Indefinite Integrator

By

Amit Sasturkar
99005037
amit

Sarvjeet Singh
99005029
sarvjeet

under the guidance of
Prof. S. Arunkumar

Course : CS293
Year: 2000-2001
Sem: 3

Introduction

There are mainly two approaches to write a program – either we enumerate all the steps involved in accomplishing a particular task or we can give the basic framework required to learn new things. While the first approach is much simpler most of the times, the domain in which it can solve problems is limited. In the second approach even very difficult tasks involving intelligent decisions can be successfully completed.

Our project is on Artificial Intelligence. Our aim is to show that a machine can learn and is capable of making intelligent decisions. For this we have chosen Indefinite Integration as domain of learning. The main idea behind learning any task can be shown by making it learn integration. Integration involves making decisions based on abstract properties of the integrand.

This “idea” of learning can be successfully applied to many industry related problems. Currently many large-scale industries are using robots etc. to automate tasks such as painting in automobile industry. But if the task is changed a bit it is very difficult to make the robot adapt to the new task. Using adaptive learning techniques it can be programmed to learn things in a specific domain and it can be taught any new task in that domain.

Humans are the best “*programmed machines*” known. We have great ability to adapt to a multitude of situations. If the inner workings of human brain are understood and same techniques are applied to construct expert systems then we can expect them to be capable of highly intelligent behavior with application across various domains.

Implementation and Design Theory

Language of Implementation: C++ - which is an object-oriented language so the program can be easily extended.

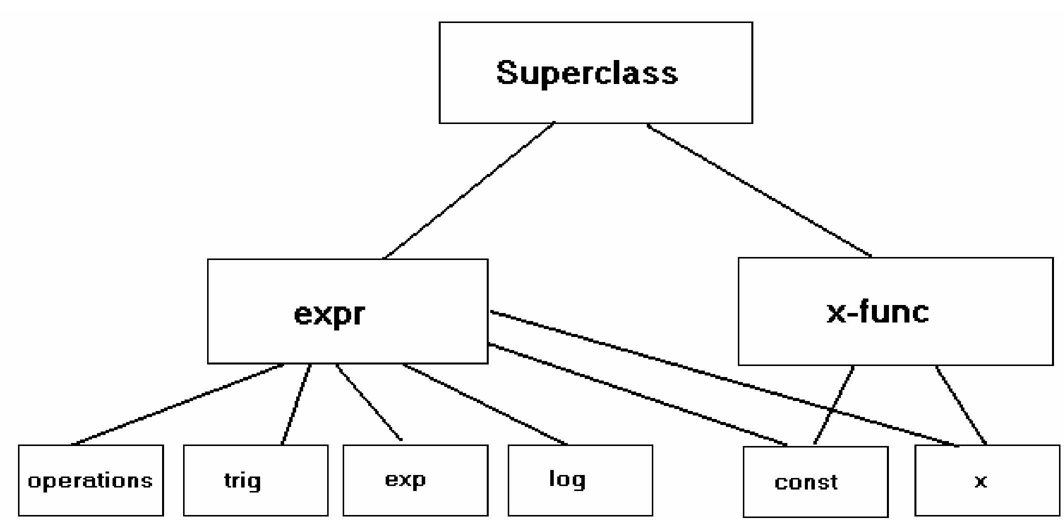
Main Components of the program:

Expression Class:

In C++ there is no support of symbol manipulation. Hence we have implemented this class. This class provides the basic functions required for symbolic representation of expressions and their manipulations.

Every expression is an instance of the expression class and it consists in turn of several other expressions. Thus every expression is a hierarchical representation of classes.

Hierarchy of classes:



Pattern matching

To make abstract decisions an interface was needed to extract the properties of expression. Our pattern matching algorithm accepts patterns of the form F(x) F(sinx) etc. and reports for two patterns p_1 and p_2

1. p_1 and p_2 match exactly. Example : x+Sin(x) and Sin(x)+x
2. p_1 and p_2 are disjoint. Example: Sin(x) and Cos(Sinx)
3. p_1 is subset of p_2 . Example : Sin(Cos(x)) and F(Cosx)

4. p_1 is superset of p_2. Example: $F(x^2)$ and $F(x)$

Rule representation

For representation and learning of new rules, rules are represented in the form of a rule tree. Rule tree abstracts the procedures for adding and applying new rules. It uses the pattern-matching algorithm. Each node contains pattern and the manipulation to be applied. It also has a probability associated with it that determines it applicability in comparison to other rules at the same level. Depending on the kind of matching that occurs a new rule is added in the proper place in the rule tree. For any node in the tree, all its children are its subsets and its parent is its superset. Manipulations are not limited and can be further added in the code. After adding a new manipulation rule-tree can be made aware of how to call it and its requirements.

Achievements

1. We have made a very general framework for creating a learning integrator.
2. Our implementation of pattern matching and rule tree is highly extensible.
3. We have provided a uniform interface for adding rules that is independent of rule being added.
4. We have provided a server side web interface. It minimizes the time required for computation and reporting. Also other servers can directly "ask" our web server for specific integrals without *manually* loading the web page and giving the integrand.

Shortcomings

1. We have not programmed the integrator to learn mathematical concepts.
2. We haven't implemented the functions to make the integrator learn tricks of integration. But we have made all the functions (pattern-matching etc.) required for this purpose except a few which require a lot of mathematical juggling.

Scope for future work

1. Learning by example: The integrator can be extended to identify recurring patterns and extract a suitable rule and add it to rule tree.
2. Domain Knowledge: The integrator can be given domain knowledge and can hence be converted to an expert system.
3. Error correction by feedback: If the integrator gives an erroneous answer the user can guide it to the right answer and it will accordingly modify its rule-tree.
4. User levels: User levels can be provided so that a user does not unknowingly corrupts its knowledge base by giving it wrong rules
5. Forgetting: If in the course of time the probability of a rule decreases below a threshold level the rule can be removed.

References

Books

1. Ford,Nigel - How machines think: a general introduction to artificial intelligence; John Wiley, Chichester, 1987.
2. Russel, Stuart, Norvig, Peter; Artificial intelligence: a modern approach; Englewood Cliffs: Prentice Hall Intl., 1995
3. Holland, John H.; Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control and artificial intelligence; Cambridge: MIT Press, 1992

Web references

1. http://www.cs.berkeley.edu/~russell/ai.html - AI on the Web
2. http://www.geocities.com/mentifex/theory1.html - Mind theory
3. http://nabil.vuse.vanderbilt.edu/nabil/Adaptive_Learning.htm - Adaptive Learning Environments
4. http://www.geocities.com/mentifex/theory5.html - Know Thyself!

Some commercial integration softwares available on the web

1. http://www.wolfram.com/
2. http://www.can.nl/Systems_and_Packages/Per_Purpose/General/AXIOM/
3. http://www.rrz.uni-koeln.de/REDUCE/

Know Thyself!

Know Thyself: The Mentifex Design for Artificial Intelligence

(1981)

Standard Technical Report Number: MENTIFEX/AI-5

by Arthur T. Murray

(Not copyrighted; please distribute freely.)

Once we know all there is to know about the workings of the human brain, we will have a choice of several obvious approaches to the task of teaching students the essential workings of the mind. We could teach about the brain-mind in terms of how it evolved through the eons, or how it develops in the life of the individual, or how it functions in a mature specimen.

This article presents the author's model of the workings of the brain-mind, not in terms of sweeping generalizations but on the ultimate and unambiguous level of the switching-circuit logic of nerve cells. You are invited to comprehend this mind-model - to refute it if it is erroneous, or, if it makes sense to you, to use it in fulfilling the ancient imperative, "Know thyself!" Either way, you the sovereign mind are offered something to react against, and possibly a revelation of your inmost mental nature.

Of three obvious approaches to explaining the mind inside the brain - evolution, individual development, and static functioning in maturity – this author chooses the third route and seeks to describe your mature mind as you read and comprehend this article.

The other two approaches - evolution of the mind in the species, development of mind in the specimen - would inherently contain directions for the starting-place and the order of presentation of all essential details about the brain-mind. In both cases, we would simply describe how a single-cell creature turned into a brain of one hundred billion cells.

But let's take the hundred billion cells and find an obvious point of departure for describing a model of the organization and function of that purposive web of cells, the brain. Let us approach the function of the evolved, mature mind from the obvious starting-point of sensory inputs into the mind.

This article leads you through a functional model of the brain-mind. Although the brain is perhaps the most complex structure on earth, it is no more than a three-dimensional arrangement of flows of information. The information-flows are arranged in such a way as to achieve consciousness and thought.

Each flow of information is along one of the dimensions of the mind. If you are to comprehend this mind-model, you must understand each dimension and also the very concept of dimensionality. The dimensions play a double role in this article: firstly as the building-blocks of the mind for you to comprehend both one by one and as a grand edifice, and secondly as the chief arguments to convince you of the validity of the mind-model.

Dimensionality is the quality of being dimensional, of having dimensions. The mind is not a seething lump like an anthill, but a strictly dimensional structure. Although the brain is curved and convoluted, the mind inside the brain is rigidly straight (like a taut string or a beam of light) in all its dimensions, and orthogonal through ninety degrees wherever the information in one dimension changes its direction of flow into another dimension.

Although the mind exists within the brain, the mind is not a material, physical being. The mind is a structure composed purely of information. The physical structure of the brain determines the informational structure of the mind, but these two structures are not identical. Put it this way: The brain holds information, and information holds the mind. The brain is organized physically, but the mind is organized logically.

The dimensionality of the mind is crucial to its logical structure. In some parts of the mind, information must be kept apart, while in other parts of the mind information must flow together. The dimensions of the mind serve the purposes of isolating and combining information.

The first dimensional component of your mind is the straight and linear record of its sensory input, in parallel with the straight and linear "keyboard" of its motor output. Please examine the "mind-diagram" appearing with this article.

A polarity exists between the mind and its environment. An environment to develop in is just as essential to the mind as a brain to exist in.

A second polarity exists between our sensory perception of the environment and our motor manipulation of the environment.

These two polarities - organism/environment and sensory/motor - constitute sufficient logical differentiation for the genesis of an informational loop.

Your mind sits at one end of the loop and contemplates your environment at the other end of the loop. Your environment is the whole cosmos, including your body, brain, and mind. Your mind starts out as tabula rasa, "a clean slate." As your mind develops and fills with knowledge, it tries to mirror internally the cosmos which it perceives externally. Who can say which is the agent - the cosmos organizing minds, or mind organizing the cosmos?

Your mind starts out as an empty, but vastly capacious, link in the loop. Information starts in the environment and flows in one direction through the loop: through your senses into the mind, and from your mind out through the motor nerves to the environment.

It takes a while for your neonatal pathways - sensory and motor - to communicate internally and thus to close the loop with the environment. The sensory and motor pathways develop in parallel along the temporal dimension of the mind.

Although your mind is constantly thinking and acting in the present, its existence stretches off into the past. Every thought which you think in the present, shapes your mind for the future. Your mind is the sum of all its past reality.

It is critical to your comprehension of this mind-model that you think of the sensory and motor pathways as flowing in parallel, but in opposite directions, along the temporal dimension of the mind. When we go on now to examine in detail the sensory-input system, you must keep in mind that the sensory and motor systems develop and operate side by side in lock-step fashion.

A human brain has the five commonly acknowledged senses of vision, audition (hearing), the tactile sense (touch), gustation (taste), and olfaction (smell), plus a few other senses such as the sense of balance and the somesthetic sense.

According to this mind-model, all the senses feed into the mind in parallel in a flat array like a woven rug. For each sense, be it vision or audition or smelling the flowers, there is a flat channel of perception and memory flowing along the time-dimension of the mind.

The nerves from the sense-receptors travel to the brain. Inside the brain, the sensory information from vision, and perhaps other senses, undergoes the pre-processing of feature-extraction before it enters the mind. In feature-extraction, basic patterns are discriminated to reduce the work-load and hasten the operation of the conscious mind. In the brain there operates a principle of rendering automatic (and subconscious) as many things as possible.

After the information in any one sensory pathway has reached the brain and gone through all required feature-extraction, the information enters the mind by entering the permanent memory channel for that particular sensory modality. Short-term memory and permanent memory are identical in terms of physical location, but they differ with respect to the associative processes which catalog the memory-traces and control their future accessability through recall. In other words, short-term memory is not a function of location, but rather of associativity. This assertion is supported better by the large-scale mind-model than by any local arguments which may appear in this topical discussion of memory.

The distinction between preliminary portions of the brain and the mind itself is based upon a functional demarcation line beyond which information is free to flow not just along its original dimension but orthogonally sideways out into other dimensions of the mind. In other words, the mind is circumscribed and defined by its own dimensionality.

It is important that you now comprehend both a specific design for memory and a general concept of memory. It is axiomatic that whatever macroscopic information can be transmitted can also be recorded. To record information during transmission, one simply captures samples of the information at a rate quick enough to catch all instances of significant change in the information.

The brain-mind records the informational content of each sensory channel by routing the information through what is both a transmission channel and an extremely long series of engram-nodes. Once each sensory information-flow passes the demarcation-line into the mind, the information in each sensory channel floods the transmission "fibers" of that permanent memory channel. Each fiber in the memory channel is like a series of millions of nodes. Within the particular memory channel for each sense, there are thousands of the nodal fibers. Your oldest memories were deposited and permanently, unchangeably fixed in the first nodes of the lifetime-long memory channels. At each moment of sensation and perception, all the simultaneously occupied nodes among all the memory fibers of each memory channel irrevocably fix their contents. The group of nodes fixed on parallel fibers at one moment in time is like a "slice" of memory of that moment in time.

You start out with your sensory nerves and pathways going through any required feature-extraction and then feeding into immensely long channels of tabula rasa memory. Your myriad moments of experience are deposited in densely packed "slices" of and by simultaneity.

Each sensory (and motor) memory channel is like a flat ribbon flowing across the logical surface of the mind. The memory-ribbon is composed of thousands of nodal fibers. The first experiences go into the first nodal slices. Subsequent experiences have to travel through all the slices of previous experience to reach and occupy fresh nodal slices, which will then be filled and fixed with the experience of the moment, before serving as a bridge to all future moments.

Although it is critical for you to understand the essential characteristics of the permanent memory channels in this mind-model, these essential characteristics are not introduced here all at once. Advance notice can be given, however, that each sensory memory channel serves three main purposes, simultaneously and everywhere along the memory channel: transmission, memory, and comparison.

Each sensory memory channel is like a pipeline full of nodal fibers. The nodal fibers are already there, genetically provided and ready to receive engrams of memory. The pipeline is gradually filling up with memory slices all through your lifetime. The memory-slices are so densely packed that you could live to be over a hundred years old and not run out of fresh, unused, tabula rasa memory locations. The gradual fixation or consumption of memory-slices is like a slow burning fuse, so long that it takes over a hundred years to burn to the end. Even if you did run out of fresh memory-spaces in our old age, you would still function as an intelligent mind with full retenion of your many decades of old memories and with the loss of only your ability to remember each passing moment of the present. You could still speak, for instance, several languages and do anything else that you learned to do before your tabula rasa memory ran out. This assertion is another one which ought to be judged in the light of the total mind-model.

The flatness of each memory-channel matters to the brain, but not to the mind. The serial order or arrangement of the nodal fibers does not matter at all. Note that the information recorded in a flat slice of memory is certainly not "flat" information. The flat memory channel for the tactile sense of touch contains a sensory mapping of the whole surface of the body. The flat auditory memory channel contains a mapping of a broad range of frequencies of sound. The flat visual memory channel contains two-diensional images in a one-dimensional series of fiber-nodes. The mind does not know and does not care that the images are flat. When the mind associatively recalls an image-slice, the one-dimensional memory-slice springs to life as if it were the two-dimensional image seen through the eye.

We are really getting into the dimensionality of the mind when we bring in the idea of associativity. Sensory information flows into the mind along the time-dimension, but it moves sideways within the mind along the associative dimension. Every sensory memory slice is attached to a "concrete associative tag" that is like a fiber flowing at a right angle to all the fibers in the flat memory channels of the time-dimension. These concrete associative tag-fibers are not shown in the mind-diagram, because they would completely black out the mind portion of the diagram. They are called "concrete" (as opposed to "abstract") because they coordinate by simultaneity all the sensory memory-slices of "concrete" experience. They are called "associative" because they are the mechanism by which the mind associates a memory-slice in one sensory modality with memory-slices in all other sensory modalities and even in the same sensory modality. For instance, they are the mechanism by which you might associate the sound with the image of a dog, and vice versa.

A single associative tag governs a whole memory-slice and associates it with all the rest of the mind. It may look as though there is a tremendously unworkable ratio of the vast information that can be contained in the slice to the unitary, off-or-on information that can flow over the tag, but it will be argued in this article that the vast information stored in any sensory memory channel flows sideways to the core of the mind solely over aggregates of these unitary, off-or-on "concrete associative tags." In other words, each lifetime-long permanent sensory memory channel is quite isolated unto itself and does not flow at its end into some region of further or final processing of the sensory information. Wherever the sensory memory channel comes to an end, it just stops. Let us hope that the end of our tabula rasa memory channels is so remote that we never reach it in our natural lifetime. (In an artificially intelligent robot we might recirculate the memory channels by looping around and erasing the oldest memory-slices just before reaching the end of the first full loop of the memory-slices.)

Each sensory memory channel is isolated unto itself, except for the associative tags which lead away at right (orthogonal) angles from the time-dimension of the memory channel. Over an associative tag, you can go from one sensory memory channel into the memory channels of all other senses. For instance, you can go from vision to audition, or from olfaction to vision. But you can go only at a right angle; you can not cross directly by associative tag from a present memory-slice to one laid down years or even minutes ago. Each associative fiber that interconnects all the senses is a guarantee of simultaneity. The associative tags are laid down at each successive moment of the fleeting present, and they can never after be disconnected or altered. As the poet says, "The moving finger writes, and having writ moves on."

You must have a thorough comprehension of the sensory and motor plane or "grid" of the mind before you study the two levels of superstructure by which mankind achieves rational intellect. You can maintain that thorough comprehension as we examine the three levels of complexity which are operative at the peak of the human central nervous system. The three levels to be studied are:

1. The sentient plane of the sensory/motor grid. (The interface between the external world and the core of the mind.)
2. The abstract core of the mind. (This core brings a central nervous system to the level attained by "smart" mammals, such as dogs.)
3. The linguistic spiral in the abstract core of the rational mind.

It is important to go level by level so that you see clearly what the mind is capable of at each level and what is still lacking. You should be certain to understand the situation at each lower level before you study a higher level. As with a ladder of evolution, each level makes sense by itself and without reference to any higher level.

So far we have discussed the sensory input part of the sensory/motor grid, which is the flat two-dimensional substratum of the mind. It remains only to explain the role played by the motor-output side of the grid, and then you should have a sufficient comprehension of the first of the three levels of the mind.

Let us call this sensory/motor grid at the lowest level of mind the "sentient grid." If we were to examine an animal or automaton that had only such a "sentient grid" at the summit of its central nervous system, that creature would be severely limited in its capabilities. It would have the power of brute sensation, and its repertoire of motor behaviors might consist of many reflex and instinctual actions which it would be able crudely to link with sensory inputs as triggers for the initiation (or cessation) of motor activity. Now let us examine the motor memory channels, in accordance with the mind-diagram.

The motor memory channels are the polar opposite of the sensory memory channels. The motor memory channels contain memory slices not of external experience, but rather of internal, dynamic activation of themselves. This difference is critical for your understanding of the sentient grid at the bottom level of the mind. Motor memory is not passive, it is dynamic. If you make associative access to a motor memory node on a motor memory fiber, you unavoidably send out a signal to contract a muscle at the destination of the associated motor nerve.

As you examine the mind-diagram, notice that the sensory memory fibers flow in parallel with, but never touch, the motor memory fibers. Yet the sensory side of the mind controls the motor side of the mind. "Concrete associative tag fibers" flow between the sensory and the motor sides of the sentient grid. As was discussed above with reference to the sensory modalities, concrete associative tags flow at a right angle to all the lifelong memory channels. Just as the memory fibers are all in parallel, likewise all the associative tags in the flat sentient grid flow in parallel. By flowing in parallel, the associative tags preserve the historical record of each successive moment in time.

If a central nervous system did not have memory as a record of experience (and as an enabling mechanism for learning), then its sensory nerves would have to lead directly to its motor nerves. No variations of behavior would be possible, and the whole organism would be pre-programmed genetically to respond to stimuli always in the same way.

When evolution introduces memory channels, it is essential to buffer or separate the sensory and motor systems so that they do not fuse together and so that what intercourse occurs can occur with great discrimination and precision. Therefore, the sensory and motor channels do not meet head-on, but rather they attain a close proximity and then flow in parallel. At each successive moment in time and experience, the sensory and motor memory channels have the possibility of becoming linked by nodal fusing at both ends of the particular concrete associative tag fiber which was provided genetically for that moment in time. The whole lifelong tapestry of experience has a fresh, new, blank, concrete associative tag fiber for each moment of experience, like a corduroy road made out of logs.

But just how do the associative cross-tags link up sensory experience with motor dynamism? Why do we call it motor "memory," when no experience is recorded there?

The motor memory channel is like a giant keyboard of a piano. The purpose of the motor memory is not to record events, but to cause them. Or, we could say that the purpose of the motor memory is to cause an event and then remember how to cause it again.

In the infant organism of our sentient being, a mechanism of "random dynamics" permits various motor nerve cells to fire spontaneously. When a motor nerve fiber in the motor memory channel fires, it causes muscle-activation. Then information starts flowing in the sentient loop. While the infant organism randomly moves its limbs, it experiences aspects of that motion through its sensory apparatus leading into its sensory memory channels. At each moment in time during the random motion, nodal fixation at both end-regions of a concrete associative tag fiber is associating passive sensory engrams with dynamic motor engrams. Before long, control of the motor apparatus ceases to be random and spontaneous. Instead, associative control passes over to the sensory side of the sentient grid.

In the mature organism, all motor activation occurs across associative tag connections laid down in the past, and present associative tag connections are made solely for the purpose of re-affirming or updating or strengthening sensory-to-motor connections made in the past.

This immediately previous statement offers an explanation why motor-learning time in infancy is crucial to the development of motor skill. During infancy, the organism has the benefit of the random and spontaneous firing of its motor control elements. The sensory side of the sentient grid seizes upon these random firings and takes control of them. Once a particular pattern of sensory memory has taken associative control of a particular pattern of motor memory, all subsequent uses of that control-loop are recorded and thus re-affirmed by concrete associative tag, and a habit of routine or kill becomes entrenched.

Note that this mind-model offers an explanation for volition, although the explanation is different for each of the three levels of mind. On the level of the sentient grid, and in the absence of any higher superstructure, volition consists of automatic response to the stimulus of a sensory pattern. No leeway is allowed in the response to a given stimulus, but varying stimuli are allowed to elicit varying responses.

Notice something general about this information-loop in which the sensory and motor pathways do not meet but instead launch into a parallel race into the future. Remember, the interior of the mind is trying to mirror the exterior of the environment. Well, just as things are not steadfast and "hardwired" out in the environment, likewise on the inside the associative sentient grid, by flowing through time and allowing all manner of novel associative connections, can be just as varied and changeable internally as the environment is externally. However, an organism with no nervous level higher than the sentient grid is forced to learn unchanging laws from its environment, and such a sentient being is not free to make its own decisions by letting logical data freely interact internally. The sentient organism lacks an abstract core of the mind where the strict bondage of stimulus-response can be broken down on the one hand and goal-directedly built back up again on the other hand.

In other words, if you now comprehend the associative sentient grid which is the lowest of the three levels of mind, you are ready to proceed to the examination of the second level of mind. That is the abstract core which further buffers the sensory and motor memory channels to such a degree that the formerly ironclad and inviolable principle of simultaneity in stimulus-response is overruled in one way but kept intact in another.

The second level of mind is roughly on a par with the central nervous system of dogs or monkeys or horses. Learning and Pavlovian conditioning are possible. The organism can be so "smart" as to impress humans and generate a sense of kinship.

After eons of evolution, when an organism attains the second level, the sentient grid of the first level is still present and operative in the now more evolved organism. The sentient grid neither withers away nor changes significantly in its operation. Indeed, in the literature about brains you will find a generally accepted principle to the effect that lower levels of brains are designed to operate rather independently of higher levels in the event of successive breakdown or impairment starting from the topmost levels. The principle is that the higher level dominates by consistently inhibiting the lower level, so that, if the higher level is damaged or removed, the lower level is no longer inhibited and functions in a role perhaps of inadequacy but certainly of the best coping ability that the impaired brain has to offer.

The second level of the mind-model is that of the abstract core of the mind. If this second level seems ridiculously simple to you, wait until we fashion from it earth's most complex mechanism on the third level. But you are correct if you deem simple the innovation worked upon the sentient grid to raise it to the second level. The innovation is so simple that perhaps you will now deign to consider how easily evolution (which "does not make a leap") could have stumbled upon the wonderful innovation.

In the sentient grid of level one, there are two massive neuronal flows at right angles to each other. The one massive flow is that of the permanent memory channels, both sensory and motor. These memory channels flow along the time-dimension of the grid. The other massive flow is that of the concrete associative tag fibers which cover in blanket fashion all the memory channels so as to provide their only internal avenue of connection. Every associative tag fiber is at a right angle to whatever memory fiber it touches. A memory fiber flows through the time-dimension, but an associative fiber is frozen at, and indeed represents, a particular, concrete moment in the lifetime of the organism.

The innovation in the second level - the tiny step in evolution - involves the lifetime-long memory fibers that flow along the time-dimension. On the merely sentient level, these fibers are supposed to contain either sensory or motor memory, because they are connected either to sensory input or motor output. In a level-one system, all memory fibers are "dedicated" - either to sensation or to motor activation - and since the fibers are not free, the level-one organism is not free. If evolution had never progressed beyond level one, we humans might still be starfish or barnacles. But the step or stumble among the dedicated memory fibers was unavoidably, beckoningly easy to make, and somehow somewhere long ago in the primordial eons the great escape was made and they got loose! Some of the supposedly dedicated memory fibers got away from their origin as elongations of the pathways to the external world. Getting loose from the external world, they became creatures of the internal world - and rational mind was on its way.

The mind-diagram of this article is actually more descriptive of level two than of level one or three. Note the central core of time-dimensional memory fibers which are not attached and not dedicated to either the sensory or motor side of the brain-grid. Since these memory fibers at the core of the mind are unattached and undedicated, we call them "abstract" fibers.

Once evolution stumbled and let loose of a few of the lifelong memory fibers, these formerly dedicated, now abstract fibers turned around and took over the course of evolution. As the embodiment of the negentropic principle, they became an "abstract" vault of the mind and an ordering force. They set about creating internal order within the mind. On level two they passively accepted order from without, and next on level three they will actively impose order from within.

Throughout this article, the term "abstract fiber" refers only to fibers in the abstract core of the mind. The term "concrete fiber" refers only to the associative tag fibers which lie at right angles to the time-dimension of both the abstract and the experiential fibers. So there are three types of fibers in this mind-model: experiential (sensory or motor), abstract, and concrete.

When the abstract fibers got loose from their dedication, they did not lose their ability to store memories within their nodes that lie along each fiber like a chain of beads. They lost neither their orthogonal juxtaposition to the concrete associative fibers nor their ability to fuse nodes and thus be tagged by the associative fibers. Since they no longer had any direct source of memory data, either sensory or motor, the abstract fibers could henceforth be filled with memory-data only by receiving inputs sideway from the concrete associative tags, and that indirect, abstract function is what they fulfill even to this day. An abstract fiber in the core of the mind serves associatively as a unifying fiber which crosses all time-boundaries and interconnects potentially all original and re-occurring instances of the experience of a particular pattern of perception. A sensory memory fiber is for sensation; an abstract memory fiber is for perception.

In order to understand how an abstract memory fiber works, you must keep in mind the two-fold mechanism of original association and subsequent reaffirmation. The original, neonatal sensory inputs to level two of the mind flow first directly into memory nodes in the sensory memory channel and thence indirectly, associatively, via the concrete associative tags, into memory nodes in the abstract memory channel. In a newly constructed organism (such as a baby), the first memory deposits are of a very low level of complexity. The abstract memory channel stands ready to receive and record whatever inputs are fed to it across the associative tags. Therefore, in the earliest moments of memory, identical engrams are formed in the sensory and the abstract memory channels. At its neonatal origin, the abstract memory channel mirrors the sensory memory channels. Remember, the abstract core of the mind is trying to mirror the external world, which it must perceive through the medium of the sensory channels.

However, as time goes by, each abstract fiber becomes extremely differentiated from its neighbors. The original level of complexity of the data in the abstract memory channel is on the order of off-or-on, yes-or-no. This irreducibly simple logical content is the mirrored reflection of the jumble of data in the sensory memory channels. The sensory memory channels never actually become organized internally, but the abstract memory fibers do become organized. Order develops within the abstract memory channel through the incessant and potent mechanism of associative reaffirmation.

Please examine the abstract memory channel from the point of view of identical contents being held both in the sensory memory channels and in the abstract memory channel. Suppose that through the eye a particular feature, such as a geometric line, has been seen and recorded, first in the visual memory channel, and simultaneously by associative tag in the abstract memory channel. Every subsequent time that that particular feature is seen again along the same sensory memory fiber, two important events will occur. The one rather simple event is that the sensation of that feature will be recorded one more time within a freshly fixed node at that point along the sensory memory fiber where the march of time is presently fixing nodes by imultaneity across a wide, associative front. Meanwhile, as the signal of the sensed feature travels along the sensory memory fiber and briefly floods that fiber at every point, the originally fixed node is faithfully doing its duty as a comparison device. By simple unitary logic, it recognizes the (umpteenth) reoccurrence of the signal of the same sensed feature with which it was originally fixed, or written as an engram.

The sensory memory node, stimulated by the transient signal, blips out a signal across its associative tag over to the related node on the related abstract memory fiber. Now in turn the abstract memory node, stimulated by the transient associative signal, blips out a signal which travels down the abstract memory fiber to where unfixed tabula rasa nodes are being fixed by every data-laden moment of the present. So now we have a mirror phenomenon occurring both in the sensory memory fiber and in the abstract memory fiber. The associative tag fiber of the present moment fuses across nodes on both the abstract memory fiber and the sensory memory fiber. Thus the logical content and the "dedication" of the abstract memory fiber are reaffirmed by simultaneity in the present moment of perception.

The concrete associative fiber of the present moment of perception will fuse with sensory and abstract nodes wherever two or more signals are present orthogonally. Suppose that the eye of the organism is seeing an image or pattern composed of many features. Each extracted feature floods its own sensory memory fiber within the visual memory channel. The concrete associative fiber of the present, which is activated by an internal clock of the brain, fuses nodes with each feature-fiber that is momentarily being ctivated by the total sensation of the image or pattern. Therefore, this concrete associative fiber is henceforth irrevocably linked to the group of features which comprise the seen image. Henceforth this associative fiber can either recall the image internally or recognize the image seen again externally. The concrete associative fiber is now an associative "tag" attached to the image.

Although the associative tag may connect to many fibers in the sensory memory channel, it can connect to as few as one single fiber in the abstract memory channel. Thus a single fiber in the abstract memory channel can come to represent a whole class of fibers in the sensory memory channel, and lo, an abstract concept is born.

If you pause to think, you may see how it makes sense that often multiple fibers will be activated in the sensory memory channel while only one or a few fibers are activated in the abstract memory channel. In the neonatal period, there may be a releasing mechanism which lets loose of only a few abstract fibers at a time. Or the abstract fibers may compete to be the first abstract fiber to be reaffirmed by the associative tag over to a bundle of sensory fibers comprising a pattern. The main thing is, each abstract memory fiber can serve as a reaffirmative collection-point for associations to a whole class of similar sensory patterns. Voila, pattern recognition occurs. The abstract fiber is not in the thick of sensation; it stands aside and is abstract.

An abstract memory fiber (spoken of in the singular he e, although a gang of thousands of logically fused fibers is meant) can become the physical and logical seat of a concept within the mind. For instance, a dog that knows and recognizes its master will have at least one abstract memory fiber which serves as the ultimate, concentrated association-point for all memory-information related to the dog's master. This assertion is so serious and so evocative of hasty disbelief that it is now time to invoke the force of the dimensionality of the mind.

The level-two mind has two dimensions, the lifelong time-dimension and the simultaneity-dimension. Within the level-two mind (and the level-three mind), memory fibers all flow in parallel and only along the time-dimension. You know from experience that your mind has held a concept of something or other, such as a concept of the sun around which our earth orbits. All your knowledge of the sun is tied to that concept, and that concept is tied to the word "sun." Of course, your conceptual knowledge of the sun could be broken down into ingredient concepts, such as the concepts of warmth or light or chariots. But is seems as if you have one unitary point within your mind where all the constituent concepts are subsumed under the operative concept of "sun." So the dimensionality of your concept of "sun" is punctiform. If your concept of sun were triangular or circular, you would not be able to focus your mind upon the same pinnacle of conceptuality each time that you thought about the sun.

But your concept of the sun is not only unitary, it is also quite constant over time. Just as a point extended through space becomes a line, likewise a unitary concept held constant over time can best be represented, both physically and logically, as a unitary fiber (or its logical equivalent, a gang of fused fibers) flowing along the time-dimension of the mind. So the dimensionality of a concept is double: it is punctiformly unitary and it is chronologically linear.

Does it seem ridiculous that this mind-model claims that perhaps a single gang of fibers in your brain holds your concept of a thing such as the sun, or of your pet dog, or of yourself - your concept of ego? But think: the concept-fiber is operative not by itself, but by virtue of the myriad associative tags leading from it. Many concepts are interrelated and they contribute to the composition of one another. Conceptual fibers are associated not just to sensory data, but also to one another within the abstract memory channel. Therefore a slice of your abstract memory channel is like a conceptual topography. The maze of concepts is like a stick-forest of interrelated points of knowledge. Concepts are neighbors or relatives of one another not by physical proximity, but by logical proximity.

Your pet dog has a stick-forest of concepts, but, alas! he has no words (or symbols) attached to them and therefore he can not manipulate them in a rational way. Even though your dog may hear words quite often, he does not develop the use of words. Your baby, however, quickly develops the use of hundreds of words. How is the level-three mind of your baby different from the level-two mind of your dog?

On the third level of mind, rational intellect springs into being in a process whereby rigid informational structures arise amid the hodgepodge informational milieu which was level two. These new structures arise as the means to express relationships among concepts. They are to some degree logical structures and to a larger degree linguistic structures. The structures remove the mind from the bondage of immediate, concrete experience and allow the genesis of abstract thought.

We can first examine the existence in the mind of a vocabulary of words solely with respect to level two, and then we can describe the level-three structures which govern these words in linguistic thought.

Let us discuss the relationship between word-memories in the auditory memory channel and image-memories in the visual memory channel. Let us confine our discussion to concrete nouns which are readily linked to concrete images.

First of all, the association between the two memory channels is a two-way street. Activation of the image can evoke the word in auditory memory, and activation of the word can evoke many images in visual memory. Notice that "word" here is singular, but "images" is plural. This difference obtains because a single word can serve as a control-symbol for a whole class of images.

For instance, if you see any one of many varieties of dog, the word "dog" can come to mind in your auditory memory channel. If many people listening to a story hear the word "dog," they will probably summon up quite varying images of dog to instantiate the concept of "dog."

Humans with words as control-symbols have an extreme advantage over the level-two minds of animals. The word attached to a concept makes that concept utterly and fluidly manipulable within the ratiocinative structures of the mind. Even though the word is an extended string of phonemes, it behaves logically as if it were a unitary point.

Indeed, in the level-three mind, each word is attached to a unitary point, namely the abstract conceptual fibergang associated with the word in the abstract memory channel.

In a level-one mind that contained words, there would be a direct associative link between an image and a word. In the level-three mind, concrete associative tags do not flow directly between images and words. Instead, from the sensory memory channels the associative tags make contact with the abstract conceptual fiber, which is the focal embodiment of a particular concept and which serves as a unifying point for the development and linguistic activity of the concept. If a linguistic structure is going to control a vocabulary of words, each word must have a sort of "handle" upon it, by which the word, as a symbol, can be controlled. That handle is the abstract conceptual fiber.

The abstract memory channel is the set of all abstract memory fibers. An "abstract conceptual fiber" is an abstract memory fiber which happens to hold a concept (by gathering up all the associative tags of the concept). Therefore the set of all abstract conceptual fibers is a subset of the set of all abstract memory fibers.

Thus far in our discussion, a concept has a tripartite existence within the brain-mind. Firstly, the word exists as a short string of sounds within the auditory memory channel. Be aware that no word will exist at only one memory location within the auditory memory channel, but rather each word will be recorded there in hundreds or thousands of historical instances, depending upon how frequently the word is used. Furthermore, be very aware that, since each instance of the word is the same string of sounds (phonemes), all instances of a word within the auditory memory channel are logically equivalent. Since the auditory memory channel is not just a transmission-channel, and not just a memory-channel, but also a comparison-channel, any one instance of a word can quickly be compared with all other instances of the same (or even a similar) word, so that a word existing in thousands of spots within the auditory memory channel functions as if all the spots were interconnected, as indeed they are. To illustrate this point, think of the word "dog" and how you can conjure up many different images of "dog."

The second part of the tripartite existence of a concept is at the abstract conceptual fiber for the concept. The abstract conceptual fiber is the main and focal seat of the concept within the mind. From the abstract conceptual fiber, thousands of concrete associative tags flow across the sentient mind-grid to make reference to and control word-engrams in the auditory memory channel. If you hear (or think) a particular word through your auditory memory channel, that word instantly gains access, across at least one of the concrete associative tags, to the abstract conceptual fiber for that word so that your understanding of that concept is activated within your mind. Likewise, if, in the interplay of concepts within your mind, that particular concept fiber is activated, the following scenario takes place.

From the activated concept-fiber, thousands of concrete associative tags flowing in parallel are activated in parallel. Only one of them has to reach the word-engram in your auditory memory channel for that word to be activated and flow through the channel to the present-most end of the consumed portion of the tabula rasa channel. In all likelihood, many of the tags will gain access to the word, but, since it is the same word in all instances, your mind will hear just one standard production of the constituent sounds of the word. Note, however, that the parallel activation of thousands of concrete associative tags serves, by sheer redundancy, to make for an extremely reliable mechanism for the internal recall of words during verbal thought. Note also that your auditory memory channel is a self-perceiving channel. Although word-engrams are controlled en masse by the abstract conceptual fiber outside of the auditory memory channel, we are consciously aware of the words only as they flow within the auditory memory channel.

The third part or area of the tripartite existence of a concept within the mind is spread out over all the sensory memory channels which are associatively connected to the abstract conceptual fiber of the concept. If the concept is evocative of images (or sounds or smells or feels or tastes), then from the abstract conceptual fiber many concrete associative tags will flow out orthogonally over to the sensory memory data which the unitary concept represents. An abstract conceptual fiber may be associatively connected to many visual images, not all of which are necessarily identical or even similar to one another. Remember, a word is always the same, but most images will have at least minor differences. Such a state of affairs is fit and proper, because a word is an unchanging symbol, while an image is just a variable slice of the rich pageantry of experience.

An abstract conceptual fiber reigns supreme as the unitary point under which or towards which all the constituent information of a concept is subsumed. The abstract concept develops or grows by the accretion of concrete associative tags over time. The abstract conceptual fiber is not itself a symbol, but it is often attached quite fixedly to a symbol, namely a word in the auditory memory channel.

The abstract conceptual fiber governs both the word attached to the concept and also the sensory data associated with the concept. An abstract conceptual fiber can have concrete associations not only to sensory engrams, but also to other abstract conceptual fibers. This ability of a concept to exist within a network of related concepts allows the genesis of such truly abstract and intangible concepts as our notions of "honesty" and "courage."

Remember that all the abstract conceptual fibers flow in parallel in a flat plane along the temporal dimension of the mind. Logical relationships among abstract conceptual fibers are determined not by physical position, such as contiguity or proximity, but solely by interconnection over concrete associative tags. Thus, although the fibers lie in a flat plane across the surface of the brain-mind, their associative interconnections can generate the analog of superstructures or hierarchies among the abstract conceptual fibers.

To discuss the psycholinguistic nature of language, we must for the first time in this article introduce the notion of the control of one abstract conceptual fiber over one or more (i.e., thousands) of other abstract conceptual fibers. Up until now we have discussed how one fiber might influence another fiber, but not how one fiber would dominate another.

The ability of a nerve-cell to require the summation of multiple inputs before firing permits some fibers to control others. In that portion of the abstract memory channel which we may henceforth call the "linguistic cable," some abstract fibers gradually take on the role of governing and dominating whole classes of other fibers. For purposes of simplicity and clarity, we will discuss here only two linguistic classes of words: nouns and verbs.

As an infant learns nouns, he or she also subconsciously assigns an abstract fiber in the "linguistic cable" to the control of the whole class of nouns. As each new noun is learned, a concrete associative tag is bonded from the general noun-control fiber over to the abstract conceptual fiber of the particular noun. From the noun-fiber in turn a concrete associative tag goes to the engram of the word in the auditory memory channel. Gradually the noun-control fiber latches on to a burgeoning "family" of nouns, all segregated conveniently as a class so that they will remain distinct when ther parts of speech are learned.

Suppose that the infant, seeing and recognizing an object, wants to name that object in a blurt of speech. The "wanting" is actually the build-up of logical tension within the abstract memory channel. The general noun-control fibergang is activated by the confluence of all the logical tension stemming both from the perceived object and from the internal state of the infant. This general noun-control fibergang sends a blanket semi-activation signal to all the nouns in the vocabulary of the infant. In a way, all the noun-fibers are being invited to activate their word-engrams in the auditory memory channel. But, because of the multiple-input requirement, no noun-fiber can fire solely on the basis of the blanket semi-activation signal going out to all nouns as a class. Only that noun-fiber will fire which is already or simultaneously semi-activated, so that the two semi-activations cause full activation, and a recall-signal is fired over to the word-engram in the auditory memory channel.

Remember, the infant is seeing an object out in the real world. The perception of that object causes associative links to filter through and semi-activate the one noun-fiber within the whole class of nouns. The desire to speak a word causes the general noun-control fiber to send the blanket signal to all the noun fibers. The two semi-activation signals - the blanket one and the specific one - meet in the appropriate noun-fiber and cause it to fire a recall-signal over to the word-engram stored in the auditory memory channel. In this system, if the infant has not yet learned the most appropriate word for the perceived object, he or she will blurt out some nearly appropriate word which bears the closest associative relationship to the perceived object. The word chosen by the infant may sound funny to adults, but it makes sense within the mind of the infant.

In like manner, an abstract control-fiber for each part of speech governs all the members within the class of that part of speech. When the infant goes on from learning nouns to learning verbs, likewise a general verb-control fiber governs all available verbs.

Once we clearly make the point here that one abstract gang of control-fibers for a particular part of speech can govern all the members of the class of that part of speech, we then have finished the fundamental description of level three of the mind and we have described the part-of-speech building-blocks which make up the sentence-structures in natural human languages.

If we describe a particular human language, we move from the internal domain of genetically provided, universal deep features of the level-three mind out to the external field of cultural tradition. We see the innate ability of the human mind to segregate or classify various parts of speech, and we see the cultural ability of the mind to concatenate part-of-speech control-fibers into sentence structures. The combinatorial power of the linguistic portion of the abstract memory channel allows many influences to affect and determine the dynamic operation of sentence structures. These influences can include considerations of number, logic, time or tense, emotion, and so on. Any semantic consideration that can be conceptualized (preferably subconsciously) can be represented as a control-fiber which figures in the composition of sentence structures within a natural language.

This article does not attempt to formalize the representation of natural language within a machine mind. We avoid such formalization by means of utter simplification, and then we leave the elaborate formalizations to the expert professional linguists.

Our utter simplification of human language consists here in treating language as if it had only two parts of speech: nouns and verbs. We want to simplify language so utterly that the reader will, on the one hand, grant that noun-plus-verb is the essential core of human language, and, on the other hand, comprehend how this design for a mind generates utterances consisting of noun plus verb.

Therefore, instead of formalizing an elaborate design for one of the natural languages, we ask the following common-sense questions. Is it not clear that a mind which can grasp the concept of the doer of some action and then link that concept, expressed as a noun, with another concept, that of the action itself expressed as a verb, has performed the basic linguistic feat which is both representative and definitive of human linguistic achievement? Is not everything else refinement and enhancement?

This design does not beg the question by declaring an easy system of syntax and by ignoring semantics. The foregoing bulk of this article has laid the semantic groundwork for proposing that part-of-speech control-fibers are the semantic building-blocks which the mind concatenates into the sentence-structures or syntax of a human language. This informal simplification of language is meant as a common meeting-ground for a view of language and a view of the brain-mind.

Each abstract-memory control-fiber gang for a part of speech becomes a node on a sentence-structure of concatenated nodes. The nodes are concatenated by a spiral of linguistic habituation. Just as an associative tag fetches a word stored in the auditory memory channel, another associative tag attached to the end of the stored word sends a signal back to the sentence-structure reporting that the task of one node is complete and that now the next node should go into operation. Thus dynamic control of the se antically driven process of sentence-generation shifts back and forth between the abstract memory channel where the syntax is stored, and the auditory memory channel where the words are stored. This shifting back and forth, although it happens in the flat plane of the mind grid, is extended over time and is logically complex enough to be the flat analog of a spiral winding through time.

Each use of a sentence-structure reaffirms the habituation of the sentence-structure. Any typical node in the sentence-structure can be added or deleted by the habituational device of practice. The associative tags which operate under the (short-term) domination of a sentence-structure exercise their own (long-term) domination over the sentence-structure by reaffirming and habituating it. Change is caused from without, but then each subsequently identical loop of the spiral takes hold of what was initially change and habituates it into a long-term structure.

The concatenated nodes of sentence-structures within the abstract memory channel reach over, so to speak, via associative tags and string together words and morphemes within the auditory memory channel. We hear our own verbal thought within our auditory memory channel.

When this system of generating sentences is worked in reverse, it comprehends sentences by decoding all the associations among concepts conveyed by the linguistic sentence-structure. In the comprehension of a sentence, new associative links are formed among the abstract conceptual fibers in the abstract memory channel of the receiving mind. The sentence is recorded both as an episode in experiential memory and as a slight rearrangement of the associative links among abstract conceptual fibers in the abstract memory channel.

In this system, an incoming sentence does not have to be believed. The entrenched, pre-existing associative links in the receiving mind can withstand and overwhelm the links asserted by the linguistic structure of an incoming sentence.

This design seeks to explain how a multi-lingual speaker can keep his or her languages apart and avoid running them together while speaking. Since the vocabulary items are all segregated down at the deep levels, they remain segregated at the highest level, that of the particular language.

If you build an artificial mind, do not try to program it like a computer. Build it, turn it on, and commence teaching it.