Command Control and Information Systems in the Age of Knowledge-Centricity

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Abstract

We are in the age of Knowledge Centricity (we will call it Knowledge in short). The age of Knowledge is an age of revolutionary change for businesses and military alike brought about by advancements in networking. These advancements are founded on rapid advancements in Telecommunications and Information Technology. Command Control and Information Systems (C2IS) is a medium by which military organizations exercise command and control. In the Knowledge era, C2IS design must also undergo a revolution to help the information users harness the right information, help them make a deeper appreciation of the situation, and enable them to make better and faster responses. This paper articulates an architecture for a C2IS build for the Knowledge Age, called Command Control Knowledge System (C2KS). The approach moves away from the traditional approach for C2IS design, which is based on C2 processes, to one centered on the human's knowledge creation, and sharing processes. This paper will also present a system currently under development at the SAF Center of Military Experimentation called Mission Mate, which is SAF's prototype of a C2KS.

Introduction

This generation can be called the knowledge-centric era. As cliché as it may sound, this notion "knowledge-centric" is not merely a fad, but it represents a deep paradigm shift in doing business, and building systems. Some trends in business and military thinking manifest this shift.

For the military community the new way ahead is Network-Centric Warfare. The Singapore Armed Forces' equivalent is called Integrated Knowledge-Based Command and Control (IKC2). The fundamental shift in thinking is that given greater proliferation of information due to the advancements in info-communications technology, warfighting units and individuals are empowered to do more. The concept is epitomized by the phrase "Power to the Edge" coined by Alberts and Hayes. This "Power" is founded on knowledge.

Knowledge-Centric C2IS, henceforth called C2KS (C2 Knowledge System) in short, deals with the last mile to the commander and soldier where networks and information leaves off. While proliferation of data and information to soldier will greatly empower individuals, the next important question is how he may access and exploit this information. The developments of C2KS involve the modeling of the human's processes for knowledge sharing and construction, and information search processes, and to design and develop a C2IS that facilitates these

processes. It moves away from the traditional way of building C2IS, which is to build systems around specific, and linear C2 process models, and towards a generic, non-linear human-cognitive model. This paper aims to explain the concepts behind C2KS and explains the architecture for a C2KS System called Mission Mate that is currently being developed in the SAF Centre of Military Experimentation (SCME).

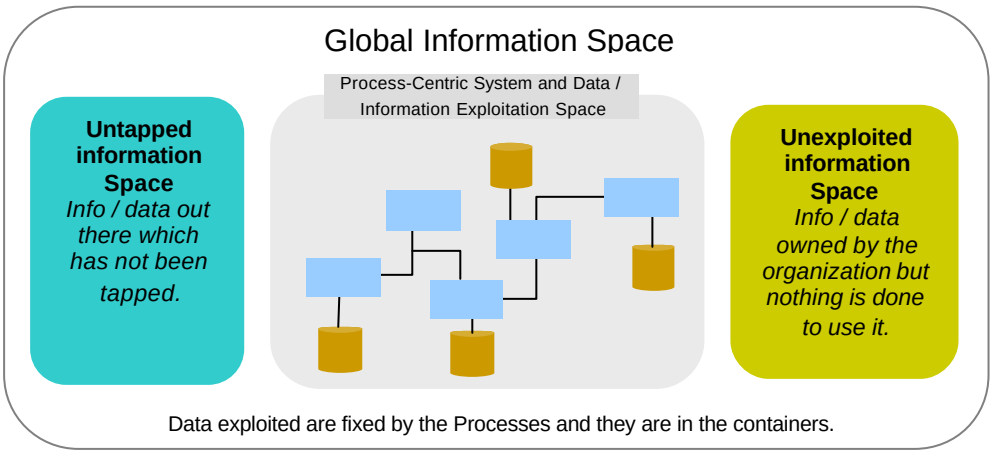
The SAF and DSTA Experience.

The Singapore Armed Forces (SAF) and DSTA (Defence Science and Technology Agency) have started building C2IS since the 80s. Today, all SAF Military Services have some form of C2IS to support their work processes. The traditional way by which C2IS was developed is to first define the work processes and for the engineers to develop a system to support these processes. However, SAF and DSTA's experience is that C2IS systems are often not adaptive enough. Further analysis found that the processes built for the system has become outmoded over the course of the development period, which may take two to three years, due to change in doctrinal thinking or commanders. Another reason is that the operators defining the system usually do not know fully what the C2IS should be; operators are also in a state of discovery as to how best to use such a system. The System development discipline has overlooked some important facts of life, which is that C2 processes is often in a state of flux because of constant changes in organization and people, and the unpredictability of the operation environment.

The Knowledge-Centric Design.

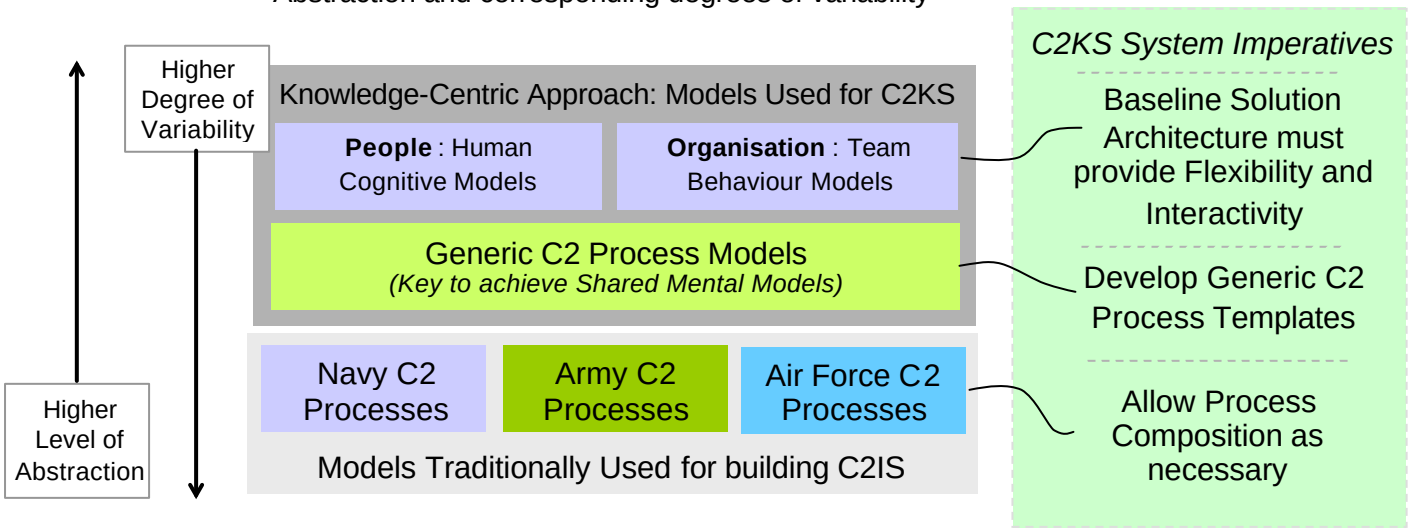
The exploitation of knowledge must originate from the human, who is the real expert and not an 'Expert System'. The traditional C2 aims to be the latter, and it can be a hindrance to decision making because it constraints the exploration of information space and the thinking processes of the human. Figure 1 shows the situation of our data and information due to the process-oriented design. Processes shape the information space to provide just enough information for the processes. As a result, a large part of potentially important information is left unexploited or untapped.

Figure 1 : Data and Information Exploitation by Process-Oriented Systems – a Fraction of the Global Information Space



The Knowledge-Centric approach aims to free up data and information constraints by focusing on generic human cognitive and team models as a basis for developing C2KS architecture. It aims to determine an alternative model for designing the foundation architecture. Figure 2 shows several process models of different levels of abstraction and their relationships with change. It shows that the human cognitive and team behaviour process models are at a higher level of abstraction, compared with specific domain C2 processes. It shows also that the relationship of abstraction with variability of processes (change) is in the inverse, which means that specific C2 processes are likely to change more frequently compared to human-cognitive and team models. The reason for high variability of domain C2 processes is the Commander who has varied command styles, and he changes every few years. The reason for low variability for human-cognitive processes is because of its basis on theories of cognitive science, which does not change as fast. So, the knowledge-centric approach is to base its architecture design on the models of least variability, that is, the human-cognitive and team models of searching for information, sharing knowledge, and the creation of knowledge. The next lower level of abstraction consists of generic C2 models that provide more specific processes for the Command and Control Domain. They are models that are common and consistent across the three Military Services. Variability in this domain is smaller because over time, doctrines and processes for C2 becomes mature, resulting in many best practices that is propagated to succeeding generations. However, changes to this system could be brought about by transformational ideas. For example, new organizations could come together, or functions that were previously not integrated are converging to form new processes, e.g. C2 and external support functions such as logistics, and HR. In this domain, generic templates of processes could be used to give organizations a baseline of standard practices. At the lowest level, processes are specific and often unique to business domains. Here, systems should be given the flexibility to build new processes as necessary, and this will be facilitated by a service-oriented design of the system.

Figure 2: Process Models of People and Organisation – Levels of Abstraction and corresponding degrees of variability



Foundations

Human-Cognitive and Team Process Models and the Characteristics of C2KS

Cognitive Science is a new science and it will be some time before a Unified Theory of Cognition emerges. Nonetheless, there are useful results from this discipline that could help inspire the architecture of C2KS.

The Real Expert is the Human.

The work of Gary Klein and Klein Associates suggests that the real expert is the human and Information Systems ought to work around the human and not the other way round. Klein did innumerable studies on decision-making under stress and discovered that human decision-making is based on patterns accumulated through experience. His Recognition Primed Decision Model (RPDM) suggests that a human makes decisions by picking up cues from the environment, and apply decisions based on experiential patterns linked to these cues. For Klein, IT systems are assets that will improve decision making significantly, but they should do no more than facilitate a person's thinking process.

Based on these ideas, a C2KS should help a person achieve situation awareness rather than make decisions for him. So a C2KS must be firstly an effective visualization (information presentation) tool that helps people and teams to *See* their environment. The visualization experience for a person in the C2KS should be dynamic and interactive, allowing him free access to different information, providing him with different ways to manipulate, aggregate, or combine the information and data, and enabling him to discover cues pertinent to him in the process.

Memory is Structural (Semantic Memory).

In the area of information and data access, it is not about "solving the Information Overload" problem, but more about the means and processes by which human search for information, and think. The former is a bottom-up, and AI (Artificial Intelligence) approach that tackles the problem by applying filters to the sea of data, and then presenting a short-list to the user. This approach is typical of most search engines, and the outcomes whilst often useful are usually not entirely satisfactory. There is also a danger of over-filtering the information. The shortcoming of this approach is also the shortcoming of AI in general, which is the inability for a machine to encapsulate the entire inferencing capability and knowledge of the human in all its "filters". Contrast the search-engine mechanism to a "Community of Practice" approach, e.g. a context-based website. Given familiarity with this community, an information user would be able to find highly useful information quite easily. If the website is designed well, the individual human user is able to identify clearly with the mental model of the community; each and every turn around the information space leads him to relevant information.

An area of development in Cognitive Psychology is in semantic memory structures – the way our brain search and retrieves information. The work of Allan Collins and Elizabeth Loftus on Spreading Activation Theory showed that given priming of concepts, a person is likely to recognize the concept faster than without a prime. For example, if a person were shown the

colour green, he would be able to recognize the word GREEN faster than without the prime. The underlying theory is that concepts in our minds are linked with different degrees of association between them. The activation of a certain concept will at the same time spread and cascade the activation to other concepts. So, the notion of Warship will be linked to concept of Anti-Surface Warfare, and to the concept Coastal Defence. Hyperlinking, a concept introduced in the Internet, is effective because relevant information is linked together; finding one idea leads one to other interesting and relevant ideas.

An interesting technology related to the Semantic Memory idea is the Semantic-Web, which aims to conceptualize information on the Internet. Borrowing this idea, the C2KS should aim to encapsulate knowledge (semantic) structures as close to the mental model of the communities as possible – a form of "Smart Push". Powerful search engines could be used to bring information navigators to the doorstep of the knowledge web (Smart Pull – 'AI approach'). Beyond that, the navigator moves through the knowledge web from context to context, community to community according to associations between the ideas. The navigator should have the freedom of maneuver across the entire knowledge space. The webbed knowledge space ensures that each turn does not bring the navigator to a totally foreign space that breaks his train of thoughts.

Thinking is Structural – Developing a Train of Thoughts

To arrive at an understanding of the battlespace situation, an operator needs to piece together the strings of information available to him and construct his train of thoughts. In a team environment, this train of thoughts is constructed collectively. Gestalt psychology suggests that the process of thinking is to search to relate each aspect of a problem situation to each, and to create a structure of understanding. The emphasis is on the organization of ideas.

Constructing the train of thoughts has two purposes. First, it aids the human and team thinking processes. Secondly, it serves to communicate – *Explain* and *Persuade.* For example, a Command team after building up a picture that they now understand has a subsequent task to convince (persuade) their commanders of their ideas. After satisfying the commander, their task is to explain to their subordinates or their partners of their intentions. Hence, the narratives "drawn" by the team must be clear, concise, and precise.

C2KS should provide the means for an operator or a team to organize their thoughts as information flows in from their search process. It should provide the means for them to *Draw, Plan* and narrate their ideas using the most appropriate media. For example, a plan is best illustrated graphically. A validation of plans is best illustrated using modeling and simulation. The C2KS should also provide the means to carry out computations on the fly to aid thinking. Traditional C2IS system builds functions tightly coupled to processes and does not give the users the flexibility to attempt new strategies to tackle their problems. A C2KS should provide functions as free floating services to be called as and when a person's instincts demands, and provide the facility even for a smart user to develop his own functions if necessary. For example, software such as Microsoft Excel or Word provides very useful Macros editors that allow a user to encode their own functionalities. C2KS with such capabilities is apt for a new generation of users, who is likely to be technologically savvy.

Knowledge Networking

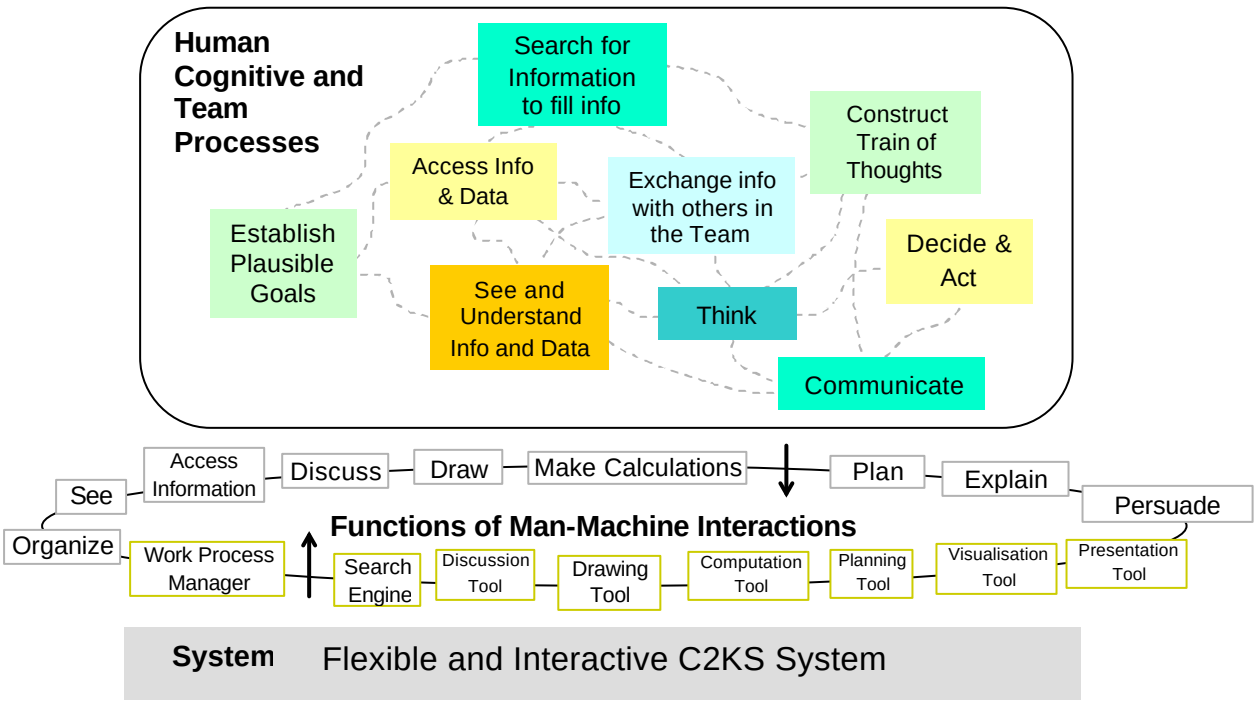
Sir Isaac Newton said he stood on the shoulders of giants. An author James Burke wrote a book called the Knowledge Web that showed, amongst other linkages, how Louis Pasteur's work on bacteria in 1854 would eventually lead to the invention of the ubiquitous wax-card cups that we get from MacDonald's today. The underlying idea is that knowledge builds upon knowledge. The current thinking in knowledge management circles is that of knowledge networking – a rich and dynamic activity, in which knowledge is exchanged, developed and evolved by knowledge workers. This activity is natural and is one of the key functions by which the human and his collective operate.

C2KS should provide services that address this fundamental need for humans to communicate and exchange knowledge and ideas (*Discuss*). Today, technologies such as Email and Chat is commonplace and are killer applications simply due to the fundamental need of humans to connect with each other. The next line of emerging technologies are white-boarding tools and process workflow engines that allow teams to *Organize* their information transactions.

Supporting Cognitive and Team Functions: Flexibility and Interactivity

In summary, the authors have painted a simple picture of the basic activities that occur at the human cognitive and team behaviour domains. The contention of the authors is that a C2KS must be built to facilitate these basic processes first, before serving the more specific areas of needs. These functions are: see, access information, discuss, draw, make calculations, plan, explain, persuade and organize (See Figure 3). In order to support these functions, the C2KS must be a flexible and interactive system. Figure 3 serves also to illustrate the fact that the human cognitive and team processes are non-linear in nature. Consequently, the C2KS must be able to adapt to the spontaneity of the interactions.

Figure 3: Principles of Interaction between Human/Team and C2KS: Flexibility and Interactivity



Generic C2 Process Models and Generic Templates

The next level of process models consists of command and control processes that are generic to different Military Services. Identifying process models and the supporting data structures at this level helps streamline work process models between different parties. Such models are likely to change over time but changes are gradual. Variation is likely to be imposed only if the organization has to work with external organizations in new circumstances or if there are fundamental changes in doctrinal thinking. Over time, these processes and their data structures will be refined and improved to become best practices, making them more persistent. Finally, an important reason why generic process models ought to be developed is to impose consistency across the organization to ensure that communications between disparate parties are effective – to achieve shared mental models.

The C2KS framework should provide modifiable process templates to allow new processes to be introduced as required. To note, these components are also not meant to be the complete set but individual domains should have the liberty to add additional processes to their portfolio as required. This will ensure that a high degree of customization is achieved for each domain. The processes can be broadly divided into three categories:

Battlespace Awareness Processes

This group contains processes and components that deal with Battlespace Awareness. A key element of this group is the Common Operational Picture (COP). The COP represents the common focal point for teams working together to share information. Different Military Services have largely the same processes in place to consolidate their Operational Picture, although the way by which information is presented can be different. Some data structures may also be inconsistent. Over time, the motivation is to create similar presentation structures such that there will be familiarity of information access sites across the Services portals.

Planning and Decision Making Processes

Broad planning strategies across the organization are also consistent throughout, although specific planning processes between Military Services and their sub-domains are usually unique. Here, generic process templates would focus on Joint planning activities where consistency in planning artifacts and data structures is important. This refers to planning between different Military Services, or between different functional domains.

Battle Management Processes

Battle Management Processes must ensure integrity and timeliness of information being exchanged. Co-ordination between parties may not involve heavy information content, but interactions must be precise and handled real-time. Adopting common information models can eliminate ambiguities in information transacted. Over time, common process structures and best practices in the areas of co-ordination structures, alert mechanisms, and intent dissemination would be developed.

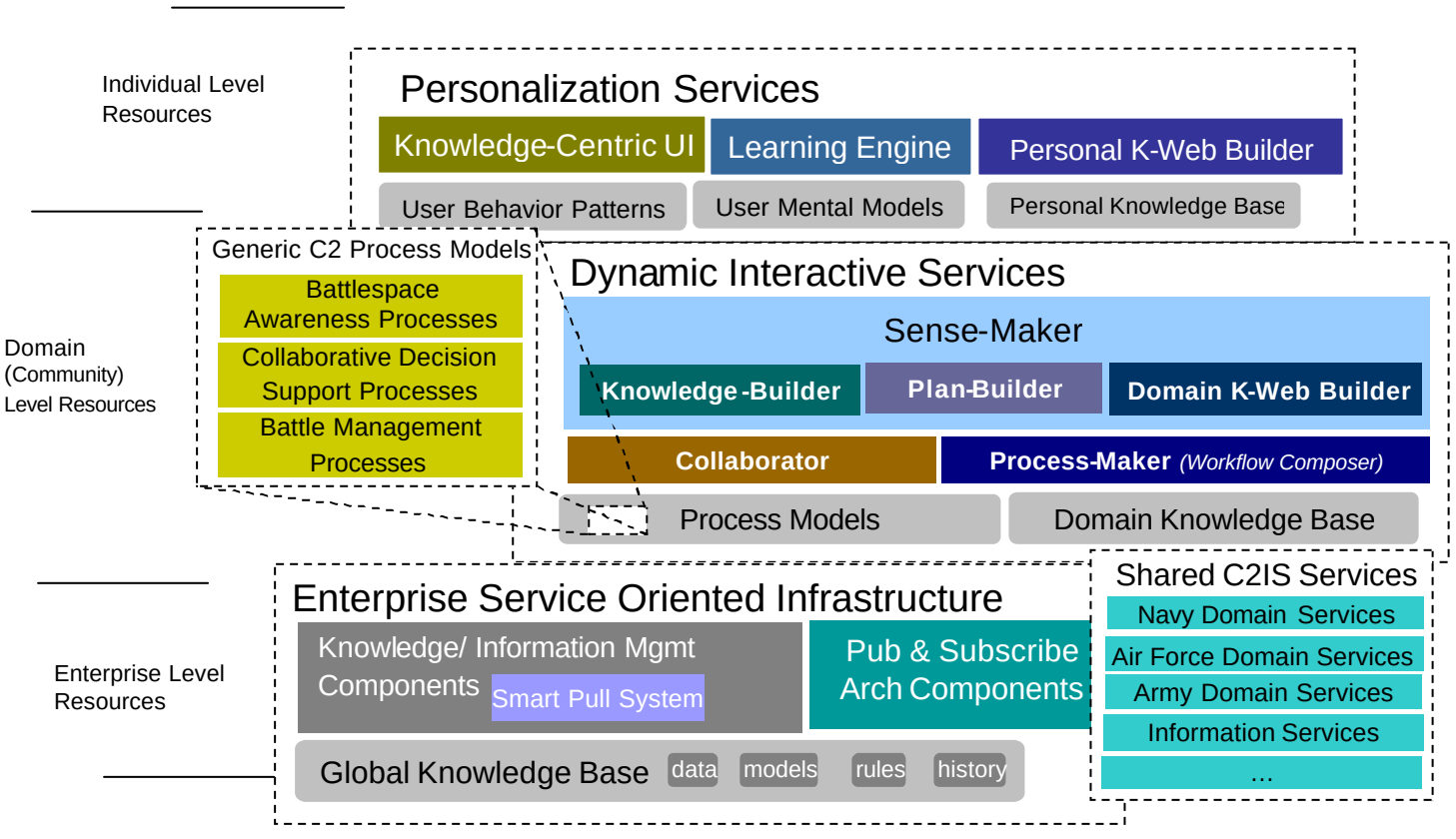
Command, and Control Knowledge-Centric System

C2KS Architecture

The architecture for C2KS is shown at Figure 4.

Enterprise Level: Enterprise Service-Oriented Architecture. The necessary foundation of the system is an Enterprise Service-Oriented Architecture (SOA) for the Enterprise Level. The SOA approach considers applications to be services offered not to stove-piped organizations, but to the entire Enterprise. This ensures that the information and applications of the Enterprise is a shared commodity (indicated as Shared C2IS Services box in Fig 4), and open for subscription by anyone in the network if necessary, and subjected to security policies. It also ensures a high degree of scalability of capabilities such that services can be plugged into the Enterprise Architecture once it is built. The SOA foundation is necessary for C2KS because only by breaking down processes into fine modular functions, can a high degree of adaptability be achieved. The idea is that with a Process-Maker in the Domain Level, services can be put together to create new systems to serve new communities on the fly.

Figure 4: C2KS Service-Oriented Architecture



Domain Level: Dynamic Interactive Services. The dynamic interactive services provides the basic freehand services for the user to appreciate the situation (See), compose his thoughts (Draw), plan, discuss, share, explain, organize etc. It consists of three main components:

Sense-Maker.

The Sense-Maker is a knowledge composition tool. It helps the user in the all the basic functions except for *Organize*.

The Knowledge-Builder component helps the user in the functions of See, Draw, Explain and Persuade. It is a hypermedia composition tool that brings together different ways of seeing, ranging from map graphics, to imagery, to video, and to virtual reality, depending on the most appropriate means. Given a set of visualization tools, such as graphs, charts, even freehand illustrations, the narrator, which could be an individual or a team, attempts to construct his train of thoughts, and eventually use the narration to explain and persuade his commanders to endorse his plans. Given his approval, they may again use the same narration, augmented with the Commander's directions, to explain to his subordinates and mission partners the plan of action.

The Knowledge Web Builder (KWB) provides depth to the information presented on the Knowledge-Builder. It serves to link ideas to a larger web of ideas in tandem with the user's line of query. To achieve "Smart Push", the KWB let the domain information owners publish their information according to domain semantic models. This could be done either manually or by automated means that could be developed based on Natural Language Processing (NLP) techniques. The principle for development and publication of knowledge web is for domain information owners to define their own semantic structures and link their knowledge base to this structure. Distributing the information search responsibility to multiple domains and its members is essentially a divide-and-conquer method that promises wider exploitation of the information space. At the Enterprise Level, Information mediators could develop meta-semantic structures to link different semantic structures that belong to different domains.

Finally, a Plan-Builder helps the narrator make calculations, think and reason with his issues, and plan his courses of action. The Plan-Builder would provide computation tools that help the narrator compute distances, resources requirements, or anticipate problems as he constructs his plans. One of the tools is Situation Ecology Time Slider Tool that allows the user to move his picture backwards in time to look at prior events and also forwards to extrapolate the situation. Looking back allows him to look at causal factors leading to the current situation, while looking forward allows him to watch how events could unfold by pure extrapolation. Meanwhile, a Decision Ecology Time Slider tool tracks past decisions made, and projects outcomes according to future decisions that are being planned. Looking at future decisions allow him to see the influence of his decisions on the situation and allow him to spot potential pitfalls. The Decision Ecology tool is an interactive tool that allows the user to ask "what if" questions.

Finally, if he is technologically savvy, he would use the Plan-builder to construct intelligent software agents, or develop simple to sophisticated codes ('macros') using scripting languages that can be stored and shared with others in the Enterprise.

Process-Maker

The Process-Maker is a work process manager that helps the user and teams organize. With the Process-Maker, it is no longer necessary to define processes during system development, but new processes can be developed on the fly. This allows the user to try out new processes, observe information transactions, look for information roadblocks, and refine the processes to perfect the C2 operations. As discussed above, a set of generic C2 process templates needs to be defined to ensure process level interoperability between systems. These are Battlespace Awareness, Collaborative Decision Support, and Battle Management Processes. Similar to Business Process Templates such as Rosetta Net, these process templates will be stored and be pulled out if a similar process is required.

Collaborator.

The Collaborator is a set of support services that ensures that the Sense-Maker and the Process-Maker can be used collaboratively between different people in a real-time or asynchronous manner. The Collaborator provide basic communication infrastructure such as Chat, Email and White-boarding. In addition, it provides additional features to monitor the collaboration and update the members on the progress of the process. If at any point of time the collaboration is broken due to network failures, it stores and continues to track developments independently and synchronizes actions when the network is up again.

Individual Level: Personalisation Service.

At the individual level are personalization services. This is the personal space of the individual. He has full control over how he chooses to see and use information. With behavior monitoring and learning engines, which could be personalization agents, some of the typical habits of the individual could be modeled and captured. The habits could be re-applied to provide greater customization to the user. The individual will also have his own knowledge base that stores his own collection of information. In a peer-to-peer architecture environment, this knowledge base will be "webbed" using the Personal Knowledge Web Service, and published. This will allow other members to access and gain insights from the information he has collected. In a way, these services will further expand the information exploitation space for the Enterprise, and at the same time, enhance the pull capability for the user – Smart Pull.

Mission Mate – A First Version of C2KS

Mission Mate is a first version of C2KS that is being built at the SCME. The main components that are available at this stage are the Knowledge-Builder, Collaborator and the Enterprise SOA foundation. Construction of the Plan-Builder, Personalisation Services, and Process Maker are in progress and could be available by the end of 2004.

Figure 5 shows the services being published and available to the Enterprise. Services are plug and playable, and exposed to any user in the Enterprise. The left hand column in the figure shows the set of services available to the Enterprise. Services could range from information services to planning services. The system is built on a common architecture framework based on a set of technical architecture standards and protocols. Using a common framework allows different developments to progress simultaneously across the organization without compromising on interoperability. Based on this common framework, a new development will immediately be plugged into this architecture and appears as a service to the Enterprise. The service will be interoperable with other services in the sense that the outputs of one service (its information products) could also be used in other services as inputs (service composition) or simply for display.

Figure 5: Services Oriented Architecture of the Mission Mate – C2IS functions presented as Services to the Warfighting Enterprise.

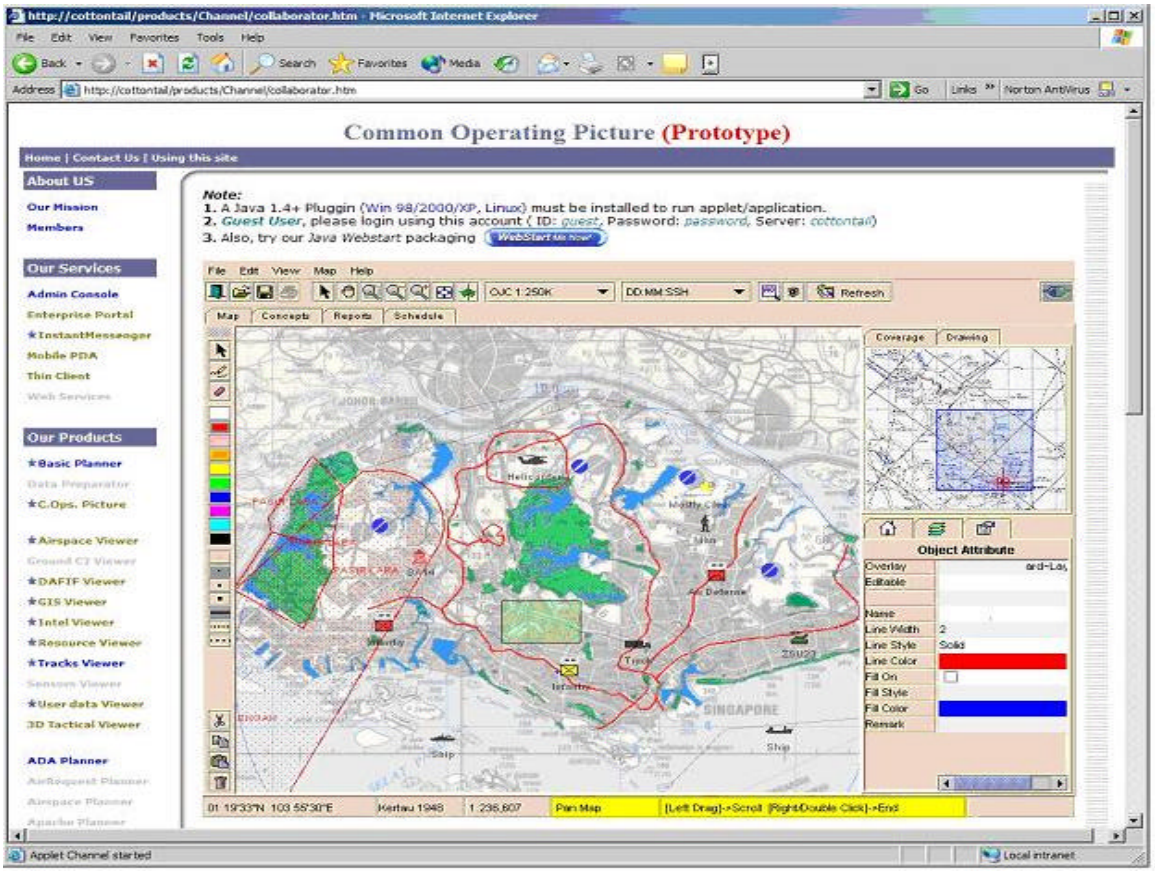


Figure 6 shows is a screen capture of Mission Mate in the collaboration mode (part of the C2KS Collaborator). It shows collaboration in progress between two different parties that could be situated physically apart. The picture shows how the system allows users to draw and articulate their ideas on a white-boarding screen to communicate their ideas across a virtual organization. The collaboration tools allow simultaneous real-time planning and so could significantly reduce C2 process cycles. Drawing tools allow users the freehand to articulate his ideas effectively. The development team will also be adding a palette of visualization tools to provide more options for people to express their ideas. Book-marking facilities are also available to allow users to move back to earlier ideas during the discussions.

Figure 6: COP and the underlying Information Architecture

Figure 7 shows the Common Operational Picture of the Mission Mate and the underlying information architecture of the COP in XML schema. The schema is defined as part of standard protocols under the common architecture framework that shall be promulgated to the organization. This standard XML schema defines a standard of information exchange across different systems. By doing so, different parts of the organization could develop front-end user interfaces according to the needs of their users to achieve high levels of customization, without compromising on the underlying interoperability. With this schema, information exchange can be achieved between disparate systems although they may be built using different technical solutions.

Figure 7: COP and the underlying Information Architecture

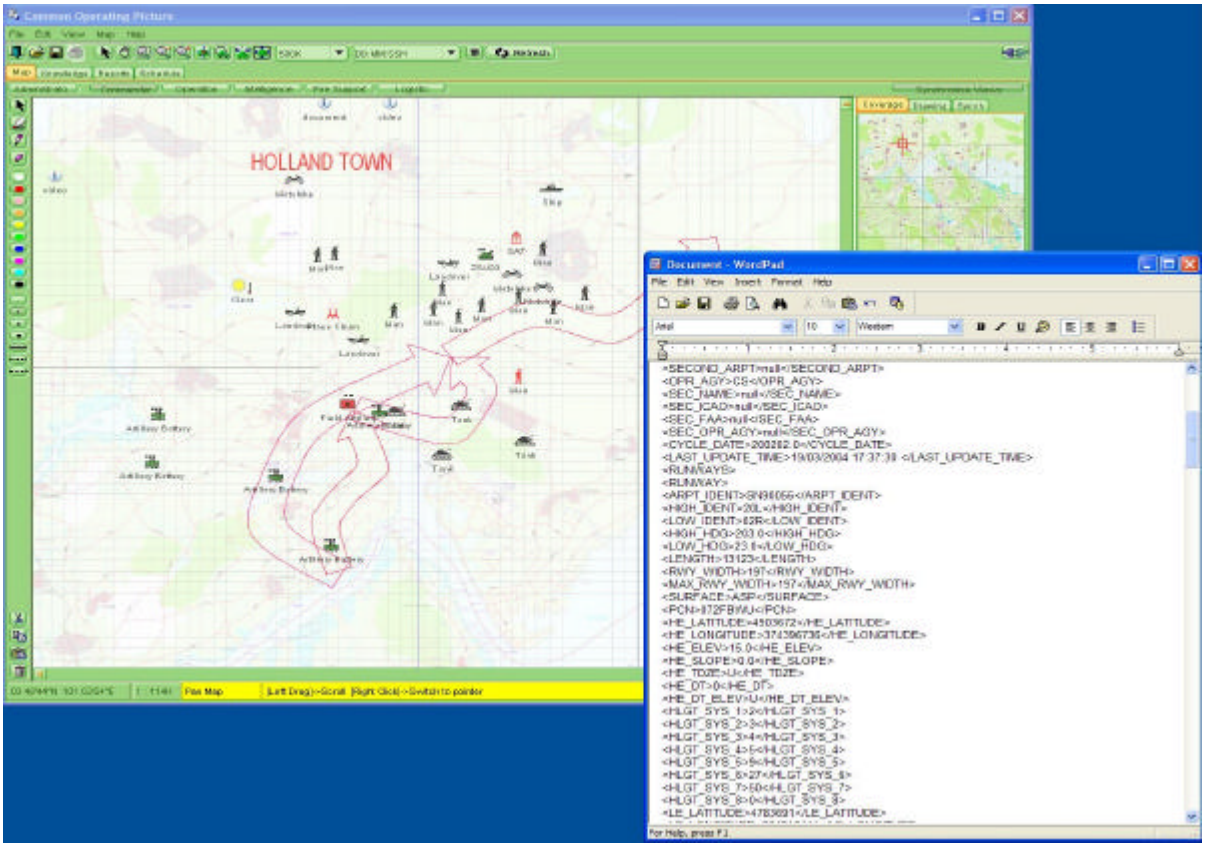
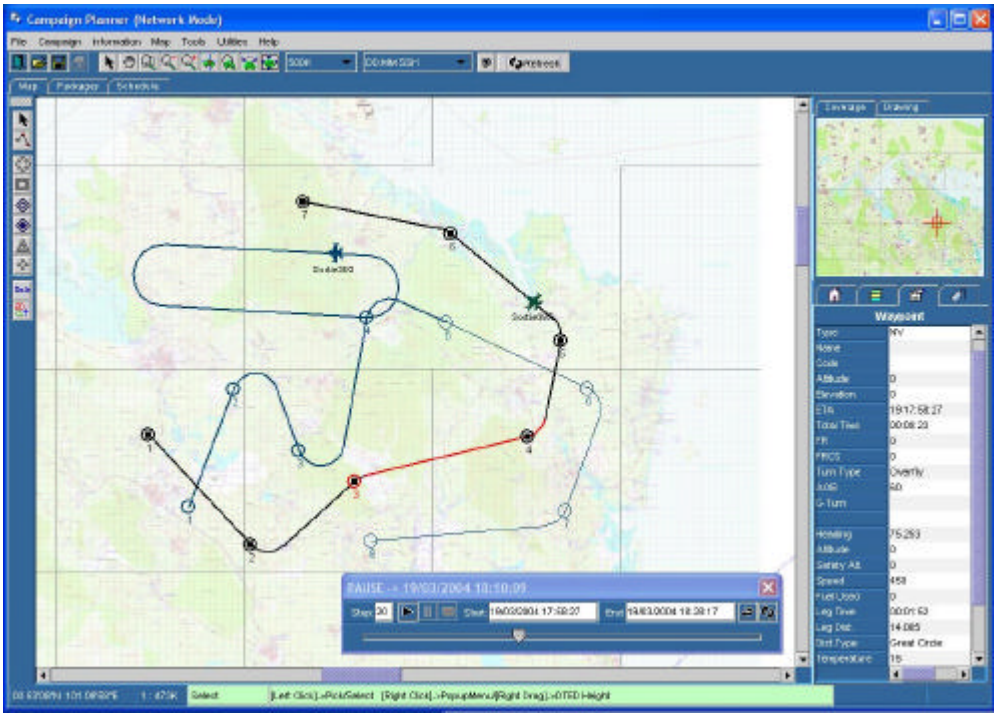


Figure 8: shows Decision Ecology Time Slider, which is a part of the Plan-Builder, applied to a flight-planning scenario. In the diagram, two flight plans were developed. The slider at the bottom of the picture could be advanced forwards and backwards to see the position of the airplanes and help determine the influence and impact of the flight plans on each other. The time slider helps the user conduct mental simulation and ask "what if" questions. It allows the user to interactively look ahead to see the likely impact of his decisions and plan on future outcomes, so that he could iteratively refine his plans.

Figure 8: Decision Ecology Time Slider



Conclusion

The C2KS is like a D-I-Y C2IS. Its underlying philosophy is to allow users or teams to construct a C2KS on-the-fly that best fit their C2 processes. This design breaks away from traditional way of constructing C2IS systems, which tends to build a system around processes. Unfortunately, this always results in unsatisfactory design because people and organization changes, and also more often then not operators defining the system do not fully understand how the C2IS should be. The principle of design for C2KS is simple. It is to provide the human and his team with a set of basic capabilities that support fundamental functions such as See, Plan, Discuss etc. In addition, the system is designed with flexibility and interactivity as the fundamental principles. Given these foundational capabilities, C2KS systems could be constructed on the fly to adapt to changes in C2 processes that is strongly influenced by changes in the operational environment. Technology is ready to do this with service-oriented architecture technology maturing.

C2KS is an experiment for the SAF, and its Defence Technology partners. It is apt that the Mission Mate experiment is conducted in SCME. The constant, and high rate of flow-through of

operators through the halls of SCME for experimentation ensures that the system is well tested and refined over and over again.

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Biographies

LTC Cheah, Mervyn graduated in 1995 from Cranfield University/Royal Military College of Science with a Masters in Defence Technology. His thesis involved the research and development into an interoperable knowledge-based engineering software for application in the military defence. He also holds a first class honours in Computer Science. LTC Cheah is an Artillery officer by vocation and has commanded an Artillery Battalion. He also had staff tours

in the Joint and Army Departments focusing on C4I developments. He is currently the Head of the SAF Centre for Military Experimentation (SCME).

Mr. Tan Chee Ping is the Division Manager of the Simulation and Wargaming Solutions (SWS) Division in Defence Science & Technology Agency. He graduated from the National University of Singapore, majoring in Computer Science. Mr. Tan has more than 17 years experience in system design, system development and project management. His work experience includes aircraft avionics software, mission planning systems, Command & Control (C2) information systems, and Wargaming and Simulation systems. Mr. Tan has been actively involved in technology and architecture work since the early 90s. He leads the efforts in the development of the C4I Technical Architecture and plays an instrumental role in the development of the Integrated Knowledge-based Command & Control (IKC2) technical framework.

LTC Lock Pin, Chew is a Naval Officer and is the Head of Command Post of the Future, SAF Centre of Military Experimentation, and concurrently the Division Manager of Knowledge-Based Solutions Division (KBSD) in Defence Science and Technology Agency. He has been involved in the conceptualisation and development of the IKC2 with the SAF. His current work involves Command Post Experimentation with the Military Services. He is also involved in the IKC2 Enterprise Architecture Developments, Information Architecture Developments for C2IS systems, and the development of the prototype Mission Mate system in the SAF Centre for Military Experimentation. Lock Pin has a Masters of Technology Degree in Knowledge Engineering and a Bachelor of Science Degree in Physics.