COMPARISON OF THE COMPUTER

AND THE BRAIN

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The evolution of man came long before the evolution of the computer. But in a sense man's brain **is** a computer, an analog computer. Through understanding digital computers, we are beginning to draw conclusions as to the operation of the human brain. Likewise, as we better understand the human brain, we can use that knowledge to create better computers From our present knowledge of both areas we can compare the qualities of both.

The brain shall be examined from two perspectives: Callatay's Brain Model and Rasmussen's Model of the Human Data Processor. The computer shall be considered as a standard von Neumann stand-alone which is a fairly common machine being used at the time of this writing. Parallel processing is mentioned, an idea taking form in computers but best utilized by the brain which "implemented" the idea first.

In comparing two types of computers, in this case an analog and a digital one, the hardware shall be considered first. In the Callatay Brain Model, there are several notable hardware features the brain has over the computer: (1) processing of approximate data, (2) very large database, (3) content addressability of memory, (4) noise elimination, and (5) fast response to threatening stimuli.á1

Computers do not accept approximate data. Callatay says that sensations from the outside world are fuzzy, and therefore cannot be processed by computers. This idea, he says, may come from classical programming: business computers are programmed to prevent errors that fuzzy data frequently produce. In addition, he says the following:

> Sophisticated pattern recognition programs can analyze and classify data but they need complex mathematical algorithms processed by powerful arithmetic processors. Approximate data are not analyzed at the machine code level, except for pattern recognition by analog hardware. The processing of fuzzy data must be built into the brain.á2

The brain is also superior to the computer in that it has a very large database. When one reads a book, he memorizes thousands of episodes. This rate of memorization remains the same throughout one's lifetime. Common sense in humans is due to man's large and easily accessible memory. Callatay says that a human memory can contain billions of relations: many more than there are in any computer's direct access storage.á3

The brain's database is an additive database. The central memory is not modifiable. New information is recorded without modifying previous memories. Callatay states that in the brain model no operation can erase existing information. Hence the database is called additive.

Unlike logic programming which has "garbage collectors" to reclaim released memories, the brain has no such need to do any "house cleaning." Perhaps this is due to its very large size:

> The number of potential connections in man is computed as follows: There are about 10 10 neurons in the cerebrum, one third of which are spiny cells with an average of 10,000 spines, therefore there are about 3.10 13 potential pointers in the brain. But no more than 1 to 6% of these spines can be used to prevent excessive confusion. Thus man has 10 12 pointers. As he is awake and active during 3.10 9 seconds during his lifetime, he can add about 1000 pointers per second. In the model, these connections are irreversible and are transformed at once from a disconnected state to a full conduction state.á4

The brain with its content addressability of memory retrieves information very quickly in comparison with a computer. That is to say that the brain's access time is shorter than that of a computer memory. Large amounts of data such as in a scene may be recognized at a glance. Sort, merge, and reorganization algorithms are not appropriate to the brain. "Content addressability seems to be a primitive feature of brain hardware".á5

Regarding noise, for a machine the old saying goes:

"Garbage in, garbage out." Noise is less apt to hinder pattern recognition in man than in computer. Callatay says there must be some hardware organization making it possible to discard irrelevant data.á6

Finally, the brain demonstrates that it is a fast processor in its ability to make a fast, intellegent response when threatened. The response time is typically about 300ms whatever the type of input. Callatay surmises that the brain does not iterate:

> During reaction time, very few sequential instructions can be executed in the brain, whatever stimulus is presented. Brain programs have fixed durations, whatever the sensation. Therefore the brain does not iterate. It uses other algorithms and other hardware.á7

The brain has many features not found in computers, but there are some computer design principles missing in the brain: numbers, an arithmetic processor, a logical unit, and other features.

Callatay states that cell irregularities make it unlikely that a harware address (a number) can enable each neuron. Because there is no addressing scheme, indexed arrays cannot exist. "Physical symbols, not structured numbers, are directly represented in the brain."á8 The brain has no arithmetic processor. "A highly ordered adding machine cannot be built with loosely connected neurons. Doing arithmetic requires a complex, learned, conscious behavior."á9

Natural construction does not allow for the design of a logic unit, inherent in any computation.á10

The computer has fast instruction. The switching time of computer circuits is in the nanoseconds; the shortest interval between two impulses in a neuron is about 1 to 3 ms. Callatay says that the brain must use parallelism to solve recognition problems faster than computers.á11

The brain lacks registers for data or addresses. Registers represent the state of the microprocessor. The brain has no need to store addresses. "In the brain, addresses in registers are replaced by local activations directly in the memory cell."á12

The computer has stages in memory. Fastest access in the computers on-board memory. Next fastest access would be a fixed disk. Slower still is a diskette drive or a CD ROM. To process rare information, data must be moved to memory first. "One cheap brain device replaces all these systems."á13

Computer memory also differs from brain memory in that, unlike the brain's additive database, computer memory can be overwritten. To simulate the brain's memory, a very, very large computer memory would be needed as no memory is intended to be reused:

> A Write to memory is not a simple instruction. First the computer has to find an empty space.

> Then it must detach it from the list of available spaces. Then it adds a knowledge network node, using mirocodes or subprograms (Lisp does this). Object oriented programming languages write objects of any size. In the brain model as in applicative programs, no operation can erase existing information. Hence the database is called additive.á14

Finally, computers are in theory blessed with reliable circuits. Computers never make undetected errors according to Callatay because software method assumes this. Neurons, however, are not so reliable.á15

The next step is to compare how the two very different hardware are programmed. The brain's programming is known as behavior while the computer's programming is pure logic.

The brain generates self-learned rules of behavior Callatay responds to objections to this automatic learning. First, he affirms that a selective system defined in the theory of evolution explains the diversity of man's knowledge. He says that it refers to an organism having many potential devices. This is opposed to an instructive system where the context creates new functions. Callatay expounds on his brain model's selectivity:

> The brain model may be called selective, as the environment selects some of the potential connections (spines) for storing knowledge. This

network must include the ability to learn any language (Marshall, 1980). This is not a problem from a mathematical point of view. To learn one language, the brain has to select one million of pointers from among 3.10 13 potential connections. Learning time and the possibility of the confusion of tongues limits the number of languages which can be learned.á16

Second, he says that although the variety of the world is such that the condition of a rule will probably never be repeated, the probability of repetition can be computed for processing in each of the distributed feature detectors and for classifiers with fuzzy pattern recognition. He goes on to say that local repetitions are computable, because the model prevents the creation of more than a few million categorized results. "Classifiers may be designed for a given repetition frequency."á17

Although it has been stated that no system can know a priori which data must be selected from numerous irrelevant information, Callatay says that the brain is able to sift the relevant data:

> Relevant data in the above context is sensory information which could change the outcome of the action. Data may be relevant for one rule and not for another. Relevant information is hidden among manifold sensory data. One can assume a natural

> grouping of related features in the brain, reducing data by generic selection, e.g. arm sensory data are linked to arm commands.á18

Callatay then explains three brain mechanisms to isolate relevant clusters. (1) Many unnoticed events are memorized. A conditional reflex may be set by a stimulus never consciously noticed. (2) Data is redundantly recorded. When a type of behavior rule is frequently repeated, this most relevant rule acquires a larger weight for the decision process. (3) Rules based on irrelevant data have more of a chance of being unsuccessful. Irrelevant information is gradually filtered out by a habituation mechanism equivalent to suppression.á19

With the above learning mechanism alone the brain cannot find the best sequence of actions for acheiving a given goal; however, Callatay states that although a successful sequence will be repeated, there is the possibility of finding a better sequence through the random generator required for learning by trail and error.á20

The trial by error method of learning alone is too slow to explain the speed of human performance. Callatay points out some relevant brain model features:

> My model cannot, in its present state, implement all of Piaget's improvements, but it can already classify data, repeat successful action sequences, avoid repetitive behavior, find the most exciting

> and rewarding action, switch behavior, and solve goal directed problems. This method is far from a simple trial and error procedure: the method is to learn from experience, but with trials cleverly managed.á21

The computer does not "learn" automatically it must be taught from the outside exactly what it should do. Programming for computers is done with logic programs. Logic programs are not understood by the brain (directly). The brain has no microprocessors hence logic programs cannot be processed there. Microprocessors and arithmetic logic units (ALU) do not seem to exist in nature according to Callatay.á22

These logic programs, however, can fail when there are processor or software errors. Large programs (especially a a brain behavior simulation program) are very hard to debug; operating systems, for example, are known for being buggy. Callatay says that in his brain model, a failure is followed by a fast restart procedure with a simple recovery:

> This fast restart is an advantage of using a historical database. In addition, the breadth-first search of logic programming suggests various alternatives in parallel to continue the behavior: an available alternative prevents a hang-out followed by a recovery.á23

At this point it should be apparent there are several differences between the computer and the brain. However, the brain can be modeled as a type of computer and can be used to define a better type of computer. Rasmussen considers the case of the human as a data processor while Callatay suggests a better form of computer.

Rasmussen's model of the human operator in a control system shows the operator receiving information and instructions, processing, and taking actions. As the computer is only useful in a certain environment, the human and his brain are considered in a useful environment, also. The operator is shown to have four features. (1) information processes, (2) goals and intentions, (3) models & stategies, and (4) performance criteria.á24

Rasmussen divides the human data processor into two processors: the subconscious processor and the conscious processor. According to Rasmussen, the subconscious processor must possess an efficient internal dynamic world model to account for several features of human behavior:

> In familiar situations, complex and precise sequences of actions can be released by simple cues and performed at a pace too fast for simple sensory feed-back control. Furthermore, human attention is very selective. The operator is not constantly scanning the environment in order to obtain information; generally he/she predicts very well when and where in the environment changes may make

> observations necessary, i.e. operators have "process-feel"(Bainbridge, 1974b).á25

This dynamic world model is formed by extracting and storing dynamic patterns from the input information and stores a time-space representation of the behavior of the environment. á26

In close communication with the internal world model is a mis-match detection system which alerts the conscious processor if there is deviation in the environment with the predictions of the internal world model.á27

The perceptive system provides the information input which sifts the higher level features from the data received from the environment. Rasmussen comments that parallel processing is involved:

> The necessary feature extraction in the perceptive system appears to rely upon parallel processing in a preconditioned high capacity network, and its efficiency depends upon simultaneous presence of items of information which are correlated with, and can be structured in terms of, familiar time-space patterns.á28

The immediate goal and intention is necessary to make proper use of the dynamic world model for a given job assignment. According to Rasmussen, in real-life work situations a large degree of freedom is left to the human even though the overall goal is stated unamiguously. Thus, subjective performance criteria and emotional preferences are important factors in the use of the internal world model.á29

The role of the conscious processor varies. It passively monitors the subconscious processor during routine tasks and actively bridges mismatches of the subconscious processor, switching the subconscious processors state, following interrupts caused by less familiar situations. The conscious processor is also able to perform problem solving by evaluating alternatives and making decisions and plans based on prediction.á30

Callatay appears to be on the same track as Rasmussen except he is coming from the computer perspective. Whereas Rasmussen is modeling the brain as the human data processor, Callatay is demonstrating that a database machine is safer for parallelism, an important feature believed to be used in the brain. He asserts that one processor can only process one item at a time such as one might explore paths in a maze. Many processors in an abstract space can explore many independent categories simultaneously. "In a database machine, this happens as one unit, as contradictions concern one category and knowledge of one category is concentrated in one knowledge node: parallelism is safe, because exceptions can be discovered and stopped."á31

In conclusion, by comparing the function of the brain to that of the computer we can see that each has its own abilities and limitations. The brain is not prepared to be a massive efficient number cruncher, and the computer is not ready to replace the brain's abilities such as image recognition and self-programming. The brain will probably continue to evolve as it becomes more highly educated, while the computer shall evolve as it is improved by those highly educated minds.

Notes

á1 Armand de Callatay, _Natural and Artificial Intellegence_ (New York: Elsevier Science, 1986), p. 115.

á2 Callatay, pp. 74, 115.

á3 Callatay, p. 115.

á4 Callatay, p. 77.

á5 Callatay, p. 115.

á6 Ibid.

á7 Ibid.

á8 Callatay, p. 113.

á9 Ibid.

á10 Ibid.

á11 Callatay, p. 114.

á12 Ibid.

á13 Ibid.

á14 Callatay, p. 77.

á15 Callatay, p. 114.

á16 Callatay, p. 90.

á17 Callatay, p. 91.

á18 Ibid.

á19 Ibid.

á20 Callatay, p. 92.

á21 Ibid.

á22 Callatay, p. 71.

á23 Ibid.

á24 Jens Rasmussen, "The Human as a Systems Component" in _Human Interaction with Computers_, ed. H. T. Smith and T. R. G. Green (New York: Academic Press, 1980), p. 69.

á25 Rasmussen, p. 70.

á26 Ibid.

á27 Rasmussen, p. 73.

á28 Rasmussen, p. 72.

á29 Rasmussen, pp. 72-73.

á30 Rasmussen, p. 73.

á31 Callatay, pp. 78-79.

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