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Project Ensayo: Designing a Virtual Emergency Operations Center

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***Abstract*— Hurricane Katrina was one of the most expensive and devastating natural disasters in American history [41]. Over half a million people were affected by the hurricane, and the US energy infrastructure was severely damaged [41]. Hurricane Katrina and other natural disasters clearly show the need for improvements in crisis management, especially in training and collaboration among federal, state, and local governments [1,41]. In this paper, we describe Project Ensayo: a socio-cognitive--technical simulator and training facility for upper level emergency managers and a tool for cognitive scientists to study the decision making process under emergency conditions. In particular, we describe how the underlying architecture accommodates the various learning requirements inherent in a dynamic, evolving, and unique organizational structure situated in a highly variable complex threat environment.**

***Keywords*—virtual emergency operations center, training simulator, expert systems, crisis management, decision making**

I. Introduction

"It has been argued by researchers that under a crisis situation, humans tend to make decisions more "naturally" or "intuitively" rather than wholly 'rational.' It is believed that experience and extensive practice dealing with uncertainly and time stress within a particular domain is the only way to improve crisis decision-making skills" [24]. Psychological theory and research demonstrate that experience and deliberate practice play a major role in improving performance [12,13].

Most training in the current crisis management arena is conducted via live or face-to-face "table top" exercises [1]. This means that training requires participation from many individuals and consumes a great deal of resources, thus restricting the frequency and extent of exercises. Despite the benefits, there are a number of limitations to exclusive use of face-to-face training solutions. First, crises can be rare events for which emergency responders are ill-prepared, as training choices must be made about which events are most likely to occur. For example, a recent wildfire in southern Georgia, a rare event, turned out to be the largest in over 50 years. Moreover, in the middle of a crisis, few organizations have the time or resources to train new personnel since their foremost focus is on stabilizing the situation [40]. Another limitation of face-to-face solutions is that few experts are available, and each expert is constrained by limited time, experience, and perspective [40]. In addition, there is the difficulty of training teams, training selective components of the crisis hierarchy, and training upper level managers [15, 40]. In fact, while there are multiple computer-based solutions available for first responders, current research identifies a general lack of computer-based training (CBT) that targets upper level crisis managers [1]. The training that does take place, moreover, can be ineffective because most instructors use subjective measures and usually end up emphasizing outcomes over decision management processes. Finally, in face-to-face and instructor-centric solutions, there usually are inherent time delays in the feedback as experts analyze the student's progress, compare the student's actions and outcomes to the expected actions and outcomes, and tailor the feedback to the individual [1]. This is complicated further by the fact that much learning in an organization, especially in these types, is "very much a social, not a solitary, phenomenon" [39, p.125]. What must be learned is demonstrated in group, not individual, performance.

Computer-Based Solutions to Emergency Management

Computer-based solutions, when appropriately designed, show promise in addressing these limitations in incident management [18,19,49]. The CBT approaches can allow emergency managers to train new personnel outside of an

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actual disaster. CBT allows individuals to train more frequently than they otherwise would be able to in live and face-to-face exercises. In addition, CBT enables distributed access to data, resources, and training. Another advantage of CBT is that in programming the training system for evaluation, a wide knowledge base derived from subject matter experts is gathered, which allows emergency managers to reap the benefit of a collective knowledge base of expertise, rather than that of one or two individual instructor's physical presence [40]. CBT also allows emergency managers to engage in a variety of pedagogical forms, ranging from simple memory tasks to extensive event simulations. CBT affords substantial adaptive capability to adjust to heterogeneity in learner skill levels, knowledge, and abilities [23,38]. CBT also enables emergency managers to train teams and to target and train selective portions of the emergency management personnel and hierarchy. Additionally, whereas feedback is delayed in non-computer solutions, feedback can be immediate in a computer-based system. CBT also provides extensive documentation on individual and collective behavior over time. Finally, CBT allows emergency managers to posit and assess impacts of policy, structural, communication or other forms of changes and assess locations and forms of performance difficulties.

Project Ensayo: a Distributed Web-based Virtual Emergency Operations Center (vEOC)

In this project, we incorporate computer-based solutions in emergency management through the creation of a distributed web-based simulator of an Emergency Operations Center (EOC). An EOC is a secure location in which emergency management representatives from county and state agencies, as well as from private industries, come together to prepare for, manage, and coordinate recovery activities in response to an emergency situation (e.g., hurricane, tsunami, disease outbreak). There are several key features of this application. First, it targets upper level emergency managers. Specifically, these are the key decision makers and communicators (to their respective organizations or units) who have "boots on the ground" and are privy to all relevant information and events as they unfold. Second, it allows emergency managers to access databases, to coordinate emergency response, and to train in a virtual arena, thereby gleaning the relevant key benefits of CBT.

A third key feature of our system is that it allows users to train both locally and remotely. Since our system is distributed and web-based, users who are unable to come to the physical EOC have the option of logging in to the exercise from any computer on any desktop. In this way, training can continue when one or more individuals cannot be physically present for the exercise.

Another key feature of this system is that it will be augmented with artificial intelligent agents that can substitute for any individual within the EOC. This will allow training to continue when one or more individuals cannot be present for the exercise or when selective members or teams want to train further aside from the full-scale exercises.

Finally, the vEOC also serves as a research tool for cognitive scientists to study the decision making process under emergency conditions.

Design Approach

The demands of the vEOC cut across a variety of purposes. Apart from the overall control of the project, we needed to develop a pragmatic and integrated approach to design that incorporates instructional theory and assessment [14], methods of assessing formal and informal work practices [5,6], methods of assessing and addressing expertise [16,45], and human-computer interaction in instructional contexts [25,42]. For the design, we are working closely with one of the foremost emergency operations centers in the USA – the Miami-Dade County EOC in Miami-Dade County, Florida.

DESIGN METHODOLOGIES

To accommodate the core purposes, we employ four main design methodologies in creating this prototype: spiral development, model-view-controller, instructional process modeling, and user-centered application design. These serve the overall functions of Control, Efficiency, Effectiveness, and Coherence.

Control: Spiral Development

The overall and encompassing design methodology is the spiral development model [4]. This is the software engineering model in which we design and develop prototype components in iterations in which we incorporate feedback from the previous phase into the current phase.

We have split the design into three primary iterations (see figure 1). The size of the blue circles suggests the amount of effort that is required in each iteration during each phase of the software engineering cycle (i.e, Design, Build, and Evaluate). The orange chevrons indicate the start of new iterations. The yellow 4-pointed stars indicate completed validation points, and the purple 5-pointed stars indicate planned validation points. In the first iteration, we designed and deployed a single client to train in a virtual environment. Then we solicited feedback from key EOC personnel in our design [28,32] and implementation [22,29,33]. In iteration #2, we made the vEOC multi-client and we supplied server push (see section III.C). After iteration #2, we solicited feedback to validate the design again [22]. In iteration #3, we will begin implementing intelligent agents to supplant humans that are not available to participate in the exercise.

Efficiency: Model-View-Controller

We employ the model-view-controller (MVC) framework to help accommodate the various views (roles) of the user and the underlying data. The MVC framework defines a flexible architecture in which the way we make available the relevant data to the user (the view) is abstracted from the data itself (the model), as well as from the way we manipulate the data (the controller) [37].

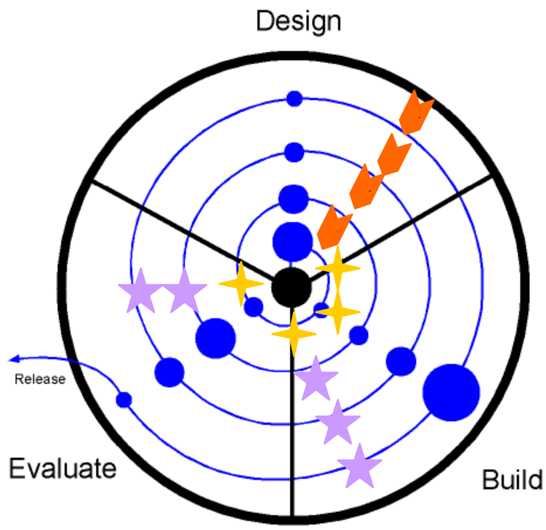

Figure 1. vEOC Spiral Design Methodology [1] and Validation Points. The size of the blue circles suggests the amount of effort that is required in each iteration during each phase of the software engineering cycle (i.e, Design, Build, and Evaluate). The larger the circle implies that more effort is required. The orange chevrons indicate the start of new iterations. The yellow 4-pointed stars indicate completed validation points, and the purple 5-pointed starts indicate planned validation points.

Effectiveness: Instructional Process Modeling

The third approach directly addresses how to design and assess instruction for complex tasks [46,47]. By viewing complex tasks in terms of four primary and interacting components (task definitions, part-task practice, domain-model support, and procedural information), this approach incorporates key underlying design principles of instruction [2,14] as well as principles of the human cognitive architecture and multimedia attributes. This approach is augmented also by addressing the socially situated and distributed context of the interactions and their impact on decision deliberations [17,42,50]

Coherence: User-Centered Application Design

Finally, we incorporate a general user-centered approach to integrate the various design results into a coherent, seamless user experience by assessing user content, functionality, aesthetics, and usability. As summarized by Clark [7], these four components are the key ingredients of user interface design. Basically, content includes the features that are on the user interface, aesthetics indicates how pleasing the user interface is to the eye, functionality includes what the user interface is capable of doing, and usability is the "user-friendliness" of the interface.

[1] Adapted from http://faculty.washington.edu/farkas/TC407/SpiralModel.gif

II. vEOC Architecture

Technologies Employed

In order to create the vEOC, we employed a variety of technologies. One of the most unique aspects is that all development and deployment is being accomplished in virtual machines (VMs) using VMware [48] and Ubuntu [44]. We do this to facilitate a faster mean time to repair and to isolate various servers from each other and from the underlying hardware. For example, we have a VM set up for show only. This VM has pure public access and therefore has been stripped of all confidential information. In addition, we have a development VM set up, which is reserved for verified builds of the prototype. Other technologies employed include XHTML, CSS, Dynamic HTML, AJAX, Reverse AJAX, PHP, JavaScript, MySQL, and Jetty. Finally, we also use the Dojo toolkit to facilitate server push [11]. Figure 2 shows how we link all these technologies together to create the virtual EOC.

Architecture

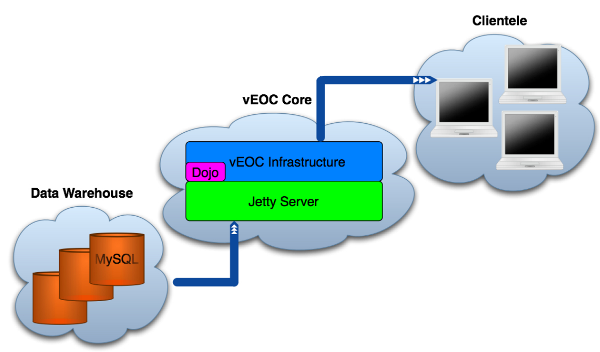

Figure 2. vEOC Architecture. The architecture consists of a data warehouse, a vEOC core, and clientele.

The architecture of the vEOC consists of a set of clients connected via the Internet to a centralized server. The server is Jetty-6.1.7. The web client connects to the servers and requests an HTML/JavasSript file, which the client web browser then renders. Any number of clients can connect to the server, limited only by the load on the server. Clients initially render the page using AJAX and then subscribe to a channel to have information concerning the exercise "pushed" to them via Reverse AJAX. In this way, clients finally are able to participate in the exercise with other clients. The data warehouse consists of a set of MySQL databases, which store user data, user profiles, access rights, scenarios, and the state of the exercise.

Server Push

We use Reverse AJAX, sometimes also called Comet [9] to implement server push using HTML, AJAX, and JavaScript.

Server push is a technology that enables the server to initiate communication to other clients over HTML channels. This differs from standard HTML because in standard HTML, only the client can initiate communication to another client or to a server. We implement this using Jetty-6.1.7 [21] and the Dojo toolkit [11].

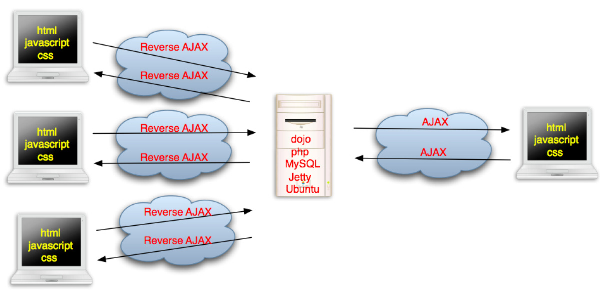

Figure 3. Server Push. Clients initially render the page using AJAX and then subscribe to a channel to have information concerning the exercise "pushed" to them via Reverse AJAX.

VEOC INFRASTRUCTURE

The vEOC infrastructure consists of a set of interconnected modules. (see Figure 4) The modules include a mapping/GIS module, an analytics, chat/IM module (VOIP), scripting module, a user interface module, a dashboard module, a report module, a virtual reality module, and an interactive advisor module. We now explain each module and its corresponding functionality in depth.

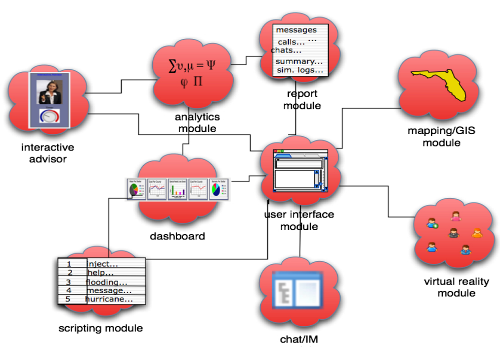

Figure 4. vEOC Infrastructure. Nine Major Modules Comprise the vEOC Infrastructure.

Mapping/GIS Module

The mapping/GIS module is the place in which we incorporate GIS/mapping capabilities.

Analytics

The analytics module is the place in which we do necessary calculations to support other modules.

Chat/IM Module (VOIP)

The chat/IM module deals with a local chat function. To implement this, we use Reverse AJAX [9] to create a real-time collaboration environment.

Scripting Module

The scripting module stores the code that deals with implementing automatic sending of injects from the script stored on the server to the clients who are participating in the exercise. It also deals with the user input status and pushing the response of the inject from the single user to the other clients.

User Interface

The user interface module is the location in which the sections of code reside that deal with the display of information on the server to the user. It is mostly client code, and it consists of HTML and JavaScript.

Dashboard

The dashboard module provides real-time feedback to the trainee concerning the effect of his/her decisions on various aspects of the available resources. One of the categories, for instance, is water per shelter. If the trainee makes a decision that affects the amount of water per shelter, then the dashboard will update and show a decrease or increase in the amount of water per shelter. This is a feature requested by the crisis decision making researchers to help offer the trainee immediate feedback of the results and impact of his/her decisions [28]. Note that the dashboard can be turned off when the system is being used for real time training.

Report Module

The report module is the central location for the code that generates report templates and reports. This module also enables one to save, create, import, export, and search through reports.

Virtual Reality Module

This is a plug-in module that enables one to incorporate virtual reality into the vEOC.

Interactive Advisor Module

The interactive advisor module is the place in which we implement the interactive advisor. Currently, we are using JESS version 7.1.2 [20]. The interactive advisor provides real-time feedback to the trainee based on his/her crisis management decisions. It analyzes the decisions of the trainee and compares the decision to the "correct decision" based upon standard operating procedures (SOPs) and current subject matter expert opinion. It then offers the trainee feedback and advice on his/her decision.

III. VERIFICATION AND VALIDATION

As we stated before, current research in disaster management is severely hampered by a number of factors: (1) Events are for the most part 'one-of-a-kind' in the sense that they present themselves as an instance of a potentially infinite number of variables which describe the event. A hurricane characterized with little rain and very high winds, for example, will have a different impact than one characterized by lower speed winds but high precipitation. (2) Restoring a community to continuity requires the collaboration of a number of different organizations, both public and private, that typically do not collaborate together, under high stress and urgency. (3) In many instances the people involved in the response will be 'new actors,' who may have no prior experience in an actual event. Due to the urgency of the event, it is unlikely that there is sufficient time to train personnel once the emergency happens. In addition, as with any other team activities, there may be natural barriers to the successful collaboration of the involved personnel. (4) There are few opportunities for emergency management personnel to receive feedback on their approach to the response tasks.

In order to develop a validation environment that accurately represents the constraints described above, we defined the following: (1) Use existing scripts from prior training events to establish a base of action for the training scenario that is both realistic and varied. The scripts used for training events originate from actual emergency events that may have occurred sometime in the past. (2) We will give actors different roles, with a description of their specific operational context, to establish a baseline for decision-making. Responses will be compared against actors that have not been provided with information about their specific context. (3) Actor response to the events will be tracked, and performance of 'experienced' players will be compared against that of 'naïve' players. (4) The Ensayo infrastructure is equipped with a scorecard that enables actors to review the results of their actions as it relates to one or more specific outcomes. For instance, if the actor allocates a forklift to satisfy a specific request such as clearing a road, he/she would see the number of available resources go down, but also the outstanding unresolved complaints would decrease.

We are validating our software in two distinct phases: software verification & validation (V&V) and design validation. For the software V&V phase, we will solicit a software analyst and volunteers from the Notre Dame student body, and for the design validation, we will enroll EOC personnel and cognitive decision-making researchers.

A. *Software Verification & Validation*

The goal of this phase is to test the software functionality and to identify software errors and logic errors. Emergency management procedural or functional errors are tested in the design phase.

B. *Design Validation*

Design validation is split further into emergency management validation and decision-making validation. The emergency management validation phase tests the design as a training tool for emergency managers, and the decision-making validation phase tests the design as a tool for cognitive scientists to study decision-making under emergency conditions.

1) Emergency Management Validation

Following the software validation phase, we begin the emergency management validation phase. The goal of this phase is to identify emergency management procedural and functional errors as well as to obtain EOC personnel feedback on trainer content, aesthetics, functionality, and usability [7].

2) Decision-making Validation

Finally, in this phase, we run an experiment with various researchers. Again, the goal of this phase is to identify decision-making procedural and functional errors as well as to obtain research personnel feedback on trainer content, aesthetics, functionality, and usability [7].

IV. PROTOTYPE DEMONSTRATION

We have successfully demonstrated our laboratory prototype that includes the first two phases of design. Because some of the information is sensitive to the Miami-Dade EOC, we have created a special prototype that has been cleared of all sensitive information. It is available to the public at http://veocblue.cse.nd.edu/ LoggedInYUITakeTwo.php.

V. CONCLUSION

In this paper, we discussed a virtual emergency operations center architecture and infrastructure. First we provided background and introductory rationale as to why computer based training and decision-making solutions are necessary. Next, we described the architecture and infrastructure in detail. Then we discussed how we verify and validate our design with a group of students and a group of real EOC personnel and researchers. Finally, we concluded with future directions for this work.

VI. FUTURE WORK

Our next step is to continue building the software prototype. In particular, we need to build artificial intelligence into the system to create agents that are able to supplant EOC personnel when they are not available to participate in the exercise. This next stage includes the development of a knowledge base for the interactive advisor. Finally, we will need to research more viable statistics for the dashboard to create real-time feedback for the decisions.

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