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The Imitation of Man by Machine

The view that machines will think as man does reveals misunderstanding of the nature of human thought.

Ulric Neisser

Popular opinion about "artificial intelligence" has passed through two phases. A generation ago, very few people believed that any machine could ever think as a man does. Now, however, it is widely held that this goal will be reached quite soon, perhaps in our lifetimes. It is my thesis that the second of these attitudes is nearly as unsophisticated as the first. Yesterday's skepticism was based on ignorance of the capacities of machines; today's confidence reflects a misunderstanding of the nature of thought.

There is no longer any doubt that computing machines can be programmed to behave in impressively intelligent ways. Marill (*1*) does not exaggerate in saying, "At present, we have, or are currently developing, machines that prove theorems, play games with sufficient skill to beat their inventors, recognize spoken words, translate text from one language to another, speak, read, write music, and learn to improve their own performance when given training." Nevertheless, I will argue that the procedures which bring about these results differ substantially from the processes which underlie the same (or other) activities in human beings. The grounds for this assertion are quite different from the "classical" reasons for skepticism about thinking machines, but the latter should be considered first. This amounts to reviewing the similarities between men and computers before stressing the differences.

First of all, it was formerly maintained that the actions of a mechanism would never be purposive or self-directed, whereas human behavior can be understood only in terms of goals and motives. Two counterexamples will be enough to show that this argument has become untenable. In the realm of action, it is difficult not to be impressed with the "homing" missile, which pursues its target tenaciously through every evasive action until it achieves its de-

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structive goal. On the intellectual level, the "Logic Theorist" of Newell, Simon, and Shaw (*2*) is just as persistent: determined to prove a theorem, it tries one logical strategy after another until the proof is found or until its resources are exhausted. If anything, the argument from purpose cuts the other way: machines are evidently *more* purposive than most human beings, most of the time. This apparently excessive persistence reflects one of the fundamental differences to be elaborated later—one that could, however, be superficially eliminated by disconnecting the goal-setting part of the program at random intervals.

Secondly, machines were once believed to be incapable of learning from experience. We now know that machine learning is not only possible but essential in the performance of many tasks that might once have been thought not to require it. Simple problems of pattern recognition, such as the identification of hand-printed capital letters, have been solved only by programs which discover the critical characteristics of the stimuli for themselves (*3*). The success of Samuels' (*4*) checker-playing program is based on its capacity to store and use experience from previous games; no program without the ability to learn has been nearly as successful. This argument, too, is more interesting when viewed the other way. In a sense, computers learn more readily than people do: you can teach checkers to a 3-year-old computer, but not to a 3-year-old child. The reason will appear later; it is evidently not just that the computer is the more intelligent of the two.

Finally, it has often been asserted that machines can produce nothing novel, spontaneous, or creative—that they can "only do what they have been programmed to do." This is perhaps the most widely held of the negative beliefs, yet it is the first to be relinquished by anyone who actually tries to write programs for a digital computer. Long before a programmer succeeds in getting the machine to learn anything, or to behave purposefully, he repeatedly encounters its capacity to act in astonishing, unpredicted, and (usually) frustrating ways. For example, he may change a few steps in a familiar program involving thousands of instructions and find that the output printer produces reams of unintelligible gibberish. Careful diagnostic procedures are needed to discover that one comma was omitted in a single instruction. As a result the computer interpreted two small adjacent numbers as a single large number, executed the wrong instruction in the program, and continued blithely on from a point where it was never expected to be.

Such an event may seem trivial, both because the reason for the unpredicted outcome can be discovered in retrospect and because the effect was maladaptive rather than useful. But neither of these are necessary properties of unpredicted computer output. Existing programs have found original proofs for theorems, made unexpected moves in games, and the like. The belief that a machine can do nothing qualitatively novel is based on a false dichotomy between quality and quantity. What has become a truism in physics also applies to information processes: large changes in the magnitude of phenomena always imply major changes in the "laws" through which these phenomena can be understood. The result of 200,000 elementary symbolic operations cannot be readily predicted from knowledge of the elements and the program. The sheer *amount* of processing which a computer does can lead to results to which the adjective *novel* may honestly be applied. Indeed, complexity is the basis for emergent qualities wherever they are found in nature.

Some Observable Differences

It appears, then, that computers can learn, and can exhibit original and purposive behavior. What can they not do? At first reckoning, their intellectual defects seem trivial and nearly irrelevant. Nevertheless, a list of the inadequacies of present-day artificial intelligence is worth making for its suggestive value. Two or three of the inadequacies have already been mentioned. When a program is purposive, it is too purposive. People get bored; they drop one task and pick up another, or they may just quit work for a while. Not so the computer program; it continues indomitably. In some circumstances the program may be more effective than a man, but it is not acting as a man would. Nor is such single-mindedness always an advantage: the computer is very likely to waste its time on trivialities and to solve problems which are of no importance. Its outlook is a narrow one: with Popeye, it says, "I am what I am," and it lets the rest of the world go hang while it plays chess or translates Russian relentlessly. The root of the difference seems to be more a matter of motivation than of intellect. Programs have goals, but they do not acquire or use their goals as a man would.

Computers are more docile than men. They erase easily: an instruction or two can wipe out anything ever learned, whether pernicious or useful. The decision to acquire new knowledge or to destroy old memories is a deliberate one. Usually it must be taken by the programmer, though in principle the program could decide for itself. Human memory seems much less flexible. A man rarely has single-minded control over what he will learn and forget; often he has no control at all. Thus, he lives willy-nilly in an accumulating context of experience which he cannot limit even if he would. The result is both stupidity and serendipity: if he is inefficient, he also can become wise in unexpected ways. Youth is not doomed to ignorance even though it would like to be, and no one can entirely avoid growing up. A program or a programmer, in contrast, can easily prevent any change that appears superficially undesirable.

By the same token, any apparently desirable change in a program can be carried out, at least if the necessary techniques are known. There is no need to embed it in an orderly sequence of growth, no resistance from an organism that has other things to do first. In this respect artificial intelligence is conformist, and precociously so. Again this is a problem of motivation, but it is a developmental question as well. We would be rightly worried about a child who played chess before he could talk; he would seem "inhuman."

Growth is a process of self-contradiction, but computer programs are never at cross-purposes with themselves. They do not get tangled up in conflicting motives, though they may oscillate between alternative courses of action. Thus, they are good at problem solving but they never solve problem *B* while working on *A*.

Artificial intelligence seems to lack not only breadth but depth. Computers do not dream, any more than they play. We are far from certain what dreams are good for, but we know what they indicate: a great deal of information processing goes on far beneath the surface of man's purposive behavior, in ways and for reasons that are only very indirectly reflected in his overt activity. The adaptive significance of play is much clearer. In playing, children (and adults) practice modes of thought and action that they do not yet need. Free of any directing immediate necessity, skills can develop into autonomous units that can later serve a variety of ends.

Taken one at a time, these differences between natural and artificial intelligence are not impressive. All together, they give rise to the suspicion that the cognitive activities of machines and men are still substantially different. In stressing the differences, my purpose is not to disparage current work in artificial intelligence. The research that has been done and is being done has important practical implications; it is also providing us with valuable models for some kinds of human thinking. Its incompleteness is emphasized here for two reasons. For *psychologists*, I wish to stress that contemporary computer models are oversimplified in the same sense that early stimulus-response psychology and early psychoanalytic theory were oversimplified. It may be well to regard "artificial intelligence" with the same mixture of hopefulness and suspicion that was appropriate to those earlier efforts. For *programmers*, I make a prediction. As computers are used for increasingly "human" activities, either directly (as in simulation) or indirectly (as in situations where the criteria of performance are psychological and social), new and difficult problems will arise. The focus of difficulty will no longer be in pattern recognition, learning, and memory but in an area which has no better name than "motivation." In support of these assertions, I describe, in the remainder of this article, three fundamental and interrelated characteristics of human thought that are conspicuously absent from existing or contemplated computer programs.

1) Human thinking always takes place in, and contributes to, a cumulative process of growth and development.

2) Human thinking begins in an intimate association with emotions and feelings which is never entirely lost.

3) Almost all human activity, including thinking, serves not one but a multiplicity of motives at the same time.

Cognitive Development

The notion of "development" involves more than the obvious fact that a newborn baby has a great deal to learn. The intricacies of adult behavior cannot be acquired in just any order, to suit the convenience of the environment. Certain attitudes and skills must precede others. In part this is a matter of simple prerequisite learning: one must know how the pieces move before one can invent winning chess combinations. Moreover, the cumulation of learning is interwoven at every point with inborn maturational sequences. It may or may not be true that one must walk before he can run, but it is clear that neither skill can be taught to a 6-months-old baby. Therefore, no baby of that age can have the adequate conceptions of space and localization that genuinely do depend on experience. By the time a child has the opportunity to discover other rooms and other worlds, he already has a year's worth of structure with which to assimilate them. He will necessarily interpret his own explorations in terms of experience that he already has: of losing love or gaining it, of encountering potential disaster, joy, or indifference. These preconceptions must affect the kind of explorations he makes, as well as the results of his ventures; and these consequences in turn help to shape the conceptual schemes with which the next developmental problem is met. A child who could move about from the very beginning would grow into an adult complexly different from any of us.

In Piaget's (*5*) useful terminology, human development consists of two reciprocal phases: "assimilation" and "accommodation." The first is the transformation and recoding of the stimulus world which is performed by the child's cognitive equipment of the moment. Computers also assimilate in this sense; for example, they reduce photographs to bit-patterns through specialized input devices. Accommodation is harder to imitate. It refers to change in the cognitive apparatus itself, as a result of the attempt to assimilate novel material.

In a loose way, accommodation may be equated to learning, and it is evident that computers can learn (for example, by optimizing probability-weights or other internal parameters). But the most important accommodations in human development are changes in the structure of the processing itself. The child's visual and physical exploration of space does not result merely in the assignment of specific quantitative values to an innate spatial schema. On the contrary, the weight of the evidence suggests that such fundamental concepts as objective permanence, three-dimensionality, and tangibility must themselves be formed by development. And we do not yet have any realistic hope of programming this type of growth into an artificially intelligent system.

It is instructive to consider game playing from this point of view, because it has been a focus of interest for both programmers and developmental psychologists. Young children cannot be taught to play such games as checkers and chess because they cannot be reconciled to the restrictions imposed by the rules. Having grasped the idea that he should try to capture pieces, a young child proceeds to do so with any "move" and any piece of his own that comes to hand. He will avoid the loss of his own piece by every possible maneuver, including removing it from the board and putting it in his mouth. If the piece is taken nevertheless, the child may have a tantrum and stop playing. According to Piaget (*6*) there is an interesting later stage in which the schoolchild thinks of the rules as sacrosanct and eternal; it takes an adult to admit that what was arbitrarily established may be arbitrarily altered. Such a history must leave its mark on a human chess player, in the form of a hierarchical organization of purposes as well as strategies. Nothing comparable exists for the computer program, which works steadily toward its fixed goal of legal victory. There is no obvious reason to doubt that a specialized program may some day play chess as well as a man or better, but the intellectual processes of the two are likely to remain fundamentally different.

Emotional Basis of Cognitive Activity

The activity of a newborn baby is very largely organized around the satisfaction of needs. While there are intervals dominated by visual or tactile exploration, major events in the baby's life are hunger and sucking, irritability and sleep, pain and relief, and the like. This suggests that stimulus information is assimilated largely with reference to its need-satisfying and need-frustrating properties. The first accommodations to such basic features of the world as time, distance, and causality are interwoven with strongly emotional experiences. Moreover, the fluctuations of the child's internal states do not have any very obvious relation to the logic of his environment, so that months and years are needed before his thinking and his actions become well attuned to the world around him. To put it another way: the pleasure principle yields to the reality principle only slowly.

Many psychologists, such as Robert White (*7*), have recently stressed the opposite point: that activity directed toward mastering reality is present from the very beginning. They are surely right, but even the beginning of competence and esthetic pleasure depend heavily on internal structures. What the baby explores, and how he reacts to it, is not determined only by realistically important features of the environment but by the schemata with which that environment is assimilated.

Needs and emotions do not merely set the stage for cognitive activity and then retire. They continue to operate throughout the course of development. Moreover, they do not remain constant but undergo growth and change of their own, with substantial effects on intellectual activities. Some emotional growth, such as the gradual differentiation of specific fear from general anxiety, is the result of interaction with the environment. Other changes, like those of puberty, seem to be relatively autonomous. It would be rash indeed to believe that events so important to the individual's life play no role in his thinking. One fundamental way in which they exert their influence is discussed in the next section. In addition, it is worth noting that one of the most common and frequently discussed modes of learning—that of reward and punishment—operates through an open involvement of strong and historically complicated emotions.

To think like a man, a computer program would need to be similarly endowed with powerful internal states. We must imagine these states, which have both short- and long-term dynamics of their own, to be in almost complete control of information processing at first. Later their influence must become more subtle, until their final role is a complex resultant of the way in which preset internal patterns have interacted with the flow of experience. Perhaps such programs can be written, but they have not been, nor do they appear to be just around the corner.

Multiplicity of Motives

Human actions characteristically serve many purposes at once. Any activity whatever could serve as an example, but it will be instructive to consider chess playing again. Typically, a computer which has been programmed to play chess has one overriding goal—to win—and establishes subordinate goals (capturing pieces, controlling open files, and the like) when they may be useful to that end. Human chess players do this also, but for them winning is itself only one goal among many, to which it is not always related in a simply subordinate way.

For instance, a chess player may also seek the esthetic pleasure which comes from an unexpected and elegant combination. This desire has surely been responsible for the achievement of many spectacular victories in the history of chess; the search for such a combination is also responsible for an uncountable number of defeats. It is likely, too, that most players seek the experience of success, either for the internal satisfactions or for the public acclaim which it brings, or for both of these reasons. The avoidance of the inner or outer humiliation which defeat brings must also play a frequent role. None of these motives is fully interchangeable with any other. Each has its own attendant retinue of potential substitute satisfactions, reactions to frustration, and interactions with the concrete reality of the game. However, it is very possible for all of them to exist in the same chess player at the same time.

Chess can serve other purposes as well, which are certainly not without their effect on the actual sequence of moves. It is a social occasion, and serves as a vehicle for a relationship to another person. As such, chess can be an instrument of friendship, but it is double-edged because each friend is trying to defeat the other. Thus, the game becomes an outlet for aggression, in which one may aim for destruction of his opponent in an entirely nonphysical (and so nonpunishable) way. It is not only the opponent who may be symbolically destroyed. Reuben Fine, who is both grand master and psychoanalyst, has argued (*8*) that the presence of a "king" and a "queen" on the board may give chess a deeply symbolic value, so that very primitive fantasy goals can become relevant to the progress of the game.

Apart from considerations of winning and losing, playing chess may reflect many other human motives. One man may adopt what he considers to be a "daring" style of play because he wants to think of himself as a bold person; another may play conservatively for analogous reasons. Both men may be *playing* because (that is, partly because) chess is only a *game*—an activity in which they can succeed and be respected without growing up or competing in what they regard as more adult, and thus more frightening, realms. Some people probably play chess because it is at least something to do and a means of avoiding the anxiety-laden or self-destructive thoughts they might otherwise have. Others, of both sexes, may play because they somehow think of chess as a masculine rather than a feminine activity and playing it makes them more certain of their own sex identity. And so on; the list is endless.

Every sort of human behavior and thought is open to this type of analysis. No person works on a mathematical problem as contemporary computer programs do: simply to solve it. No person writes a scientific paper merely to communicate technical information, nor does anyone read such a paper merely to be better informed. The overt and conscious motives are important, but they never operate in isolation. In the early days of psychoanalysis it was fashionable to devalue the obvious motives in favor of the unconscious ones, and to assume that cognitive activity was "nothing but" a way to placate instinctual demands. This tendency is happily no longer common; "rational" activities are unquestionably important in their own right to the person who engages in them. But we must be careful not to let the availability of computer models seduce us into the 19th-century view of a man as a transparently single-minded and logical creature.

Elsewhere I have discussed the multiplicity of thought (*9*), suggesting that much in human thinking is better conceptualized as "parallel" than as "sequential" in nature. The manifold of motives that I am describing here goes beyond that assumption, although it certainly presupposes a capacity for parallel processing. The motivational complexity of thought is more easily seen as depth than as breadth. It is what makes people interesting, and it is also what gives them the capacity for being bored. It is what the "shallow" characters of poor fiction lack, and it is the source of the inventive spontaneity of real people. People succeed in using experience with one problem in solving another because, after all, they want to solve both; and both solutions are only parts of an intricate system of needs and goals. Miller, Galanter, and Pribram (*10*) have emphasized the hierarchical structure that human intentions often exhibit. Such a multiplicity of motives is not a supplementary heuristic that can be readily incorporated into a problem-solving program to increase its effectiveness. In man, it is a necessary consequence of the way his intellectual activity has grown in relation to his needs and his feelings.

The future of artificial intelligence is a bright one. The intellectual achievements of computer programs are almost certain to increase. We can look forward with confidence to a time when many complex and difficult tasks will be better performed by machines than they now are by men, and to the solution of problems which men could never attempt. Moreover, our understanding of human thinking may well be furthered by a better understanding of those aspects of intelligence which the programs display. This process has already begun: many psychologists, myself included, are indebted to computer technology for a wealth of new ideas which seem to be helpful in understanding man. But two systems are not necessarily identical, or even very similar, because they have some properties in common.

The deep difference between the thinking of men and machines has been intuitively recognized by those who fear that machines may somehow come to regulate our society. If machines really thought as men do, there would be no more reason to fear them than to fear men. But computer intelligence is indeed "inhuman": it does not grow, has no emotional basis, and is shallowly motivated. These defects do not matter in technical applications, where the criteria of successful problem solving are relatively simple. They become extremely important if the computer is used to make social decisions, for there our criteria of adequacy are as subtle and as multiply motivated as human thinking itself.

The very concept of "artificial intelligence" suggests the rationalist's ancient assumption that man's intelligence is a faculty independent of the rest of human life. Happily, it is not.

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MEETING REPORTS

Synthetic Detergents in Water and Sewage Systems

The program of the Society for Industrial Microbiology at the AAAS annual meeting included an informative symposium on "Synthetic detergents in water and sewage systems" (27 December 1962).

Since the introduction of synthetic detergents for general household use in the late 1940's, these materials have become increasingly popular until they now command about 75 percent of the household retail market for cleaning agents. The use of these products not only has caused a tremendous accumulation of animal fats (formerly used in the production of soap), but also has introduced problems in the disposal of wastes containing these materials. In contrast to the common soaps, these alkyl benzene sulfonates (ABS), particularly the branched-chain types in common use, are resistant to degradation in sewage disposal plants, cesspools, and septic tanks, and are often found in streams and ground water. While toxicity does not appear to be a problem, operation of sewage disposal plants can be adversely affected by vast accumulations of foam, and "heads" of foam equal to the amount of water sometimes appear on tap water. Numerous industries are now being adversely affected by the frothing and foaming which results from the presence of finite and measurable amounts of surface active agents in water supplies.

Particular difficulty with residues of ABS in water, according to reports at this symposium, is now experienced in areas where the water table is quite near the surface. When many new homes with septic tanks are being built, and other nearby homes draw water from wells, these synthetic compounds make their way into the drinking water. The possible simultaneous entry of intestinal viruses is considered a real public health hazard.

Recycling sewage effluent after passage through the usual disposal process diminishes the ABS concentration greatly, although this is an expensive treatment. One interesting experimental method described at the symposium is percolation of the sulfonate-laden sewage through sandy soil in a container (lysimeter) that is designed to permit samples to be taken from various levels in the soil for analysis. The mixed bacterial population in the soil can then largely degrade the detergents during a fairly long detention time. Experiments at tempera-