Whitepaper for DARPA-BAA-08-65

Mathematics of the Brain using KEEL Technology

Executive Summary:

Isaac Newton invented differential calculus. His only tools were pencil and paper. If he had access to computers with high resolution displays, he might have invented something else. This paper proposes the application of Compsim's proprietary Knowledge Enhanced Electronic Logic ("KEEL") technology as a new way to mathematically model decisions and actions that have historically been left to humans (judgment and reasoning are "right brain" parallel processing functions). The KEEL "dynamic graphical language" will be employed as a way to capture, test, package, audit, and explain human-like reasoning that could then be deployed in software applications and devices. The graphical nature of the "language" provides the notation ("the act or practice of recording anything by marks, figures, or characters."[1]) that describes how variables are displayed allows the "importance of information to be visualized" which is important for modeling reasoning and judgment. Explicit functional relationships are shown graphically, which allows complex inter-relationships to be traced (nothing is "hidden"). The "dynamic" nature of the "dynamic graphical language allows one to interact with the models as they are created and tested. KEEL is not a data flow language. If "mathematics" is considered a way to define information in an explicit way, then KEEL might be considered a new way to explicitly define solutions to complex, dynamic, non-linear, inter-related, multi-dimensional problem sets that are commonly addressed by humans.

As weapon systems, medical systems, financial systems, power systems, etc. are automated and mechanized; there must be a way to describe their behavior in a **mathematically explicit** manner. KEEL Technology not only provides the methodology of describing these "models/policies" as a new form of notation, but it is tied directly to the methodology for processing the policies on a digital computer or packaging them as digital/analog hybrid circuits.

Proposal Approach

This proposal is based on KEEL® Technology that is covered by granted (6,833,842, 7,039,623, 7,009,610, 7,159,208) and pending patents. Three basic characteristics define the approach:

1. Integration of driving and blocking signals are resolved to determine the resulting importance of information. Compsim has patented a way to accomplish this task by accumulating driving signals (reasons for doing

[1] http://www.dictionary.net/notation

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 MAY 2009	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Mathematics of the Brain using KEEL Technology	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **DARPA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**5**	

something) and then diminishing the accumulated justification by removing blocking signals (reasons not to do something).

2. Complex, unstructured problems need to be addressed. Compsim has patented a way to address webs of inter-relationships that are shown graphically. This provides the "visualization/notation" of the new form of mathematics proposed in this white paper.
3. It must be possible to implement this form of mathematics on a computerized system. For every combination of inputs, there must be only one set of outputs. Compsim has patented a way to process this model on a digital computer as a high-performance, small-memory-footprint, cognitive function.

KEEL Technology has not been evaluated as a new form of mathematics. It has been developed for other application-specific uses.

This white paper proposes that Compsim will work with parties selected by DARPA to evaluate the potential of KEEL Technology to address any desired problem sets where there is a need to model the "mathematics of the brain".

The process would include a phased approach leading to acquisition by the department of defense:

1. Train subject matter experts (SMEs/Prime Contractors) on the KEEL "language" at a formal 3 day workshop in Brookfield, WI.
2. Assist the SMEs/Prime Contractors in developing appropriate mathematical models using the KEEL "language" and testing those models in simulations of their choosing.
3. SMEs/Prime Contractors prepare a report describing: effectiveness of the notation, ease of use, performance on target execution systems, flexibility, auditability, documentation, execution resource requirements, ease of integration into existing platforms, architecture considerations.

Supporting Technical Analysis

The syntax (words used to define information types for KEEL notation) were derived from IBIS (Issues Based Information System) described by Dr. Horst Rittle in the 1970's. He identified the concept of "wicked problems". The suggestion was that "tame problems" could be addressed with a conventional formula and could achieve a *correct* answer. He was a city planner and suggested that it would be impossible to write a formula to control a city. He called problems that are looking for a *best* answer "wicked problems". IBIS focused on organizing information in hopes that the "humans" could make good decisions. He used terms like "issues" (problem statements), "positions" (options to address the issues), and "supporting" and "objecting" arguments (to support or invalidate the positions). IBIS focused on a decision *tree* model. Compsim patented a methodology to integrate the "supporting arguments" and "objecting arguments" to create

a “modified value” which is derived from the “importance” of the “position” value. This allows one to take IBIS models and select options or set priorities in tree structured problem domains (IBIS wicked problems) and make auditable judgmental decisions. This did not include any specific notation.

Example 1: A person (P) has to decide to do something, or not do something, for which P has absolutely no background to make the decision. P asks person (A) and is told P should do it. P accepts A’s suggestion with some level of confidence. If this is the only piece of information to support the decision, P will do it. P then asks person (B) and is also told to do it (again with some level of confidence in B). Perhaps P asks 10 more people and they all advise him to do it (each with P’s perception that at some level they know what they are talking about). P is accumulating justification to do the task. Then P asks another person, and that person says P should NOT do it (because P took that one piece of information and gave it more credibility than the last person that suggested P do it). The information is accumulated according to the law of diminishing returns. Similarly, the detracting information is accumulated according to the law of diminishing returns. If the decision is “to do” or “not to do” something, then if the accumulation of all the driving and blocking information is not above some threshold, P will decide not to do it. Note: This is not just an average of all the opinions.

Now consider P is given a reason that the task is **impossible**. Impossible overrides “must”. In control systems an emergency stop (open a circuit) provides the same service. Again, the fundamental algorithm accumulates justification and detracts negative arguments to get an accumulated value that is compared with a threshold to determine yes/no.

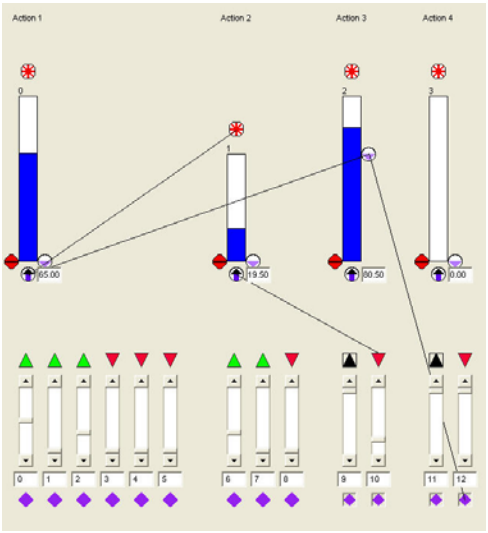
This might be considered a *lottery ticket* type of problem. Humans can think of any number of ways to spend the money from winning the lottery (supporting arguments to purchase a ticket). They might also consider the low probability of winning (objecting arguments to purchase a ticket). Depending on some threshold, some people will purchase a lottery ticket. Now assume that all lottery tickets are removed from the market. It is impossible to buy a ticket. In this case, no matter how much a person might want to buy a ticket, the ticket cannot be purchased.

Example 2: A person (P) has to allocate resources across somewhat dissociated tasks for which P has absolutely no background. P accumulates driving and blocking reasons (signals) for each task and allocates resources accordingly.

Usually humans are forced to address multiple problems simultaneously. They have to deal with travel to and from work; they have to deal with problems at work and problems at home; they have to decide how to spend their money and how to allocate their time (webs of sometimes inter-related problems that may have conflicting components like risk/reward; cost/benefit; short term/long term). New events continually arise that must be addressed. Compsim invented a way to depict these inter-related problem sets using a graphical language. One might consider this a new form of mathematics where one can model inter-related problem sets (such as those addressed by humans as they exercise judgment and reasoning). Judgment and reasoning are considered parallel processes in humans. A KEEL “engine”, the embodiment of the

language, processes all inputs and derives all outputs during what we call a “cognitive cycle”. It is effectively a “formula”, because there is only one set of outputs for a given set of inputs (although not one in the conventional sense). In one of the processing models the cognitive cycle iteratively processes all inputs and outputs until the system stabilizes. In the other processing model, the model is evaluated in advance (by reviewing the design) for an optimal processing cycle. The only effective way to understand the formula is to use the KEEL dynamic graphical language notation.

Referring to the KEEL notation:
Positions (output variables) appear as vertical bars at the top of the display area. Inputs are depicted as vertical sliders at the bottom. Their spacing defines ownership. Supporting arguments (driving inputs) have green hats pointing up and objecting arguments (blocking inputs) have red hats pointing down. The blue area within the position bars shows the instantaneous accumulation of driving inputs. Explicit functional relationships are defined with wires. Connection points (source and sink) define different types of functional relationships. There is no “hidden” functionality. Just like a conventional mathematical formula, one can “see” everything.



We call this a “dynamic” form of mathematics since one can adjust the input sliders and see the results of the cognitive cycle impact the entire formula. By visually tracing the wires, one can see the relationships and see the results of changing inputs. All inputs are processed during the cognitive cycle. Holding the mouse over connection points, one can see instantaneous “numeric values” for information.

Designing solutions using this notation, one “thinks” in terms of functional relationships: how one data item impacts other(s). Concepts like how the resolution of one item is used to control the importance of anther (or others), or how the resolution of one item contributes to others. Functional relationships are created using conventional drag and drop techniques. As soon as the functional relationship is created, the entire system rebalances and is active.

This notation can only be effective on a dynamic display, such as those that exists on all workstations today. While it might be possible to print the graphics, this would be an ineffective way to record the formula.

A new form of mathematics must be evaluated, not only for what it can do, but for how easy it is to learn and use, how it can be integrated into existing systems, how it can

be used to address specific problems, its performance, its flexibility and extensibility, and its auditability.

Using KEEL Technology as the "Mathematics of the Brain" will yield:

- Devices / Systems that can interpret information better and faster and can react better and faster will win.
- Organizations that control those devices / systems will win.
- Organizations that can accumulate these devices / systems faster will win.

KEEL® Technology is covered by granted (6,833,842, 7,039,623, 7,009,610, 7,159,208) and pending patents and requires a license from Compsim for its use or evaluation.

References

Keeley, Thomas. "Giving Devices the Ability to Exercise Reason" CITSA 2007 International Conference on Cybernetics and Information Technologies, Systems and Applications, Proceedings Volume 1; 195-200 "Best Paper"

Keeley, Thomas. "KEEL Technology Applied to Highly Distributed Loosely Coupled Systems" Eighth IEEE International Symposium on High Assurance Systems Engineering Proceedings; 300-301

Compsim LLC
PO Box 532
Brookfield, Wisconsin 53008
(262) 797-0418