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SYNAPSE: "Poly-Genetic Quantum Architecture for Command, Control, and Execution (C2E)"

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Abstract

Operations in future crisis and conflict will rely on superior networked information that will enable the warfighter to have decision superiority over the adversary, while shifting "power to the edge" of warfighting units. The creation of coherent effects on the global battlespace will also be dependent on the full integration and coherent application of all instruments of national power. The "Synapse" architecture is a visionary concept that will enable this free flow of information across the military forces, inter-agencies, and multi-national partners. The Synapse architecture has two main conceptual components. First, the development and application of quantum computing and mechanics forms the backplane for the operation of the system. This revolution in computing technology gives the system its overwhelming speed, connectivity, and interoperability with all participants. Information will be "instantaneously" available throughout the network. And second, the concept of "poly-discipline" construction of the Synapse network joins together in a real-time collaborative architecture, all of the instruments of national power. Human machine interface capabilities such as "Visual Focus Directive" (VFD) and "Full Voice Control" (FVC), will give the warfighter in the field unparalleled interface with the Synapse terminal. The result of exploring and prototyping the Synapse could be a wholesale re-innovation of a "collaborative information environment".

SYNAPSE

Introduction

"Synapse" is the name of a completely new, futuristic command, control, and execution (C2E) network. Synapse is the answer to creating the conditions necessary to enable network-centric warfare (NCW) in the year 2015. With our objective of enabling "self-synchronization" of joint forces, an intelligent system is needed that unites all forces, agencies, and organizations under a singular self-conscious command, control, and execution system. Let's take a short journey forward into the year 2015 and look at the Synapse, its characteristics, capabilities, and structure.

In any given moment, even while in the various stages of sleep, the human mind is engaged in some level of activity. While focused on a single conscious activity, the human mind can be working on solving some other problem, ordering and controlling a physical activity, at the same time experiencing a deep emotion. These concurrent processes happen whether or not the conscious mind directs them, they occur in near simultaneity, and they occur literally at the speed of light. That light speed is a function of the speed of electrical impulses from one brain cell to another, and the full connection of groups of brain cells working together to perform a function. Processes occur in parallel, one working while another is in progress. Sit down at your computer and start typing…anything. You first conduct a mental survey of interested subjects, and then decide what to type. As you begin to type, you are already doing two things at once (thinking of what to type next, and controlling your fingers on the keyboard). The electrical transaction between cells in the human brain at the cell level is called "synapse". These transactions between cells, when combined at higher and higher levels

produce actions, thoughts, and emotions, solve problems, sort data and information, and engage in reasoning, analysis, and decisions.

To fully realize the goal of self-synchronization on the battlespace, we've noted that there has to be a clear and consistent understanding of the commander's intent, high quality information and shared situational awareness, competence at all levels of the force, and trust in the information, subordinates, superiors, peers, and equipment.[1] The Synapse environment described here answers all four of the criteria listed above to achieve self-synchronization. Why do we need Synapse?

As of this writing, the United States (US) spends $billions every year to make joint and service command and control, intelligence, and support systems "interoperable". We are making some progress in this area as proven in the war with Iraq this year. However, the military services have, for years, developed their own systems to best support their service mission needs and continue to do so. Indeed, US Joint Forces Command (USJFCOM) has the responsibility for the ensuring an interoperability plan be articulated to address how the services and joint community will proceed with making their systems talk effectively to each other to support the joint force.[2] This level of thinking predates 21st century information networking by decades. We often hear the buzzword "born joint" to refer to new systems in development to support the joint force…and most recently the words "conceived joint" have surfaced.

The Synapse system takes us even further along this same spectrum of activity, but it does not stop with all things "joint". Yes, it is important, even imperative that the Joint Force Commander (JFC) will be able to exercise command of forces while applying a level of control, over his/her forces, but the Synapse system recognizes the inherent

need to coherently apply other potent instruments of National Power, along with Allied/Coalition power. The very complex battlespace of the future, marked by state and non-state actors, using legal and illegal actions to conduct asymmetric operations against the US, forces us completely out of the notion that the nation's armed forces are going to be the singularly preeminent answer to countering the forces described above on any level of warfare, from humanitarian actions to full-scale weapons of mass effect (FSWME) combat. Synapse can best be characterized as **"poly-genetic"**. (See figure 1.1) This means that the genesis for the Synapse crosses into and connects every level of power in the agencies that must work together to defeat the 21st century adversary. Coherent effects applied against the adversary must be the result of a parallel application of power elements from every source of national power. In order to harness that Power to the Edge[3] construct, a mechanism must be created to carry information to the power delivery means. The power delivery means may be military or some other source of power (Inter-agency, multi-national).

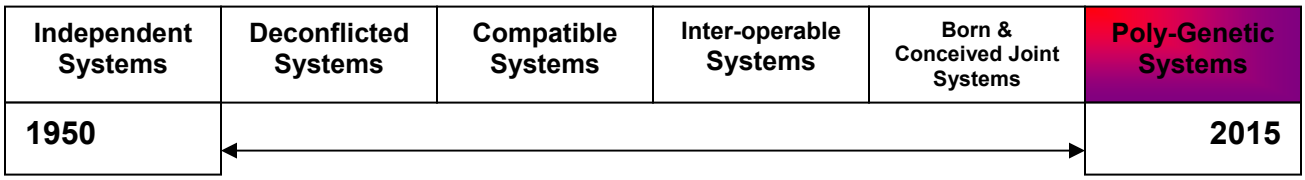

Figure 1.1
Conceptual Systems Focus Continuum

Synapse is the link between the elements of the joint force, the commander, and all other supporting agencies that can cause effects on the battlespace. Poly-Genetic architecture links entities in the network at level not possible with 20th century circuit

thinking. Much the same way that individual brain cells communicate with each other to create actions with synaptic transactions, the poly-genetic construct enables individual elements of power to transact with other power nodes in a synchronized, pervasive, parallel stream of information and decision-making power. The goal of these synthetically produced synaptic transactions is create a virtual consciousness that will enable self-synchronization for joint force elements, and all other supporting agencies/forces. The Synapse environment, when fully operational, has the characteristic of *awareness*, based on the collective inputs and transactions amongst its many nodes. The Synapse becomes highly resistant to system failure, since the synaptic transactions occur across a broad multi-path network that quickly re-directs transactions at the synaptic level whenever a single node is degraded.

System Characteristics

In recent days we've heard about or seen various computer viruses that invade a networked computer, then at a predetermined time, or as a result of operator action, get "hijacked" and instructed to perform some computational task, ostensibly in support of the perpetrator. While this form of collaborative computing is illegal, the concept of distributed computational synergy is legal and valid. It combines the processing power of many smaller machines to accomplish a task greater than can be performed on one machine alone. The Synapse borrows this concept by establishing its network and the resulting computational power through poly-genetic architecture. Every node (terminal) in the network is part of the whole. In today's networks, your PC or laptop functions as a push or pull information tool. You either send something out (push) to someone or a

group, or you search and retrieve data (pull). In these processes, however, your PC is not "contributing" anything to the network, except for the data you push. The Synapse goes beyond this premise and while you have the push/pull capability, the Synapse also executes analytical processing both for you and others. The combination of processing power of the many parts contributes to the whole.

All terminals in the Synapse are linked (on-line) via a pervasive high capacity wireless link to the other components of the system. The terminals will, in effect, be part of the Synapse system. Let's look at another way to describe the Synapse.

The operating environment of your desktop or laptop relies primarily on microcircuit technology. Microcircuit technology has overtaken the computing field in just the past 30-40 years. In the late 1950's, the US government built the NORAD Air Defense System called "SAGE", (Semi-Automated Ground Environment). At its hiatus, there were 22 SAGE facilities, each built in a huge four-story concrete blockhouse designed to withstand the nuclear weapons of the day. Each blockhouse housed the control facility for a particular air defense region, radar consoles, communications, and a vacuum tube based computer that occupied the entire third floor of the building. The relative computing power of a single SAGE computer was less than most PC's have today. The last functioning SAGE system is now on display in the Smithsonian Institute. What's amazing is that this system, with all its shortcomings in technology continued to operate well into the 1980's before being replaced by the first integrated technology system for air defense. The transition from SAGE to present day servers and microprocessors has occurred in just the past 20 years or so.

The above story on SAGE technology is the backdrop for this next discussion. In the next 15-20 years, with the technological explosion at the exponent level, the vision for Synapse is not only reasonable, but it is inevitable. You might think that building a command, control, and execution system built on poly-genetic constructs is a stretch. But as we have already seen above, the concept of distributed computational collaboration is already a reality. Synapse harnesses the power to deliver to the warfighter a comprehensive, fully aware picture of the battlespace. The foundation of the Synapse operating environment is the application of **Quantum Processing.** Quantum processor physics has established a new and exciting frontier of processing mechanics, based not microcircuit technology, but on the properties of information transfer at the sub-atomic level. These properties enable a form of "teleportation" that equates to instantaneous transfer of sub-atomic properties, and thus information attached to that transfer. Its quantum processing that enables Synapse to develop and interact throughout the poly-genetic network. One of the World's leading professors of nano-technology describes quantum processing as follows:

> Quantum processors are being hailed as the ultimate computer, potentially able to do millions or billions of calculations simultaneously, unlike today's computers, which calculate sequentially. Quantum nano-processors would be a thousand times smaller than today's silicon-based microprocessors, breaking into a new realm beyond Moore's Law. Moore's Law is an observation by Intel co-founder **Gordon Moore** that the number of transistors on a computer chip - an indication of the chip's computing power - doubles roughly every 18 months[4].

Stated another way:

> Quantum information processing employs superposition, entanglement, and probabilistic measurement to encode and manipulate information in very different ways from the classical information processing underlying current electronic technology. Dramatic advances in quantum computational algorithms based on the parallelism resulting from quantum mechanical state evolutions, have led to experimental efforts to implement small-scale quantum logic devices. …theoretical work on decoherence, optimal universal quantum computation, and scalable quantum arrays, seeks to define and facilitate the physical implementation of scalable quantum computations[5].

The International Society for Optical Engineering[6] hosted a conference in 2002 that explored the following quantum physics related problems:

Quantum Processor Architectures

- ion-trap quantum processors
- quantum-dot processors
- NMR quantum processors
- superconductor quantum processors
- cavity QED processors
- single-photon processors.

Quantum Communication Networks

- quantum cryptography networks
- quantum teleportation networks
- non-locality systems.

How quantum processing can affect the network performance of Synapse can be described by the following paragraph:

> The astounding promise of quantum computing is based on the fact that each quantum bit is entangled with every other bit in the computer, so that a single manipulation affects them all. Though these capabilities aren't necessary for word processing or simple math calculations, they would speed immensely data encryption and decryption or quantum mechanical calculations. (Whaley)

Current research efforts, such as taking place at the University of California, Berkeley, are at the leading edge of implementation of quantum processing for the future. Quantum technologies will form the foundation for the Synapse. Figure 1.2 below shows a graphical depiction of the progression of computation constructs with the approximate dates that specific computational constructs came into the mainstream of automation.

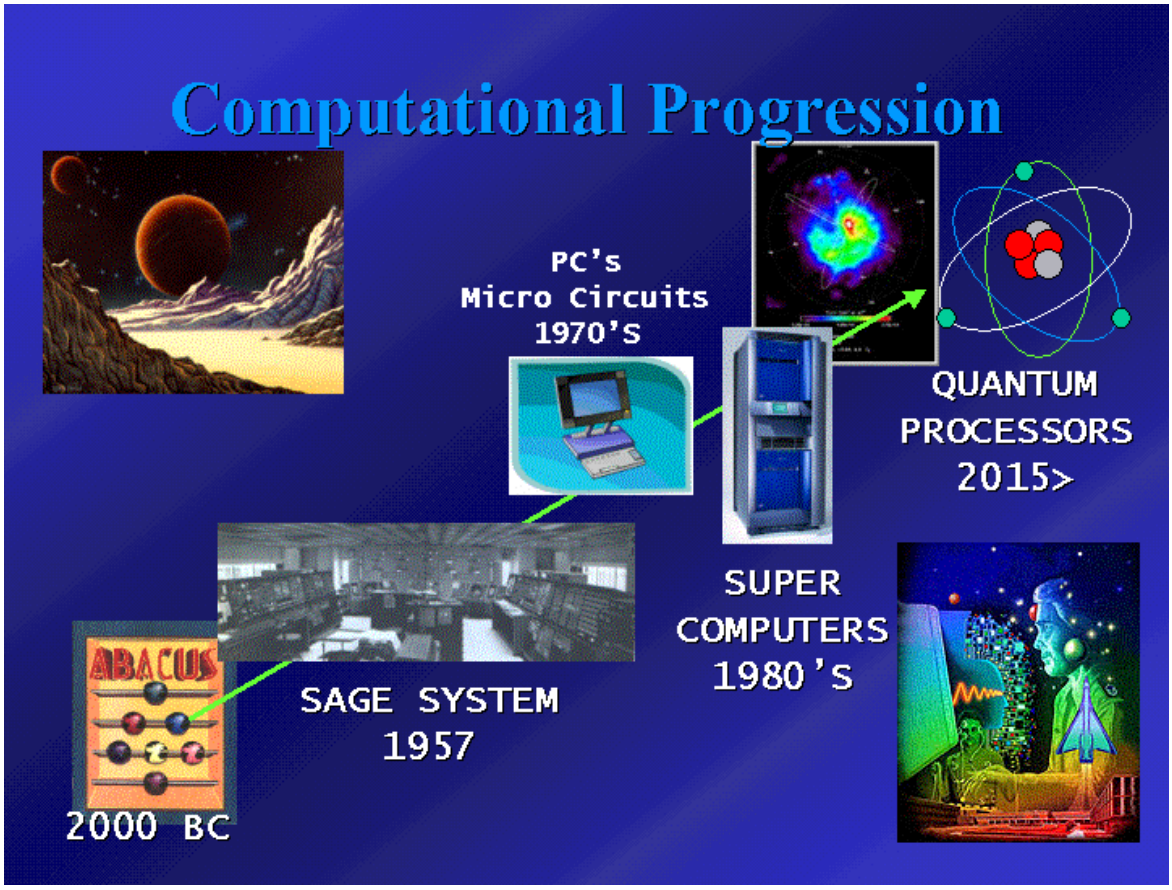

Figure 1.2

Computational Progression Graphic

Information. The commodity and product of Synapse has to come from somewhere. It comes from all elements and nodes of the system. An individual terminal has its own "sensors", linked to whatever weapons systems and units it is a part of. This single terminal "senses" what is happening within its segment of the battlespace. This sensed data is instantaneously assimilated into the Synapse. The Synapse correlates all input and sensed data to provide the operator with a reconstructed awareness of the battlespace, to include operational displays, the actions of other units in progress, direct collaboration with command elements, and a pervasive delivery of updated intelligence analysis. Since

Synapse ingests data from throughout the poly-genetic structure, the loss of one or more terminals has minimal impact on the overall synaptic architecture and will continue to operate.

Capabilities

The Synapse is a singular C2E architecture that extends throughout the joint force and across other government agencies. The terminals will all look the same, and all use the same operating language and human interface protocols. Because the Synapse is pervasive, it will have the capability to process and display a worldwide operating picture of enemy and friendly forces, supported by parallel "sensing" of data from ISR sources both germane to the joint force, and from other poly-genetic sources. Synapse will conduct its own analysis of intelligence information while correlating enemy force data on a continuous basis. Using pre-determined algorithms, Synapse will provide a predictive analysis of enemy intentions that can be used by the warfighter, or modified by command elements as needed. All this exists with the goal of enabling "self-synchronization" for the warfighter. Synapse will have in-bedded collaborative tools for various force capability packages to use to coordinate actions, and have the capability to instantaneously assimilate those actions and likely outcomes into the network so they can be accesses and observed by other units. The Synapse, will include something similar to the present day Air Tasking Order (ATO) planning tool that will allow planners and commanders to conduct some level of deliberate planning, though the Synapse, when fully operational, will most likely support fully decentralized execution in real time through self-synchronization, and therefore obviate the need for any long-range cyclic planning. Cyclic planning as a approach to command and control[8] will not be central to

operations in 2015 as network centric warfare using Synapse enables forces to operate only on a clear understanding of command intent, with the exceptional performance of the Synapse providing decision-quality information, decision recommendations, attack recommendations, near instantaneous phase I battle damage assessment (BDA), and an on-demand access to imagery, processed electronic emissions data. The Synapse will have the capability to interface directly with a new emerging concept of "Swarming Entities" (SE). SE will use digital pheromones to communicate with each other on enemy attacks, threatening forces, and advise to avoid threats, much the same way as ants communicate these instructions through chemical pheromones[9]. Synapse will have the capability to coordinate robotic operations for a robotic force by direct interface with the robotic systems and be able to pass coordinating instructions to the robotic force.

Structure

Synapse, as described in this paper will potentially have thousands of terminal-sensors in the hands of everyone from the National Civilian Leadership, to government supporting and integrated agencies, to fielded forces at all levels. The Synapse architecture will consist of the terminal-sensors, regional "controllers" whose function will be to direct system configuration to optimize the performance, and several global "controllers" which will have multi-path redundancy to auto-reconfigure the network based on performance. There will be no single central processor, which eliminates the single-point failure problem.

Terminal-sensors are wireless…no hard-wired connections so the warfighter can take it anywhere. The terminal-sensor display has several man-machine interface (MMI) protocols. The first is visual focus directive (VFD). VFD is a future technology

extension of present day helmet-mounted targeting system in use by attack helicopter crews. The Synapse VFD will allow the operator to focus on a screen icon to navigate the network. As the operator focuses on each icon, the display reacts by either presenting the requested action, or by drilling down to other levels' icons for successive focusing. This feature is hands-off control of the terminal-sensor. The other MMI will be voice control. The C2 Battle Lab at Hurlburt Field, FL has already demonstrated a basic form of this technology effectively. In the C2BL initiative allowed ATO planners to speak to the computer to build the air battle plan, assign aircraft to specific mission lines, assign tankers, ISR, and SEAD support. This development cut time to plan an ATO from 8-12 hours, to about 3 hours[10]. The Synapse voice control interface (VCI) will mimic the VFD, so operators will be able to navigate in a similar fashion using both visual direction and voice control. A standard keyboard for manual entry will back up these two features. Synapse will be a special kind of quantum network, a *programmable quantum gate array*[11].

Conclusion

The world within which we exist is changing so rapidly every day, that it is difficult at best to fully comprehend, or even imagine, the advances in technology over the coming 10-20 years. This inevitable progression of exponentially growing technology will result in the design and fielding of ever more sophisticated decision support systems and smart sensors, all linked at the poly-genetic level to effectively coalesce the many sources of National Power against any adversary. The Synapse, as described herein, is a vision of what could be the world's first synaptic transaction command, control, and execution system to capitalize on advancing nano-technology

using the foundation of quantum processing at the sub-atomic level. The Synapse also includes new concepts for human-machine interface and ISR sensing ingestion and analysis, which could have far reaching application beyond the Synapse.

NOTES

1. Alberts, Dr. David S. and Hayes, Dr. Richard E., Power to the Edge, Command and Control Research Program (CCRP), Department of Defense, June 2003.

2. Department of Defense, Transformation Planning Guidance, April 2003.

3. Power to the Edge, Chapter 10.

4. Whaley, Professor Birgitta, Extract of Research Activity, University of California, Berkeley, 2003.

5. Ibid.

6. The International Society for Optical Engineering, Conference Announcement Message, 2002.

7. Whaley.

8. Power to the Edge, Chapter 2, pp. 20-21.

9. Costa, Keith J., Defense Information and Electronics Report, "Pentagon Studying How to Control 'Swarming' Unmanned Systems, 15 August 2003.

10. Analysis based on the author's personal observation and experience with the experimental voice recognition and speech inject systems during development testing, C2 Battle Lab, Hurlburt Field, Florida, 2002.

11. Vlasov, Alexander Yu., Abstract, Quantum Processors and Controllers, arXiv: quant-ph/0301147 v3, 25 May 2003.

About the Author

Mr. Oppelaar retired from active duty in the USAF as a Lt Col in 2002, having spent nearly 23 years in command and control. He has been an instructor at the Command and Control Warrior Advance Course at Hurlburt Field, Florida, and has been the Contract Lead for the Creating Coherent Effects Department at US Joint Forces Command, Joint Experimentation Division (J9). Mr. Oppelaar now supports the development of the United States Ballistic Missile Defense System as a requirements engineer for the Command and Control, Ballistic Missile Defense and Communications (C2BMC) system element. He has written exploratory papers on *Time-Spectral Targeting for Future Joint Fires*, and *Operating-in-Constructive Reality*.