# Symbolic and Non-Symbolic Knowledge Representation

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Abstract

In order to integrate connectionist models and symbolic AI techniques, knowledge must be represented in an appropriate form. In this paper, we introduce the general characteristics of the different types of knowledge representation and the integration possibility.

## 1. What is Symbol Systems

Certain connectionists might look on symbolic AI as an absolutely artificial convenience to model human cognition or mind. They would argue that symbols and symbol systems can hardly be implemented in the massively parallel architectures and processing mechanisms that the biological brain is based on. However, we human beings are surely partly characterised by the use of symbol systems such as natural languages and logic formulas. It is generally believed that the development of natural languages and the ability to form abstract concepts have led to the evolution of human intelligence. [1] state the physical symbol system hypothesis as follows:

> *A (Physical) symbol system has the necessary and sufficient means for general intelligent action.*

They admit that this is an empirical hypothesis and there is no way of demonstrating the connection between symbol systems and intelligence on purely logical grounds.

However, they claim that existing AI systems give empirical evidence as to the sufficiency of symbol systems for producing intelligence, and that the symbolic behaviour of man is evidence as to the necessity of having a symbol system whenever intelligence is exhibited.

Before investigating the integration of symbolic AI and connectionist models to model human cognition, we should agree on the definition of symbols and symbol systems, since various definitions of symbol systems may be possible. In the following, we will focus on strict symbol systems that are usually used as the basis of symbolic AI.

A symbol system consists of symbols that are basically physical tokens. If we define a symbol just as a physical token, the phenomena which

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work as symbols will be very varied. For example, the tail-wagging dance of bees is a symbol to represent where nectar is, whereas the Union Jack is the symbol of the United Kingdom. However, symbols of this level lack an important factor to describe human intelligence, that is, a structuring ability. Such symbols must be disqualified for the organiser of human intelligence because they cannot describe intricate information, but just single concepts. [1] define symbols that are sufficient to handle human intelligence as follows:

> *Symbols are physical patterns that can occur as components of another type of entity called an expression (or symbol structure).*

Such symbols are capable of describing knowledge because they have much higher capability than representing just single concepts. Based on this definition symbolic representation of knowledge is defined as follows:

(1) Symbols explicitly represent concrete or abstract concepts as identity tags or labels.

(2) An atomic symbol represents a single concept, whereas a structure of atomic symbols represents a combination of more than a concept, e.g., two concrete concepts can be related by an abstract concept.

Then, what is a symbol system? [1] describe it as a machine that produces an evolving collection of symbol structures, and [2] provides a more detailed definition as follows:

(1) A symbol system consists of symbols and explicit rules that are described as a series of symbols included in the system, since a symbol system is self-contained.

(2) Explicit rules are used to manipulate (combine and recombine) symbols purely syntactically. When an explicit rule is applied to symbols, the condition has to be 100 % satisfied. This is what the adjective 'explicit' for rules denotes.

## 2. Disadvantages of Symbol Systems

### 2.1. Lack of Ambiguity

Symbolic information is always deterministic in the sense that a symbol only indicates a discrete concept that is completely independent from others. For example, a symbol 'apples' always indicates just 'apples' but never 'pears' (in fact 'Japanese pears' exactly look like 'apples' in shape). In this sense, a symbol system cannot handle ambiguous information. If we try to add an ambiguous flavour to a symbol just by appending a series of adjective symbols, nothing will an effect the original symbol at all. For instance, 'apples' could be modified to 'apple-like fruit'. In human minds, the meaning of the original symbol 'apples' may be changed, but that occurs outside the symbol system. Within a symbol system, such a process only appends an additional symbol '-like' onto the original one.

### 2.2. A Closed World

Symbols handled within a symbol system are completely isolated from the real world. They are like products manufactured at a factory in an isolated island that do not have any means of transport to another land. As a result, such products will be useless for the people who live

outside the island, even though the factory has all the necessary tools and materials to completely finish them.

In a symbol system, tools are explicit rules, materials are symbols, the products are the strings of symbols manipulated by the rules, and the transport facility is the human interpretation. Despite the fact that any symbol can be translated by a set of other symbols, such a translation does not produce a real implication from the original symbol to the real world object but just a closed chain of symbols. This means that a symbol system alone can never display the meaning of a symbol. This is only provided by the human interpretation. [2] describes this as the symbol grounding problem.

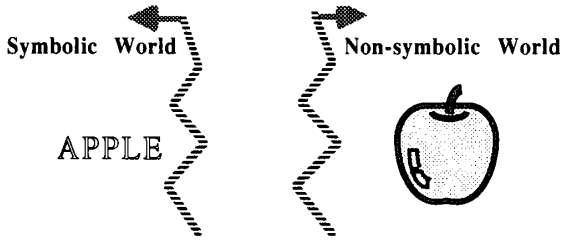


Figure 1. Symbolic and Non-symbolic World

## 3. What is Non-Symbolic Information

The complement of symbolic information may be called non-symbolic information that is defined as follows: each piece of non-symbolic information is a physical copy of a concept in a partial or complete form. It can be a picture, sound, or anything else that is neither a symbol nor composite of symbols but the real projection of a concept. In a certain aspect, non-symbolic information itself can be seen as a reconstruction of the original concept providing that the projection quality is infinitely high. Conversely speaking, the ambiguity of information could be expressed as the degree of projection accuracy. Unlike symbolic information, non-symbolic information has the ability to display its meaning with the certainty degree, to a certain extent.

## 4. Joining a Symbolic and an Non-Symbolic World

Although it is obvious that a symbol system is a useful framework to model human cognition with the existing symbolic AI techniques, it has certain limitations as well. On the other hand, a sort of system based on non-symbolic information seems to have the potential to solve the problem of symbol systems, such as the lack of abilities to express ambiguity and to let symbols grounded on the real world objects (mentioned in 2.2.2). In such a case, why not simply combine these two systems to get both advantages together?

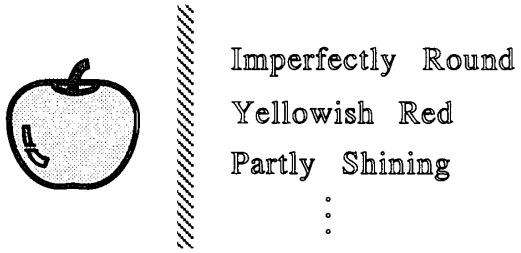


Figure 2. Information Complexity of Words or a Picture

In reality, however, finding a method to combine non-symbolic information with a symbol system can be troublesome. As it is obvious from the definition, symbolic information and non-symbolic information are substantially different; hence they do not meet naturally. In a conventional computer the former can be much more compactly represented than the latter because every unit of symbolic information is just a collection of discrete elements, while in the human mind the latter may be more easily held than the former since a great deal of information can be squashed into a unit of non-symbolic

information in a mingled form. For example, a photograph of an apple gives a lot of information at once, such as its imperfect roundness, yellowish redness, partly shiny appearance and so forth as illustrated in Figure 2. It seems much easier to remember and recall the image of an apple appearance than the descriptive symbolic expressions.

Clearly, the difference between symbolic and non-symbolic information is found in their nature. This will certainly prevent them from being combined. The solution to the problem may be introducing a third system of some kind in between. This should be a sort of system that mediates the two different types of information. In other words, the connection between them can be made via the third system that takes a middle position in nature. This can be called a semi-non-symbol system.

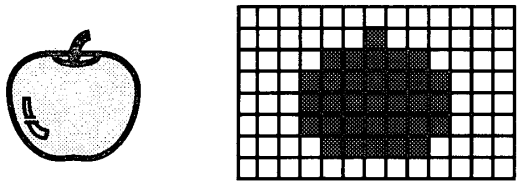

Figure3. Non-symbolic Information vs. Semi-non-symbolic Information

What is a semi-non-symbol system? Let us take a visual image as an example of non-symbolic information. In this case, the system may look like a board on which binary primitives are regularly arranged. A certain aspect of non-symbolic information, e.g., shape or colour, can be represented in the board as a pattern of binary primitives. The converted information represented on the board may be called semi-non-symbolic information, since the information is non-symbolic as a whole but it is a collection of discrete elements. Figure 3 illustrates the idea.

Relating a symbol with a unit of semi-non-symbolic information will be much less complicated than with pure non-symbolic information. This is because semi-non-symbolic information is expressed as a collection of explicitly discrete data. The necessary wiring process is simply to join a symbol with the binary primitives that form a semi-non-symbolic image (see Figure 4). Although a semi-non-symbolic image becomes coarser than the original non-symbolic information owing to the digitisation effect, any visual sensors available including the human eyes possess more or less the same characteristics.

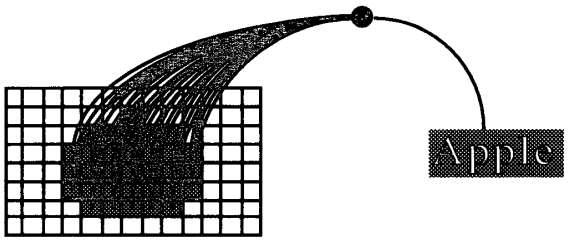


Figure 4. The Relation of a Symbol and a Unit of Semi-non-symbolic Information

As mentioned above, each semi-non-symbol system can be regarded as a feature detector of a certain aspect [3]. A combined system of symbol and semi-non-symbol systems becomes much firmer if various aspects of semi-non-symbolic images support a symbol. Thus, a symbol needs to be linked with several semi-non-symbol systems. On the other hand, a semi-non-symbolic image can be connected to various symbols since a feature may be shared by a number of symbols. It may be even better if the link between a symbol and a semi-non-symbolic image is individually weighted. This is because every semi-non-symbol system, accordingly a semi-non-symbolic image, has a different degree of importance to characterise a particular symbol.

The quality of features, i.e., how many semi-non-symbolic images are discriminated in a semi-non-symbol system, will depend on the resolution quality of semi-non-symbolic systems, while the quantity of features, i.e., how many features characterise a symbol, will be proportional to the number of available semi-non-symbol systems.

## 5. Summary

Although a symbol system is a useful framework to model human cognition with the existing symbolic AI techniques, it has certain limitations. On the other hand, a system based on non-symbolic information seems to have the potential to solve the problem of symbol systems. To take both of the advantages for effective information representation, the two systems should be combined together. However, the substantial differences in nature prevent to do so. To fill the gap, a certain mediator system, that is called semi-non symbolic systems, should be chosen.

## References

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