Preliminary
An Introduction to Machine Cognition

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Abstract

Cognition has been defined as the ability to obtain the knowledge, comprehend that it is knowledge, store this knowledge in an organized manner, realize when this is needed, retrieve it, and then use it to reason or problem solve. ( ) Cognitive psychology questions how people learn, store, and use information. (Martindale 1991)

There is no consensus about the definition of intelligence, in spite of the 1948 conference trying to define it. (Sternberg)

This paper will start by trying to define cognition and its various components. How this can be implemented in a non-biological entity will then be discussed.

Introduction

Simon defined the problem solving cycle of first identifying the problem, creating a number of potential solutions, evaluating each of these, and then by deciding which outcome would be the best given the utility demanded by the problem. (Newell & Simon, 1972)

Most of the Simon model has been built in the machine environment (computer) often called a Model Based Decision Support System (MBDSS) but the entire process, including the cognition portion, has yet to evolve onto silicon. This remaining part, where the system actually gains knowledge and becomes smarter, has yet to be accomplished.

It has been said that if the Encyclopedia Brittanica had legs and could walk, that with all of its knowledge, it would walk off of a cliff. (Freedman)

Some areas of cognition are: pattern recognition, attention, memory, visual imagery, language, problem solving , and decision making. (Reed) Neisser (in Reed) connected cognitive psychology to all processes that transformed, reduced, elaborated, stored, recovered, or used sensory input.

Knowledge

Knowledge has been defined many ways, with no consensus on its exact meaning. The broadest sense of the term will be used in this paper. Stretching on one end from low level knowledge (which is often overlooked) to the most esoteric. How to walk or climb stairs is assumed by many, but is indeed a form of low level knowledge. Understanding nuclear fusion or quantum mechanics and string theory is on the opposite end of the spectrum. Understanding language is somewhere in the middle.

This knowledge is stored in the form of mental representations that symbolize

relationships and objects, based upon perception of the external world. This perception is not a constant, but is an active representation of a model that is built in each person's mind. Each person builds their own unique model based upon their thought process and past experiences. (Martindale)

Memory

There are two basic memory areas, the episodic and the associative. The former is memory of experiences, of results from prior decisions and is also called experiential knowledge. The latter is the set of information about the subject matter, associated with the problem to be decided.

Memory is also split into short term (STM) and long term (LTM).

Both types are dynamic and are updated continuously. Experiential might receive new information on a regular basis, or as something occurs. Going to school or reading a book are sources of associative memory. If the system was connected to a continuous source, such as a news wire service or the Internet, this knowledge base would be growing constantly. Filters would be required to keep all but information directly connected to the problem from entering the knowledge base.. This part, while it sounds simple, is really a major obstacle to the development of such a system.

Experiential is in many ways an easier task. Every time a decision is made, the data is put into memory, with an identification tag. At some point later when news arrives about the decision having been good or bad, then this record is retrieved and the outcome is recorded. e.g. A loan is made to a friend, and the outcome is if it is repaid or not. In human terms, this is learning from experience. If information about other such decisions being made becomes available, this knowledge should also be added. In human terms, this is called learning from other's mistakes and is considered a sign of intelligence.

The information must be converted to knowledge, and then stored in such a way that it can be easily allocated and retrieved as needed. And then found and extracted when needed.

Memory Organization

Computers store data in files, data bases, and linked lists, but the organization of the biological brain is not fully understood. It is typically discussed as being in two basics categories, short term memory (STM) and long term memory (LTM). The former is of limited capacity and is for very short term application, such as remembering a telephone number that was just looked up for the purpose of immediate dialing. LTM is of very large capacity and lasts for a long time. Current theory states that it lasts forever except in cases of physiological damage. Allocation is often a problem.

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Metacognition

Knowledge about cognition is metacognition. It is a strategy of how one monitors, models, and controls the cognitive functions. (Anderson & Oates 2007)

Metareasoning

There are two main areas of metareasoning; 1) scheduling and control of deliberation, 2) using higher order knowledge about reasoning process. There is some overlap between these two areas. (Anderson & Oates 2007)

Pattern Recognition

How objects in the environment are identified is a basic description of pattern recognition (PR). In order to recognize a pattern a set of patterns must already exist in long term memory to which the current one can be compared. (Reed) When one of our senses encounters something, it tries to compare it to stored patterns in LTM. There is much variation in the object that is trying to be recognized from many things such as lighting, perspective, size, coloration, sound, background, timing, environment, and variability in the object or pattern itself. Perceptual generalization allows the recognition of such.

Current computers have clock speeds around 3 gHz. The biological brain is electro-chemical and runs at about 1 kHz, over six orders of magnitude slower. Yet humans are very good at recognizing patterns, visual, audio, and situational, far superior to any computer system employed currently.

There are three theories of how patterns are recognized: feature, structural description, and templates. (Reed) (Ashcraft) Human pattern recognition combines all three of these, as needed. Shape recognition ignores variations in size, color, position, brightness, and orientation. Some animals, including humans, can recognize a shape from its outline. (Fischler & Firschein)

Templates utilize matching of the whole image or situation. This does not contain any description of the pattern itself. The degree of overlap is a measure of similarity. some problems relate to size, variability, how they differ, and alternative descriptions. For pure template recognition, rotating, resizing, and change of perspective are all required in an attempt to match up the patterns. It was pointed out that the number of comparisons required for all of the possible variations of each possible image would be excessively large and therefore template matching has been ruled out as the sole method for human PR.

Features describes patterns in terms of parts or components. The whole is broken down into the smallest pieces, building blocks of the whole. Distinctive features, in one but not others can aid in differentiating. For example in differentiating between an upper case letter P and and R, one can see that the difference is in the tail that exists on the R. The same is true between an upper case O and Q.

Structural description concerns the relationship among and between features. This is built upon the features and so structural theory is based upon feature theory, but then continues to describe how the features interact and/or are related. (Reed, 2000) This relates to how the different parts meet, how long, how many, and the intersections,

Added to this is some logical thoughts about the environment and inference. Where is this thing that is being identified, and what time is it? What are other conditions? What other objects are with or near it? Add knowledge from LTM to enhance the picture. This is called conceptually driven processing effects that combine higher level knowledge and context with

the lower level sensory processes and affect the perceived image . (Ashcraft)

Rarely is an exact scene repeated, considering perspective in space, angle of approach, and lighting. When combining the near infinite variety of configurations and orientations, it becomes apparent that the number is too large to try and match patterns. Each scene is partitioned into individual pieces, separated by numerous differences including distance, color, material, reflectivity, texture, and more.

Using feature and structural description can reduce the search space by several orders of magnitude, allowing template recognition to make the final decision.

Human pattern recognition is (usually) performed subconsciously, in that we look at something, know what it is, but do not think about how we know that. It begins with feature recognition, comparing components of the whole object to objects in long term memory. Structural recognition then describes some relationships among the items, and finally template recognition makes the exact identification. This entire process can be considered to be recursive, as the initial feature recognition must be broken down into pattern recognition.

Additionally, the biological brain is massively parallel with many processes proceeding concurrently. Different parts and features are recognized simultaneously and then these results are then further processed to the next stage.

An example is when one sees a car. If it was up above in the air, it would not make sense. If it was parked in front of a sports car dealer, the story would fit together. Then one would recognize the overall shape, see the four tires, the doors, steering wheel, and a few more other standard items. This being in the context of being parked on the ground in its context would be decided as a car. Further steps would be to notice its overall shape and if it was low and sleek, it would be decided as a sports car. At this point, template matching would try to decide if it is a Ferrari, a Lamborghini, or an Alfa Romeo. This whole process is performed concurrently in various portions of the brain.

Perceptual confusion is the measure of the frequency of two patterns mistakenly identified as each other (Reed)

Biological Neural Network

The human brain contains in the range of 4×10^{10} to 10^{11} neurons, each, by latest theory, can have up to about 10^5 interconnections. Other life forms have smaller numbers, with animals like an abalone having only a brain stem.

Artificial Neural Network

There exists many programs to emulate one aspect of the performance of a biological neural network. These programs create generalized data driven function approximators, that map input to output patterns. Currently, these programs have typically a hundred or less neurons, which is negligible compared to the brain of a homo sapien.

The knowledge is stored in the connection weights, but the most elusive part is how these weights are achieved in the biological network. The artificial brains have an external mathematical program that sets these weights via many different methods, all complex calculations, usually using a gradient or a derivative, none of which is done in the biological version. An exploited search, such as a genetic algorithm or simulated annealing can also be used.

Cognition in a Non-Biological Environment

As was shown from the above, cognition is a highly complex process, with many concurrent activities, both conscious and subconscious. In each generation, the mind has been described according to the present technology. In early concepts in the era of agro-economies, the mind was seen to grow, with predetermined patterns, similar to plants. In the beginning of the industrial revolution, hydraulic metaphors were created. Freud formulated a thermodynamic regulated machine. Currently in the era of microprocessors and (relatively) high powered computers, the brain is considered to be a massively parallel neural computer. (Martindale)

The first step is to decide what is to be done; and the second, how it will be done.

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