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The evolution of artificial intelligence since the 1950s is discussed, especially as it is being applied in radiology to image processing. Developments in artificial intelligence are now being used to provide a new approach to image processing. Initially, the computer dealt with numeric representations using languages such as FORTRAN and BASIC. Now symbolic languages such as LISP and PROLOG have expanded the use of the computer into nonnumeric symbolic reasoning that is just being applied to image understanding. This paper explains the new languages and their application to image understanding.

Artificial intelligence (AI) is a term usually applied to inanimate objects, and in the last two decades it has become associated specifically with computers (1). In the early 1950s, many people became excited about the potential abilities of the computer. Large computer companies sold their products with the claim that the machine could do anything once the proper software programs were written. The program writing was viewed as a trivial task, something that could be easily accomplished in an Aristotelian fashion: we had only to discover the method within ourselves. Everyone was optimistic about the ultimate power of the computer, and many became interested in cybernetics, the potential ability of the computer to think.

As it is defined in this decade, AI means the ability of a machine to think like a person. Despite much research, however, little is known about the way a human being thinks. A three-volume series entitled *The Handbook of Artificial Intelligence* also struggles with the definition (1).

There is some quantitative meaning in intelligence. Broadly defined, the more complicated the thought process, the more we identify it as intelligent. Thus, the person who can put together a 1,000-piece jigsaw puzzle is considered intelligent, while the one who can put together a 10,000-piece puzzle is considered even more intelligent. In the realm of the computer, the machine is considered intelligent if it can perform the same thought processes as the human being.

A frequent argument against the existence and utility of AI is that a human being can conceptualize in ways that a computer cannot; eg, the person can recognize that the glass is half-empty rather than half-full. However, the human brain is capable of a complicated set of processes that operate in a specialized environment. Although one may compartmentalize the various senses as well as the multitude of reasoning processes in a human being, a complex interplay of all the senses and the intellect is an essential component of the human mind.

To isolate the essence of the human intellect, Turing in 1950 suggested an easy test to determine whether a computer can think (2). He placed in one room a person, in another a computer, and in a third room an interrogator who communicated with both the person and the computer only by teletype. The interrogator would decide which room contained the person and which the computer. Communication was allowed only through teletype communication. In Turing's reasoning, if the computer could fool the interrogator into believing that it was a human being, that would prove the computer could think.

The Development of Numeric Computer Languages

Although many people were interested in cybernetics in the 1950s, the first computer designers directed its development toward an atmosphere which was not conducive to abstract thought. The computer's basic instructions are written in a numeric language, and its basic memory depends on a binary system of counting. By analogy, it is as if someone has only two fingers instead of ten with which to represent a number. Scientists, statisticians, and mathematicians saw that the computer provided a way to deal with very complicated numerical processes. A new field of applied mathematics developed in which the computer began to be viewed as a complicated calculator. A computer language called FORTRAN was developed to TRANslate and then to calculate FORmulas. This language was also highly efficient, since each FORTRAN statement could embody as many as two or three hundred machine language statements. Machine language is a set of instructions understood by the machine itself; a translator, called a compiler, translates FORTRAN instructions into machine language.

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The problem with languages like FORTRAN is that we do not generally use numbers to think abstractly. To speak, sing, play music, understand language, or write books does not require a complex set of mathematics, nor are these activities amenable to numerical models. A typical FORTRAN program contains algebraic statements such as:

$$x = y + 5$$

There is no easy way in FORTRAN to say, "a tree has green leaves attached to branches that are supported by a trunk," although one might calculate a model that would predict the force of wind necessary to topple the tree.

The Development of Artificial Intelligence Languages

Because of the limitations of numerical languages like FORTRAN, those interested in AI recognized that another language was needed to deal with symbols. Many were tried, but the one most used in the United States is LISP (3), developed in 1960 by John McCarthy at the Massachusetts Institute of Technology. Another, called PROLOG (4), is used in Europe and Japan.

LISP is a list processing language in which words are called atoms, and a sentence in parentheses is called a list; hence:

(this is a list)

The commands in LISP are used to take lists apart and put them together, to make logical tests on lists, and to apply properties to lists and atoms. The three basic commands in LISP are car, cdr, and cons. The line with the prompt indicates writing on a computer screen, both input and output. The commands are as follows:

```
→ (car '(this is a list))
results in (→ is the computer prompt)
→ this
and
→ (cdr '(this is a list))
results in
→ (is a list)
To put things back together, the following is done
→ (cons 'this '(is a list))
results in
→ (this is a list)
```

In the above fashion a sentence can be taken apart and put together. Although we could not talk about the properties of trees in FORTRAN, it is easy to do so in LISP.

```
→ (putprop 'leaves 'green 'color)
tells the computer the color of leaves is green
and
→ (get 'leaves 'color)
returns
→ green
which answers the question: What color are leaves?
```

Artificial Intelligence Applications

From this basis, LISP has been used to build programs that take on an intelligent nature. In medicine one of the best known is MYCIN by Edward Shortliffe (5). The program interacts with incomplete information about a patient's infection and is able to advise the physician in natural English about how to treat it. This program uses a set of IF-THEN rules called productions that allow it to think. In a production system, rules are linked together to reason symbolically about a particular topic. At present, AI has programs in X-ray diffraction and oil exploration that exhibit greater intelligence than a person's about those areas.

Image Processing

Although the term *image processing* usually refers to a computer process, this broad term has different meanings in different areas. An AI model can be used at many different levels of image processing. At the lower level, the model understands the topology of line drawings; hence, it will "know" that certain types of corners constructed with lines will form only a convex surface, while others will form only a concave surface. At a higher level, another AI model might understand the relationship of various objects formed from the line drawings.

Much of what is known about computer image processing comes from the NASA space program. Because transmissions from space usually were noisy, images had to be "cleaned up" to be useful to a human being. Because noise superimposed on the images was understood, much of it could be removed. However, image processing of space pictures did not require that the picture be recognizable; since noise had to be removed, the process had to understand the noise. Certain types of radiologic procedures use this kind of image processing. To eliminate noise, simple filters are often used during the process of digital subtraction angiography in an attempt to make the vessels appear more clearly.

However, the type of image processing being discussed involves the efforts of the image-processing computer to achieve a diagnosis based on information in an image. As in AI, image processing has undergone changes related both to the numerical capacities of the computer and the recent evolution of symbolic languages such as LISP and PROLOG. An early study of the detection of breast cancer illustrates this point (6).

Breast Lesion Detection and Classification

The initial problem was to read a xeromammogram by detecting and then classifying a questionable area or lesion. Since breast tissue has a symmetrical distribution from left to right, dominant lesions were initially found by using a mathematical technique that would permit the numerical differentiation of tissue in the left breast from tissue in the right. If significant differences were found between the two breasts, image-identifying routines were applied to those areas.

This local method worked as follows: A benign lesion is generally circular with definite edges that are unrelated to the surrounding breast tissue, whereas a malignant lesion usually has poorly defined edges, spicules radiating from its center, and associated microcalcification. Routines were written to measure different parameters such as spicules, smooth edges, homogeneity in the middle of the lesion, and microcalcifications; the computer was taught the difference between malignant and benign lesions through a method known as the nearest neighbor technique. This technique uses a measure of distance called the parameter space to determine how near an unknown object is to a known object (7-9).

For example, since the property of being round is the opposite of the property of being spiculated, it is possible to project a continuum from the round measurement at one end to the spiculated measurement at the other. The further assumption is then made that something that is round has a measurement of zero, whereas something that is spiculated has a measurement of ten. Thus, a lesion that measures five on such a continuum is considered to be indeterminate (ie, neither definitely malignant nor definitely benign), whereas a lesion that measures nine is more likely to be malignant, and a lesion that measures one is more likely to be benign.

In this classification system, symbols were used in a mathematical way to describe breast cancer, spicules, calcifications, etc. No attempt was made to connect the various symbols logically to make a diagnosis. The classification technique merely related the symbolic parameters to theoretical points in parameter space in a way that cannot easily be described in English.

Bayes' Classification

In this technique, objects are classified according to their joint and disjoint probabilities. Bayesian probability is similar to the nearest neighbor technique in that it measures distance between two objects in parameter space. However, it differs in that each type of measure is associated with a number or a probability rather than using a symbolic statement about that measure, such as "fuzzy border." To determine whether something is malignant or benign, a statement of the fuzziness of three is used, or the probability that it is fuzzy is calculated. One disadvantage of this method is that a large data set would contain many numerical measures that do not subjectively describe the appearance of an object in natural language. The nearest neighbor technique and Bayesian probability work well where many statistics are amassed to cover all possible circumstances under which something might occur, but there is no need to describe in English what is happening.

Symbolic Versus Numerical Representations

In complicated systems, a numerical method for recognizing an object or series of objects and their relationships is difficult. Because the descriptions and knowledge of most things in radiology are at best only partial, no complete probabilistic system can describe these images. Also, what the physician sees on an image is related to the patient's clinical situation. For instance, if a patient has no symptoms but is seen to have an infiltrate on a chest radiograph, it is highly probable that the finding will be termed a chronic scar or carcinoma rather than acute pneumonia. The model of the disease coupled with the findings on the image determine the diagnosis. A numerical representation of such a clinical situation is almost impossible. It is much easier to develop a system that uses words in a language we understand, not a foreign mathematical language.

Consequently, AI systems are used in identifying the current models of disease. At Henry Ford Hospital, we have developed an AI model that attempts to identify one of five diseases in the head. A set of computer programs uses this AI model to ask questions of the radiologist and reason symbolically about disease. It enables a clinician who reads a radiograph to interact with the computer to answer symbolic questions (10,11). The model is then used to make a diagnosis of the picture.

The essence of our model is a production system that consists of many rules using a stylized form of natural language to form interconnected rules. The person giving the rules to the computer understands the stylized form of natural language and can easily enter another rule in the same language and style. Because one rule will imply statements that are used in another rule, a cascade effect is possible in attempting to reason about disease. The rules are stated in an English-like syntax that allows the thoughts of the clinician to be translated immediately into the central processing unit of the computer. An isomorphic transformation of a descriptive scene into a numerical scene is not needed to produce an analysis, since an ordered descriptive scene is sufficient in itself both to describe and to analyze a picture. In this disease model, both clinical history and image parameters in the picture interact with each other to provide a diagnosis.

While this seems to be a powerful technique with much promise, it is difficult to extract rules from the mind of the clinician and design image-processing routines to interact with a production system that understands a picture. Although this AI model is not yet a threat to the diagnostic skills of the radiologist, I suspect that within the next 15 years machines will interpret radiographic findings using techniques similar to these.

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