

Battlespace Representation for Air, Space, and Cyber

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Abstract – *We present a summary of a body of work executed over the last eight years addressing battlespace representations in the domains of air, space, and cyber. We couch this presentation in an historical context and relate it to design principles as well as user-centered design processes. We summarize the work in each of the domains and conclude with some thoughts about supporting real work in applied settings.*

Keywords: visualization, agile work environment, work-centered support systems, air, space, cyber

1 Introduction

Visualization has a long history. Its value is well illustrated by the work of Dr. John Snow. Between 1831 and 1854, Great Britain suffered four major outbreaks of cholera. Throughout this 20-year period, and despite volumes of recorded data on casualties, the situation baffled the local authorities as well as the scientific community. Snow created an overlay of the victims in a single neighborhood, and observed that the epicenter of the epidemic converged at a water pump on the corner of Broad Street and Cambridge Street. ¹ The map can be viewed at <http://www.ph.ucla.edu/epi/snow/highresnowmap.html>.

Similarly, battlespace representations have a long history of evolution and use. One of the authors once worked with a senior leader in the Cockpit Integration Office at Wright-Patterson Air Force Base (WPAFB) who frequently declared his NUTS theory: “Nothing under the sun.” The theory was based on the notion that technology changes, but the ideas stay the same. Thus, 3D displays, while a current technology trend, were used in WWII; they were cardboard models of targets carried in the bombers to allow bombardiers to see how the target would look with current shadows. See Figure 1 for an example.

Command and control has changed as well as targeting. Figure 2 illustrates a WW II-era command center built in tunnels near Dover, England. The plotting table was used to keep track of aircraft movements as radioed in by spotters. The concepts, in both cases, 3D models and command and control centers are thus demonstrated to not be novel; the concepts stay the same, but the technology to support them is ever-changing. The ever-changing technology landscape leads developers of Battlespace representations to both stay

abreast of current technology and to seek invariants that can be used to shape or guide designs.



Figure 1. A cardboard model used by bombers.

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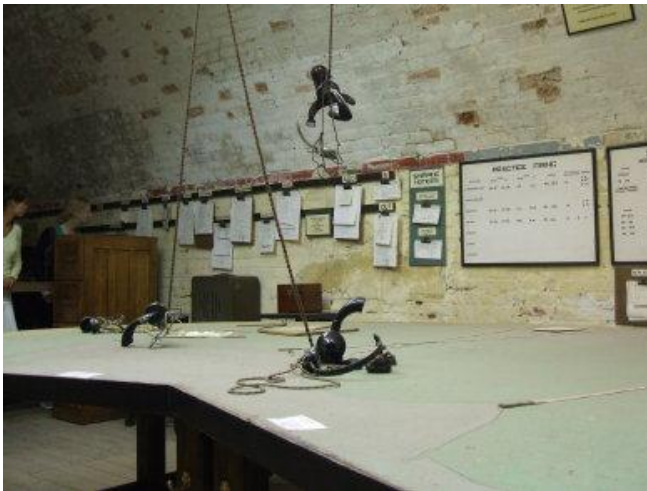


Figure 2. WWII plotting table in Dover tunnels 1.

2 Stable Design Principles

What is invariant is the human perceptual and cognitive apparatus that underlies the sense-making process when using current display technology and techniques. Thus, the relationship between and among displayed objects, their color, texture, and contours and the use of those relationships and properties in telling a story, communicating a situation to the user or operator, is critical. Display or graphics designers must be deeply aware of the needs of their users.

Also invariant are the notions of visual momentum, visual search, isomorphism, vernier acuity, Stroop effect, and Gestalt closure. Graphic or interface design can either induce or reduce visual search, dependent on the task at hand and the relationship between and among display elements. The Stroop effect, which manifests itself as interference in the processing of the names of colors written in colors other than those of the color being named, illustrates verbal and visual conflicts in processing information.

Strategies such as Shneiderman's "Overview first, zoom and filter, then details-on-demand."² or McCracken's progressive refinement in which the broad context is conveyed in the upper left of the display, and successively refined left to right and top to bottom, with the bridge between context and data being appropriately designed levels of abstraction/levels of detail.³

Yet another concept is the notion of surface structure vs. deep structure of the interface. This concept addresses issues such as system transport delays, which can manifest themselves at the user interface and thus impact the user's experience. Ignoring the effect of time delays on the delivery of data to dynamically updating displays can have deleterious, even catastrophic results (think Ground

Collision Avoidance Systems) GCAS). All of these elements (and more) are the underpinning of good display design. In order to support "connecting the dots" or making information available "at-a-glance" these human perceptual and cognitive factors must be addressed. Their consideration and integration in the interface development process are critical for success. This was as true in Snow's day as it is today.

3 Air Force UDOP Family of Systems

The Air Force Research Laboratory (AFRL), 711th Human Performance Wing (711th HPW), Battlespace Visualization Branch (AFRL/RHCV) has sponsored a series of Small Business Innovative Research (SBIR) efforts dating back to 2004 aimed at developing Command and Control (C2) Battlespace Representations for Air, Space, and Cyber. The Design Knowledge Company has won five of those contracts. These include the Satellite Threat Evaluation Environment for Defensive Counterspace (STEED), Local/Distributed Operational Collaborative User-Centered Support System (LOCUS), 4D NETcentric Framework For Operational C2 Environments (4D NETFORCE), Air Operations Community (AOC) System Engineering Toolkit (ASET), and Air, Space and Cyber User-Definable Operational Picture/Common Operational Picture (ASC&U/C). These are summarized in Figure 3. Space Weather Information Fusion Technology (SWIFT), Bridge for Usable Collaborative Knowledge Integration (BUCK-I), and Visualization of Information for Satellite Tactical Applications (VISTA) are plug-ins to the core UDOP technology and support battlespace operations in air, space, and cyber. These capabilities have matured to the point of being the work environment for the JMS program of record, and being used in the 2011 Joint Expeditionary Force Experiment and Advanced Concept Event. An overview is provided in Figure 3.

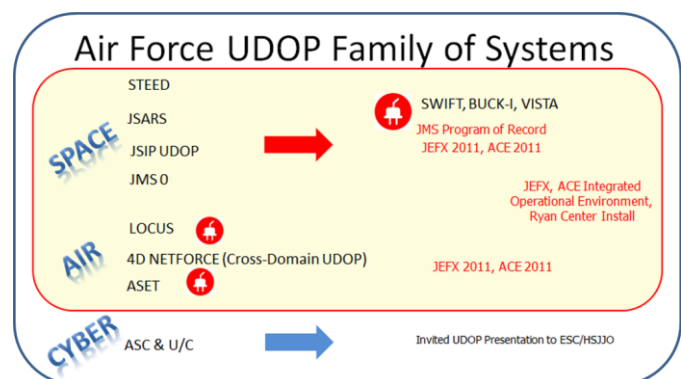


Figure 3. Family of Agile Work Environments

4 User-Centered Design

The United States Air Force has a long history of user-centered design. Each of the projects described began with an understanding of the user population. Cognitive task

analyses were performed, pertinent documents reviewed, users interviewed, and work processes observed. The key to our success is that TDKC cognitive and human factors engineers work closely with our software development team to ensure that we build a work environment that focuses on a single, unified user interface to multiple systems that is tailorable for individual users. This integrated team approach is critical because our JMS experience has demonstrated that legacy tools as well as many different vendors may be contributing services to support diverse functionality, each having different styles and thus requiring the cognitive and perceptual integration task to be done in close collaboration with the UDOP software development. We next describe space, air, and cyber visualizations in the form of Agile Work-centered Environments (AWEs) developed for AFRL/RHC.

4.1 Space

Space assets are critical to our military superiority, thus making them targets for attacks. These attacks were difficult to detect using current (2003) tools available at Space Operations Squadrons (SOPS) or Joint Space Operational Center (JSpOC) because the degradation effects may be gradual and appear to be isolated. Improved user work-centered technologies were needed to assist the operator in detecting otherwise imperceptible trends and to rapidly gather the information needed to report the incident. Neural networks were being refined for counterspace operations and could detect some trends, but this technology lacked the flexibility needed for warfighters to perform their own analyses. Current (2003) technology lacked advanced collaboration methods to communicate results of analyses across echelons; an example of this is communicating a finding from SOPS to the 14th Air Force. To address this problem, AFRL/RH sought innovative proposals to develop a Work-Centered Support System (WCCS) that bridged the gap between the analyst and the numerous information sources available, as well as collaboration across echelons. The resulting STEED project evolved through a series of steps into the Joint Space Operations Center (JSpOC) Mission System (JMS) UDOP. An example of one of the JMS UDOP perspectives is shown in Figure 4. JMS is built on a net-centric, Service-Oriented Architecture (SOA). STEED employed a variety of visualization approaches to build situation awareness support. These include 2D and 3D geovisualizations using NASA WorldWind, standard graphical user interface tools such as pick lists and tree structures, task-customized small multiples, and various time-based views, among others.

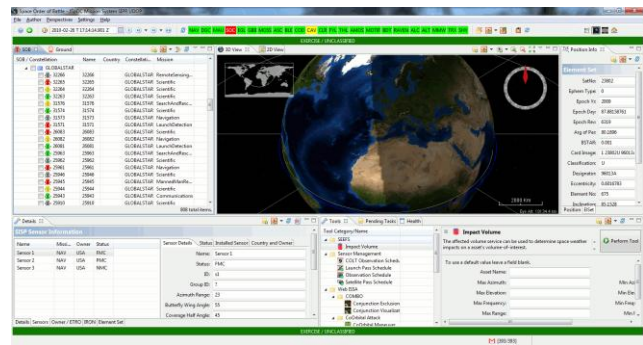


Figure 4. Using the Space Order of Battle Perspective to select a GLOBALSTAR asset.

4.2 Air

The 4D NETFORCE effort assessed the requirements to transform the existing TDKC STEED into a Command and Control (C2) environment to support work in Air Operations Centers (AOCs), providing integrated 2D and 3D spatial and temporal displays. The result of our investigations, working with the AOC experts from Teledyne-CollaborX, was that this goal was fully achievable. We identified open source tools to integrate various information sources such as InfoWorkSpace (IWS), email, databases and electronic chat, and created an ability to run Microsoft products such as Word, Excel, and PowerPoint inside of the 4D NETFORCE framework; this is critical because many AOC products are captured using Microsoft (MS) tools. A sophisticated data loader supports the import of data from a variety of data sources, including legacy stove-piped systems, JSeries messages, and net-centric services. 4D NETFORCE has been used at the 2011 Joint Expeditionary Force Experiment (JEFX) and Advanced Concept Event. It incorporates all of the UDOP core technology found in JMS. A sample perspective from the 4D NETFORCE capability is shown in Figure 5.

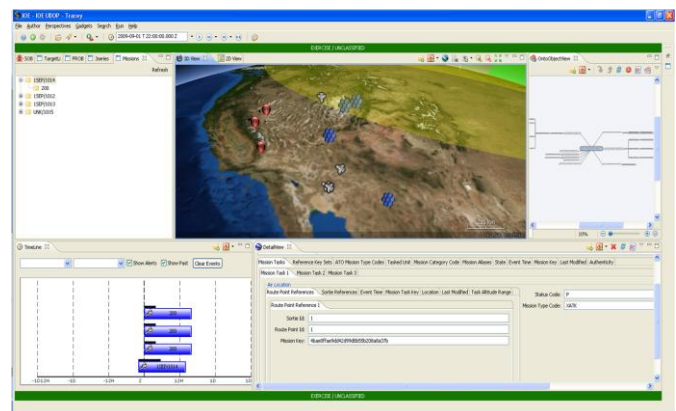


Figure 5. Air picture with order of battle, map, timeline and tasking views.

4.3 Cyber

Major General Ellen Pawlikowski, while Deputy Director of the National Reconnaissance Office (NRO), was asked at the 2009 AMOS conference about the biggest threat to space assets. Her answer was “Cyber.”

Focusing on visualizations, data handling and design, and operator aiding, the ASC&UC project is extending the existing UDOP capability into a comprehensive command and control (C2) visualization space and shared collaboration space for Air, Space, and Cyber warfighters. Meeting this challenge, The Design Knowledge Company (TDKC) is building a principled framework for visualization to ensure visual coherence over the three domains. Developing new innovative collaboration and visualization components that can integrate across space, air, and cyber domains will yield a robust and adaptable framework for lowering the cost of current and future developments and provide a much-needed synergy across development. A preliminary example of a cyber perspective is illustrated in Figure 6.

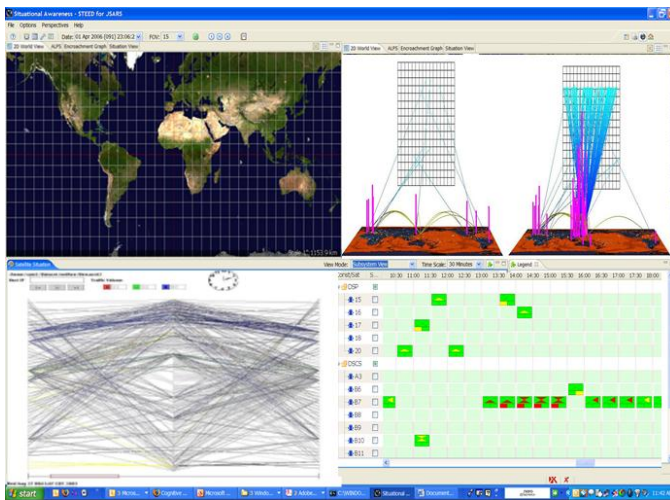


Figure 6. Cyber perspective showing map, data, and small multiple visualizations.

4.4 Cross Domain Work Environment

TDKC has derived a toolkit and framework from the components developed across all of the projects described above. The Agile Work-centered Environment (AWE) core contains the capability that is supported across all domains. AWE allows us to very rapidly integrate domain-specific data sources to develop tailored work environments. TDKC cognitive engineering processes define the information and knowledge required to support work₄; our design knowledge guides the structure of the user interface, and our software

development processes and usability testing ensure reliable, usable end products.

Using the AWE toolkit and accompanying processes, TDKC is building an AWE supporting situation awareness for the nuclear arsenal. The AWE toolkit brings the capability to develop what Lt. General Bob Elder, at the time Commander, 8th Air Force, called game-changing integration across domains, illustrated in Figure 7.⁵

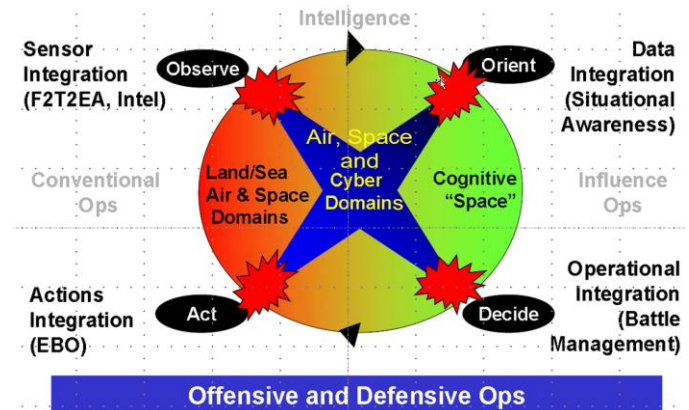


Figure 7. General Elder's Conception of Game-Changing Integrated C2.

5 Conclusions

Figure 8 borrows another graphic from Gen Elder's 2007 NDIA presentation. This graphic shows the 2007 vision of moving our command centers from having a multitude of stovepiped tools and data bases each with its own display to a set of services that can share data and present a single User Defined Operational Picture. In 2006-2007, there existed in the AOC some 88 different stand-alone tools. During a CTA conducted with JSPOC operators, the authors identified more than 75 different tools in use.

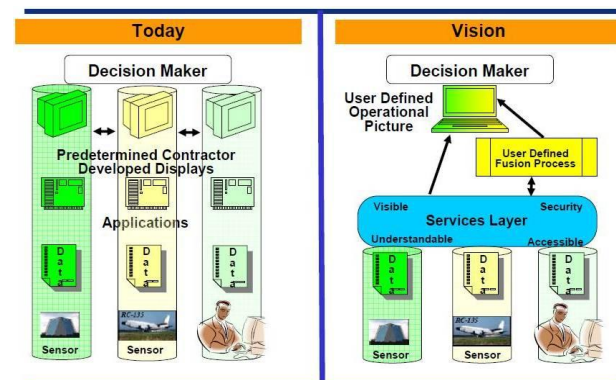


Figure 8. Evolution from legacy stovepiped systems to services-driven UDOP.

We've made considerable progress, particularly on the technology side. SOA has allowed us to move away from stovepiped tools and databases. However, this doesn't make decision maker's task any easier unless the data is fused and presented in a way that facilitates sensemaking. Bringing all this data together requires much more than simply hanging legacy tools or new applications on a SOA. Roth et al assert that "In too many cases, the introduction of computer technology has placed greater requirements on human cognitive activity. ...systems that provide access to more data or that automate more processes do not necessarily simplify the user's task or guarantee improved performance."⁶ Somehow must get from an overabundance of data to decision quality information. This requires correlating data in time and space, putting the right data together, dealing with conflicting data as well as metadata, and presenting the data to the decision maker in a way that is easily understandable.

Much of data fusion takes place in the grey matter of the human. Understanding how humans fuse data to reach conclusions is an important area of research. Visualizations are for the purpose of allowing humans to understand something – to get meaning. Designers must understand the applied work space to know what meaning is needed; they must have a deep understanding of the real work. Issues include more than providing individual pieces of information, but providing context and integrating the information in a meaningful way. We must also consider facilitation of shared understanding for collaboration.

Creating visual representations for individual applications is easy; creating a holistic operator environment is difficult. Operators and decision makers need the UDOP to be a holistic information composition expressed thru interactive visualization. The technology solution should amplify the human cognitive expertise and minimize interaction overhead.

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