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The Right Information... and Intelligent Nodes

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Abstract

The concept of Network-centric Warfare is powerful in terms of emphasizing the importance of accessing information by the warfighters, but just accessing information is not sufficient for future warfare. To achieve information superiority, a Warfighter-centric approach is required in addition to the Network-centric concept. In a Warfighter-centric approach, we focus on both the individual warfighter's informational needs and the needs of decision support information flow across all echelons and services for effective achievement of decisive operations. The architecture and mechanism of Intelligent Nodes allows both the Network-centric and Warfighter-centric paradigms to merge.

This paper describes a multidisciplinary methodology for developing intelligent software assistants. Such assistants will continue to evolve during the military training, exercises and combat, to learn the informational needs of the individual warfighter and combat groups. This symbiotic aggregate of man and computer we call Intelligent Nodes⁶ [Dawidowicz E., et. al. 2002, and Dawidowicz E., 2001].

Such devices will communicate with humans using a Natural Language such as English and possess faculties capable of 'comprehending'; the commander's intent, doctrine, mission execution process; assist in course of action development and analysis, planning and collaboration. These faculties are critical in developing the Common Operational Picture (COP), Common Relevant Operational Picture (CROP) and aiding commander's Situational Understanding (SU). User biometric⁷ identification for system access authorization, network security, spoofed information identification and filtering are additional benefits of Intelligent Nodes.

1.0 Introduction

The structure of Intelligent Nodes and their method of knowledge interchange are consistent with military doctrine. The consistency is evident in terms of decision support

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⁶ In 2001, Dr. John Salasin coined an appropriate name for the proposed Joint DARPA program as Network-centric Infrastructure for Command, Control and Intelligence (NICCI). The US Army proposed and continues to evolve the Intelligent Node concept as an application enabler for NICCI.

⁷ "Biometrics are automated methods of recognizing a person based on a physiological or behavioral characteristic. Among the features measured are; face, fingerprints, hand geometry, handwriting, iris, retinal, vein, and voice." from The Biometric Consortium site at <http://www.biometrics.org/html/introduction.html>. The additional aspects of physiological or behavioral characteristic are manners with which we work on the computer such as speed of typing, mousing/clicking the mouse or sequences associated with invoking software applications.

functioning, hierarchical information dissemination and constructs that systematically and collaboratively support the Military Decision-Making Process (MDMP) in particular and the Battle Command in general. [Dawidowicz E., et. al. 2002].

The right information at the right time to the right place is a vague and largely misunderstood requirement needed to support the Battle Command process. In reality achieving such information requirements is easier said than done. In complex situations one frequently encounters tremendous difficulties in attempt to define, which information is right and when/where it should be delivered. Today the information dissemination effort is mainly focused on getting packages of information across the battlespace or across the World in a similar way as the Postal Service delivers letters and parcels. It is left to the humans in the loop to determine what is the right information, when this information becomes important and where this information belongs.

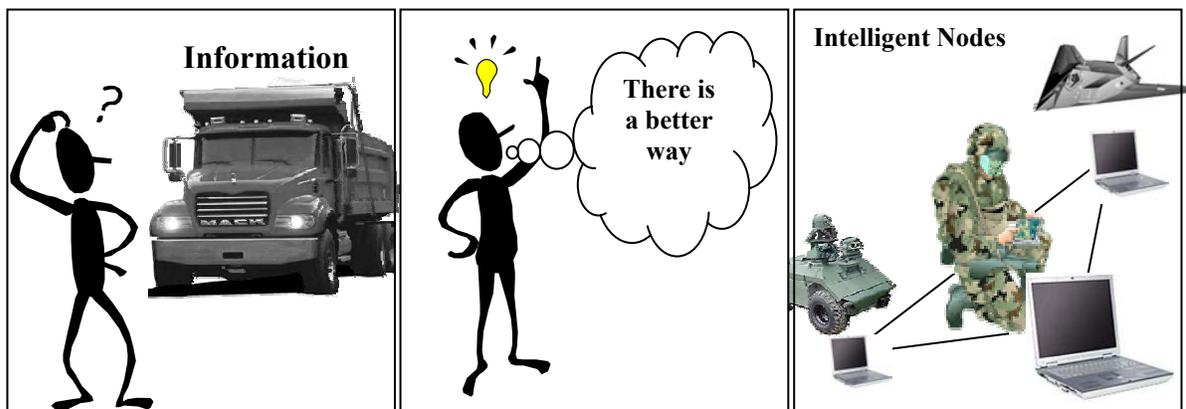


Figure 1. Solution to information overflow can be elegant, effective and pragmatic

Today the humans in the loop serve as intelligent nodes and they work very hard to accomplish the tasks required of them. The volume of information however, keeps increasing with sources ranging from the World Wide Web to military networks of sensors. These humans need assistance and that assistance should come from the computers that they already possess. But do we currently have the technology that can assist our warfighters with the ongoing information explosion? The purpose of this article is to show that we do have such technology and that we can build the electronic extensions to existing intelligent nodes. The term Intelligent Nodes will be used here to describe a hybrid, a symbiosis of human and machine intelligence (Figure 1).

1.1 A Bit of History

But first let us look back at the recent history of communications and Artificial Intelligence (AI). The invention of the telephone allowed people to communicate over long distances and nearly simultaneously. It is not surprising that, at the dawn of digital communications, Claude Elwood Shannon, a scientist from Bell Labs in Murray Hill New Jersey, in 1948 published a remarkable work "A Mathematical Theory of Communication". In this paper he defines the problem of communication: "*The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain*

physical or conceptual entities." Had Shannon addressed the subject of information today he probably would go further and look at messages not only in terms of unaltered transmission of digital strings of ones and zeroes, but at the meaning they may represent. However, he did mention that the determination of the meanings of such messages is left to the system that the messages are addressed to.

In 1953 Claude Shannon gave Marvin Minsky and John McCarthy summer-jobs at Bell Labs and in 1956 McCarthy and Minsky initiated the first AI conference at Dartmouth College. At this conference McCarthy coined the term **AI**. Classical AI has not provided any practically significant results since it has remained within the boundaries of its original constraints. However, AI has produced useful methodologies and ideas that were put forth by its original researchers and stimulated many minds since. Today we are ready to reach new heights and expand from Classical AI to pragmatic Intelligent Systems.

2.0 The Enabling Elements

Fortunately today we have the technology that can transform information into a decisive power [A. Meystel, J. Albus, 2002]. There is not one, but several elements that when put together allow us to build an electronic device that can intelligently assist the warfighters/decision-makers on the battlefield. These elements are relatively simple to comprehend, but to have a better appreciation of these devices we would have to look at natural intelligent systems such as humans.

2.1 Cognitive Process

First let us ponder a question about how we think and what the process is that allows us to be intelligent? Let us see:

1. We all start with a goal.
2. We plan to achieve the desired goal by imagining processes that manipulate required objects. (These objects exist in a multi-resolutional representation framework that is discussed later)
3. We build relationships between objects, develop a set of plans and select the best or near best plan that allows us to achieve our goal
4. We simulate the execution of potential plans, weigh the results and then select the 'best' plan for execution
5. While we execute our plan we continuously monitor the execution of the plan we set in motion.
6. Plans rarely go according to the way we intended them to precede and we have to plan continuously until we achieve our final goal state.

These six bullets provide the coarse framework that describes human cognitive processes that is native to us and can be implemented on any computer. Notice that this process is common and is employed by decision-makers across all echelons. That suggests scalability across echelons and BFAs. But it is not that simple. One size does not fit all. Brig. Gen. Huba Wass de Czege, U.S. Army (ret) and Maj. Jacob D. Bieber, state the following: "One must understand that information relevant to decisions required at one echelon does not necessarily include all information needed for decisions required at another echelon" [H. Wass de Czege, J.D. Bieber, 2001]. This suggests that multi-

resolutional representation is required for each echelon, and also for each functional area across the battlefield. Multi-resolutional representation is another key element.

2.2 Multi-resolutional Representation

What is multi-resolutional representation? We reason in terms of objects, their properties, functions and relations to other objects. Each time we focus our attention on the object's details (or the smaller objects that make up the object of our attention) we go down a level to a level of higher resolution. The level of resolution is proportional to the degree of detail required to describe an object. The level of resolution is relative. The upper echelons make decisions in low levels of resolution and require more abstract concepts to make decisions. The lower echelons receive orders from upper echelons and have to interpret them using a higher level of resolution. For more effective communication we all express our ideas at the lowest possible resolution. The ideas, and concepts emerge or come to the low-level surface as a result of generalizations at a higher level of resolution. The upper echelon requires a low level of resolution while the low echelon requires a high-resolution level of resolution. Confusing? Let us consider an example and attach a level of resolution label to every step.

1. Someone decides to travel from city A to city B (low level of resolution but high level of decision). This is an upper echelon decision.
2. Should one take a car or use public transportation? (More details begin to appear and we begin to see higher levels of resolution beginning to emerge)
3. Driving a car to city B requires dodging potholes; paying attention to the road, and speed limits. (This is a high level of resolution since we have to pay attention and react relatively fast to the changing road conditions, and everything that comes our way). This is a lower echelon decision.

Had we used the information at the level of resolution required for step 3 in step 1 our decision to take a trip would have become a very long and tedious process. The multi-resolutional representation of objects is not only native to our reasoning process, but is also instrumental in dramatically reducing computational complexity. By the 'rule of thumb' the complexity valued at 1,000,000 steps could be reduced⁸ to 1,000 steps or 10^{2n} is reduced to 10^n . This means that the computational time is reduced from one hour and a half down to one minute and illustrates a dramatic combinatorial simplification that can be achieved by using multi-resolutional representation.

In the light of a military example - the Army division commander is not necessarily interested in the exact actions that a squad will take under his/her command to accomplish a given mission. The commander will assume that the chain of command that exists between him/her and the relevant squad leader will work out those details. However, the commander will be interested in the actions, location, capability and situation of his/her brigades, battalions and other supporting forces. This is commonly referred to as "force-level control" and is in general exercised, for ground forces, at one echelon up and two echelons down. [T Bryant, R. Hartel 2001]

⁸ This estimate is based on path finding algorithm of a 10000x10000 square maze by using conventional vs. multi-resolutional approach.

In the light of another example: if one were to brief a commander on sub-unit status - i.e. A-Company is GREEN while B-Company is AMBER. What have you really told the commander that will help him/her exercise battle command? Depending on the situation, a much greater level of resolution is required and different means of depicting the actual logistics status beyond a color code would be required. Intelligent Nodes could potentially drill up and down through these levels of resolution based on user need. They can also provide the underlying and supporting data to whatever "battlefield visualization" method is being utilized. This flexibility will certainly be a desired capability of future systems

2.3 Entity Relational Network of Knowledge and Computational Infrastructure

So far we have looked at a cognitive process and pointed out that such a cognitive process spans many levels of representation. To evolve this concept further we need a vehicle that will be instrumental in transcending different levels of our multi-resolutional representation framework. The Entity Relational Network (ERN) functions as computational infrastructure and high performance information storage. The concept of an entity relational model was introduced by P. Chen [Chen P. P, 1976] and served as the foundation for developing relational databases. However, ERNs are much more than a way of storing data. They serve as concept emerging structures that are continuously built using earlier processed and newly incoming information. The concept of ERNs coupled with multi-resolutional representation is a powerful way of addressing complex problems.

ERNs are stimulated by input. The stimulus propagates deep into higher levels of resolution and triggers a response, which propagates upward with contextual relevance to such stimulus (Figure 2).

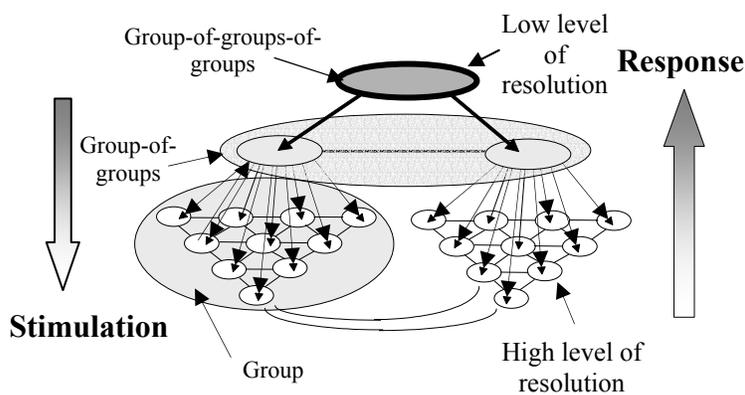


Figure 2. Concept of ERN in Three levels of resolution

The ERNs are analogous to the way we cluster objects based on their relationships and details. These details are the smaller objects that make up the coarser objects. Reasoning using coarser objects is easier than reasoning in terms of smaller objects. However the level of resolution within which we reason depends on the problem at hand and the number of

objects is about the same⁹ at any level. When we drive a car we focus on the attributes that make it operate such as: starting, accelerating, braking and steering. We are not concerned how these functions are mechanically or electro-mechanically accomplished, unless we have to repair these malfunctioning functionalities. Focusing attention at a

⁹ The term about the same signifies that object population varies between different levels by a factor of less than 10.

certain level of resolution and traversing these levels of resolution allows us to make complex decisions.

ERNs perform important functions:

1. Provide focusing attention by clustering conceptual objects
2. Allow quick examination of relationships and provide powerful concept visualization
3. Allow passages or pointers to other ERNs by performing decomposition and disambiguation.

But one more capability is required - the capability to test our decisions before they become a plan of action. The Elementary Loop of Functioning (ELF) provides this capability and a few more.

2.4 Elementary Loop of Functioning

An Intelligent Node is made up of many nested ELF's that collaboratively work together. These ELF's are designed to specialize in terms of function and levels of resolution and are placed within the Intelligent Node framework to reflect that. Based on need, additional ELF's can be generated at runtime to fill a functional or resolutional void.

The Elementary Loop of Functioning is responsible for generating the hypothesis or courses of action¹⁰ (COA) using ERNs. The potential COAs are tested for feasibility within the ELF's contemplation cycle by simulating possible outcomes (Figure 3). The contemplation cycle simulates and performs analyses for potential COAs.

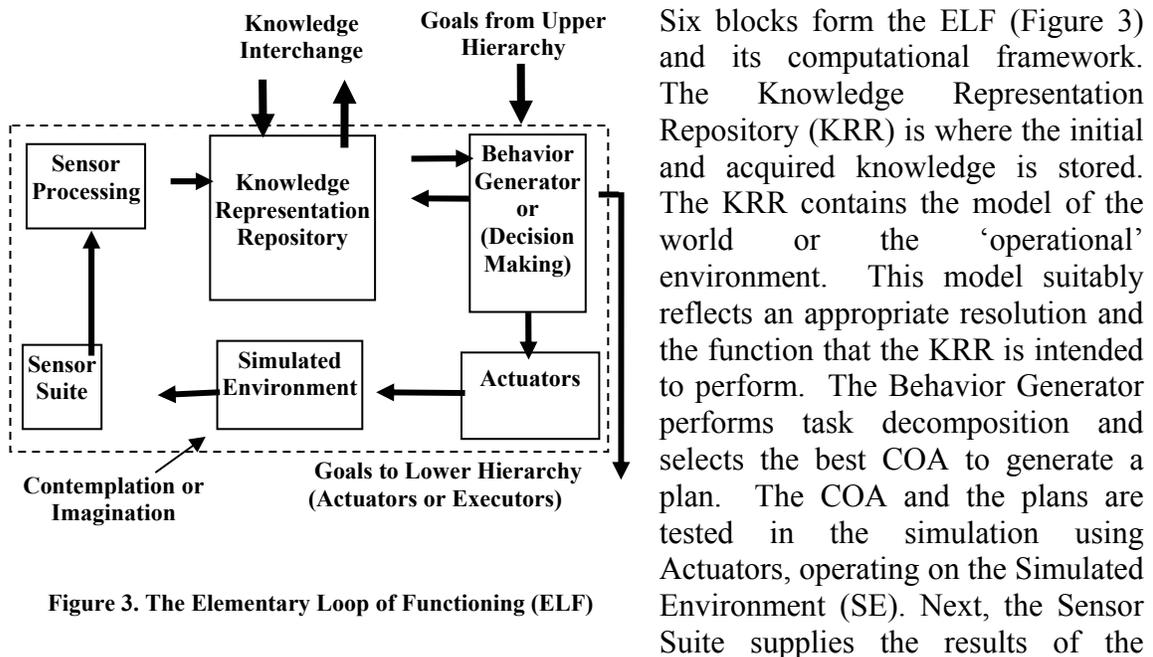


Figure 3. The Elementary Loop of Functioning (ELF)

simulation to Sensor Processing. Sensor Processing delivers the results that are to be interpreted by the BG via the KRR. Every block within the ELF communicates with each

¹⁰ The Course of Action generation and analysis is an integral part of MDMP. In this particular case it is used in a general sense where the system searches for the meaning of information and how it relates to the battlespace.

other. Symbol grounding is achieved when these communication messages are correctly interpreted among all six ELF blocks.

3.0 Applications

The applications of Intelligent Nodes are as diverse as the application of intelligence. The Intelligent Nodes can be employed as assistants within the entire MDMP¹¹ to perform gathering, disambiguation, correlation, clustering, and fusion of information [Dawidowicz E, et. al. 2002]. They are ideal in generating the COA, doing COA, and planning and providing the Commanders Critical Information Requirements (CCIR) [L. Rebbapragada et. al 2002]. They may autonomously initiate certain processes because they will anticipate the information requirements based on the evolving situation. With all these capabilities there are two that are important to achieve the symbiotic relationship between the warfighter and computer. These two capabilities are Natural Language (NL) understanding and Intelligent Battlefield Visualization.

3.1 *Natural Language*

The bulk of messages containing information are written in natural language. It is acknowledged that computer understanding of natural language is instrumental in achieving reduction in manpower [S. A. Carey, et al 2001]. The product of this effort resulted in the development of the Battle Management Language¹²(BML). The BML lexicon is a good starting point for Intelligent Nodes evolving capabilities required to achieve warfighter-computer linguistic interoperability.

Allowing the computer to have natural language faculties can open critical opportunities not only in understanding warfighters informational needs, but also to respond to human queries with pertinent explanations in English.

3.2 *Intelligent Battlefield Visualization*

In the past we have paid a great deal of attention to Battlefield Visualization (BV). Intelligent Battlefield Visualization is important since methodologies of displaying data affects situational interpretation. The products that we have use imbedded rules for transforming database information into its graphical representation. Battlefield visualization was a great step toward providing the decision-maker with a picture that is

¹¹ MDMP is a small part of the battle command process. As the pace of operations increases, the formal MDMP does not happen as often. The product of MDMP is a plan analogous to a tree. The branches of such a tree are continuously pruned during the execution phase. MDMP becomes a kind of mental process rather than a formal process. With a rapid pace of operations, the formal, methodical use of MDMP by a commander and his staff during ongoing conflict/operations becomes more and more truncated. Modifications to the original plan (branches and sequels-FRAGO's) are made, rather than "new" planning conducted. Because of this, Intelligent Nodes would more appropriately address the overarching concept of Battle Command rather than the narrower task of conducting the MDMP. Intelligent Nodes could certainly be described in relation to all the processes associated with maintaining situational awareness and understanding, and assisting a commander and staff in exercising Battle Command.

¹² BML is a implement that will give commanders and staffs direct interaction between standard Army Command, Control, Communications, Computers, and Intelligence (C4I) components and supporting the models and simulations that the Army uses to drive both testing and training on the C4I systems. Its vocabulary is derived from doctrinally sound military terms and graphics.

'worth a thousand words'. One of the BV advanced examples of this effort is DaVinci¹³. Today we can go further. The rules for visualization are subject to a particular functionality, mission, echelon and emphasis on critical elements. It is impossible to have all of the required rules preprogrammed. These rules emerge in the knowledge processes [Meystel A, Dawidowicz E. 2002] where the machine understands the events and translates these events into customized visualization to support the combined arms commander. Intelligent Nodes have the necessary faculties for generating these rules based on original design, warfighter request, and emerging emphases based on emerging circumstances.

4.0 Conclusion

To achieve information superiority we need intelligent systems. Intelligent systems normally require very large computational domains, caused by combinatorial explosion of the problem search space. Their decisions emerge from this permutation explosion. By employing multi-resolutional representation we can dramatically reduce this combinatorial problem.

A system of Intelligent Nodes can serve as a transitional command and control platform for the Objective Force. The concept of Intelligent Nodes seems futuristic, but we have the methodology to implement it today. Intelligent Nodes could be developed with a limited set of nominal capabilities in a very short time. These nominal capabilities however will far exceed the capabilities of today's command and control systems.

This paper discusses only the basic elements of the methodology behind Intelligent Nodes and the potential applications of this technology. The methodology however, is well defined in the literature [Meystel A., Albus J., 2002] and has proven itself in the fields of Intelligent Control systems and the development of autonomous vehicles. The current limitations of these devices are manifested by sensory input in both resolution and modality, but not by the underlying architecture.

The Intelligent Node infrastructure provides a novel approach to information and knowledge exchange between the warfighters. Training the warfighters to use Intelligent Nodes is reduced to a minimum since their functioning is analogous to the human cognitive process and is augmented with a natural language capability. Intelligent Nodes evolve during the training exercises and meet the criteria "**...fight as we train, train as we fight...**" well.

The very same tools that are being employed by the Military Decision-Making Process are also employed by Intelligent Nodes. Information is tightly coupled with the reasoning processes that are in turn tightly coupled with the physical world. This way the terrain and battlespace entities become the very objects with which the Intelligent Nodes reason in context.

¹³ Distributed Analysis and Visualization Infrastructure for C4I (DaVinci). Is a part of the Agile Commander ATD, CECOM RDEC's C2D developed DaVinci, as an advanced suite of decision aid software tools that will enable execution-centric, mobile Command and Control (C2). DaVinci will replace the BPV system currently used by III Corps, 4ID, XVIIIAB Corps and USFK

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¹⁴ MIP-Multilateral Interoperability Program

¹⁵ MSC2 FOSC- Multi-Service Command And Control Flag Officer Steering Committee