time needed to go from the first object to the second is proportioned to the real distance of the objects on the map. With this experimental technique, it is experienced several times that the scanning time linearly depends on the real distance of the two objects, namely, the bigger the real distance between the two points, the longer the time needed to scan the way. On the basis of these evidence, it can be believed with reason that the images—ie. these kinds of analogous mental representations—have spatial properties that are similar to the properties of the objects and activities of the real world.

The above survey has been taken regarding the notion of mental representation in cognitive science and the important experiments that prove its existence. Moreover, two such series of experiments were explained that are types of analogous mental representations; they researched the properties of images. The most important results of the experiments in the aspect of this paper were the following: on one hand, similar operations can be done on the images in the mental space as on the objects of the physical space, on the other hand, in many aspects the properties of the mental space containing the mental representations are the same as the properties of the physical space.

4 The relation of the cognitive map and the mental action–reaction movements

The mental representation develops with the growth of a living creatures’ intelligence; its complexity increases. As the living creatures’ sensory organs become finer, more precise, their emotions also become more complex, more combined. Thus, their mental action–reaction behavior also abstracts. The examination of the mental action–reaction behavior becomes more and more difficult as the intelligence of the pilot animal increases. So, the best living creatures for the mental action–reaction experiments would be unicellular animals or amoebas, but it is very difficult to make a correct test environment. The only possible reaction that can be analyzed correctly is the movements caused by an external, physical action (eg. shock). Our research is based on the extensive experimental results of the paradise fish (*Macropodus opercularis*) [12, 13, 14]. The model is created for the case of escape movement through fear. (Fig. 6)

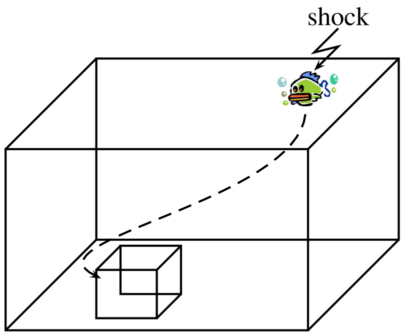

Figure 6: The movements of a shocked fish in the fish tank

The action–reaction movement of a living creature is based on a very complex process. In this process the cognitive map plays a very important role, as all the information that the living creature collected, experienced from its surroundings, environment is stored in it. The cognitive map has a similar structure to the living space of the animal. It is also granulated, it is built up from many small building blocks and each is responsible for a small part of the physical space. All blocks have the same attributes and during the learning process the degree of these attributes are set. The blocks are independent, there is no kind of interaction between the neighbor blocks. It is also very important that the animal can localize itself in the cognitive map according to the information received by the sensory organs.

The action–reaction movement process is controlled by the emotional center. When an action (eg. shock) happens, the emotional center selects the important attributes from the cognitive map and they are copied to the dynamic map. The dynamic map is similar to the cognitive one, but it changes much faster, so it is able to contain information about current dangers, smell of food, etc. Some attributes of the dynamic map may be overridden by a sense organ if the space stored in the cognitive map differs from the real, experienced environment. In the modified dynamic map the emotional center may also redefine the degree of the attributes. Then the dynamic map is processed and a potential surface is created which is transferred to the movement center where the new direction is decided. The cognitive map is mainly static, the attributes are just slowly modified in little steps by the dynamic map. (see Fig. 7)

The simulation environment in our research is the following: the paradise fish has been living in a 3D aquarium for a long time. During his life, he exhaustively explored his living environment, he mentally mapped it. He knows the different places, caves of the aquarium where he feels safe. This became part of his mental knowledge, so the learning process is finished, there is no kind of feedback from the dynamic map to the cognitive map. To verify the correctness of the neural structure proposed later, the paradise fish is frightened, electrically stimulated and it is checked whether the shocked fish swims to the cave where he is safe.

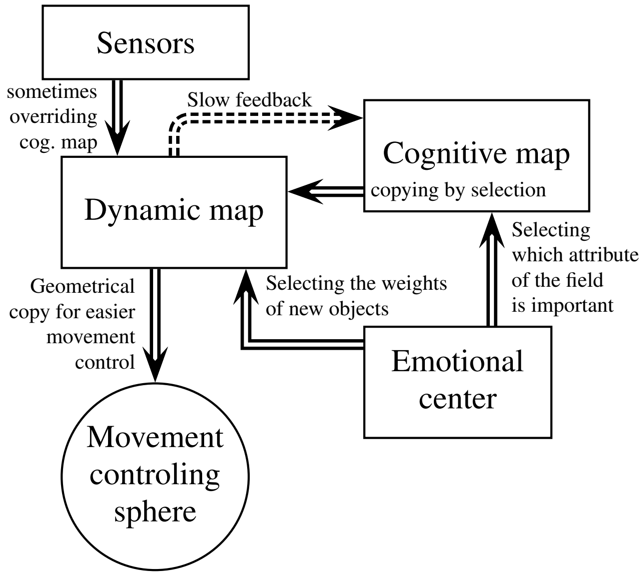

Figure 7: The block scheme of the movement process

5 An artificial neural network realization of the cognitive map

The cognitive map in the living creature's brain is built up of a great number of neurons. If the structure of the real cognitive map is built up of artificial neurons an artificial cognitive map is obtained which has almost the same capabilities as the real one. It is not possible to fully simulate the real cognitive map, because on one hand the real structure, the connection system of the neurons is not exactly known, only hypotheses exist, and on the other hand if the real structure is known there is not enough computational capacity at the actual development level of the microelectronics technology to simulate the parallel functioning of millions of neurons, even in an application specific device, processor. Thus, this paper introduces a much simpler model that is based on biological researches and hypotheses, and also takes into consideration that the model should be easy to implement in software and hardware environment.

The model uses the fundamentals of the artificial neural networks that is well described in [15, 16, 17]. The proposed model uses similar elements that are known in an ANN, but in some cases they are not controlled and connected as usual. The conformation of the applied neuron can be seen on Fig. 8. The body of the neuron makes a sum of inputs, and forms the output to be normalized by an $f(.)$ nonlinear transfer function (typically sigmoid). The inputs, that are mostly coming from the emotional center, select the actual data to be summed. The data is stored in the

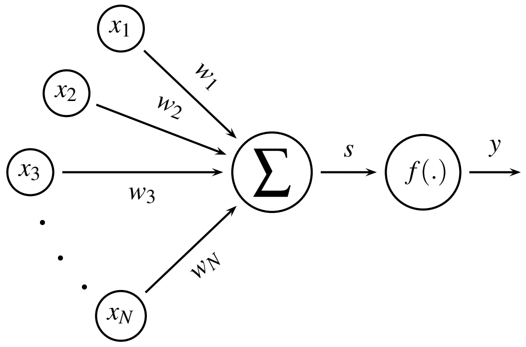

Figure 8: The conformation of the neuron used in the cognitive map

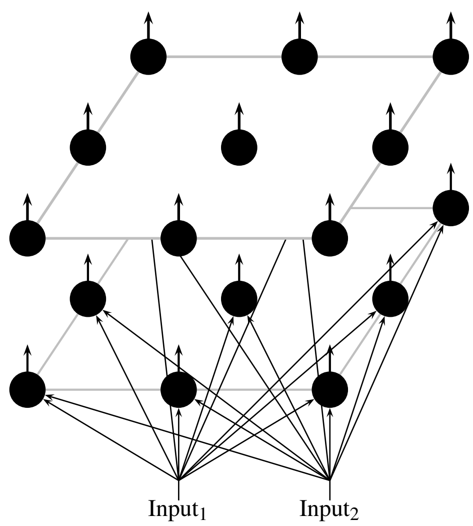

Figure 9: Structure of the artificial cognitive map

weights of the input lines. These weights—taking values between 0 and 1—that represent the intensity of the specified attributes at the point of space that the neuron is in charge, are multiplied by input values.

The artificial cognitive map is constructed from these neurons. The position of the neurons in the neural network represents the position of the area it contains information about. By placing many neurons next to each other, the physical space is mapped into a cognitive map. There is no kind of connection between the neurons, this is only a single layer ANN. All the neurons have the same inputs driven by the emotional center. The mental information is stored in the weights of the connections that indicate the partnership of the attribute, how good or bad the place the neuron is responsible for is, from the point of view of an attribute. Fig. 9 shows this structure,

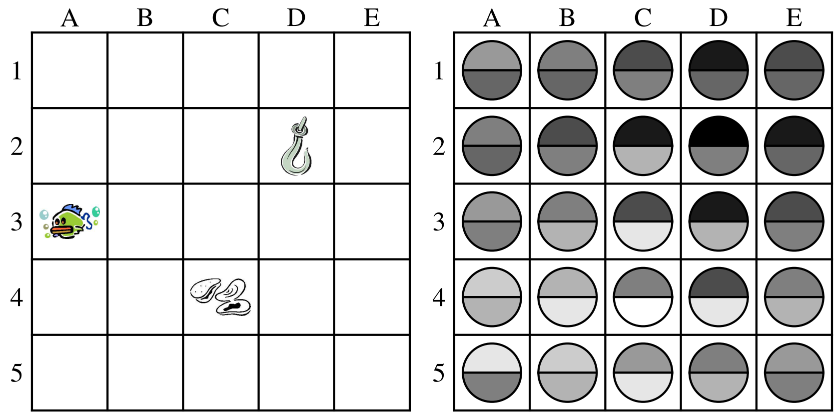

Figure 10: A sample 2D space and its potential map

where for better visualization only the neurons on the first level are connected with the input values. The inputs are summed and then normalized by a sigmoid function resulting the output of each neuron. Each output value is the potential of the part of the space it symbolizes in the aspect of the attributes selected by the emotional center, and from these outputs a potential surface in 2D or a potential space in 3D is created.

This potential space is very important, because it governs the decision of the fish about his route. He tries to swim to the place where the potential is the lowest. Eg. a simple sample 5×5 2D physical space can be seen on Fig. 10. A hook is placed at D2 that symbolizes that it is a dangerous place for the fish. If he swims there he feels physical attack, electrical shock, etc. At C4 some food is placed. This means that the fish always finds there some food. If our fish lives in this physical space he learns that it is better to avoid D2, the potential of the place D2 and its surroundings increases, the potential of the place where he feels safe decreases. A similar situation happens at C4, but at C4 and its surroundings the potential decreases, because the fish always finds some food there and it fills him with happiness. The potential of those places where he rarely or never finds food increases. The potential map after learning can be seen on Fig. 10. The upper parts of the circles represent the potential of danger and the lower parts the potential of hunger. The darker the half circle is the higher the potential of the place is. As it is mentioned earlier, it depends on the emotional center which attributes are selected for an action. Eg. when the fish feels hunger the emotional center selects both food and danger attributes with the same partnership, because he wants to avoid the physical attacks. But if he does not find food and he becomes more and more hungry the importance of getting food without physical hurt is decreasing, and in the selection of attributes the ratio between the hunger and danger is more and more shifted towards the hunger.

A geometrical copy of the resulting potential map is created for the movement control. As the fish can localize itself in the living space based on the resulting potential map, he can decide his next place to swim.

6 Hardware and software implementation of the cognitive map

6.1 Software implementation

The correctness of the proposed artificial model for the cognitive map was verified by a software implementation. As it is assumed that the paradise fish has been living for a long time in its virtual fish tank, so the learning process has been finished, only the static cognitive map is implemented. This simplification can be made because the structure of the cognitive map and the dynamic map is the same, and as the fish explored carefully the sensors do not provide new information about the environment. In the implementation the real structure of the proposed model is intended to be created, the running speed is not important.

The software is written in C++. The neuron is implemented as an object. For each neuron the input weights and the transfer function can be set. The neurons are stored in a 3 dimensional tensor, the coordinate of the neuron in the tensor determines the part of the simulated space it stores information about. The outputs of the neurons are placed in another 3D tensor, which represents the potential space. The next coordinate of the fish is calculated by a guiding algorithm discussed in [18, 19, 20].

6.2 Hardware implementation

The software implementations are very useful in the development stage of an ANN model, but most benefits only realize when it is implemented in a hardware environment. One of the most advantageous property of the neural networks is the parallelism. Even a software implementation running on the fastest sequential processor cannot provide realtime responses and learning for networks with large number of neurons and connections. Parallel processing with multiple simple processing elements, on the other hand, can provide tremendous speedups. In the proposed model, the number of neurons increases exponentially the growth of the size of the simulated environment, so it is applicable to implement it in a hardware.

The structure of the proposed can be seen on Fig. 11. In the hardware implementation the cognitive map is separated into two elements, into a cognitive map and a processing network. This separation have to be made because on one hand it is impossible to make a neural chip containing thousands of neurons even with the state of the art microelectronic technology, and on the other hand it would be a waste of resources as from the surrounding potentials the new direction can be determined with enough precision, thus 50–100 neurons are enough. The cognitive

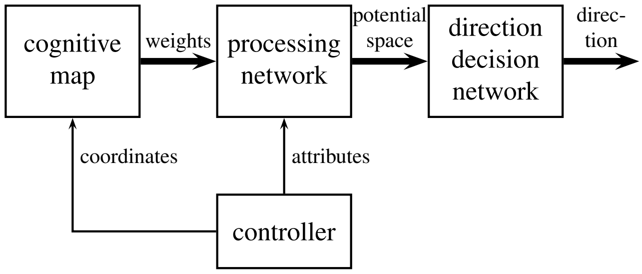

Figure 11: Hardware structure of the artificial cognitive map

map only stores the weights of the neurons, it does not make any calculation, processing. The cognitive neural network is implemented in the processing network. It contains about 50–100 neurons. The third element of the hardware is another neural network responsible for the determination of the new direction of the movement based on the potentials calculation by the processing network.

The most applicable microelectronic devices are the memories and FPGA devices. The cognitive map can be stored in memories as it is possible to update easily and to store great amount of data efficiently. The processing network and the direction decision network can be efficiently implemented in FPGA devices, as it allows to realize any kind of neural structures. Further researches are needed to find the optimal number of processing neurons, the parameters of transfer functions, etc. Another important question is the precision of the input and output parameters that mainly determines the wiring structures.

7 Conclusion

In this paper an artificial neural network model is proposed as a possible realization of the cognitive map. Using this model the system can be equipped with some kind of biologically intelligence that enables basic action–reaction behavior. The fundamentals of both software and hardware implementations, the neural networks implemented in integrated circuit is discussed.

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