



APPLICATION BRIEFS 2006



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Air Force Maui Optical & Supercomputing Site (AMOS)

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WELCOME

This is the twelfth annual edition of Maui High Performance Computing Center's (MHPCC) *Application Briefs* which highlights some of the successes our staff and customers have achieved this year.

MHPCC, established in September 1993, is an Air Force Research Laboratory (AFRL) Center managed by the University of Hawaii. A leader in scalable parallel computing technologies, MHPCC is chartered primarily to support the Department of Defense (DoD) and other federal government organizations.

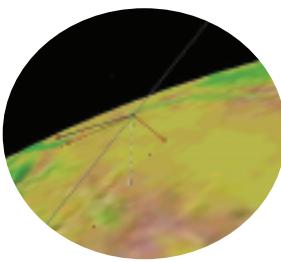
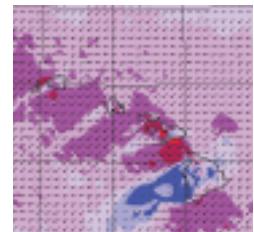
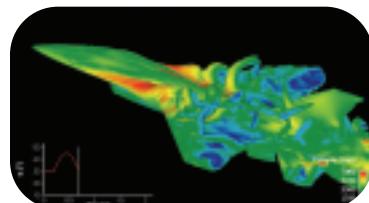
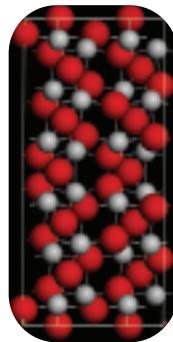
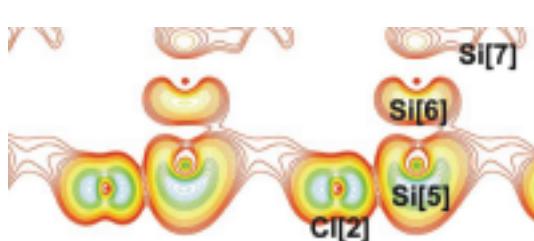
MHPCC offers an innovative environment for High Performance Computing (HPC) applications. This includes:

- Computational Resources: Stable and secure parallel computing platforms for prototyping, benchmarking, and testing applications. MHPCC is ranked as one of the top HPC centers in the Department of Defense in terms of computational capabilities.
- High-Speed Communications Infrastructure: OC12 connections, offering 620 megabit per second (Mbps) capacity, provide direct access to MHPCC resources — over the Defense Research and Engineering Network (DREN) and the Hawaii Intranet Consortium (HIC).
- Support Services: An expert staff provides MHPCC users with systems, network, and applications support in addition to assistance with code porting, optimization, and application development.

MHPCC is a well-established member of the High Performance Computing community, participating in collaborations and partnerships that extend its capabilities. MHPCC is a direct contributor to the Department of Defense as a:

- Allocated Distributed Center within the DoD High Performance Computing Modernization Program (HPCMP). MHPCC provides resources to the DoD research community, as well as Pacific Region DoD organizations, including the Air Force's Maui Space Surveillance Complex.
- Center within the Air Force Research Laboratory. MHPCC works closely with DoD and other government researchers to support Research, Development, Testing, and Evaluation (RDT&E) efforts.
- Air Force Research Laboratory resource for the Air Force Maui Optical & Supercomputing Site (AMOS).
- Member of Hawaii's growing science and technology community.

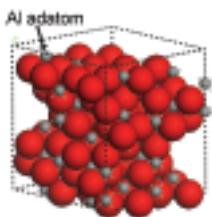




APPLICATION BRIEFS

The user application briefs in this publication represent selected research efforts that have taken place at MHPCC during 2006. Each Application Brief was written by an individual researcher or research team, and reflects their first-hand experiences using MHPCC resources. These articles reflect the diverse nature of our users and projects.

The Application Briefs in this document are the result of the efforts of more than 50 authors. We acknowledge the contributions of each of these individuals and are grateful for their work. We welcome back those authors who have become regular and frequent contributors. We also welcome those making their MHPCC Application Briefs debut this year.



The shaded box at the top of each brief's first page is a short summary of the article. Author and/or organizational contact information can be found in the shaded box at the end of each brief. The notation at the bottom of each page indicates each project's primary functional area (DoD, Government, or Academic).

All the efforts described in this document were performed using resources provided by the Department of Defense (DoD) High Performance Computing Modernization Program (HPCMP). Additional sponsorship has come from a variety of Research, Development, Test and Evaluation sources, including the Offices of Research and the Research Laboratories in the Defense Services.

Thank you for your support.

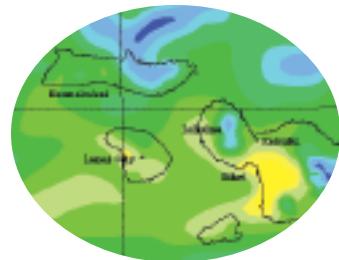
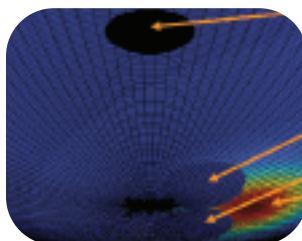
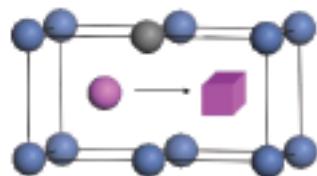
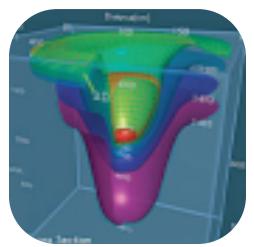
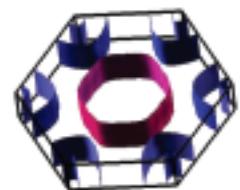


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Computational Stability and Control Analysis of the F-16

Scott A. Morton, Stefan Götz, David R. McDaniel

Flight-testing is presently the only cost-effective method to determine the Stability and Control (S&C) characteristics of full-scale new or modified aircraft or air armament at representative flight conditions. The benefits from such a "virtual flight-test" method to the areas of aircraft stability and control, flight simulation, and aircraft and weapon certification could potentially result in savings reaching into the billions of dollars.

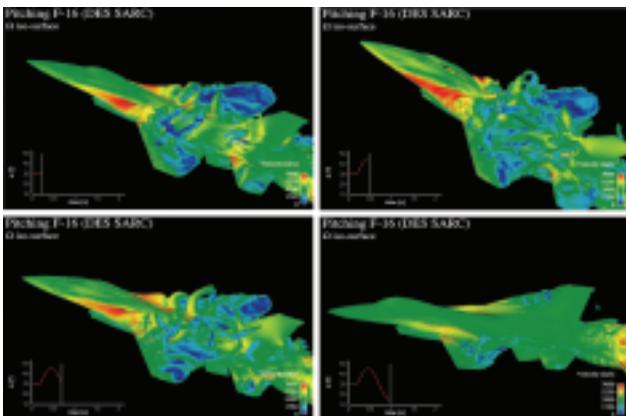


Figure 1. Detached Eddy Simulation of an F-16 in sinusoidal pitching motion (instantaneous vorticity iso-surface colored by magnitude of velocity).

Project Overview: Flight-testing is presently the only cost-effective method to determine the Stability and Control (S&C) characteristics of full-scale new or modified aircraft or air armament at representative flight conditions. By combining advanced Computational Fluid Dynamics (CFD) codes with control surface deformations and inner-loop flight control laws, an S&C simulation capability is being developed that will help decrease the costs and risks incurred by flight testing and post-design-phase modifications. To date, high-fidelity CFD data has been gathered for a rigid, maneuvering F-16 with fixed controls using the grid motion and Detached-Eddy Simulation (DES) capabilities of Cobalt. The maneuvers under study are inspired by flight test maneuvers and dynamic wind-tunnel testing techniques. However, the CFD environment has the advantage of simulating complex maneuvers that can not be realized with traditional flight or wind-tunnel testing. The aircraft responses to the maneuvers are analyzed using linear and nonlinear System Identification (SID) and Artificial Neural Networks (ANN). The resulting models may be used to extract S&C derivatives or to perform real time 6-DOF/aeroelastic simulations of the vehicle in conditions susceptible to spin, tumble, or lateral/longitudinal instabilities. The benefits from such a "virtual flight-test" method to the areas of aircraft stability and control, flight simulation, and aircraft and weapon certification could potentially result in savings reaching into the billions of dollars.

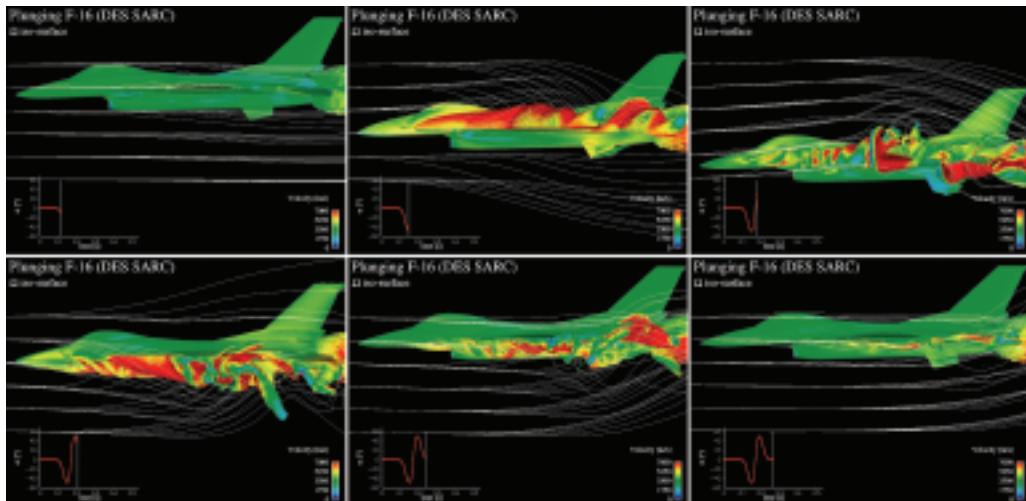


Figure 2. Detached Eddy Simulation of an F-16 undergoing a plunge pulse (instantaneous iso-surfaces of vorticity colored by velocity magnitude and instantaneous streamlines).

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Resources: 128-256 processors on *Tempest* at MHPCC, 128 processors on *Iceberg* at ARSC, 128 processors on Compaq SC45 at ASC, and 128 processors on *Blackbird* at USAFA

Sponsorship: DoD HPC/AF Seek Eagle Office Institute for High Performance Computing Applications of Air Armament (IHAAA), DoD High Performance Computing Modernization Program (HPCMP), Arctic Region Supercomputing Center (ARSC), and the National Research Council (NRC)

Pan-STARRS Image Processing Pipeline Software Development

Bruce Duncan, Michael Berning, Robert DeSonia, David Robbins

Pan-STARRS (Panoramic Survey Telescope and Rapid Response System) is an innovative new design for a wide-field imaging facility being developed for the Air Force Research Laboratory by the University of Hawaii (UH) Institute for Astronomy (IfA). UH IfA is the prime contractor and leader of the project. Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) is designing the charge-coupled devices (CCD) for the project. Science Applications International Corporation (SAIC) is a subcontractor to the IfA working on the database aspect of the project, and Maui High Performance Computer Center (MHPCC) is supporting IfA in the development of the data processing pipeline. By using four comparatively small co-located telescopes, the Pan-STARRS team plans to deploy an economical system that will be able to observe the entire available sky several times each month. The near-term goal is to discover and characterize Earth-approaching objects, including asteroids and comets that might pose a danger to our planet. The huge volume of images produced by this system will also provide valuable data for many other kinds of space scientific programs and products. This paper summarizes the MHPCC contractor team development work performed to date.



Figure 1. PS1 has been installed in the former LURE facility.

IfA decided in December 2003 to develop a one-telescope prototype system, PS1, which will be essentially one quarter of the total system and will be completed ahead of the full PS4 observatory.

PS1 will have the same optics design and camera design as anticipated for the full version of Pan-STARRS. PS1 has been constructed inside a building that previously housed the Lunar Ranging Experiment (LURE) observatory atop Haleakala, Maui. A new dome was placed on the building. Figure 1 shows an aerial view of the PS1 site, while Figure 2 shows the new PS1 telescope structure in its dome. PS1 will allow the team to test all of the technology and subsystems that are being developed, including the telescope design, the cameras, and the data processing and reduction software. PS1 will be used to make a full-sky survey that will provide astrometric and photometric calibration data that will be used for the full Pan-STARRS survey. First light for PS1 is scheduled for June 2006, with deployment of the full PS4 system in approximately two additional years. Sites on Mauna Kea and Haleakala are being considered for the PS4 system, and site evaluations have been performed in parallel at both locations.

Research Objectives: The full system, PS4, will be composed of four individual telescopes of 1.8 meter aperture observing the same region of sky simultaneously. Each telescope will have a three-degree field of view and be equipped with a CCD focal plane mosaic with more than 1.4 billion pixels. Pan-STARRS will cover 6,000 degrees squared per night in the survey mode and search for potential killer asteroids. The whole available sky as seen from Hawaii will be observed three times during the dark time in each lunation. Camera exposure times will vary between 30 and 60 seconds and IfA anticipates that Pan-STARRS will reach a limiting magnitude of 24. The focal plane will employ orthogonal transfer charge coupled devices (OTCCDs) that allow the shifting of charge along rows and columns, thus providing on-chip image motion compensation that is the equivalent of traditional "tip-tilt" image compensation, but without moving parts. Each raw image from a single Pan-STARRS camera will contain two gigabytes of data and it is estimated that the raw data rate will be several terabytes per night for the full telescope.



Figure 2. The new PS1 telescope structure viewed atop Haleakala, Maui.

Methodology: The Image Processing Pipeline (IPP) team was committed to executing the most conscientious software development program as possible at the outset of the PS1 build phase. This phase began in April 2004. The primary objective was to develop a sound product, utilizing software development techniques and tools which provide the best return on investment (labor and capital expenditures) without compromising quality. The key parts of the PS1 IPP development cycle plan include program planning and control, software planning and management, software requirements and architecture, software detailed design, coding, and unit testing. Future team plans beyond the period covered by this writing include integration testing, qualification testing, hardware and software integration testing, system qualification testing, and operations. The Pan-STARRS IPP software development team was organized such that UH IfA personnel had the overall lead for the work, and they developed the software requirements and algorithms definition for each build cycle. The MHPCC contractor personnel wrote the Software Design Description documentation, reviewed and helped refine algorithms as necessary, and performed coding, unit testing, and quality assurance of the associated source code and documentation. Software deliveries made by the MHPCC team included a Software Version Description document, which accurately described the requirements satisfied by the delivery and the results of internal testing. Doxygen and ManPage programming documentation were also provided. Other standards, methods, and tools employed on the project include:

- IEEE 12207 and MIL-STD-498 Systems and Software Engineering Practices and Disciplined Team Software Process Regimen
- ANSI 'C' Programming Language and Callable Functions Implementation
- Perl for Flow Control and High Level Image Processing Functions
- Object-Oriented Design (OOD) model accomplished in C via Coding conventions
 - * Object's data attributes are grouped into a C struct arrangement and the associated methods are named with the struct name as a prefix
 - * Software hierarchy:
 - psScripts
 - psModules
 - psLib (Library)
 - Industry standard applications/utilities, such as GNU Compiler Collection (GCC), 'C' Flexible Image Transport System Input Output (CFITSIO), Fastest Fourier Transform in the West (FFTW) library, and the GNU Scientific Library (GSL)
 - Glib C Library and GNU C extension (compiled by gcc)
- Linux x86 and Mac OSX compatibility
- Portable Operating System Interface (POSIX)
- Compliance with Industry and Pan-STARRS Project Coding Standards
- Concurrent Version System (CVS) - Software version control
- Bugzilla - Defect and Bug tracking and disposition
- GForge - Software collaboration/management/tracking/test point generation tool
- Software metrics tracking, including Defect/Bug classification and status, Requirements Verification, and Test Points Tracking, etc.

Results: Deliveries of the first twelve releases of PS1 IPP software represented on-time deliveries and substantial milestones in the progression of the overall Pan-STARRS project, while increasing our team software process acumen. Cycles thirteen and fourteen, which will occur from July-December 2006, will focus on regression testing and improving exception handling for camera, object, and trend analysis; and astrometry modules and image combination and difference modules.

Significance: The Pan-STARRS system will provide unprecedented capabilities to the astronomical and scientific communities when completed. The MHPCC contractor team is continuing to support IfA by developing application software source code and documentation that is at the very core of the Pan-STARRS system. The project team will continue working diligently to support the PS1 prototype system, with the longer-term goal of supporting the fielding of the full four-telescope PS4 system.

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Sponsorship: Air Force Research Laboratory

Acknowledgement: The MHPCC contractor team wishes to express its thanks to UH IfA for its pioneering work and leadership on Pan-STARRS, and its support of the MHPCC team.

High Performance Computing Software Applications for Space Situational Awareness

Francis Chun, Concetto Giuliano, Paul Schumacher, Charles Matson, Bruce Duncan, Kathy Borelli, Robert DeSonia, George Gusciora, Kevin Roe

The High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA) has completed its first full year of applications development. The emphasis of our work in this first year was in improving space surveillance sensor models and image enhancement software. These applications are the Space Surveillance Network Analysis Model (SSNAM), the Air Force Space Fence simulation (SimFence), and physically constrained iterative deconvolution (PCID) image enhancement software tool. Specifically, we have demonstrated order of magnitude speed-up in those codes running on the latest Cray XD-1 Linux supercomputer (*Hoku*) at the Maui High Performance Computing Center. The software applications improvements that the HSAI-SSA has made, has had significant impact to the warfighter and has fundamentally changed the role of high performance computing in SSA.

Introduction: The mission of the High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA) is to support SSA needs of stakeholders by developing high performance computing (HPC) software applications for SSA. The Institute collaborates directly with experts and end users in the joint Space Control mission area in order to identify those "leverage points" at which HPC can be applied to make a strategic difference in how the mission is performed. The HSAI-SSA has had a successful period of performance thus far during FY06, working with multiple software applications, as briefly highlighted below.

Project Updates: There are currently three applications that the Institute is helping to develop; two in Strategic Goal 1 (Astrodynamics) and one in Strategic Goal 2 (Image Enhancement). All three applications now run on the Maui High Performance Computing Center (MHPCC) newest Cray XD-1 Linux super cluster named *Hoku* (or star in Hawaiian). The two astrodynamics projects are the Space Surveillance Network Analysis Model (SSNAM) and SimFence. SSNAM is used by Air Force Space Command to analyze the performance of the global space tracking network, or SSN, and is being re-engineered to run as a scalable parallel process. We have demonstrated about a 3-fold overall speedup and up to a 6-fold speedup to date in the load balanced Loop processing for SSNAM (see Figure 1) when comparing 50 processors (25 nodes) on *Hoku* (*Hoku* 50) and a cluster of 8 PCs in Colorado Springs (COS 8).

SimFence¹ is a detailed physical model of the Air Force Space Fence, a unique, multi-static, continuous-wave surveillance radar. This radar system is a network of sensors in its own right and accounts for nearly half of all radar detections of space objects being made by the

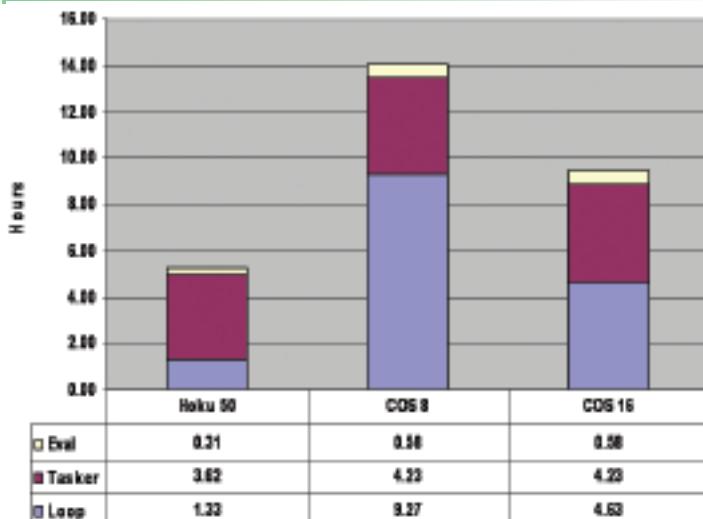


Figure 1. MHPCC improvements to SSNAM show overall speedup of approximately 3x and loop speedup > 6x.

global space surveillance network. SimFence is complex because the system has thousands of separate but precisely phased radiating elements in antenna arrays that total more than 12 miles in length. HPC techniques have improved the runtime of this model by nearly two orders of magnitude (greater than 97-fold initial speedup) which are well beyond the capability stipulated for the original goal. A further 8-fold speedup was also achieved recently through parallelization enhancements; specifically load-balancing the worker processors so that they all complete their assignments in roughly the same time. Figure 2 is a schematic illustrating the load-balancing.

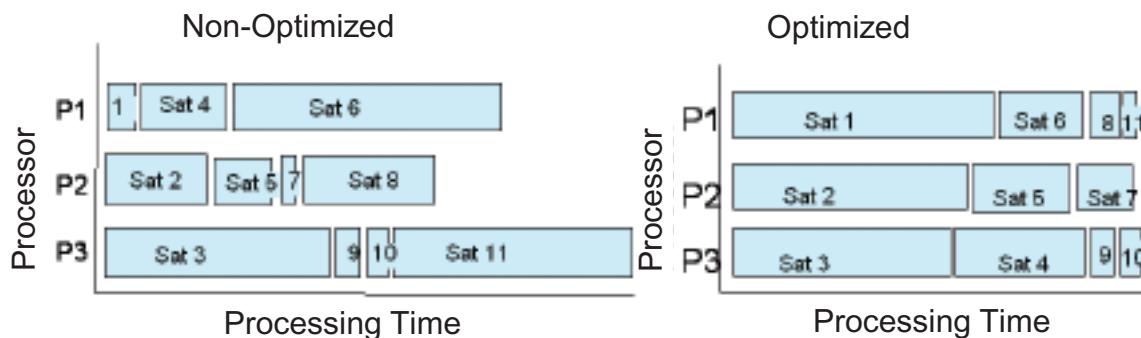


Figure 2. Load-balancing in SimFence allows all processors to complete their work in roughly the same time.

Strategic Goal 2 (Image Enhancement) applications attempts to improve the resolution of images obtained from existing electro-optical sensors by applying a state-of-the-art new image processing algorithm. The physically constrained iterative deconvolution (PCID) algorithm, when applied to a sequence of images of the same object, achieves the theoretically optimum gain in image resolution, beyond which no method of any type can improve upon. PCID is one version of a multi-frame blind deconvolution (MFBD)² algorithm. Moreover, it provides a measure of how close to optimum a particular image reconstruction has come. Other image processing algorithms can run faster, but none can do better in reconstructing the image. The MHPCC team has done extensive profiling of PCID and identified the fast fourier transfer (FFT) process as the "long-pole-in-the-tent." Parallelizing and optimizing the FFT implemented in PCID (called FFTW) down to row level has helped the team achieve about a 20-fold speed up when using 64 processors (see Figure 3).



Figure 3. MHPCC improvements to PCID implementation shows speedup >10x.

Conclusion: With a rather modest funding effort, the HSAI-SSA has, in its first full year, made significant progress in developing HPC SSA applications for the warfighter. We've been able to demonstrate order of magnitude speed-up in space surveillance models and image enhancement software. We've employed proven software engineering practices to demonstrate scalability and to identify the "knee" in the performance curve. In short, HSAI-SSA is well-focused and bringing the right technical expertise together with the right computing resources to develop, test, and transition Department of Defense HPC software applications in this critical area.

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Interface Electronic Structure and Possible Superconductivity in CuCl/Si(111)

S. H. Rhim, R. Saniz, Jaejun Yu, A. J. Freeman

The search for higher critical temperature superconductors has often led physicists to try to find materials presenting alternative pairing mechanisms. This work has two-fold significance from a broader point of view: (1) The two dimensional metallicity at the interface of two insulators opens research to a new type of system, and (2) it identifies an alternative structure and sets a new direction for the search for superconductivity with a pairing mechanism other than phonon mediation.

among them, a dielectric-metal-dielectric sandwich structure.² From the experimental point of view, in 1985 Mattes and Foiles³ reported nearly ideal diamagnetism in CuCl/Si at temperatures between 60~150 K, and interpreted their findings as a possible manifestation of exciton mediated superconductivity.

Research: In this project, we reviewed⁴ and extended the first-principles study of the electronic structure of CuCl/Si(111) superlattice, using the highly precise full-potential linearized augmented plane wave (FLAPW)⁵ method. Notably we found that as a result of charge transfer between the CuCl and Si layers, which are insulators in their bulk form, two-dimensional (2D) metallic states arise at the interfaces. The conducting planes at the interfaces are sandwiched by the highly polarizable dielectric layers. The 2D metallicity is clearly observed in the Fermi surfaces (Figure 1) and in the conducting charge density (Figure 2). The CuCl/Si superlattice is, therefore, a realization of the dielectric-metal-dielectric geometry. With superconductivity in mind, we estimate the superconducting critical temperature, T_c , of the CuCl/Si superlattice based on the conventional electron-phonon (e-p) coupling within the rigid muffin-tin approximation.

Introduction: The search for higher critical temperature superconductors has often led physicists to try to find materials presenting alternative pairing mechanisms. This is because it is generally thought that the relatively low energy scale of the conventional phonon mechanism limits its capability to lead to higher critical temperatures. As early as the 1960's, well before the discovery of the cuprates, an exciton pairing mechanism¹ in molecular chains was suggested to obtain higher transition temperatures than with the phonon mechanism. Following the same idea, several alternative geometries were proposed,

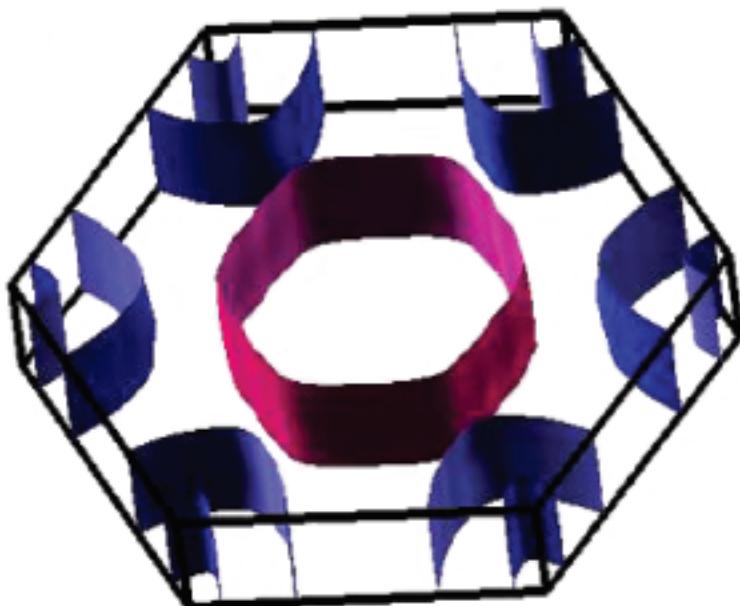


Figure 1. Fermi surfaces of 2-(CuCl)/8-Si superlattice (with relaxed atomic positions). The red sheet presents hole-like band, while the blue sheet does electron-like band. Two metallic bands exhibit well their 2D nature in its character.

The results indicate that e-p superconductivity could indeed exist at the interface of two semiconductors, with a T_c of the order of 1~10 K. On the other hand, we find that the coupling is clearly not strong enough and the T_c 's obtained are too low to account for the previously reported nearly ideal diamagnetic susceptibility at high temperatures. Thus, if the latter is due to superconductivity, the pairing mechanism must be other than phononic. The present work has two-fold significance from a broader point of view: (1) The two dimensional metallicity at the interface of two insulators opens researches to a new type of system, and (2) it identifies an alternative structure and sets a new direction for the search of superconductivity with a pairing mechanism other than phonon mediation.

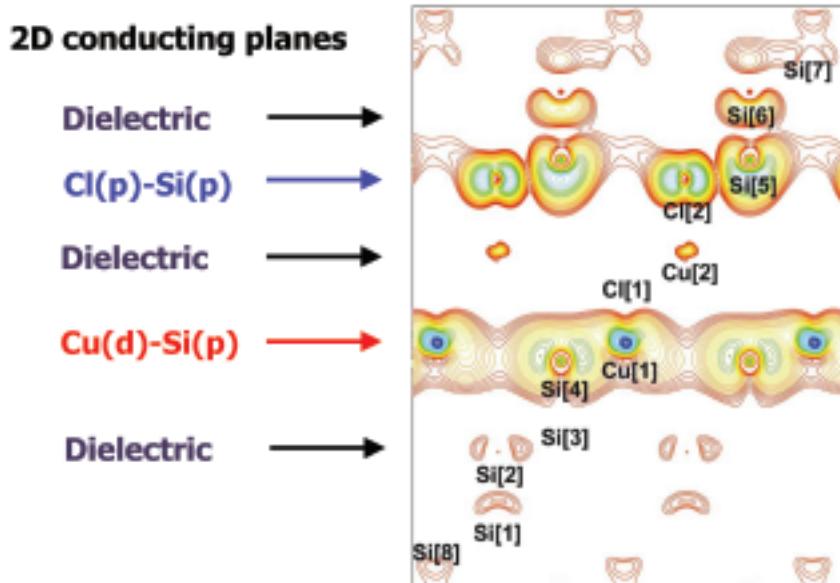


Figure 2. The charge density of the 2-(CuCl)/8-Si superlattice around Fermi energy. The metallic slabs are well represented and their character is also written left of the figure. The Cu-Si interface, denoted in red, corresponds to hole-like band in Figure 1, whereas the Cl-Si interface, denoted in blue, does to electron-like band in Figure 1.

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Sponsorship: DOE Grant No. DE-FG02-88ER 45372/A021

Lightcurve Inversion Program for Non-resolved Space Object Identification

Charles Wetterer, Clayton Stanley, James Stikeleather

An object's brightness as a function of time is dependent on its shape, rotation rate, orientation to the Sun, and orientation to the observer. Astronomers use these "lightcurves" for asteroids to determine physical parameters about the asteroid without actually resolving it. The lightcurve inversion techniques employed to accomplish this can also be applied in Space Object Identification (SOI) of Earth-orbiting satellites too small or too far away to be imaged directly. Over the past year, US Air Force Academy (USAFA) cadets and faculty have implemented one such forward-modeling lightcurve inversion technique using Matlab. Development and testing of the program for parallelized use on a supercomputer was accomplished during a High Performance Computing Modernization Program (HPCMP) sponsored Cadet Summer Research Program (CSRP) in June 2006. Testing was done using generated lightcurves of ellipsoids and attempting to regenerate the correct shape using the program.

a closed set of facets. Each facet has a surface area, normal direction, and knowing the viewing angles to the Sun and to the observer. The total brightness of the synthesized object is determined by summing over all visible facets of the model. An observed lightcurve can be compared to these synthetic lightcurves and chi-squared minimization of all configurations can then be used to determine which set of parameters produces a synthetic lightcurve that best matches the observed lightcurve. This and other techniques can be used to possibly determine shape and orientation characteristics of satellites, rocket bodies, and space debris as well.³

Initial development of the program began during a Summer 2005 HPCMP-sponsored CSRP and was completed during a Fall 2005 USAFA cadet research project. Extensive modifications to the program were accomplished during another cadet research project in Spring 2006 to include incorporating specular reflections,⁴ shadowing, and constructing more complicated objects. HPCMP sponsored this Summer 2006 CSRP to transition the program for parallelized use on a supercomputer to enable searches over larger parameter spaces.

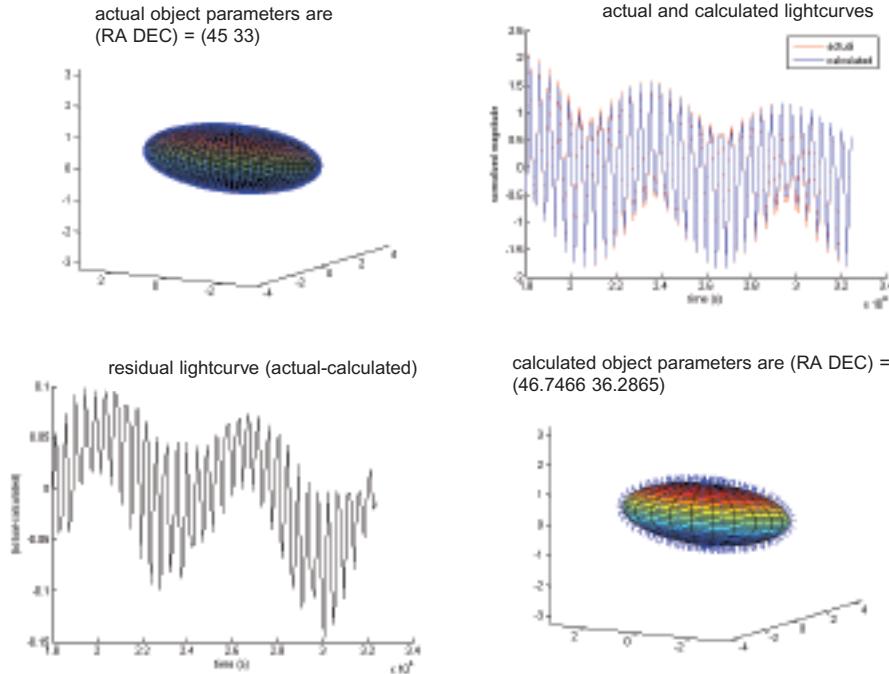


Figure 1. Output showing 5,000 facet ellipsoid modeled by 500 facet ellipsoid with lightcurve comparisons.

Results: The program was successfully modified to run parallelized on a Cray XD-1 Linux computing system (*Hoku*) realizing a 40x increase in speed over a PC when using 26 processors. More importantly, due to PC memory limitations, some jobs impossible for a PC can now be accomplished on *Hoku*. We began testing the program's utility for non-resolved SOI by first generating lightcurves using ellipsoids with specific parameters for shape, reflection properties, rotation rate, and rotation axis position in a geostationary orbit and observed 100 times over four hours and then used the program to search through parameter space to see if the known models could be found and reproduced using chi-squared minimization (see Figure 1 for an example). These initial results have been very encouraging.

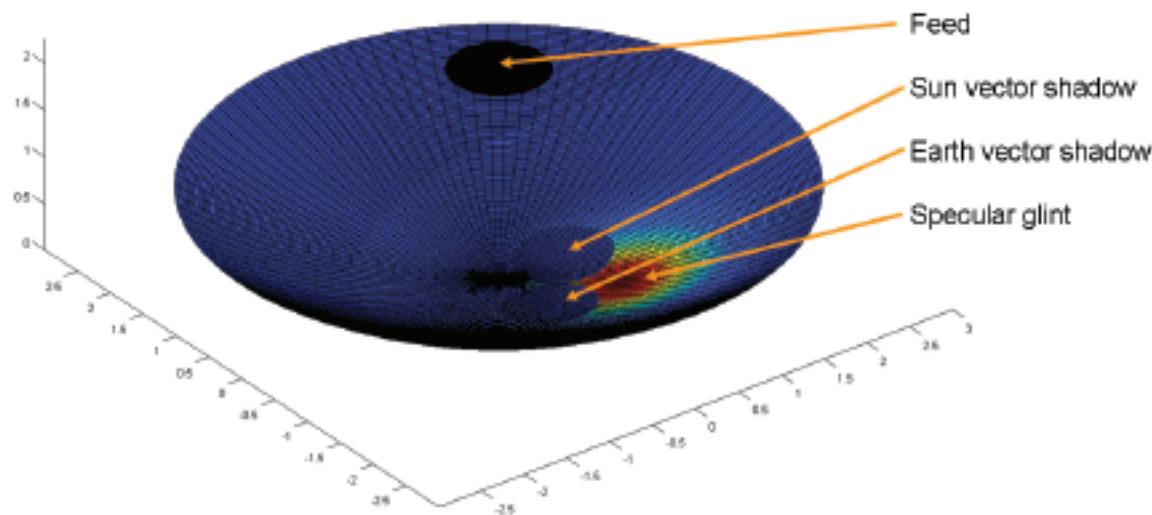


Figure 2. Model of 10,000 facet Earth-facing parabolic dish and feed with 20° declination offset. Specular glint and shadows of feed (both Sun and observer) are clearly evident.

Significance: This research addresses an issue at the heart of Space Situational Awareness, namely non-resolved SOI. Additionally, the results of this and other related cadet and faculty research are being incorporated into the physics curriculum at USAFA, providing cadets invaluable experience with observation and analysis techniques at the forefront of Air Force relevant research. Specifically, the goal is for cadets to be able to both observe and model reflections from solar panels, satellite buses, and parabolic dishes on geostationary satellites (see Figure 2 for an example model).

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Sponsorship: High Performance Computing Modernization Program (HPCMP) and AFRL/DE's High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA)

Acknowledgements: Brian Birge (Boeing LTS - June 2005 CSRP cadet mentor) and Doyle Hall (Boeing LTS - for advice to faculty and cadets during Fall 2005 and Spring 2006 semesters)

The Effects of Platinum on Thermal Barrier Coating Performance

Kristen A. Marino and Emily A. Carter

Jet engine performance and durability is influenced by the lifetime of thermal barrier coatings (TBCs) which are applied to the engine's components. Failure of TBCs depends in part on atomic level mechanisms that are difficult to study experimentally. Calculations based on quantum mechanics allow us to study materials on the atomic level. Pt has been shown to increase TBC lifetime. This project examines the influence of Pt on atomic level mechanisms in TBCs which may offer suggestions for improving the lifetime of TBCs.

in the bond coat delays the time to spallation, but the mechanism by which Pt achieves this is not known. Our objective is to determine if Pt's role is to inhibit high temperature diffusion of various elements in the bond coat alloy; hence we are examining diffusion mechanisms in NiAl with and without Pt. While several mechanisms have been proposed for Ni diffusion in NiAl, controversy about which is the dominant mechanism still remains. Once an understanding of these atomic level mechanisms is found, and the effects of Pt are determined, we hope to offer suggestions for improving the design of TBCs, ultimately increasing their lifetime.

Methodology: Our density functional theory calculations are performed in the Vienna *Ab Initio* Simulation Package, VASP. The generalized gradient approximation (GGA) for electron exchange and correlation and the frozen core all-electron projector augmented wave (PAW) potentials are used. The plane wave basis set used in VASP allows for modeling crystals using periodic boundary conditions. We first need to calculate defect formation energies (see below) and determine optimum structures of the initial and final states of diffusion pathways by relaxing the atomic coordinates. The climbing image nudged elastic band method (CINEB) method is then used to determine the minimum energy path for diffusion between the initial and final states from which the activation energy of the mechanism can be calculated.

Introduction and Objective: Thermal barrier coatings are applied to jet engine components for protection from the high operating temperatures of the engine. The performance of the engine is limited by the lifetime of the coating; once the coating spalls, the engine parts are subjected to higher temperatures decreasing their durability. These coatings consist of three parts: a metallic bond coat, a ceramic topcoat, and a thermally grown oxide layer which grows between the bond coat and ceramic layer. The lifetime of the coating is determined by the adhesion of the oxide layer to the bond coat, which is often comprised of NiAl doped with Pt. Experiments have shown that the presence of Pt

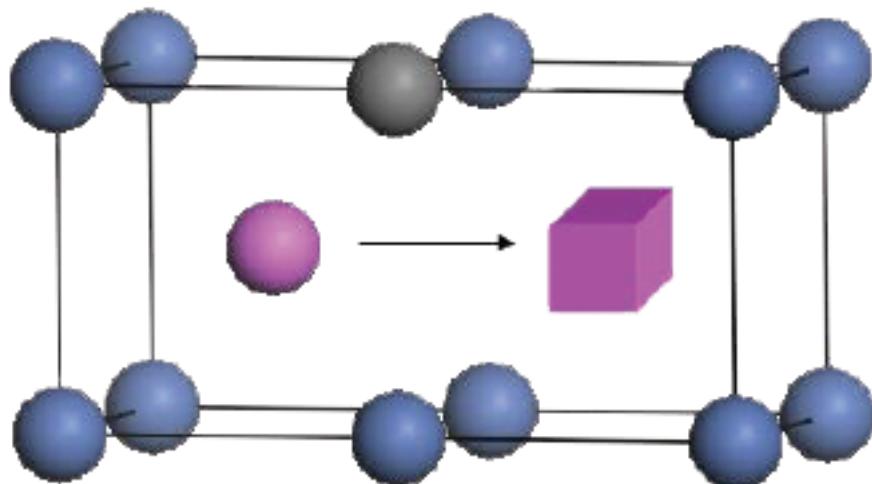


Figure 1. NNN Al jump in (Ni,Pt)Al. The Ni atoms are blue, the Pt atom is grey, and the Al atom is pink. The cube represents the vacancy and the arrow shows the path the Al atom takes in the jump. The activation energy for this jump is higher when Pt is present when Pt is not present.

Results and Significance: NiAl has a CsCl structure consisting of two interpenetrating simple cubic lattices, one for each atomic species. Pt is known to sit in Ni lattice sites. Self-diffusion in NiAl occurs by a vacancy mechanism due to the large size of Ni and Al atoms. In addition to Ni and Al vacancies, several of the proposed mechanisms involve antisite atoms, which are Al atoms on the Ni sublattice or Ni atoms on the Al sublattice. Results thus far have indicated that the presence of Pt can affect the formation energy of vacancies and antisite atoms and the activation energy for diffusion in NiAl. The formation energy of a Ni vacancy in NiAl and a Ni antisite atom is not affected by Pt. The presence of Pt decreases the formation energy of an Al vacancy. Interestingly, the formation energy of an Al atom, which is positive in NiAl, becomes negative when Pt is present. A negative formation energy may indicate that an Al antisite atom is a stable defect in NiAl when Pt is nearby. Proposed diffusion mechanisms for Ni in NiAl involve Al vacancies and Al antisite atoms.

The simplest type of diffusion mechanism in NiAl, next nearest neighbor (NNN) jumps, has been examined. Pt does not affect the activation energy of Ni diffusion by NNN jumps, but increases the activation energy of Al jumps. Pt may inhibit Al diffusion in NiAl. NNN jumps are not a likely diffusion mechanism in NiAl because the preexponential factor was calculated to be much lower than experimentally determined values. More complicated diffusion mechanisms are being explored.

Understanding how Pt affects diffusion in NiAl may allow for improvements to the design on TBCs. Increasing TBC lifetime will result in improved performance and durability of jet engines components thereby decreasing maintenance time and cost.

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Sponsorship: Air Force Office of Scientific Research

Understanding Aluminum Oxide Growth in Thermal Barrier Coatings

Berit Hinnemann and Emily A. Carter

Military aircraft jet engines are limited in service lifetime by the failure of thermal barrier coatings (TBCs) that protect the metal from the extreme heat of the combustion gases. We use state-of-the-art electronic structure calculations to study failure mechanisms in atomistic detail. The ultimate goal is to use this knowledge for the design of better TBCs. A TBC consists of several layers, an outer layer of a ceramic heat shield, a middle layer of aluminum oxide, which acts as a corrosion barrier, and a bond coat metal layer, which ensures adhesion of the aluminum oxide and the underlying superalloy (see Figure 1). During service, the aluminum oxide layer grows and ultimately causes delamination and failure of the TBC. The objective of our project is to understand the growth mechanism and how it can be slowed down so that longer TBC lifetimes can be achieved.

Research Objective: A crucial aspect of TBC failure is the growth of the aluminum oxide layer which is located between the bond coat alloy and the heat shield ceramic. As soon as the oxide has reached a thickness of ~3–10 μm , the coating spalls off. It has been shown experimentally that the early transition metal dopants Hf, Y, and Zr slow down the growth of the oxide layer and the suggested explanation is that they block the diffusion of Al ions through the crystal. In this case, the growth presumably occurs by diffusion by inward diffusion of O ions, which is significantly slower. The atomistic details of this mechanism are poorly understood so far, and our objective is to elucidate them using electronic structure calculations. These calculations on realistic yet computationally accessible systems allow us to understand binding and diffusion in atomic detail and in this way to provide information which is not directly accessible for experiments.

Methodology: We use density functional theory as implemented in the Vienna *Ab-initio* Simulation Package (VASP). The ion cores are described by the projector-augmented wave (PAW) method and we use the PBE exchange-correlation functional. Building a structural model of the alumina layer is challenging, as it is polycrystalline and diffusion predominantly occurs along grain boundaries. Thus, we are building model systems of representative grain boundaries and studying diffusion along these defects. As a first approach and "benchmark system," we have studied adsorption and diffusion of Al, O, and Hf on the $\text{Al}_2\text{O}_3(0001)$ surface.

Results and Significance: We find that both Al and Hf bind on the same site on the $\text{Al}_2\text{O}_3(0001)$ surface, but Hf binds significantly more strongly than Al. Their diffusion pathways on the surface are similar, but Hf seems to have a higher diffusion barrier than Al. This suggests that Hf indeed blocks Al diffusion. O absorbs on a different site and also has a different diffusion pathway. This offers an explanation as to how Hf can slow down oxide growth, but not stop it completely. Currently, we are investigating whether these findings hold for diffusion along grain boundaries as well.

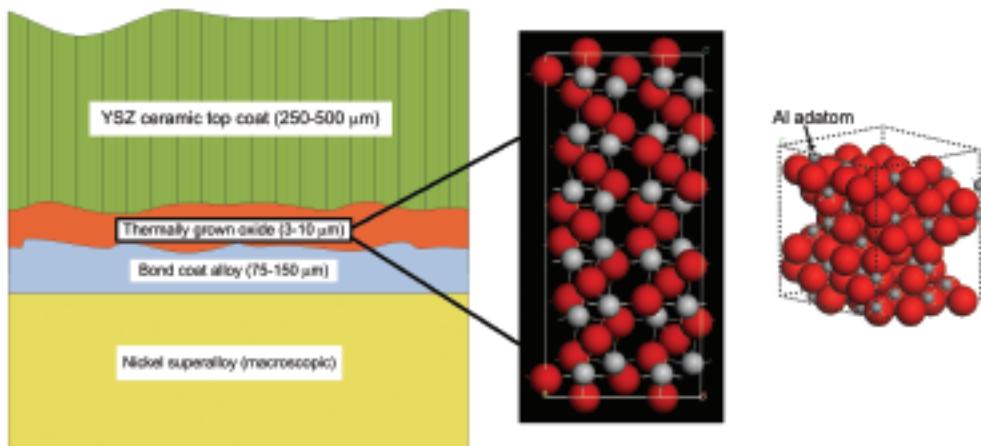


Figure 1. Right: Schematic cross-section of a TBC (not to scale), Middle: Model of the $\Sigma 13$ ($10\bar{1}4$) grain boundary in $\alpha\text{-Al}_2\text{O}_3$, Left: Model of the $\text{Al}_2\text{O}_3(0001)$ surface with an adsorbed Al adatom. Aluminum atoms are shown in gray and oxygen atoms in red.

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Sponsorship: Air Force Office of Scientific Research

Cirrus Cloud Analysis for Airborne Laser Terminal

Donald C. Norquist

The High-Altitude Pseudo-Satellite (HAPS) experiment requires estimate of the probability of cloud-free line of sight (PCFLOS) between the proxy satellite (aircraft at 65 K feet) and the receiving aircraft. These data sets will be used to determine the PCFLOS between HAPS aircraft for typical months at the locations.

Imagery grids were combined with daily numerical weather prediction model forecasts executed on the MHPCC supercomputer for February 2003 as a trial month. Analyses yielded retrievals of cirrus top and base height and optical depth for the relevant wavelength in 5 km X 5 km picture elements for circular areas of radius 200 km centered on locations of interest. These data sets will be used to determine the PCFLOS between HAPS aircraft for typical months at the locations. This in turn will give guidance on the likelihood of communications outages in the experiment.

Research Summary: An analysis of cirrus cloud coverage was conducted in preparation for a field experiment that would prototype laser communication links from satellite to high-altitude aircraft. The High-Altitude Pseudo-Satellite (HAPS) experiment requires estimate of the probability of cloud-free line of sight (PCFLOS) between the proxy satellite (aircraft at 65 K feet) and the receiving aircraft. Hourly satellite

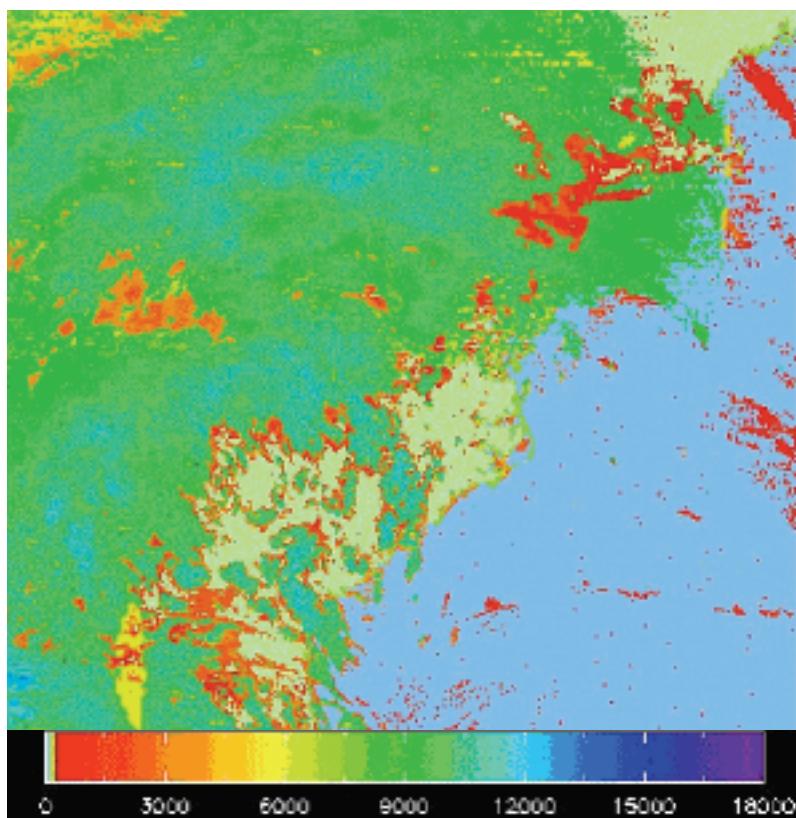


Figure 1. Display of cloud top height (meters) over the eastern U.S. on 3 February 2003 at 1746 UTC, as retrieved from the GOES-8 geostationary meteorological satellite imagery using atmospheric pressure, temperature, and height profiles from the MM5 weather model. Land surfaces are beige and water surfaces are light blue. For reference, Cape Hatteras appears in the center of the image.

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Sponsorship: Department of Defense

Acknowledgements: Ms. Farzana Khatri, Massachusetts Institute of Technology, Lincoln Laboratory, for requesting the support for the HAPS experiment; Lt. John Myers, AFRL/VSBYA for production executions of the cloud analysis algorithm, and Gary Gustafson and Bob d'Entremont of AER, Inc. for the cloud detection and property retrieval algorithm software.

High-Resolution Forecasts to Support AMOS Using WRF

Kevin P. Roe

The Hawaiian Islands contain a variety of microclimates in a very small region. Some islands have rainforests within a few miles of deserts; some have 10,000 feet summits only a few miles away from the coastline. Because of this, weather models must be run at a much finer resolution to accurately predict in these regions. The Weather Research and Forecasting (WRF)^{1,2,3} modeling system (version 2.1.2) is run from a coarse 54 km horizontal resolution (surrounding an area of approximately 7000 by 7000 km) nested down to a 2 km horizontal resolution (and 55 vertical levels) daily. Since the computational requirements are high to accomplish this in a reasonable time frame (as to still be a forecast) WRF is run in parallel on MHPCC's Cray Opteron cluster. Utilizing 32 nodes (2 processors/node) the WRF model is run daily over the above conditions in under 4 hours for a 48 hours simulation. Although these forecasts are relatively new, over seven years of numerical weather simulation experience with MM5 and RSM have contributed to its effective use. Operators at the telescope on Haleakala, Maui, utilize this WRF simulation in their daily planning.

Research Objectives: The telescope operations on Haleakala are highly dependent on weather conditions on the Hawaiian Island of Maui. If the wind speed is too high then the telescope cannot be utilized. Problems also exist if there are clouds overhead. Rainfall and relative humidity are also a factor in determining the capabilities of the telescopes. Lastly, optical turbulence (or "seeing") is predicted over Haleakala using the output conditions from WRF.⁴

In order to effectively schedule telescope operations, an accurate weather prediction is extremely valuable. Current forecasts that are available from the National Weather Service (NWS) give good indications of approaching storm fronts but only at a coarser level (10-12 km resolution). Because of this and the location of the telescope on Maui this can be insufficient for their needs. The additional benefit of the telescope operators having access to an accurate forecast (even for only a day in advance) is that they can still perform some scheduling. If a storm is predicted they can plan maintenance for this time period. This allows the operators to function more effectively by giving them the capability to schedule downtime. This in turn saves time, improves operating efficiency, and potentially saves money.

Daily Operations: Every night at Midnight Hawaiian Standard Time (HST), a PERL script is run to handle all the operations necessary to produce a forecast on MHPCC supercomputers, prepare images of weather fields (wind, temperature, relative humidity, rainfall, cn₂, etc.), and post it to the MHPCC web page (<http://weather.mhpcc.edu>).

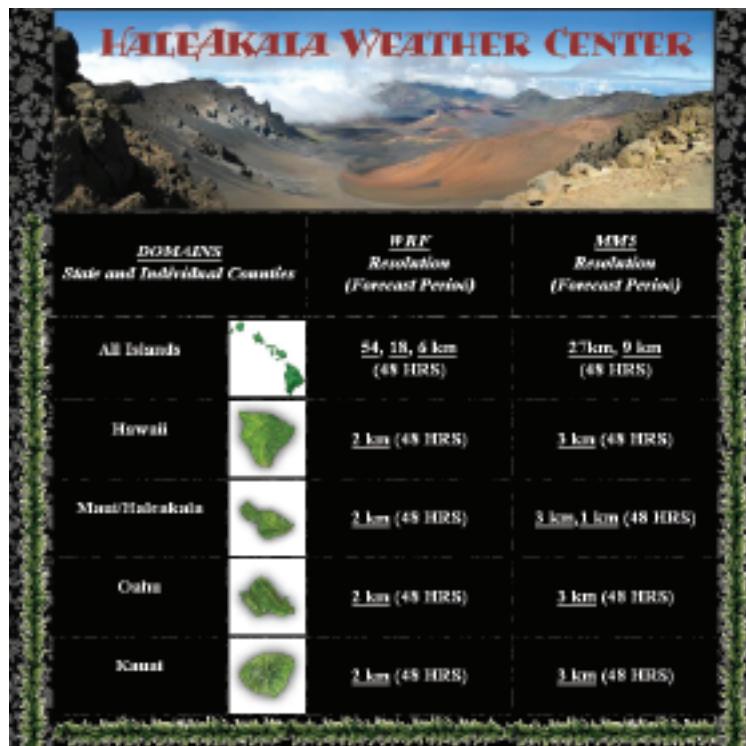


Figure 1. Haleakala Weather Center Homepage.

Web Output: Now that the above processes have created images, they must be made available for the telescope operators. This is accomplished by posting the images to the MHPCC web page; specifically, <http://weather.mhpcc.edu>. This title page gives the user the option of what area and resolution they would like to examine. From the title page, the user can select the all island area at a 54, 18, or 6 km resolution or 1 of the 4 counties (Hawaii, Maui, Oahu, and Kauai) at a 2 km resolution. Once one of the above has been selected, the user is transported to a web page that initially includes an image of the wind in the selected area. On this regional web page, the viewer can select to see the previous or next image through the use of a small JavaScript. If the viewer prefers, an animation of the images (in 1 hour increments) can be started and stopped. Finally, the user can select any of the other images from a pull down menu. If the viewer would like to change the field being examined, a pull down menu on the left side of the page will transport the user back to the main menu, a different county, or allow them to choose a different weather field.

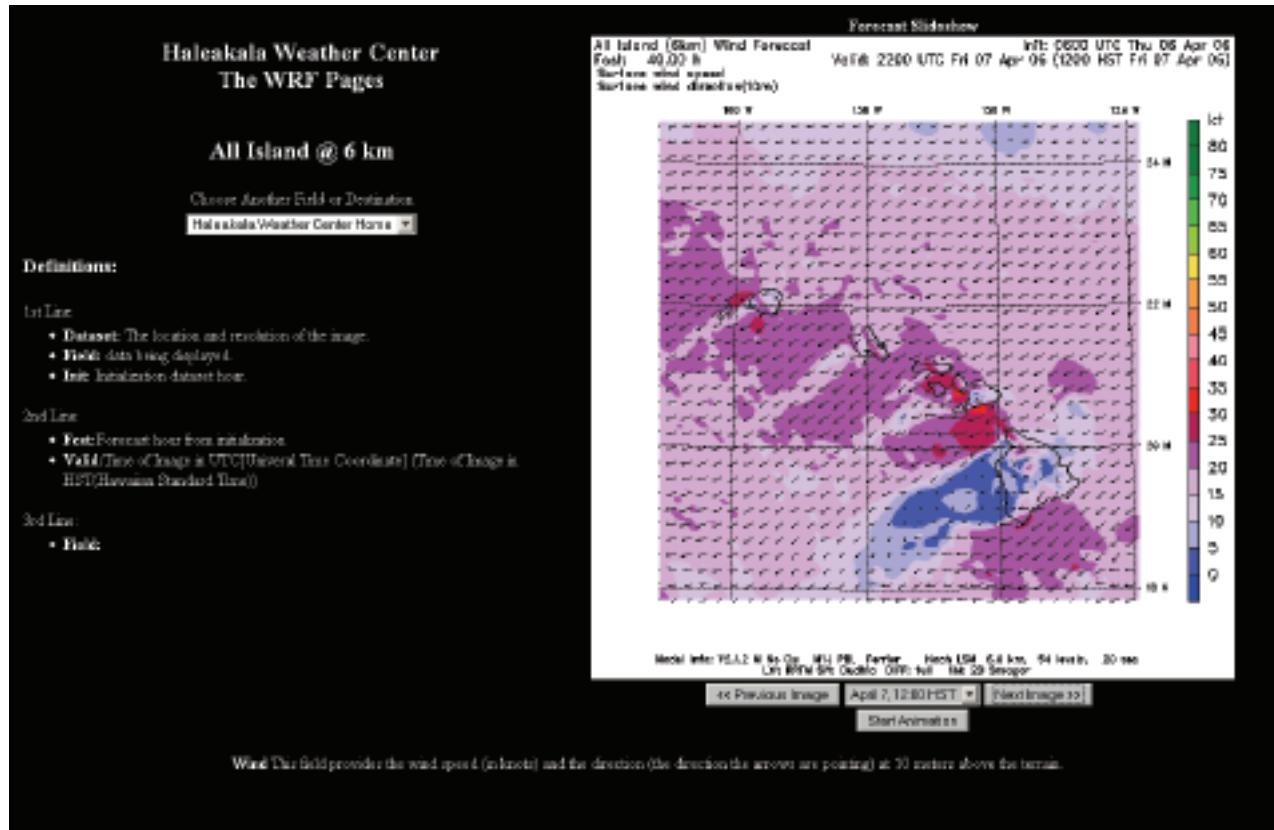


Figure 2. Surface windspeed and direction for the Hawaiian Archipelago.

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Sponsorship: Air Force Research Laboratory

Acknowledgement: MHPCC would like to thank the Maui Space Surveillance System for their cooperation and feedback on this project.

Data Farming Under Unix/Linux

James Rosinski, Bob Swanson, Bruce Duncan

Data Farming is the process of using a high performance computer or computing grid to execute a simulation thousands or millions of times across a large parameter and value space. The result of Data Farming is a "landscape" of output that can be analyzed for trends, anomalies, and insights in multiple parameter dimensions. Data Farming is used extensively in the Marine Corp's Project Albert work performed at the Maui High Performance Computing Center (MHPCC).

Data Farming Nomenclature: First some nomenclature: a single model execution instance for Project Albert data farming is called a "replicate." A single set of input data space values is called an "excursion." A data farming job is made up of multiple data space changes, so there are usually a number of excursions requested by the user. For instance, the user may want to vary a weapon range passed to the model from 10 to 100 in steps of 10. This requires the data farming system to create separate model input files where the weapon range value is set to 10, then to 20, then 30, and so on for a total of 10 excursions.

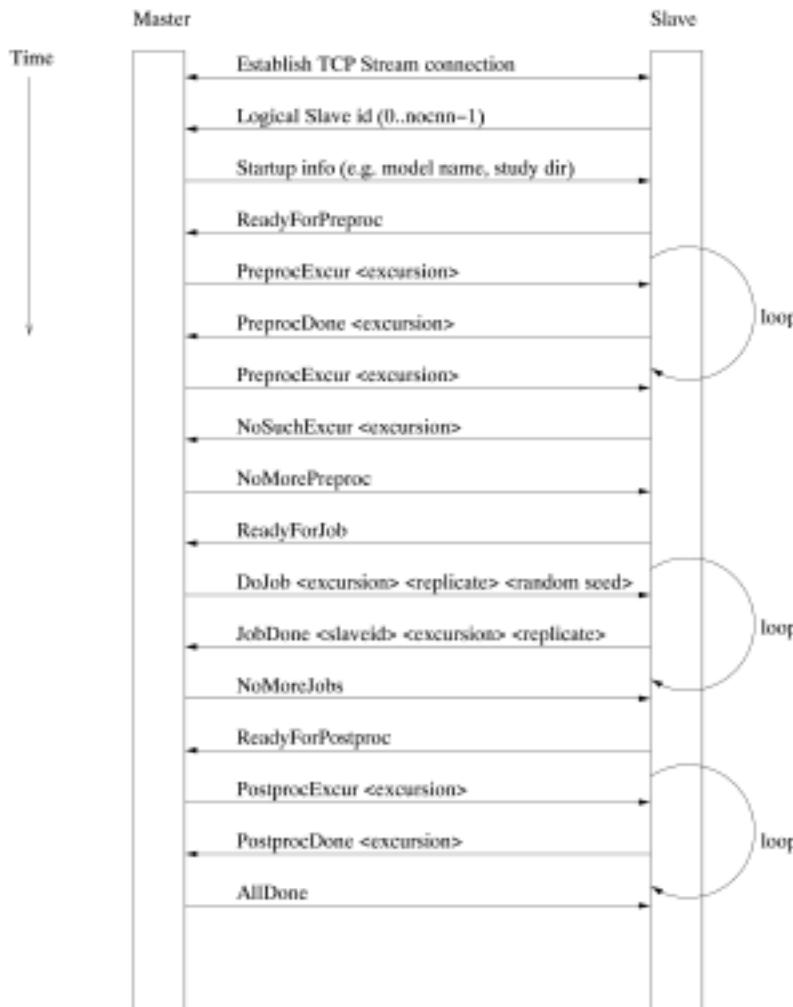


Figure 1. Time sequence of communication events between master and slave(s).

Technical Challenge: Throughout the life of Project Albert, the software developers at MHPCC have been working to meet the challenge of executing very large numbers of model execution instances in parallel. A number of approaches have been used, including the recently-developed Job Execution Manager (JEM) product. That product was described in a previous Application Brief. This document describes a new approach for executing job-based model runs on the large-scale high-performance shared computing systems at MHPCC.

Randomness: In addition to varying the data space values, users want to study the behavior of the models when the starting random seed number is changed. The agent-based models used in Project Albert can be very sensitive to random behavior, so researchers are interested in reviewing the results from a non-trivial sample of model executions where the input space values are the same, but a different random seed is used. Thus, our system must execute a single excursion multiple times with different seeds. Given the above example, the user may want to try 100 different seeds with each excursion. Thus, the total number of model executions (replicate runs) in this study would be 1,000. We call this set of excursions and random seeds a "study."

Batch Execution Systems: Historically, Project Albert batch job-based execution systems developed at MHPCC ran all replicates (100 in the above example) for an excursion in a single job on the large-scale computing equipment (*Tempest*, *Huinalu*, *Hoku*, etc). This approach limits the amount of parallelism that can be exploited. And over time, it became unwieldy, as individual model instances required increasing amounts of execution time. A better approach would be to run each replicate in a single job. Experience with the batch job managers on the machines (e.g., LoadLeveler on the AIX systems, and the Maui Scheduler on *Huinalu*), however, showed that submitting 1,000 or more jobs was an untenable approach. A system was needed that would support the replicate as the smallest atomic execution entity, but which would not require large numbers of jobs to be submitted.

Technical Approach: Project Albert staff at MHPCC have developed a job-based execution system that provides control of model executions down to the replicate level, but which are managed from a single multi-node batch job. The system is based on a set of Perl scripts, and run in an environment where there are many multi-processor compute nodes that have access to a shared file system. Scripts have been created to run on the *Hoku* machine and the production *Tempest* machine. The architecture is described in the following sections.

Master/Slave Architecture: The programming model used in this Perl-based approach to data farming is master/slave. In this system the job of a single master process is to send instructions individually to an arbitrary number of slave processes, manage the responses, and send out further instructions as necessary. The slaves do each bit of assigned work in parallel with one another, and report back the results to the master. This tightly-coupled process is repeated until no more work remains. Normally, the slaves will execute instances of Project Albert models, but in principle they can execute any task that can be invoked on a command line. For testing purposes, the Perl scripts can execute a "placebo model" which is a do-nothing set of code that just expends CPU time. Thus, the overall architecture can be tested without the extra complications of a Project Albert model execution.

The time sequence of communication events between master and slaves is depicted in Figure 1.

Depending on the instruction received from the master, each slave will do one of three things:

1. Pre-process by generating an excursion file
2. Execute a replicate (thus invoking the model program)
3. Post-process an excursion by marshaling the created output files for further handling

Figure 2 shows the communication network between the master and the slaves.

Job Processing: A job represents a single study for data farming purposes. The job is prepared by a user with access to the large-scale computing system at MHPCC. The user prepares a shared disk working area for the job, then edits a batch system-specific script (e.g., LoadLeveler, PBS) that will start the processing. Examples of user-settable parameters within the script include the number of processors to use, and the location of input files specific to the study. The user then submits this script as a job. As the job executes, logs are written in the shared area. They provide information about the progress of the job and details about any model or script failures. When the job is completed (or has been canceled by the user), the user can check the output logs to determine if all replicates have been successfully executed. If one or more replicates are missing, the batch system-specific script can be altered to indicate a "rerun" condition, and resubmitted. The new job will "fill the holes" for the missing replicates. Once all results are present, the user can execute a final script to marshal all output results and can then transfer the marshaled output to other machines, as needed, for further output processing.

Experience: This system has been in production use at MHPCC for the first half of 2006, and has proved itself to be very useful, providing a much more manageable framework for job execution on the large-scale computing machines. Using this system has added additional capability to Project Albert to help fulfill the customers' needs for execution of large numbers of model instances in support of Data Farming.

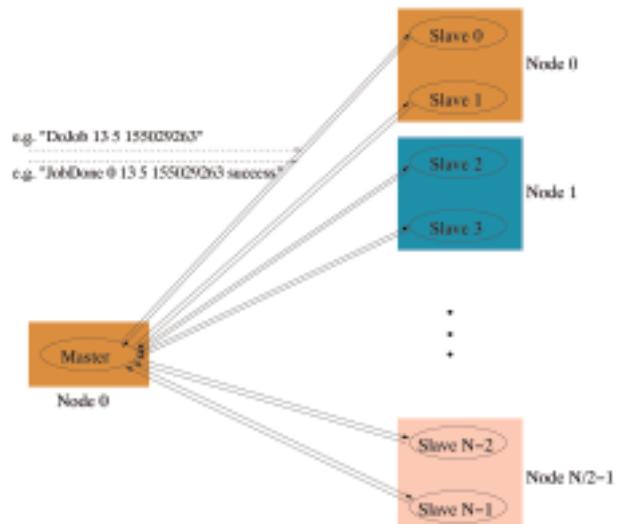


Figure 2. Communication network between master and N slave(s) running on N/2 compute nodes. Channels are bi-directional and always between master and slaves-never slave-to-slave.

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Resources: IBM P3/P4 (*Tempest*), IBM Linux Supercluster, Cray XD-1 (*Hoku*), and Windows clusters at MHPCC

Sponsorship: Marine Corps Warfighting Laboratory (MCWL)

High-Resolution Forecasts to Support AMOS Using MM5

Kevin Roe and Duane Stevens

The Hawaiian Islands contain a variety of microclimates in a very small region. Some islands have rainforests within a few miles of deserts; some have 10,000 foot summits only a few miles away from the coastline. Because of this, weather models must be run at a much finer resolution to accurately predict in these regions. NCAR's Mesoscale Model Version 5 (MM5)^{1,2,3} is run from a coarse 27 km resolution (surrounding an area of approximately 5000 by 5000 km) nested down to a 1 km resolution daily. Since the computational requirements are high, to accomplish this in a reasonable time frame (as to still be a forecast) MM5 is run in parallel on MHPCC's IBM SP4s. Utilizing 32 processors the MM5 model is run daily over the above conditions in approximately six hours. These forecasts have been in place for over four years now^{6,7,8} and are being utilized by operators at the telescope on Haleakala, Maui.

some scheduling. If a storm is predicted the operators can plan maintenance for this time period. This allows them to function more effectively by giving them the capability to schedule downtime. This in turn saves time, improves operating efficiency, and potentially saves money. In addition, optical turbulence (also called seeing or CN²) is now being predicted and utilized.

Daily Operations: Every night at midnight Hawaiian Standard Time (HST), a PERL script is run to handle all the operations necessary to produce a forecast, prepare the data, and post it to the MHPCC Web page (<http://weather.mhpcc.edu/mm5>). The procedures the script executes are:

- 1) Determine and download the latest global analysis files from NCEP for a 48-hour simulation,
- 2) Begin processing by sending these files through MM5's REGRID program,
- 3) Take the output data files from REGRID and input into INTERPF,
- 4) Prepare the MM5 model for the current simulation,
- 5) Submit the MM5 run to MHPCC's IBM SP4 (*Tempest*) for execution (daily reservation starting at 1 A.M.),
- 6) Average daily run requires 5-6 hours for completion on 32 processors (a single P4 node),
- 7) Data is output in one-hour increments,
- 8) Data is processed in parallel to create useful images for meteorological examination,
- 9) Convert images to a Web viewable format,
- 10) Create the Web pages for these images, and
- 11) Post Web pages and images to MHPCC's Web site.

Research Objectives: The telescope operations on Haleakala are highly dependent on weather conditions on the Hawaiian Island of Maui. If the wind speed is too high then the telescope cannot be utilized. Problems also exist if there are clouds overhead. Rainfall and relative humidity are also a factor in determining the capabilities of the telescopes. In order to effectively schedule telescope operations, an accurate weather prediction is extremely valuable. Current forecasts that are available from the National Weather Service (NWS) give good indications of approaching storm fronts but only at a coarser level (12 km resolution).^{4,5} Because of this and the location of the telescope on Maui this can be insufficient for the operator's needs. The additional benefit of the telescope operators having access to an accurate forecast (even for only a day in advance) is that they can still perform



Figure 1. Maui Space Surveillance Site located atop Mt. Haleakala.

Web Output: Now that the above processes have created images, they must be made available for the telescope operators. This is accomplished by posting the images to the MHPCC Web page; specifically, <http://weather.mhpcc.edu/mm5>. This title page gives the user the option of what area and resolution they would like to examine. From the title page, the user can select the all island area at a 27 or 9 km resolution, one of the four counties (Hawaii, Maui, Oahu, and Kauai) at a 3 km resolution, or the summit of Haleakala at a 1 km resolution. Once one of the above has been selected, the user is transported to a web page that initially includes an image of the temperature in the selected area. On the regional Web page, the viewer can select to see the previous or next image through the use of a small JavaScript. If the viewer prefers, an animation of the images (in one hour increments) can be started and stopped. Finally, the user can select any of the images from a pull-down menu. If the viewer would like to change the field being examined, a pull down menu on the left side of the page will transport the user back to the main menu or allow them to choose a different field. Lastly, if the JavaScript becomes a problem for the viewer's browser, they have the option of being switched to a non-JavaScript equivalent version Web page.

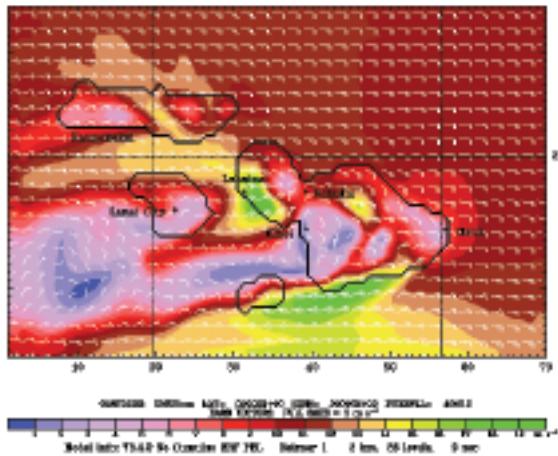


Figure 2. Windspeed and direction for Maui County.

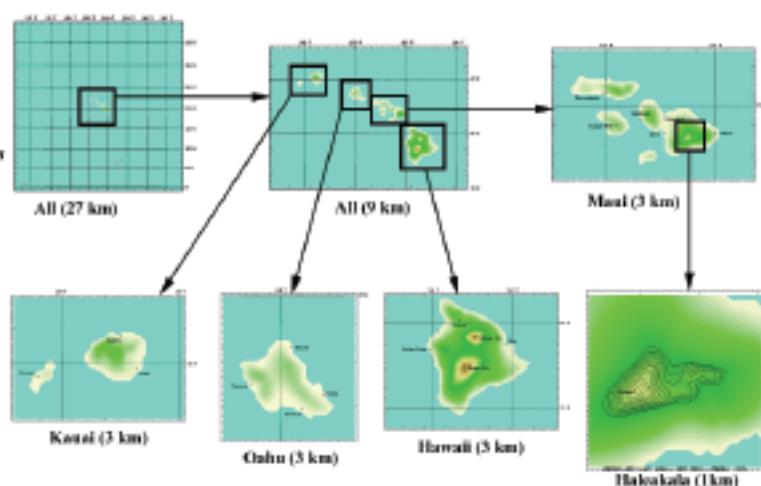


Figure 3. Computational domain breakdown of MM5 simulation.

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URL: <http://weather.mhpcc.edu/mm5>

Resources: IBM SP4 at MHPCC

Sponsorship: Air Force Research Laboratory

Open Source Data Exploitation and High Performance Computing: Facilitating Predictive Analysis of Terrorist Organizations

Maria Murphy, James Rosinski, Bob Dant, Kathleen Carley,
Jeff Reminga, Mike Kowalchuk

National Security is a top priority for our government. Tools to improve the collection and use of information related to counterterrorism efforts are continually being sought after and enhanced. The Joint Intelligence Center Pacific, Counter Terrorism Division (JICPAC-CTD) has tasked the Maui High Performance Computing Center (MHPCC) to evaluate and expand the capabilities of a suite of dynamic network analysis tools developed by Carnegie Mellon University (CMU) to support the intelligence analyst. This suite of tools makes use of open sources of data (e.g., news feeds, public databases, the Internet) to create social networks for analysis. Analysis of very large networks generated from open sources and exploitation of the predictive capabilities of tools can be difficult to accomplish in a timely manner. MHPCC makes use of parallel and distributed computing to address these issues.

Background: The CMU suite of software tools consists of:

- Automap: creates a social network using open source data,
- ORA: analyzes networks to pinpoint agents of interest, and
- DyNet: provides reasoning under varying levels of uncertainty about dynamic networked and cellular organizations, their vulnerabilities, and their ability to reconstitute themselves.

In a typical scenario, an analyst would run a set of measures (formulas used to express social characteristics) on an existing network in ORA. This process assigns a value to each entity in the network for a given behavioral characteristic such as leadership, specialized skills, and knowledge. Using these measure values to rank individuals in the network, the intelligence analyst can decide to take a course of action (strategy) to 'isolate' a specific agent or group of agents from the network. DyNet is used to determine how the network might change over a period of time if this isolation strategy is followed. The output of DyNet is a new network that can be analyzed to assess the impact of the strategy on the original network or evaluated using ORA to determine new individuals of interest.

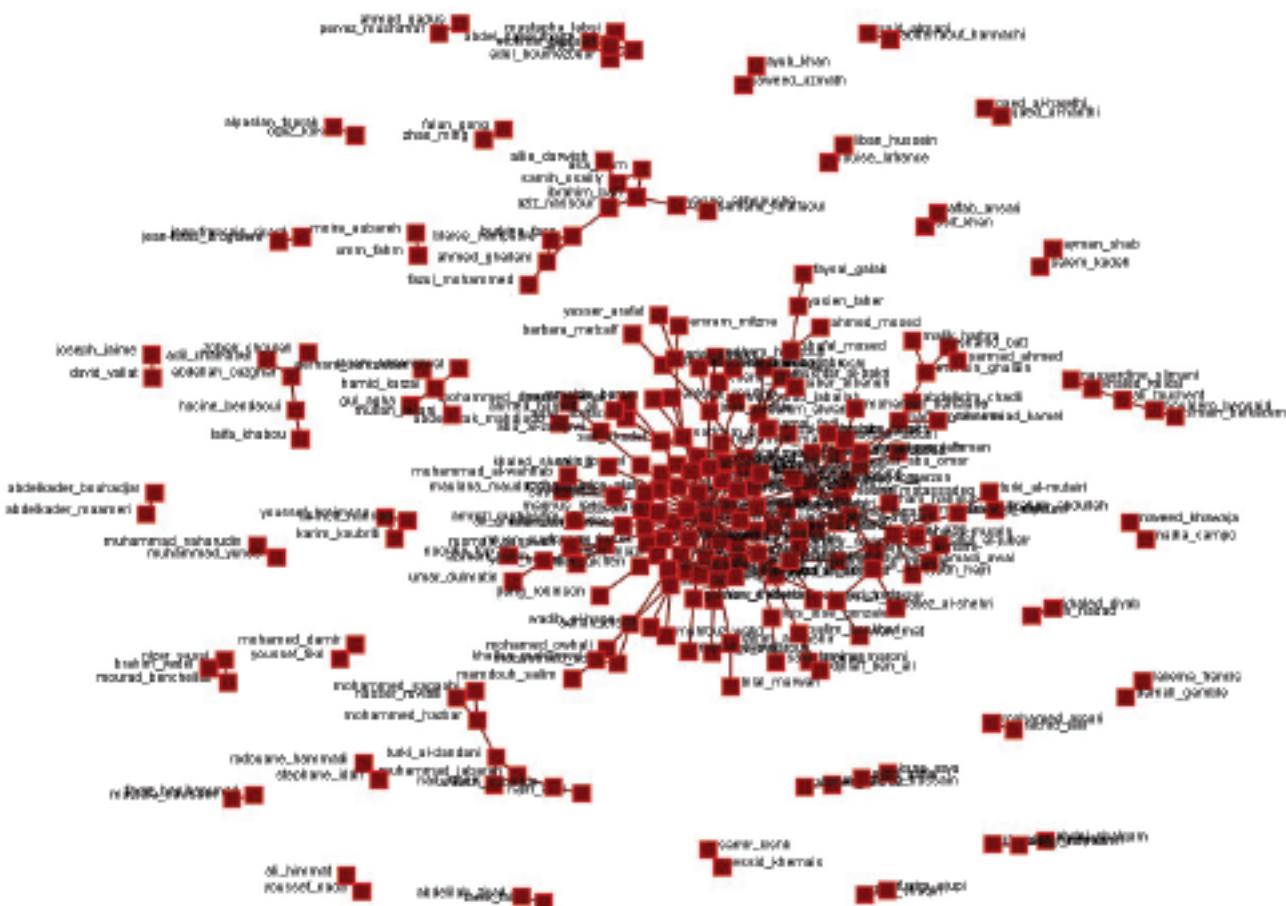


Figure 1. Visualization of a 2,000 entity network in ORA.

At CMU these tools were run on individual workstations with a relatively small number (hundreds) of agents in the network. Figure 1 shows the agents in a network of approximately 2,000 entities displayed in the ORA Visualizer. The challenge was to be able to perform organizational risk analysis on the much larger networks that would result from combining existing JICPAC data sources with open data sources. In addition, a solution for automating the repetitive task of running DyNet with different isolation strategies was required. Normally, after running the ORA measures on a network, analysts would review the rankings for the measures of interest and formulate several isolation strategies based on their own evaluation of the results. The effectiveness of the strategy is not known until after the simulation is run. The isolation strategies the analyst chose may or may not yield interesting results or show any impact on the existing network. Selecting a new strategy using trial and error was time consuming.

Methodology: The MHPCC team has worked closely with CMU's Computational Analysis of Social and Organization Systems (CASOS) developers to determine opportunities for improving scalability and performance of the ORA and DyNet applications. Both applications were written in Java and C++ and share some of the same supporting libraries. Although the programs were being used predominantly in a Windows environment, they were easily portable to Linux. The use of non-proprietary formats (plaintext and XML) for ORA and DyNet input and output files simplified the process of evaluating the tools.

Suggesting changes that would maximize performance but minimize changes to the code was important to the task of evaluating and testing these applications. ORA and DyNet were tested using datasets of various sizes, and the methods in both applications and their support libraries were profiled. A simple improvement to ORA scalability was to distribute the measures across processors, since interprocess communication isn't required. DyNet was launching multiple runs of the same simulation differentiated by random seeds in one instantiation. The simulations could take advantage of parallelism by distributing these runs across processors and combining the results at completion.

Finally, a method had to be devised to maximize the productivity of analysts attempting to evaluate the effectiveness of isolation strategies on a network. The data farming paradigm was developed at MHPCC to glean information from a large parameter space. In data farming, a simulation is run many times across a large parameter and value space. The result is a "landscape" of output that can be analyzed for trends, anomalies, and insights. In the case of DyNet, data farming would allow the analyst to evaluate the impact of numerous network configurations and identify potential new agents of interest within a reasonable amount of time.

Results: In response to the MHPCC performance analyses and recommendations for ORA and DyNet, CMU made modifications to their code, including changes in data structure implementation, supporting library code, and random number generation that improved performance by more than an order of magnitude. On a single workstation, generating ORA measures on a large network (thousands of agents) was difficult to impossible to accomplish due to memory limitations. By distributing the ORA engine's calculation of measures across processors on a Linux cluster (one measure per processor), we were able to increase the possible size of a network to 30,000 agents, with the total number of entities supported reaching 90,000. Along with the aforementioned changes to DyNet and distributing randomized simulations, the maximum number of agents was increased from 500 to 10,000.

The data farming framework, a separate software development effort, was used to handle requests for DyNet simulations. MHPCC can now 'data farm' any network with isolation strategies specified by the analyst and return the results. Figure 2 shows the process for farming various isolation strategies across multiple processors running DyNet.

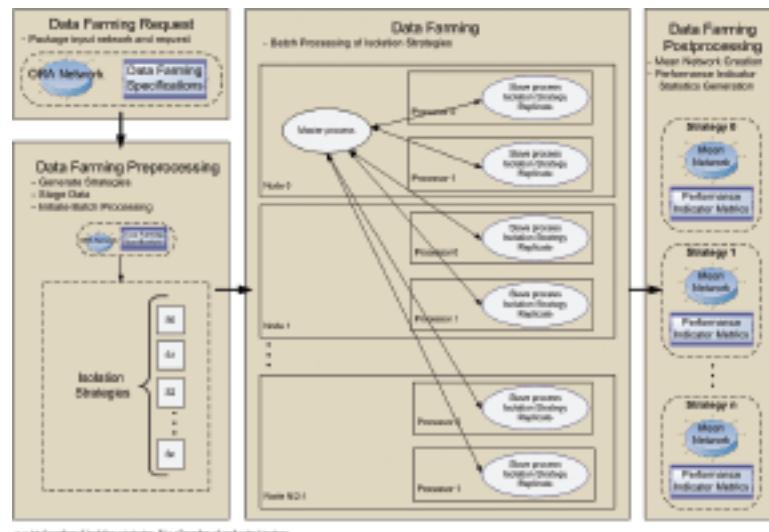


Figure 2. Data farming process for isolation strategies.

The Master process orchestrates the parallel execution of DyNet instantiations by the Slave processes. The isolation strategy is replicated as many times as the user specifies and differs only in the random seed used. Each Slave process in the diagram is capable of handling an arbitrary number of replicate runs. For example, if there are $n = 10$ isolation strategies and 5 replicates are requested per strategy, then there would be $N = 50$ total replicates, and therefore, 50 total runs. The Slaves communicate with the Master as each replicate finishes. After the replicates are completed for each isolation strategy, the output networks are combined into mean networks, and the performance indicators for each strategy are collected. This would result in ten mean networks in the above example, since the five new networks created from the five runs per isolation are combined.

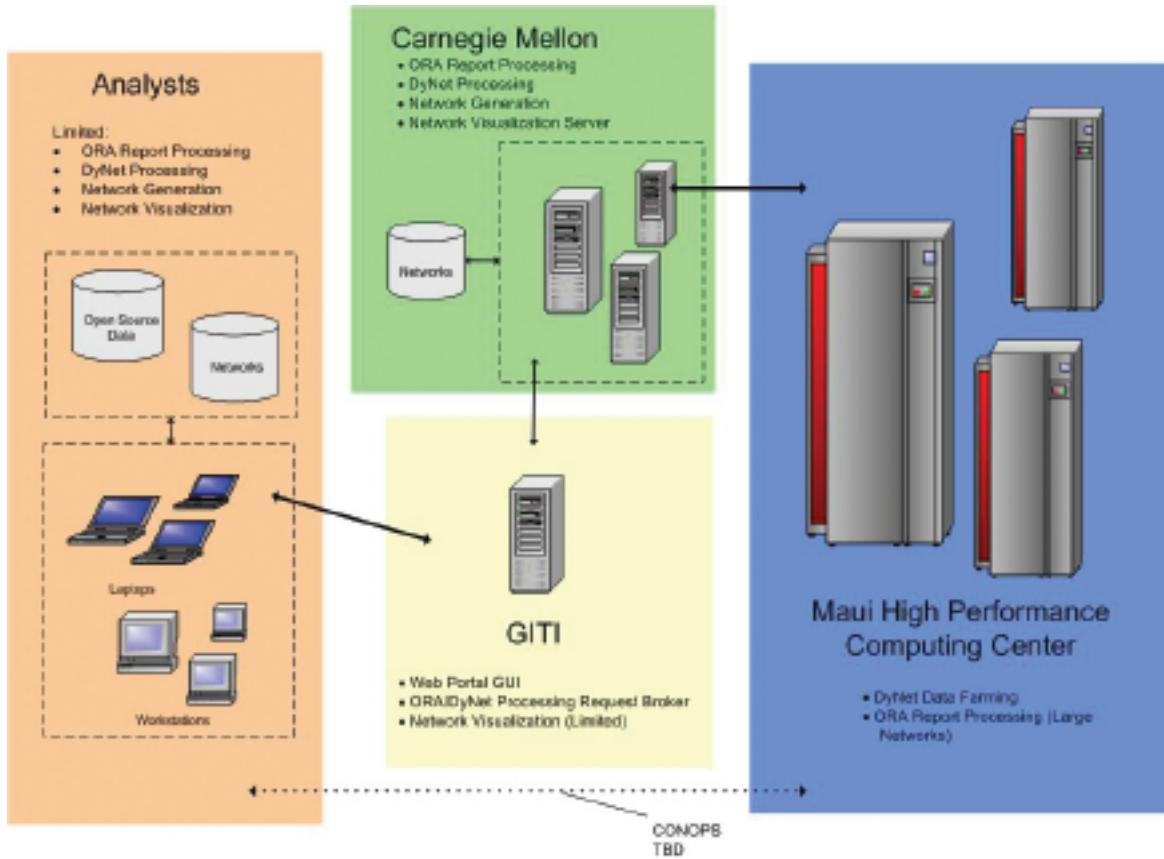


Figure 3. Key players and roles in Open Source Exploitation task.

Significance: We have continued our collaboration with CMU, and are also working with Global InfoTek, Inc. (Giti) to provide web front-end access to CMU dynamic network analysis tools, backed by high performance computing capabilities at MHPCC. As a result of distributing ORA and DyNet processing and utilizing a data farming framework, we have begun to evolve the analysis of social networks from a single-workstation, single-user environment to a more automated multi-processor, end-to-end system capable of providing operational analysis of dynamic social networks (Figure 3).

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Sponsorship: Joint Intelligence Center Pacific (JICPAC)

Sub-laser Cycle Structures in Coulomb Explosion of Molecular Hydrogen

Szczepan Chelkowski and André D. Bandrauk

Exremely intense and short flashes of laser light are now available. Such intense light can extract two electrons from a hydrogen molecule in a few femtoseconds ($1 \text{ fs} = 10^{-15} \text{ s}$). The remaining two positively charged nuclei are then not screened, they strongly repel each other and the molecule disintegrates. In recent experiments kinetic energy spectra of exploding nuclear fragments were measured with very high precision. We performed numerical calculations based on time-dependent Schrödinger equation which allows us to understand regular structures seen in recent experiment. We show that regular structures seen in the spectra give us information about the time dependent wave function at the Coulomb explosion time.

Research Objectives: Over 40 years after the first laser was constructed, experimentalists have recently achieved laser powers sufficient to accelerate particles to the speed of light in a few femtoseconds.¹ A commercially available small laser can break a simple hydrogen molecule into protons at laser intensities slightly over 10^{14} W/cm^2 (so far most intense laser provides 10^{20} W/cm^2). Such multiphoton processes (a single molecule absorbs over 20 photons in such a process) constitute a significant theoretical challenge since standard approaches based on perturbation theory cannot be used. The exact description requires solving the time dependent Schrödinger equation on parallel computers. We developed theory and codes for solving this problem.^{2,3} Recently, using the MHPCC *Tempest* machine we computed the Coulomb explosion kinetic energy spectra of H_2 and D_2 molecules in order to interpret the current experiment at the National Research Council in Ottawa.⁴ The structures seen in the measured spectra appear to be independent on various laser parameters (such as polarization, intensity, wavelength, pulse duration) in wide ranges. The calculated spectra are shown in Figure 1a. They show similar isotopic effect as in experiment.⁴ We show in Figure 1b the shapes of the wave packets projected on a surface form which the Coulomb explosion occurs. We believe that the structures seen in the spectra are directly related to the shape of the wave packet at times when the laser pulse reaches maximum or minimum.

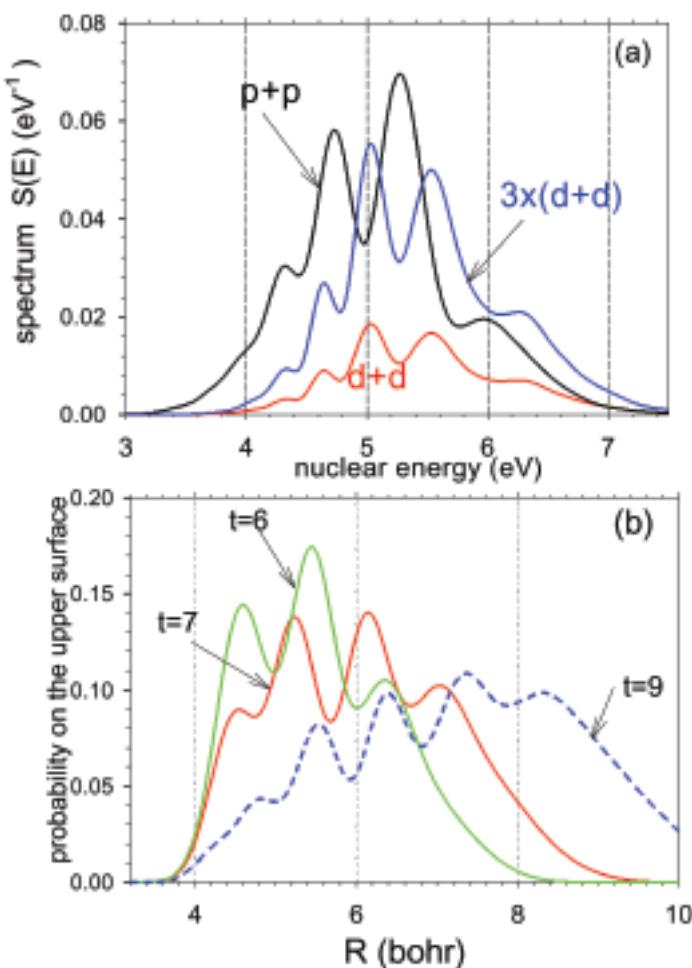


Figure 1. The calculated spectra are shown in Figure 1a. Figure 1b shows the shapes of the wave packets projected on a surface form which the Coulomb explosion occurs.

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Sponsorship: Natural Sciences and Engineering Research Council of Canada

Object Centric Intelligent Agent Information Fusion for Space Situational Awareness

Chris Cox, Erik Degraaf, Rick Wood, Tom Crocker

The Department of Defense has identified the need for improved space surveillance capabilities, consistent operating picture development, and net-centric operations in order to maintain United States military superiority. Recognizing these needs, Raytheon has developed an architecture and approach for performing multi-source and multi-INT information fusion to optimally provide the required information. As an initial step to demonstrating key components of the system, Raytheon has developed an information fusion demonstration using a microsat deployment as a test case, showing the ability to sort out and track all objects without a human in the loop. This demonstration has been installed on the MHPCC systems and modified to run on the AMOSPHERE display system as the initial step towards more expansive and detailed simulation development.

Research Objectives: The Department of Defense has identified the need for improved space surveillance capabilities, consistent operating picture development, and net-centric operations in order to maintain United States military superiority. With the advent of significantly improved sensors planned for deployment over the next decade, the number of catalogued objects is predicted to increase by an order of magnitude. The projected increase in numbers of objects, tracks, and intelligence data will magnify many of the existing Space Situational Awareness (SSA) challenges. This will be compounded further by the proliferation of technologies such as micro/nanosatellites, launch capability, and our dependence on space systems, creating a much more complex information processing and decision making environment. While the decision space has become larger and more complex, there is a need to reduce the overall operating costs associated with SSA, resulting in better and faster operating picture development needing to be performed using fewer operators.

Recognizing the need for improved SSA, Raytheon has developed an architecture and approach to performing multi-source and multi-INT information fusion in the net-centric environment that is based on the association of intelligent software agents with individual resident space objects. The core technologies draw on sensor netting and data fusion, intent determination technology, and intelligent agent based systems developed for other programs. The combination of these technologies with a systems based approach to meeting future requirements for SSA will permit automation of object track prediction, maintenance, assessment, and knowledge gathering, as well as inter-object conjunction, interaction, and reaction assessments in a distributed event driven architecture. Further, the information processing architecture and sensor netting capabilities are extensible to allow existing SSN sensors, future space based systems, and other data sources to be exploited.

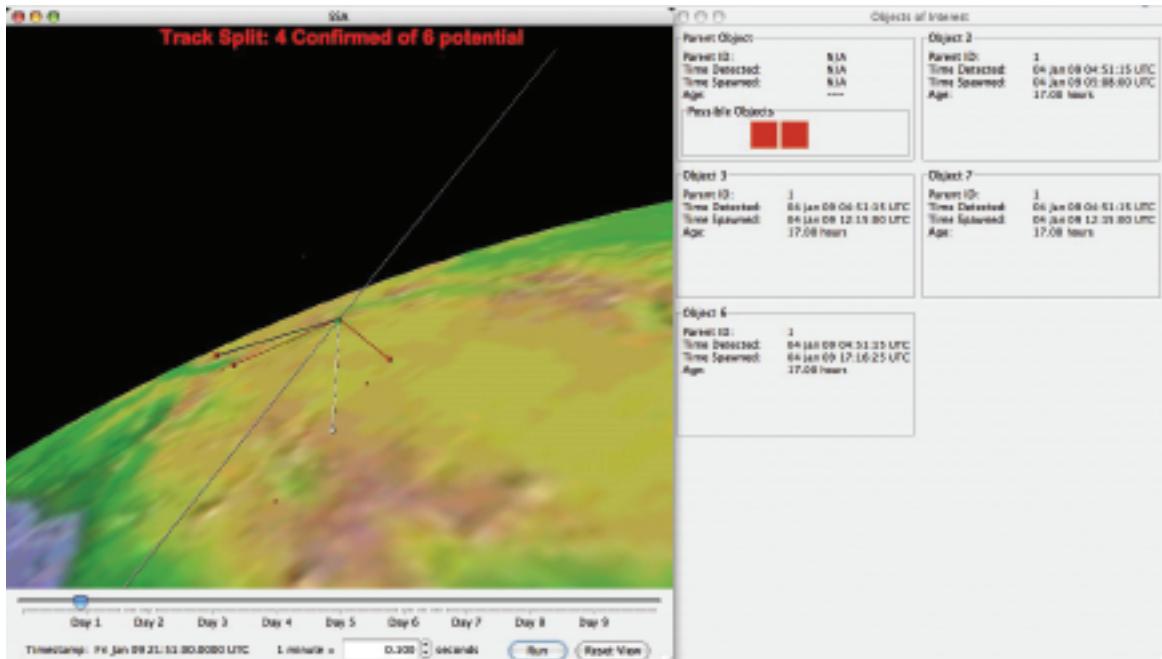


Figure 1. Screen snap of Raytheon Microsat information fusion demonstration. At this time in the simulation, four Microsats of the six have been positively identified, and two more are probables. The figure shows the parent deployment vehicle, the Microsats, and the current estimates of the positions relative to the parent (ball and stick figures).

The goal of the envisioned data fusion system is to provide the "right" SSA information when needed:

- ▶ To expand knowledge of the location, character, and behavior of objects in Earth orbit or near Earth trajectories
- ▶ To generate impact assessments and decision prompts in real time
- ▶ To provide actionable assessments of dynamic activity/intentions
- ▶ To provide multiple levels of abstraction to decision and operational processes at each level in the chain from the individual sensors through the command and control
- ▶ To provide multi-INT assessments while recognizing the need for operating within a multi level security environment
- ▶ To support improved tasking and cross-cueing of DoD and intelligence assets in a net-centric environment
- ▶ To minimize human analyst and operator dependence for basic functions

The planned effort will use simulations and demonstrations to identify feasibility, capabilities, and requirements for application of the technologies in the net-centric SSA environment. The first step has been to rehost a Raytheon-developed microsat demonstration on the MHPCC *Hoku* system, which was completed in 1Q CY06. This demonstration tests a few of the key capabilities that are intended to be part of an intelligent agent based system:

- ▶ Multiple Hypothesis Track
- ▶ Measurement association
- ▶ Multiple object evaluation

The scenario used for the demonstration was a simulated deployment of six microsats from a parent object in a sun synchronous orbit. High priority track from Shemya, Eglin, and three S-Band sensors, was modeled using noise and resolution limitations. The sensor resolution limitations, coupled with the proximity (~125-400 m) of the objects to each other and the parent, provided a good initial test of the capabilities. Figure 1 shows a screen snap of the demonstration part way through as confirmed and possible new objects are identified in the deployment scenario. The simulation correctly develops tracks of objects and conditions for spin off of object agents within 34 hours of the deployment event *without human intervention*.

This successful initial test demonstrates the feasibility of improving SSA using some of the enhanced technologies that have been identified for the information fusion capability. The next efforts will expand the simulations to include the full agent architecture, as well as add event detection and multiple satellite interaction assessment capabilities.

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Resources: Cray XD-1, *Hoku* at MHPCC

Sponsorship: MHPCC

Acknowledgements: ESC (Raul Diaz, 850 ELSG/NSA)

High Fidelity Circular Array Simulation

Donald J. Fabozzi, Charles Franz, Bob Dant

Traditional airborne surveillance simulations have been limited in either spatial or temporal fidelity due to the expensive software and hardware requirements. Recently, advances have been made which provide the rapid deployment of high-fidelity scenarios through a modular visual programming environment on a High Performance Computer (HPC). Based on the visual programming environment Khoros, the Radar Analysis Simulation Tool (RAST-K) is a flexible simulation for quickly prototyping airborne surveillance configurations containing radar system features, point targets, and USGS maps. Additionally, RAST-K has been ported to a Linux cluster to simulate realistic flight scenarios. As flight scenarios involve parametric changes between Coherent Processing Intervals (CPIs), additional interfaces were developed to control platform, target, and environmental attributes to correctly model realistic airborne radar surveillance. To improve processing efficiency on the HPC, interfaces were developed which partition the simulation, signal processing, and visualization across processors.

Methodology: The methodology involved:

- 1) The establishment of a high-fidelity single CPI pulse-to-pulse simulation capability. Radar Analysis Simulation Tool for Khoros (RAST-K) software was selected to meet this requirement, as shown in Figure 2.
 - 2) The development of a capability that would replicate single CPI's and apply real-world, time-dependant principals.
 - 3) The development of the execution and visualization interfaces for the multi-CPI system to run on a High Performance Computer (HPC).

Research Objectives: The primary objective of this research effort is to establish a simulation and modeling testbed to support the UESA radar system at the Makaha Ridge Test Facility, Kauai, HI, shown in Figure 1. This testbed was established to model the high-fidelity single CPI (pulse-to-pulse) radar returns and investigate multi-CPI platform deployment characteristics.



Figure 1. UHF Electronically Scanned Array (UESA) radar system located at the Pacific Missile Range Facility (PMRF), Hawaii.

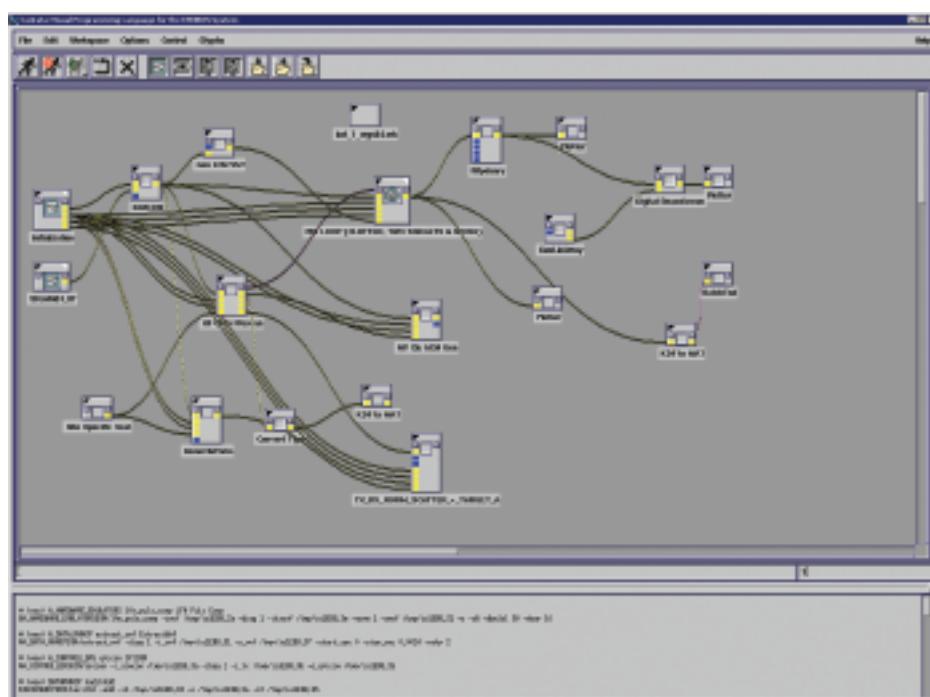


Figure 2. UESA single CPI pulse-to-pulse simulation.

Results: AFRL/MHPCC fielded a distributed computing system consisting of a Linux application, a file server, and a 16-node cluster to support the simulation environment.

The developed system generates multiple CPI radar returns, each representing a realistic radar return, in near real time. The system has been tested in the Socorro, NM, Makaha Ridge, HI, and China Lake, CA regions with various excursion types at each location. A typical use is to investigate the degree of shadowing and reflectivity from a position in space, as pictured in Figure 3. The left-hand figure shows the platform positioned at the center of the picture emanating due south over the San Gabriel Mountains in California. The right-hand picture in Figure 3 shows the labeled GIS terrain map. As shown, the ability to quickly associate surveillance radar returns with digital maps provides the analyst with advanced decision making tools.

The RAST-K system is a considerable time saver for multi-CPI simulation in that the generation of 162 beam positions, which normally takes about 45 minutes on a single processor desktop, now takes about 4 minutes. Further, this data partitioning model is highly efficient at nearly 70-90 %, taking into account the node-scheduler availability.

Significance: The U.S. Navy is currently investigating a host of radar surveillance concepts that resolve thousands of targets, while maintaining a scanning mode. As such, the development of actual, as well as simulated, systems is providing the leading capabilities to meeting those goals. The RAST-K simulation system at MHPCC is currently unique in that it provides both high-fidelity pulse returns, as well as multi-CPI realistic radar returns. The impact of this simulation capability to DoD surveillance research and development efforts can potentially be very significant.

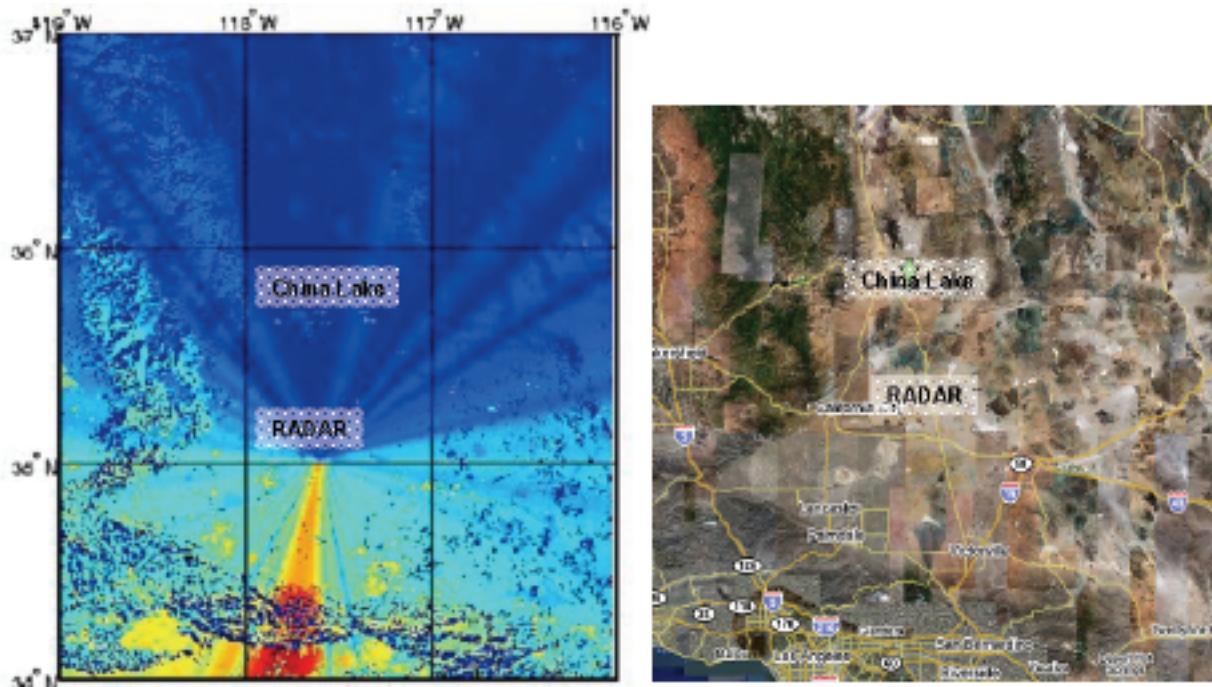


Figure 3. UESA "Searchlight" beam illuminating the China Lake, California region, along with accompanying map. This was modeled with the RAST-K system at MHPCC.

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Resources: 16 node IBM Linux Cluster at MHPCC

Sponsorship: Office of Naval Research

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Managing the Enterprise of the Nation's Premier Naval Cargo Tracking System: Unified Management Toolkit v1.0

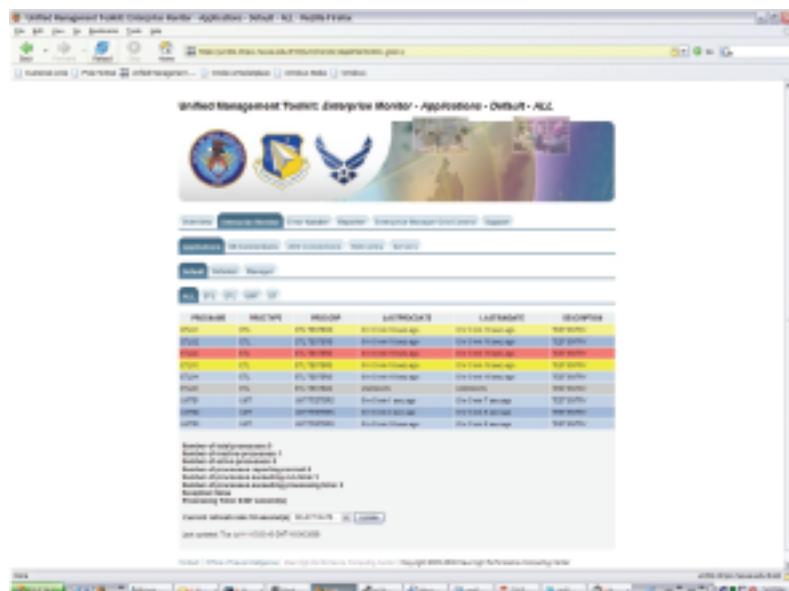
Ron Viloria

The MHPCC team was tasked to develop a tool that would monitor and manage various aspects of ONI's (Office of Naval Intelligence) infrastructure in a centralized and coherent manner. Various implementations were considered with the final result being a lightweight, easy to deploy, and easy to use web application capable of running in any servlet container. By utilizing the latest techniques for Java/Perl and leveraging the high performance computing assets at MHPCC, application monitoring and management were streamlined providing a better, more scalable, minimal maintenance enterprise solution. MHPCC's *Tempest* (IBM SP3/SP4) and *Huinalu* (IBM Linux Supercluster) computing resources were utilized for development and testing of the Unified Management Toolkit server and Java/Perl client application programming interfaces (API).

Research Objectives: The Office of Naval Intelligence uses a variety of tools to manage the nation's premier cargo tracking system. The MHPCC undertook the task of unifying the functionality of enterprise management with the primary objectives of making production operations easier to manage, and to facilitate the identification of potential problems before they escalate into major ones. Using advanced technologies and techniques, MHPCC Application Engineers have developed an architecture that not only facilitates the identification of problems in the data processing flow, but is scalable, modularized, and maintainable as well. The effort utilized MHPCC's *Tempest* and *Huinalu* computing resources for implementation and testing. The *Tempest* resource consisted of one IBM Power4 node containing 32 processors and 32 GB of RAM, and the *Huinalu* resources consisted of 32 nodes each containing dual Intel 933 Mhz processors and 1 GB of RAM. Dell servers are also being utilized which consisted of Dual 3 Ghz Intel CPUs with 2 GB of RAM.

Methodology: The primary goal of the Unified Management Toolkit (UMT) is to make the job of an operator in a production environment easier. Each operator has their various methods of monitoring applications, connections, amount of data processing, etc. Operators use SQL tools, OS tools, watch log files, monitor scripts, and other one shot techniques to get the job done. The UMT simply consists of a server component web application, as well as Java/Perl Client application programming interfaces (API). The server component attempts to mimic the functionality of the various operator tools using Groovy, a higher level Java based scripting language, and serve them from a single web application. In UMT v1.0, the main module that was developed was the Applications Monitoring Module, which monitors the health or progress of any Java/Perl client. A preexisting client app can be monitored by the UMT by simply adding a single environment variable for the path to client api libraries, one line in the startup scripts, one line of source code to instantiate the UMT Client object, and a last line to issue the "checkin" calls. At the moment the client API updates a database for the UMT server component, which in turn calculates at regular intervals whether specific thresholds have been exceeded.

Significance: Multiple teams help manage ONI's enterprise. For the Data Translation and Loading (DTL) operations team at ONI alone, potentially 50+ processes can be monitored simultaneously through a single remote user interface that is secured with HTTPS and basic authentication. This translates into time savings for the operator and minimizes downtime when problems are detected easily and early. Due to the use of an agile and dynamic Java scripting language, the UMT infrastructure allows easy extensibility options and quicker turn around time for new features and enhancements.



As for the UMT client API, any future updates/upgrades will no longer impact deployment due to dynamic loading of libraries/modules at runtime. Changing the API implementation from using a database connection to a web service for example would only need an API upgrade, via dragging/dropping of new api libraries, with no impact to client applications.

Future Work: The initial release contained only the Applications Monitoring module. There will be more modules in the near future regarding the monitoring of database connections, web links, servers, and JMS connections. There will also be a reporting module, error handling, interactive SQL, and starting/stopping of servers. Architectural enhancements will also include the Grails Web Framework integration, Jasper Reports integration, embedded persistence, and interfacing with Oracle's Heavy Duty Enterprise Manager Grid Control product.

Monitoring Without UMT v1.0

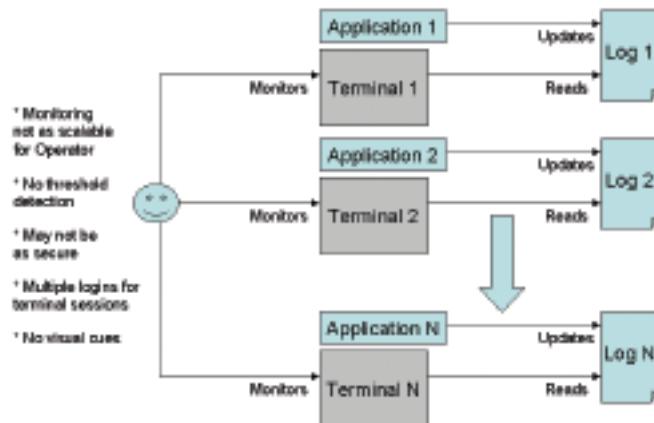


Figure 2. Monitoring without UMT v1.0

Monitoring With UMT v1.0

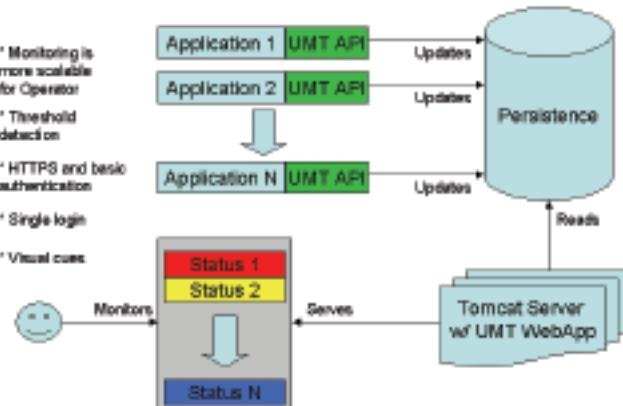


Figure 3. Monitoring with UMT v1.0

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Resources: *Tempest* (IBM SP3/SP4), *Huinalu* (IBM Linux Supercluster), and UMT nodes (DELL Servers) at MHPCC

Sponsorship: Office of Naval Intelligence (ONI)

Acknowledgement: The author would like to acknowledge the MHPCC Roving Island team for providing the development infrastructure, the Office of Naval Intelligence for the tasking, and FreightDesk Technologies for their continued support.

Theater UnderSea Warfare (TUSW)

Michael Berning, Bob Dant, Carl Holmberg, David Solomon, Thomas Meyer

The Air Force Research Laboratory Maui High Performance Computing Center (AFRL/MHPCC) maintains a Linux cluster for dedicated Theater UnderSea Warfare (TUSW) use. This TUSW cluster provides high performance computing resources to TUSW users for computationally intensive undersea warfare (USW) simulations. The cluster is designed to be easily expandable and has secure connectivity (via SIPRNet) to Pearl Harbor (Commander Task Force-12, CTF-12), allowing 'remote' access to the AFRL/MHPCC computing resources on Maui for computationally intensive acoustic modeling. TUSW software, such as STAPLE (Scalable Tactical Acoustic Propagation Loss Engine) and AAT (Asset Allocation Tool) has been integrated to demonstrate "reachback" high performance computing during fleet exercises. Ocean environmental data (Figure 1) have been provided via a connection to the Virtual Natural Environment Net Centric Services (VNE-NCS) database. TUSW resources have been successfully demonstrated during Silent Fury (SF), RIMPAC, and Undersea Dominance (UD) exercises in the Pacific Theater, as well as during several "Local" CTF-12 (Pearl Harbor, Hawaii) training activities.

Methodology: Research efforts for the TUSW program (Year 4) at AFRL/MHPCC focused on: 1) Supporting 'real world' Naval exercises (e.g., Silent Fury, RIMPAC, Undersea Dominance), 2) Installing and testing upgrades to STAPLE, AAT, and Grid Manager software on the TUSW cluster, 3) Providing secure connectivity (via SIPRNet) to CTF-12 (Pearl Harbor, Hawaii), CTF-74 (Yokosuka, Japan), and the Tactical Support Center (TSC) at Marine Corp Base Hawaii (MCBH, Oahu), 4) Developing the TMS capability to distribute and manage TUSW applications on the TUSW cluster, and 5) Providing upgrades, patches, and security enhancements to the TUSW cluster operating system (OS), to ensure an efficient, reliable, and secure operating environment for TUSW users.

Research Objectives: TUSW program objectives for Year 4 activities at AFRL/MHPCC include: 1) Integration of automated Modular Ocean Data Assimilation System (MODAS) field updates into MHPCC TUSW cluster for use in real-time exercises, 2) Creating a connection to MODAS data via the Virtual Natural Environment Net Centric Services (VNE-NCS), 3) Completion of the implementation and documentation of the TUSW Manager/Scheduler (TMS) system, 4) Providing reliable shore-based high performance computing power by porting operational USW databases and executing computationally intensive acoustic models, and 5) Supporting the testing and evaluation of the TUSW system during Naval exercises.

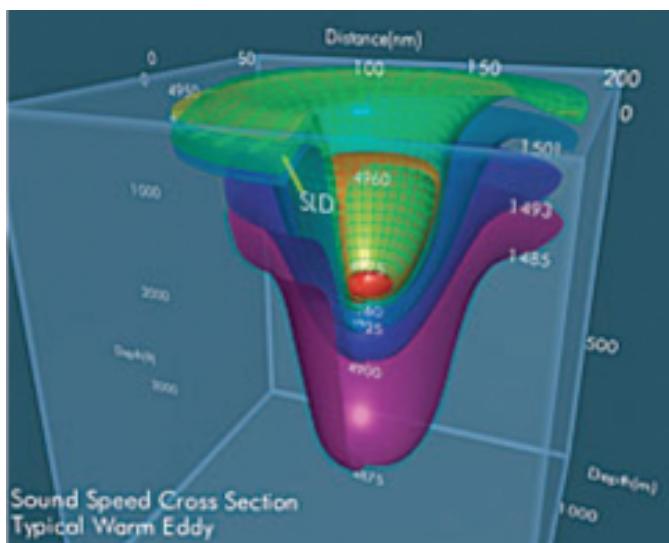


Figure 1. Display of Modular Ocean Data Assimilation System (MODAS) generated speed-of-sound distribution for a typical warm eddy.

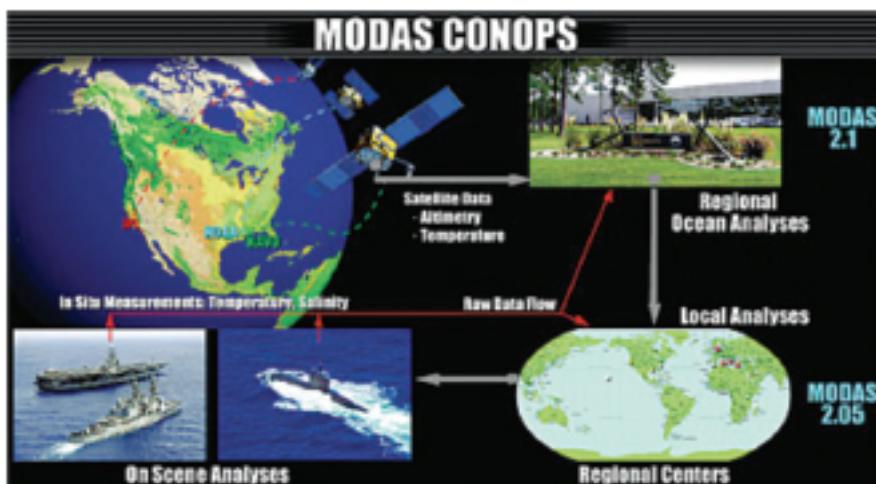


Figure 2. Modular Ocean Data Assimilation (MODAS) Concepts of Operation.

AFRL/MHPCC successfully integrated a set of software tools, including the Scalable Tactical Acoustic Propagation Loss Engine (STAPLE) to calculate sound transmission losses through the ocean, and access to the VNE-VCS to enable daily updates to STAPLE's environmental data provided by MODAS (Figure 2).

Results: In Year 4 of the TUSW program, AFRL/MHPCC completed implementation of a TUSW Manager/Scheduler (TMS) shown in Figure 3. TMS was designed to translate general user requests into TUSW application specific requests, which are then launched by TMS in a manner, which facilitates efficient utilization of the TUSW cluster. The TMS was designed to support high-volume, short-duration jobs demanded by TUSW applications, and to manage and schedule the execution of the jobs on the TUSW cluster in an optimal and efficient manner. The TMS also integrated knowledge of application resource demands and database bathymetry synchronization, so as to provide a robust and data-centric computing environment. The TMS was built with Java technology for portability and its architecture is extensible such that it can support many other cluster-based applications beyond TUSW. A detailed TMS Architecture document was written by AFRL/MHPCC, such that the technology can be reused on future ONR efforts.

The advantages of using TMS are as follows:

- o Client developers do not have to code to a specific application's interface
- o Client developers are shielded from changes to an application's interface
- o Client developers can focus on a specific application's data and its corresponding problem domain issues, and not the invocation mechanisms necessary to exercise the relevant application
- o Client development organizations do not need an account on MHPCC's development cluster to work with an installed application. Note: The overhead of maintaining access, not to mention security issues, can become significantly burdensome for all concerned parties using the current system
- o Client developers do not need to have expertise in high-performance cluster computing
- o Encapsulates cluster functionality and features to simplify the client application
- o Incorporates high-performance computing cluster expertise in order maximize cluster efficiency
- o Monitors both the cluster and participating applications, thus resulting in higher reliability and robustness
- o Promotes system scalability, which is independent of the number of clients and applications
- o Schedules applications across the cluster, which maximizes total throughput for all, or can be "tuned" to give higher priority to various applications

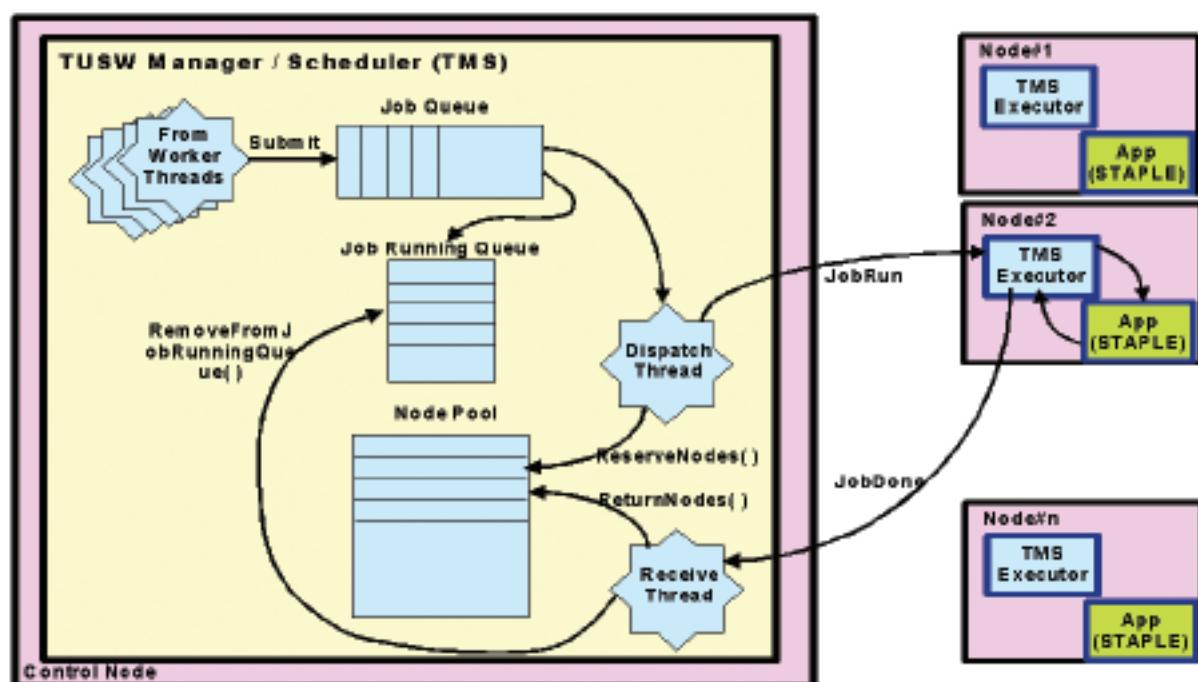


Figure 3. TUSW Manager Scheduler (TMS).

Future TUSW developmental efforts will include additional testing of the high performance computation 'reach back' concept during fleet exercises, enhancements to the TUSW Manager/Scheduler, performance benchmarking, and installation of enhanced/upgraded software models and tools.

AFRL/MHPCC Visualization efforts in Year 4 of the TUSW program included the development of a multi-platform interactive software application for viewing graphical representations of geo-referenced USW data within a three-dimensional geo-spatial environment (Figure 4). Built into an interactive viewer were tools for defining and zooming to a geographic Area of Interest (AOI), using USW contacts and targets having Naval Tactical Data System (NTDS) symbology and models. Terrain and bathymetric data were converted into geometries having multiple levels of detail and draped with geo-referenced aerial imagery. These databases represented both historical and concurrent measurements, such as bathymetry, bottom loss, sound velocity, ocean temperature, and potentially any of the multitudes of other available measurements.

Significance: The Office of Naval Research (ONR) has promoted research and development of innovations that will provide technology-based options for future U.S. Navy and Marine Corps capabilities. The primary goal for TUSW is to implement a 'leap ahead' command center for the future, for knowledge development, environmental analysis, and resource allocation for undersea warfare. These new technologies will be transitioned to the acquisition community for eventual integration into the Navy's operational USW fleet and the Marine Corp's warfighting inventory.

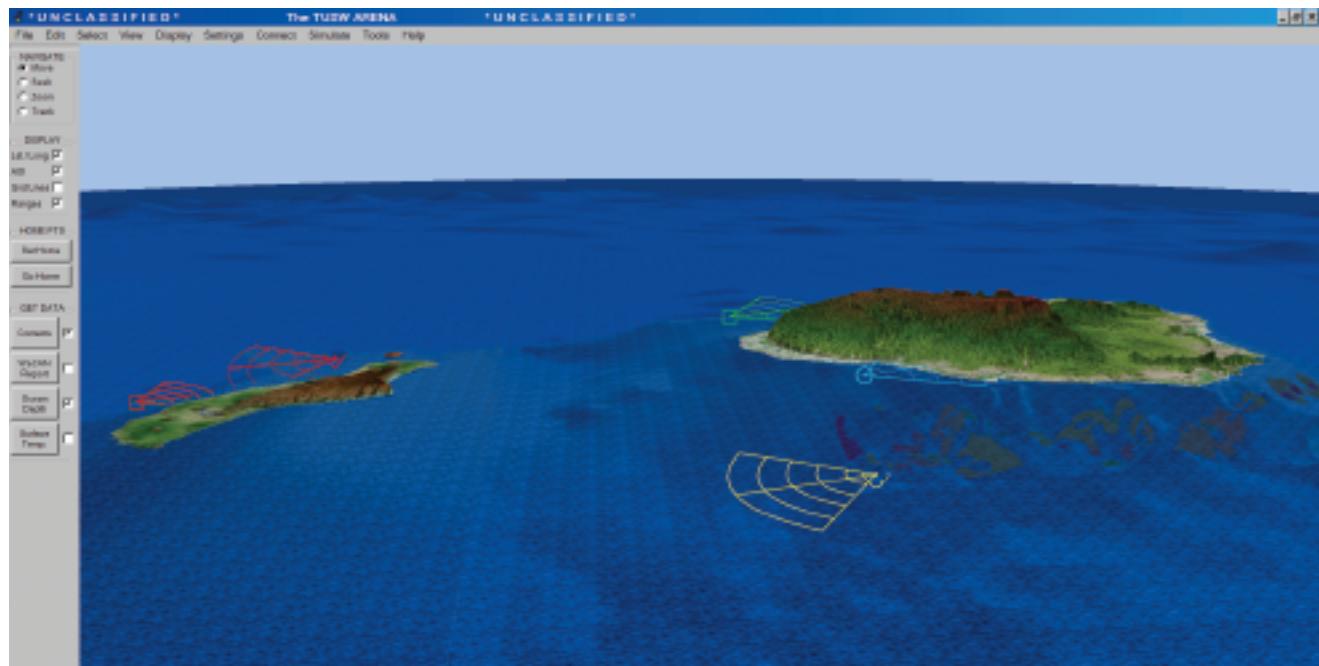


Figure 4. 3D geo-spatial data environments, fused with interactive manipulation of contacts displayed with NTDS (Naval Tactical Data Systems) symbology provide better visualizations of warfare scenarios.

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Acknowledgement: The authors wish to thank Mr. Clifton Ching at the Naval Undersea Warfare Center (NUWC) and the Office of Naval Research (ONR) for their support of this research project.

Electron-Impact Excitation of n=3 States of Hydrogen

Igor Bray and Philip Bartlett

In this project we consider electron-impact excitation of atomic hydrogen n=3 states at energies below the n=4 excitation threshold. We find that incorporation of the target continuum is vital in order to obtain accurate n=3 excitation results.

Background: Atomic hydrogen is the most abundant species in the universe. It is observed via the detection of photons that arise upon deexcitation after typically electron-impact excitation. To fully understand the observations it is necessary to know the electron-impact excitation cross sections for electron energies that are typical in astrophysical plasmas. The energy range considered here is between the n=3 and n=4 excitation thresholds, where there is a rich resonance structure.

We use two methods for calculating e-H cross sections, denoted by PECS¹ and CCC-L.² Both of these take into account the virtual excitation of the H continuum, unlike the R-matrix.³ In the figure we present several calculations and find generally good agreement amongst all except R-matrix and the J-matrix⁴ results at small energies. The variation with the R-matrix is expected, but we suspect that the J-matrix calculations had some numerical problems at the lower energies. We are confident that the new calculations have established benchmark results that may be used with confidence in astrophysical models.

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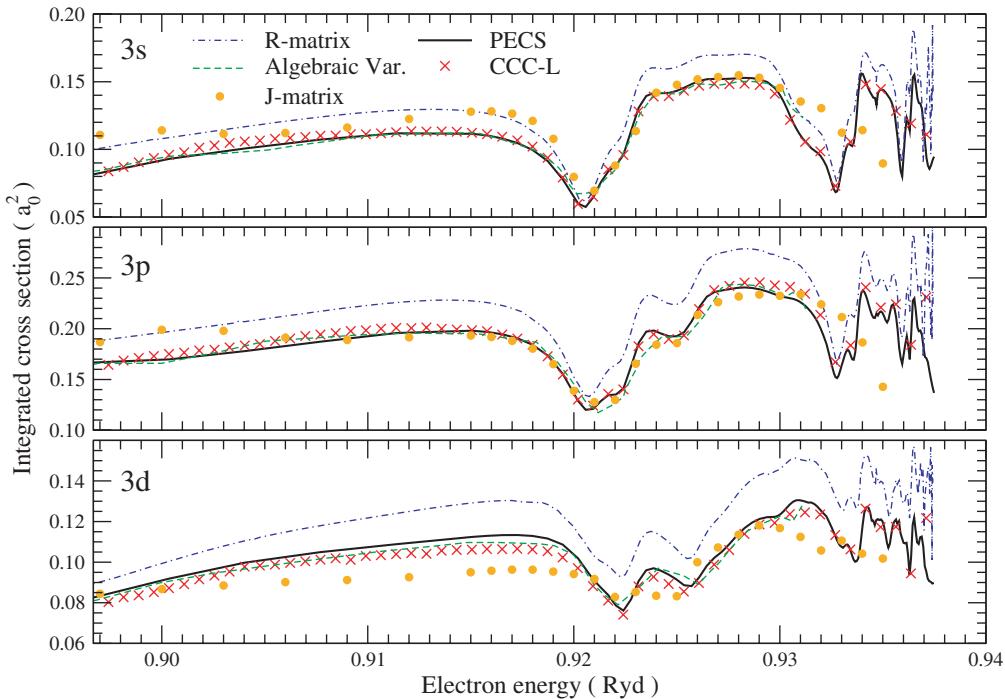


Figure 1. Cross sections for electron-impact excitation of the n=3 states

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The Unmanned Systems Test Bed

Brian Kruse, Jeff Beck, Matthew Burnham, Richard Cook, Jonathan Dann,
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The primary objective of the Unmanned Systems Test Bed (USTB) program is to develop new training, test, and evaluation concepts and capabilities for unmanned systems and to conduct a series of demonstrations. The Central Test & Evaluation Investment Program (CTEIP) has teamed up with the U.S. Army Corps of Engineers Topographic Engineering Center (TEC) to examine how to augment DOD Test and Training Range resources with new capabilities in support of unmanned systems. DOT&E is particularly interested in finding effective uses for advanced visualization software and high-performance computing assets to support the needs of unmanned systems. Related goals include leveraging the Test and Training Enabling Architecture (TENA) for cross-range and cross-facility data collaboration, and running TENA in a parallel processing environment. Accordingly, the initial stages of the USTB program focuses on applying advanced visualization and high-performance computing technologies to support the needs of unmanned systems users.

Research Objectives: The U.S. military services are evolving their warfighting systems with an increasing emphasis on unmanned vehicles. Although the trend began with intelligence, surveillance, and reconnaissance (ISR) assets (e.g., Predator and Global Hawk), it is evolving to include combat vehicles (e.g., Armed Predator and Air Force and Navy Unmanned Combat Air Vehicle) and utility platforms (Quick Delivery ACTD). The evolving network-centric warfare concepts of all services rely increasingly on unmanned platforms. The associated command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems are adopting interoperability standards that include unmanned vehicle mission planning, control, and data dissemination. Recent DOD R&D efforts reflect emphasis toward all types of unmanned systems: air, ground, sea-surface, and underwater platforms. Transformational programs such as the Army's Future Combat System and Navy's SSGN point to future capabilities dependent on unmanned systems. Consequently, future operations may involve the employment of unmanned vehicles at all echelons of command and interoperability and integration of mixed unmanned vehicle types. It is increasingly important for the individual services and the Joint Commands to develop concepts and facilities for training exercises, CONOPS development, and system T&E which include single and combined unmanned vehicle operations. Although much of this will be accomplished in distributed exercises involving computer-generated virtual environments and simulation, it must also include live exercise components on a test range that provides for air, ground, sea-surface, and underwater unmanned vehicle operations.

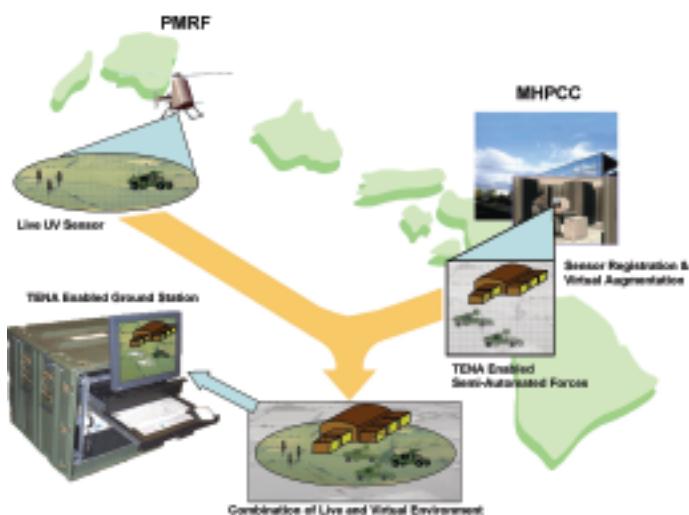


Figure 1. USTB GENERAL Concept.

The USTB Concept

The key concepts behind this test bed are as follows:

1. Capture three-dimensional terrain data of the test range.
2. Utilize the terrain data to render a realistic view of the environment unmanned system is operating in and simulate a virtual flythrough in real time and synchronized with the movement of the unmanned system.
3. Integrate any sensor data (e.g., video camera) from the unmanned system with the synthetic scenery. Project the live video like a spotlight on the rendered synthetic scenery providing a window to the real world displaying any movement, change, or action in the observed area.
4. Integrate simulated entities (buildings, troops, vehicles, etc.) with the real environment to support an augmented environment that mixes real and simulated entities to support various test, evaluation, and training scenarios.
5. Integrate this advanced visualization and simulation system with standard battlespace management software.

Figure 1 illustrates the USTB concept showing how the rendered synthetic scenery, live video stream captured by the unmanned system sensor, and real and simulated battlespace entities are combined to create a unified battlespace environment.

The USTB System Components

Figure 2 shows a simplified view of the USTB system architecture that supports the general concept depicted in Figure 1. The real video stream and the telemetry information are sent down from the unmanned system to the ground station located either at the Remote Maui Experiment (RME) site or the Pacific Missile Range Facility (PMRF) located on Kauai. From the ground station the video and the telemetry data are sent to the Maui High-Performance Computing Center (MHPCC) over the Defense Research Network (DREN) via an OC-12 (622 Mbits/sec) fiber link. Processed information is sent back from MHPCC to RME/PMRF over the same data link to be displayed by the ground station.

1. Terrain data capture: Three-dimensional terrain datasets are captured by a LIDAR¹ system and combined with existing elevation and imagery datasets available from the USGS and other commercial sources yielding high-resolution terrain data with highly accurate geospatial coordinate information.
2. Terrain database management and scene generation software: Scene generation software interactively renders the terrain data, video stream, and simulated entities from the appropriate viewpoint. Currently Terrex SOFViz is utilized as the underlying terrain database management and scene generation software library.
3. Video projection and alignment software: This software component receives the live video stream from the camera on the unmanned system, processes the video, and prepares it to be integrated with the synthetic scenery.
4. Battlespace management software: This software is utilized to manage real and simulated entities. Its user interface is a two-dimensional-map-like view that depicts the entities (troops, buildings, ground vehicles, aircraft, ships, etc.) as icons. At the ground station, the battlespace management software output is displayed separately and side-by-side with the scene generation software output (merged video and synthetic scenery). Currently Joint Semi-Automated Forces (JSAF) software is utilized as the battlespace management software.
5. Test & Training Enabling Architecture (TENA) Middleware: All the software components are integrated via the TENA middleware. All data (video, telemetry data, etc.) are passed among the software system components as TENA data objects.

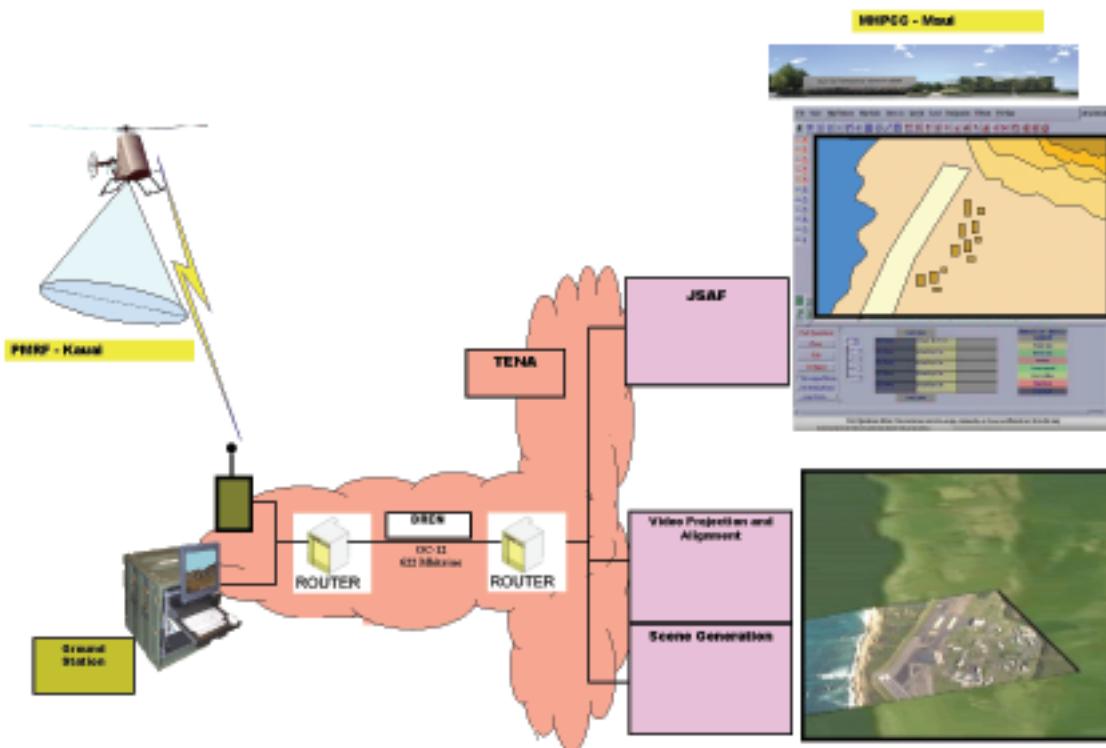


Figure 2. USTB System Architecture.

Reference Note:

¹Light Detection and Ranging uses the same principle as RADAR. The LIDAR instrument transmits light out to a target. The transmitted light is reflected and scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the LIDAR is used to determine the range to the target.

Methodology:

Video Projection: The goal is to integrate and render the video stream and the synthetic scenery in real time, and to make the video appear as part of the synthetic scenery. The term video projection refers to utilizing a projection algorithm to map the video onto the three-dimensional synthetic scene. Simplest projection may involve matching the four corners of the video frame with pixel locations on the synthetic scenery by utilizing video and unmanned system telemetry and texture mapping the video frame onto this area.

Video and Unmanned System Telemetry: The telemetry data feed from the unmanned system is utilized to perform the video projection. This includes the sensor telemetry (azimuth angle, zoom factor, etc.) and the unmanned system telemetry (GPS location, yaw, pitch, etc.). In general, a three-dimensional object (in this case the video camera) has six degrees of freedom: three coordinates x, y, and z and some kind of rotation, for example, three angles alpha, theta and gamma, describing its position and orientation relative to a reference frame. In our case, the relative position of the camera with respect to the unmanned system will be provided as the sensor telemetry, and the position of the unmanned system relative to the earth will be provided as the unmanned system telemetry. This will be sufficient to calculate the position and orientation of the camera relative to the earth.

Video Alignment: The terms video alignment, video image registration, and video registration are often used interchangeably in the industry, and they refer to detecting and matching (i.e., aligning or registering) the image information from a video with a previously captured image of the same scenery. This usually involves image processing to detect shapes, edges, and features on the video frame and the previously captured image, matching the features from both, and aligning them. In our case, the video equivalent is the live sensor data from the unmanned systems and the previously captured image equivalent is the LIDAR data.

This can yield the following benefits:

1. Better alignment of the video and the synthetic scenery can be achieved by image processing the video frame and the synthetic scenery and finding matching features. If, for example, edges, features, or objects in the video can be detected and matched with the edges, features, or objects in the synthetic image sequence, a much better positional alignment between the two can be achieved.
2. Since the positional accuracy of the LIDAR terrain data is significantly better than the position information of the GPS on the unmanned system, better geolocation information for the objects observed in the video can be calculated by utilizing the geocoordinate information from the synthesized background. This can be used to determine the absolute location of the stationary objects and features (buildings, roads, etc.) in the video and to determine the relative location of the transient and moving objects (troops, vehicles, etc.) in the video relative to the permanent and stationary objects.

The primary goal is to align and register observed video frames in real time to rendered views of the scene derived from the LIDAR terrain dataset. A secondary goal is to obtain accurate coordinate information for the permanent and transient objects, features, and entities observed in the video by utilizing the LIDAR terrain dataset that has been precisely aligned to geocoordinates.

Video Synchronization: The projected video and the synthetic scenery may have to be synchronized in the time domain also. The video stream and telemetry data are transferred as asynchronous data packets over a network. There are multiple delay components in the loop from the unmanned system to the high-performance computing resources and back to the ground station. These delays include multiple network delays and multiple hardware and software component delays. Due to these delays and the asynchronous nature of the network traffic, if uncompensated, the merged video and synthetic scene can be off by many seconds and by 100s or 1000s of frames. This may yield mismatches and artifacts that are not acceptable (e.g., the synthetic scenery and the video may depict significantly different viewing angles).

The main challenge is to accurately correlate the viewpoint for the synthesized scene and the actual sensor camera. Therefore, to achieve accurate synchronization between the synthesized image sequence and the video stream, the telemetry information (GPS data, camera angle, zoom factor, etc.) and the live video steam both have to be stamped by the same time clock. TENA data object architecture supports this need.

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Creating a Research and Development Space Object Catalog

Thomas Rippert, Michael Hruska, Bradley Hutchison

The current Space Surveillance Network is unprepared for the introduction of new technologies that will increase the observable objects by a full order of magnitude. This project will scale down the project to a self-contained lab research and development scale to leverage systems engineering techniques to develop and evaluate possible improvements and techniques that can then be applied to the operational space catalog.

Research Objectives: This research was intended to create a lab research and development catalog with the capability to create a space catalog similar to the one currently maintained by the Space Control Center (SCC) in Colorado. The creation of the space catalog would follow the Systems Engineering Management Process (SEMP) to design, create, test, and evaluate several courses of action that could then be considered for implementation into the current Space Catalog. This project will extend into a year-long thesis course.

Background: The current catalog of space objects was created in 1957 with the launch of Sputnik. The catalog's initial purpose was to warn against potential Russian satellite flyovers of military assets. As the number of objects in space grew so did the capabilities of the fledgling Space Surveillance Network (SSN). A constant increase in the number of satellites as well as manned spaceflight makes predicting potential conjunctions with debris an essential task. However the early network was limited by its resources: radar and optical telescopes with different primary missions, as well as limited computing resources. With the addition of dedicated sensors and high performance computers, the SSN has grown to meet the demands of tracking over 13,000 objects in orbit ranging from 10-30 cm in diameter; however the network is working at near capacity. Due to the ad-hoc growth of the SSN there are shortcomings in the network: bandwidth limitations prevent transmission of the most accurate tracking data to sensors; uncorrelated tracks (UCTs) are primarily correlated by hand by a handful of highly trained analysts; non-metric data is not incorporated in determining track assignment by objects. The SSN is about to be augmented with a new S-Band radar capable of resolving objects in the 2-10 cm diameter range. This creates a critical problem: a growth from 13,000 detected objects to 100,000 objects instantly. In its current state, the SSN is unable to handle that number of observations and objects.



Figure 1. Modified image from USSTRATCOM (<https://www.stratcom.mil>) representing each of the 22 sensors and command nodes in the Space Surveillance Network.

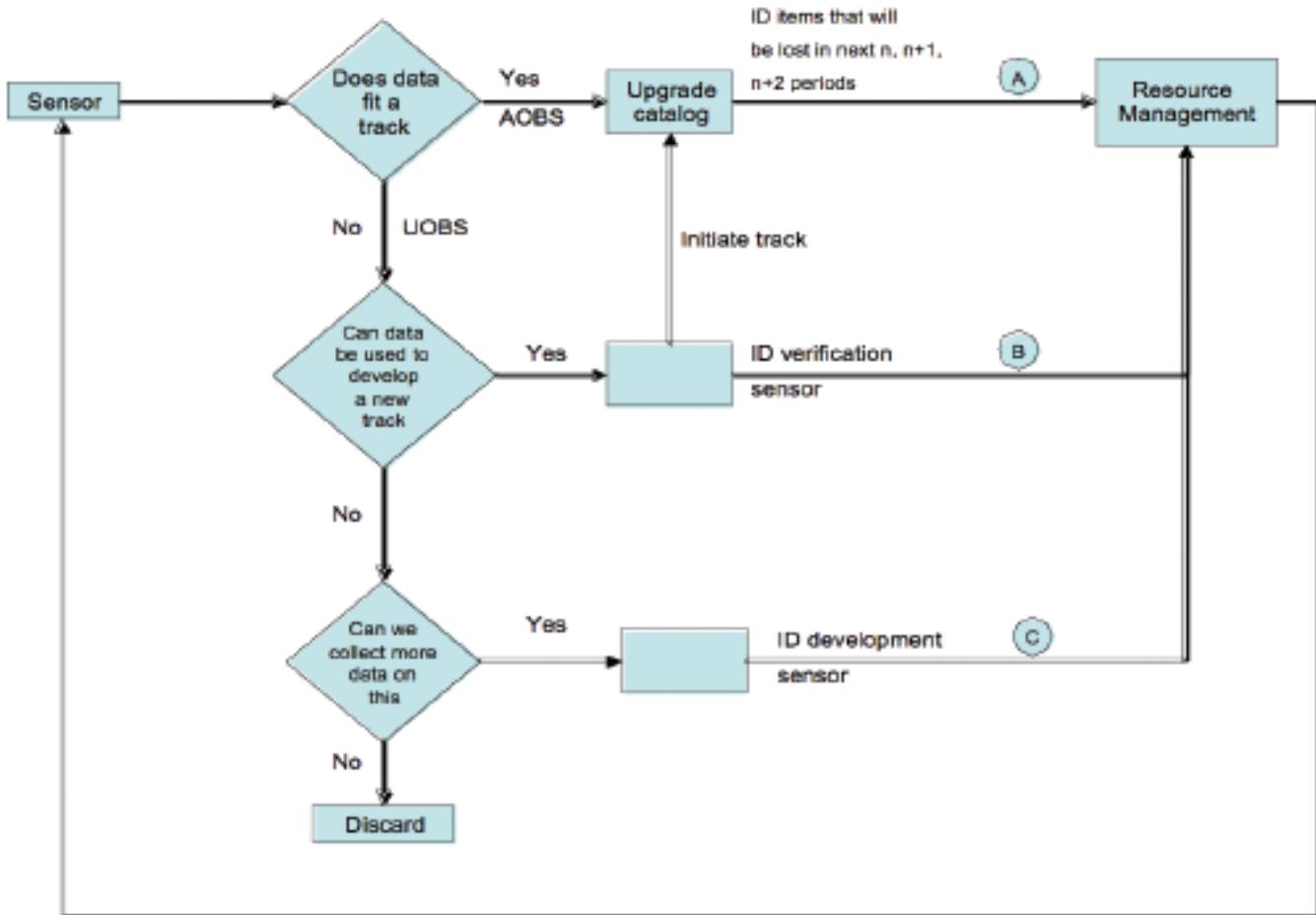


Figure 2. Functional flow diagram for cataloging all detected space objects to include uncorrelated tracks (UCTs).

Methodology: Using a systems engineering approach to this problem enabled us to simplify it into solvable parts. We analyzed the Space Surveillance Network as a system and looked at it by its components. After gaining an understanding of the functions and processes within the SSN we were able to make some important assumptions. We made the assumptions that we would have all of the information from the current space object catalog to include all functioning satellites so all future detected objects can be identified as debris and that it is neither necessary nor feasible to trace newly found UCTs to their launch with sufficient legal merit. Once we made these simplifying assumptions we determined the system's functions by speaking with the stakeholders and researching the SSN. Any alternative we are to generate must detect objects, associate detections, identify tracks, catalog tracks/objects, manage sensors, and manage computing resources. Figure 2 is the functional flow diagram we created as an algorithm for handling detections from any of the sensors in the SSN. It is a visual representation of the functions the system will be required to perform. In order to produce recommendations to change the current system, a method of evaluating each course of action must be implemented. We can evaluate any feasible alternative system by using a values hierarchy as seen in Figure 3. The values hierarchy is a pictorial representation of the stakeholder's qualitative values, including the fundamental objective, functions, objectives, and evaluation measures. Figure 3 does not show the evaluation measures in this brief. Once weights are established for each function we will be able to create utility curves for each evaluation measure and assign quantitative values to each feasible alternative. Rank ordering each generated alternative will allow us to recommend the best alternative to the decision maker.

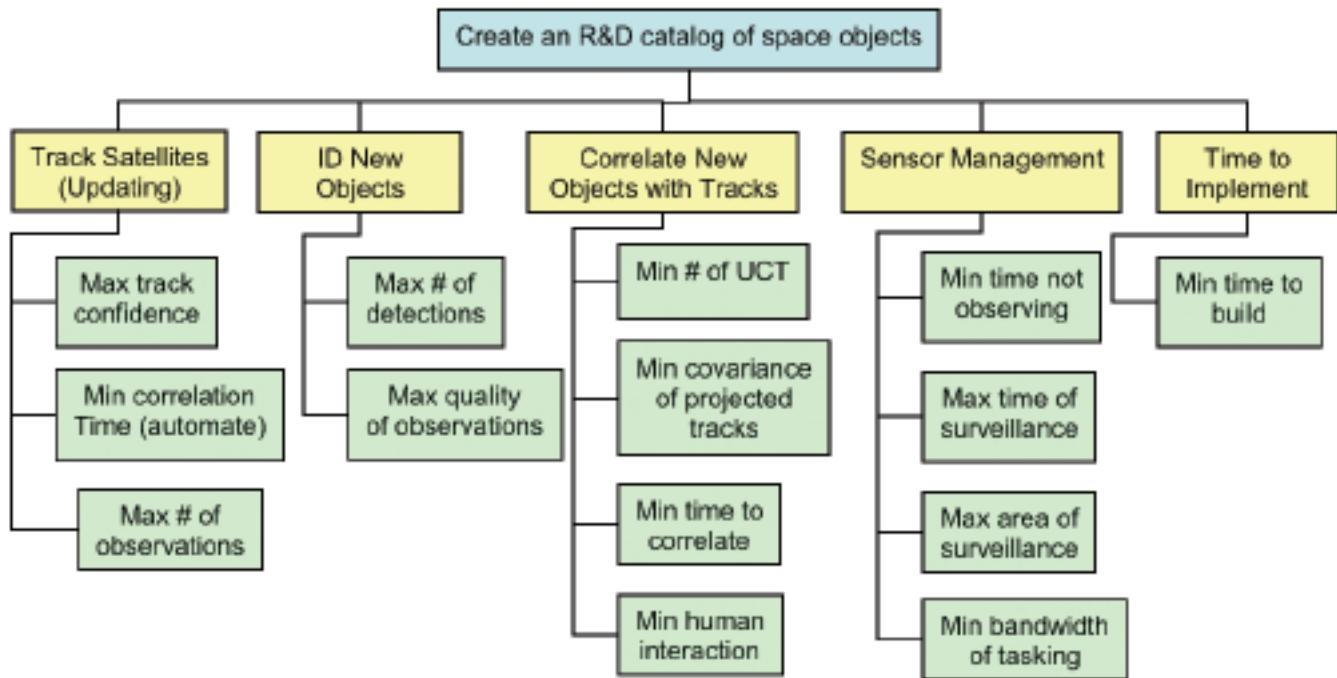


Figure 3. Top tier of the Values Hierarchy to be used in alternative scoring and evaluation.

Significance: The SEMP allows for thorough and unbiased development and evaluation of many potential courses of action. The best course of action can then be implemented on a small-scale lab catalog to verify real-world performance. The recommended course of action will benefit from the big-picture approach of the problem as a system. Additionally elements of the R&D catalog system can then be adapted and integrated into the SSN as desired or practical.

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