19th ICCRTS

"C2 Agility: Lessons Learned from Research and Operations."

Title **Design of a Multi-Touch Tabletop for Simulation-Based Training**

Primary Topic Topic 2: Organizational Approaches, Collaboration, Social Media / Networking

Alternate Topic Topic 5: Modelling and Simulation

Authors

Christophe Bortolaso
christophe.bortolaso@queensu.ca
Queen's University, Kingston, ON, Canada

T.C. Nicholas Graham
nicholas.graham@queensu.ca
Queen's University, Kingston, ON, Canada

Stacey D. Scott
stacey.scott@uwaterloo.ca
Systems Design Engineering, University of Waterloo
200 University Avenue West
Waterloo, ON, N2L 3G1, Canada

Matthew Oskamp
7mao@queensu.ca
Queen's University, Kingston, ON, Canada

Doug Brown
dgbrown62@gmail.com
Directorate of Land Synthetic Environments, CFB Kingston
Kingston, ON, Canada

Liam Porter
liam.porter@ca.thalesgroup.com
Thales Canada, Defense and Security Centre Kingston
945 Princess St.
Kingston, ON, K7L 3N6, Canada

Point of Contact Christophe Bortolaso

Address Queen's University, School of Computing
Goodwin Hall, Room 557
25 Union St.
Queen's University
Kingston, ON
Canada, K7L 3N6

Phone (+1) (613) 572-6083

Email christophe.bortolaso@queensu.ca

Design of a Multi-Touch Tabletop for Simulation-Based Training

Christophe Bortolaso[1], T.C. Nicholas Graham[2], Matthew Oskamp[3]
{[1]christophe.bortolaso, [2]nicholas.graham, [3]matthew.oskamp}@queensu.ca
Queen's University
Kingston, ON, Canada

Stacey D. Scott
stacey.scott@uwaterloo.ca
Systems Design Engineering
University of Waterloo
200 University Avenue West
Waterloo, ON, N2L 3G1, Canada

Doug Brown
dgbrown62@gmail.com
Directorate of Land Synthetic Environments
CFB Kingston
Kingston, ON, Canada

Liam Porter
liam.porter@ca.thalesgroup.com
Thales Canada
Defense and Security Centre Kingston
945 Princess St.
Kingston, ON, K7L 3N6, Canada

Abstract. The Canadian Army relies heavily on simulation-supported command and staff training exercises. Small groups of retired officers, called interactors, orchestrate the exercise behind the scenes using computer-based simulation tools to emulate troop actions in the field. The officers being trained work in a simulated headquarters, and contact the interactors by radio, chat or telephone.

The quality of the training experience highly depends on the ability of interactors to perform a realistic and educationally beneficial scenario. Modern simulation tools provide deep and rich functionality, but at the cost of complex user interfaces that interactors find difficult to learn and to use. Since each interactor sits at a separate computer, the design of the simulation room is a hindrance to collaborative tasks such as planning or coordinated maneuvers.

In this paper, we present OrMiS, a tabletop-based simulation interface that provides interactors with an efficient and usable way to collaborate while simulating the actions of military units. We emphasize how field observations and feedback from experts helped us identify key features of OrMiS to support individual and collaborative activities. Finally, we report on results from a usability study, which demonstrates how its features can ease interactors' work to provide the best training experience.

Introduction

The Canadian Army relies heavily on simulation support to train officers in executing effective Command and Control (C2) at the formation headquarters and unit command post levels. In these exercises the Primary Training Audience (PTA) is composed of officers practicing tactical decision-making in a simulated command headquarters. Interactors – typically retired military officers - play the role of troops on the battlefield. The PTA in a C2IS enabled command headquarters can communicate with officers in the field via radio and chat, plan missions and operations while maintaining situational awareness via the battle management system (BMS) software and monitor the operation using feeds from unmanned aerial vehicles and vehicle Global Positioning System (GPS) transmitters. The interactors use simulation software to carry out the orders they receive, for example using point and click mouse-based computer interactions to specify the routes that vehicles take as part of a convoy.

Simulation-supported or Computer Aided Exercises (CAXs) provides numerous advantages over exercises carried out in the field (or FTXs). Simulations permit the inexpensive mounting of large-scale exercises by avoiding the costs of field deployments. They enable actions, which are cost prohibitive and cannot normally be performed repeatedly in real-world collective training events such as blowing-up buildings. Simulation-based training therefore allows officers to be trained more frequently, at a lower cost, and in some ways more realistically. However, the quality of the training experience highly depends on the ability of interactors to perform a realistic and educationally beneficial scenario. Modern simulation tools provide deep and rich functionality, but at the cost of complex user interfaces that interactors often find difficult to learn and to use.

As an alternative to current simulation tools, we present the Orchestrating Military Simulation (OrMiS) system, which provides users with a multi-display and multi-touch digital tabletop-based simulation interface. OrMiS is based on a physical tabletop (similar to traditional map tables) where a small group of people can work together to manipulate and observe a simulation. Similar to modern Smartphones and tablets, OrMiS provides a touch interface, where dragging out a route with a finger moves units, and where the map can be panned and zoomed with familiar gestures.

In this paper, we report our experience first analyzing interactors' practices and then designing the OrMiS simulation interface. Through field observations and interviews with staff from the Command and Staff Training and Capability Development Center (CSTCDC), we identified that the quality of the exercises is constrained by a mismatch between existing simulation interfaces and interactors' expertise, collaborative practices, and workflow. Existing simulation tools are complex and difficult to learn. Days of training are required prior to each exercise to make interactors productive; interactors are sometimes hired based on their knowledge of the simulation interface rather than on their military expertise. Because each interactor sits in front of a PC, interactors can find it difficult to coordinate their actions, such as coordinating an artillery strike with an assault. Finally, interactors are forced to switch between their screen and physical map when impromptu events occur during an exercise because existing simulation tools poorly support collaborative planning.

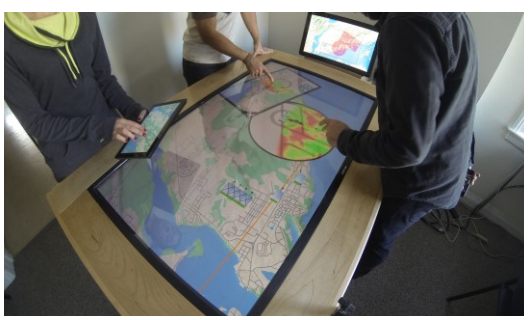

Figure 1. OrMiS supports military simulation and C2 by allowing small groups of people to collaborate around a shared touch surface. OrMiS is based on a large multi-touch table, handheld tablets, and a radar view display.

In this paper, we present the design of OrMiS and show how it's large table-based form factor and touch interface address these problems of ease of learning, coordination and support for planning. We first provide background in tabletop interaction in general and survey earlier efforts to use digital tabletop interfaces for planning and C2. We then show how OrMiS was designed to be easy to learn, while helping with coordination and planning tasks. Finally, we report on the enthusiastic feedback from the use of OrMiS by officer candidates.

Background

Large tabletops naturally support collaborative work by enabling face-to-face communication, pointing and gestures, and seamless awareness of others' activities (Gutwin & Greenberg, 2002). These properties have led researchers to explore the benefits of digital tabletops for computer supported collaborative work in collocated situations.

Hardware technologies for large multi-touch surfaces have made tremendous progress over the past five years. Touch detection technologies now enable multiple users to interact simultaneously on large areas with their fingers and sometimes with styli. While technologies such as the capacitive screen popularized with the Apple iPhone are only now achieving scalability to large form factors, others such as infrared frames enable touch surfaces up to 100" and more. Display technologies have also improved dramatically. Modern high-resolution displays are capable of displaying 3840 x 2160 pixels, facilitating the display of big datasets such as maps and the rendering of small images and text. This progress has led to a significant drop in pricing. Companies such as Microsoft PixelSense[1], MultiTaction[2] and PQ Labs[3] now offer commercial interactive tables for significantly less than $10,000.

Decisions around how to position and orient the content displayed on a tabletop (Kruger, Carpendale, Scott, & Greenberg, 2004) are key to achieving fluid interaction and smooth collaboration. For example, objects oriented toward and close to an individual are understood by others as belonging to that person, whereas objects located in the middle of the table are often shared by the group (Scott, Sheelagh, & Inkpen, 2004). Similarly, an object intentionally occluded at the bottom of a pile is typically considered no longer relevant for the ongoing task, or stored for later use. Techniques have been proposed to move and rotate objects with only one finger (Hancock, Carpendale, Vernier, & Wigdor, 2006) and to manage occlusion between physical items resting on tabletop displays and virtual objects (Javed, Kim, Ghani, & Elmqvist, 2011; Khalilbeigi et al., 2013).

Co-located collaboration around a tabletop also introduces problems of physically reaching parts of the table, leading to physical interferences (one person's arm getting in the way of another's). Doucette et al. have shown that people working around a table try to avoid physical touching as much as possible. This can lead them to fall back to turn-taking (Doucette, Gutwin, Mandryk, Nacenta, & Sharma, 2013), losing a primary benefit of a shared surface that it allows people to work at the same time. Similarly, conflicts can occur when two people try to simultaneously access the same elements. For example, if two people try to pinch-to-zoom a map on a digital surface at the same time, the result is unpredictable and confusing. Previous research shows that relying solely on social protocols to prevent or resolve such conflicts is frequently insufficient (Morris, Ryall, Shen, Forlines, & Vernier, 2004). Tabletop interfaces should therefore provide support to limit both physical and interaction conflicts.

Finally, when collaborating, people frequently switch between working together and working separately. For example, when planning routes in a C2 tool, planners may focus separately on the units for which they are responsible, then discuss global goals, then return to individual planning. This type of collaboration is called mixed-focus collaboration (Gutwin & Greenberg, 1998), and applies to activities such as brainstorming (Geyer, Pfeil, Höchtl, Budzinski, & Reiterer, 2011), route-planning (Tang, Tory, Po, Neumann, & Carpendale, 2006) and information analysis (Isenberg, Tang, & Carpendale, 2008). The challenge in the design of a tabletop tool to support this kind of work is to support both styles of work, and to provide seamless transitions between them so that people do not lose context or have difficulty returning to their focused work after collaborative discussions. Many interaction techniques such as personal viewports (Ion et al., 2013; Scott et al., 2010), lenses (Forlines & Shen, 2005; Tang et al., 2006) or sharable containers (Hinrichs, Carpendale, & Scott, 2005) have been designed and tested to support different levels of collaboration.

---

1 Microsoft PixelSense: http://www.microsoft.com/en-us/pixelsense/default.aspx
2 MultiTaction: http://www.multitaction.com/
3 PQ Labs : http://multitouch.com/

Tabletop Interfaces for Geospatial Content

For centuries, people have used tabletops to collaboratively work with maps. With the widespread availability of Geographical Information Systems (GIS), digital tabletops have become a compelling medium for collaboratively interacting with the contents of maps. Digital maps support zooming and panning and dynamic update of a map's contents.

The first map-based tabletop systems provided simple interfaces, relying mainly on social protocols and on the intrinsic properties of tabletops to ease collaboration and workspace sharing. For example, LIFE-SAVER (Nóbrega, Sabino, Rodrigues, & Correia, 2008) was designed to support flood disaster response operations. This system first displayed a 3D rendered map on an interactive table to allow experts to analyze flooding simulations in a collocated manner. Similarly, MUTI (Nayak, Zlatanova, Hofstra, Scholten, & Scotta, 2008) supports decision-making in disaster management through a zoomable digital map and a set of oriented controls. In these early systems, little attention was paid to how best to support collaborative work.

When several users have to interact on the same space, an obvious solution is to provide personal viewports on the map, windows that allow each person to have and manipulate their own view. This avoids the possibility of physical awkwardness as people try to touch the same part of the map or need to reach around each other, and allows all users to zoom and pan their personal view as they choose. For example, uEmergency (Qin, Liu, Wu, & Shi, 2012) supports forest fire responders by proving real time geolocated information on a large tabletop. To support mixed focus collaborative tasks, uEmergency displays a shared interactive map as well as individual windows and widgets for each user. The same approach is also used in eGrid (Selim & Maurer, 2010), which provides multiple rotating views of the same map to support the analysis of a city's electrical grid. This approach of splitting the same map into multiple views on a tabletop display is an efficient way to support individual work while maintaining workspace awareness. However, much of the main advantage of a tabletop is lost, since people are no longer looking at the same global image, and lose awareness of what others are doing. This approach is therefore not suitable for tightly-coupled collaboration where users are attempting to discuss and manipulate a single part of the map (Tang et al., 2006).

Finally, another emerging approach is to provide each user with a personal hand-held device (such as a tablet) showing a personal view of the map. This is another form of personal viewport, but where the private map appears on a separate physical device, not on the table. For example the Tangible Disaster Simulation System (Kobayashi et al., 2006) divides the output space by combining a tabletop display with two external screens showing a 3D first-person perspective of the map and charts describing the underlying disaster simulation. Preliminary evaluations revealed that users like the multi-display approach of their system, allowing one user to interact with the map while the other monitors the results on the external screen. A more recent approach consists of physically splitting the input space by providing tablets to the users around a tabletop display. For example, the SkyHunter project (Seyed, Costa Sousa, Maurer, & Tang, 2013) enables geological exploration by providing a tabletop and multiple tablets to a group of users. Predefined gestures allow users to transfer part of the map from the table to a tablet and back, thus enabling individual and group work and transitions between them. Recent controlled studies showed that this combination of table and tablets is beneficial for teamwork (Wallace, Scott, & MacGregor, 2013) which makes this approach very promising.

Tabletop Interfaces in Military Training and Operations

In the domain of C2, the use of advanced interaction paradigms were began in 1977 with a system called QuickSet (Cohen et al., 1997). This system provides a pen and gesture-based interface to control LeatherNet, a C2 system for training platoon leaders and company commanders. This new interface was a first step in easing collaboration and awareness by providing ways to share the same view of the battlefield.

Despite the fact that the military has a rich history working with tables, few research projects have focused on this domain. The Digital Sand Table (Szymanski et al., 2008) is an early attempt at bringing a digital tabletop to military C2 systems. Experiences with this system showed the collaborative benefits that a face-to-face configuration around a digital C2 application could provide and also highlighted well-known digital tabletop design challenges such as orientation, height of the table and user identification. Similarly, the Comet project[4]—a collaborative project between the US Army's Communications-Electronics Research, Development and Engineering Center (CERDEC) and Microsoft showcased at the 2010 Army Science Conference—proposed a digital tabletop interface to enable collaborative access and manipulation of maps and videos to support C2 operations. Around the same time, Canadian naval simulation researchers at Defense Research and Development Canada (DRDC)-Atlantic in conjunction with academic partners proposed the ASPECTS system (Scott et al., 2010), which provided a digital tabletop system to support C2 in naval operations by providing real-time monitoring of ships' locations. ASPECTS used oriented personal viewports on the tabletop, and provided pie-menus and role-based interaction based on user identification with pens. ASPECTS primarily focused on monitoring and intelligence analysis activities, whereas our OrMiS system enables direct command execution of simulated assets, such as routing of simulated vehicles and troops in the field.

The increasing availability of commercially available deployable, even ruggedized, digital tabletop systems also indicates a growing demand from defense and security customers for digital tabletop support in the field. In 2007, Northrop Grumman demonstrated the TouchTable[5], an 84-inch digital tabletop environment that supported collaborative interaction with geospatial data. The FAA's Cyber Security Incident Response Center installed a TouchTable to help cyber analysts identify and respond to cyber-attacks against the FAA's network[6]. Around the same time, Northrop Grumman also demonstrated a 3-dimensional digital map tabletop, called the TerrainTable[7]. Activating mechanical pins in the table to distort a silicone skin physically formed the shape of the terrain. As the terrain is formed satellite pictures of the map were displayed through an overhead projector. Neither product is currently available as commercial-off-the-shelf (COTS) products from Northrop Grumman, though may well be available as custom-orders. This early work, along with recent advances in digital tabletop hardware platforms, however, paved the way for currently available product offerings, for example the iCommand[8] Table by AAI / Textron Systems, which provides a multi-touch based digital tabletop interface to a cloud services-based battlefield map data. The iCommand system offers a distributed interface across digital tabletop and other multi-touch devices, such as an interactive wall or smartphones, to visualize units' position in real time in the field or in command posts. Similarly, HDT Global[9] and Steatite Rugged Systems[10] currently offer portable (i.e. foldable) digital tabletop systems that can be deployed in the field to forward command posts. Both systems provide a multi-touch interfaces to existing C2 software systems.

Despite the above research and commercial products, there are still relatively few digital tabletop systems currently available in real-world military training or operational contexts. Designing useful and usable collaborative tabletop interfaces that provide effective support for real C2 tasks is remarkably challenging. However, we believe it is possible through careful, iterative design in close collaboration with domain experts. This paper contributes to this domain by documenting the OrMiS interface, and providing lessons learned in designing a digital tabletop interface to support military simulation-based training exercises.

Designing for Simulation-Based Training

When conducting simulations to help train staff officers in command and control (C2) techniques, the Canadian Command and Staff Training and Capability Development Center (CSTCDC) relies on retired military officers (called "interactors") to role-play officers in the field and to enact simulated troop actions (Roman & Brown, 2008). As depicted on Figure 2, a standard setting includes the PTA located in a mocked-up command headquarters, communicating by radio or text chat with "officers in the field". The PTA use BattleView[11] a command and control

[4] *Cerdec Comet Multitouch http://www.cerdec.army.mil/about/comet.asp*
[5] *Northrop Grumman's War table: http://news.cnet.com/8301-17938_105-9773294-1.html*
[6] *http://www.irconnect.com/noc/press/pages/news_releases.html?d=125335*
[7] *Northrop Grumman's TerrainTable: http://blogs.walkerart.org/newmedia/2006/05/16/art-com-northrop-grumman-and-audiopad/*
[8] *ICommand: http://www.aaicorp.com/products/unmanned/icommand*
[9] *Command Table: http://www.hdtglobal.com/products/command-control/audio-video-display/60-interactive-command-table/*
[10] *Rugged Interactive Mapping Table: http://www.rugged-systems.com/products/rugged-monitors/interactive-mapping-table.html*
[11] *BattleView: https://www.thalesgroup.com/en/content/battleview-newly-integrated-canadian-armys-tactical-c2-system*

application on personal computers (PCs) and paper maps to perform battle management and operational planning. The position of units on the field are periodically updated on BattleView, whose main map view is displayed on a wall, making it visible to all the officers in the headquarters (see Figure 2A).

The officers in the field are role-played by interactors who relay observations to the PTA and carry out their orders. The interactors are, in fact, located at desks with PCs located in a private room "behind the scenes", and use simulation tools that mimic battlefield troop movement and combat engagement (see Figure 2B). The interactors use simulation software to control a set of units. In the back of the interactors' room, a set of screens display a map showing the global state of the mission. In the middle of the room, a large paper map of the mission's area of interest is located on a table (called a "bird table"), with small paper icons to represent the units' positions. The interactors primarily use this table to collaboratively plan the simulation before it begins. Because of the difficulty of keeping the table's paper markers updated, the table is rarely used after the exercise begins.

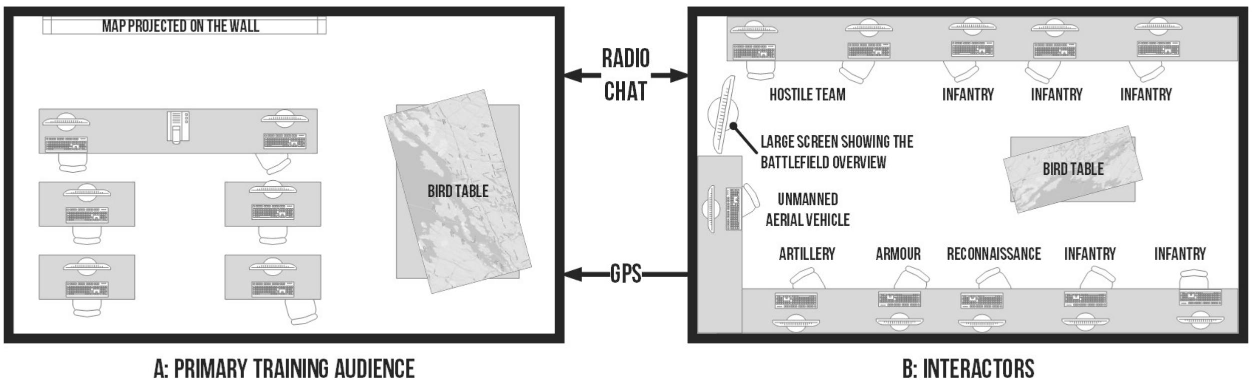

Figure 2. Diagram of a typical training setting

The simulation software allows interactors to mimic troop movement and combat engagement. Two popular simulation tools are ABACUS[12] (cf. Figure 4) and JCATS[13]. Simulation tool interfaces are composed of a full-screen map view with a large set of accompanying controls. The units are displayed directly on the map using standard military symbology. Interface controls allow operators to set the position, orientation, heading and rules of engagement of units, to organize units' hierarchy, to perform combat operations, and to create routes. Each interactor is in charge of a set of units, typically split according to the units' ORder of BATtle (ORBAT).

Over the past three years we have visited the CSTCDC three times to observe live simulation exercises. These field observations, in conjunction with supplementary interviews with simulation experts, have revealed that the quality of the exercises is constrained by three main issues with the current infrastructure:

1. **Interface Complexity**: The interfaces of existing simulation tools are complex, and thus require significant training and expertise to use. This creates logistical problems in finding interactors who are experts both in military C2 and in the simulation tool. A lack of qualified personnel limits the number and size of simulated exercises that can be held.
2. **Weak Support for Coordinated Tasks**: Tightly coordinated actions between interactors are poorly supported by the existing tools. This is largely due to the physical setting, where interactors sitting at individual PCs have difficulty communicating with each other and maintaining a global awareness of other interactors' actions within the (digital) battlefield.
3. **Poor Flexibility when Plans need to Change**: Due to unexpected actions on the part of the PTA the interactors' plans may change. Re-planning requires particularly intensive communication and requires reference to the state of the battlefield. The physical layout of the current PC-based infrastructure makes re-planning difficult, requiring

---

[12] *ABACUS (Advanced Battlefield CompUter Simulation) - http://www.raytheon.com/*
[13] *JCATS (Joint Conflict and Tactical Simulation) - http://www.jtepforguard.com/jcats.html*

interactors to leave their desktop PCs and move to the physical bird-table. But this is hindered by the fact that the physical markers on the bird table have become out of date with respect to the simulation. Furthermore, once the re-planning is complete and the interactors return to their PCs, they no longer can see the new plan sketched out on the bird table, and must enact it from memory.

To solve these issues, we implemented the Orchestrating Military Simulation (OrMiS) system, which provides an interface for interactors based on a multi-touch tabletop surface and supplementary displays. OrMiS provides interactors with an efficient and easily learned way to perform simulations while supporting collaborative manipulation of units. In the following section, we provide a brief overview of the OrMiS system prototype. We then illustrate how OrMiS addresses the issues identified above.

OrMiS: Bringing Multi-Touch to Simulation-Based Training

OrMiS provides small groups of interactors an interface to move units and perform combat actions while sharing a common overview of the battlefield. OrMiS is a multi-display environment (MDE) composed of a multi-touch table, multiple tablets to provide personal views, and additional screens displaying an overview of the battlefield. Interactors can either work together on the table, or separately using the tablets. The devices are synchronized over the network, so actions performed on one device are immediately propagated to the others. This diversity of devices offers a large range of possible configurations detailed later in the paper.

OrMiS: The Interactors' Interface

As shown in Figure 3, OrMiS displays a topographic map from a top-down perspective. Operators can pan the map by dragging with two fingers and zoom the map with a pinch gesture. As with standard map applications (e.g. Google Maps), the resolution of the map display automatically increases with the zoom level, showing details that are not visible on the overview. The map can also be zoomed using bifocal lenses and personal viewports, as described in the following sections.

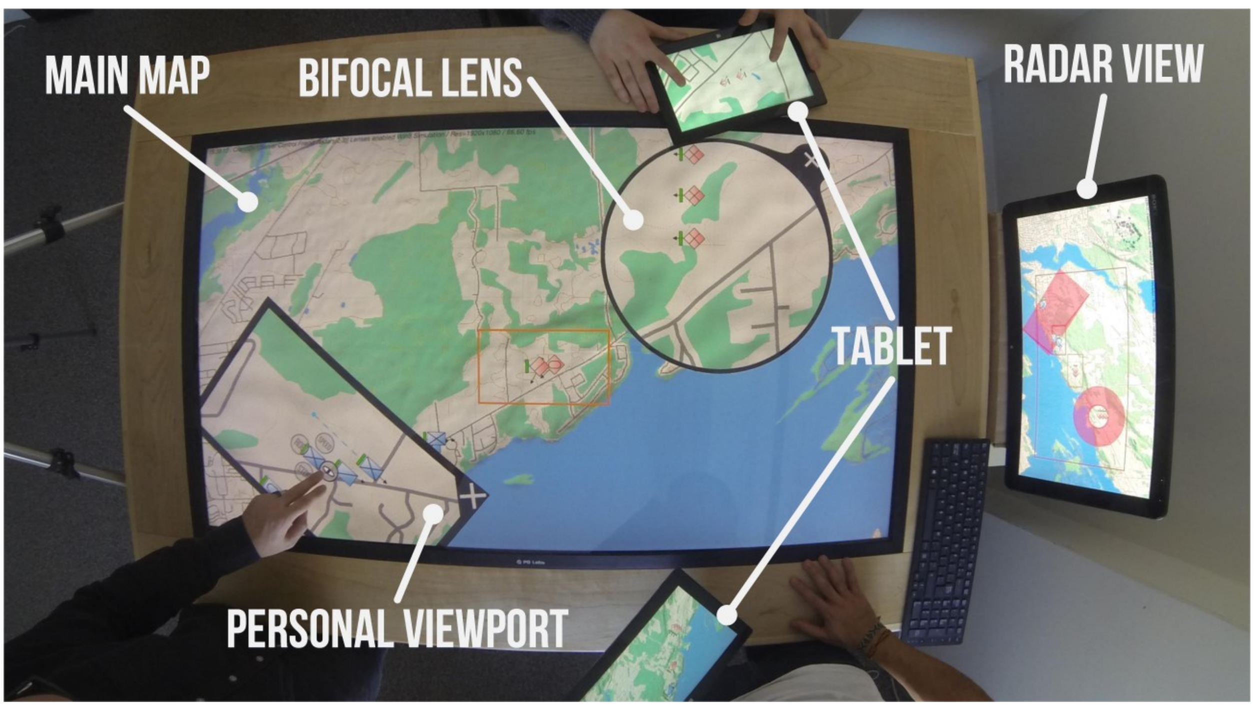

Figure 3. The OrMiS system

Units positioned on the map are depicted using standard MIL-STD-2525B symbology. Operators can tap on a unit to access specific controls such as to specify the unit's heading, rules of engagement or speed. Visibility and attack range are displayed by overlays on the map. A line of sight overlay is shown when an operator selects a unit or sketches a route. Operators can change a unit's heading by selecting and rotating it. Combat begins when opposing units (i.e., friend and foe) move within range and visibility of each other, respecting the rules of engagement for each unit type.

Routes can be created, modified, or deleted using single finger gestures, as detailed below. Two types of routes are supported: *permanent routes*, which are created from the map and can be used by multiple units at the same time and in any direction, and *one-time routes*, which are created from individual units and disappear when the associated unit reaches the route endpoint. A one-time route can be connected to a permanent route to drive units onto it.

OrMiS Technical Setup

OrMiS's interactive table is built from a PQ Labs G4S multi-touch frame and a 55" high-definition television housed in a custom-built wooden frame. The OrMiS software application was implemented in C# using the Unity[14] game engine. This engine eases 3D programming and provides fast rendering and a very responsive interaction. OrMiS is compatible with Windows 8 and TUIO[15] multi-touch inputs. The maps of OrMiS are generated using the InterMAPhics GIS (Kongsberg Gallium, 2013). Multiple surfaces are synchronized over a network using the Janus software toolkit (Savery & Graham, 2012).

Overall, the OrMiS prototype provides the features required to perform a simple but realistic exercise. With OrMiS, small groups of interactors can plan and then direct a scenario through a simple touch-based tabletop interface. OrMiS provides ways to work individually as well as in tight collaboration without having to switch between workstations.

Addressing Ease of Learning

Existing PC-based simulation systems used by interactors are difficult to learn. Most interactors are retired military officers. While they typically have several decades of military experience, they are largely not expert computer users. Individual interactors usually participate in simulation supported training exercises only a few times a year, and so need to be trained (or re-trained) prior to each exercise. Given the complexity of the existing simulation software interfaces, this typically involves several days of training prior to a live simulation exercise. This substantial training time becomes prohibitive both in terms of the time and costs associated with ramping up interactors before each exercise. Our interviews with simulation center staff revealed a strong desire for simulation tools that were easy for interactors to learn and use. The next section describes specific aspects of the existing simulation tools that present challenges for learning and use. We then illustrate how the OrMiS tool addresses these challenges.

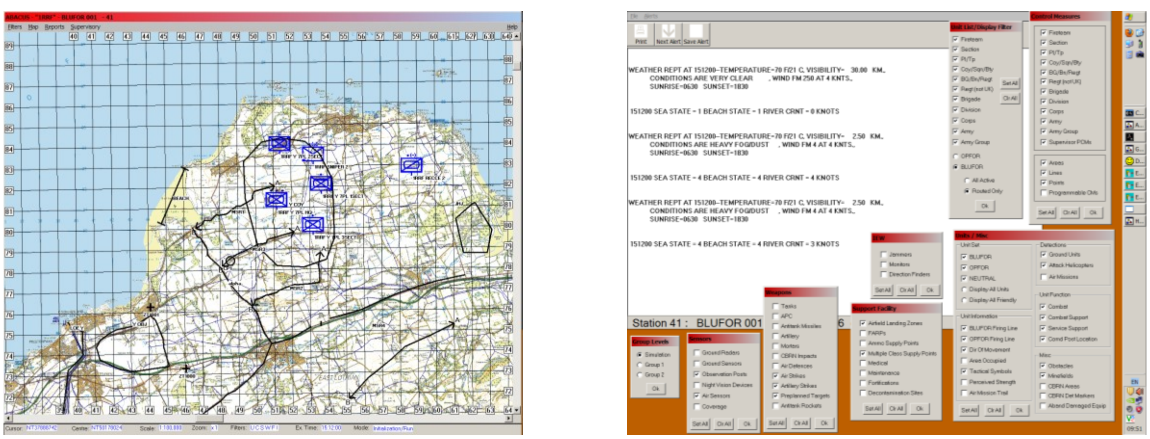

Figure 4. The ABACUS interface displayed on two screens

---

[14] *Unity game engine - http://unity3d.com/*
[15] *TUIO (Tangible User Interface Objects) - http://www.tuio.org/*

Usability and Scalability Issues

The complexity of existing simulation tools such as ABACUS or JCATS raises usability and scalability problems during exercises. The operator interface is based on a map depicting part of the battlefield and the units under an interactor's control. The interactor uses a profusion of controls to perform actions such as plotting routes, operating vehicles, firing weapons, checking units' line of sight, and filtering which units and terrain features are displayed on the map. Interactors use two side-by-side computer screens, with one screen typically used to display the map and the other to displaying a set of windows for these controls; this is depicted in Figure 4. Interactors need to become sufficiently proficient with all interface controls in order to be fully operational during the live simulated exercises. This requires substantial expertise, and consequently a great deal of training.

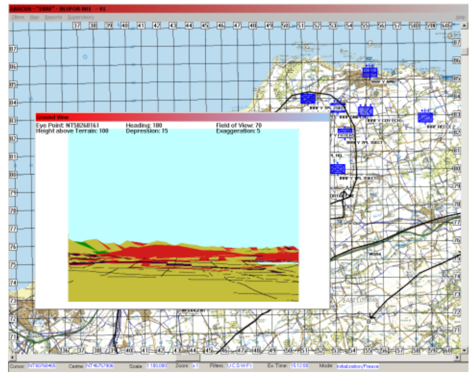

Figure 5. The ABACUS Line of Sight visualization

In addition to the complexity introduced by the sheer number of controls, some of the features themselves are difficult to use. For example, in ABACUS, a unit's line of sight is represented as either a cross-section elevation graph or a 3D view in a pop-up window. These views are decoupled from the related position on the map (see Figure 5). Interactors must first know which function initiates this line of sight tool, and must be capable of navigating the 4-step dialogue required to specify the desired visualization. They must then manage the cognitive cost of interpreting the line of sight view and relating it to the underlying map view that appears in a different window. In practice, interactors rarely use this view, instead preferring to use the map's contours lines to estimate line of sight, which sacrifices the accuracy of the information being used to perform their actions.

The difficulties interactors face in navigating the interface of existing simulation tools limits the number of units each interactor can be assigned. In addition, the technological sophistication required to use these interfaces limits the pool of available interactors. To mitigate these problems, the simulation center staff assigns interactors' roles (e.g., reconnaissance or amour) based on their knowledge on specific features of the tool rather than on their military expertise. A simpler interface would aid scalability by allowing interactors to be responsible for more units. Moreover, making the tool easier to learn and use would reduce the number of required interactors, and thus create significant cost-savings.

Simple, Touch-Based Controls Improve Usability and Scalability

When designing OrMiS, we strongly emphasized the simplicity of the interface. We used traditional user-centered design methods, regularly evaluating the usability of our interface with military experts. We followed a parsimonious design process, adding features only when we could demonstrate that they were needed. This led our final design to be controllable with a small number of touch actions and controls.

Operators can drag, tap, or long press (i.e. touch and hold) elements to directly see the effects on the display. For example, a simple drag gesture originating from a unit icon automatically creates a one-time route for the associated unit (see Figure 6A). Tapping on their first or last waypoints can extend routes. When the route is planned, operators can tap on a unit to display a pie menu that enables route creation, as well as all actions related to unit control. When the unit is driving along the route, the waypoints can still be modified. In this case, the unit will adapt its trajectory in real time to the new waypoint position. With this technique, moving units on the map becomes easy, allowing interactors to react efficiently to situations where time is an issue, such as escaping from an enemy.

Similarly, a unit's line of sight can be displayed by simply tapping on its icon. This displays the line of sight directly in the form of a viewshed around the unit (see Figure 6B). The heading of the unit can be modified with a circular widget (see Figure 6B). To hide the line of sight and circular control, operators simply tap the unit again. This visualization tool enables the interactors to easily organize formations of units to cover a specific area.

Similarly, to limit the number of controls, various feedback indicators are displayed automatically only as needed. For example, a small label indicating the terrain type (e.g. forest, road, water, land) is automatically displayed close to an operator's point of touch. This feature supports terrain exploration and provides information without the need of any additional control. Similarly during route planning, portions of the route that intersect with any non-drivable terrain (e.g. water) blink in red.

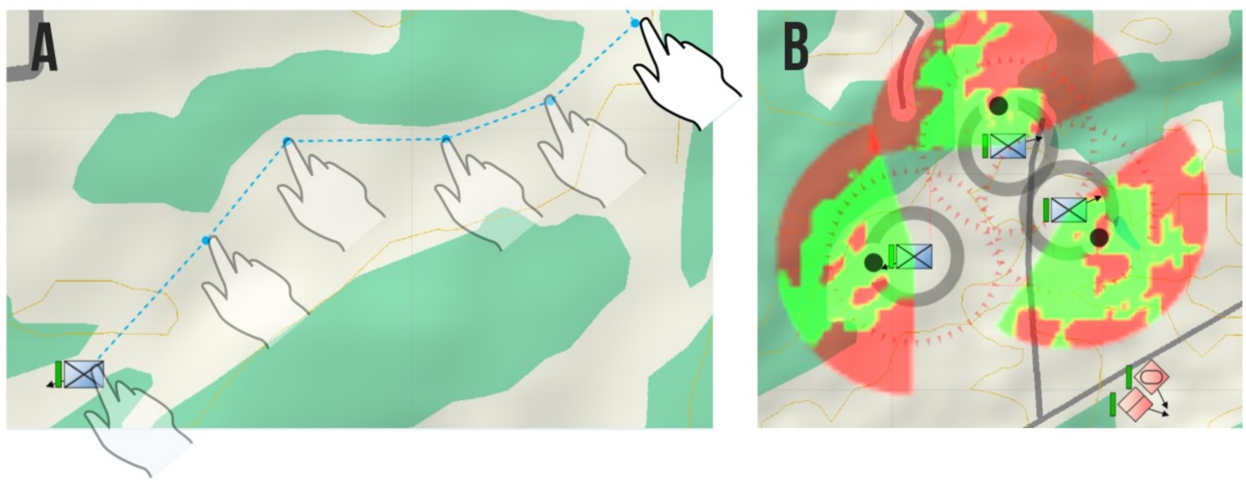

Figure 6. A) Routes are specified using a simple dragging gesture – B) The units' viewshed in OrMiS

In contrast to the existing simulation interfaces, all of the OrMiS controls described above have the advantage of being located directly in the context of the elements with which they are associated (e.g. unit, map, route) rather than on separated controls or external windows. To interact with the system, operators no longer need to switch between controls and the map, but can directly apply their actions to the units themselves. As we describe below, both simulation experts and PTA officers have reported that the OrMiS interface can be learned in minutes. This is in sharp contrast to the equivalent features in the ABACUS and JCATS simulation tools, which require days of training before each exercise.

Supporting Coordinated Tasks & Awareness

Previous studies on effective group practices have shown that tools should support both *explicit* and *consequential* communication (Baker, Greenberg, & Gutwin, 2001). Explicit communication involves planned, intentional behavior, such as verbal expression, or non-verbal actions such as pointing or gesturing. For example, an interactor who calls across the room to initiate an attack is using explicit communication. Consequential communication occurs when a person does not necessarily intend to communicate with another person, but nonetheless conveys information to an observer. For example, an interactor positioning his/her units in a specific formation may communicate the intent to attack to someone watching his/her actions. Consequential communication between interactors relies on their common understanding of military tactics and procedures, and on their ability to observe each other's actions.

The current physical setting of the simulation room and the existing PC-based simulation tools hinder both explicit and consequential communication. OrMiS provides a shared physical and virtual workspace for interactors to perform their actions, and thus improves support for both explicit and consequential communication.

PC-based Setting and Communication Issues

Existing simulation tools poorly support both explicit and consequential communication. As mentioned previously, each interactor sits in front of an individual PC at a separate desk that is possibly at quite some distance from other interactors in the room. This physical arrangement limits opportunities for explicit communication between interactors during an ongoing exercise. Rather than talk directly, we have observed that interactors call to each other across the room. This does not work for extended or complicated conversations. When calling across the room, interactors cannot reference shared materials, such as pointing at a map. Instead, they need to turn or stand up and walk to another interactor's workstation. In practice, they are rarely willing to do so, and the quality of coordination suffers. The current physical arrangement makes it difficult to coordinate complex scenarios that involve dependencies between units being controlled by different interactors. For example, interactors using the existing simulation tools find it challenging to move infantry units along a road while flanking a tank. This scenario requires the two interactors controlling the infantry and the amour units to look at each other's screens or to verbally communicate across the simulation room while performing their actions. Another scenario requiring tight coordination between interactors is passage of lines, where a unit passes through another unit's position with the intention of moving into or out of contact with the enemy. The successful execution of passage of lines is critical and is often a determining factor in the outcome of a combat.

These scenarios are so difficult to perform with existing tools that in practice, the interactors typically change the ORBAT so that the tightly coordinated units are under the control of only one person. This requires a high level of expertise with the simulation interface. As we will see, OrMiS improves explicit communication between interactors to directly enable high degrees of coordination, allowing such complex scenarios to be carried out without the need for interactors to change location, to call across the room, or to modify the order of battle.

The current physical setting and existing simulation tools also limit consequential communication between interactors. With JCATS and ABACUS, interactors share the state of the battlefield on their screens, and thus, theoretically can observe the actions of other interactors within the battlefield context. In practice, however, interactors typically filter out other interactors' units and zoom and pan to different parts of the map, as their current task requires. This means that other interactors' actions may not be observable and interactors may not be aware of important movements executed by their colleagues. To help with global awareness, a large monitor in the back of the room displays a map of the complete battlefield (see Figure 2). However, interactors rarely look at this screen, since they are typically focused on their own PCs. When interactors are working on separate parts of the map, consequential communication is insufficient to maintain awareness of other interactors' actions.

OrMiS Supports Communication with Space-sharing Techniques

With OrMiS, we aimed to improve explicit and consequential communication by allowing small groups of interactors to work together around a digital tabletop. The tabletop interface naturally improves awareness by providing a shared physical and virtual workspace and enabling face-to-face communication. Therefore consequential communication is supported through peripheral vision around a shared tabletop and explicit communication is facilitated by the physical configuration of the group around a shared workspace.

However, relying solely on a shared tabletop is not sufficient to support activities where interactors need to view different parts of the map at different levels of detail. Different scenarios bring different requirements in collaborative work around the table. For example, two interactors may plan routes for different units on different parts of the map, and in both cases requiring a detailed view of their part of the map; this would be a form of loosely coupled coordination, as they are working to the same global objective, but at the moment are working separately. This first scenario requires little (if any) explicit communication, but consequential communication may be important to retain general awareness of the locations of the other interactors units.

Conversely, two interactors working on a passing through the lines scenario will want to see the same part of the map in detail, each controlling the units for which they are responsible. This latter scenario is an example of tightly-coupled coordination, where the interactors are working closely together and attending carefully to the other interactor's actions. In this scenario, both explicit and consequential communication is important.

To assist with these requirements to support both loosely and tightly-coupled collaboration and both consequential and explicit communication, we implemented a set of interaction techniques, each adapted to different situations:

1. The **main map** (Figure 7A) provides a shared space for interactors. The map can be zoomed using a standard pinch gesture. The main map is suitable, for example, for tasks where several interactors need to move units in a coordinated manner, or for the passing through the lines scenario described above. The main map supports explicit

communication by providing interactors with a shared map that they can point to in discussions. It also supports consequential communication through the fact that the map is visible to all interactors, providing ongoing awareness of the state of the simulation.

2. **Bifocal Lenses** (Figure 7B) provide a circular area that can be zoomed independently of the map itself. As the name implies, a bifocal lens magnifies the part of the map over which it is placed. Therefore the position of the lens shows others what part of the map is being used. Lenses foster consequential communication by indicating to others where an interactor is working. Lenses are particularly useful when two interactors need to maintain awareness while working with detailed views of different parts of the map, as with the scenario of two interactors planning routes for units in different parts of the map.

3. **Personal viewports** (Figure 7C) provide a rectangular area that can be panned and zoomed independently of the main map. Unlike bifocal lenses, personal viewports do not magnify the part of the main map where they are located, but are independent of the main map. Personal viewports are typically controlled by one person, and can be positioned and oriented over top of the main screen. Therefore, viewports provide support for explicit communication by enabling face-to-face communication. However since they are decoupled from the main map, it can be difficult for a person to determine what part of the map someone else's viewport is showing, thus limiting consequential communication. Therefore, viewports are suitable for loosely coupled tasks where interactors need to work simultaneously on the map while requiring a low level of awareness. For example, viewports are suitable when interactors need to defend different locations on the map while requiring awareness about where engagements are taking place.

4. **Tablets** (Figure 7D) provide viewports on the shared map that are displayed on a separate hand-held device. Tablets allow people to work independently around the digital tabletop. Actions performed on a tablet (e.g., moving a unit) are directly propagated through the network to the other displays. Tablets are similar to personal viewports, but provide a higher degree of privacy, and do not take away screen real estate from the main map. Tablets provide poor awareness of others' actions, since it may not be easy to see what other people are working on. Tablets are best for individual work requiring a low level of awareness. Therefore, tablets are similar to personal computers in their support of explicit and consequential communication but are particularly useful for individual actions.

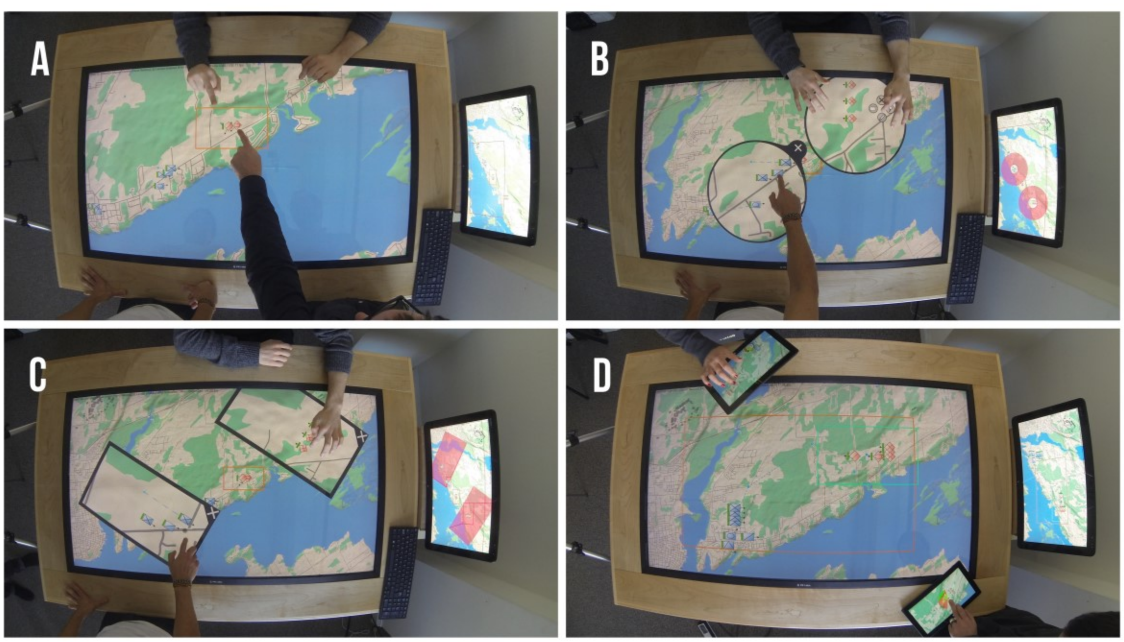

Figure 7. OrMiS in three different settings: A) Only the main map is shown, ideal for planning, B) Operators with bifocal lenses working on close parts of the map, C) Operators with personal viewports working on separated parts of the maps, D) Operators with individual tablets around the table.

In addition to these techniques, OrMiS also provides a general overview of the battlefield on a separate screen. This radar view (see Figure 3) is synchronized over the network so that changes performed on the table or on the tablets are shown immediately. The radar view displays the entire battlefield at all times, providing general awareness information even when the main map is zoomed. The radar view shows the position and area shown by the main map, lenses, personal viewports and tablets within the battlefield. Similarly to the large monitor in the setup currently used by the CSTCDC (Figure 2), this view provides general awareness for interactors throughout the simulated exercise.

These four space sharing techniques and the radar view support a continuum of collaboration scenarios, from the main map for tightly coordinated actions to individual work on tablets around the tabletop. In addition, the use of each technique conveys different information about interactors' work and position on the map. With OrMiS, interactors can choose whichever interaction technique best suits the current collaborative scenario, and as a result provides the level of support for consequential and explicit communication required by the given situation. In the next section, we address the third and final issue identified in the existing simulation environment: flexibility to plan ad-hoc or impromptu changes.

Flexibly Supporting Changes in Plans

A typical military training exercise is organized around four major steps: planning, battle management, battle updates and after action review. First, interactors plan their movement based on PTA's orders. This usually includes war-gaming on a large bird-table as depicted in Figure 2. Then, interactors execute the plan using the simulation tool on their PCs. During the plan's execution phase, interactors regularly provide updates to the PTA. When the exercise is finished, interactors and the PTA gather and proceed to an after-action review to confirm how training objectives were met, whether collective training was confirmed, and to discuss lessons learned. In practice, unforeseen events occur regularly, forcing the PTA and interactors to reconsider their plan. Next, we detail the nature of these unforeseen events and how it impacts the interactors' workflow.

Re-Planning and Workflow

During simulations, many forms of unexpected events may arise. For example, the PTA officers might change their plan after receiving updates from the interactors and provide truly unexpected orders. Similarly, the exercise directing staff or the training confirmation authority (i.e. the officer in charge of educational aspects of the simulation) may ask interactors to change their plan or to let an adverse event unfold for pedagogical reasons. Re-planning can happen at any time during the exercise. For instance, the PTA officers may ask interactors to change the direction of units on a route or simply to change the sequence of actions to be performed. Reasons for such changes are various and related to the strategy adopted by the trained officers in the headquarters.

We observed that the interactors' reaction to unforeseen events depends on the impact of the event on the original plan. If the event requires minor re-planning, the lead interactor verbally communicates the changes to other interactors. Because interactors are retired officers with a significant experience this type of minor re-planning is usually performed without problem. On the other hand, if major re-planning is needed, interactors usually gather around the bird table to re-plan. Because the paper map on the bird table is not automatically updated, interactors have to manually position the units on the table before proceeding to the planning phase. In the meantime, one interactor is left in charge of monitoring all the units while the others are re-planning. Therefore, only automated movements (e.g. moving along a defined road, performing a pre-programmed patrol, etc.) can be performed, potentially impacting the realism of the simulation. For example, units' reactions to an attack may be delayed or orders sent by the PTA can be missed.

A Diversity of Co-located Setups

As described in the previous section, OrMiS provides a set of interaction techniques to support both individual and collaborative work on and around the digital tabletop. These techniques enable interactors to work together on the table with various degrees of coordination or to work independently on tablets. For example, in the early phase of the exercise, the main map on the tabletop provides a shared space to a small group of people, enabling those people to communicate face-to-face, using speech, pointing and gestures. During battle management, the lenses, personal viewports and tablets allow interactors to work in different ways depending on the level of coordination and awareness required. For example, two interactors can work closely using the tabletop while the others perform independent work on their tablets.

Because these techniques are located directly on or around the interactive tabletop, the effort for transitioning between them is minimized. First, switching between performing the exercise and a planning activity is straightforward. When performing the exercise, if unexpected events occur, interactors can immediately switch to a re-planning phase by simply looking at the tabletop display in front of them. Then, the table's edges enable interactors to leave their tablets aside with minimum effort (see Figure 3 and Figure 7D). During collaborative planning, interactors can still monitor their own units directly on their tablets, through a personal viewport or by looking at the radar view. For example, if an unexpected attack happens, the event appears directly on the tabletop display and on the radar view. Concerned interactors can then immediately respond without interrupting the planning phase. Finally, the repositioning of the units on the table is avoided since the state of the battlefield is automatically updated by the system. Once the plan has been changed, the transition to battle management can be achieved in the same way. Thus, transitions between different work styles and activities are therefore straightforward with OrMiS's physical design.

Next, we report on how officers-in-training experienced the OrMiS interface during an exploratory study.

User Feedback about OrMiS

When designing OrMiS, we solicited regular feedback from military officers and simulation experts to understand the required features and to get feedback on OrMiS' interface. We also assessed the usability of OrMiS with a group of officer candidates. We now report on their feedback.

We invited six pairs of officer candidates from a nearby military university to perform a simple but realistic scenario with OrMiS. There were 12 male participants, between the ages of 18 and 30 years old. All participants held the Basic Military Officer Qualification–Land (BMOQ-Land), requiring knowledge of the topographical standards used in military maps, as well as basic troop deployment strategies. Each pair was asked to perform the scenario illustrated in Figure 8. The scenario was introduced to the participants as follows:

> *"Infantry units (1B. located to the west) and armour units (1A. located to the east) have been operating separately. The commander has ordered a new mission involving a platoon of infantry and armour elements. Your task is to move the infantry and armour to the rendezvous point (2) and then proceed towards the objective (3). There is a high risk of enemies located in the wooded area flanking the main road. Send your armour with infantry escorts to sweep the forest in order to avoid ambush."*

This scenario was designed in collaboration with senior military officers. In the scenario depicted in Figure 8, one participant controls the armoured units located at 1A, and the other controls the infantry units located at 1B. Their first task was to rendezvous at position 2. They were then to move through hostile territory to the objective position 3, with the infantry flanking the armour in order to flush out any enemies located in the woods.

Participants were first trained in the OrMiS system, and allowed as much time as they wished to become familiar with the application and the interaction techniques. The version of OrMiS presented to participants was limited to the use of the main map, bifocal lenses and radar view; the personal viewports and tablets were not available. Training time typically lasted 15 minutes. Participants had no time limit and on average spent 9 minutes to complete the scenario (*M*=9:12,

Figure 8. Scenario used during the study

SD=2:00). After completed the exercise, participants were asked to complete a usability questionnaire based on the System Usability Scale standard (Brooke, 1996) including questions related to the main features, the lenses, main map and radar view. Participants were then interviewed.

Results

All participants completed the task without encountering any significant usability issues. When interviewed, participants were very positive about the interface. They found the interface easy to use and appreciated using the table to collaborate and to enact their plans. One participant stated: "*I really liked the table, it was very intuitive*". Participants also liked the labels indicating the terrain type. One participant said: "*when we clicked it would tell us if it was water, road, etc. and that was really handy. I liked that.*" Similarly, when asked about the usefulness of OrMiS, one participant said "*…for planning the route, I found it was actually pretty good!".* These results indicate that operators enjoyed the OrMiS's interface when performing the scenario.

In terms of collaboration, participants successfully took advantage of the different interaction techniques to split their work. All the groups used lenses for the first part of the scenario (from 1A/1B to the rendezvous on 2 on Figure 8) where no specific coordination was required. Participants expressed strong positive feelings about the lenses because they allowed users to work simultaneously without disturbing each other. The majority of the groups switched to the main map in the second part of the scenario (from 2 to 3 on Figure 8) where units had to be tightly coordinated. Prior to switching to the main zoom, most users quickly discussed which way to proceed to coordinate their units. As expected, the tabletop setting eased face-to-face communication. Participants also noticed the limitation of both interaction techniques. Several participants experienced overlapping problems between the lenses when working physically closely on the table: "*when we are close, the lenses stack together even if there is a lot of terrain between the two lenses*". This shows the importance of providing the zooming feature in the main map so that collaboration is possible around closely located points.

The scores obtained with the SUS questionnaires confirmed this feedback and revealed some interesting differences between the features. Lenses and main map respectively obtained an average SUS score of 65.4% (*SD*=3.2) and 67.5% (*SD*=5.1) indicating a high level of usability for both techniques. However, the radar view was perceived as less usable, obtaining only a 19% (*SD*=3.58) usability score. During the interviews, participants reported that they did not use the radar view much. We believe that since there were only two participants and four units, participants did not require the radar view to maintain a global view of the battlefield.

Over all, these results confirm that OrMiS enables a pair of people to perform a simple but realistic scenario with minimal training, allowing the pair to complete their task, and communicate in both explicit and consequential forms. This is in a sharp contrast to the current setting using simulation tools like ABACUS or JCATS, which require days of training and significant efforts to maintain awareness and perform tightly coupled movements.

Lessons Learned

In addition to these results, the participants provided us with insightful feedback helpful to the design of multi-touch systems supporting simulation-based training. Two participants reported ergonomic and orientation issues: "*The table should be higher or angled … there is clearly one side that's better*". One participant complained about pain in his neck at the end of the study, indicating the importance of making the height of the table comfortable for extended touch interaction. As participants were working face to face, one member of each pair saw the map upside-down, and had to make an additional cognitive step to correctly interpret cardinal references. We believe that the introduction of tablets and personal viewports that can be oriented will solve this problem.

Participants reported that they had to verbally communicate to avoid conflicts when working together on the main map: "*[We] had to create a seniority of who was allowed and who was in control of the board, because at some points I would go touch something and it would screw him up, … so we had to have one person who would say don't touch it until I'm done*". This result is in line with previous findings in digital tabletop research showing the importance of social protocol when working on shared spaces. Simple interaction techniques like using two fingers for panning (instead of the more traditional one-finger panning) can reduce unintentional actions and consequently conflicts.

Conclusions and Future Work

In this paper we first provided an overview of the state of the art in tabletop research for collaborative work and more specifically for map-based applications. Through this literature review we illustrated that collaboration around tabletop requires specific support to the various collaborative work styles.

We presented OrMiS, a multi-display environment dedicated to military simulation based-training. OrMiS combines the best of existing space-sharing techniques dedicated to interactive surfaces. The OrMiS system provides a simple interface combining zoom, lenses, personal viewports, tablets and radar views to provide maximum flexibility during the exercises. We showed step by step how the features of OrMiS solve important usability, coordination and communication issues encountered by interactors during simulations. To assess the usability of OrMiS, we reported on feedback from officer candidates at a military university. Our results show that users are able to perform a simple but realistic scenario with minimal training with OrMiS, and they overwhelmingly enjoyed using the tool. We also highlighted some interesting limitations of OrMiS such as orientation issues of the map or the usefulness of the radar view when few units have to be monitored. Further studies will be required to investigate the impact of the issues of interactors' performance and cognitive workload.

Overall, we learned that tabletop based-systems constitute a promising approach for future simulation systems. The costs of tabletop hardware have dropped substantially over recent years, making them more widely accessible. As illustrated with the design of OrMiS, a strong emphasis must be placed on the software interface to build efficient and usable systems. The different types of collaborative group work are a central aspect in the success of tabletop-based interfaces. This is particularly true in a context such as simulation-based training, where coordination and awareness can impact heavily the simulation quality.

However, due to physical constraints, interactive tabletops can accept only a limited number of users. Large simulations may involve up to 20 interactors, potentially implying the use of multiple tables. Further work is required to investigate the use of multiple tables, each supporting a small group of interactors. In addition, we believe that tabletop based interfaces can also constitute relevant solutions for C2 activities outside the training sphere. As we have argued, tabletop interfaces are particularly suitable for planning. An adapted tabletop interface would allow collaborative planning, execution and monitoring of C2 strategies.

Acknowledgements

This work has been supported by the SurfNet Strategic Network, the GRAND Networks of Centres of Excellence, and the LEIF Transatlantic Exchange Program, and in partnership with Thales Canada and the Command and Staff Training and Capability Development Center. We would like to gratefully acknowledge the contributions of Andrew Heard, Eric Ingle and Amir Sepasi to early versions of OrMiS.

References

Baker, K., Greenberg, S., & Gutwin, C. (2001). Heuristic Evaluation of Groupware Based on the Mechanics of Collaboration. In *Proceedings of the 8th IFIP International Conference on Engineering for Human-Computer Interaction (EHCI '01)* (pp. 123–140). Springer-Verlag. Retrieved from http://dl.acm.org/citation.cfm?id=645350.650731

Brooke, J. (1996). SUS - A quick and dirty usability scale. In A. Jordan, Patrick, W., Thomas, Bruce, Weerdmeester, Bernhard, A., McLelland, Ian (Ed.), *Usability Evaluation in Industry* (pp. 189–194). CRC Press. doi:10.1002/hbm.20701

Cohen, P. R., Johnston, M., Mcgee, D., Oviatt, S., Box, P. O., Pittman, J., … Clow, J. (1997). *QuickSet : Multimodal Interaction for Distributed Applications*. *Proceedings of the fifth ACM international conference on Multimedia - MULTIMEDIA '97* (pp. 31–40). New York, New York, USA: ACM Press. doi:10.1145/266180.266328

Doucette, A., Gutwin, C., Mandryk, R. L., Nacenta, M., & Sharma, S. (2013). Sometimes when we touch: how arm embodiments change reaching and collaboration on digital tables. In *Proceedings of the 2013 conference on Computer supported cooperative work - CSCW '13* (pp. 193–202). New York, New York, USA: ACM Press. doi:10.1145/2441776.2441799

Forlines, C., & Shen, C. (2005). DTLens: multi-user tabletop spatial data exploration. In *Proceedings of the 18th annual ACM symposium on User interface software and technology - UIST '05* (pp. 119–122). New York, New York, USA: ACM Press. doi:10.1145/1095034.1095055

Geyer, F., Pfeil, U., Höchtl, A., Budzinski, J., & Reiterer, H. (2011). Designing Reality-Based Interfaces for Creative Group Work. In *Proceedings of C&C '11* (pp. 165–174). New York, New York, USA: ACM Press. doi:10.1145/2069618.2069647

Gutwin, C., & Greenberg, S. (1998). Design for individuals, design for groups: tradeoffs between power and workspace awareness. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work - CSCW '98* (pp. 207–216). New York, New York, USA: ACM Press. doi:10.1145/289444.289495

Gutwin, C., & Greenberg, S. (2002). A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work*, *11*(3-4), 411–446. doi:10.1023/A:1021271517844

Hancock, M. S., Carpendale, S., Vernier, F. D., & Wigdor, D. (2006). Rotation and Translation Mechanisms for Tabletop Interaction. In *First IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TABLETOP '06)* (pp. 79–88). IEEE. doi:10.1109/TABLETOP.2006.26

Hinrichs, U., Carpendale, S., & Scott, S. D. (2005). Interface currents: supporting fluent face-to-face collaboration. In *ACM SIGGRAPH 2005 Sketches on - SIGGRAPH '05* (p. 142). New York, New York, USA: ACM Press. doi:10.1145/1187112.1187284

Ion, A., Chang, Y.-L. B., Haller, M., Hancock, M., Scott, S. D., & Chang, B. (2013). Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. In *CHI 2013* (pp. 3149–3158). ACM. doi:10.1145/2466416.2466431

Isenberg, P., Tang, A., & Carpendale, S. (2008). An exploratory study of visual information analysis. In *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (pp. 1217–1226).

Javed, W., Kim, K., Ghani, S., & Elmqvist, N. (2011). Evaluating physical/virtual occlusion management techniques for horizontal displays, 391–408. Retrieved from http://dl.acm.org/citation.cfm?id=2042182.2042218

Khalilbeigi, M., Steimle, J., Riemann, J., Dezfuli, N., Mühlhäuser, M., & Hollan, J. D. (2013). ObjecTop: occlusion awareness of physical objects on interactive tabletops. In *Proceedings of the 2013 ACM international conference on Interactive tabletops and surfaces - ITS '13* (pp. 255–264). New York, New York, USA: ACM Press. doi:10.1145/2512349.2512806

Kobayashi, K., Narita, A., Hirano, M., Kase, I., Tsuchida, S., Omi, T., … Hosokawa, T. (2006). Collaborative simulation interface for planning disaster measures. In *CHI '06 extended abstracts on Human factors in computing systems - CHI EA '06* (pp. 977–982). New York, New York, USA: ACM Press. doi:10.1145/1125451.1125639

Kongsberg Gallium. (2013). InterMAPhics. Retrieved May 31, 2013, from http://www.kongsberg.com/en/kds/kongsberggallium/products/intermaphics/

Kruger, R., Carpendale, S., Scott, S. D., & Greenberg, S. (2004). Roles of Orientation in Tabletop Collaboration: Comprehension, Coordination and Communication. *Computer Supported Cooperative Work (CSCW)*, *13*(5-6), 501–537. doi:10.1007/s10606-004-5062-8

Morris, M. R., Ryall, K., Shen, C., Forlines, C., & Vernier, F. (2004). Beyond "social protocols": multi-user coordination policies for co-located groupware. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work - CSCW '04* (p. 262). New York, New York, USA: ACM Press. doi:10.1145/1031607.1031648

Nayak, S., Zlatanova, S., Hofstra, H., Scholten, H., & Scotta, A. (2008). Multi-user tangible interfaces for effective decision-making in disaster management. In S. Nayak & S. Zlatanova (Eds.), *Remote Sensing and GIS Technologies for Monitoring and Prediction of Disasters* (Environmen., pp. 243–266–266). Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-540-79259-8

Nóbrega, R., Sabino, A., Rodrigues, A., & Correia, N. (2008). Flood Emergency Interaction and Visualization System. In M. Sebillo, G. Vitiello, & G. Schaefer (Eds.), *Visual Information Systems. Web-Based Visual Information Search and Management* (Vol. 5188, pp. 68–79). Berlin, Heidelberg: Springer Berlin Heidelberg. doi:10.1007/978-3-540-85891-1

Qin, Y., Liu, J., Wu, C., & Shi, Y. (2012). uEmergency: a collaborative system for emergency management on very large tabletop. In *Proceedings of the 2012 ACM international conference on Interactive tabletops and surfaces - ITS '12* (p. 399). New York, New York, USA: ACM Press. doi:10.1145/2396636.2396710

Roman, P. A., & Brown, D. (2008). Games, Just How Serious Are They? In *Proceedings of Interservice/Industry Training, Simulation & Education Conference* (p. 11 pages).

Savery, C., & Graham, T. C. N. (2012). Timelines: simplifying the programming of lag compensation for the next generation of networked games. *Multimedia Systems*, 1 – 17. doi:10.1007/s00530-012-0271-3

Scott, S. D., Allavena, A., Cerar, K., Franck, G., Hazen, M., Shuter, T., … Scott, S. D. S. D. S. D. (2010). Investigating Tabletop Interfaces to Support Collaborative Decision-Making in Maritime Operations. In *Proceedings of ICCRTS 2010: International Command and Control Research and Technology Symposium*. Santa Monica, CA, USA, June 22-24.

Scott, S. D., Sheelagh, C., & Inkpen, K. M. (2004). Territoriality in collaborative tabletop workspaces. In *Proceedings of the 2004 ACM conference on Computer supported cooperative work - CSCW '04* (pp. 294 – 303). New York, New York, USA: ACM Press. doi:10.1145/1031607.1031655

Selim, E., & Maurer, F. (2010). EGrid: supporting the control room operation of a utility company with multi-touch tables. In *ACM International Conference on Interactive Tabletops and Surfaces - ITS '10* (p. 289). New York, New York, USA: ACM Press. doi:10.1145/1936652.1936720

Seyed, T., Costa Sousa, M., Maurer, F., & Tang, A. (2013). SkyHunter: A Multi-Surface Environment for Supporting Oil and Gas Exploration. In *Proceedings of the 2013 ACM international conference on Interactive tabletops and surfaces - ITS '13* (pp. 15–22). New York, New York, USA: ACM Press. doi:10.1145/2512349.2512798

Szymanski, R., Goldin, M., Palmer, N., Beckinger, R., Gilday, J., & Chase, T. (2008). *Command and Control in a Multitouch Environment*. *26th Army Science Conference*. Orlando, Florida. Retrieved from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA503423

Tang, A., Tory, M., Po, B., Neumann, P., & Carpendale, S. (2006). Collaborative coupling over tabletop displays. In *Proceedings of the SIGCHI conference on Human Factors in computing systems CHI 06* (Vol. pp, pp. 1181–1190). ACM Press. doi:10.1145/1124772.1124950

Wallace, J. R., Scott, S. D., & MacGregor, C. G. (2013). Collaborative sensemaking on a digital tabletop and personal tablets. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13* (p. 3345). New York, New York, USA: ACM Press. doi:10.1145/2470654.2466458

List of Acronyms

BMOQ-Land	Basic Military Officer Qualification–Land
BMS	Battle Management System
C2	Command and Control
CAXs	Computer Aided Exercises
CERDEC	Communications-Electronics Research, Development and Engineering Center
CSTCDC	Command and Staff Training and Capability Development Center
DRDC	Defense Research and Development Canada
FTXs	Field Training Exercises
GIS	Geographical Information Systems
GPS	Global Positioning System
MDE	Multi Display Environment
ORBAT	ORder of BATtle
OrMiS	Orchestrating Military Simulation system
PTA	Primary Training Audience