

Can We Define Levels Of Artificial Intelligence?

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Abstract

The paper argues for a graded approach to the study of artificial intelligence. In contrast to the Turing test approach, such an approach permits the measurement of incremental progress in AI research. Results on the conceptual abilities of pigeons are summarized. These abilities far exceed the generalization abilities of current AI programs. It is argued that matching the conceptual abilities of animals would require new approaches to AI. Defining graded levels of intelligence would permit the identification of resources needed for implementation.

1 Introduction

In the context of engineering and computer science literature, the word intelligence has generally been used without defining it. Solving a specified problem, that often requires searching or generalization, is taken to be a sign of AI, which is often assumed to have an all or none quality.

A recent text defines AI to be the “study of the computations that make it possible to perceive, reason, and act” ([24], page 5). Since nearly all engineering may be taken to enhance the abilities of humans, such a definition is so broad so as to include almost all computations. If the perception, reasoning, and action of this definition are related to human agents in a more immediate sense, the question arises as to why that should be so. Can’t we speak of intelligence in the context of nonhuman agents? That such a change in perspective may be advantageous is what we wish to show in this article.

Intelligence in humans is normally defined in terms of the responses to standardized tests. Not everyone believes that such a test, that leads to a numerical value, is a good measure of innate intelligence. There are those who believe that intelligence must be taken to be multidimensional and any scalar measure

is fundamentally flawed. Human intelligence definition is a controversial field and it is not crucial to our discussion. We only wish to make the point that regardless of how intelligence is defined—as a scalar or a vector—it is associated with a spectrum of values.

If we consider the biological realm, we find that all animals are not equally intelligent at all tasks; here intelligence refers to performance of various tasks, and this performance may depend crucially on the animal's normal behavior. It may be argued that all animals are *sufficiently* intelligent because they survive in their ecological environment. Nevertheless, even in cognitive tasks of the kind normally associated with human intelligence animals may perform adequately. Thus rats might find their way through a maze, or dolphins may be given logical problems to solve, or the problems might involve some kind of generalization [7]. These performances could, in principle, be used to define a gradation.

If we take the question of AI programs, it may be argued that the objectives of each define a specific problem solving ability, and in this sense AI programs constitute elements in a spectrum. But we think that it would be useful if the question of gradation of intelligence were to be addressed in a systematic fashion. The question is best examined in an ecological context; a similar case for an ecological study of machine vision has been made by Gibson [6]. In this paper we present parallels with animal intelligence to define a context in which the question of the ability of AI programs should be addressed.

2 The Turing Test

In many ways, such as abstract generalization, current computers are fundamentally deficient in comparison to biological organisms. One might ask why has the discipline of computer science not generally recognized it. It appears that a pre-occupation with comparisons with human thought distracted researchers from considering the rich set of possibilities regarding gradations of intelligence. The prestige of the famed test for machine intelligence proposed by Alan Turing [20] in 1950 was partly responsible for such a focus.

The Turing test proposes the following protocol to check if a computer can think: (1) The computer together with a human subject are to communicate, in an impersonal fashion, from a remote location with an interrogator; (2) The human subject answers truthfully while the computer is allowed to lie to try to convince the interrogator that it is the human subject. If in the course of a series of such tests the interrogator is unable to identify the real human subject in any consistent fashion then the computer is deemed to have passed the test of being able to think. It is assumed that the computer is so programmed that it is mimicking the abilities of humans. In other words, it is responding in a manner that does not give away the computer's superior performance at repetitive tasks and numerical calculations.

The asymmetry of the test, where the computer is programmed to lie whereas

the human is expected to answer truthfully is a limitation of the test that has often been criticized. This limitation can be overcome easily if it is postulated that the human can take the assistance of a computer. In other words, one could speak of a contest between a computer and a human assisted by another computer. But this change does not mitigate the ambiguity regarding the kind of problems to be used in the test. The test is not objectively defined; the interrogator is a human.

It has generally been assumed that the tasks that set the human apart from the machine are those that relate to abstract conceptualization best represented by language understanding. The trouble with this popular interpretation of the Turing test, which was true to its intent as best as we can see, is that it focused attention exclusively on the cognitive abilities of humans. So researchers could always claim to be making progress with respect to the ultimate goal of the program, but there was no means to check if the research was on the right track. In other words, the absence of intermediate signposts made it impossible to determine whether the techniques and philosophy used would eventually allow the Turing test to be passed.

In 1950, when Turing's essay appeared in print, matching human reasoning could stand for the goal that machine intelligence should aspire to. The problem with such a goal was that it constituted the ultimate objective and Turing's test did not make an attempt to define gradations of intelligence. Had specific tasks, which would have constituted levels of intelligence or thinking below that of a human, been defined then one would have had a more realistic approach to assessing the progress of AI.

Perhaps this happened because the dominant scientific paradigm in 1950, following old Cartesian ideas, took only humans to be capable of thought. The rich tradition of cognitive philosophy that emerged in India about four thousand years ago [1, 2, 12, 13] where finer distinctions in the capacity to think were argued was at that time generally unknown to AI researchers. The dominant intellectual ideas ran counter to the folk wisdom of all traditions regarding animal intelligence. That Cartesian ideas on thinking and intelligence were wrong has been amply established by the research on nonhuman intelligence of the past few decades [7].

To appreciate the larger context of scientific discourse at that time, it may be noted that interpretations of quantum mechanics at this time also spoke in terms of observations alone; any talk of any underlying reality was considered outside the domain of science. So an examination of the nature of 'thought', as mediating internal representations that lead to intelligent behavior, was not in vogue. Difficulties with the reductionist agenda were not so clear, either in physical sciences or in the study of animal behaviour.

3 On Animal Intelligence

According to Descartes, animal behavior is a series of unthinking mechanical responses. Such behavior is an automatic response to stimuli that originate in the animal's internal or external environments. In this view, complex behavior can always be reduced to a configuration of reflexes where thought plays no role. According to Descartes only humans are capable of thought since only they have the capacity to learn language.

Recent investigations of nonhuman animal intelligence not only contradict Cartesian ideas, but also present fascinating riddles. It had long been thought that the cognitive capacities of the humans were to be credited in part to the mediating role of the inner linguistic discourse. Terrace [19] claims that animals do think but cannot master language, so the question arises as to how thinking can be done without language:

Recent attempts to teach apes rudimentary grammatical skills have produced negative results. The basic obstacle appears to be at the level of the individual symbol which, for apes, functions only as a demand. Evidence is lacking that apes can use symbols as names, that is, as a means of simply transmitting information. Even though non-human animals lack linguistic competence, much evidence has recently accumulated that a variety of animals can represent particular features of their environment. What then is the non-verbal nature of animal representations?...[For example] learning to produce a particular sequence of four elements (colours), pigeons also acquire knowledge about a relation between non-adjacent elements and about the ordinal position of a particular element. ([19], page 113)

Clearly the performance of animals points to representation of whole patterns that involves discrimination at a variety of levels. But if conceptualization is seen as a result of evolution, it is not necessary that this would have developed in exactly the same manner for all species. Other animals learn concepts nonverbally, so it is hard for humans, as verbal animals, to determine their concepts. It is for this reason that the pigeon has become a favourite with intelligence tests; like humans, it has a highly developed visual system, and we are therefore likely to employ similar cognitive categories. It is to be noted that pigeons and other animals are made to respond in extremely unnatural conditions in Skinner boxes of various kinds. The abilities elicited in research must be taken to be merely suggestive of the intelligence of the animal, and not the limits of it.

In an ingenious series of experiments Herrnstein and Loveland [8] were able to elicit responses about concept learning from pigeons. In another experiment Herrnstein [9] presented 80 photographic slides of natural scenes to pigeons who were accustomed to pecking at a switch for brief access to feed. The scenes were

comparable but half contained trees and the rest did not. The tree photographs had full views of single and multiple trees as well as obscure and distant views of a variety of types. The slides were shown in no particular order and the pigeons were rewarded with food if they pecked at the switch in response to a tree slide; otherwise nothing was done. Even before all the slides had been shown the pigeons were able to discriminate between the tree and the non-tree slides. To confirm that this ability, impossible for any machine to match, was not somehow learnt through the long process of evolution and hardwired into the brain of the pigeons, another experiment was designed to check the discriminating ability of pigeons with respect to fish and non-fish scenes and once again the birds had no problem doing so. Over the years it has been shown that pigeons can also distinguish: (1) oak leaves from leaves of other trees, (ii) scenes with or without bodies of water, (iii) pictures showing a particular person from others with no people or different individuals.

Herrnstein [9] summarizes the evidence thus:

Pigeons and other animals can categorize photographs or drawings as complex as those encountered in ordinary human experience. The fundamental riddle posed by natural categorization is how organisms devoid of language, and presumably also of the associated higher cognitive capacities, can rapidly extract abstract invariances for some (but not all) stimulus classes containing instances so variable that we cannot physically describe either the class rule or the instances, let alone account for the underlying capacity.

Amongst other examples of animal intelligence are mynah birds who can recognize trees or people in pictures, and signal their identification by vocal utterances—words—instead of pecking at buttons [21], and a parrot who can answer, vocally, questions about shapes and colors of objects, even those not seen before [17].

Another recent summary of this research is that of Wasserman [23]:

[Experiments] support the conclusion that conceptualization is not unique to human beings. Neither having a human brain nor being able to use language is therefore a precondition for cognition... Complete understanding of neural activity and function must encompass the marvelous abilities of brains other than our own. If it is the business of brains to think and to learn, it should be the business of behavioral neuroscience to provide a full account of that thinking and learning in all animals—human and nonhuman alike.

The question of the relationship between intelligence and consciousness may be asked. Griffin [7] infers animal consciousness from a variety of evidence:

- I. Versatile adaptability of behavior to novel challenges;
- II. Physiological signals from the brain that may be correlated with

conscious thinking;

III. Most promising of all, data concerning communicative behavior by which animals sometimes appear to convey to others at least some of their thoughts.

Consciousness implies using internal images and reconstructions of the world. Purposive behavior is contingent on these internal representations. These representations may be based on the stimulus from the environment, memories, or anticipation of future events.

4 Gradation of Intelligence

An extremely important insight from experiments of animal intelligence is that one can attempt to define different gradations of cognitive function. It is obvious that animals are not as intelligent as humans; likewise, certain animals appear to be more intelligent than others. For example, pigeons did poorly at picking a pattern against two other identical ones, as in picking an A against two B's. This is a very simple task for humans. Herrnstein [9] describes how they seemed to do badly at certain tasks:

1. Pigeons did not do well at the categorization of certain man-made and three-dimensional objects.
2. Pigeons seem to require more information than humans for constructing a three-dimensional image from a plane representation.
3. Pigeons seem to have difficulty in dealing with problems involving classes of classes. Thus they do not do very well with the isolation of a relationship among variables, as against a representation of a set of exemplars.

In a later experiment Herrnstein et al. [10] trained pigeons to follow an abstract relational rule by pecking at patterns in which one object was inside, rather than outside of a closed linear figure. Wasserman [22, 23] devised an experiment to show that pigeons could be induced to amalgamate two basic categories into one broader category not defined by any obvious perceptual features. The birds were trained to sort slides into two arbitrary categories, such as category of cars and people and the category of chairs and flowers. In the second part of this experiment, the pigeons were trained to reassign one of the stimulus classes in each category to a new response key. Next, they were tested to see whether they would generalize the reassignment to the stimulus class withheld during reassignment training. It was found that the average score was 87 percent in the case of stimuli that had been reassigned and 72 percent in the case of stimuli that had not been reassigned. This performance, exceeding the level of chance, indicated that perceptually disparate stimuli had amalgamated into a new category. A similar experiment was performed on

preschool children. The children's score was 99 percent for stimuli that had been reassigned and 80 percent for stimuli that had not been reassigned. In other words, the children's performance was roughly comparable to that of pigeons. Clearly, the performance of adult humans at this task will be superior to that of children or pigeons.

Another interesting experiment related to the abstract concept of sameness. Pigeons were trained to distinguish between arrays composed of a single, repeating icon and arrays composed of 16 different icons chosen out of a library of 32 icons [23]. During training each bird encountered only 16 of the 32 icons; during testing it was presented with arrays made up of the remaining 16 icons. The average score for training stimuli was 83 percent and the average score for testing stimuli was 71 percent. These figures show that an abstract concept not related to the actual associations learnt during training had been internalized by the pigeon. And the performance of the pigeons was clearly much worse than what one would expect from humans.

Animal intelligence experiments suggest that one can speak of different styles of solving AI problems. Are the cognitive capabilities of pigeons limited because their style has fundamental limitations? Can the relatively low scores on the sameness test for pigeons be explained on the basis of wide variability in performance for individual pigeons and the unnatural conditions in which the experiments are performed? Is the cognitive style of all animals similar and the differences in their cognitive capabilities arise from the differences in the sizes of their mental hardware? And since current machines do not, and cannot, use inner representations, is it right to conclude that their performance can never match that of animals?

Another issue is whether one can define a hierarchy of computational tasks that would lead to varying levels of intelligence. These tasks could be the goals defined in a sequence, or perhaps a lattice, that could be set for AI research. If the simplest of these tasks proved intractable for the most powerful of computers then the verdict would be clear that computers are designed based on principles that are deficient compared to the style at the basis of animal intelligence.

5 Recursive Nature of Animal Behavior

A useful perspective on animal behavior is its recursive nature, or part-whole hierarchy. Considering this from the bottom up, animal societies have been viewed as "superorganisms". For example, the ants in an ant colony may be compared to cells, their castes to tissues and organs, the queen and her drones to the generative system, and the exchange of liquid food amongst the colony members to the circulation of blood and lymph. Furthermore, corresponding to morphogenesis in organisms the ant colony has sociogenesis, which consists of the processes by which the individuals undergo changes in caste and behavior. Such recursion has been viewed all the way up to the earth itself seen as a living

entity. Parenthetically, it may be asked whether the earth itself, as a living but unconscious organism, may not be viewed like the unconscious brain. Paralleling this recursion is the individual who can be viewed as a collection of several “agents” where these agents have sub-agents which are the sensory mechanisms and so on. But these agents are bound together and this binding defines consciousness. An interesting question that arises out of this reasoning is whether an organism as well as a super-organism could be simultaneously conscious. It appears that such nested consciousness should be impossible. Fischer [5] has argued that the mind must be seen in the society’s connectionist network.

Logical tasks are easy for machines whereas AI tasks are hard. It might well be that something fundamental will be gained in building machines that have recursively defined behavior in the manner of life. But how such machines could be designed is not at all clear.

A hierarchy of intelligence levels can be useful also in the classification of animal behavior. There does not appear to be any reason that experiments to check for intelligent behavior at different levels could not be devised. Furthermore, experiments could be conducted to determine the difference in ability for individual animals. That such experiments have not been described until now is merely a reflection of the peculiar history of the field.

6 Holistic Processing and Quantum Models

In recent years there has been increasing examination of the question of the wholeness associated with intelligent processing. Neural activity in the brain is bound together to represent information; but the nature of this binding is not known. The brain constantly reorganizes itself based on the information task [18]. On the other hand, quantum mechanics has provided a new understanding of the physical world although its philosophical implications are quite contentious and murky. Quantum mechanics is a theory of “wholes” and in light of the fact that the eye responds to single photons—a quantum mechanical response—and that the mind perceives itself to be a unity, one would expect that its ideas would be applied to examine the nature of mind and of intelligence. But for several decades the prestige of the reductionist program of neurophysiology made it unfashionable to analyze this question.

Meanwhile, the question of the nature of information, and its observation, has become important in physics. The binding problem of psychology, and the need to postulate a mediating agent in the processing of information in the brain, has also brought the ‘self’ back into the picture in biology. Oscillations and chaos have been proposed as the mechanisms to explain this binding. But we think that the strongest case can be made for a quantum mechanical substratum that provides unity to experience. Such quantum mechanical models of consciousness have attracted considerable attention; this work is reviewed in [14, 15].

Quantum computing in the style of Feynman and others [3, 4, 16], is con-

sidering the use of lattices or organo-metallic polymers as the apparatus; on the other hand, microtubules, the skeletal basis of cells that consist of protein polymers, have been proposed by Hameroff and others [11] as supporting quantum mechanical processes. My own work has examined the basic place of information in a quantum mechanical framework and its connections to structure. This work shows that although many processes that constitute the mind can be understood through the framework of neural networks, there are others that require a holistic basis [15]. Furthermore, if each computation is seen as an operation by a reorganized brain on the signals at hand, this has a parallel with a quantum system where each measurement is represented by an operator.

Feynman [3] has argued that it is not possible to simulate quantum mechanics on a traditional computer. If it is accepted that intelligence has a quantum mechanical basis, then it would follow that Turing-machine models of intelligence will come up short. This will lead to several questions. What hardware basis is required before intelligence can emerge out of a quantum structure? Does intelligence require the presence of the notion of self?

7 Concluding Remarks

Study of animal intelligence provides us with new perspectives that are useful in representing the performance of machines. For example, the fact that pigeons learn the concept of sameness shows that this could not be a result of associative response to certain learnt patterns. If evolution has led to the development of specialized cognitive circuits in the brain to perform such processing, then one might wish to endow AI machines with similar circuits. Other questions arise: Is there a set of abstract processors that would explain animal performance? If such a set can be defined, is it unique, or do different animal species represent collections of different kinds of abstract processing that makes each animal come to achieve a unique set of conceptualizations?

We have argued that animal behavior ought to be used as a model to define a hierarchy of intelligence tasks. This hierarchy is likely to be multidimensional. Various kinds of intelligence tasks could define benchmark problems that would represent the various gradations of intelligence. Such gradations may be used to define the progress of AI programs.

The computational hierarchy related to these tasks is another interesting issue. What results would emerge from an examination of this issue remains an open question.

The approach of defining gradations of intelligence has the potential of taking the human interrogator out of the test. The gradations could be defined in terms of the depth of the interactions between the interrogating program and the interogee machine. But can such an interrogating program be devised so that it is more than a set of problems assembled by human agents?

References

- [1] Beck, G. (1993). *Sonic Theology*. University of South Carolina Press, Columbia.
- [2] Dyczkowski, M.S.G. (1987). *The Doctrine of Vibration*. State University of New York Press, Albany.
- [3] Feynman, R.P. (1982). "Simulating physics with computers." *International Journal of Theoretical Physics*. 21, 467-488.
- [4] Feynman, R.P. (1986). "Quantum mechanical computers." *Foundations of Physics*. 16, 507-531.
- [5] Fischer, R. (1990). "Why the mind is not in the head but in society's connectionist network." *Diogenes*. 151, 1-28.
- [6] Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Houghton Mifflin, Boston.
- [7] Griffin, D.R. (1992). *Animal Minds*. The University of Chicago Press, Chicago.
- [8] Herrnstein, R.J., Loveland, D.H. (1964). "Complex visual concept in the pigeon." *Science* 146, 549-551.
- [9] Herrnstein, R.J. (1985). "Riddles of natural categorization." *Phil. Trans. R. Soc. Lond.* B 308, 129-144.
- [10] Herrnstein, R.J., W. Vaughan, Jr., D.B. Mumford, and S.M. Kosslyn. (1989). "Teaching pigeons an abstract relational rule: insideness." *Perception and Psychophysics* 46, 56-64.
- [11] Jibu, M., Hagan, S., Hameroff, S., Pribram, K.H., Yasue, K. (1994). "Quantum optical coherence in cytoskeletal microtubules: implications for brain function", *BioSystems*, 32, 195-209.
- [12] Kak, S.C. (1993). "Reflections in clouded mirrors: selfhood in animals and machines". Symposium on *Aliens, Apes, and AI: Who is a person in the postmodern world*, Southern Humanities Council Annual Conference, Huntsville, AL, February 1993.
- [13] Kak, S.C. (1994). *The Astronomical Code of the Rgveda*. Aditya, New Delhi.
- [14] Kak, S.C. (1995). "On quantum neural computing." *Information Sciences*, 83, 143-160.

- [15] Kak, S.C. (1995). "Quantum neural computing." In *Advances in Imaging and Electron Physics*, Peter Hawkes (ed.). Academic Press, New York, pp. 259-313.
- [16] Lloyd, S. (1993). "A potentially realizable quantum computer." *Science*, 261, 1569-1571.
- [17] Pepperberg, I.M. (1983). "Cognition in the African Grey parrot: preliminary evidence for auditory/vocal comprehension of the class concept." *Anim. Learn. Behav.* 11, 179-185.
- [18] Pribram, K.H. (1971). *Languages of the Brain: Experimental paradoxes and principles in neuropsychology*. Brandon House, New York.
- [19] Terrace, H.S. (1985). "Animal cognition: thinking without language." *Phil. Trans. R. Soc. Lond.* B 308, 113-128.
- [20] Turing, A.M. (1950). "Computing machinery and intelligence." *Mind*, 59, 433-460.
- [21] Turney, T.H. (1982). "The association of visual concepts and imitative vocalizations in the mynah." *Bulletin Psychonomic Society*, 19, 56-62.
- [22] Wasserman, E.A. (1993). "Comparative cognition: Beginning the second century of the study of animal intelligence." *Psychological Bulletin*, 113, 211-228.
- [23] Wasserman, E.A. (1995). "The conceptual abilities of pigeons." *American Scientist*, 83, 246-255.
- [24] Winston, P.H. (1992). *Artificial Intelligence*. Addison-Wesley, Reading.

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