Human Factors Issues in the Use of Virtual and Augmented Reality for Military Purposes – USA

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PAPER 1 – AIR FORCE RESEARCH LABORATORY – MESA, AZ

PAPER 2 – ARMY RESEARCH INSTITUTE (ARI)

PAPER 3 – NAVAIR ORLANDO TRAINING SYSTEMS DIVISION

PAPER 4 – NAVAL POSTGRADUATE SCHOOL

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PAPER 6 – U.S. ARMY RESEARCH, DEVELOPMENT, & COMMAND (RDECOM) SIMULATION & TRAINING TECHNOLOGY CENTER (STTC)

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Paper 1 – Air Force Research Laboratory – Mesa, AZ

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1.1 AREAS OF INTEREST

- Enabling the DoD vision of achieving training transformation.
- Fulfilling the Air Force's Distributed Mission Operations vision by providing capabilities to train airmen to meet Combatant Commanders' requirements.

1.2 CURRENT RESEARCH PROJECTS

1.2.1 Distributed Mission Training (DMT)

DMT is a shared training environment comprised of live, virtual, and constructive simulations allowing warfighters to train individually or collectively at all levels of war. DMT allows multiple players at multiple sites to engage in individual and team participation to full theater-level battles. It allows participation, using almost any type of networkable training device, from each weapon system and mission area. Additionally, computer-generated, or constructive, forces can be used to substantially enhance the scenario. This combination of live, virtual, and constructive environments allows nearly unlimited training opportunities for joint and combined forces from their own location or a deployed training site.

1.2.2 DMT Air

DMT for aircrew complements flying training by providing capabilities to gain knowledge, skills, and experience for infrequently practiced tasks and missions. Since DMT is not constrained by airspace limitations or by number of aircraft available, pilots and controllers can learn to conduct complex missions in high-threat environments focusing on enhancing the individual and team skills required for mission success.

Training Systems Technology Research: USAF F-16 pilots and AWACS controllers participate in training research exercises using the F-16 DMT testbed at AFRL/HEA in Mesa, AZ. Pilots ranging in experience from Mission Qualification through Weapons School use the testbed to enhance their skills. Research is focused on developing training strategies that emphasize specific training needs and include validated measures of performance to track progress. In addition, coalition training research exercises are conducted using real-time, secure links to defence laboratories in Canada and the UK. US, Canadian, and British warfighters use DMT to plan, brief, fly, and debrief simulated composite force, coalition missions.

High-Resolution Visuals: The full field-of-view visual displays currently used in the F-16 DMT testbed provide high levels of immersion into the synthetic environment but lack the resolution required for within-visual-range air combat and close air support missions. Research is in progress to increase resolution in immersive displays to eye limiting (20/20 visual acuity) resolution. The objective of the 20/20 Immersive Visual Display System for the DMT-Aircrew program is to develop, integrate, and demonstrate a high fidelity visual display system for flight simulators. This Air Combat Command (ACC) Category 1, Advanced Technology Demonstration will significantly enhance the visual system for fighter simulators such as the F-16 by developing and integrating technologies that will improve the resolution of the simulated visual and sensor imagery while reducing the overall cost of the image generation and display system. This display system will provide bright, high-resolution (20/20 acuity) imagery wherever the pilot looks. The resulting system will eliminate the need for target projectors that restrict the number of high-resolution targets that can be displayed or channel the pilot's attention to specific areas within the scene. In addition, this display system will improve the pilot's perception of size and distance over real-image displays. This Advanced Technology Demonstration is scheduled for completion in FY 05.

The approach for achieving the objective is through contracted efforts to design, develop, and deliver:

- High resolution, full color laser projectors capable of displaying over 10 times the number of pixels currently displayed by high resolution projectors; and
- High performance, low cost image generators based on commercial technology that can provide high resolution visual and sensor imagery at 60 HZ.

The Next Threat System: Constructive (computer-generated) entities are a vital component of DMT. Constructive entities serve as both friendly and threat aircraft and provide an Integrated Air Defense System incorporating missiles, radars, and a command network. TNTS is an object like electronic warfare environment system designed to be HLA compliant. The design purpose of TNTS is to accurately depict Electronic Warfare considerations in distributed mission training.

Distributed Training Network Guard: Opportunities for team and inter-team training using DMT are limited by the different levels of security required by different systems. The Distributed Network Training Guard will greatly enhance DMT and Distributed Mission Operations (DMO) by allowing distributed simulations to interoperate at their native classification levels. DTNG will expand the range of possible scenarios exploited by DMO, and further enable warfighters to "train the way we fight" in a distributed, secure, high-fidelity, full-mission training synthetic battlespace. The DTNG is a Category I Advanced Technology Demonstration program that delivers a capability to transfer data between High-Level Architecture (HLA)-based distributed simulation networks executing at multiple security levels, thereby providing a critical element in realizing the full potential of the DMO concept. The operating component of the DTNG is a physical, real-time automated network guard that supports real-time two-way data transfer between HLA simulation federations operating at different security levels. The parameters for this guard are set pre-mission via a standalone interface that provides the security and federation domain experts with a tool to develop and review reclassification rules that govern the transfer of objects, attributes, interactions, parameters, and the execution of cross security-level, Run-Time Infrastructure operations for cross-federation object models. These rules can be Boolean "yes/no" rules, or more sophisticated guising or sanitizing rules. For example, a filtering rule may zero out, clear, or null the data values of attributes, sub-attributes, parameters and subparameters. Guising or sanitizing rules allow these attribute or parameter values to be changed within the constraints of the data type. For example, an F-22 operating within the high-side federation could be guised to appear as an F-15 on the low-side federation.

Space: DMT is not limited to aircrew training. A major goal of the DMT – Space R&D program is to develop and demonstrate a variety of technology delivery and performance support options that will provide faster, better, cheaper, seamless training and mission performance support. Another goal is to facilitate integration of products from this effort into our Distributed Mission Operations synthetic battlespace permitting space and missile operations that include the capacity to provide performance support and training to new operators within the context of mission planning and rehearsal. This work provides the scientific and technology foundation for future large-scale research for distributed training and rehearsal technologies for Space and Missile Operations. More specifically, we plan to collect into a database the operational requirements for space and missile operations mission rehearsal and training as well as specify alternative science and technology solutions to address identified needs.

Air and Space Operations Center: In 2000, the Air and Space Operations Center (AOC) was designated an official Air Force weapon system. This designation levied a requirement to develop a comprehensive training program for AOC warfighters from initial qualification through advanced and continuation training. The Air Force recognized that AOC training was previously accomplished on-the-job in an ad-hoc fashion. The goal of the current research effort is to ensure that AOC training methods and technologies provide the operators with the training required to employ the AOC as an effective warfighting instrument. AFRL/HEA is working with ACC/DOY and AFC2ISRC/DO to gain access to AOC subject matter experts to define the mission essential competencies (MECs), and knowledge, skills, and experiences required to develop an expert AOC warfighter. MEC definitions are also needed if AOC crews are to be "certified" for operations.

Security Forces: The objective of Security Forces DMT research is to develop, demonstrate, and evaluate a computer-driven, simulation capability to support training in command and control of USAF security forces. The S&T value resides in three areas: research and development of realistic computer-generated forces to serve as stimuli for decision-making, development of simulation training scenarios to support learning objectives underlying mission essential competencies, and collection/analysis of empirical data to determine usability and training value.

1.2.3 Night Vision Training System (NVTS)

The goal of the NVTS program is to produce high fidelity, deployable, low-cost, NVG simulation that will enable mission training, preview, and rehearsal whenever and wherever necessary. NVTS is a research and development effort that will continue development and transition to users. The NVG imagery is based upon the modeling of the unique two-dimensional NVG effects such as halos, gain response based on an accurate characterization of goggle sensitivity, gain, resolution, color, and field of view. The imagery is presented through a head tracked CRT-based display mounted in an actual NVG shell. This approach allows for the correct eye-point for all crewmembers. Each display requires at least one channel of imagery. The three-dimensional world incorporates high-resolution material-classified imagery, and accurate per-texel radiometric response of surface reflectance and aspect. The current approach results in a single database which will support completely correlated visible and multiple sensor simulation.

1.2.4 Uninhabited Aerial Vehicle Synthetic Task Environment

AFRL/HEA's Mesa Research Site has established a Performance and Learning Models Lab (PALM Lab) with the mission of conducting empirical research and creating computational process models for understanding human performance and learning. Architectures for developing computational process models of human behavior in dynamic, time-critical environments have only recently reached a state of maturity that makes them useful in a military modeling context. Computational process modeling provides value in both basic research on human behavior representation and processes, and also in applied research on technologies for improving warfighter training. Broadly stated, our objectives in the current PALM Lab basic research program are to (1) advance the state of the art in computational process modeling of human-system interaction in dynamic, time-critical environments of relevance to the warfighter, and (2) transition products and lessons learned both to the scientific community and to applied research involving warfighter modeling. In pursuing these objectives, our first goal is to develop a computational process model representing the behavior of an Uninhabited Air Vehicle (UAV) operator. This model is being developed with the Atomic Components of Thought-Rational (ACT-R) human behavior modeling architecture. ACT-R has evolved into an embodied cognitive architecture that provides theory-based mechanisms for representing perceptual inputs, cognitive processes, and motor actions, making it useful for modeling interactive tasks like operating a UAV.

In summary, PALM Lab researchers are using and advancing the state of the art in human behavior representation. Results of these efforts will lead to an improved scientific understanding of modeling idioms and representational assumptions useful in accounting for behavior in complex, dynamic, time-critical domains.

1.3 RESULTS ACHIEVED TO DATE

1.3.1 Distributed Mission Training (DMT)

DMT research efforts at AFRL/HEA incorporate both enhancements to VR/VE technologies and development of training strategies and interventions that take advantage of these technologies.

1.3.2 DMT Air

Training Systems Technology Research: These efforts are focused around the specification of Mission Essential Competencies (MECs) for a selected group of warfighters such as F-16 pilots. MECs along with specifications of required knowledge and supporting competencies describe the capabilities expected from warfighters that are required to accomplish their missions. MECs are derived from detailed interviews with subject matter experts and are used to define the objectives for any training event. Using MECs as the foundation, training syllabi have been to develop individual and team air combat skills for different sets of training objectives and levels of experience. DMT Air Training Effectiveness research has expanded to focus on coalition air operations through establishment of international cooperative research agreements with Canada and the UK and with Australia. Coalition, composite force training missions have been conducted with forces located in Mesa, AZ, Toronto Canada, and Bedford, UK.

Products developed this year include:

- Procedures and analysis tools for crew, team, and individual cognitive task analysis methods
- Mission Essential Competency specification for Air-to-Air, Air-to-Ground, AWACS, and SEAD Coalition MECs for Air-to-Air, Air-to-Ground and AWACS
- Validated competency-based syllabi for Air Combat DMO
- Knowledge- and skill-based learning and performance assessment tools
- Automated grade sheet mission evaluation metrics

- Scenario-based performance assessment methods
- Mission planning and analysis tools
- Cost-benefit training utility trade-off models
- Tools for career field education and training management and reshaping

1.3.3 High-Resolution Visuals

Products developed this year include:

- Assessed line rate and antialiasing effects on aspect recognition using legacy testbed visuals
- Integrated and evaluated MetaVR PC-IG in DMT testbed
- Assessed low altitude cueing in PC-IG / M2DART for altitude, velocity, and heading tasks
- Completed initial system resolution and antialiasing research
- Assessed spatial and temporal properties of COTS displays
- Developed digital interface for high-resolution, laser projector
- Demonstrated 5120 x 1024 real-time imagery on high-resolution, laser projector
- Demonstrated monochrome holographic collimating display
- Upgraded high-resolution, laser projector to full-color using prototype red laser

The Next Threat System: TNTS has been developed in two versions. The ground version runs on a PC and provides EW simulation for distributed simulation exercises. The airborne version is a mini computer, rack-mounted system that taps into the aircraft's signal bus and provides EW simulation to on-board displays. The airborne system has been installed and tested on an MC-130P aircraft. Specific attention is paid to accurately implementing sensor scanning and target detection in realistic situations. Sensor modeling is designed to be true to real world performance in the guise of beam pointing. Beam pointing in the TNTS is true to the description in EWIR. TNTS detection and tracking is allowed only within the beam of the sensor as the sensor scans (as applicable) and not based on presence with a scan volume. The utilization of "real world" clutter is limited by the data base used to describe the terrain in the scenario data base. Local area clutter is to be specified by the scenario database using, initially, DMA surface codes to describe the clutter reflectivity and the correct geometry to correlate its effect. Currently, such clutter is constrained to the terrain under the target or the terrain at the point of contact between the beam and the surface. Other basic considerations include the initial implementation of ECM effects.

Distributed Training Network Guard: On 20 February 2003, the Air Force Research Laboratory, Warfighter Training Research Division (AFRL/HEA) in Mesa AZ, successfully demonstrated the capabilities of the DTNG via a live, real-time demonstration. Attendees included more than 90 DoD and DoD contractor personnel representing many of the 33 mission training centers that make up the DMO community. In addition, system program offices including ASC, ESC and SMC, and Navy and Army representatives attended the event. News of the successful demonstration piqued the interest of Mr. William Davidson, SAF/AA, who subsequently visited the site on 22 May 2003 to view a demonstration of the DTNG and to discuss the future challenges of the program. Thus far, the DTNG has been a success and the Category I Advanced Technology Demonstration is expected to be closed by mid FY04. Beyond the ATD, the DTNG will transition to the MLS testbed at Det 4, Theater Aerospace Command and Control Simulation Facility, Kirtland AFB NM, for certification and accreditation as well as operational test and evaluation. Det 4 has been designated as the DMO Center of Excellence by the CSAF and was chosen to lead the implementation of the DMO concept. AFRL will work directly with Det 4 to provide continued support for the DMO concept and development of the DTNG. On 16 July, the DTNG was briefed to the Top-Secret and Below Interoperability Guard Review Board at the Defense Intelligence Agency (DIA). AFRL was notified that DIA will sponsor DTNG for Certification and Accreditation. Det 4 is expected to achieve Certification and Accreditation for DTNG by Mar of 04.

Space: Satellite Operations Simulator (SOpSIM). The Satellite Operations Simulator (SOpSim) concept offers the first system-selectable space operations training system, scalable to a given training environment. Utilizing high fidelity visual representation and an astrodynamically correct model serving as the engine for the simulation, SOpSim brings to the space operator a never before available visually and astrodynamically correct space operations mission training and rehearsal tool. Leveraging the DMT concept and technology, space operations personnel can now train individually, as an entire console crew, and up to an entire Space Operations Center (SOC). SOpSim is an innovative PC-based simulator that addresses the mission training and rehearsal of space operations. Utilizing SOpSim, space operations trainers can mitigate risks historically inherent with satellite operations training. Having never before had a dedicated training system, satellite operations training was the burden of on-the-job training with live mission systems. SOpSim eliminates the risk associated with this by taking the training off line, and removing the billion-dollar mission platform from the process. SOpSim can now train operators on traditionally high-risk satellite maneuvers in the low risk environment of high fidelity simulation. This coupled with the first visualization of the satellite operations significantly enhances the element of training transfer.

Air and Space Operations Center: In FY03 AFRL/HEA's research team developed and defined the first set of MECs and specifications of Knowledge, Skills, and Experiences for warfighters in the Combat Operations and Combat Plans Divisions of the AOC. In FY04, we will use this as a framework to assess the current state of training in the AOC community. Through a series of closely administered surveys we will identify existing gaps in the current training with respect to the defined MECs required for operators in those divisions. This will provide a basis for Air Combat Command to determine Continuation Training requirements and impacts to Mission Qualification Training and Initial Qualification Training. Additionally, this will allow us to develop competency-based, instructionally-principled training scenarios for simulation-based training for AOC warfighters.

Security Forces: Developments in the past year include:

- Obtained letter of support for R&D from HQ USAF/XOF and HQ ACC/SF.
- Conducted training needs analysis with participation of 46% of active duty security forces officers; direction of security forces for air base defense identified as high-need training area.
- Coordination with subject matter experts accomplished at the 99th SFS/GCTS (ACC), 37th TRG (AETC), and the Air Mobility Warfare Training Center to develop baseline capability.
- Baseline simulation capability developed, demonstrated, and evaluated for usability and model validity at 96th SFS/GCTS and 37th TRG.
- Input from field evaluations used for spiral development of revised capability.
- Revised simulation capability demonstrated and evaluated for usability and model validity at 96th SFS/GCTS and 37th TRG.
- Presentations and/or technology demonstrations delivered to HQ USAF/XOF, Force Protection Battlelab, Air Force Security Forces Center, and all major command security forces directors.

- Presentations and technology demonstrations delivered to HQ AFRL/CV, HQ AFRL/XPH, SAF/AQRT, OSD/DDR&E, ARI/IFRU, and US Military Academy.
- Developed and submitted a proposal for evaluation of simulation technology as a means of security mission preview; submitted proposal to AEF Battlelab, Force Protection Battlelab, and Wing Commander at AL Udeid Air Base.
- Independently developed and submitted an Education and Training Technology Application Proposal (ETTAP) for field evaluation of SecForDMT to the 37th TRG.
- Effort underway to obtain support from HQ USAF/XOF for operational, test, and evaluation to determine training value.

Night Vision Training System (NVTS): The physics based approach used in NVTS has been adopted by the USMC for the Night Attack Harrier (AV-8B) simulators, the USN F-18 DMT, the USAF F-16 Mission Training Center and, National Training Center as well as Weapons Systems Trainer and Unit Training Device programs. The system as developed for use in Night Vision Goggle (NVG) training research at AFRL/HEA includes a correlated photographic and material-classified database covers 380 nautical miles by 420 nautical miles of the Nellis AFB training rang derived from multi-spectral satellite imagery, aerial photography, material spectral response data, and Digital Terrain Elevation Data. The NVG sensor simulation uses a physics-based approach to provide an accurate in-band, radiometric response for the NVG gain and special effects (such as halos). It senses at aperture radiance as defined by the reflectance and aspect of the material-coded texel under illumination. As the illumination level and angle change in the simulation, the amount of light reflected from each texel to the viewpoint changes in real time, providing directional lighting effects. Selected combat effects have recently been modeled and include several types of explosions, missile trails, flares and tracers. All of these effects include near- and in-view effects for haloing, gain, and noise. High-resolution helmet-mounted displays present the simulation to the user. These displays incorporate miniature cathode ray tubes (CRTs) mounted inside NVG shells to provide the same form, fit, and function of actual NVGs, with the same weight and center of gravity as the NVGs being modeled. The CRTs use the same phosphor as current NVGs in order to provide the same color and decay characteristics. Current Helmet Mounted Displays have a display resolution up to 1700 pixels by 1350 lines, non-interlaced, refreshed at 60Hz. A Phase II Small Business Innovative Research program is developing a Helmet Mounted Display to support the Panoramic Night Vision Goggle. The Introductory NVG academic courseware is in use by the USAF, USN, and USMC. The NVG Instructor's course is required for all USAF NVG instructors.

Uninhabited Aerial Vehicle Synthetic Task Environment: AFRL/HEA researchers have designed and implemented a Synthetic Task Environment (STE) for the Predator Uninhabited Air Vehicle (UAV). This STE includes a high-fidelity simulation of a UAV operator station and provides a first target domain for HEA's computational process modeling of human behavior. With continuing basic research funding from AFOSR, PALM Lab scientists are now using this STE as a research testbed. Efforts to model the behavior of the UAV Operator have centered on basic maneuvering – foundational skills required for controlling the aircraft. Later in the research program, after validating the basic maneuvering model against performance data, eye movement data, and verbal protocol data from subject matter experts, efforts will turn to extending the model's capabilities. Eventually, it will represent the behavior of an operator completing a simulated reconnaissance mission.

1.4 COLLABORATIVE PARTNERS

Combat Air Forces:
- Air Combat Command
- USAFE
- PACAF
- AF Reserve
- Air National Guard

Air Education and Training Command
Air Force Office of Scientific Research
United States Air Force Academy
Aechelon Technology, Inc.
SDS International, Inc.
McDonald Research Associates
Lockheed-Martin
L3 Communications
Boeing
Evans & Sutherland
Silicon Light Machines
Fire Arms Training Systems
Northrop Grumman
Simulation Technologies, Inc.
Solipsys
Mak Technologies
Metrica, Inc.
Micro Analysis and Design
Aptima, Inc.
Cubic Defense Systems
Surface Optics Corporation
Diamond Visionics
Stottler Henke, Inc.
Adacel Technologies, Ltd.
The Group for Organizational Effectiveness
Defence R & D Canada
Defence Science and Technology Laboratory (UK)
Defence Science and Technology Organisation (AU)
NATO Research and Technology Organization
Army Research Institute/Infantry Forces Research Unit
Defense Advanced Research Projects Administration
Navair – Orlando
Office of Naval Research
Army Research Institute
National Research Council
US Joint Forces Command
Chandler-Gilbert Community College
Maricopa Community Colleges
University of South Florida
University of Central Florida
University of Georgia
Arizona State University
University of Tennessee
Texas A & M University
Colorado University – Boulder
Oklahoma University
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1.6 VR R&D LABORATORY FACILITIES

1.6.1 F-16 DMT Testbed

The F-16 testbed consists of four high-fidelity, F-16 Multi-Task Trainers (MTTs) equipped with full field-of-view Mobile, Modular Displays for Advanced Research and Training (M2DART) visual display systems, two AWACS Air Weapons Controller stations, a control and observation console, constructive threat generation systems, data recording systems, performance assessment systems, and two replay/debrief systems.

Each M2DART consists of nine, rear-projection screens faceted around the cockpit providing the full field of view for an F-16 pilot. The screens provide xx ft-L of brightness with yy:1 contrast. Out-the-window imagery for two of the cockpits is provided by SGI Reality Monster Computer Image Generators (CIGs). Out-the-window imagery for other two cockpits is produced by Personal Computer (PC) based CIGs. These CIGs manufactured by Aechelon Technologies, Inc. and SDS International Inc. provide comparable imagery to the Reality Monsters using commercial, off-the-shelf PC hardware. The control and observation console consists of ten, large display screens that show the forward view and selected cockpit information from all four F-16s together with a plan-view of the engagement and radio communications. Cockpit displays, radio communications, and the plan view are recorded for replay in one of two debrief facilities. Using the debrief systems, instructors can replay, fast-forward, and rewind recorded scenarios while zooming in and out of the plan-view displays.

1.6.2 Night Vision Training Laboratory

The laboratory facilities include an NVG simulation development system comprised of an SGI Onyx and a PC image generation system, a psychophysics human factors laboratory, a precision equipment measuring lab including a variety of NVIS measuring and testing equipment, a multi-media courseware development system and specialized cameras for collecting NVG imagery, an NVG academics training facility including two eyelanes, a multi-media classroom, a terrain model board and associated NVG instructional materials. The academic training facility is located at Luke AFB.

1.6.3 High Resolution Visual Displays Laboratory

Unique Facilities:

- Dedicated M2DART Visual Testbed
- Laser Projector Lab
- PC-IG, projector, and display test lab
- PC-IG systems from a variety of vendors
- Collimating and retro-reflective displays
- Head-mounted display facility (under development)
- DMT testbed available for follow-on training effectiveness studies

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Mr. Donald Lampton, Dr. Larry Meliza, Dr. John Barnett, Dr. Paula Durlach

2.1 AREAS OF INTEREST

- Use of VR/VE for dismounted Infantry training.

2.2 CURRENT RESEARCH PROJECTS

Virtual Environment Research for Infantry Training and Simulation. The objective is to develop, integrate, demonstrate, and evaluate technologies, techniques, and strategies for using virtual simulations for individual, leader and small unit training, mission rehearsal, concept development, and test & evaluation. Emphasis is being placed on developing the capability within Virtual Environments to conduct night, MOUT (Military Operations in Urban Terrain) and contingency operations. The more recent experiments have also examined instructional strategies and training interventions unique to training teams in distributed VEs.

2.3 RESULTS ACHIEVED TO DATE

Initiated a program of experimentation to investigate behavioral sciences issues in the use of VR for military training in 1992. Following an initial analysis of the task requirements for dismounted soldier training, and a review of previous VR training research, four experiments were conducted to investigate interface effects on the capabilities of participants to perform simple tasks in VR. Variables investigated included the type of control device, amount of task practice, stereoscopic vs. monoscopic helmet-mounted displays (HMDs), and type of display device (monitor, Boom, or HMD). Three experiments were performed that addressed the effectiveness of VR for teaching route and configuration knowledge of large buildings, and the transfer of this knowledge to the real world. The results of these experiments led to a program of basic research on distance estimation in VR. The next phase of the research investigated the use of VR to represent exterior terrain for training both land navigation skills (identifying landmarks and learning routes) and terrain knowledge. Finally, research was conducted investigating the use of VR for training more complex tasks. This included experiments examining the effects of self representation on performance, the training of two-person hazardous materials teams, and distributed team training in underway. Overall, the program has conducted 16 experiments involving over 600 human subjects. Knerr 100 et al. (1998) provides an overview of the results of the first phase of the program (1993 – 1998), along with recommendations for the use of VR for dismounted soldier training.

Beginning in 1999, increasing emphasis within the program is being placed on the development of technologies and techniques for the training of Infantry leader tasks. In 2000/2001 we developed and released for free a new library called the Virtual Environment Software Sandbox (VESS).

2.4 COLLABORATIVE PARTNERS

- US Army Simulation Training and Instrumentation Command
- US Army Research Laboratory, Human Research and Engineering Directorate
- US Army Research Laboratory, Computer and Information Sciences Directorate
- US Naval Air Warfare Center Training Systems Division
- University of Central Florida Institute For Simulation and Training

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2.6 VR R&D LABORATORY FACILITIES AVAILABLE

- Silicon Graphics Workstations including an Onyx Reality Engine Rackmount System (3 Graphics Pipes, 8 CPUs, 12 RMs, MCO), an Onyx RealityEngine Deskside (4 CPUs, 4 RMs, MCO), an Onyx RealityEngine Deskside (2 CPUs, 2 RMs) a Crimson RealityEngine Deskside (2 CPUs, 4 RMs, MCO), an Octane (2 CPUs. OCO), and several High Impact, O2, Indy, and Indigo Systems.
- Evans and Sutherland ESIG 2000 dual channel image generator
- SIMNET 8-channel image generator and M1A1 Tank Simulator
- Numerous Networked PCs
- Virtual Research V8 HMD (2)
- Virtual Research VR4 HMD (3)
- Virtual Research Flight Helmet (2)
- VPL EyePhones
- Fake Space Labs, high resolution 2-color BOOM
- CrystalEyes (4)
- Howlett CyberFace II
- Ascension Flock of Birds tracker, extended range with 8 sensors
- Ascension Flock of Birds tracker, extended range with 2 sensors
- Ascension MotionStar tracker, extended range with 16 sensors
- Polhemus trackers with multiple sensors (3)
- LogiTech Acoustical trackers (2)
- Crystal River Convolvotron
- IST ChordGloves™ (4 pairs)
- IST VE Motion Treadmill
- Mirage Display System
- Auto Cad
- Alias
- ElectroGIG
- GMS
- GRASS
- MultiGen
- Neo Visuals
- S-1000
- Strata Vision-3D

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3.1 AREAS OF INTEREST

- VEs for the acquisition and use of spatial knowledge
- Haptics (virtual touch and feel), cross-sensory display substitution, depth perception
- Modeling of individual differences in spatial cognition at the individual and team level
- Effectiveness of VE technology for small team training; tracking technology
- Locomotion methods in VE
- 3D spatial sound

3.2 CURRENT RESEARCH PROJECTS

3.2.1 Virtual Technologies/Environments (VIRTE) Demonstration I; Expeditionary Warfare Combat Vehicles and Craft

This program is developing a series of interoperable, deployable combat simulations that support training, mission planning, and rehearsal in Expeditionary Warfare. By using PCs, and maximizing the use of Government-owned software, the simulations will be deployable, inexpensive, and easy to maintain.

The three Expeditionary Warfare Platforms that were developed are the Landing Craft, Air Cushion (LCAC), the Expeditionary Fighting Vehicle (EFV) (previously known as the Advanced Amphibious Assault Vehicle (AAAV)), and the helicopter. Each of these platforms offers unique simulation and training challenges. The goal of the program is to demonstrate Human-centric designs that meet a variety of challenging goals. VIRTE simulations will be able to form a federation using DoD's High-Level Architecture (HLA) and interact in a highly complex synthetic environment consisting of realistic weather (rain, wind, fog, etc.), ocean environment (wave height, sea state, surf zone, etc.), man-made features (buildings, obstacles, craters, etc.), and other vehicles.

3.2.2 Virtual Technologies/Environments (VIRTE) Demonstration II; Close Quarters Battle for Military Operations in Urban Terrain (CQB for MOUT)

VIRTE Demonstration 2 is developing the technologies and infrastructure to allow Marines and Seals to interact with the virtual environment in a more realistic and natural manner than is currently possible.

By tracking the entire body, instead of just the head and the weapon, the avatar in the virtual world will be much more realistic. Advances in Head Mounted Displays (HMDs) will allow greater immersion and improved realism. The simulation infrastructure will allow much more natural interaction with the virtual world. For example, a Marine or Seal will be able to kick open doors, move furniture with his body, and observe realistic, physics based weapons effects.

Today's infantry must quickly adapt to diverse situations, from high-intensity warfare to peacekeeping missions, functioning in small teams and with increasing physical, emotional, and intellectual demands. Due to reduced live training opportunities, VIRTE will need to provide a level of visual, audio, and haptic fidelity that has not been available in a single synthetic exercise. Warrior acceptance of such advanced training technology will require detailed effectiveness data developed, collected and analyzed by a thorough human centered design process, with continuous user input into spiral developments, then tested in training transfer studies.

3.3 RESULTS ACHIEVED TO DATE

3.3.1 VIRTE Demonstration I, Combat Vehicles and Craft

VIRTE Demonstration I developed three unique interoperable Expeditionary Warfare simulations in FY 02 and FY 03. They share a common networked synthetic battlespace, but they are very different in their technologies and applications. The three Expeditionary Warfare platforms that were chosen are the Landing Craft, Air Cushion (LCAC), the Expeditionary Fighting Vehicle (EFV) (previously known as the Advanced Amphibious Assault Vehicle (AAAV)), and the helicopter. The VELCAC uses a gaming engine (Gamebryo) to develop high fidelity virtual cockpit for all three crew positions. The architecture allows a single crew to train in their position and supports team training of the entire crew. The VEEFV uses a medium fidelity mockup of the interior of the vehicle and provides gunnery and team training. The same software can be used for Embedded Training and also supports laptop operations. The VEHELO uses a Chromakey approach and a HMD to combine a low fidelity physical mock up with the virtual world. It also supports a laptop configuration.

3.3.2 VIRTE Demonstration II, Close Quarters Battle for Military Operations in Urban Terrain (CQB for MOUT)

A prototype testbed has been developed at NRL and it has been used to test and integrate component technologies. A government-owned, PC based, HLA compliant, game quality simulation infrastructure has been developed and demonstrated. A government-owned 3D spatial sound software package has been developed and integrated into the simulation architecture. Real-time control by an individual, using only their body, of a virtual avatar has been demonstrated. Various methods of locomotion in VE have been tested. Magnetic, passive optical, and active optical tracking systems have been tested and integrated. The new PhaseSpace tracking system is the result of an ONR funded SBIR.

3.4 COLLABORATIVE PARTNERS

- ONR (Office of Naval Research)
- NPS (Naval Post Graduate School)
- NRL (Naval Research Laboratory)

- ARI (Army Research Institute)
- U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI)
- U.S. Army Research Development and Engineering Command (RDECOM)

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3.6 VR R&D LABORATORY FACILITIES AVAILABLE

NAVAIR Orl

Prototypes of VELCAC, VEEFV, VEHelo, and ISMT-E are available for demonstration.

NRL

VIRTE Demo 2 prototype using VICON tracking system; PhaseSpace Tracking System.

NPS

See section 7F for details.

Paper 4 – Naval Postgraduate School

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4.1 AREAS OF INTEREST

The MOVES Institute's mission is research, application, and education in the grand challenges of modeling, virtual environments, and simulation. Specialties are 3D visual simulation, networked virtual environments, computer-generated autonomy, human-performance engineering, immersive technologies, defense/entertainment collaboration, and evolving operational modeling.

4.2 CURRENT RESEARCH PROJECTS

4.2.1 3D Visual Environments – Technical Director: Dr. Don Brutzman

NPS has been instrumental in standardizing the extensible 3D (X3D) graphics specification, collaborating with the Web3D Consortium, ISO, and WWW Consortium to produce a synthesis of the Virtual Reality Modeling Language (VRML) and the Extensible Markup Language (XML) to exploit X3D graphics for Web-based viewing of 3D scenes. The addition of geospatial representations, humanoid animation, DIS networking capabilities, advanced 3D rendering, computer-aided design interchange, and other capabilities makes 3D graphics and visualization broadly available on the Web.

In scenario authoring and visualization for advanced graphics environments (SAVAGE), we have built sophisticated open-license military models in X3D as part of the SAVAGE project. Dozens of students have contributed high-res models for ships, aircraft, submarines, land vehicles, robots, humanoid behaviors, environmental effects, etc. The SAVAGE archive is a multiple-CD set documenting over 700 military models, scenarios, theses, etc.

Autonomous underwater vehicle visualization is also a MOVES concern. NPS provides sophisticated capabilities in modeling and visualizing oceanographic data collected by underwater robots. With Office of Naval Research (ONR) sponsorship, we have participated in fleet battle experiments to assess minefield-clearance by robots, and translate telemetry and communicate messages to the global Command-and Control System (Maritime) mine-warfare environmental-database-analysis library.

In XML for operations orders, we can auto-generate large-scale VEs corresponding to regional (and potentially theatrical) operations. This new capability can be communicated via existing message circuits, but for actual deployment, a common vocabulary with common semantics is needed; NATO's battlespace generic hub (BGH) appears a good candidate for such a model. We are showing how BGH can be expressed in XML for modeling joint and coalition tactical scenarios. This work is seen as necessary for enabling worldwide battlespace presence, monitoring, and visualization. Applications to homeland defense and assessment of the effects of weapons of mass destruction provide further challenges.

DoD modeling and simulation (M&S) must identify and adopt transformational technologies of direct tactical relevance to warfighters. The only software systems that composably scale to worldwide scope utilize Web technologies; therefore an extensible Web-based framework offers promise in scaling up M&S systems to benefit training, analysis, acquisition, and operational warfighters. We are defining an extensible modeling and simulation framework (XMSF) to exploit Web-based technologies. Government, academic, and industrial experts are working under investigators from the Naval Postgraduate School, George Mason University, SAIC and Old Dominion University. XMSF is a composable set of standards, profiles and recommended practices for Web-based modeling and simulation. XML-based markup languages, Internet technologies, and Web services will enable a new generation of distributed M&S applications to emerge, develop and interoperate. The precepts of XMSF are:

- Web-based technologies applied within an extensible framework will enable a new generation of M&S applications to emerge, develop and interoperate.
- Support for operational tactical systems is a missing requirement for such M&S applications frameworks.
- An extensible framework of XML-based languages can bridge forthcoming M&S requirements and open/commercial Web standards, while supporting existing M&S technologies.
- Compatible, complementary technical approaches are now possible for model definition, simulation execution, network-based education, network scalability, and 2D/3D graphics views.
- Web approaches for technology, software tools, content production and broad use provide best business cases from an enterprise-wide (worldwide) perspective.

4.2.2 Networked Virtual Environments – Technical Director: Dr. Don Brutzman

MOVES continues research in networked virtual environments through NPSNET-V, a platform for investigating new concepts in related design. It features composable components, and can be extended at runtime; it is graphics-standard agnostic, and can use entirely new network protocols loaded at runtime. It has been used to test new ideas in interest management, security, and dynamic extensibility.

Cross-format schema protocol (XSFP) is a technique for saving XML data in binary format. XML data can be read by many platforms, but it is verbose, storing all data as strings. XSFP uses XML in bandwidth- or storage-constrained environments, increasing processing speed in data-intensive XML documents. MOVES is developing DIS libraries in many contexts (e.g. Java, X3D, and browser plugins), and describing DIS protocol in terms of XML and XSFP.

4.2.3 Computer Generated Autonomy – Technical Director: John Hiles

In 2002, the MOVES Institute established the Center for the Study of Potential Outcomes to employ our connector-based, multi-agent systems (CMAS) concept and cognitive science in modeling terrorist behaviors. The first project of the center is Project IAGO.

Project IAGO (integrated, asymmetric, goal organization) aims to develop a conceptual model and prototype implementation of a cognitive model of the decision-making and dynamic behaviors of terrorists. The object is to develop an anti-terrorist tool for intelligence analysts, enabling them to explore a complex, hyper-dimensional space of terrorist capabilities and possibilities in a social space, with potential for identifying infrastructure vulnerabilities and detection/prevention opportunities. This work also explores benefits and limitations in applying the CMAS concept, n approach conceived by MOVES professor John Hiles and inspired by the information exchange and -processing techniques that have evolved at the cellular level.

Initially, IAGO will construct a prototype cognitive model for exploring terrorist behaviors, in three phases:

- **Phase 1: Demonstration Model.** Initial design and implementation to generate software components that capture fundamental CMAS concepts of tickets, connectors, and templates. Lessons from phase one provide the software foundation for phase-two activities.
- **Phase 2: Proof-of-Concept Model.** This phase produced an initial prototype implementation of mental blending, a cognitive-psychological model of creative thought in which perceptions and concepts are combined under the guidance of generic problem-solving mental spaces and goal motivations to create cognitive blends (see cognitive training agents below). Development is ongoing to yield more complex blended spaces from the initial mechanisms.
- **Phase 3: Domain Demonstration**. The next phase is application and demonstration of the blended-mental-space modeling approach to represent influences and dynamics in forming terrorist behaviors leading to decisions and actions and to show the potential of the approach as a useful model for analysts. Early work with experts has resulted in a characterization of decision elements influencing terrorist behaviors. This information enables formulation of initial generic spaces and goals for interplay with an information stream, to produce behaviors comparable to real-world actions.

While our funding for IAGO was small in FY2002, the project shows great promise. In 2002, the Defense Threat Reduction Agency contracted with the MIIS Center for Non-proliferation Studies for a literature review of existing terrorist-behavior models. Two-hundred-and-sixty-five models were studied, and IAGO emerged in the top ten.

Cognitive training agents are also under intensive research. In January 2003, the MOVES computer-generated autonomy team reached a milestone. Using a multi-agent system combined with CMAS technology we developed over the last three years, we demonstrated that our software could do what cognitive psychologists call cognitive blending, producing cognitive-integration networks. That is, our software was able to create new knowledge in situ based on what it was doing and what it wanted to accomplish. Until this time, advanced multi-agent work has only been able to demonstrate the ability to adaptively explore problems with intent and purpose. Software blending means that multi-agent software can now be built to answer questions such as, “What do you know?” “How do you know that?” or (most importantly for training), “What are you doing?”

In the next year, we intend to extend these experimental results to create adjustable cognitive training agents that will add new capabilities to training. The cognition of these agents will be built-in and applicable to a range of applications. Specialization will take place outside these capabilities (for example, a specific application will require specific input and output routines (sometimes referred to as input and actuator suites), and an application-specific set of meta-data packages that we call generic spaces, which would describe the types of cognitive operations needed in that particular area).

Training software equipped with cognitive-training agents could ultimately take on the following capabilities:

- Training involving competition with virtual opponents would add adversaries that adapt, deceive, and could explain what they were doing and why.
- Training for tasks not involving problem solving could self-adjust to press students to their limits of understanding, then offer explanations of their boundaries and what additional work might expand them. In this and the following training applications, cognitive training agents guide the training software rather than act as adversary.
- Training for problem solving where innovation and discovery are demanded could continually alter the situation to keep it open and freshly challenging.

Not all training software would benefit from these properties. But important benefits can be derived from software that adapts and incorporates discoveries into knowledge that it produces as it goes.

4.2.4 Human-Performance Engineering – Technical Director: Dr. Rudy Darken

We find two fundamental barriers to achieving the transformation in training the CNO has called for: (1) the cost of simulation for training is too high, and (2) the development cycle from mission-need to product is too long. Low-cost simulators and the bringing training to the fleet swiftly will have an immediate impact on the individual warfighter. HPE has been focusing on these issues through the VIRTE program to develop high-fidelity deployable trainers.

Our work includes the development of a Chromakey- augmented training environment, whereby the near-field cockpit of a helicopter is captured with a camera and mixed with a simulated "out the window" view, allowing inexpensive reconfigurable training to occur. Similarly, we are developing a "suitcase" simulator for close-quarters battle for the second phase of VIRTE, miniaturizing as many components as possible to facilitate shipboard usage. This will be integrated with our forward-observer trainer towards a full spectrum combined-arms training capability. A common theme is the use of open standards and computer gaming technologies to increase performance while driving down development costs. All simulations for training developed in our laboratory undergo thorough testing both in house and in the fleet to determine their value in transfer of training.

As a part of DARPA's augmented-cognition (Aug-Cog) program, MOVES is researching a context machine to "improve the performance of the human-machine symbiosis by an order of magnitude or greater," thereby contributing to Aug-Cog's goal of improving warrior/computer interactions, advancing systems-design methodologies, and re-engineering military decision-making at a fundamental level. MOVES is exploring the computer science behind creating a system able to determine a situation's context and thereby assist in accomplishing its goals. Using a game engine to simulate real-world inputs and provide a means of output, MOVES has built a prototype system and continues research into the artificial intelligence and other factors required to determine context and act upon it.

In addition, MOVES has evaluated the training effectiveness of a damage-control trainer built at University of Illinois, Urbana-Champaign. We evaluated the system on surface-warfare officers stationed at NPS to understand the efficacy of the system in training DCAs. We expect to present our findings at ONR Workshop in May. Funding for HPE has been provided by ONR, N61M, DARPA, and the FAA.

4.2.5 Immersive Technologies – Technical Director: LCDR Russ Shilling, USN

The immersive technologies directorate met major milestones in 2002. The goal has been not only to apply virtual environment and video-game technology to training tasks, but also bridge the gap between these technologies and the operational- warfare environment.

First, technologies were advanced for the development of a sourceless postural tracking system using magnetic and inertial sensors to accomplish full-body tracking in a virtual environment. The unique and exciting part of this technological advance centers on a tracking device only slightly larger than a quarter. Patents for this device are measured the physiological impact of VE technology and emotion/arousal on cognitive abilities in a training task.

Finally, using the student-built cave system and other visual technologies, we are combining entertainment techniques, video-game technology, and advanced display design to solve problems associated with information management in network-centric warfare tasks, especially in command and control (video games routinely use various strategies to allow players to track and manipulate hyper-dimensional data within game play).

We will see if some of these same strategies can be applied to helping planners, analysts, and operators track multi-dimensional data sets associated with the fusion of large amounts of tactical data from different sources in a live warfare setting. At the same time, we will be examining game engines and editors to see if traditional methods of war gaming might be better implemented or improved using game-engine technology. Results of this research will be presented at ForceNet in April 2003.

4.2.6 Evolving Operational Modeling – Technical Director: LCDR Alex Callahan, USN (ret)

The technical directorate for evolving operational modeling became established as the configuration manager for the naval simulation system (NSS), an analytical model with unique capabilities for representing network-centric warfare.

The directorate coordinated efforts between SPAWAR Systems Center, San Diego, developers and testing agencies to ensure the quality of delivered versions, and continued to nurture a broad base for operational analysis across government, military, and commercial interests, with NSS as the focal point.

Evolving Operational Modeling obtained tasking in several key areas of NSS employment, including analysis of alternative platforms for the multi-mission aircraft program. The directorate prepared draft curriculum materials for a new course, applied combat modeling, providing insights into the application of combat models (using NSS as the exemplar) to military operational analysis.

The directorate led a working group of faculty from operations research and MOVES to review the combat modeling curriculum at NPS. As a result of these efforts, existing combat modeling courses have been revised, greater infrastructure has been provided for the war-gaming analysis course, and a school-wide wargaming policy and advisory committee has been established to revitalize application of warfare gaming across multiple disciplines.

4.2.7 Defense/Entertainment Collaboration Creative Director: Alex Mayberry

The MOVES Institute has been in the press continually with our *America's Army* project (see Appearances, below). *Newsweek* has toasted "the legendary Naval Postgraduate School" in the aftermath of *AA* and its success, and we will soon be in *Newsweek* again.

AA has engendered much faculty and master's-student interaction, yielding several completed theses this year, and has brought NPS much positive media attention. It has inspired the CNO to task the Naval War College's strategic studies group (SSG) to perform a study on the utility of massively multi-player gaming as the basis for the development of future large-scale M&S systems. That study reports out to the CNO in July 2003. The MOVES director gave a presentation on the project to the SSG in December 2002 for that study. The last two SSG plenary meetings have discussed massively multi-player gaming.

AA is highly approved by the sponsor for its transformation of Army recruiting. As of the 3rd of September 2003, there were 2M+ registered players of *AA,* with 1.3M+ having completed basic combat training in the game. Over 218M+ game missions have been completed, and some 100K gaming hours per day are played.

To understand the dividends of the game from the US Army perspective, a look at traditional recruiting is in order. The army spends $2B (two billion) per year to attract and enlist 120,000 recruits (80,000 army, 40,000 national guard). That's $16,666 per soldier.

Twenty percent (or 24,000) of these recruits drop out during basic combat training with the excuse that the army was not what they expected and combat training was not for them. With them goes $400M in wasted recruiting expenditure. In addition, the army has spent $75K each for training; thus, the army's loss per annum from this dropout group is $2.2 billion.

America's Army cost $7M to build over the first twenty-four months, a tag equivalent to that of 420 recruits who wash out (if we count recruiting costs alone). If the game encourages only 120 potential waverers to stick with it, it's broken even, counting recruiting and training costs. And of course, if it attracts those who would not otherwise have considered an army career, it's worth $92K apiece.

The Army estimates *AA* has the potential to save some $700M-$4B per year. With respect to recruitment, actual results won't be known for four or five years, when the current raft of thirteen- and fourteen-year olds will be old enough to join. The hope is that through realistic role playing and exploration of a soldier's job, the important work of the military will be among the options that compatible young men and women will consider when planning a career.

Improvements are continually made. By August 2003, occupations within the game will include infantry, medic, engineers, RSTA/Scouts, and Special Forces:

- Medic/91W & combat lifesaver: Four missions, from AIT at Brooke Army Medical Center through an STX under field conditions. These missions are pass-fail and enact expert information on combat lifesaving. This training conveys lifesaving information applicable to the population for homeland defense. One mission will incorporate training to recognize the symptoms of nerve agent as well as immediate self- and buddy-aid for nerve-agent casualties (funded by FORSCOM).
- Special Forces: Several missions to replicate the Robin Sage exercise as apart of SFAS with emphasis on land navigation and escape and evasion. These missions will qualify players to enter specialized S.F. training and be assigned in multiplayer S.F. missions.

New units and weapons added into *AA:*

- Stryker: the Stryker debuted in May in a transport- and support-by-fire role within a new online, multiplayer mission. Coverage of the SBCT within the Game expanded throughout the summer of 2003.

- TACOM-ARDEC is funding incorporation of the objective individual combat weapon (OICW) and the shoulder-launched multipurpose assault weapon/bunker-defeat munition (SMAW-D) into the game.

Having a successful online game inside the MOVES Institute is like having your own particle accelerator. Lots of proposed applications and interesting research are coming in the door.

Many related training applications using the *AA* code base as a starting point are being considered. We have funding from one project that's using *Operations* for treaty verification pre-planning, and an Air Force group is looking at funding a training level within the game that will deal with force protection.

Infantry soldiers at Fort Benning are using *Operations* before setting foot on the real range. Also, the Army's objective force is having us integrate prototypes of their new weapons systems into *Operations* to evaluate their potential utility. We are building special levels of the game for the Special Forces, both for recruiting and SF training.

We have strong interest from Commander Naval Surface Forces Pacific in our building a game for material-assessment training. They have approved both proposal and schedule and are raising funding for the project. One extraordinary possibility, raised by the undersecretary of defense's office, is massively multiplayer (MMP) gaming. The *AA* project is being looked at both as a model of how such an effort could be carried out within government and as possible starting point for a MMP project. The work involved might include the procurement (or development) of a government-owned game engine capable of full-spectrum combat modeling and large-scale inter-operability integration, as well as a programming interface for modeling individual and organizational behaviors and stories.

An additional goal would be a rapid prototyping interface to the MMP that would allow any mission to be put together nearly overnight.

4.3 RESULTS ACHIEVED TO DATE

- In 3D visual simulation and networked virtual environments, we have created the extensible modeling and simulation framework (XMSF), an effort cited as the most important strategy for connecting DoD modeling and simulation to C4I systems.
- Our terrorist behavior-modeling effort, Project IAGO, is listed among the top ten in a DTRA survey of two hundred and sixty five models.
- Our Chromakey augmented training environment has been deployed to helicopter squadron 10 (HS-10) to study its utility in flight navigation training.
- Our achievements in immersive technology include a pending patent for our inertial tracker. Sounds we and LucasFilm's Skywalker Sound recorded, of an LCAC for a Marine Corps training VE, were used for a hovercraft in the movie *Minority Report.*
- Our *America's Army* is the fastest-growing online game ever, and has won or been runner-up for several best-game-of-the-year awards. The project is cited as a transformational model for turning the PC game into a communications medium and demonstrating how innovative projects can succeed within DoD. *AA* is expected to save $700M to $4B annually and has inspired the CNO's strategic studies group to consider massively multi-player gaming for combat modeling; other defense agencies are pursuing similar studies. The game is the first successful defense/entertainment collaboration, as spelled out in the National Research Council report, "Modeling and Simulation – Linking Entertainment and Defense."

- We have applied techniques from VE and entertainment to enhance comprehension of complex tactical information in "live" command-and-control settings. We showed that radio, radar, air-traffic control, and possibly UAV communications could be improved using spatialized cues over headphones, presenting results at the ForceNet 2003 conference.

We support our students through courses and funded research directly related to our mission. Our projects provide DoD- and DoN-relevant thesis topics for officer students. Funded projects indicate serious interest in our research and educational abilities. In FY2002, MOVES had $11.4M in reimbursable funding. As of mid-FY2003, we had some $12M in reimbursables (forty-four accounts from thirteen sponsors).

MOVES has expanded greatly, currently employing sixty-eight faculty and staff. Students working in institute projects increased from forty to sixty-eight, hailing from twelve curricula (MOVES, CS, OR, IT, IS, NSA, IW, meteorology, ME, ECE, UW and C4I); see theses on our website.

4.4 COLLABORATIVE PARTNERS

4.4.1 Civilian

4.4.1.1 Academic

- Boston College
- California Polytechnic State University
- Carnegie-Mellon University
- California State University, Monterey Bay
- Clemson University, Department of Psychology
- ENIT, France
- George Mason University
- Georgia Tech, Modeling and Simulation Research and Education Center (MSREC)
- Institut National de Recherche en Informatique et en Automatique, France (INRIA)
- Miami University
- MIT Lincoln Laboratories
- MIT Research Laboratory of Electronics (RLE)
- Old Dominion University, Virginia Modeling, Analysis, and Simulation Center (VMASC)
- Queens University, Kingston, Ontario
- University of California, Berkeley, Center for Design Visualization
- University of Central Florida, Department of Industrial Engineering
- University of Central Florida, Institute for Simulation and Training
- University of California, Santa Cruz
- University of Newcastle, Newcastle-upon-Tyne
- University of Virginia
- University of Wisconsin

4.4.1.2 Corporate

- Bios Group
- Boeing
- Dolby Emergent Designs
- Epic Games
- John Mason Associates
- Lucasfilm Skywalker Sound
- Lucasfilm THX
- Microstrain
- MITRE
- Potomac Institute
- Science Applications International Corporation (SAIC)

4.4.1.3 Non-Profit

- Center for Naval Analysis
- Fraunhofer Center for Research in Computer Graphics
- High Performance Computing Center, Maui
- Institute for Defense Analysis
- Monterey Bay Aquarium Research Institute (MBARI)
- Monterey Bay National Marine Sanctuary
- Sea Grant
- S.E.A. Lab Monterey Bay

4.4.2 Military and Federal

4.4.2.1 Air Force

- Medical Command, San Antonio

4.4.2.2 Army

- Army Research Office
- Assistant Sec. Army for Manpower & Reserve Affairs
- Office of Economic & Manpower Assessment
  - Sponsorship: OEM Analysis, US Army Training Analysis (TRAC Monterey), US Army Training and Doctrine Command (TRADOC), US Army Operational Test Command, Fort Hood (USAOTC)
- US Army Operational Test and Evaluation Command (OPTEC), Fort Hood
  - Sponsorship: High-resolution database creation

4.4.2.3 Marine Corps

- Marine Corps Combat Development Command (MCCDC)
  - Sponsorship: Adaptive Exploration of Agent-Based Command and Control Simulations
- Marine Corps Combat Development Center Training and Education Command (MCCDC TECOM)
  - Sponsorship: Scenario authoring and visualization for advanced graphical environments (SAVAGE)
- Detail Marine Forces Pacific
- Training & Education Command

4.4.2.4 Navy

- Chief of Naval Operations, CNO-N6, Space Information Warfare Command and Control Directorate
  - Sponsorship: SimSecurity, a distance-learning and virtual laboratory for information assurance
- Commander, Helicopter Anti-Submarine Wing, Pacific Fleet (CHSWP)
- Commander, Submarine Development Squadron TWELVE
- HS-8 – Helicopter Anti-Submarine Squadron EIGHT, FRS
- HS-10 – Helicopter Anti-Submarine Squadron TEN, FRS
- Naval Aerospace Medical Research Lab
- Naval Oceanographic Office
- Naval Postgraduate School Distance-Learning Resource Center
  - Sponsorship: Joint-Combat Modeling Class (MV/OA4655)
- Naval Postgraduate School Institutionally Funded Research Program (NIFR)
  - Sponsorship: Scenario authoring and visualization for advanced graphical environments (SAVAGE). Detail
- Naval Sea Systems Command, Advanced Systems & Technology Office
- Naval Submarine School
- Naval Research Laboratory
  - Sponsorship: Automatic determination of safest routes for aircraft in enemy radar environments
- Navy Modeling & Simulation Management Office, N6M
  - Sponsorships: NPSNET-V: an architecture for constructing scalable, dynamically extensible, networked virtual environments
- NPSNET-V: DBP, vrtp for adaptive XML-based streaming of 3D behaviors and X3D
- Navy Toxicology Detachment, Wright
- Patterson Air Force Base
- Space and Naval Warfare (SPAWAR) Systems Center, San Diego
  - Sponsorship: Joint Simulation System (JSIMS) Marine Corps amphibious operations modeling

- Naval Undersea Warfare Center, Newport (NUWC)
  - Sponsorship: Scenario authoring and visualization for advanced graphical environments (SAVAGE). Detail
- Naval Air Warfare Center, Training Systems Division (NAWC-TSD)
- Office of Naval Research
  - Sponsorship: Immersive audio
- Office of Science and Development (OSD)
- Defense Advanced Research Projects Agency (DARPA)
- Defense Modeling & Simulation Office (DMSO)
  - Sponsorship: Scenario authoring and visualization for advanced graphical environments (SAVAGE). Detail
- Defense Threat Reduction Agency (DTRA)
  - Sponsorships: DIS-Java-VRML, STRP and HLA/RTI gateway for physically based battle-damage assessment
- Scenario authoring and visualization for advanced graphical environments (SAVAGE).
- Federal Aeronautics Administration
  - Sponsorship: VIRTE (Virtual Technologies and Environments)
- National Aeronautics and Space Administration (NASA Ames)
- National Reconnaissance Office
  - Sponsorship: NPSNET-V: an architecture for constructing scalable, dynamically extensible, networked virtual environments
- National Science Foundation
  - Sponsorship: Virtual Vaudeville
- Office of the Director, Operational Test & Evaluation
- Office of the Secretary of Defense, Extensible-Markup Language Message-Text Formats (XML-MTF) working group
  - Sponsorship: Generic hub: auto generating and distributing shared virtual environments for US and Allied operations orders using XML and X3D
- US Joint Forces Command Joint Experimentation Directorate (USJFCOM J9)

4.4.2.5 Foreign Military

- Bulgarian Military
- Czech Republic Military

4.5 LITERATURE PREPARED BY RESEARCHERS

4.5.1 Theses and Dissertations

Arisut, LTJG Omer, Turkish Navy. "Effects of Navigation Aids on Human Error in a Complex Navigation Task." MS in MOVES, 2002.

Aronson, MAJ Warren., USA "A Cognitive Task Analysis for Close Quarters Battle." MS in computer science in cooperation with MOVES, 2002.

Back, LT David, USN. "Agent-Based Soldier Behavior in Dynamic 3D Virtual Environments," MS in MOVES, 2002.

Brannon, LTCOL David, USMC and Villandre, MAJ Michael, USMC. "The Forward Observer Personal Computer Simulator (FOPCSIM)." MS in computer science in cooperation with MOVES, 2002.

Calfee, LT Sharif, USN. "Autonomous Agent-Based Simulation of an AEGIS Cruiser Combat Information Center Performing Battle Group Air Defense Commander Operations," MS in MOVES, 2003.

Campbell, LT James, USN. "The Effect of Sound Spatialization on Responses to Overlapping Messages," MS in operations research in cooperation with MOVES, 2002.

Desypris, LT Georgios, Hellenic Navy. "Enhancement of Learning Process in Web-based Courses Using Combined Media Components," MS in computer science in cooperation with MOVES, 2002.

Dickie, CAPT Alistair, Australian Army. "Modeling Robot Swarms Using Agent-based Simulation," MS in operations research in cooperation with MOVES, 2002.

Greenwald, MAJ Thomas W., USA. "An Analysis of Auditory Cues for Inclusion in a Virtual Close-Quarters Combat-Room Clearing Operation," MS in MOVES, 2002.

Harney, LT James W., USN. "Analyzing Tactical Effectiveness for Anti-Terrorist Force Protection (AT/FP) Using X3D Graphics and Agent-Based Simulation," MS in MOVES, 2003.

Krebs, CDR Eric M., USNR. "An Audio Architecture Integrating Sound and Live Voice for Virtual Environments," MS in MOVES, 2002.

Lennerton, MAJ Mark, USMC. "Exploring a Chromakeyed Augmented Virtual Environment as an Embedded Training System for Military Helicopters," MS in computer science in cooperation with MOVES, 2002.

List, MAJ Robert, USMC. "A Rendering System Independent High-Level Architecture Implementation for Networked Virtual Environments," MS in computer science in cooperation with MOVES, 2002.

Michael, LT Robert, USN and Staples, LT Zachary, USN. "Targeting Networks: Stimulating Complex Adaptive Systems for Accelerated Learning and Organizational Impotence," MS in MOVES, 2003.

Mowery, MAJ Samuel, USMC. "Enhancing the Situational Awareness of Airfield Local Controllers," MS operations research in cooperation with MOVES, 2002.

Orichel, CAPT Thomas, German Army. "Adaptive Rules In Emergent Logistics (ARIEL)," MS in MOVES, 2003.

Osborn, CDR Brian, USN. Dissertation, "An Agent-based Architecture For Generating Interactive Stories," Ph.D. in computer science in cooperation with MOVES, 2002.

Peitso, LCDR Loren, USN. "Visual Field Requirements for Precision Nap-of-the-Earth Helicopter Flight," MS in MOVES, 2002.

Perkins, MAJ Keith M., USA. "Implementing Realistic Helicopter Physics in 3D Game Environments," MS in MOVES, 2002.

Reece, CAPT Jordan, USMC. "Virtual Close Quarters Battle (CQB) Graphical Decision Trainer," MS in computer science in cooperation with MOVES, 2002.

Sanders, MAJ Richard, USA, and Scorgie, LT Mark, USN. "The Effect of Sound Delivery Methods on a User's Sense of Presence in a Virtual Environment," MS in MOVES, 2002.

Spears, LT Victor, USN. "Terrain Level of Detail in First-person, Ground-perspective Simulation," MS in MOVES, 2002.

Thien, CAPT Robert, USMC. "Realistic Airspace Simulation through the Use of Visual and Aural Cues," MS in computer science in cooperation with MOVES, 2002.

Ulate, LT Stephen O., USN. "The Impact of Emotional Arousal on Learning in Virtual Environments," MS in MOVES, 2002.

VanPutte, MAJ Michael, USA. "A Computational Model and Multi-agent Simulation for Information Assurance," Ph.D. in computer science in cooperation with MOVES, 2002.

Wu, LT Hsin-Fu, USN. "Spectral Analysis and Sonification of Simulation Data Generated in a Frequency Domain Experiment," MS in operations research in cooperation with MOVES, 2002.

4.5.2 Conferences: Accepted/Published Papers

Andrade, S., Rowe, N., Gaver, D., and Jacobs, P. "Analysis of Shipboard Firefighting-team Efficiency Using Intelligent-agent Simulation," *Proceedings of the 2002 Command and Control Research and Technology Symposium,* Naval Postgraduate School, Monterey, CA, June 11-13, 2002.

Barkdoll, T.C., Gaver, D.P., Glazebrook, K.D., Jacobs, P.A., and Posadas, S. "Suppression of Enemy Air Defenses (SEAD) as an Information Duel," *Naval Research Logistics 49*: pp. 723-742, 2002.

Blais, C.L., Brutzman, D., Harney, J.W., and Weekley, J. "Emerging Web-Based 3D Graphics for Education and Experimentation," *Proceedings*, Interservice/Industry Training, Simulation, and Education Conference, Orlando, December 2002. Nominated, best paper, ITSEC.

Blais, C., Brutzman, D., and Harney, Weekley, J. "Web-based 3D reconstruction of scenarios for limited objective experiments," *Proceedings*, Summer Computer Simulation Conference, San Diego, July 2002.

Brutzman, D., Zyda, M., Pullen, M., and Morse, K. "Extensible Modeling and Simulation Framework (XMSF) Challenges for Web-Based Modeling and Simulation," findings and recommendations report, Technical Challenges Workshop, Strategic Opportunities Symposium, Monterey, October 2002.

Gaver, D.P. and Jacobs, P.A. "Battlespace/Information War (BAT/IW): a System-of-Systems Model of a Strike Operation," Naval Postgraduate School Technical Report, NPS-OR-02-005, August 2002.

Shilling, R., Zyda, M., and Wardynski, C. "Introducing Emotion into Military Simulation and Videogame Design: *America's Army: Operations* and VIRTE, "in *Proceedings of the GameOn Conference,* London, 30 November 2002.

Shilling, R.D. "Contribution of Professional Sound Design Techniques to Performance and Presence in Virtual Environments: Objective Measures." *Proceedings of 47th Department of Defense Human Factors Engineering Technical Advisory Group Meeting,* September 2002, San Diego, CA.

Shilling, R.D. "Enhancing Performance in Tactical Environments Using Immersive Auditory Displays and Data Sonification Techniques." ONR Cognitive Sciences Workshop, George Mason University, 2002.

Shilling, R.D. "Entertainment Industry Sound Design Techniques to Improve Presence and Training Performance in VE," European Simulation Interoperability Workshop, London, England, 2002.

Shilling, R.D., Zyda, M., and Wardynski, E. "Introducing Emotion into Military Simulation and Videogame Design: *America's Army: Operations* and VIRTE," European Simulation Office, Game-On 2002, London, England, 2002.

Trefftz, H., Marsic, I., and Zyda, M. "Handling Heterogeneity in Networked Virtual Environments," *Proceedings of IEEE VR,* Orlando, Florida, 25-27 March 2002.

Trefftz, H., Marsic, I., and Zyda, M. "Handling Heterogeneity in Networked Virtual Environments," *Presence*, Vol. 12, No. 1, February 2003: pp. 38-52, (revised from IEEE VR 2002 paper).

VanPutte, M., Osborn, B., and Hiles, J. "A Composite Agent Architecture for Multi-Agent Simulations," 11th Computer Generated Forces and Behavioral Representation Conference, Orlando, FL, May 2002.

4.5.3 Invited Papers

Stanney, K.M. and Zyda, M. "Virtual Environments in the 21st Century," in *Handbook of Virtual Environments – Design, Implementation, and Applications,* Lawrence Erlbaum Associates, Publishers, Mahwah, NJ, 2002.

Zyda, M., Mayberry, A., Wardynski, C., Shilling, R., and Davis, M. "The MOVES Institute's *America's Army: Operations* Game," Proceedings of *ACM SIGGRAPH 2003 Symposium on Interactive 3D Graphics,* 28-30 April 2003: 217-218, color plate, p. 252.

Zyda, M. and Bennett, D. "The Last Teacher," in *2020 Visions,* from the Summit and Press Conference on the Use of Advanced Technologies in Education and Training, US Department of Commerce, 17 and 27 September 2002.

Zyda, M., Hiles, J., Mayberry, A., Wardynski, C., Capps, M., Osborn, B., Shilling, R., Robaszewski, M., and Davis, M. "Entertainment R&D for Defense," *IEEE Computer Graphics and Applications,* January/February 2003.

4.5.4 Books, Chapters

Cockayne, W. and Darken, R.P. (in press). "The Application of Human Ability Requirements to Virtual Environment Interface Design and Evaluation." *Handbook of Task Analysis for Human-Computer Interaction*. Diaper, D. & Stanton, N. Eds.

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Paper 5 – Naval Research Lab (NRL) in VR

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5.1 AREAS OF INTEREST

There are three main Virtual Reality (VR) facilities at the Naval Research Laboratory. The first, the Immersive Simulation Laboratory, is directed by Dr. Jim Templeman and focuses on exploring Human Computer Interaction challenges and techniques for enhancing immersion (Templeman, Denbrook & Sibert, 1999). The second facility, the Virtual Reality Laboratory, is directed by Dr. Lawrence Rosenblum and focuses on many of the technical aspects attendant with using VR as well as Augmented Reality. The third facility, the Warfighter Human Systems Integration Laboratory (WHSIL), is co-directed by LT Joseph Cohn and Dr. Roy Stripling. The focus of this facility is on developing and evaluating VR tools for supplementing training within the US Navy-Marine Corps, including the development of novel methodologies for detecting, assessing and enhancing performance. These latter two facilities will be discussed in greater detail in the following sections.

5.2 CURRENT PROJECTS: WHSIL

5.2.1 Creating Effective First Person Training Tools: Evaluating Locomotion Interfaces

Despite the potential advantages, several practical limitations of VR systems challenge their utility as training tools. One significant limitation is the method by which individuals control their movement within the VR. The optimal control method for training purposes would allow the user to move through the VR by performing identical movements in the real-world. Such a system would thus enable the trainee to experience first-hand and with true fidelity, the speed, intensity, and precision of movements required to perform the real-world operations. For vehicle based applications, such as flight or tank simulators, this mapping of real to virtual interfaces is fairly straightforward. System developers need only copy those elements of the real cockpit, together with their functionality, that are deemed necessary for training purposes. On the other hand, for non-vehicle based applications, such as those that enable individual infantrymen to train combat operations in an urban setting from a first person perspective, this mapping is anything but straightforward. Ignoring the more complex question of how best to recreate virtually the many sensory stimuli experienced in the real world, a more basic question is simply one of practicality. In vehicle based applications, movement is effected through a proxy, the cockpit instrumentation, whereas in a first person application, movement is effected directly through the individual. While it is a relatively simple task to create virtual, active, models of vehicle interfaces, it is an extremely complex task to do so for the ‘human’ interface.

There are numerous surrogate control methods which may address this problem. The simplest involve using keyboard entries or a high degree of freedom joystick (i.e., one capable of supporting a wide range of movements including body rotation and translation with independent control of head orientation). At the other extreme, full-body optical tracking enables real movements to be tracked and translated by the VR system either into identical movements in VR (e.g., ducking, peaking around corners, and head or body turning), or into the movements that these ‘physical gestures’ are meant to represent (e.g., walking-in-place interpreted as walking forward in VR). Intermediate solutions also exist, which, for example, combine real-world orientation tracking (through inertial or optical trackers) with joystick controls for translation. While conventional wisdom suggests that greater fidelity will translate into enhanced training impact, this notion is seldom put to the test and in reality this likely depends on the specific training application as well.

The WHSIL facility is conducting a series of experiments intended to provide a fundamental understanding of the mapping between control system ‘fidelity’ and the training impact for tasks common to CQB in urban terrain. Rather than test every system available, we have selected representative systems from either end of the extreme. This approach was adopted based on the assumption that if no differences between these extremes were found, then the intermediate solutions would not, in principle, be different either. While it is likely that each control interface may have an impact on the breadth and/or quality of training, it is both necessary and useful to evaluate operator performance capabilities with the designated control systems in a simplistic setting first. If a given system is found to be unable to support roughly the same precision of user movement, then further comparisons become moot.

5.2.2 Multi-Modal Sensory Integration for Training Transfer

Given that VR systems supporting urban ops will be required to provide a much more robust set of sensory information, it is crucial to develop a comprehensive model of multimodal integration in support of enhancing the degree to which VR training enhances real world performance. Within such a framework, one can start to pose research questions in an effort to more fully characterize a comprehensive model for multi-modal sensory integration in support of training transfer. The ultimate goal is to explore these relationships using conventional training transfer studies, combined with a ‘sensory knockout’ paradigm, in which different levels and types of sensory stimulus are varied, leading to a better of understanding of the relationship between multi-modal sensory integration and training transfer.

Two efforts are currently being pursued. The first focuses on Haptic information – the form of sensory stimulation acquired through collisions with objects (Caldwell, 2000; Durlach & Mavor, 1995). Most VR training simulations essentially ignore the haptic domain, relying instead on the visual domain and to a lesser extent, the auditory one, to provide trainees with the range of information typically encountered in the real world. This approach has been favored in part due to limitations of current technology. Haptic interfaces must render any number of a wide range of sensations (e.g. force, vibration, texture etc) while minimizing restrictions on movement, a synergy of requirements that has yet to be achieved. Currently, haptic interfaces are extremely bulky, have significant latencies, and fail to capture the range of frequencies/amplitudes typically encountered in real world settings.

Yet, haptic cues play a critical role in supporting fully immersive VR systems: during a single training exercise, trainees may repeatedly contact walls, furniture and other objects as well as each other. Additionally, given the un-naturally narrow field-of-view HMD displays currently available, haptic information is even more essential for making the user aware of where, when, and what kind of contact is made with virtual objects outside of their limited field-of-view. In the real world, these collisions provide trainees with critical information that ultimately supports their mental model of the environment; in the virtual one, which lacks these cues, the mental model is consequently much poorer. When supported, training systems in which the haptic information is coupled with visual information show great promise (Merril, 2000). When absent, the lack of multiple-modality information adversely affects the degree to which the VR training enhances real world performance (Cohn, Burns, Helmick & Meyers, 2000; Birch and Bitterman, 1949; Paivio, 1991). Thus, there is great training potential for developing a method for providing this information during immersive VR training.

The system under development will provide haptic information in a manner that is both sensorally meaningful and in synchrony with other virtually represented information modalities. The device will minimally encumber the wearer, who will already be required to wear an HMD and other devices. It will fit comfortably on a range of body sizes and be quick and easy to put on and to take off. It will also be mechanically robust, operating over a range of environmental conditions (temperature, humidity, excessive use) and should not require overly-burdensome power supplies. Finally, the system should provide a flexible application programming interface for device control.

Auditory cues also play a pivotal role in providing trainees with comprehensive training experience (Greenwald, 2002). In order for such cues to be salient when integrated into a VR system, they must be delivered in such a fashion as to preserve both the spatial and temporal qualities of the 'real' cues (Brockhurst, 1995). Since the information extracted by the human auditory system is dependent on the structure of the individual's receiving organ, models supporting the transmission of these stimuli are typically developed based on individual Head Related Transfer Functions (HRTFs) (Kistler and Wightman, 1992). Yet, this is often a laborious exercise, requiring specialized equipment and hours of data collection from each individual. Moreover, a wide range of individuals are expected to utilize these VR systems. In order to support the level of independent operation necessitated by current training needs, a new approach is mandated. This approach must be validated both in terms of the *technology*, as well as the *level of performance enhancement* attributable to the inclusion of this modality. Current research focuses on developing and validating techniques for rendering spatialized audio cues quickly and effectively.

5.2.3 Alternative Visual Displays

Personnel training and mission rehearsal are costly, logistically demanding, and potentially dangerous. VR training systems hold the potential to solve these problems, but have so far fallen short on their promise, in part, because the technologies are seldom truly low-cost or well suited for true deployment. Or, when they are designed to be minimally costly and maximally deployable, the trade-offs made to obtain these gains come at the expense of the types of training that they can support.

High-end VR systems rely on high-fidelity HMDs which alone can cost more than $20,000 each. Even at these high costs per unit, however, these devices offer poor peripheral vision, which may impair the training value for many applications. High-end VR systems also rely upon complex tracking technologies to maintain consistency between the user's movements and movement within the VR. In addition to high cost and fragile calibration procedures, these systems generally demand a large footprint for effective operation. An alternative high-end approach is the use of CAVE technologies. Based on rear-projection systems and advanced tracking technologies, these systems eliminate the problem of limited peripheral vision, however, they remain high-cost, and actually increase the system foot-print. Low-end VR systems can be as simple as desktop displays or single screen projection systems. They offer much lower costs, much smaller foot-prints, and are generally easier to use. However the trade-off for these gains is the lack of an immersive experience, which may impact their training effectiveness for many tasks important to the Navy and Marine Corps.

A largely unexplored middle ground is the use of small-footprint 'wrap-around' video display systems. Such systems may be based on low-tech solutions such as multiple front-projection screens, or a single wrap-around (circular) front projection screen. These systems provide fully immersive experiences with maximal support for peripheral vision and require only one degree of freedom tracking to determine the orientation of the user. These systems are potentially very deployable and easy to use as well. Wrap-around video display systems may thus be ideal for training military tasks that require 360° situational awareness, such as dismounted urban operations and forward air observers. At the time of this writing, the WHSIL facility has plans to pursue a rigorous evaluation of the training values of two different wrap-around video display systems. Experimental evaluation will be made within the context of training for MOUT operations as a model for training in dismounted operational tasks in general. Final assessment of training value will occur within the context of a real-world training transfer experiment and will include an assessment of system deployability (based on system cost, cost to transport, ease of use, and size of footprint).

5.2.4 System-Independent Measures of Team Performance

The primary goal of developing *any* training system is to provide a level of training that translates to enhanced performance on the types of real world tasks being simulated. The principal benefit that VR systems have over real world training is that they offer instructors the chance to train situations that would be too hazardous or too costly to actually practice in the real world. On the other hand, there is currently a lack of effective team performance models, theories, and metrics, which could predict a priori how effective a training system will be before it is actually implemented, as well as inform future development efforts. Further, there is a void of empirical studies that demonstrate team training transfer from VR systems. Given the increasing reliance on VR training systems in military environments, there is a critical need to identify methodologies for the objective measurement and assessment of individual and team performance to ensure that training systems are effective at facilitating the development and maintenance of targeted training objectives and lead to transfer of training back to the operational environment.

Current measures of team performance suffer from a heavy reliance on discrete, subjective (i.e. trained observer) ratings or discrete objective outcome measures. Consequently, these measures may be considered 'derivatives' of true information and, as developed, reveal little about the dynamic processes through which teams respond, evolve and develop. Using the paradigm of Urban Operations, in which small teams ($n \leq 4$) are tasked with a common goal, the members of the WHSIL facility are pursuing numerous methods, stochastic and deterministic, for calculating optimal team behavior in a wide range of settings, including those of imperfect information. This is because maximizing team performance is the key to quantifying team performance across the board, insofar as the behavior of any non-optimal team may be rated by its resemblance to that of the optimizing team.

In control theoretic terms, at each point in time a given team has a set of choices available to it, corresponding to its "control variables." The actual physical changes that result from these control variable decisions determine the spatial, time-dependent characteristics of the team, known as the "state variables." Since a team's primary task is to strategize based on the options available to it and its foes, a team's goal can be reinterpreted in this context as determining its control variables optimally as functions of the state variables. We categorize the wisdom, level of optimality of a respective team's control variable functions by means of a game-theoretic payoff function. In order for a team to be optimal, it must maximize or, depending on the construction, minimize its payoff function over the domain of control, space variables. In addition, the theory assumes initial values for these differential equations, i.e., that at each point in time one has knowledge of all of the state variables involved and that he can thus input the solutions of the differential equations to predict future values. While this is the case in situations of perfect information, in many military and other "games," there is a critical shortage of knowledge regarding enemy position, firepower, and other vital state variable values. Importantly, the hypotheses herein have wider implications beyond the improvement of existing training regimens. Insofar as they engender an algorithm for optimal combat performance, applications of differential game theory ought to play a pivotal role in any attempt to create automaton warriors. Indeed game-theoretic notions have been utilized in applications of artificial intelligence to related fields.

5.3 VR LAB

5.3.1 Mobile Augmented Reality

Many future military operations will occur in urban environments. In principle, many of the difficulties in these environments can be reduced through providing individual combatants with better situation awareness. The Battlefield Augmented Reality System (BARS) is investigating new ways of delivering situation awareness in real-time to the individual combatant in the field. Rather than hold a laptop or PDA, the user wears a see-through head mounted display and a wearable computer. The position and orientation of the user is tracked and graphics are rendered directly in the display, providing heads-up and hands-free access to information. Research in the Virtual Reality Laboratory (VRL) is focused on the issues of developing effective representations, user interactions and hybrid tracking techniques.

5.3.2 Uncertainty Visualization

The "Visualization of Battlefield Uncertainty" is focused on visualizing and analyzing the impact that environmental uncertainty has on active acoustic detection schemes used for ASW target state prediction. Acoustic transmissions, which are used for detecting targets, are subjected to environmental conditions such as internal waves, thermal currents, varying degrees of soil densities (when bouncing off the sea bottom and sea mountains) and surface scatter. Estimates for the environmental conditions are translated into environmental uncertainties such as transmission loss, reverberation level and bounce absorption. These environmental uncertainties are used to better predict locations and headings of targets. The project's emphasis is to develop display and analysis techniques that exploit the underlying characteristics of the multi-value, multivariate environmental uncertainties so that the researchers developing target state estimations can better understand the impact of the environmental uncertainty estimates. Rich-content and easy-to-understand display tools were developed to convey the environmental uncertainty data to research statisticians. Advanced visualization hardware including a 4-wall immersive room was utilized to provide an analysis environment for the researchers to study the statistics. The future direction of the project is to extend the tools and develop capabilities for appropriate end-users (e.g., sonar operators) that allow for early detection and prosecution of threats.

5.3.3 Multi-Modal Interaction

The Interoperable Multi-Modal Interaction and Display System (IMMIDS) system is developing the capability to control several C2 system interfaces with a multi-modal combination of the naturalistic input modalities of speech and gesture. The interfaces include (1) a 2D map-based interface, where the user gestures with a 2D digital pen on a tablet computer, (2) a 3D map-based virtual reality (VR) interface, where the user gestures with a 6 degree-of-freedom tracked flightstick, and (3) a mobile, wearable augmented reality (AR) system, where the user gestures using head orientation, eye gaze orientation, and arm pointing gestures. Typical examples of the types of commands which the system can recognize include: (1) "phase line red <indicate line with ink, or outdoors with pointing gesture>", (2) "there is a sniper in this building <indicate

building with ink mark, or outdoors by pointing>", "mine field <indicate area with ink, or pointing gesture>". Interacting in a naturalistic, multi-modal manner will yield a number of advantages. First, naturalistic input modalities bring the level of abstraction of the human-machine discourse closer to that employed when humans talk to each other. This can reduce the training necessary to use the system, and it can facilitate pervasively-aware interfaces, where the system tracks human-human discourse and provides information relevant to the conversation. Second, multi-modal I/O has a number of advantages over uni-modal I/O. Among the most compelling is mutual disambiguation; this is the property where one modality can correct interpretation errors in another modality. Studies have shown that this property can reduce recognition errors by 45%. Another advantage is that a single modality can be employed when appropriate; for example, gesture only when silence is needed, or voice only when the hands are occupied.

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5.6 WHSIL FACILITIES AVAILABLE

- Four networked, high-end immersive systems
  - Four NVIS Head Mounted Displays
  - Two tracking systems:
    - PhaseSpace Optical Tracking Systems (8 cameras per system)
    - Eight InterSense InterCube2 inertial trackers (2 Cubes per system)
- One Single Screen projection system
  - HP LCD projector
  - Hit Detection System
- Numerous PCs
- Two Kaiser Head Mounted Displays

5.7 VR LAB R&D LABORATORY FACILITIES AVAILABLE

- Immersive Room (CAVE)
- Responsive Workbench
- ORAD DVG 8 nodes Cluster
- SGI ONYX Workstations
- Numerous multiprocessor PCs
- Trackers:
  - Ascension Flock of Bird medium range (magnetic)
  - Ascension Motion Star (wireless)
  - Polhemus Magnetic Trackers
  - InterSense IS900 Trackers (ultrasonic – inertial)
  - Dynasight Optical Tracker
- 6 DOF Motion Stage 0.01 mm 0.1 deg accurate
- Optical See-through displays:
  - Stereo Sony Glasstron
  - Mono Sony Glasstron
  - Stereo Video See-through
  - Microvision Retinal-scanning display

- CyberGrasp/Cyberforce hand and arm force feedback device
- Phantom Haptics Display
- Plasma Screens
- Quantum 3D Termite Wearable Computers
- A variety of Wearable computers / equipment / modules
- Ashtech Differential Kinematic GPS (3DOF position)
- ADU5 6DOF GPS tracker (6DOF position and orientation)
- Video capture and editing hardware

Paper 6 – U.S. Army Research, Development, & Command (RDECOM) Simulation & Training Technology Center (STTC)

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6.1 AREAS OF INTEREST

Training Simulation Technologies (TST) for Homeland Security – This research area includes the Virtual Emergency Response Training System (VERTS), Dismounted Infantry Semi-Automated Forces (DISAF), Individual Combatant Virtual Simulation, and the Massively Multi-Player Simulation for Asymmetric Warfare Science and Technology Objective (STO).

6.2 CURRENT RESEARCH PROJECTS

6.2.1 Virtual Emergency Response Training System (VERTS)

This program focuses on developing a simulation capability to train First Responder, Civil Support Teams (CST), and Incident Commanders on tasks required to deal with a weapons of mass destruction incident. The VERTS suite consists of fully immersive and desktop simulators for live trainees networked together with a semi-automated force application (SAF). The suite also includes medical simulation capabilities. CST members would be able to train medical tasks on a Human Patient Simulator (HPS).

6.2.2 Dismounted Infantry Semi-Automated Forces (DISAF)

DISAF was developed to add Dismounted Infantry to the virtual battlefield in a realistic fashion. The Infantry capabilities of simulations such as SIMNET SAF and ModSAF have been limited to the low-fidelity viewpoint of tanks. The primary focus of DISAF has been the development of tactical behaviors for Individual through Squad level operations. DISAF is based on the OTB SAF architecture. DISAF includes support for Military Operations in Urban Terrain (MOUT) and rural terrain operations. Most of the DISAF behaviors are based on validated military Combat Instruction Sets (CISs). A database development process was developed to generate Compact Terrain Database (CTDB) Multiple Elevation Surface (MES) structures from visual database files. DISAF supports ‘c7’ terrain with MES capabilities. DISAF provides an enhanced 2D Plan View Display (PVD) to support display of MES buildings and new Individual Combatant (IC) icons.

6.2.3 Individual Combatant Virtual Simulation

This research initiative focuses on overcoming the critical challenges for dismounted soldier simulation by building on the previous efforts in the development and use of virtual simulations. RDECOM is currently working to enhance the capabilities of the Soldier Visualization Station (SVS). The SVS is a PC based, high fidelity, virtual simulation system developed to serve as a training simulator for the small unit leader with a focus on Military Operations in Urban Terrain (MOUT). An acoustic tracking system is used to identify the position/posture of the immersed soldier. The tracking system recognizes sensors located on the weapon and hat worn by the soldier. The SVS operates from a rear-screen projector, a standard PC, and low-cost software. Features include real-time 3D graphics, directional audio, and a unique user interface into the virtual battlefield. The SVS enables the realistic and effective integration of an individual participant into a networked simulation.

6.2.4 Massively Multi-Player Simulation for Asymmetrical Warfare

STO OBJECTIVE – Conduct research and generate technology needed to perform large-scale (massively multi-player (MMP)), persistent (long term), distributed simulation environment operations in support of asymmetric warfare training. Technology will allow Joint and Army Special Operations Battle Staffs and the Psychological Operations Community to engage and counter simulated asymmetrical and conventional warfare operations, interactively, in varying urban settings and realistic scenarios.

The Army lacks a high-level training and analysis capability for long duration, asymmetric missions such as multi-year anti-terrorist operations in Afghanistan and the Philippines. Current training opportunities are focused on conventional warfare and are limited to short duration missions. The objective of this research is to develop a large-scale, persistent, distributed simulation environment to train users for asymmetric threats and conventional warfare in a large theater of operation. The research will also focus on developing tool sets to construct the physical environments and to setup the conditions (economy, religions, social structures, etc.) within those environments. Weapons of Mass Destruction, terrorists' actions, crowd & hostage situations, peacekeeping, psychological operations, and civil affairs will be possible interactions faced by the users. Users will interact with and against numerous people in the environment not against scripted computer intelligence. Armed Forces will be able to engage in such simulation environments anytime, anywhere via the Internet and other communication interfaces. Transition objective is to use the software as a potential front-end simulation driver to a WARSIM / OneSAF exercise.

6.3 RESULTS ACHIEVED TO DATE

- Developed the prototype virtual simulation identified by the VERTS Operational Requirements Document (ORD).
- Transitioned DISAF capabilities to the One Semi-Automated-Force (OneSAF) team for incorporation into OTB 2.0.
- Developed the prototype Individual Combatant virtual simulation identified by the Program Manager Ground Combat Tactical Trainer (PM GCTT) as a likely candidate to satisfy the requirements of Soldier CATT.

6.4 COLLABORATIVE PARTNERS

- Army Research Institute (ARI)
- Army Research Laboratory (ARL)
- Program Executive Office Simulation Training and Instrumentation (PEO STRI)

- Fort Benning Dismounted Battlespace Battle Lab (DBBL)
- Special Operations Command (SOCOM)
- Maneuver Support Center (MANSCEN)

6.5 VR R&D LABORATORY FACILITIES AVAILABLE

- Soldier Visualization Station (Stand up and workstations)
- Mixed Reality MOUT experimental facility
- Various virtual systems that rely on a wearable computer for image generation
- Massively Multiplayer Environment