Geometric and Network Model for Knowledge Structure and Mindspace

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ABSTRACT

This paper describes an adaptive, complex network architecture for knowledge representation in virtual mindspace. Structures and processes for knowing, remembering, thinking, learning, deciding, and communicating describe a virtual geometric space (mathematical model) of a notional mind. This mindspace model can be visualized as a workspace and this paper provides a glimpse of a virtual model of the mind.

Keywords: Mind, Network, Communication, Language, Model, Mathematics, Geometry

1. INTRODUCTION

The basic foundations for our mindspace framework (mathematical model) are:

1) The mindspace (storage space for knowledge) has an inherent dynamic geometric and network structure -- an architecture that provides for remembering, thinking, learning and communication.
2) The basic elements of mathematics (cardinality, direction, connection, and thus network structure) are hard-wired in the human mind to provide the capability to build the structure of the mindspace and execute the processes.
3) In this mindspace structure, there are regional (lower-dimensional) structures formed as densely filled polytopes that show supreme architectural and structural efficiency -- orthogonal dimensions, extremely dense storage and patterned arrangements, and highly connected.
4) Knowledge location is important, links and connections are important, dimension is important, and dynamics are very important. The knowledge mindspace network provides an efficient, effective, and powerful structure for ideas and links -- remembering, thinking, learning and communicating.
5) The organization, connections, complexity, patterns, dimensionality of the structure of one's mindspace corresponds to a form of intelligence.
6) Our mindspace structure is more complex geometry than previously considered distance-based ontologies and taxonomies in cognitive space models and more robust than vector-space (linear) models for language or learning.

Some definitions that provide for the description of the mindspace and our model:

- ideaspace: Virtual (extremely high dimension) infinite space of all ideas
- mindspace: Virtual (extremely high dimension) uniquely structured space/network of all ideas of a unique sentient entity
- mindset: the dynamic collection of beliefs (to include knowledge), perceptions, and recalled experience of a sentient entity (the known points)
- idea (knowledge/information/thought): a point (or region) in ideaspace or mindspace with its connection to other information.
- communication: transmits language from speaker to listener, who tries to establish (find) the point or region in the entity's own mindset, modifying the mindstate. The point exists before the language is received. If the communication was successful, the idea is or becomes part of the listener's mindset.
- learning: active process that results in a change to the mindspace

We focus on the geometric and network descriptions of this architecture using network metric techniques (attributes, measures, properties). We show examples of how these mathematical structures are assembled into a mindspace architecture. Another example provides for visualization of how geometric and network structures change during the process of learning.

Our mindspace model, previously introduced in Arney [1], is considerably more sophisticated in terms of dimension and structure than other models. In its simplest views, building a mindspace is like creating a library --- placing ideas in a logical organization – or building the Internet – linking information. However, it is much more complex than either of these. In this paper, we use network architecture analogies to describe these complex aspects of mindspace structure. In many ways, we are restricted by our low-dimensional vision and become limited as we consider such higher-dimensional geometry.

2. GEOMETRIES

We begin by briefly describing the roles geometries that play in the fundamental concepts of knowledge as was described in more detail in Arney [1, 2]. The architecture of a mindspace is forever changing and growing --- becoming more and more complex, vast and elaborate. The original mind structure starts with one rather simple, linear dimension --- virtual in its conceptualization and innate in this virtual component of the brain, literally coded in the DNA. Before birth, thoughts enter the mind becoming ideas (data) of basic knowledge. These simple thoughts of survival and comfort (determination of hot, cold, comfort, pain) come from senses and enter into a rudimentary mindspace structure. The mind forms this virtual space from nature's only innate and omniscient form of language – the coded language of geometric mathematics in the DNA. This structure comes from instinctive mental capabilities to measure (determine more, less, the same). From that instinct comes number sense (crude counting and direction --- up, down, many, few) and eventually a construction of order and characterization and finally a sufficient geometry of a network to store the knowledge that enters the mind from the senses. That one-dimensional geometry of a developing mind is initially like an elementary school number line -- able to hold organized ideas in mind locations. As more learning takes place, the structure of the one-dimensional mind is too limiting for the types of complex thoughts that have formed. It is only then that the virtual mind uses its innate quality to grow and expand into an entirely new dimension giving the mind a new perspective on all previously held ideas and changing the way new ideas are stored and connected. As thoughts need new depth and complexity, the mind constructs more and more dimensions. Not all of these dimensions are orthogonal or even useful for very long. Some of the dimensions overlap in strange but important and powerful ways to create a growing structure with an extremely complex geometry. This learning, growing, expanding process continues as people become learners and thinkers possessing amazing minds with highly efficient capacities to learn and remember and understand. Memory and knowledge come from the basic organization of the mind --- placing the right ideas in the right places, keeping related ideas appropriately linked.

The mindspace globally possesses a large, detailed, highly connected, high-dimensional network architecture that stores important ideas in this organized and efficient structure. The rich internal ontology/taxonomy makes basic ideas highly accessible and readily available to enable the mind to learn, think, dream, and hope. The mind also has local or regional (lower-dimensional) areas called polytopes that show supreme efficiency – and dense in the storage and arrangement of ideas. They are special geometries built by the mind in a special form to store information involving a specific topic. Usually the topic area will hold a large number of related ideas involving profound understanding of a complex topic. A highly developed polytope is the result of constructive learning to efficiently and neatly place the results in a compact multi-dimensional solid region for organizational purposes. The result is a geometric structure representing substantial topical knowledge. The size, shape, and organizational health of a polytope are indicative of its design and use by the mindspace.

Our model places human perspectives within the geometry of virtual spaces where each individual entity has its own mindspace, resulting in a unique categorization/storage of ideas and many processes that make up the notion of thought. This geometric model of the mindspace was described by Arney [1, 2]. Meadows [1] and Edwards [2] describe similar two-, three- or low-dimensional geometric space to describe and categorize thoughts, memories and ideas. These models are also appropriate for artificial intelligence knowledge representation.

3. MINDSPACE MODEL

We briefly describe elements of our mindspace model that was introduced in Arney [1]. Mindspaces, like the one described, can be understood as "workspaces of the mind" as described by Baars [5], and, therefore, through this paper, we provide a glimpse of a mind's structure and processing. Unfortunately, we have no precise way to describe or visualize the vastness of the intricate high-dimensional space or the complex geometries of the mind.

4. STRUCTURES

Polytopes

The non-linear, complex geometric forms of related ideas are mathematical polytopes. They take up large, densely compact regions encompassing several dimensions in a mindspace. These are special geometries built by the mind in a special patterned form to store information involving a specific topic. Usually the topic area will hold a large number of linked ideas involving profound understanding of a complex topic. A highly developed polytope is the result of constructive learning to efficiently and neatly place the results in a compact multi-dimensional region for organizational purposes. The result is a geometric network structure representing substantial topical knowledge. The size, shape, and organizational health of each polytope are indicative of its use by the mindspace.

Dead Zones

The nearly empty areas of a mindspace are either immature regions of new construction ready to be filled with new ideas or spaces that contain old sets of ideas that have been mostly forgotten or discarded as unimportant or unneeded. It may seem like a waste to have an entire dimensional sub-region of a mind completely or nearly empty. However, these structures are the results of an active mind that constantly moves forward in its thinking and perspective. Valuable ideas stay in the active mindspace, and abandoned, unimportant ideas fade away. Small finite dead areas of the mind are hardly important to the overall vastness of a functioning active mind. Likewise, the mind has the capacity to forget, confuse, misplace, and be sloppy or lazy.

5. NETWORK

When describing the network architectures, in particular the connections of ideas, simple notional visualizations enable us to see some of the networking aspects of the mindspace. However, because we are limited to two-dimensional projections, many of the characteristics of the mindspace remain hidden although formal network metrics can help us understand the higher dimensional structures. We show simulated examples in two dimensions even though they are restrictive and far simpler than real mindspace structures.

Example 1: In Figure 1, we show a simple mindspace idea that contains a network of 24 nodes. This type of simple network structure is the building block for the myriad of structures in a mindspace.

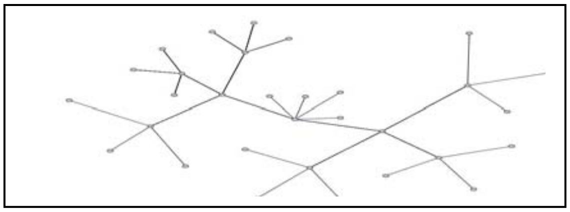

Figure 1: A notional 24-node idea showing its network-like structure and links

Figure 2 shows the same structure with simulated data that could come from a simple report an entity (human worker or an intelligent machine) has to track weather and work data.

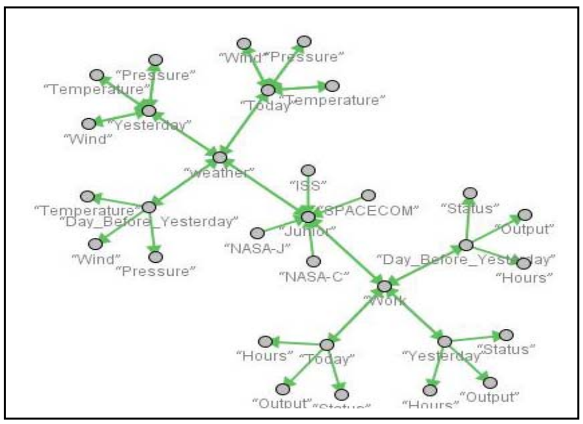

Figure 2: The simple 24-node idea with organizational data for a 3-day period.

This kind of idea structure can become more complex as more ideas are linked or more information is needed to be tracked. Figure 3 shows a 9-day structure of the same data types found in Figure 2.

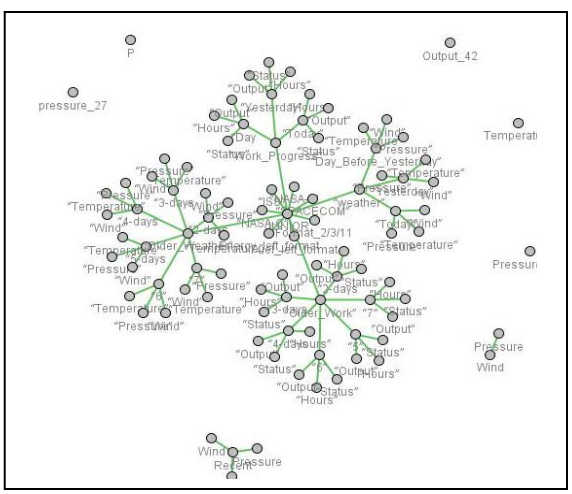

Figure 3: The same simple idea as it increases in size to 90 nodes to hold 9 days of data.

The network structure can show various types of mind organization. Figure 4 shows a seemingly random structure (on the left) and an over- or strangely-organized (circular) structure on the right of the same data as shown in Figure 3.

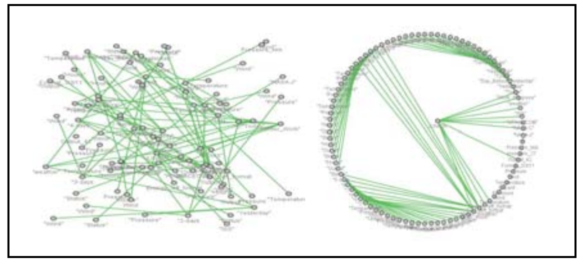

Figure 4 (left and right): The same data as shown in Figure 3 in random network form on the left and in a circular network form on the right.

So far, our ideas in this example have been very simple. Figure 5 shows the notional network structure for a more complex idea with numerous links but no central or focal point and therefore, a large, but linearly patterned idea.

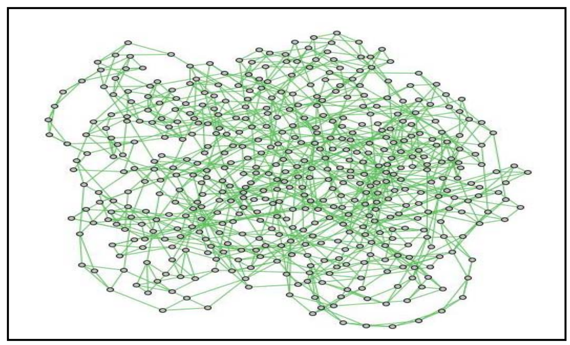

Figure 5: This network of 300 nodes is highly connected with no focal aspects.

Figure 6 shows a dense network of a complex idea with many basic foundations and foci that weave together different concepts. Figure 6 also shows a few isolated ideas that are not linked to the central one or, in some cases, the links to these components of the idea are no longer active and valid having been discarded by mindspace processes.

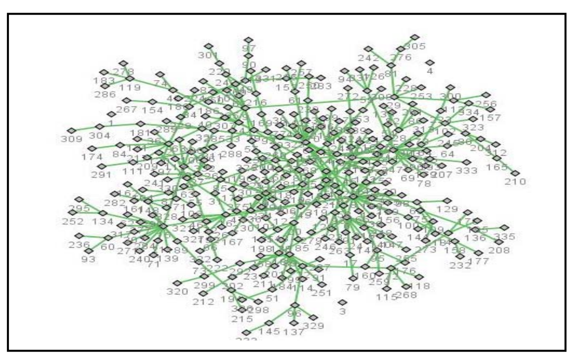

Figure 6: This mindspace idea shows a dense network structure of 350 nodes.

Sometimes the isolated simple facts are as significant as the structure network of the main idea. Figure 7 shows an example of this situation with a central core of ideas along with many isolated but patterned ideas in the mindspace.

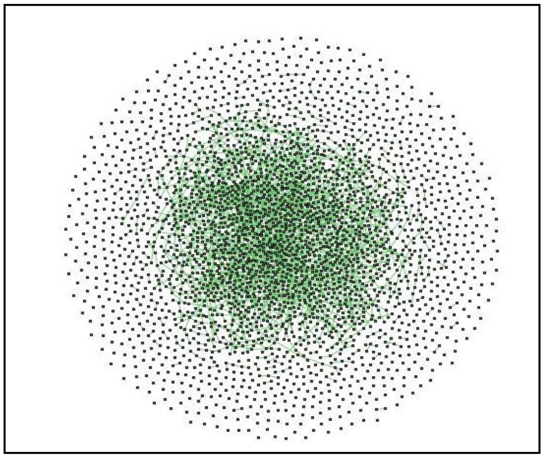

Figure 7: This dense network of a complex main idea is surrounded in the mindspace by isolated, but simple data ideas.

6. PROCESSES

We now take a brief look at some of the processes that take place in the mind -- thinking, learning, memorizing, intuiting, inquiring, deciding, creating, forgetting, imaging, and communicating. These mindspace processes affect the richness, robustness, clarity of ideas. They can take lesser value ideas (data or information directly from sensors or mindspace locations) and enhance them through the process to higher-values of knowledge or intelligence by linking the ideas in building a network-like framework for the thought. The ultimate goal is a mindspace that contains knowledge and possesses robust processes to assemble complex thoughts and produce intelligence. Both structure and processes contribute to this goal.

Thinking

The mind actually multi-processes by accessing, combining and, therefore, thinking several ideas at once. These ideas may be for related purpose or not. Accessing all these ideas in a rapid fashion provides for a powerful process. The duration of the activation of thought is created by a combination of efficiency, intensity, and function of the thought. The simultaneous accessing of many ideas for one purpose indicates a complex, multifaceted thought encompassing many basic or sub-thoughts. The more patterned in either space or time, the more organized or ordered the thought. And when the basic ideas are located in topical polytopes, the intensity and efficiency of the process can be enhanced. Thinking has many different aspects --- sometimes the mind analyzes existing ideas, sometimes combines ideas, and sometimes uses reasoning to refine an idea. While some kinds of thinking can be casual and informal, critical thinking is much deeper and more formal. Critical thinking examines the evidence that supports the idea and then uses the idea to make a decision, solve a problem, or answer the question under consideration.

Learning

What happens when someone needs to know something new? Learning pathways are forged to idea locations in the mindspace. This makes for a mind-expanding process. New ideas are constructed, linked into an existing idea when appropriate, and eventually the mind gains an entirely new perspective. One possible result is the unfolding of an entirely new dimension in the mindspace. Recently learned material and some previously known material is migrating to this new dimensional space. This event is the expansion of a mind.

Another learning process could just expand a current idea by linking new components to existing. The following example shows a learning simulation of a basic skill usually learned early in childhood. The intent of the example is to show that the dynamics of the mind are as complex as its structure and processes.

Example 2 (Learning Simulation): In this example, we start with a mind that knows the idea (skill) of the addition operation in arithmetic. This mindspace has connected the addition idea (skill) to other basic number ideas as shown in Figure 8. This network of ideas becomes one connected idea that enables the mind to think in a more sophisticated and capable manner as it processes arithmetic addition.

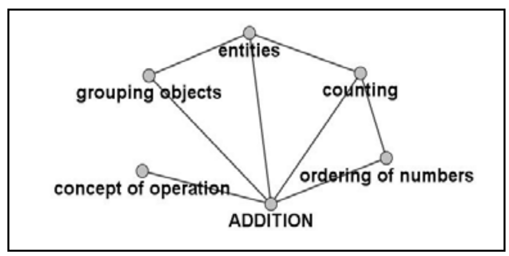

Figure 8: This is a notional mindspace model for a learning entity that knows "addition".

In this example, as the mind obtains the new idea (skill) of subtraction through learning, it connects this new idea to its previous idea of addition and some of the other the associated ideas in the network. This learning act produces the new idea structure as shown in Figure 9.

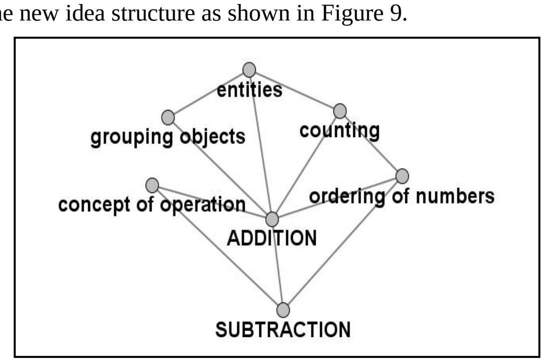

Figure 9: The new mindspace model once the entity has learned "subtraction".

This new network of ideas then empowers the learner to further its learning and thinking capabilities by connecting three new ideas to the network and strengthening existing links. Figure 10 shows the result of adding new ideas (skills) of “counting backwards”, “negative numbers”, and “number-line” to form the new network for this idea.

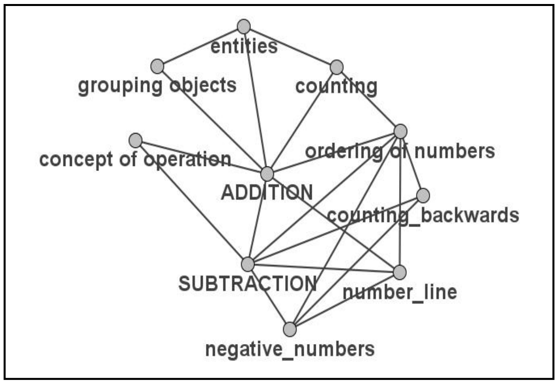

Figure 10: The notional network of the idea grows as new ideas connect to existing ideas.

Finally, the mind is able to construct even further and more complex ideas in its dynamic learning mode. More sophisticated ideas for “sequences” and “relationships” join this network structure through the processes of learning and thinking to produce the highly-connected network idea for “addition” shown in Figure 11. The complexity of the network grows as learning takes place and capabilities increase.

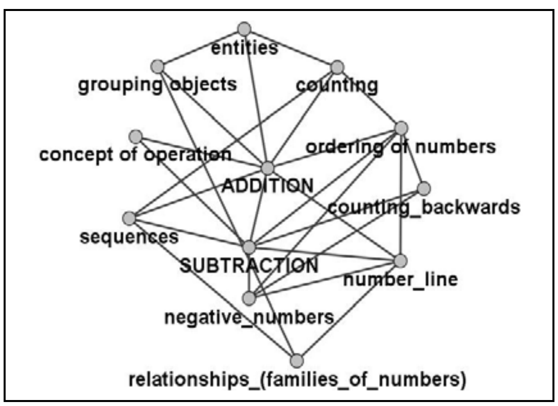

Figure 11: This dynamic learning simulation reaches its next stage with 12 highly-connected nodes. The “addition” node is directly connected to 8 other nodes.

Of course, this simulation example is extremely simplified because of dimension and visualization limitations. However, the dynamics of learning and thinking can continue to enrich existing ideas and connections. Even the more complex network model for the idea of “addition” in a more mature learner as shown in Figure 12 is highly simplified. However, the richness of connections and ideas clusters of a polytope are visible in this model shown in Figure 12. This idea model is probably more in tune with the simple ideas that populate the mindspace of many entities**.**

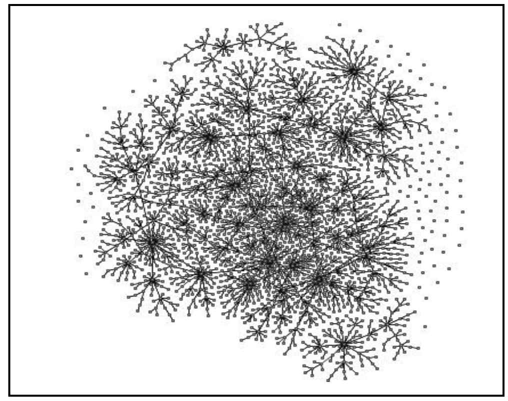

Figure 12: This notional model of the connections and ideas for arithmetic skills in a mature learner show clusters and isolated idea components of various sizes and shapes.

Memorizing

Some people are adept at memorizing lyrics and tunes of songs. This is a skill that shows how an organized mind can learn new patterned information. Often the storage area for songs is an efficient, special designed polytope. Memorization of highly ordered facts or numeric data --- such as phone numbers or sets of alphabetic data – can be an organized process. Some minds build special structures for this kind of data --- patterned, but not at the complexity level of idea polytopes – and other minds use normal memory locations for this kind of information as well. The mind’s ability to build taxonomies and ontologies (mind maps of spatial representations of ideas) to store basic information enables it to hold considerable trivia and facts related to all sorts of topics.

Intuiting

The ability to perform advanced skills can be limited by memorization since there is no context or connections for the mind processors to use. On the other hand, minds can have plenty of productive intuitive intrinsic memory – such as driving a car, riding a bike, adding and subtracting single digit numbers learned from math facts, sounding and even sight reading.

Inquiring

Inquiry-based learning, driven by asking deeper questions about a topic, also produces new idea structure. Inquiring is a natural process some minds are extremely well suited to perform. Essentially, it is the questions that drive the curiosity to learn (assemble/create) new ideas by asking questions that have to be assembled with other ideas to create new ideas. At each step, the ideas become deeper and richer as more questions are asked. The mind guides itself to learn and develop deeper understanding of topics, building both knowledge, network links, and thinking/inquiry skills. Inquiry is a natural process for some minds. The ultimate goal is to adopt new perspectives as the questions lead to ideas, thoughts, processes, and knowledge previously unknown to the mindspace. Successful inquiry leads the mindspace to change its structure.

Deciding
Some decisions are intuitive --- the issues are well understood and organized. In an intuitive streamlined decision process, the mind moves information in and out of its decision processor -- quickly eliminating poor choices and finding the optimal. Deeper decisions can take much more processing effort. An organized mind can keep information in a near priority order in a compact and patterned structure. Then the decision processor sorts through the preference-ordered list and weighs the attributes. Complex decision making can be much more involved in terms of accessing information from scattered locations throughout the mindspace. By its very nature, complex decision processing is more deliberate and extensive. More sophisticated reasoning (inductive—inference --- deductive) is used along with determining probabilities of outcomes. In this complex case, the decision process includes analysis of many diverse measures of costs and benefits and other considerations.

Creating
Some minds have a natural capacity to assemble ideas in new ways to invent or create entirely new ideas. The act of assembling and connecting ideas can be a result of inquiring, thinking, learning, or deciding or some combination of these processes being performed in an iterative and complex process.

Forgetting
One reason the mind has empty areas or isolate ideas is that it forgets many ideas and connections that were once important. An efficient mind allows unneeded clutter to disappear. It is for efficiency that the mind forgets some things that it will never need to use again. But still there are some unneeded, outdated things that will stay forever stored in the mindspace. .

Imaging
A significant mental function is the mind's ability to learn, think, create, decide, dream using graphic images and not word ideas. The mind is able to store versions of the graphic images. These mental images are compressed or possibly distorted images of what is actually seen, but once in the mind they are the mind's version of reality. Then mindspace processors are able to retrieve the images and use them to produce new thoughts through analysis of the stored image or to remember the situation that created the image. These images are essentially powerful ideas that can be used in many mind processes --- thinking, learning, deciding, inquiring, creating, hoping, and dreaming. The mind can store and retrieve dynamic images in enough detail to play back entire scenes --- like video replays or trailers of a movie. Imaging is an extremely powerful mind process for most people.

Communicating
While there are many models of communication and speech, the ones most compatible with our mindspace model are from Chomsky [6, 7] and Chafe [8]. The communicating aspect of our model was explained and highlighted in Arney [1]. As expected, the purpose of speech, whether to provide information, persuade, entertain, or express emotion, has significant effect on speech patterns and word choice. The intent of communication is to guide listeners to form an idea in their mind that would then lead them to the idea that the speaker wants them to have. The pathway from and to that idea is language.

7. MINDSPACE ENVIRONMENT

Like any biological process, the processes of the mind are affected by the mind's environmental situation and vise versa. Sometimes, the mind can be bogged down by the person's emotional and physical state. The reality is that the mind id always degraded. Extreme environmental conditions can adversely or positively affect mind processing. Sometimes, deliberate reasoning processes are shut down and the mind goes into an efficient, quick-reaction mode. Deep thought is less likely during a stressful situation since one of the most debilitating emotional conditions is stress. In general, the environment reflects situational awareness. The more the person feels she knows about her situation, the better her environment and vice versa.

8. CONCLUSIONS

Our model establishes a theoretical geometric framework for the network structure and knowledge processes of the virtual mindspace. At this juncture, low-scale, simple examples and notional frameworks are produced to enable simple forms of the model to be understood and visualized. Further development and testing of the model's framework and network measures are needed to validate the model.

9. REFERENCES

[1] D. Arney, "Communication Modeling: Geometric Model of Mindspace or a Romance Language of Many Dimensions," **Proceedings of the 4th International Conference on Knowledge Generation, Communication and Management,** 2010.

[2] D. Arney, "Communication Modeling: Geometric Model of Mindspace," **Proceedings of the Army Technical Symposium**, 2010.

[3] S. Meadows, **Child as Thinker: The development and acquisition of cognition in childhood,** New York: Routledge, 2001.

[4] D. Edwards, **Discourse and Cognition**, London: Sage, 1997.

[5] B. J. Baars, "Metaphors of consciousness and attention in the brain," **Trends in Neurosciences**, Vol. 21, No. 2, 1998, pp. 58-62.

[6] N. Chomsky, **Rules and Representations**, New York: Columbia University press, 1980.

[7] N. Chomsky, **Reflections on Language**, New York: Pantheon, 1975.

[8] W. Chafe, **Meaning and the Structure of Language**, Chicago: University of Chicago Press, 1970.