

# Cognitive Primitives for Automated Learning

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**Abstract.** Artificial Intelligence deals with the automated simulation of human intelligent behavior. Various aspects of human faculties are tackled using computational models. It is clear that brain as a cognitive machine is significantly different from a computer. A general intelligent machine needs to incorporate primitives that are identical or similar to those intrinsic to human. We argue for the identification, verification, and development of technologies that will deliver core primitives that are fundamental to human cognition that are applicable to various domains. Mnemonics for aural and for visual cognition are presented in [2, 3]. We propose a generalized set of cognitive primitives that can be specialized to various applications viz. a) Existential, b) Structured Recurrence, c) Relative Attachment, d) Harmonized Counterparts, e) Cordial Counterparts and e) Discriminate Counterparts.

**Key words:** Science of intelligence, brain model, cognition, primitives.

## Introduction

Science of Intelligence [1] involves the basic theory and systems that involve understanding brain structure, cognitive processes, artificial intelligence (computational) models, and others. Science of the brain explores the physical and analytical aspects of brain and aims to study the principles and model of natural intelligence at a molecular level. Cognitive Science studies human mental activity, such as perception, learning, memory, thinking, consciousness etc. In order to model and implement machine intelligence, artificial intelligence attempts simulation, extension and expansion of human intelligence using artificial machines – specifically using computers. These disciplines work together to explore new concepts, new theory, and new technologies and methodologies to create and implement models that can imitate human intelligence.

What is learning? Cognition is a process of acquiring knowledge or skill. Acquiring and assimilation of information and knowledge is inherent to learning. But what constitutes knowledge and/or skill? As one assimilates information it is unclear if it is knowledge, relevant knowledge, or ability (skill) or pertinent skill. An alternate definition for learning can be: A lasting change in cognition resulting from experience, potentially directly influencing behavior. So what is cognition? Mental functions such as the ability to think, reason, and remember. Experiences include external inputs and its processing. Behavior is a processed response to an input. Thus we could say learning is a process through which external inputs enable acquiring knowledge and/or skill that affect the state of an organism such that its subsequent behavior may be altered.

Many have addressed the ways and means by which humans receive external input. Aural and visual inputs are the ones that are studied significantly. Natural language processing addresses the methods and technology of recognizing sounds and applying linguistics to recognize information. These techniques are further applied for linguistic responses. Image processing and pattern recognition aim to recognize objects and concepts, from optical input and images, using stored entities and processing techniques.

Machine learning is to enable a computer system to autonomously acquire and integrate knowledge. The capacity to learn from experience, analytical observation, and other means, is expected to result in a system that can self-improve and thus achieve better performance.

The technology with which input is 'scanned', converted, and subsequently used varies with application and models used for storing and matching the resident knowledge. Applications use algorithmic methods that result in accurate or approximate identification.

Stored knowledge use raw images and databases, Petri-nets, Bayesian networks, connectionist networks, and logical relational knowledge base. Various processing methods are used that integrate the content from the knowledge base and the rules used by experts in solving problems intelligently. Logic programming, production systems, neural networks, and other tools are used for computing so as to arrive at a desired solution. Techniques used vary from case-based reasoning, decision tree learning, meta learning, regression and statistical approaches.

What has eluded researchers is the ability to completely and accurately embody software solutions with techniques so easy and natural to humans. And, every domain of application presents its own challenges – whereas humans are able to seamlessly handle various domains with ease. Additionally, humans tackle indeterminate and fuzzy input and still achieve great degree of dependable solutions.

Applications software are 'trained' on test cases devised and labeled by humans, scored so as to estimate its usefulness, and then tested on real-world cases. The results of these real-world cases are in-turn reflected upon by human developers to further train the software in an attempt to improve its effectiveness.

We need to develop a framework that embodies human problem solving characteristics and then utilize those for developing 'software' solutions emulating intelligence. One could argue that newer technology and 'software' development methods different than current one may need to be developed. So be it.

## **1. Cognition: How, Why and What?**

We believe that in order to enable cognition we need pertinent set of core primitives. Every living organism is enabled with basic primitives. The usage and application of these with various degrees of flexibility, interdependence, and variations achieve cognition and which affect subsequent response(s). Cognitive functions are thus the result of concerted application of these core primitives.

Learning requires cognition as a primary step. Different organisms possess various cognitive abilities and various levels of these abilities. This in-turn is intrinsically involved with the input-output mechanism enabled in the organism.

Cognitive abilities involve aural and visual input and integrate these with analytical processing of this input. Language, music, and other forms of sound based communication use aural aspects. Input is received through the ear (or other forms of sound capture) and output could be voice generated. A systematic methodology for generating aural chants is proposed and shown capable of generating a variety of 'musical' sequences in [4]. Object, face, and scene recognition (static or dynamic) require visual input (eyes). A simple visual perception model is presented in [5]. Similar model is used in [6]. Response may be aural and/or physical - movement reconfiguring of self. Cognition of analytical concepts involves a re-evaluation and re-organization of internal knowledge to arrive at a verifiable and applicable new knowledge.

The primary aim of cognition in humans and animals is to effectively interact, communicate, and create. Primal instinct as well as intended actions enable an organism to interact and communicate. Intelligence - or semblance thereof - is firmly a consequence of what is cognizant to the organism and what has been assimilated through its experiences. Additionally, the ability of the organism to inclusively, and effectively, utilize the imbibed knowledge towards intended communication and interaction reflect its intelligence.

## **2. Need for Intelligence Primitives**

In May 1997, IBM's Deep Blue Supercomputer played a fascinating match with the reigning World Chess Champion, Garry Kasparov. IBM scientists have taken pains to emphasize that Deep Blue is just a glorified calculator. Whether a machine like Deep Blue, which combines lightning-fast search power with a large database of knowledge, can be said to 'think intelligently' depends on one's philosophical inclinations. From the perspective of a Turing test - Deep Blue could be construed to be intelligent. But the methods and techniques used in playing the game of chess by Kasparov and by Deep Blue were far from being similar.

Deep Blue utilized brute computational methods involving symbolic storage and matching algorithms. It could manipulate a given input, from the move made by Kasparov, and suggest an output which was then transmitted to the game. Kasparov on the other hand recognized a move on the board, and arrived at the next move based on experience, abstracted and short-cut techniques, and other pre-planned moves.

How do we define intelligence and how can we decide who or what has it? This remains among science's unsolved and possibly unsolvable, problems. The model and the methods applied by Kasparov significantly differ from the techniques used by Deep Blue. What are those? Are they made up of big blocks of intelligent capabilities or are they made up of simpler elements collectively reflecting higher order capability?

We believe that cognition, as well as intelligence, is a result of a bottom-up constructivist model in which a core set of capabilities are integrated into different models so as to achieve higher cognitive capabilities. A simple analogy is the use of Boolean primitive constructs (AND, OR, and NOT) to create higher order artifacts and circuits, and ultimately a microprocessor. An enormous amount of effort by a generation of engineers and scientists has contributed to this technological marvel. So also, we believe that a versatile and capable intelligent machine can be built only from ground-up using core cognitive primitives – implementable using current or newer technologies.

Cognition, and learning, occurs in two modes. Incidental cognition, and learning, is an involuntary phenomenon where, through innate ability, an organism involuntarily receives input and assimilates this information. When we passively listen to a song and are then able to recognize it later - we have undergone incidental cognition. Incidental cognition might occur numerous times. Significant amount of cognition occurs this way throughout the life of an organism.

Intentional cognition is a process consciously applied involving input and a deliberated output for verification and authentication. Repetitive with corrective action is typical in intentional cognition. When we learn to write a letter or symbol or learn to play catch we employ intentional cognition. In either case the cognitive process is incremental in nature. One recognizes a piece of a song after having recognized, multiple times, smaller parts of that song. Finally the entire song is recognized as an aggregation of the smaller pieces. Cognition utilizes the ability of recognize 'known' elements and its 'presence' in a larger context.

We propose a hierarchy of cognitive capabilities that can be utilized constructively to develop higher order capabilities. These primitives do not define a complete set needed for constructing intelligent systems. But any system that needs to be constructed should be based on capabilities, constructed using the primitives, pertinent to the intended domain.

### **3. Cognitive Primitives**

We propose generic mnemonic or cognitive capabilities. Hierarchical, inclusion of and use of these primitives pertinent to different domains can enable systems/organisms to imbibe and recognize elements from its input.

Definition 1: An element or item,  $i$ , is an input that is aural, visual, or physical.

Repeated input of the item to the system results in the system imbibing it. The number of repetition can be system specific and once a threshold number of repetition occurs, the item is assimilated for further use. An input is recognized if it matches an already assimilated item matched by a process of decomposition. Once an item has been abstracted (imbibed) into the consciousness (or knowledge base) of a system, subsequent recognition of this item is atomic.

Definition 2: A component,  $c$ , is a composition of atomically recognizable elements.

Input to the system can be a complex combination or steam of elements. Recognition of such complex input is a result of recognition of its elements and their combinations.

Definition 3: The granularity of a component  $c$ ,  $g(c)$ , is the number of elements used in recognizing it through decomposition to match known elements.

Definition 4: The size of a component  $c$ ,  $z(c)$ , is the minimum granularity of  $c$  in recognizing it.

Definition 5: The expressiveness of a component  $c$ ,  $x(c)$ , is the set of elements used in recognizing it.

Definition 6: The shape of a component,  $c$ , is the minimum  $x(c)$  of  $c$ , and is denoted  $s(c)$ .

Definition 7: Two components,  $C1$  and  $C2$ , are said to be balanced iff  $s(C1) = s(C2)$ .

Definition 8: Two components,  $C1$  and  $C2$ , are said to be discordant iff.  $s(C1) \neq s(C2)$  and  $s(C1) \cap s(C2) \neq \{\}$ .

Definition 9: Two components,  $C1$  and  $C2$ , are said to be distinct iff  $s(C1) \cap s(C2) = \{\}$ .

We first propose primitives that enable a system to recognize elements and recognize simple organization of known elements.

Primitive 1 - Existential (E): The ability to be cognizant of the existence of an item.

Primitive 2 - Structured Recurrence (SR): The ability to recognize a simple recurrence of an item.

Primitive 3 - Relative Attachment (RA): The ability to recognize relative juxtaposition of two items.

**E**( $i$ ) implies an atomic cognition of  $i$  using **E**. **SR**( $i$ ) implies the atomic cognition of a cogent recurrence of  $i$ . For aural input the recurrences are beat synchronized recurrence. For visual input the recurrences are simple spatial adjacencies.

**RA**( $i, \mathbf{rj}, j$ ) implies the recognition that items  $i$  and  $j$  are placed per **rj** - a specified order of connection or join. For aural inputs **rj** is a specific time ordered sequencing. For visual input it can be a specific relative spatial placement of the items.

**E, SR, and RA** are fundamental primitives that recognize inputs based on elements that are atomically recognized without resorting to partitioning of input into various components.

When input is complex then these can possibly be recognized as an arrangement of components that can be recognized individually. Components may be a result of simple or complex combinations. Primitives or recognizing the combinations are proposed as.

Primitive 4 - Harmonized Counterparts (HC): The ability to recognize associated balanced components.

Primitive 5 - Cordial Counterparts (CC): The ability to recognize associated cordial components.

Primitive 6 - Discriminate Counterparts (DC): The ability to divide and recognize two distinct components.

**HC, CC, and DC** are primitives that enable the recognition by dividing input into one or more recognizable components. These primitives assist in partitioning the input such that the commonality among the components is distinguished.

#### 4. Capable Systems with Intelligence

A system capable only with **E** can only recognize the existence or absence of an item. A system capable of **E** and **SR** can recognize simple recurrence of a known item. Thus it could have the ability to recognize a linear arrangement of visual element or a chronological repetition of a note. Thus this system possesses a

higher level of cognitive capacity. Systems that are additionally capable of **RJ** recognize the placement of two known items in distinctive relative position. Thus, for visual input it may recognize two inputs conjoined end to end, or top to bottom, co-centric, or some other distinctive arrangement. For aural inputs it could be one element before other, played simultaneously, or some time delayed occurrence.

**HC** is a capability that helps a system to quickly identify components composed of identical elements. This represents a capacity to drive recognition of components that are possibly balanced or identical. **CC** enables a system to identify components that are similar but does note differences. These differences are meaningful distinguishing characteristics. **DC** assists the system to partition input into smaller components to enable easier recognition. This process helps cognition by a process of divide-and-conquer.

The following table shows a possible set of types of Learning Systems (**LS**) based on a hierarchical set of capabilities they possess.

Learning System	Enabled Capabilities
<b>LS(I)</b>	{E, SR, RA}
<b>LS(II)</b>	{E,SR,RA, HC}
<b>LS(III)</b>	{E,SR,RA, HC, CC}
<b>LS(IV)</b>	{E,SR,RA, HC, DC}

## 5. Conclusion

We have proposed and defined fundamental mnemonic capabilities applicable for cognition. Mnemonic capabilities enable a system/organism to atomically match input with learned knowledge. The ability to record experiences as part of its history and the ability to abstract/imbibe knowledge from this history of experience are also fundamental to a cognitive system. Using these capabilities learning systems are proposed that are capable of various degrees of cognition. A constructivist approach forms the guiding principle for our paper. Based on these we have developed mnemonics for aural perception in [2] and for visual perception in [3].

## 6. Current and Future work

We have constructed a music formulating (COMPOSE) systems based on the capabilities customized for aural cognition [4]. This system enables a naïve formulation of symphony using simple combination of primitives developed in [2]. Survey on the use of these capabilities, have shown the affinity and use of these musical structures [5]. A theory on natural language formulation is presented in [6] that utilize aural mnemonics. Similar studies using proposed visual mnemonics will be undertaken and the results of which subsequently used in simple recognition software. We will be developing systems that can be used to test these primitives for visual cognition.

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