SECTION 5

Perception Mechanism Details

The perception mechanism as developed so far, the *perceptron*, is a simple, one-output, system that would appear to be a possible building block or prototype design for more complex rational systems. This system is not a complete control system, let alone a rational system, for any life form. It is only a possible basic building block of such nervous systems.

There are many various nervous systems, those of humans, apes, snakes, worms, ants and so forth. This building block need not achieve any spectacular or sophisticated performance such as composing a symphony or originating Newton's Laws. It need merely be a component, one of at least hundreds if not millions of similar components, in a system that for example enables an ant to walk, seek food, etc.

The problems of adapting the *perceptron* to multi-systems, let alone the problems of managing to obtain true intelligence from such systems, are yet to be addressed. However, even as the simple, one-output model that the perceptron is, it requires a *teacher*, external to the system, to direct it in its learning. It is the *teacher* who decides whether and how much to increase or decrease the thresholds after each input image is processed. But, how is that to be done in a neural system ?

THE "TEACHER" – THRESHOLD CHANGES

This is not a difficult question as it turns out and the solution relates to instinct.

What can *instinct* be except *pre-learned behavior* somehow embedded in the nervous system. The nervous system consists essentially only of neurons. Instinct cannot be a result of the neural interconnections; they are too fixed, invariable. If *instinct* is to be embedded in it, the only available way is in the thresholds of various neurons.

It may well be that an aspect of evolution, of variation among individuals of a specie, variation that gradually or suddenly leads to a different type specie, is that of some of the new individual's neurons having different threshold settings as the individual is born, hatched, or whatever than the parents had at their birth. The individual would therefore have different pre-learned perception mechanism parameters because the ones it was born-with are different.

To find the *teacher* we ask, how do we humans, and the other animals, learn something ? It is done by repeating, repeating that which is to be learned over and over until it "sinks in". There is no other way that we or any animals learn. Explanations, demonstrations, experiences are only the means to learning. The learning only happens when the lesson is repeated sufficiently enough that it "sticks".

There is only one explanation of that effect that is plausible and reasonable, as follows. Since:

- In the operation of real world nervous systems there is no external *teacher* to adjust the thresholds, and yet
- learning does occur in such real world neural systems, and
- that can only take place by means of threshold changes [the physical “wirinng” interconnections are fixed, not adjustable], and
- things are learned by repetition of the thing over and over until it is learned,

then it must be that

- the threshold changes are automatic, that they occur by a simple, inherent process within the neuron.

Whenever a neuron "fires", that is delivers a *1* output because a majority of its inputs and its threshold so correspond, then its threshold naturally and automatically must decrease slightly so that a similar "firing" will be more likely under subsequent similar input conditions. Whenever a neuron "does not fire", that is it effectively delivers a *0* output because a majority of its inputs with its threshold is not present, then its threshold naturally and automatically must increase slightly so that a similar "non-firing" will be more likely to occur under subsequent similar input conditions.

That would be a behavior of learning by repetition. The repeating of successes is the repeating of the same, or very similar, inputs and thus obtaining the same output. That would tend to change the threshold of the neuron in the direction that makes the same outcome even more likely.

The repeating of failures would tend to, at least, break up the above pattern of developed successful thresholds. It might, at most, correspond to the learning of the "failure" by its repetition. In fact, what happens if a human or an animal lapses in regular practice or rehearsal of something learned ? We begin to gradually forget it, to lose the skill, to find it somewhat harder to remember the point. That would exactly correspond to the gradual decay of learned thresholds if they are not regularly reinforced by repetition, by practicing the learned behavior or fact.

This is not an unreasonable situation. The neuron is an electrochemical device. Its operation is the propagation of electrical potentials that are generated and transmitted within the neuron by chemical actions. The "firing" of a neuron, the delivering of an output amount of electrochemical energy, would logically be expected to temporarily deplete the neuron’s available supply of energy, depleting its threshold, which itself is an electrochemical element in the neuron's overall functioning. Likewise, the absence of "firings" could be expected to give the ongoing restorative actions of the neuron, its metabolism, the opportunity to accumulate more threshold.

The point here is not to specifically analyze these electrochemical processes, processes the analysis of which would be a lifetime activity for a microbiologist. Rather, the point is that:

- the learning-type threshold changes really do occur in the neurons of any and all nervous systems, whether of ant or man, and
- there is no other source for the directing of those changes than that of the effect of simple repetition, and
- simple repetition corresponds in any case to the way in which we humans learn things in the real world.

In Summary,

- there is no external teacher,
- the function of a teacher is performed by a neuron's firing slightly reducing its threshold and non-firing allowing a neuron's threshold to slightly recover,
- both processes are part of the normal electrochemical functioning of the neuron, expending energy in firing and metabolism restoring energy when resting.

SYNCHRONIZATION

Another question with regard to this perception system concerns the synchronization of its operation. The analysis and discussion has implicitly contained the idea that all of the data from the sensors (the retina) are simultaneously available at the input to each first level neuron and are evaluated there simultaneously. Likewise, it has been implicitly assumed that all of the first level neurons simultaneously deliver their outputs as inputs to the second level neuron for its evaluation of them and so forth for multiple layers.

All of that simultaneity seems quite unlikely in a real biological neural system where the travel paths over various different neural dendrites and axons will be of different lengths so that the time of travel of their electrochemical signals in the various neurons must be different. In addition it would not seem reasonable that nature rely on such exact same processing or reaction time relative to the threshold within each of the neurons.

This even raises the question as to what does the "non-firing" of a neuron mean as it is used in the discussion of thresholds and their changes. The implication is that at a time or under a set of conditions where a "firing" or a "non-firing" could or should occur it is the "non-firing" that occurs and is observed. How does this happen ?

This same problem exists in human-made logic systems as employed in digital computers. Those machines always employ a "clock", an overall synchronizing mechanism. The clock is an oscillator, a generator of a train of pulses (`1's`) at a preset constant rate or frequency. Essentially, the input to every flip-flop, every memory element, is *`and-ed`* with the clock pulses.

With that "clock" arrangement, regardless of what goes on in between the clock pulses, it is only the conditions at the time of the clock pulses that cause the next logical step in the operation of the digital computer's logic. For that system to exist in a biological rational system it would be necessary to have the clock generator, some kind of oscillator, as a part of that system somewhere within it, and to *and* its output at the input to every neuron.

It is very clear that biological neural systems do not have some same input that appears at every neuron, whether from a "clock" or from anything else. The brain simply is not constructed that way. Neurons connect densely to other neurons and sensors that are physically near to them, less densely to those that are somewhat distant, and rarely or not at all to those that are very distant (excepting sensor neurons that carry signals from distant sensors to the brain and motor neurons that carry signals from the brain to distant muscles).

Then, how is a biological logic system synchronized ? It isn't. It simply is not (evolutionarily was not) practical to employ such a system in a biological rational mechanism. So, the systems evolved with the ability to operate without synchronization. In that sense almost all of the time all neurons are putting out a 0 signal. Then from time to time (so to speak) occur the exceptions, the pulses of 1 signals here and there as the neural logic dictates. Those signals from neurons produce excitatory or inhibitory neural inputs to other neurons.

Depending on how they interconnect to the particular neuron that neuron experiences +1 and -1 inputs in consequence Furthermore, that neuron experiences 0 inputs most of the time, that is inputs of "nothing happening". Such an input from some other neuron or sensor means "just now the source sensor or neuron is not participating -- the Boolean variable or variable combination that it represents is not part of the logic being effected at this moment".

The neurons cannot emit output pulses continuously. After a firing, an output, a period of time must elapse during which the neuron metabolism produces sufficient electrochemical recovery from the expenditure involved in the output firing. During that time inputs received may enter into the determination of the neuron's next firing - the "when" of that firing because of their affecting the amount of recovery the neuron must achieve and the "what" of that firing by their affecting the net electrochemical changes of state within the neuron.

The non-synchronized mode of operation of such neural systems facilitates another characteristic of living neural systems. Even though the systems are essentially binary in that they transmit pulses that are treated as present or not present, 1's and 0's, those pulses also convey valuable non-binary information: that of *how much*.

Whether the sensor is one that detects touch or temperature at a point on the body or one that detects sound in the ear, or light in the eye, the information conveyed to the neural system by sensor outputs is that of both *what* and *how much*. The *what* depends on where the sensor is located and how it relates in physical position and neural network logic to the rest of the system. The *how much* is communicated by the rate of such sensor neuron firings, by the rate of pulses output by the neuron.

More frequent pulses are caused by, and therefore signify, brighter light or louder sound or more harsh touch sensation. Less frequent pulses imply the opposite. It is simply that the greater the rate at which the sensor receives excitation energy the greater is the rate at which it is able to deliver output energy in repeated firings.

During the period that a neuron is recovering from its most recent firing and changing electrochemically until it reaches a state that is able to produce another firing, that neuron may receive a number of input pulses on one or more of its input dendrites. That conveys information as to *how much* as well as *what* to the neuron's operation. This unsynchronized mode with magnitude conveyed by pulse repetition would appear to not be completely compatible with the simple logic system operation that was presented in the previous section. However, the net operational and logical effect is still retained. The *1's* are set by the logic; the *0's* are always there when not *1's* by logic.

The neuron implements a piece of Boolean logic which is determined by its fixed input connections and its variable threshold. That piece of logic in conjunction with those of similar other neurons implements an overall complex Boolean logic corresponding to the defining of some universal. But, the neuron does not do that by understanding and operating Boolean majority logic in an overt sense. The neural network simply automatically adjusts its thresholds, on the basis of repetition-learning, until the appropriate resulting output ends up occurring.

The combination of the neural majority logic and the learning-directed variable thresholds naturally leads toward the objective of the learning: identification of the related universal. The simple system described in the previous section is a *static* system. But, with synchronization removed the system becomes *dynamic*. It responds to *how much* data. It deals with input patterns in *time* as well as in *array space*, that is patterns which include elements of both kinds in their input.

Multiple Universals

Each neuron receives input from a number of sensors and/or other neurons (tens, hundreds, and in many cases thousands of inputs). Each neuron's output is input to a number of other neurons. This extensive interconnection is schematically illustrated in Figure 5-1, below.

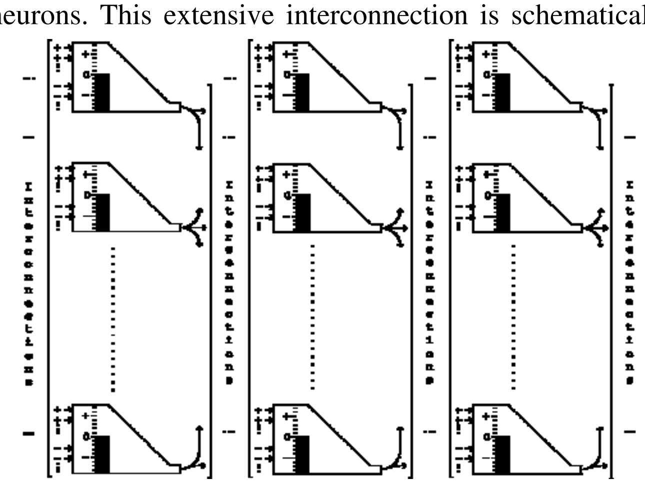

Figure 5-1

The figure also illustrates a structure of the neurons in layers. The layered structure is more pronounced in neurons near to sensor arrays, but occurs to some extent throughout a large scale neural system. Deep within such systems there are more interconnections within layers as well as between them, a diffusing of the sharp layer boundaries depicted in the figure.

Considering, for example, the case of vision, the number of universals to be perceived is quite large. And, mechanisms for perceiving each of those universals must be replicated a large number of times over the field of vision or whatever the input sensor system is. That is because the significance of such universals is not only that of which universal is involved but that of where in the input array it appears. Thus it would be quite impractical for individual neurons to be dedicated to participating in only a single universal. Far too many neurons and far too large a network or brain would be needed.

The actual situation must be more like that of the above Figure 5-1 where each of the second layer neurons has an output that is a different result derived from the same overall set of first layer neurons. Each first layer neuron's output participates in a number of universals, a number of next layer logic processes and their outputs, a number of particular Boolean logic expressions, all simultaneously.

For example, the top neuron in the middle layer (column) of the above Figure 5-1 is, relative to the left layer, in the same role as the rightmost neuron (output neuron) of the earlier Figure 4-2, reproduced below.

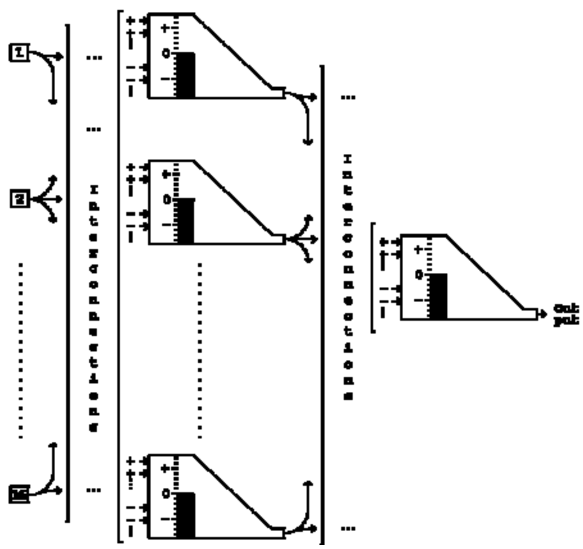

Figure 4-2 (repeated)

Each of the middle layer neurons of Figure 5-1 is, relative to the left layer, in an output neuron role of Figure 4-2, but each is implementing a different logic, a different universal because each has a different set of inputs. Likewise, the top neuron in the middle layer (column) of the above Figure 5-1 is, relative to the right layer, in the same role as the left column neurons (first level neurons) of Figure 4-2. Each of the middle layer neurons of Figure 5-1 is, relative to the right layer, in an input neuron role like the role of the left column neurons of Figure 4-2.

Thus, in input role a neuron supplies input to many other neurons that are in output role relative to it. As a result the input role neuron participates in implementing a number of different universals simultaneously.

The involvement of individual neurons in a number of universals simultaneously is necessary not only because the otherwise inefficient use of neurons would require too many neurons in the system. It is also unavoidable given the complex system of interconnection. While it has some drawbacks in its effect on the logic system it also offers a quite tremendous advantage.

The significant drawback is that the threshold of an individual neuron is changed by actions involving any of the universals in which it participates. So to speak, having been thoroughly trained on *cross-ness* and having its threshold well adjusted for that purpose, it then must learn *circle-ness* and in the process of being so trained its threshold is further changed. That most likely would degrade its ability to identify crosses. Over a period of experiencing inputs randomly varying between circles and crosses the threshold would become the best compromise achievable for perceiving either of the inputs.

The effect of this kind of behavior is experienced by us on the large scale. Having learned some thing fairly well and then progressing to further related learning we find that our learning of the former thing has degraded somewhat.

The quite tremendous advantage, however, of individual neurons participating in a large number of different universals is that that multiple participation creates the capability for *thinking* to take place. However, treatment of that process must be deferred to later sections while the remaining details of neural perception of single universals are resolved.

THE NEURAL INTERCONNECTIONS

The operation of these neural systems depends on two variable quantities: the interconnections between neurons and the threshold adjustments. Selection of the interconnections is only available as a variable during the design phase, while the physical device is being built. Any neural system, whether biological or man made is ultimately "hard wired", a fixed system of interconnections for practical logic purposes.

Of course in biological neural systems the system is not "hard wired" during the initial formation and immature growth phase, which may go beyond the first part of the period after birth, hatching or whatever. But, in any case, the issue is that of how those interconnections should be (are in biological systems) for optimum performance.

This problem is best approached by the process of imagining the designing of such a system The fact of the matter is that, initially, we have no idea how to interconnect the sensors and neurons and the neurons with other neurons. That, is the key to the solution. Nature had no idea, originally, either. Under that circumstance the best choice is randomness.

The interconnections determine (in conjunction with the thresholds) the specific Boolean logic that will be implemented by that part of the system. However, we have no idea what the specific logic is, nor what it should be. If we knew the logical interconnections for the desired universal we could "wire them in". But, we do not know the logic even if we did know the intended universal. And, in any case, we need a system that can deal with any universals, with any input.

That is the point. A biological neural system has to be able to deal with a great variety of inputs. It is not possible to design in advance for all of the possibilities. Given that, then the only way for a neural logic system to maximize its ability to deal with the unknown is to use random interconnections.

Of course there is one alternative, that of including every possible interconnection alternative in the neural system. That would certainly equip it to deal with all situations. However, that is impossible to do. With the immense numbers of neurons the interconnection possibilities are just too inconceivably large. And every added neuron adds even more interconnection requirements than it contributed to satisfying.

Our biological system is not like a merchandise bar code reader in the check-out of a market, which device is designed to deal with only a very specific input. Rather, we humans and the other animals must deal with all the variety of experiences that are encountered in life. Our neural system must be flexible. Any systematic method of interconnection inevitably must favor some logic and disfavor other logic. Only a random interconnection system yields a system able to deal with any (or at least most of the) logic required of it.

Random interconnections is also the easiest and most natural system for nature to implement. It requires no plan and no control. It calls for merely allowing what happens to happen.

Then Darwin's variation and natural selection step in. Some "random" interconnection systems turn out to perform better than some others. ("Perform" here means promote the success of the life form, its ability to reproduce and perpetuate its specie.) The process tends over time to select optimal interconnection systems.

But "optimal" depends on the specific situation being dealt with. Vision systems have existed in nature for hundreds of millions of years. There has been sufficient time and experience for the optimal set or family of retinal first order universal processing interconnections to develop to optimum. Whether the being is a fish, a dinosaur, a mammal of prehistoric times or man, the fundamentals of vision are well defined by experience and are largely the same: detection of size, motion, corners, solid areas, etc.

But, what is optimal brain operation for astronauts, steelworkers, gourmet chefs ? Man experiencing so many different geographies, weathers, food supplies, dangers, and so on confronts a thinking need that cannot be predetermined. While his vision system may be well defined, the needs of his thinking system are very broad. The most likely success is one that can adapt to any circumstances.

Thus, at the higher levels of neural systems, randomness is most likely still the optimum design even though specific sub-systems, vision, digestion, breathing, can be and evolutionarily have been optimized in special ways.

The point of this is that, if one were designing an artificial intelligence, random interconnections would be called for (although employing our brain's pattern of greater density of interconnection to near neurons and less to distant ones). The point is that random interconnections is apparently the case in the cerebral cortex, the "thinking part" of our brains as compared to the retina, the seeing (but not understanding what is seen) part of the eye.

PROCESSING OF UNIVERSALS

One simple level of first order universals processing is not enough to operate the vision mechanism. For example, it contains no provision for dealing with changes from input image to input image, changes which carry information about motion, growth, death (lack of change) and so forth. The same is true of any other sensory input system, hearing and so forth.

The process already described must take place again a number of times. At the first level the sole input was data from the sensor array. At the next level the input is that data and the output of first level neurons. Processing can then yield a more highly processed second level, and third, and so forth. This performs a few levels of re-mapping, re-encoding, and further re-mapping and encoding of the first-level or prior-level, itself mapped and encoded, description in terms of somewhat more sophisticated universals.

The system progresses from simple, fundamental micro-universals to more and more sophisticated and abstract universals. While it is convenient to think of the operation as taking place in discrete layers of neurons and to ignore inputs to earlier level neurons that come from later level neurons, that does not conform to the real situation. In the evolutionarily developed "wired-in" systems like the early levels of vision processing that is somewhat the case; however, even there there is interaction such that levels are not completely discrete.

But for the more sophisticated higher levels of neural activity, those closer to or actually part of the intelligent processes, the concept of levels and arrays must yield to a complex broad body of interaction. Yet that body still operates on the underlying principles of universals, learning by threshold adjustments and majority logic implementations of Boolean logic.

Which leads to the next level of sophistication in neural mechanisms:

What are thoughts and memory ?