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MACHINE INTELLIGENCE, A FOREWORD: THE BRAIN AS ELECTRONIC CIRCUITRY; ELECTRONIC CIRCUITRY AS A BRAIN

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We introduce a series of reports that attempt to resolve the conflict between the desire to build a thinking machine and the claimed impossibility of discussing the general design in rational language. We present the basic structure of our investigation and its position in current controversy without supporting argument.

We look at nonliving intelligence and the biological brain through a smoky glass and see--electronic circuitry. This is the electronic age. We approach the design of a machine brain as a problem in reverse engineering.

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THE BOTTOM LINE

For those who have no time to read a report about such esoteric matters as brain anatomy and philosophy, we put the bottom line first. There is no such thing as an intelligent control that is not a thinking control.[1] We can have an intelligently constructed device, or a machine that displays intelligent behavior, or an intelligently programmed control. We cannot have an intelligent machine that is not a thinking machine.

BACKGROUND

We are investigating the foundations on which we can design an intelligent machine and, if practical, build it. This subject has engaged us for some time. We decided to encapsulate our experience in the construction of thinking machines. See entries under Johnson or Scanlon.

Our goal is to make an electronic brain, a device that thinks. We start at the bottom, not the top. Starting at the bottom means reverse engineering the mammalian brain--picking out the elementary circuits of the brain, one by one. It means a progression from the simplest of animals to man. At no point do we expect something really new to appear, only an elaboration of the old.

We take the position of interactive dualism which recognizes a mind and a brain. We know our minds. We know that we are aware. We simplify life if we proceed as though all other brains are similarly associated with minds. However, it is not given to man to see a mind as object. We cannot comprehend how mind and brain interact: it is a mystery. Our lives can be happier if we accept this limitation on our understanding. To the question, "How shall we know if a machine is thinking?" our answer is, "Build the machine first. Then see if a mind comes to be associated with it."

The brain is the material structure we wish to realize in silicon. The mind, by contrast, is the subjective pole that associates with the objective brain. The brain is the pathway through which the signal energy flows. All volition, all emotion, all desire is of the mind. The mind makes all decisions, all choices. The brain is passive. We would say nothing of it that we would not say of an electronic circuit.

Man cannot visualize the relationship between brain and mind, but that is not a fatal impediment. It lies outside our universe of possible experience, as do many other things. We live inside an opaque, possibly translucent, bubble. We can know everything inside the bubble, we may poke at the bubble, just possibly we may see light coming into the bubble. If we could only stand outside the bubble, we should see everything clearly. But we do not expect that in this life. Meanwhile we would stand easy in the presence of mystery.

We are investigating techniques for building an intelligence. We are devising circuitry with which a mind might become associated, and building into this circuitry enough complexity that we might communicate with this mind. At the same time we are exploring the implications of the mind-brain association in animal life, and of the kinds of neural circuitry that allow us to talk with other minds.

The mammalian brain is the model. We assume that the electronic phenomena associated with the functioning brain describe it completely. We assume we can move an electronic circuit from one substrate

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[1]Before being tempted to define intelligence or thinking, one should think long and hard about improving the following:
North: That direction on the left hand of a person facing due east.

to another. We deny vitalism[2] and especially the notion that animal and metallic electricity differ[3]. We believe Maxwell's equations do not require additional terms for different substrates. We suggest there are helps, hindrances, and distractions. The helps are neuroanatomy, neurophysiology (except borrowed computer science ideas), and electrical engineering. The hindrances are philosophy, psychology, mathematics, logic, linguistics, and artificial intelligence. The distractions are computer science and clever programming.

Everyone is free to choose when selecting a framework for the mind-brain problem. But it does seem, however, that if we are to discuss electronic phenomena, the tools of the electrical engineer should help. We don't overlook the molecular basis of brain activity; we just focus on a different level. Molecular engineering is for another generation. We live in the electronic age.

Our basic premises are straightforward:

1. We look at the brain as a passive electronic device.

2. Experience is the molecular trace left by signal energy flowing through the circuitry.

3. We can satisfactorily explain the activity of the brain as the interplay of varying potentials and currents. This activity is independent of the substrate (organic molecules) and we may transfer it to a different substrate (silicon) without loss of function.

Signal energy from the sensory neurons passes through the thalamus and spreads out through the cerebrum, finding its way through paths that other signal energy altered earlier. It then converges on the basal ganglia and the cerebellum and transforms itself into motor commands. The energy flows through the thalamus. If this constellation of sensory and motor energy has caused problems in the past, part of the energy (because of potentiated synapses) will flow to the reticular nucleus of the thalamus. This nucleus inhibits the thalamic neurons that relay sensory and motor signals. The residual signal energy continues to evoke motor commands from the basal ganglia. When the present pattern of energy does not flow through to the thalamic reticular nucleus, the relay neurons are disinhibited and the signal energy flows through to the muscles as commands.

If the inhibition continues for more than a fraction of a second, we call it thinking. This formulation provides a reasonable explanation for the observation that an expert is a person who has a personal acquaintance with every possible error in his field.

Along the way we develop the notion that thought depends on experience, not on words. Words, as such, are nothing but one great big circular definition. The proper procedure to get the experience needed to think about intelligent machines is to examine brains, build electronic neurons (neuromimes), and connect them in networks. A workable substitute is to simulate the neuromimes or the network on a computer--preferably one with analog-digital capabilities. In this way we may create images and ideas that are independent of words, but with which we can associate words for purposes of communication.

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[2]The doctrine which states that the processes of life are not explicable by the laws of physics and chemistry alone and that life is in some part self-determining.

[3]We allude to the great battle between Conte Allesandro Volta and Luigi Galvani. Volta was right, but, serendipitously, Galvani was even more right.

In designing a thinking machine, we must say something about how the human brain works. We need not explain the brain correctly in every detail; a good set of flowcharts is enough. A thinking machine must stand by itself. We should be happy if the act of design gives us some insight into what mental activity is, but our purpose is to make the machine.

In the light of our hypothesis about how thinking proceeds, talk of originality is idle since the interplay of received ideas must dazzle us all. This is especially true of the mind-brain. From the long list of people who have presented theories about the mind-brain relationship, we assign priority to two individuals. It was Charles Darwin who launched the idea of the evolution of the mind-brain in *The Descent of Man*. Wilder Penfield visualized the cerebrum as accessory to the thalamus, and suggested a region (not a point) in the diencephalon (mainly the thalamus and the hypothalamus) functioned as the primary interface between the mind and the brain, (Penfield, 1975).

Of any demonstration based on mathematics or symbolic logic, we ask: Is this meant to further the design? If we view the human brain as an electronic device, then any argument that a machine cannot think is also an argument that a man cannot think.

We rule out all arguments of the form: You can't do it because.... Let the guiding rule be: Will this contribute to the design of an electronic intelligence?

There are positions that are fatal to any attempt to develop an electronic brain:

Only man has a mind.
Man is the only rational animal.
Only man can envision things that are not present.
We cannot understand the brain apart from its molecular action.

Logicians, mathematicians, psychologists, and analytic philosophers have little relevance to our effort until the machine is running. Their expertise may be useful during the fine tuning. There is little profit for these persons in electronic design. Their specialty is shifting a discussion about things to an argument over words. We will judge their speculations as entertainment. We should not expect them to be happy with this assessment.

Finally, there is the question of human competence. Is the brain more complicated than the mind is clever? We needn't worry. If we can't do the job, we shall not understand why!

THE HISTORY

The history of man's attempts to create automata is of interest because it illuminates the inborn need of man to build a machine that thinks. Some automata were put together but most were left to the imagination even as is done today. In each century the designers made use of the technology of their day: hydraulics, clockworks, relays and solenoids. Today we speak of integrated circuits and use a computer to model our ideas.

Another approach was to talk about how the brain works and how man should know if a machine were thinking. Unfortunately, most of the persons following this path never took time to look at a brain. The general impression is that there is something inside the skull with about as much structure as a bowl of oatmeal. This glop organizes itself, and that is about as much as we want to say about the brain. The talk then moves on to representations, learning, memory, and the sentential calculus[4].

[4]The sentential calculus is a manipulative algebra of symbolic logic.

Philosophy should have been of some help, but philosophers are a provincial lot. They tend to observe the local prejudices and traditions of their time. We live in the age of analysis, but analysis alone will not build an electronic brain (Winograd and Flores, 1986).

AN APOLOGY

Neuroscientists have traditionally viewed brain theorists as little children playing in a sandbox, and rightly so. Neural networks, which bear only the vaguest resemblance to biological reality, are touted as embodying the essence of intelligence (Grossberg, 1988:A12). Computer programs, that manipulate the pixels from a TV camera, are said to be doing the computations that the human brain ***must*** do. They dissect the computer programs, remove the algorithms and place them to one side. Then they proclaim that this heap of oddments contains the ***general principles of intelligence*** (Marr 1982:19, Hildreth and Hollerbach 1987:605-642). If by computation we mean the manipulation of symbols, then it is the mind that computes. The brain knows no symbols.

An alternative exists. We say it is possible to build a thinking machine. No one can prove us wrong except ourselves. The neuroscientists have amassed an enormous number of data on the interconnections between the brain centers, large and small. We say it is permissible to rearrange these data as a schematic diagram, to simulate the wiring in computer programs, and to breadboard the wiring in an electronic laboratory. We can energize the circuit and see what happens.

An equally vast conglomerate of data exists on the symptoms of human brain pathology and the behavior of laboratory animals with lesioned brains. We can deactivate the corresponding portions of our circuitry and observe the results. These are reasonable steps on the road to building a thinking machine.

We are not interlopers, ill-mannered dilettantes, if we do not presume to tell neuroscientists what their research means, or what they should do next. If the future shows that the essence of the thinking brain is not the flow of electrical currents, then it will prove our whole approach wrong. But none can show that now.

Who then is the peer group to whom we address ourselves? First, we address neuroanatomists and neurophysiologists, none of whom should discount our claims about the mammalian brain. Second, we address electrical engineers and make only reasonable statements about circuitry. Third, we address anyone who has seriously considered what the building of a thinking machine might entail.

THE PLANNED ATTACK

A feeling, learning, thinking, doing machine is our goal; we want to create a machine that has a subjective view of the world, that has a mind associated with its circuitry. The machine must want to do things. In doing things, the machine shall learn; and having learned, it will think. We do not talk of machines that ***exhibit intelligent or purposive behavior***, that merely manipulates symbolic logic. We speak of a thinking machine, a machine that could be taught a calculus, of a machine that could devise a calculus. The distinction is important to us. Our aim is a machine that thinks and acts at the human level. We work at intermediate goals, simple enough to be done on the equipment we have, yet complex enough to suggest another step on the path to the summit.

We want to produce a thinking machine--nothing less, nothing more.

Our times constrain us. Eighteenth-century intellectuals could envision a clockwork brain. Similarly, the 1990s limit us to an electronic device, an integrated circuit. Once we understand these constraints, we must look at the brain as a fluctuation of potentials and a flow of currents. The molecular biologist sees something different, he sees molecules interacting with molecules, making molecules. We see the

substrate as irrelevant and consider only that which can be in common between a human brain and a thinking machine. Until someone shows that Maxwell's equations need another term to deal with an organic substrate, we will say that a potential does not know its father; a volt is a volt wherever it appears.

We suggest 2050 as the target year for construction so that there will be no expectation of immediate results, and so that there will be plenty of time for the needed advances in electronics. What experiments and speculations will start us off on that road? Computer programs that recognize faces, manipulate imaginary blocks, or prove theorems shall not seduce us. These programs furnish convincing demonstrations for impressing the unsophisticated, but we want something more. We want to impress ourselves.

We hold that to proceed with the design of an intelligent machine we need a certain attitude, a viewpoint, that is not popular among academics. Specifically we do not agree with the following.

> "The study is to proceed on that basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it."[5]

On the contrary, we have always believed that what is ***true in principle***, is ***false in reality***; and the more precisely we attempt to describe, the more ambiguities we uncover.

We do not use complicated mechanisms to explain mental activity. We concentrate on simple neural qualities that can survive molecular replacement. We do not postulate a monstrous, hardwired device, specified in every detail, but simple organizing rules that the available genome can carry out.

Anthropocentrism, man as center of existence, cripples a designer of electronic brains. We see a continuum from the one celled animal to man. When two cells first clumped together they started communicating. In the sponge, most primitive of multi-celled animals, the results of inter-cellular communication are visible to the naked eye. The human brain evolved from the first cell that differentiated as a neuron. We reject any hint that man is unique. We must close our ears to ***only man thinks, man is the only rational animal***, and ***language is necessary for thought***, and ***only man can talk***.

Our need to check theory against experience constrains our approach to an explanation of brain function. The area is unique among intellectual activities in that we are thinking about thinking. Not only is the effort recursive, but everyone is a self-appointed expert in the field. Subjective experience is ready at hand. We all know what it is to view experience with emotion, to be driven by our feelings. Why should we not use that which is free? Since we have forsworn the rationalistic approach, why should we pay attention to their taboos? However, we do not reject any of the laboratory findings of the behavioral psychologists or of the cognitive scientists. In fact, we are ever-mindful of their results.

It is necessary to be comfortable in, or at least aware of, certain metaphysical areas. The universe appears both continuous and discrete. Other minds exist. We know the mind only as subject and the brain only as object. Otherwise we appear naive.

Since the brain is our model, we describe it as a passive electronic device. This is a partial explanation. The mind is the electromagnetic field associated with the circuitry. The abstract circuitry of an electronic device is independent of its substrate. We follow the circuitry of the brain as much as possible. Any deviation from this structure is dangerous, as it may invalidate our existence proof. We have no faith in shortcuts that have no foundation in the anatomy of the brain, such as the sentential

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[5]Quoted from a grant application to the Rockefeller Foundation by a 1956 Dartmouth summer conference. (McCorduck 1979:93.)

calculus and its child, artificial intelligence. The building of a machine brain is a problem in electronic design, an exercise in reverse engineering, a matter of putting together a vast assemblage of simple parts according to a schematic that is complicated because of the number of units. This is only a first attempt; there is plenty of time for elaboration.

Furthermore, our description must be reasonable and satisfactory to the neurophysiologists. If it is not acceptable to them, it is not acceptable to us. We will devise an electronic circuit based on our model. The circuit must be reasonable, or at least possible, for the year 2050. The problem is incredibly complex, but its possibility (or impossibility) is not to be shown by words. Only the actual building of machines will tell what is possible. These machines must be able to support a mind. To the complaint: ***We don't know enough about the brain; we answer: Some feel we have already more neural data than we can handle,***

> It threatens to become a clutter.
>
> Patricia S. Churchland

and anyway we must make do with what we have.

We present drives as the general level of neural activity in a brain center.

Of the model, we should be aware that although the anatomy is human, the circuitry is that of the general mammalian brain. The marvelous techniques of tract tracing, of saying which neurons are connected to which, are invasive and destructive. We must use them on a living animal. We may not ethically apply them to a human. Even an autopsy is delayed by our natural respect for human life, so that when the human brain is available for inspection it has started to digest itself. We would not have it otherwise. Although we know a great deal about the circuitry in rats, and cats, and nonhuman primates, about the best we can say for human circuitry is that we do not expect any great surprises. We expect an expansion, more areas, but not a difference in kind (Nauta and Feirtag 1986:64-67).

We must keep clear in our mind what a thinking machine entails. It is an electrical phenomenon. We can have no distinction between animal and mechanical electricity. We propose only to exchange the substrate from organic to inorganic molecules. We affirm that there is no difference in kind between the functioning of the neural circuitry in the simplest of organisms, and that of man. The human brain is complex. It has perhaps 10^{11} or 10^{12} elements, with 10^{16} connections. The best we can hope to do is to set out principles of organization, not details.

ON CLEVER STATEMENTS

There are three pillars on which we erect our discussion of the human mind-brain and the thinking machine.

> *We approach the brain as a material object, a thing we can poke at and take apart.*
> *We insist that it is the mind that experiences, feels, and decides.*
> *We stamp a date on our opinions, because that which is True today is out of fashion tomorrow.*

There is a certain fluency, a certain mastery of phraseology, that can more than make up for competence in the underlying discipline. A cleverly turned sentence outweighs a knowledgeable, but mangled, insight every time. Will style and diction help us build an electronic brain? Will sophistry? We can only put down our observations and hope for the best.

RECAPITULATION

The mammalian brain is our model of a thinking machine. We are reverse engineering the mammalian brain onto a nonliving substrate. It follows, therefore, that the pertinent disciplines are neural science and electronic engineering. The neural anatomists and physiologists are best positioned to say how the brain is connected and what the brain processes are. The electronic engineers are best equipped to realize these processes in practical circuitry.

We take a simple approach, viewing the brain as an electronic device. Although this view is simple, it fits our age. Although it ignores the molecular reality, this is the common procedure used by electronic engineers. Engineers tend to think of currents flowing, not too much about what they are flowing through, and as little as possible about the solid state physics involved.

The brain, as an electronic device, must be genetically specified. The specific circuitry demanded by computation is not possible; there is only enough genome to establish general patterns. We say that thinking and emotion are really simple things. We present the electronic circuit for the materialists and the mind associated with it for the idealists. The dualists may have both.

The brain is our existence proof that intelligence is possible. It is our model. Our mind is our inspiration. It is the basis of our faith that we can think about thinking. The computer is our tool.

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