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OrMiS: Use of a Digital Surface for Simulation-Based Training

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(More details on OrMiS and its application can be found in our published papers. These include an overview of OrMiS and its design goals (Bortolaso et al., 2013). We have studied in detail the tradeoffs between lenses, radar views and tabletop-level zoom (Bortolaso et al., 2014). Finally, we have shown how a multi-surface map table can support a variety of terrain visualization techniques (Oskamp et al., 2015).)

Introduction

The Canadian Army uses simulations 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. Retired military officers (called interactors) act out the role of troops on the battlefield. Trainees operate in a mocked up command headquarters – a room with tables, maps, computers and communications equipment. Trainees use radio and chat programs to communicate with officers in the field, use battle management software to plan missions and operations and to maintain situation awareness, and use unmanned aerial vehicles (drones) to monitor the operation. In simulations there of course are no troops and vehicles in the field. Instead, 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 exercises provide numerous advantages over exercises carried out in the field. Simulations are much cheaper than field deployments, enabling large-scale exercises at low cost. They enable actions, which would be cost prohibitive or dangerous in real-world training, 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 depends on the ability of interactors to enact 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 developed OrMiS, a system for Orchestrating Military Simulation (figure 1). OrMiS provides users with a multi-display and multi-touch simulation interface based on a digital tabletop. OrMiS follows the conventions of traditional map tables where a small group of people can work together to observe the state of a battlefield. Unlike traditional map tables, OrMiS can also be used to control a simulation, allowing users to plot routes and positions for vehicles. 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 pinch gestures. Lenses can be used for focused work; separate tablets can be used for private work, and radar views provide group context.

Figure 1. OrMiS supports military simulation 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 chapter, we report our experience analyzing interactors' practices and show how this informed the design of OrMiS. 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. Currently, interactors sit in front of a PC, making it difficult for them to coordinate their actions. In order to collaborate, interactors are forced to switch between their screen and a physical map when impromptu events occur during an exercise.

In this chapter, 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 command and control. We then show how OrMiS was designed to be easy to learn, while helping with coordination and planning tasks. Finally, we report on 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. 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 can be 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.

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 maps. Digital maps support zooming and panning and dynamic update of the map's contents.

The first map-based tabletop systems provided simple interfaces, relying 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 pioneering 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 efficiently supports individual work while maintaining workspace awareness. However, much of the advantage of tabletops is lost, since people are no longer looking at the same shared display, and possibly 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. 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

Despite the fact that the military has a rich history working with tables, few research projects have focused on using digital tabletops to support command and control activities. The Digital Sand Table that face-to-face work around a digital command and control application could strongly support collaboration. Similarly, the Comet project (Cerdec Comet Multitouch, http://www.cerdec.army.mil/about/comet.asp)—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 command and control. Canadian naval simulation researchers at Defense Research and Development Canada (DRDC)-Atlantic in conjunction with SurfNet researchers proposed the ASPECTS system (Scott et al., 2010), which provided a digital tabletop system to support naval command and control by providing real-time monitoring of ships' locations. ASPECTS used personal viewports on the tabletop, and provided pie-menus and role-based interaction based on user identification with pens.

Companies specializing in defence and security have explored digital implementations of the traditional map table. In 2007, Northrop Grumman demonstrated TouchTable , an 84" digital tabletop supporting collaborative interaction with geospatial data. The FAA's Cyber Security Incident Response Center installed a TouchTable (Northrop Grumman's War table: http://news.cnet.com/8301-17938_105-9773294-1.html) to help cyber analysts identify and respond to cyber-attacks against the FAA's network (http://www.irconnect.com/noc/press/pages/news_releases.html?d=125335). Around the same time, Northrop Grumman also demonstrated a 3-dimensional digital map tabletop, called the TerrainTable (Northrop Grumman's TerrainTable: http://blogs.walkerart.org/newmedia/2006/05/16/art-com-northrop-grumman-and-audiopad/). Activating mechanical pins in the table to distort a silicone skin physically formed the shape of the terrain. As the terrain was formed, satellite pictures of the map were displayed through an overhead projector. 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 (iCommand: http://www.aaicorp.com/products/unmanned/icommand) 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 (Command Table: http://www.hdtglobal.com/products/command-control/audio-video-display/60-interactive-command-table/) and Steatite Rugged Systems (Rugged Interactive Mapping Table: http://www.rugged-systems.com/products/rugged-monitors/interactive-mapping-table.html) 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. This chapter 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 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 shown in Figure 2, a standard approach locates trainees in a mocked-up command headquarters, communicating by radio or text chat with "officers in the field". The trainees use BattleView (BattleView: https://www.thalesgroup.com/en/content/battleview-newly-integrated-canadian-armys-tactical-c2-system) a command and control application on personal computers and paper maps to perform battle management and operational planning. The positions of units in 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 trainees and carry out their orders. The interactors are, in fact, located at desks with personal computers located in a private room, and use simulation tools that mimic battlefield troop movement and combat engagement (see Figure 2B). 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", as it provides a bird's eye view), 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.

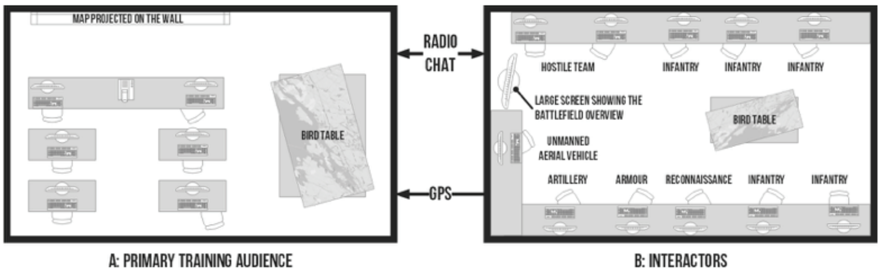

Figure 2. Physical layout of a typical simulation-based training session.

The simulation software allows interactors to mimic troop movement and combat engagement. Two popular simulation tools are ABACUS (Advanced Battlefield Computer Simulation - http://www.raytheon.com/) and JCATS (Joint Conflict and Tactical Simulation - http://www.jtepforguard.com/jcats.html). 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 symbols. 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' command hierarchy.

We 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, requiring significant training and expertise to use. 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:* If the trainees perform unexpected actions, the interactors may need to adjust their training strategy. Re-planning requires 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 interactors to leave their desks 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. 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.

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 range of possible configurations, detailed later in the chapter.

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, 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.

Units positioned on the map are depicted using standard military symbols. Interactors 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 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.

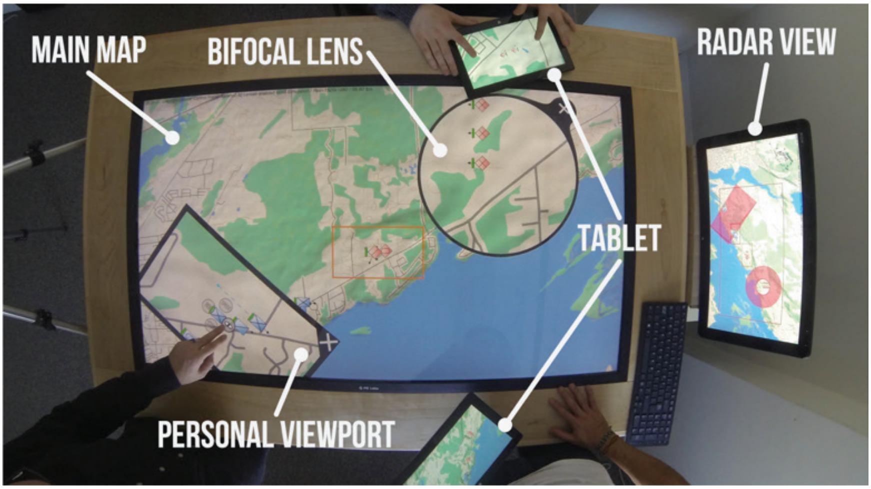

Figure 3. The OrMiS system combines a digital tabletop, a radar view display, and tablets for private work.

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 game engine (http://unity3d.com/). This engine eases 3D programming and provides fast rendering and a very responsive interaction. OrMiS is compatible with Windows 8 and TUIO (Tangible User Interface Objects - http://www.tuio.org/) 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).

Over all, OrMiS 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

Our interviews with simulation center staff revealed a strong desire for simulation tools that were easy for interactors to learn and use. Most interactors are retired military officers who have high expertise in military command and control, but are not experts in simulation tools such as

ABACUS or JCATS. Interactors typically participate in simulation supported training exercises once or twice a year, and so need to be trained (or re-trained) prior to each exercise.

The interactor's interface in ABACUS or JCATS shows a map of the battlefield including the units under the interactor's control. A profusion of menus support 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 displaying the map and the other displaying the menus (Figure 4). Interactors need to become sufficiently proficient with all interface controls in order to work in the real-time of live simulated exercises.

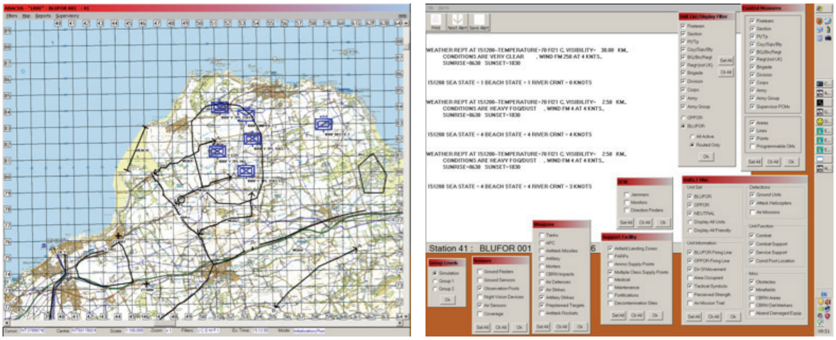

Figure 4. The interface of the ABACUS simulation tool displayed on two screens.

The interactor's interface in ABACUS or JCATS shows a map of the battlefield including the units under the interactor's control. A profusion of menus support 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 displaying the map and the other displaying the menus (Figure 4). Interactors need to become sufficiently proficient with all interface controls in order to work in the real-time of live simulated exercises.

Simple, Touch-Based Controls Improve Usability and Scalability

We designed OrMiS to be easy to use. We applied 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.

Interactors 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 route for the associated unit (see Figure 6A). Tapping on the first or last waypoints can extend a route. When a unit is driving along a route, the waypoints can still be modified. The unit will adapt in real time to new waypoint positions. This allows interactors to easily specify routes, and to quickly react to situations, such as the need to escape from an enemy.

Similarly, a unit's line of sight can be shown by tapping on its icon, in the form of an isovist visualization (see Figure 6B). The heading of the unit can be modified with a circular widget. To hide the line of sight and circular control, the interactor simply taps the unit again. This visualization tool allows interactors to easily organize formations of units to cover a specific area.

Similarly, to limit the number of controls, 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 without the need of additional controls.

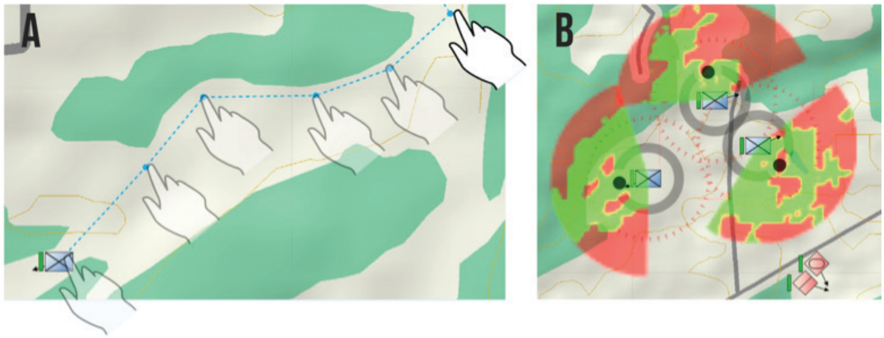

Figure 5. A) Routes in OrMiS are specified using a simple dragging gesture; B) Three units' isovist viewsheds.

In contrast to the existing simulation interfaces, all of 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 separate interface elements or in external windows. To interact with the system, interactors do not 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 officer trainees 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

The current physical setting of the simulation room and the existing PC-based simulation tools hinder both explicit and consequential communication. Explicit communication involves planned, intentional behavior, such as verbal expression, or non-verbal actions such as pointing or gesturing (Baker, Greenberg, & Gutwin, 2001). 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.

OrMiS provides a shared physical and virtual workspace for interactors to perform their actions, and thus supporting both explicit and consequential communication.

PC-based Setting and Communication Issues

Existing simulation tools poorly support both explicit and consequential communication. Interactors sit at their own desks, using a PC, possibly distant from other interactors with whom they are coordinating activities. This physical arrangement limits opportunities for explicit communication between interactors during an ongoing exercise. We have observed that rather than talking directly, 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 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.

These scenarios are so difficult to perform with existing tools that in practice, the interactors typically change ownership of units 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

OrMiS supports both 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. 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. For example, two interactors may plan routes for different units on different parts of the map, both 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 coordinating the passage of units through the lines need 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 the requirement to support both loosely and tightly-coupled collaboration and both consequential and explicit communication, we implemented in OrMiS a set of interaction techniques, each adapted to different situations:

1. *The main map* (Figure 6A) 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 space that they can point to in discussions. It also supports consequential communication through the fact that it is visible to all interactors, providing ongoing awareness of the state of the simulation.

2. *Bifocal Lenses* (Figure 6B) 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. The position of the lens shows others what part of the map is being used, fostering consequential communication. 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 6C) 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. 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, limiting consequential communication.

4. *Tablets* (Figure 6D) 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.

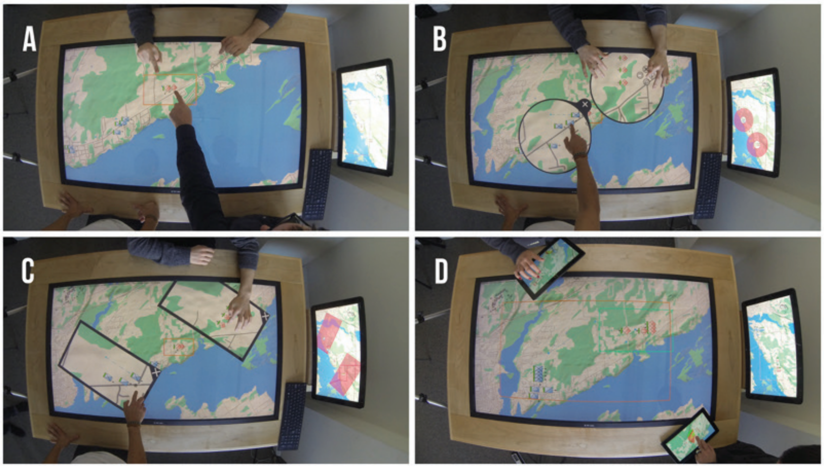

Figure 6. OrMiS in three different settings:
A) Only the main map is shown, ideal for planning,
B) Interactors with bifocal lenses working on close parts of the map,
C) Interactors with personal viewports working on separated parts of the maps,
D) Interactors with individual tablets around the table.

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 trainees' orders. This usually includes war-gaming on a large map 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 trainees. When the exercise is finished, interactors and the trainees gather and perform an after-action review to confirm how training objectives were met and to discuss lessons learned. In practice, unforeseen events occur, forcing the trainees and interactors to reconsider their plans.

Re-planning and Workflow

During simulations, unexpected events may arise. For example, the officer trainees might change their plan after receiving updates from the interactors and provide truly unexpected orders. 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 significant experience in command and control, 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. Meanwhile, 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 or performing a pre-programmed patrol) 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 at different levels 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 low. When performing the exercise, if unexpected events occur, interactors can immediately switch to a re-planning phase by looking at the tabletop display in front of them. During re-planning, interactors can place their tablets on the table's edge to ease collaborative work over the table itself (see Figure 3 and Figure 7D). During collaborative planning, interactors can 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, OrMiS' physical organization around a table and tablets ease transitions between different work styles and activities.

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 7. 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 7, 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 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, 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.

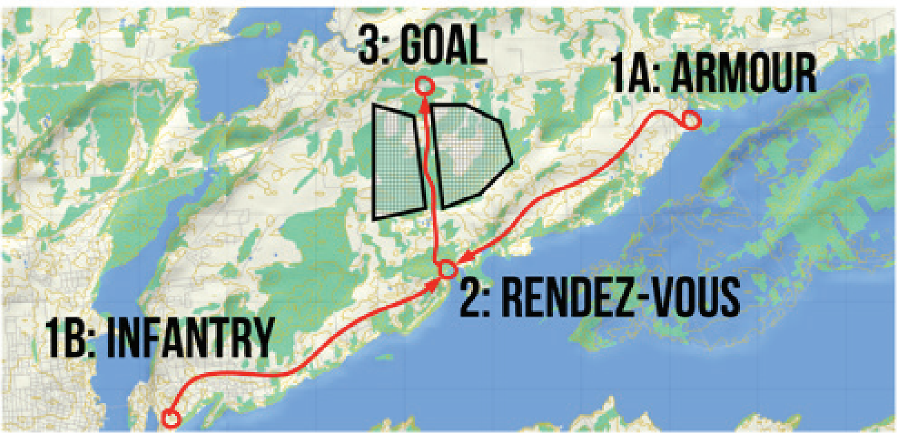

Figure 7. Collaborative scenario used during the study.

Results

All participants completed the task without encountering significant usability issues. In interviews, participants were positive, reporting that 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 at 2 in 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 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 effort 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

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 how 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.

SURFNET / Designing Digital Surface Applications is a compendium of research findings from a Canadian research network that integrated innovative research in two critical areas –software engineering (SE) and human-computer interaction (HCI)– to identify critical requirements, design new engineering processes, and build new tools for surface-based application development. Funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) from 2009 to 2015, SurfNet's research clustered around three themes: Humanizing the Digital Interface, Improving Software Time to Market and Building Infrastructure for Digital Surfaces. Research was driven by the needs of four application areas: Planning, Monitoring and Control Environments; Learning, Gaming, New Media and Digital Homes; Software Team Rooms; and Health Technologies.