The Cognitive Architecture of the Human Mind

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Abstract - *The Cognitive Architecture is the initial stage in building a new type of cognitive system based on human memory called The Cognitive Database (CDB). In human cognition, human memory is the central component of human intelligence. In the computer model of cognition, all of human memory is labeled as Total Memory (TM). The basic structural element of TM is a memory node (MemNo). MemNos are defined along with a set of operations intrinsic to the creation, retrieval, update, and deletion of MemNos. In addition to covering memory, The Cognitive Architecture covers these areas: major components of a cognitive system, recursion, automaticity of association, control routine, abstraction rules, and distance measure to stop the recursion*.

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1 Introduction

The Cognitive Architecture is a blueprint for implementing The Cognitive Database (CDB). A CDB is a new type of cognitive system based on human cognition. The word *cognitive* comes from psychology, referencing the mental processes of the mind. The word *database* comes from computer science and is the general term for a collection of data. The creation of any intelligence, whether human, humanlike, or artificial, is highly desirable. Our interests are *not* focused on building a human, but on modeling human cognition at a higher level. Understand how difficult and complex of a task this is. We are trying to architect a system that can invent set theory, a system that can move from set theory to fuzzy set theory. We must accommodate the theories of medicine, economics, artificial intelligence, manufacturing and every other field of human endeavor. The first and foremost part of the system that needs to be identified is the basic element of cognition. From there, the basic elements can be combined into ever higher level structures.

2 The basic element of cognition

The basic element of cognition is a memory node (MemNo). The parts of a MemNo are themselves other MemNos. With this recursion, the information represented by a MemNo may be anything from the most basic physiological state (e.g., "I am thirsty") to a complex and deeply recursive concept (e.g., the very question of asking the brain how the brain functions).

2.1 Memory Nodes

MemNos are of many types, as all conscious aspects of human existence are represented therein. There are five types of MemNos: Sensory, Motor, Cognitive, Object and Relationship. (PST).

- Sensory MemNos are the summation of a collection of sensory experiences into a concept (sight, hearing, touch, taste, smell, balance, thirst, hunger, and so on; for example, input from the eye recognized as the concept "blue").
- Motor MemNos are the summation of a collection of commands that drive the physical effectors of the human experience into a concept (muscle movement in all its forms; for example, output of moving the hand back and forth recognized as "wave").
- Cognitive MemNos are the summation of a collection of cognitive tasks into a concept (decide, choose, think, remember, and so on; for example, the cognitive task of looking through a set of alternatives and selecting one recognized as "choose").
- Object MemNos are the summation of an unordered collection of MemNos into a concept (generalization and abstraction of objects: for example, the unordered concepts of "furry-1," "tail-3," and so on are recognized as defining the concept "dog-2").
- Relationship MemNos are the summation of an ordered collection of MemNos into a concept (relationships that are verbal, prepositional, and so forth; for example, the concepts of MemNos "drink-4," "man-2," "shake-2" are recognized as the concept "man-drinks-shake").

2.2 Memory Node operations

A set of operations are intrinsic to the operation of MemNos. As one might expect from ordinary database operations, the four CRUD operations are critical to MemNos: create, retrieve, update, and delete operations. The precise mechanism for the operations of MemNos will be described in another paper.

As seen in the functional notation on the following page, when any of the operations are applied to a set of MemNos (M_i), the result will be a new MemNo.

$$M_{new} = \text{operation}\ (M_a, M_b, \ldots) \tag{1}$$

The arguments are MemNos and the operations result in new MemNos. This property of MemNo operations is important because the operations that compare words can compare higher-level elements, such as concepts, through recursion. For example, the type of process that recognizes a wheel on a car can, through recursion, recognize the hood of the car, and recognizes the car itself. Only the content of the process changes, not the process itself.

2.3 Total Memory

In the computer model of human cognition, human memory (labeled as Total Memory, TM) is the central component of human intelligence. TM is composed of all memory subsystems including: short term memory (STM, our working memory), episodic memory (EM, our life history), and abstracted memory (AM, our mental models).

$$TM = STM \times EM \times AM \quad (2)$$

STM is the portion of human memory that models the current moment of experience. And, as that current moment passes, some partial copy is transferred into EM. As processing time permits, the experiences of EM are generalized into AM. Note that all parts of TM hold nothing more than MemNos – the recursive structural element of human cognition.

3 The Cognitive Architecture

Observe the diagram of The Cognitive Architecture in Fig. 1. The diagram shows the major components of a CDB. The architectural diagram and description helps implement the CDB.

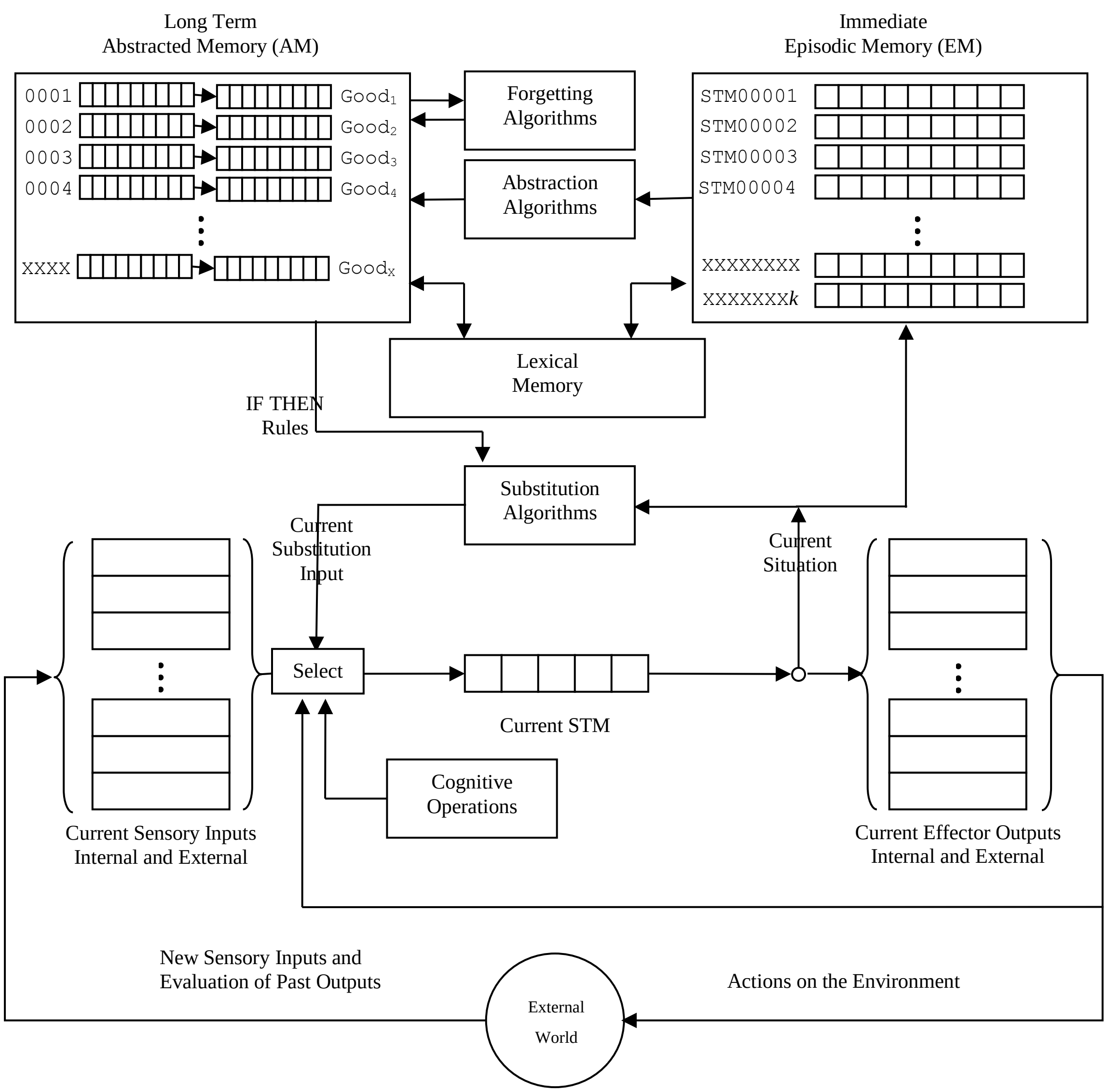

Fig. 1. The Cognitive Architecture

3.1 Components

1) Sensors: Sensory inputs are the ingredients out of which intelligence is created. Books, websites, cameras, and microphones are sources of output in the external world. Text, images, and sounds are the outputs from these sources. As shown in Fig. 1, a cognitive system has external sensors (e.g., eyes, ears, sense of touch, web input sensor, etc.) sensing external outputs and bringing them into the system's internal world as external inputs. Similarly, a cognitive system has internal sensors (e.g., memory system, hunger sensor, sense of balance, sex-drive sensor, etc.) sensing internal inputs.

2) Short Term Memory: Current STM is located in the center of Fig. 1. It holds what is currently happening to the cognitive system. In the nearby box labeled "select" are selectors that select what sensors have their inputs posted to the current STM. The current inputs selected pass through STM into EM.

3) Episodic Memory: The large box located at the top right of Fig. 1 is immediate EM, which is everything that ever happened to the cognitive system. EM records everything that ever happened in STM. EM has the same basic structure as STM, except there are k rows instead of one.

4) Abstracted Memory: The large box in the upper left corner of Fig. 1. is long term AM. It is the abstraction or generalization space. The nearby abstraction algorithms transform EM into AM. AM is constantly rewriting or changing current STM. The neighboring forgetting algorithms are where forgetting routines take place. The structure of AM is similar to EM except its rows are more tightly compressed. A goodness measure is attached to each abstraction row indicating how useful the abstraction is to the system.

5) Lexical Memory: Shown in the high center of Fig. 1 is a lexical memory or vocabulary (V = 1997, 1998, 350 v8, a, aardvark, aardvarks, abandon, …, zoos), with usage to understand sensory inputs, which are the elemental values of information in the CDB. V is a language relational database for attaching syntax to a word sensed by a web input sensor.

6) Automaticity: In the center of Fig. 1 are the automaticity rules or substitution algorithms, which automatically rewrite current STM. For example, when a CDB senses a "dog," it automatically thinks "dog," and then thinks "cat," then "leash," and then thinks "bark," and so on. In this way, it seems more human. The more humanlike we create the CDB, the more intelligent the system will appear.

7) Control Routine: The box near the bottom center of Fig. 1, within the cognitive operations box, is the main executive (ME). This is the top-level manager. For instance, ME is on a similar level as the Microsoft Excel application; anything dealing with the whole CDB goes here. Algorithms of the brain are not easily organized, because the order is not fixed. The order is more dynamic. ME is the control routine which decides when to execute what algorithms. For example, when to run the performance algorithm (PA), abstraction algorithms (AA), forgetting algorithms, or when to chunk MemNos together, etc. Sensors are a good place for ME to start because they bring input into the senses.

8) Effectors: CDB changes the external world by issuing commands to its external effectors (move robotic arm; flip on sensors/effectors, etc.). CDB also changes its internal world by issuing commands to its internal effectors (abstract, introspect, reflect, search, etc.).

3.2 Memory Algorithms

1) Performance Algorithm: The performance algorithm (PA) is where the CDB spends most of its time. It performs, senses, introspects, and it self-reflects. While the CDB is performing, AM is always trying to rewrite EM with rewrite rules, as can be seen in steps of the PA pseudo code:

```
Loop over lifetime.
    Get all inputs from sensors.
    Select new STM based on selection operation.
    Move selected new STM into current STM.
    Do any rewrite rules suggest a way to rewrite the
    current moment of STM?
        Yes, create new STM with rewritten content.
        No, continue.
    Loop back to get all inputs from sensors.
```

2) The Abstraction Algorithm: Sensory input comes into the brain faster than can be processed, so at night when we sleep (offline), we dream and try to organize inputs by integrating or connecting things. Down time is when abstracted seTs (T) and abstracted seQuences (Q) are most easily created and changed. The four transformational rules from transformational grammar (insertion, deletion, substitution, and movement) [1] are applied in a different way that we call grammatical abstraction. There are a set of three rules: {INS/DEL, SUB, MOV}. The INS and DEL rules can be seen as the same rule. The initial abstraction algorithm (AA_1), given in pseudo code, processes through the episodes of life in EM and creates useful abstractions in AM:

```
foreach Episode P in EM do
    for i = 1 to (# Experiences in P) - 1 do
        for j = (i + 1) to (# Experiences in P) do
            Experience X1 = P[i];
            Experience X2 = P[j];
            ABSTRACT1 (X1, X2);

ABSTRACT1 (Experience X1, Experience X2)
    if IS_SUB (X1, X2)
        SUB (X1, X2)
    if IS_INS (X1, X2)
        INS (X1, X2)
    if IS_MOV (X1, X2)
        MOV (X1, X2)
```

Of course, pseudo code cannot capture the true complexity of the process. For example, the IS_SUB predicate checks to see if two experiences are identical in form except for one position where they each have a different MemNo. If X_1 and X_2 do differ only in this one way, a potential object MemNo (T) is created along with a tentative relation MemNo (Q). For a more concrete example, if X_1 = "*the dog*" and X_2 = "*the cat*," then IS_SUB is true, and the sub action proceeds. The word *the* is the same on the left sides of both sentences, so a new sequence can be created, $Q_1 = \langle \text{the} \rangle$. Then, the words at the substitution position, *dog* and *cat*, are added to a new set, T_1 = {dog, cat}, and then added to $Q_1 = \langle \text{the } \{\text{dog, cat}\} \rangle$, resulting in $Q_1 = \langle \text{the } T_1 \rangle$. This means *the* can be followed by either *dog* or *cat*. The other rules have similar logic to the sub rule.

4 Learning meaning

Meaning is sensory elements being integrated and correlated among the senses. For instance, you have pictures of water, sounds of water, the taste of water, the feeling of water, the cold temperature of water, a thirst for water, and the word *water*. The association of a word to its senses becomes its meaning. The "water" MemNo points to everything about water. "Water" points to "drink," "splash," "float," "swim," "wash," and so on. Each MemNo in turn points back to "water," such as "drink" points back to "water", and it also points to "cold water". The mind is optimized for efficiency, so we only stores about 10 maximum items about "water" in current STM.

From all these inputs coming into the system at the same time, the brain has to figure what is meaningful to connect together. The whole point is to live more intelligently by finding patterns in the operation of the universe and predicting what will come next, and then rewarding correct predictions. For example, if a lion roars and eats your friend, you had better start realizing when you hear a roar, you should start running.

4.1 Thought Experiment

An attempt to learn the meaning of a sentence can now be illustrated with an example. Imagine the first experience that a CDB has is X_1 = "*the man drank the shake*." The CDB processes X_1 and creates four new sensory MemNos: S_1 = "the," S_2 = "man," S_3 = "drank" and S_4 = "shake," as well as one new relational MemNo: $R_1 = \langle S_1, S_2, S_3, S_1, S_4 \rangle$. The utility of the new MemNos are all initialized to 1.

When the CDB next processes experience X_2 as "*the man drank the water*," S_5 = "water" is created as well as $R_2 = \langle S_1, S_2, S_3, S_1, S_5 \rangle$. Applying the AA_1 to these two experiences in the episode creates one new object MemNo, T_1 = {shake, water}, and one new relation MemNo, $Q_1 = \langle \text{the man drank the } T_1 \rangle$.

As one might expect, the complex building of concepts is quite epiphenomenal, depending upon the exact sequence of experiences of the system.

4.2 Distance measure

Eventually, after experiencing many such sentences, the CDB will have formed a network of MemNos in STM. In order to stop the recursion from possibly activating more information than is useful, such as having the "dog" MemNo, followed by the "cat" MemNo, the "leash" MemNo, the "wolf" MemNo, and so on all the way to the "computer" MemNo. Therefore, the distance has to be considered and limited. An analogy of the process is the cells on the human retina. Two cells on the retina have similar experiences if they are next to each other in space. Cells further away from the points of contact have weaker associations. This is a universal principal of our universe, *not* only of humanity. The bound of the distance measure is a maximum of 10 MemNos from the source, a minium of zero MemNos, and normally activates within a distance of five MemNos. If something is more than five MemNos away, it is ignored, unless the goals or drives are great enough to throw an exception to explore up to 10 MemNos away from the MemNo being considered. Words use context to disambiguate meanings, exploiting that nearby words have closely related meanings.

5 Conclusions

The Cognitive Architecture and the CDB are evolving works. In the tradition of AI, the model is defined, and then its implications are observed in implementation. As Hawkins has observed [2], intelligence is largely held in the human memory system. This paper lays out the beginnings of The Cognitive Architecture to define human memory and the design of the Cognitive Data Base (CDB) to model human intelligence.

6 References

[1] Noam Chomsky. "Aspects of the Theory of Syntax." MIT Press, 1986.

[2] Jeff Hawkings and Subutai Ahmad. "Hierarchical Temporal Memory Including HTM Cortical Learning Algorithms." Groksolutions.com.