

# MASTER OF SCIENCE IN COMPUTER SCIENCE

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**AN IMPLEMENTATION OF SECURE FLOW  
TYPE INFERENCE FOR A SUBSET OF JAVA**  
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**Master of Science in Computer Science-September 1998**  
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Smart cards play an important role in a digital society. A smart card contains memory or an embedded microprocessor with the capability of enabling a wide variety of services, such as electronic cash in the case of memory cards and digital signature computation in the case of processor cards. A processor card can require a cardholder to authenticate herself in order to prevent others from using the card's services, from forging the cardholder's signature, for example. Authentication can be done by storing a personal identification number (PIN) or digitized fingerprint of the cardholder on the card itself. The PIN or fingerprint must always remain confidential no matter how the card is (ab)used.

This thesis addresses the problem of preserving the privacy of information stored on smart cards. Volpano and Smith have developed a static analysis for analyzing source code for information flow violations. This technique is developed further here for a language called Java Card, in which smart card applications are written. A prototype analyzer is presented for a subset of Java Card and applied to a sample card application to demonstrate its utility in protecting private information stored on smart cards.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Other (Smart Cards, Software Security, Type System)

**KEYWORDS:** Java Card, Smart Cards, Secure Flow Analysis, Type System

**SOFTWARE ARCHITECTURE FOR DISTRIBUTED REAL-TIME EMBEDDED SYSTEMS**  
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Real-time embedded systems have particularly strict requirements for accuracy, safety and reliability. A central question in the design of such systems is how to support concurrent processing without adversely affecting the timing requirements of the system. Concurrent processing is essential because the only way to successfully meet some tight real-time constraints is to use multiple processors.

This thesis focuses on the distributed scheduling problem. It proposes a distributed scheduling algorithm to allocate and schedule a set of tasks onto a collection of processors linked by a network. It further proposes a distributed software architecture for CAPS (Computer Aided Prototyping System) generated prototypes based on GLADE (GNAT Library for Ada Distributed Execution).

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The new distributed CAPS architecture is applied to several prototype examples. The results show that it is possible to build distributed real-time embedded systems under the distributed scheduling model, where sets of tasks run independently on each processor, using GLADE.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Real-Time Embedded Systems, Distributed Systems, Real-Time Scheduling, Software Architecture, Computer Aided Prototyping

### MAP USAGE IN VIRTUAL ENVIRONMENTS

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It is neither practical nor efficient to represent virtual maps as we do for paper maps in the real world due to major differences in hardware and software capabilities and requirements. Instead, the parameters can be determined that affect virtual map representation and that help to construct a mental map, and then manipulate these parameters in order to increase the effectiveness of map representation as an aid in performing navigation tasks.

The approach taken was first to determine and then investigate the parameters that affect virtual map representation through an experiment designed specifically for this thesis. The experiment examined users of an urban and open ocean virtual environment executing a set of navigation tasks with a virtual map with different orientation schemas.

The results of this study showed that, a forward-up map orientation is preferable to a north-up map orientation for egocentric tasks and a north-up map orientation is preferable to a forward-up map orientation for geocentric tasks. Under almost every possible condition, individuals with high spatial abilities will be able to use either a north-up map or a forward-up map better than individuals with low spatial abilities. Furthermore, it was found that these principles apply across types of environment with vastly different spatial characteristics, but sparse environments seem to exhibit less of a performance difference than dense environments.

**DoD KEY TECHNOLOGY AREAS:** Human Systems Interface, Modeling and Simulation

**KEYWORDS:** Virtual Environments, Wayfinding, Navigation, Virtual Maps, Spatial Visualization, Spatial Orientation, Cognitive Maps, Mental Rotation

### TWO-HANDED, WHOLE-HAND INTERACTION

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This thesis investigates the application of Human Ability Requirements (HARs) to problem of two-handed, whole-handed interaction. The methodology is derived from the use of HARs in the world of human performance evaluation. This research is based on the need to understand how humans perform tasks in order to guide the understanding of the requirements of advanced interface technology development.

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The thesis presents the background for these two areas of research, taxonomies and whole-hand interaction. It goes on to develop a taxonomy and classification of two-handed, whole-hand interaction for the real world and virtual environments. This taxonomy is used to analyze a large number of real world tasks, to further the development of a series of tests to externally validate the classification, and to analyze the tasks of the 91B Field Medic. This thesis further presents recommendation for how this methodology can be used to develop taxonomies for other areas of human interaction, for how this taxonomy can be used by researchers and practitioners, and areas of further research related to both areas.

**DoD KEY TECHNOLOGY AREA:** Human Systems Interface

**KEYWORDS:** Virtual Environment

**THE USE OF AND RUN-TIME OVERHEAD OF COMMON OBJECT REQUEST BROKER  
ARCHITECTURE (CORBA) IN THE MANAGEMENT SYSTEM FOR  
HETEROGENEOUS NETWORKS (MSHN) PROJECT**

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The goal of the Management System for Heterogeneous Networks (MSHN) is to support the execution of multiple, disparate, adaptive applications in a dynamic, distributed heterogeneous environment. MSHN consists of multiple, eventually replicated, distinct distributed components that themselves execute in a heterogeneous environment. This thesis answers the question: Is the performance of the Common Object Request Broker Architecture (CORBA) sufficient to support MSHN's inter-component communication?

This research focuses on the applicability of communication mechanisms from the CORBA 2.2 specification to MSHN. After a careful literature search, four mechanisms were identified for further examination: the Static Invocation Interface (SII), the Dynamic Invocation Interface (DII), the Typed Event Service and the Untyped Event Service. The rationale for selecting these mechanisms includes scalability, flexibility, extensibility, portability, maintainability, and manageability for the MSHN system.

A prototype of MSHN's communication infrastructure was implemented using these four mechanisms, and measured their run-time performance. The overhead added by CORBA for distributed component communication of MSHN system varied from a low of 10.6 milliseconds per service request to a high of 279.1 milliseconds per service request on UltraSparc10 boxes with Solaris 2.6 Operating System and connected via 100 Mbits/sec Ethernet. It is concluded that using CORBA mechanisms will not only substantially decrease the amount of time required to implement MSHN, but if used appropriately they will not substantially degrade performance.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** CORBA, Distributed Computing, Performance Overhead

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### SPATIAL KNOWLEDGE ACQUISITION AND TRANSFER FROM VIRTUAL TO NATURAL ENVIRONMENTS FOR DISMOUNTED LAND NAVIGATION

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Navigation and terrain familiarity are critical for mission success in the military. Virtual environments (VEs) have often been suggested as a useful tool in addressing these issues. This thesis research addresses the utility of VEs to improve spatial knowledge of and navigation performance through natural terrain compared to traditional methods. In this experiment, fifteen subjects were assigned to one of three training conditions. The map group studied the environment using only an orienteering map. The real world group studied the environment using the map and explored the actual terrain. The VE group studied the terrain using both the map and a real-time VE. Measures were taken of both route and configuration knowledge. The results suggest four conclusions. First, training conditions have no statistically significant effect on an individual's ability to obtain and demonstrate spatial knowledge of a natural environment. Second, spatial ability plays a significant role in navigation performance. Third, exposure to the actual terrain or to a virtual representation of the terrain seems to eliminate ambiguities in an individual's mental map by providing dynamic imagery to clarify propositional knowledge gained from maps. However, this factor has not been shown to improve performance by the measures used here. Fourth, a high resolution 1:5,000 orienteering map provides extensive detail and consequently, navigation performance in this experiment is not likely to be indicative of performance using a conventional 1:24,000 map.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Spatial Knowledge, Virtual Environments, Navigation, Orienteering, Geographic Information Systems, Terrain Visualization, Modeling and Simulation

### DESIGN OF A TRUSTED COMPUTING BASE EXTENSION (TCBE) FOR COMMERCIAL-OFF-THE-SHELF WORKSTATIONS

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United States Policy requires that access to and dissemination of classified information is controlled. Separate networks and workstations for each classification do not meet user requirements. Users also need commercially available office productivity tools. Traditional multilevel systems are costly and are unable to support an evolving suite of Commercial Off-The-Shelf (COTS) applications.

This thesis presents a design for a Trusted Computing Base Extension (TCBE) that allows COTS workstations to function securely as part of a multi-level network that uses high assurance multi-level servers as the backbone. The TCBE will allow COTS workstations to use commercially available software applications, while providing a Trusted Path to a high assurance multilevel server.

The research resulted in a design of a TCBE system that can be employed with COTS workstations, allowing them to function as untrusted clients in the context of a secure multilevel network.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Information Assurance, Multilevel Security, Secure LAN, Trusted Computing Base, Trusted Path

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### FACILITATING RICH ACOUSTICAL ENVIRONMENTS IN VIRTUAL WORLDS

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The visual aspect of virtual environments has advanced at a rapid pace. The audio aspect, however, has not kept pace. Current methods of building virtual models do not address the graphical and audio aspects in an integrated fashion. Furthermore, graphical programming tools have not addressed sound in a satisfactory manner.

As proof-of-concept, a modeling tool was developed to allow a user to build both the visual and the auditory environment simultaneously. A rendering application was developed that would display and browse a graphical environment, an audio environment, or a complete graphical/audio environment.

This thesis demonstrates that building both the auditory and the visual geometry simultaneously allows for rapid, easy development of both the visual and the auditory environment. Enhancements and recommendations to current software technologies and modeling languages are introduced. New models to represent audio are introduced.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Modeling and Simulation

**KEYWORDS:** Virtual Audio, Virtual Environment, 3-D Audio, Spatialized Sound, Audio Environment

### A PROTOCOL FOR BUILDING A NETWORK ACCESS CONTROLLER (NAC) FOR “IP OVER ATM”

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**Second Reader: Cynthia Irvine, Department of Computer Science**

The implementation of *label swapping* packet-forwarding technology increases the vulnerability to insider attacks. These attacks refer to unauthorized access from within an enclave to the outside network. In this thesis a protocol is proposed to counter this category of attacks. The proposed protocol provides a means for fast packet authentication. High speed is achieved by the use of a *trailer*, which allows packet filtering at Layer 2, and the use of cheap and fast message digest algorithms. To overcome the weaknesses of a 128-bit message digest algorithm, each key is designed to have a very short cryptoperiod. Such fast rekeying is implemented by key caching (the host has a table of keys). Initial performance measurements indicated that it is possible to use the protocol while maintaining very high data throughput. Specifically, the protocol implements an authentication module, called Network Access Controller (NAC). The NAC's modular nature allows it to be easily integrated with a variety of routing technologies and other security mechanisms while remaining totally independent of them.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Protocol, Network Access Controller (NAC), Internet Protocol (IP), Asynchronous Transfer Mode (ATM)

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### SOFTWARE ARCHITECTURE FOR A MULTI-LEVEL REAL-TIME SYSTEM

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When a real-time system has a mixed set of time critical tasks, including tasks with hard deadlines and tasks with soft deadlines, managing a mixed set of tasks in a timely manner becomes harder and requires a multi-level architecture. This thesis concentrates on building such an architecture.

The proposed architecture is based on the current Computer-Aided Prototype System (CAPS) architecture, which only deals with hard real-time and non-time-critical tasks. Priority-based scheduling techniques are used along with Ada tasking to schedule different levels of tasks. Periodic hard real-time polling tasks are used to insert sporadic soft real-time tasks into the system. A method is developed to assign deadlines to soft real-time tasks dynamically. Two tasking packages are added to the system for scheduling and execution of soft real-time tasks. The Earliest Deadline First (EDF) algorithm is used dynamically to schedule soft real-time tasks.

A pilot prototype is developed to test the proposed architecture via a run-time monitoring package. The results show that the proposed system guarantees that all hard real-time tasks meet their deadlines and an acceptably small percentage of soft real-time tasks miss their deadlines.

**DoD KEY TECHNOLOGY AREA:** Computing and Software

**KEYWORDS:** Real-Time Systems, Real-Time Scheduling, Hard Real-Time Systems, Soft Real-Time Systems, Dynamic Scheduling, Preemptive Scheduling, Priority-Based Scheduling, Ada 95, Prototyping, Uni-processor Scheduling

### LEVEL OF PRESENCE OR ENGAGEMENT IN ONE EXPERIENCE AS A FUNCTION OF DISENGAGEMENT FROM A CONCURRENT EXPERIENCE

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It is uncertain what effect presence has on virtual environments (VEs) but it is believed to enhance both learning and enjoyment. To date, there exist only subjective methods of measuring the level of presence in VEs. In order to effectively utilize VE technology, it is necessary to gain a greater understanding of presence and the factors that affect it. Therefore, a quantifiable method of measuring presence is needed. This metric would provide a framework for design requirements for predictable, repeatable performance in VEs.

To investigate a proposed new metric, 70 individuals participated in an experiment based on the dual task paradigm of attention theory. The purpose of the experiment was to determine the level of presence or engagement in one experience as a function of disengagement from a concurrent experience. Participants received two simultaneous experiences, one virtual, the other real, and were given quizzes on each to determine their focus of attention at various stages.

Results indicate: 1) HMDs occlude all but one of concurring experiences preventing the dividing of attentional resources; 2) Including sound increases the level of engagement in an experience and allows for dividing of attentional resources between concurrent experiences; 3) Responses to previously established presence questionnaires correlate strongly with this new measurement of engagement indicating that this

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method does have validity; and 4) Primed participants exhibit a decrease in levels of engagement in both experiences due to the focus of attention being divided.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Measuring Presence in VE and VR)

**KEYWORDS:** Modeling and Simulation, Measuring Presence, Virtual Environments, Virtual Reality, Computer Graphics. Measuring Presence in VE, Measuring Presence in VR, Telepresence

### A TASK ANALYSIS OF UNDERWAY REPLENISHMENT FOR VIRTUAL ENVIRONMENT SHIP-HANDLING SIMULATOR SCENARIO DEVELOPMENT

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While developing a Virtual Reality (VR) Ship-handling simulator for the Surface Warfare Officer School (SWOS) in Newport, RI, researchers at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, FL discovered a need for a task analysis of a Conning Officer during an Underway Replenishment (UNREP). The purpose of this task analysis was to document the tasks the Conning Officer performs and cues used to accomplish these tasks. The task analysis would ensure that the correct tasks and cues would be modeled in the VR UNREP scenario.

The approach taken was to survey cognitive task analysis models to find a notation that would document the tasks performed by a bridge team during an UNREP. The Goals, Operators, Methods, Selection Rules (GOMS) model was selected. A GOMS-like model was used to represent the sequential aspects of the UNREP task, while a table was developed to capture the parallelism of the tasks. The UNREP task analysis was then reviewed by qualified Surface Warfare Officers to validate its accuracy.

The result of this effort was a validated task analysis model of a Conning Officer during an UNREP. This model was provided to NAWCTSD in support of their future efforts in the development of a VR UNREP Ship-handling simulator scenario.

**DoD KEY TECHNOLOGY AREAS:** Computing and Software, Human Systems Interface, Manpower, Personnel and Training, Modeling and Simulation

**KEYWORDS:** Ship-handling, Virtual Reality, Task Analysis, Virtual Environment, Surface Warfare, Computer Simulation, Underway Replenishment, Computer Graphics

### HELICOPTER TERRAIN NAVIGATION TRAINING USING A WIDE FIELD OF VIEW DESKTOP VIRTUAL ENVIRONMENT

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Helicopter terrain navigation is a unique task; training for this task presents unique challenges. Current training methods rely on dated technology and inadequately prepare pilots for real-world missions. Improved training specifically tailored to address the unique needs of the helicopter community that

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capitalizes on recent improvements in desktop virtual environment (VE) technology could substantially improve the training process and reduce training costs.

Based on the input of subject matter experts in current helicopter terrain navigation training techniques and VE technology, such a system was developed and tested on student pilots performing real-world tasks. A desktop VE that presented a simple to control and learn, interactive fly-through of a terrain model was used to augment conventional training at Helicopter Antisubmarine Squadron TEN (HS-10).

Results indicate that flight time for students that received VE training was more productive than for students that received conventional training. This work justifies the next logical step: fielding a system on a long-term basis as a squadron asset. This system would provide improved training for the helicopter community and an invaluable source of research data for the Naval Postgraduate School.

**DoD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Training)

**KEYWORDS:** Virtual Environments, Terrain Association, Navigation, Training, Mission Rehearsal, Helicopters