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Intense Collaboration for Command and Control: Human and Technology Capabilities

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Focus & Convergence for Complex Endeavors

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Intense Collaboration Environments

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Abstract

Teams involved in Command and Control (C2) activities are being increasingly overwhelmed by the amount of information that is available to them, the diversity and complexity of the technologies that they need to use, and the nature and intensity of collaborative tasks. New socio-technical approaches for the design, development, and acquisition of future C2 capabilities are needed if we are to address these challenges. This article discusses the results of a multi-project program of research and development, called *LiveSpaces*, which has been undertaken over the past decade to provide people-centric environments that directly support the needs of collocated and distributed teams involved in intense collaborative activities. Research has been conducted into emerging areas of science and technology, such as ubiquitous computing, which could provide a basis for a new generation of C2 workplaces where technology is put into the backdrop of human cognitive and collaborative activities. Novel ICT-enabled evaluation, experimentation, and innovation approaches have been developed and integrated into new socio-technical approaches for the development and acquisition of future C2 capabilities.

Introduction

The rapid uptake of Information and Communication Technologies (ICT) has created a situation whereby decision-makers can have ready access to a wealth of information and have unprecedented channels of communication and collaboration. The use of ICT to provide an information edge (Alberts 2002) has been seen as a way of gaining a strategic advantage through superior situational awareness and by being able to operate within an adversary's decision cycles. However, the ready availability and enhanced capability of ICT has brought with it many challenges. The threat environment is changing since adversaries are able to easily acquire and use advanced ICT for a broader range of operational situations including the use of asymmetric warfare and terrorist activities. Also, the operational environment has become more complex in that Command and Control (C2) teams must operate within ever tighter time constraints, often dealing with multiple concurrent tasks and threats. There is little strategic advantage in simply having access to technology and information—the advantage comes from how technology can be used to enhance and augment the abilities of people.

In addition to an inherent complexity of the threat environment, there is an increasing requirement on the cognitive and social abilities of people due to a range of complex organizational and systems issues. For example, the introduction of new technologies is not without its cost in terms of human cognitive processing. Each new "tool" has its own specific modes of operation which must be learned and conformed to during the course of an activity. Even the workplaces which host the team's activities are becoming more complex through the introduction of multiple displays, video conferencing technologies, electronic whiteboards and the like. Interaction with the workplace environment itself is often accomplished through the use of multiple interface and interaction devices such as touch panels and remote controls. Also, the requirement to quickly react to multiple concurrent tasks and the need to engage with multiple specialist staff and external agencies, often from other geographic locations, creates significant collaboration challenges in terms of intensity and planning. Advantage in this increasingly complex world of work comes from addressing the many underlying socio-technical challenges and through augmenting the cognitive and social abilities of people.

The design, development, and acquisition of new capabilities to provide such advantage is not straightforward. Most acquisition systems measure success in terms of the delivery of systems within a defined time and budget. The capability and cost of ICT is largely based on commercially available components. Clearly, an information-based capability requires the underlying networks and infrastructure to provide ready access to required information and to support human collaboration. Traditional acquisition approaches have been successful in the delivery of technology components but often fail to address the more salient team requirements, especially where these teams are geographically distributed. The work of C2 teams typically requires high levels of creativity and innovation, both in terms of using ICT and information and in defining, testing, and executing a particular course of action. Capturing these types of socio-technical requirements is particularly problematic in that many team needs and processes change and adapt depending on the actual and emerging situation. In this article we argue that new approaches are needed to allow systems to be acquired in a more adaptive and ongoing manner and where end-user innovation, experimentation, and training become an integrated part of the capability development process.

An extensive program of research and development has been conducted over the past decade to address the challenges of designing, developing, and using future socio-technical capabilities to support intense collaborative activities within C2 teams. This multi-project program, called *LiveSpaces*, has been led by the Defence Science and Technology Organisation in Australia and has involved a host of partners including Universities, Cooperative Research Centers, and R&D agencies in Canada, the United States of America, and the United Kingdom through The Technical Cooperation Program (TTCP 2010). LiveSpaces has resulted in the generation of new knowledge, new approaches, and new technologies. This article presents and discusses the results of this program to date and reflects on some of the main issues, challenges, and considerations for the future.

Section 2 provides background material in areas such as Intense Collaboration, Cognitive and Social Informatics, and Ubiquitous Workspaces. Sections 3 through 5 then discuss a range of concepts, approaches, technologies, and results within the context of three successive LiveSpaces projects: Augmented Context Aware Work Environments (ACAWE), Augmented Synchronised Planning Spaces (AUSPLANS), and Command TeamNets. This story-line approach is used to help highlight how new challenges emerge and must be addressed as we move from early research and concept development, through concept evaluation, and into actual deployment. ACAWE was the initial LiveSpaces project which defined the LiveSpaces concepts and models and provided a new socio-technical basis for collaboration environments based on ubiquitous computing concepts. AUSPLANS (Evdokiou et al. 2004) then extended the ACAWE platform and developed new approaches for the orchestrated evaluation of capabilities, focusing on the use of LiveSpaces for intense distributed planning in joint task forces. Command TeamNets extended the work further to focus on how these methods might be used as a way of significantly enhancing the overall development and acquisition of C2 capabilities. As part of the project, a network of LiveSpaces environments was deployed into Australian Defence Force headquarters and Joint Training facilities as well as being linked with R&D laboratories. These environments allowed for both operational and developmental capabilities to be surfaced to C2 staff in a seamless way, thereby providing a basis for direct end user participation in the development and evaluation of capabilities on an ongoing basis. New evaluation methods and tools, such as the ICT-enabled Evaluation method and TeamScope, were developed to support new C2 acquisition and development approaches. Section 6 summarizes our findings to date and discusses future considerations before providing concluding remarks in Section 7.

Background

This section provides background information on the notion of Intense Collaboration Environments. We begin by a discussion of intense collaboration, both from an operational and a human point of view. We then extend this discussion to focus on some of the related socio-technical aspects of ICT in terms of cognitive and social informatics. This then provides the setting for a discussion of the concept of Ubiquitous Workplaces: an underlying theme for the work discussed in this article.

Intense Collaboration

In our earlier work (Vernik et al. 2003; Blackburn et al. 2004), we used the term *intense collaboration* to highlight the types of emerging challenges that would need to be addressed for those engaged in collaborative creative activities due to the inherent social, organizational, and technological change brought about by the so-called information age. Our work has focused predominantly on C2 activities at the operational and strategic levels of command in areas such as coordinated decision-making, collaborative planning, and synchronized action. Although we posited no formal definition of *intense collaboration*, we did define the main parameters and contexts for our use of the term. For example, from the outset our focus was on synchronous collaboration between and within collocated and distributed workplaces. We were particularly interested in teams engaged in creative activities, where intense interactions between people result in new knowledge, a strategy, or course of action. In this type of work, a particular physical *product* such as a document, is often not the main outcome of the work. Rather, the conduct of the activity generates new knowledge and understanding among the participants.

More recently, the concept of intense collaboration has been more formally defined. For example, Kumar et al. (2005) define intense collaboration as: "the level and frequency of interactions needed for initiating and sustaining joint action and mutual awareness of the members of the team, the flux of activities in teamwork, the evolving work-object, and the context of the collaboration situation." They propose a model with four dimensions to help characterize intense collaborative activities. These dimensions refer to the temporal arrangements of work, the ease of sharing work, the tightness of work coupling, and the uncertainty of work. Bowman et al. (2009) draw from and extend on this work to define a contextual basis for Intense Collaboration in Command and Control. They extend the contextual model of Kumar et al. (2005) to include considerations outlined by Alberts and Hayes (2006) in relation to the transformation of C2: "allocation of decision rights, patterns of interaction among the actors, and distribution of information." Together, this work provides a useful descriptive basis for defining intense collaboration and will be referred to in the discussions in this article.

Cognitive and Social Informatics

The previous section provided an organizational and team context for intense collaboration. We now extend our discussion to consider background material on the socio-technical aspects of information capability.

The interplay between people and technology has become an important research topic of late as technology becomes an integral part of how we live and work. In particular, the socio-technical challenges for teams, particularly where they are involved in time-critical decision making roles, require new understanding and theories. For example, Hutchins (1996) discusses the notion of Distributed Cognition in relation to the activities within the bridge of a ship where there are many complex relationships between people and technologies. Rather than simply focusing on the individual and internalized mental representations, he and others (Norman 1993; Winograd 1996) argue that we need to take into account externalized representations which include artifacts and other people.

Our particular focus has been on the use of ICT to enhance the cognitive and social abilities of teams. We used the term "cognitive and social informatics" to convey the multidisciplinary nature of our work and to highlight the specific types of challenges that we were attempting to address. The term informatics has been used to direct attention to research that deals with the *application* of information science and technology rather than the underlying mechanisms of computing typically associated with computer science, such as study of programming languages, data modeling, and algorithmic processes. In our work, we were particularly interested in the *intersection* of the emerging fields of cognitive informatics (Wang et al. 2009) which focuses on the application of information science and technology to study and enhance the intelligence and computation processes in humans, and social informatics which studies the design, uses, and consequences of information technologies taking into account their interaction with institutional and cultural contexts (Kling et al. 2005). We argue that research in areas such as Computer Supported Collaborative Work (CSCW) and Human Computer Interaction (HCI) lie at the intersection of cognitive and social informatics where elements of individual cognition, team, or metacognition (Letsky et al. 2008), social and cultural factors, together with computing and information sciences must be addressed in a holistic way if we are to gain advantage from new approaches for ICT-enabled distributed teamwork.

Ubiquitous Workplaces

We now turn to how we might begin to develop future workplaces to support intense collaboration, taking into account the various socio-technical considerations. New information and communications technologies are beginning to emerge which aim to make technology transparent to users and hence move the focus from technological solutions to human abilities and needs. Weiser (1991) in his seminal article on "The Computer for the 21st Century" outlined a future where computers would be woven into the backdrop of natural human interactions. He called this ubiquitous computing. Over the years, major advances in areas such as wireless devices, natural language and speech interfaces, and interactive display technologies have helped us move towards this vision.

Our early research drew from the emerging body of work on ubiquitous computing as a way to develop new types of intelligent interactive environments (Vernik et al. 2003) to help people to interact ubiquitously with each other, with their environments, and the information they use. We called these new types of environments "ubiquitous workspaces" (Vernik, Johnson, and Vernik 2004). There were several related R&D programs which were beginning to address how physical collaborative workplaces such as meeting rooms could be augmented with ubiquitous computing and intelligent systems technologies. Examples of research initiatives in this area included Stanford's Interactive Workspaces (Johanson et al. 2002), MIT's Intelligent Room (Coen et al. 1999), GMD's i-Land project in Germany (Streitz et al. 1999), and the University of Illinois Urbana Champaign (UIUC) Active Spaces project (Cerqueira et al. 2001). Much of the research focused on the infrastructure and human interfaces required for single meeting room situations.

There was also related research being undertaken into the processes and facilities needed to support extreme (or intense) collaboration within team environments, often referred to as project or war rooms (Covi et al. 1998). For example, Mark (2002) defined extreme collaboration as "working within an electronic and social environment that maximizes communication and information flow." Her study of a 16-person team that designed space missions for NASA's Jet Propulsion Lab showed that the amount of time required to create a space mission design was reduced from 3-6 months to about 9 hours by switching to a technologically rich "war room" environment.

The LiveSpaces program was initiated in Australia to take a holistic approach for the design, development, acquisition, and use of future intense collaboration environments (Vernik et al. 2003). R&D was undertaken in several areas with a particular emphasis on support for multiple geographically distributed teams engaged in intense collaborative activities. From the outset, there was a strong emphasis on evaluation and experimentation. The work looked not just at technological solutions but more broadly at how people work. In addition to considering how future technologies might be used to help people achieve desired goals, the various LiveSpace projects have developed and experimented with various workplace layouts, new types of furnishing, and new work processes and practices.

What is LiveSpaces?

LiveSpaces is a program of research and development undertaken over several years and involving several organizations and projects. LiveSpaces was designed to be a longer-term, sustainable program of R&D with mechanisms in place to support effective R&D collaboration among various organizations, research disciplines, and stakeholders. As highlighted in this article, the projects have generated a significant amount of research output and provided several new technological capabilities. More recently, the LiveSpaces name has been identified with tangible products resulting from the work such as particular physical facilities or more particularly, the LiveSpaces Operating Environment (Phillips 2008), a ubiquitous workspaces infrastructure that has been released as open source software (LOE Sourceforge site 2010). There is a danger that, in focusing on resulting technology, we lose sight of the main vision, goals, and drivers of LiveSpaces: to address a range of socio-technical issues related to teams engaged in intense collaborative activities where technology was to be made as transparent as possible. This section will attempt to redress this situation by reaffirming the underlying LiveSpaces concepts and models which were established during the first LiveSpaces project and which have remained the foundations of the approaches that have been developed and evaluated to date.

Augmented Context Aware Work Environments (ACAWE)

Preliminary LiveSpaces research was undertaken at the e-World Lab at the University of South Australia to gain an understanding of how physical spaces such as meeting rooms might be rapidly augmented using emerging ubiquitous computing and intelligent systems approaches to enhance the effectiveness of teams involved in a range of intense collaborative activities. The Augmented Context Aware Work Environments (ACAWE) project was initiated and involved staff from DSTO, the University of South Australia and a cadre of students. Early experimentation was undertaken using MIT AI lab's MetaGlue, an agent-based infrastructure which aids the integration of various workplace devices and applications. A relationship was also established with researchers at Stanford University's iRoom Project which resulted in the use of the Interactive Room Operating System (iROS) as one of the components of the initial LiveSpaces Operating Environment. User communities were engaged in the project from the outset to help researchers gain an understanding of the socio-technical challenges of intense collaboration, particularly in relation to teams engaged in creative enterprises in areas such as law (Quirchmayr 2001), national security, and emergency services. The Chief of Staff of an Australian task force headquarters became engaged in the project. He, together with some of his senior planning staff, visited the R&D team regularly and helped guide project directions. This relationship was maintained over several years and played a key factor in enabling the evaluation and transitioning of the LiveSpaces capabilities.

A key result of this phase of the work was the development of the LiveSpaces Reference Model which defined the underlying LiveSpaces concepts and provided a road map for future R&D.

LiveSpaces Reference Model

The main conceptual and architectural aspects of LiveSpaces are captured in the LiveSpaces Reference Model shown in Figure 1. This model has been used to support communication, coordination, and collaboration between various researchers, developers, and stakeholders and has enabled the R&D activity to be sustained over several years and projects. A frame of reference is particularly important when there are multiple organizations involved, often with differing objectives, and where cross discipline science and technology approaches are required. For example, as the program evolved, the team involved a mix of experienced researchers, PhD and other student projects, industry participants, engineering professionals, and analysts often working on separate perspectives of the problem.

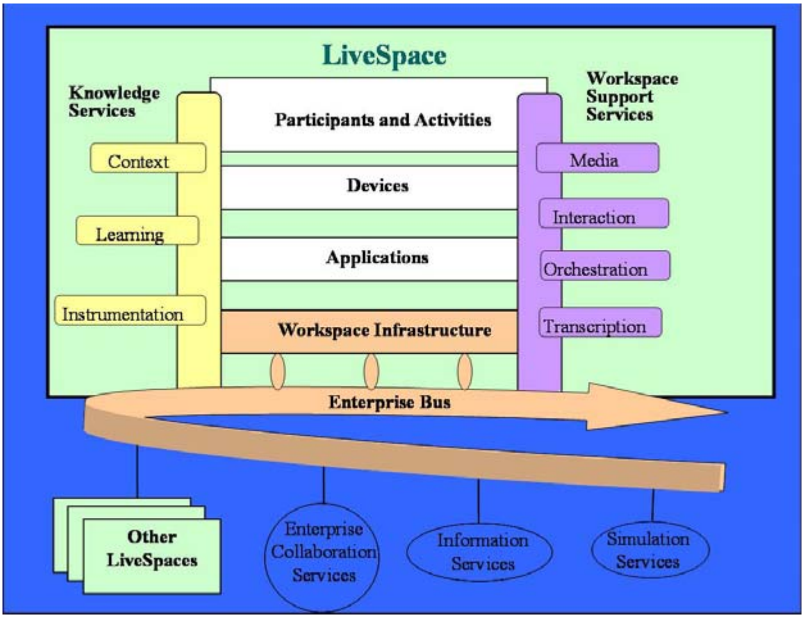

Figure 1. LiveSpaces Reference Model

The following paragraphs define conceptual and architectural constructs of LiveSpaces as portrayed in the reference model. Other papers and documents (Bright and Vernik 2004; Phillips 2008) provide actual implementation and technical details.

Enterprise Enabled. The concept of an Enterprise Bus enables LiveSpaces to be readily integrated with, and operate within, a broader organizational setting. One of the key aims of LiveSpaces was to provide mechanisms which would support successful transitioning into actual use. As such, a mechanism was required to provide command teams with ready access to enterprise-wide services such as information repositories, collaboration services such as video teleconferencing and chat, and simulation services to conduct their work. Another key focus of LiveSpaces was to support the deployment of a network of distributed LiveSpace environments. The Enterprise Bus provides the means of coordinating and synchronizing multiple distributed LiveSpace environments and supports integration with other elements and services that make up the wider enterprise.

Workplace Integration and Coordination. The Workspace Infrastructure provides for the coordination and integration of all facilities, devices, applications, activities, and services within an entire workplace, much like an operating system might provide for an individual computer. It provides support for event management, information management, and control within the workplace and interfaces to the enterprise bus to allow coordination and integration across multiple workplaces.

Knowledge and Workspace Services. The Reference Model identifies two sets of services: knowledge services, and workspace support services. Knowledge Services provide support for those aspects that help make a workspace "intelligent." These could include instrumentation services that capture and provide information on usage and interaction within a workspace, context services that have knowledge of the participants and activities, and learning services that maintain symbolic representations to facilitate and automate workspace functions. Workspace Support Services provide mechanisms that can be used to directly support workplace operations such as the transcription of speech to text; support for multiple interaction modalities such as gesture, speech, and touch; and media services that allow the management and use of various types of media including video, imagery, text, and sound as well as new media approaches such as augmented reality (Slay et al. 2003). These services can be used directly, and in combination, to implement novel workspace applications such as universal session interfaces, ambient information displays, and intelligent listeners.

Orchestration, Adaptation, and Automation. The concept of a workspace orchestration service has been explored as part of the LiveSpaces research (Blackburn et al. 2004). The orchestration service provides the means of coordinating a set of actions and activities within a workplace, much as a workflow engine might do for more traditional information processing. This service allows the development of a new class of workspace applications, called Meta Applications (or Meta Apps). Meta Apps can draw from a range of knowledge and workspace support services to automatically control, access and coordinate the various workspace facilities, devices, applications, information, and media. This then provides a mechanism to support workspace adaptation and automation. For example, Meta Apps are used to automate the setup of LiveSpaces at start up, shut down, and to support particular team activities. They have also been used as the basis of a new orchestrated evaluation approach (discussed later), and have been used for automated briefing purposes.

The following example helps illustrate how the various elements of the LiveSpace Reference Model come together to support a particular objective. From the outset, Meta Apps have helped capture, present, and demonstrate LiveSpaces results and capabilities. A major problem for R&D projects and staff is the amount of time taken in providing presentations and demonstrations of results. Moreover, staff and students are not always available when required, graduate from their studies, or move to other projects. A Meta App called e-Ghosts (Vernik, Johnson, and Vernik 2004) was developed to orchestrate, coordinate, and control multiple applications, projectors, computers, speech synthesis, display surfaces, lighting, and various types of media to communicate particular pieces of work—in a sense leaving behind the virtual footprints of the R&D staff. An embodied conversational agent application called Kayla provided the *human* interface to the orchestration service to allow for interactive control and to act as a type of session facilitator.

Intense Collaboration Space

One of the aims of LiveSpaces was not to presuppose how a workplace should be arranged or configured: the idea was to be able to rapidly configure an existing physical space, such as a meeting room, as a LiveSpace based on team needs. Over the years, several LiveSpace environments have been developed with various numbers and arrangements of displays, interaction devices, collaboration technologies, and furnishings. Figure 2 shows one of these instances—the Intense Collaboration Space. This example will be used to explain how a LiveSpace can be set up and be used for intense collaborative activities.

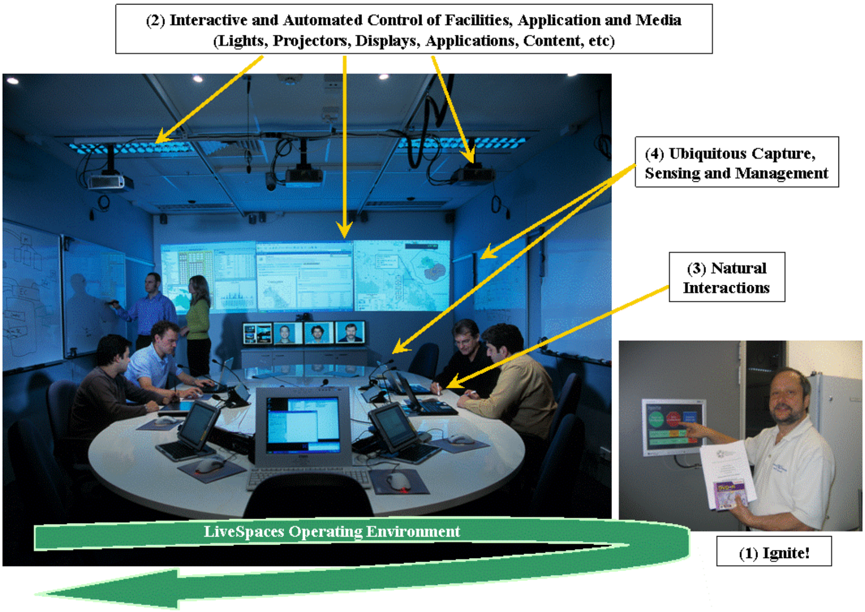

Figure 2. Intense Collaboration Space at DSTO

As discussed in the previous section, the underlying LiveSpaces infrastructure integrates all facilities, devices, and applications within a workplace. For example, when entering a LiveSpace, one central interface is used to start up the environment and to initiate a required session. This interface is called *Ignite* and is typically hosted on a touch panel at the door to the facility. Touching the green *Start* button provides an initial setup whereby lights are switched on, and any other facilities, such as projectors, are automatically initialized. The users can then select a predefined setup for a specific session or a particular configuration. For example, the convenor of the session may wish particular materials to be automatically displayed on the large displays, to use a pre-set lighting scheme and to have particular applications running on the individual screens. The activity to be undertaken might also require automatic connection to other LiveSpaces environments or the initiation of a video teleconference with remote participants. The convenor can pre-arrange the set up of the facility using a Meta App editor application. The pre-defined set up can then be invoked through the Ignite touch panel on entry to the facility.

The LiveSpaces environments are set up to best meet the way in which teams wish to work in the most natural way possible. For example, the ICS was set up with familiar collaboration tools such as white boards thereby allowing users to concentrate on the task at hand rather than be confronted with yet another unfamiliar electronic interface. The environments can host a broad range of applications including familiar applications such as *Microsoft PowerPoint*, as well as specifically designed ubiquitous workspace applications. Interaction with electronic devices such as displays is coordinated and managed by the LiveSpaces infrastructure to reduce the cognitive load on users. For example, a LiveSpaces application called LivePoint, which is based on the Stanford PointRight application (Johanson et al. 2002), allows users to use one pointing device, such as their own mouse, to interact with their own display or any of the group displays. A standard interface is provided to support the sharing of screens within and between environments. Electronic sensing devices, such as the Mimio devices (Mimio 2010) shown on the whiteboards in Figure 2, are used in the background to capture and store information in electronic form. This information is stored and managed by the environment and can, for example, be readily redisplayed on any of the surfaces. The LiveSpaces projects have experimented with a variety of techniques for supporting team needs. For example, the ICS desktops are themselves writable whiteboards and the walls made of pinboard panels to allow tangible information such as paper maps and photos to be easily displayed and used.

An important feature of LiveSpaces environments is their ubiquitous capture, sensing, and management capabilities. For example, in addition to information capture devices such as Mimios, the ICS has a broad range of other ways of providing background capture of information and activities. Close inspection of Figure 2 shows various microphones, robotic cameras and the like sprinkled through the environment. Research has been conducted into how these facilities can be used to automatically capture, transcribe, and produce the outputs or a session (e.g., a session transcript) (Zshorn et al. 2003), the use of speech technologies for monitoring collaborative activities through keyword detection, and the use of speech to help capture contextual information about the location and movement of people in the environment (Thai et al. 2008).

AUSPLANS and Orchestrated Evaluation

The Augmented Synchronized Planning Spaces (AUSPLANS) project extended the LiveSpace R&D to focus on its application and evaluation in supporting teams engaged in distributed synchronized planning activities (Evdokiou et al. 2004). The project was well resourced and included staff from the Cooperative Research Centre for Enterprise Distributed Systems (DSTC), the University of South Australia, DSTO, Boeing, and the University of Queensland. Issues addressed by AUSPLANS included the use of agile approaches for pre-planning and rescheduling of workspace activities; improved team awareness through the ambient display of information; synchronization of time-critical activities and results; coordination within media rich, multiple display environments; automated support for information management; and, the consolidation and production of team results.

An important output of the project was development of a well engineered LiveSpaces Operating Environment which could be deployed to support comprehensive evaluations involving actual planning teams. New LiveSpaces facilities were developed at DSTO and the University of South Australia and at DSTC Headquarters at the University of Queensland. LiveSpaces also underwent its first deployment to an operational defence headquarters where it was used to support evaluation, experimentation, training, and developmental activities. Several new LiveSpaces applications services, and interfaces were developed based on a host of research activities in areas such as workspace orchestration (Blackburn et al. 2004), session interfaces (Vernik 2004), speech transcription, information management, media management (Slay and Thomas 2006), and workspace simulation (Johnson 2005)

A key result of the work was the development of a new orchestrated evaluation approach based on the use of workplace orchestration and simulation services to provide a way of conducting and replaying evaluations using realistic scenarios and involving actual planning teams. This approach will now be discussed in more detail.

Orchestrated Evaluation

The experimentation and evaluation approach used for AUSPLANS was based on the use of orchestrated evaluation sessions. This approach allows the evaluation of new concepts, real systems, prototypes, and new work practices to be undertaken within a scenario-orchestrated environmental context. The approach used the LiveSpaces automation, orchestration, and workspace simulation capabilities to immerse domain experts and stakeholders into realistic workplace scenarios and situations. The orchestrated session is a framework which allows evaluation modules to be inserted and electronically administered at particular points in a work process to assess the effectiveness of particular capabilities relative to users' work processes and practices. The approach allows various evaluation techniques to be employed ranging from more formal methods based on task analysis to discount methods and surveys. In addition, it allows for the capture of new concepts and requirement. A key benefit of the approach is that it allows more control than would be allowable in field studies and allows for improved validation of evaluation results.

The scenario enacted for the AUSPLANS evaluations was an actual training exercise involving three operational phases of activity undertaken after a tidal wave devastates the small independent nation of South Tindaro, a fictitious regional country with complex socio-political characteristics. The first orchestrated evaluation activity focused on the planning of a disaster relief activity. This was followed by two other major evaluation exercises using the same situational context: the second focused on the evacuation of non combatants following political instability and the third involved a complex peace enforcement situation following a cross-boarder attack by the rival nation of North Tindoro (see Evdokiou et al. 2004 for more detail).

The orchestrated evaluation sessions were set up using a rich set of artifacts which had previously been developed and used in military exercises. This included physical artifacts such as maps through to digital artefacts such as imagery, geospatial data, photographs, and planning data. During the evaluation sessions, actual planning teams undertook the roles of a Commanders Planning Group and a Joint Planning Group. The LiveSpace environment was set up as a Commanders Planning room within a Joint Headquarters. Meta apps were used to generate immersive audio-visual presentations of intelligence briefs and to convey the commander's intent. This helped to quickly convey the operational situation and goals and to provide a sense of realism and motivation. Meta Apps orchestrated each phase of the activity, with evaluation instruments to be administered at strategic points in the activity. For example, following the completion of a particular task such as Course of Action development, the participants were provided with surveys in electronic form to capture evaluation information about particular capabilities that they were using. For example, we captured a range of evaluation data from participants about how the new LiveSpace interaction capabilities and interfaces contributed to underlying team attributes such as directed and undirected communication, co-located and distributed team awareness, understanding, recording, coordination, and reasoning.

One of the aims of the evaluations was to assess new approaches for synchronous distributed planning such as the use of new model-based planning tools to support Course of Action analysis and a new web-based Joint Planning application. As such, workspace simulation was used to represent other geographically distributed teams such as the Joint Admin Planning Group, the Operations Staff and the Legal team. We used a novel combination of workflow and agent-based simulation whereby a workflow engine was used to coordinate and enact work processes and a multi agent system called Brahms (Sierhuis et al. 1999) was to simulate work practices within the virtual LiveSpaces (Vernik et al. 2004). These virtual workplaces appeared to the team as though they are actual LiveSpaces populated with real people carrying out particular supporting tasks. They allow communication between workspaces and produce events and outputs as part of their own work processes.

Several new evaluation instruments were developed to aid with the capture of user feedback and inputs. These were administered in electronic form by the LiveSpace at strategic points during the evaluation. The LiveSpaces Operating Environment (LOE) also captured a range of contextual information needed to help analyze the results. For example, the LOE captured events to show what was displayed on a screen at a particular point in time, who was interacting with which device, and who was using tools such as Sticker chat for individual communication with another team member. The LiveSpace facilities also allow the capture of video and can be used to capture and transcribe speech utterances.

Our experiences in using orchestrated evaluation showed that we were able to effectively situate and motivate teams and hence provide realistic evaluation contexts. However, the use of workspace simulation needs careful consideration if it is to prove effective in the evaluation of distributed planning contexts. The ability to be able to replay, update, and control evaluation activities was shown to have merit. A particular benefit we found was the ability to use the LiveSpaces infrastructure as an instrument for capturing a rich account of actual team activities. This concept has been extended into what we call ICT-enabled Evaluation (Evdokiou et al. 2004) and has resulted in the development of a comprehensive toolset called TeamScope (Evdokiou and Vernik 2010).

Command TeamNets – Rethinking Capability Development

As previously discussed, consideration needs to be given as to how we might best acquire future socio-technical capabilities for command and control, particularly those that need to support teams involved in intense collaborative activities requiring high degrees of creativity, innovation and cognitive processing. The previous LiveSpaces projects helped develop and evaluate new capabilities which could prove beneficial for future C2 environments. However, these types of capabilities would be difficult to deploy using existing acquisition and development approaches.

Command TeamNets was a project which looked at how this might be achieved through the deployment of a network of federated LiveSpaces environments into operational headquarters, joint training facilities, acquisition agencies, and R&D organizations. These innovation and experimentation environments (or C2 Developmental Battlelabs) were used to support the integration, transitioning, and evaluation of new ideas, prototypes, and products. However, the focus was not simply on the development and acquisition of new technologies. These facilities were to be used to help develop new operational concepts, work processes and practices, and to support training.

Figure 3 provides an overview of the Command TeamNets approach. Central to the approach was a secure developmental network which ran in parallel to the operational network. This network allowed the hosting of a range of new command and control tools and the LiveSpaces software. A previous project called EXC3ITE (Lui and

Miron 1999) had established the network but had largely failed to support C2 capability development because the system presented as a separate and competing system to the actual operational capability, and was largely inaccessible to users. Many other efforts to host developmental tools directly onto the operational network had also failed due to the restrictions and risks associated with interfering with a strictly controlled and configured operational network capability.

The approach taken in Command TeamNets was to focus on integration at the human level by surfacing operational, off-the-shelf, and developmental applications, devices, and services within a LiveSpaces environment. The ubiquitous computing infrastructure allowed rapid integration of, and access to, new capabilities and so provided the ability to quickly augment existing operational capabilities. For example, a new integrated telepresence system and several new C2 tools in areas such as Course of Action development and scheduling, war-gaming, and team decision-making were integrated at the display and interaction level so that, to the users, the system presented as one integrated capability.

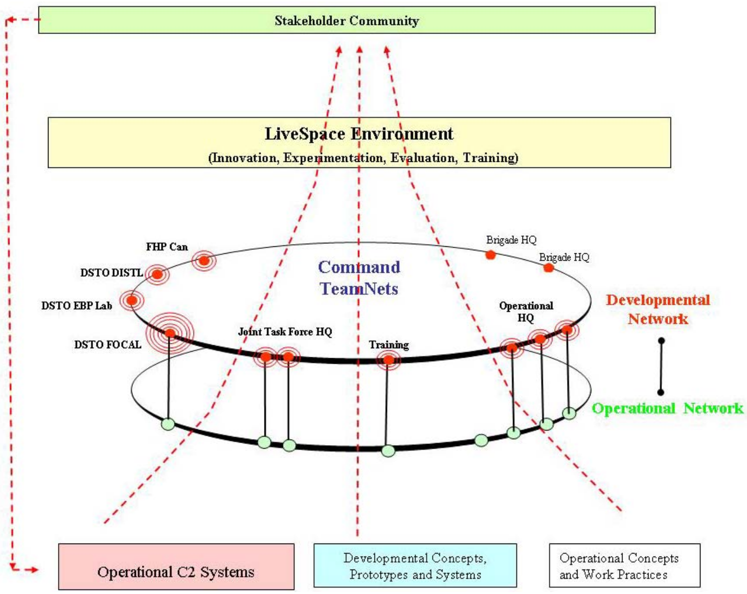

Figure 3. Command TeamNets Approach and Deployment

An important part of the overall deployment strategy was the placement of TeamNets support staff directly into operational headquarters to work hand in hand with users. The selection of these staff members was seen as particularly important in that they must understand operational concepts, have an expert knowledge of the TeamNets concepts and capabilities, and be able to engage in experimentation and capability development activities. TeamNets itself was used by these staff members to reach back to other R&D staff and to engage the acquisition community. The Command Battlelabs have been used for a range of developmental and training activities. In particular, they featured prominently in exercises where new concepts, tools, techniques, and work practices were developed and evaluated. New approaches for ICT-enabled evaluation were developed whereby the LiveSpaces infrastructure was used to capture a rich account of how teams interacted between themselves, with the information they needed, and with their systems and environment. New LiveSpaces applications were developed to allow analysts to record their observations within the context of the rich datasets captured automatically by the environment. This approach proved particularly important for those evaluations involving geographically distributed teams.

The Command TeamNets project is now complete. However, the approaches and systems remain in place and continue to be used by the Australian Defence Organisation for development of new operational concepts, new C2 capabilities, and the training of C2 teams.

Other Related Activities

The LiveSpaces R&D has been widely published and the underlying technologies have been made available to support other organizations and projects. More recently, the LiveSpaces Operating Environment has been made available as open source software (LOE Sourceforge Site). In addition to the projects discussed here, LiveSpaces approaches and technologies have been used for several other initiatives. For example, LiveSpaces was used as the basis of a national Australian Government R&D initiative in ICT-enabled Human Interactivity called HxI (Vernik et al. 2006) which was led by three major Australian R&D organizations (DSTO, CSIRO, and National ICT Australia [NICTA]) together with university and industry collaborators. The HxI Braccetto project (Schremmer et al. 2007) conceived and developed new approaches for rapidly deployable and composable collaboration systems to support teams in various domains such as National Security, e-Science, health, and emergency services. As part of the work, the Braccetto systems were deployed as Command TeamNet components and evaluated in terms of their effectiveness for supporting distributed War Gaming activities (Evdokiou and Vernik 2010). This work further developed the ICT-enabled evaluation approach and resulted in the development of TeamScope, an integrated toolset which supports the capture, fusion, and analysis of multi-media evaluation information.

LiveSpaces has also been made available to Defence Research and Development Canada (DRDC) and has been deployed and evaluated within the DRDC ACCESS Labs and at the Canadian Forces JIFC Detachment (Gouin et al. 2007). The US Air Force Research Laboratory (AFRL) has also been assessing the use of LiveSpaces approaches for future Air Command Centers. LiveSpaces has been used by the TTCP community (with participation from Australia, Canada, the United Kingdom, and the United States) for a range of activities directed towards defining, understanding, and addressing the challenges of intense collaboration in future command and control (Bowman et al. 2006).

Issues and Considerations for the Future

The LiveSpaces work to date has raised many issues. Some of the issues are related to the existing LiveSpaces technologies and environments including aspects of functionality and reliability. These are discussed in other publications (Phillips 2009; Gouin et al. 2007; Bowman et al. 2009). This section focuses on some of the broader socio-technical challenges, reflects on some of the issues of undertaking evaluations of the types of environments described in this article, and considers some of the lessons learned in relation to the development, acquisition, transitioning, and use of future C2 capabilities.

Socio-technical Challenges

Over the course of the LiveSpaces projects we have observed and evaluated many teams engaged in various activities and situations. We found that effective teams implicitly understand their goals, roles, modes of working, and the processes and practices they use. They know each others strengths, weaknesses, levels of expertise, and knowledge. They understand how to best interact with each other through established protocols. Technological support can, at best, enhance the effectiveness of teams—it cannot make a group operate as a team.

We learned quickly that it is a mistake to presuppose how a team should, or would, work. Good teams continually *innovate and adapt*. We observed many instances during the evaluation sessions where teams rapidly evolved roles and work practices based on the ready access to the new capabilities within the environment. For example, in one case, a team member evolved the role of information facilitator during a planning session by rapidly accessing and displaying information at precisely the required time and in the right place, based on his understanding of what was required for the most effective functioning of the team. In other examples, team awareness parameters, such as the size, volume, and positioning of the video teleconference information was continually adjusted in relation to team activities. The challenge is to provide accessible, flexible, and adaptive capabilities that allow the team to rapidly innovate and adapt work practices based on their specific needs. Another important related challenge is how to capture good practices in such a way that they can be readily reviewed and shared as part of an integral team development process, using the environment itself to support review and learning.

Another set of issues and challenges relates to *teamwork facilitation and mediation*. We did some early work to consider how we might use LiveSpaces facilities such as the Orchestration Service to facilitate and mediate team activities. For example, we studied the techniques that human facilitators used to keep meetings on track and how they provided cues to remind the team that they needed to move on. We developed some initial ambient interfaces to emulate this type of facilitation support. Another important aspect of team awareness is the ability to capture and display information about the progress and outcomes of a team activity to help the team reflect on, and keep track of, where they have been, what decisions have been made, etc. In addition to facilitating a team session, this information can be used to support the rapid recall of information related to the activity, such as the information sources that were used or created and information on when and why key decisions or agreements were made. We observed that a significant amount of effort was used in mediating discussions by revisiting previous decisions, "reading back" into an activity after a break, recording of team outcomes such as decisions, and the fusion and (re)formatting of team outputs.

Understanding and managing the *trade-offs between interactive and automated modes* in ubiquitous workspaces is a major challenge. For example, LiveSpaces Meta Apps have been used to coordinate and control a range of media, applications, lighting, and various devices to support activities such as orchestrated evaluation sessions and interactive briefings. In a sense, the workplace becomes a dynamic experiential environment where, just as in movie production, the most appropriate placement of images on screens, lighting effects, and timing all need to be considered to achieve the greatest effect. A major challenge is how to engender and apply a type of "director's art" (Vernik, Johnson, and Vernik 2004) into the development of these new types of applications.

The *experiential nature of future Intense Collaboration Environments* poses some interesting benefits and challenges. For example, the concept of "flow" (Csikszentmihalyi 1990) has been a focus of research to understand experiential effects and how to get people "working in the zone." When people are in flow, they have a holistic sensation whereby they act with total involvement, being fully absorbed in the activity, and having a sense of control of their environment. Flow is described as a state where attention, motivation, and the situation meet, resulting in a kind of productive harmony or feedback. Clearly, there is a relationship between the notion of flow and creative processes (Csikszentmihalyi 1997). Some preliminary investigations into team flow for distributed war gaming activities were conducted as part of the Braccetto project. This preliminary work suggests that there could be significant merit in experimenting with LiveSpaces concepts, such as workspace orchestration and Meta Apps, to create an experiential context for improved team performance.

Experimentation and Evaluation Challenges

Experimentation and evaluation of rich socio-technical capabilities, particularly when these involve distributed teams involved in intense collaborative activities, is difficult and problematic. In these situations, teams are continually adapting and innovating their work practices, the ways in which they use information, and the ways in which they interact with each other and their environments. In this article, we have discussed the use of Orchestrated Evaluation and ICT-enabled Evaluation as methods which may help address some of the challenges. However, much more needs to be done in this area. For example, field studies can help gain a certain level of understanding, but the reliability of findings is diminished in that we are unable to replay the evaluation with other teams. The use of an Orchestrated Evaluation approach may help in this respect in that it provides a framework and mechanism for dealing with situation dynamics (including in-process innovation and user adaptation) while still allowing for the application of many of our existing evaluation methods such as Usability Assessments, Cognitive Work Analysis, and Team Workload Analysis (Stanton et al. 2005). However, there are many questions that need to be addressed in relation to how the experiential effects of the environment might impact particular situations, teams, and results. In this respect, more consideration needs to be given to understanding some of the enabling criteria for distributed teamwork, such as workspace awareness (Pinelle et al. 2003).

Development and Acquisition

If we are to deal with the challenges of developing future socio-technical capabilities for C2 teams, many of the long-held tenets of systems acquisition need to be reconsidered. These include the focus on having a complete and "valid" set of requirements specifications and the focus on delivering a "product" within a particular time and budget. The types of future capabilities discussed in this article need to focus on how people work, rather than the technologies that they "might" use. Technologies should be considered as being transparent enablers of teamwork, where the capability is an integrated composite of work practices, devices, applications, information sources, media, and furnishings which can be adapted and orchestrated to best serve the working of the team engaged in specific activities.

The Command TeamNets project outlined a holistic integrated approach for the design, development, acquisition and use of such future C2 capabilities. The challenge is to employ a mechanism which engages all stakeholders, including C2 staff, developers, researchers, trainers, strategists, and acquirers, in a synergistic and ongoing manner. This type of capability development process must support innovation, broader notions of experimentation (Thomke 2003), and training as integral elements of the approach, supported by a rich social and technological network. In a sense, the development process takes place in a type of living laboratory. Our experiences have shown that the success of this type of endeavor is largely based on the quality of the embedded staff who facilitate the relevant engagements between stakeholders and enable the capture and analysis of outcomes.

Conclusion

Command and Control teams are being increasingly overwhelmed by the amount of information that is available to them, the diversity and complexity of the technologies that they need to use, and the nature and intensity of collaborative activities. This article has presented the results of a multi-project program of research and development that has developed new socio-technical approaches for the design, development, and acquisition of future C2 capabilities to address these challenges. This work has resulted in new technological capabilities, new experimentation approaches, and has demonstrated a new approach which allows systems to be acquired in a more adaptive and ongoing manner and where end-user innovation, experimentation, and training become an integrated part of the capability development process.

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