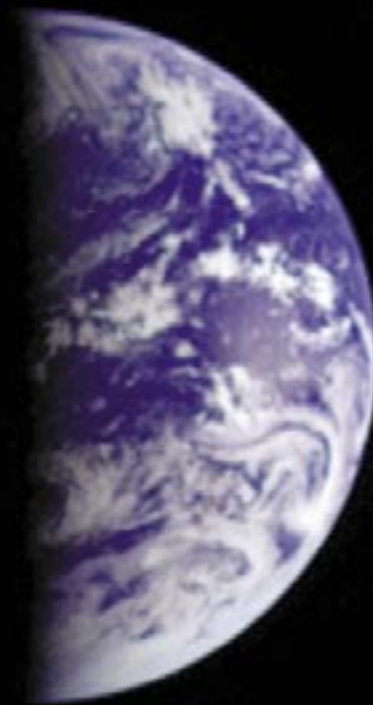


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# EEK005

A PUBLICATION OF THE ELECTRICAL ENGINEERING DEPARTMENT UNIVERSITY OF WASHINGTON  
ANNUAL RESEARCH REVIEW



A Look into the Future...

# EEK2005

ANNUAL RESEARCH REVIEW



**WELCOME**  
TO EEK2005:  
A PEEK INTO THE FUTURE

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*Past, Present, and Future* is the theme of our Department of Electrical Engineering's Centennial Celebration to be held in the spring of 2006. EEK2004 chronicled our first century of leadership in education, research, and service at UW, one of the world's premier academic institutions. This fifth edition of EEK previews the future, our second century. It extrapolates our landmark successes in pioneering many multi-disciplinary research areas, in closely coupling our research and teaching programs, in providing service to our communities and our profession, and in striving for diversity among our faculty, staff, and students. As technology drives us towards a one-world economy, our department is uniquely positioned to maintain world-class leadership in fulfilling our mission: *Excellence in Education Through Cutting Edge Research*.

As we begin our second century, our department will continue its rapid growth. This year, we plan to add three outstanding new faculty members, increase our annual external research funding above \$20 million per year, implement innovative curricula, and elevate the current top-twenty national rankings of our undergraduate and graduate Electrical Engineering programs.

Please plan to join us at our upcoming Centennial Celebration, as we welcome alumni, emeriti, friends and family to celebrate our past, present, and future with our students, staff, and faculty. Your support is vital to the continued success of our department as we look to the future.

**DAVID J. ALLSTOT**

Chair and Boeing-Egtvedt Professor  
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# NEPTUNE

## North East Pacific Time-integrated Undersea Networked Experiments

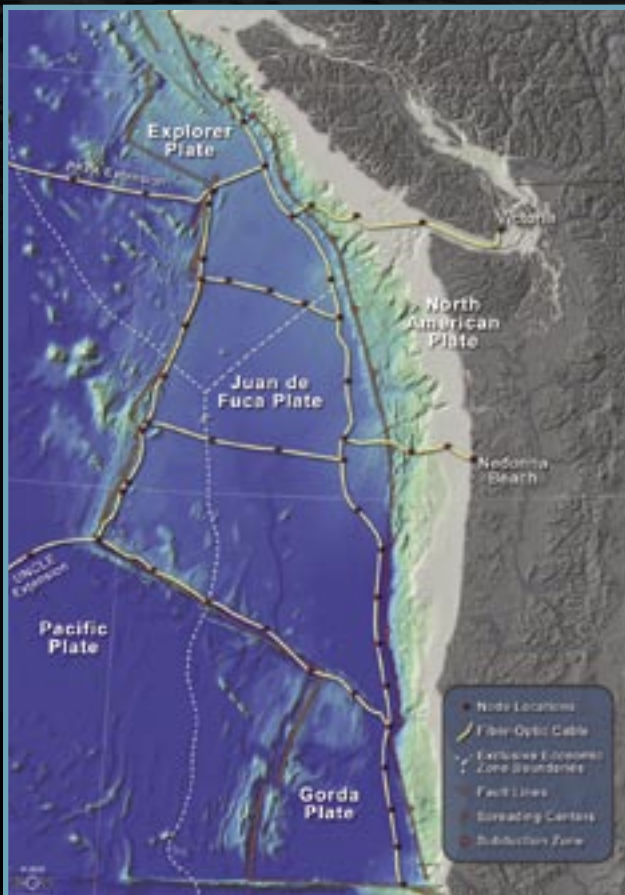
### NEXT GENERATION OCEANOGRAPHY

PROFESSORS JOHN R. DELANEY AND DEIRDRE R. MELDRUM

Historically, scientists have used ships and satellites for oceanic studies, but these approaches are limited. Ships can only be in one place at one time and satellites routinely survey only the upper portions of the water column, providing minimal information about processes at depth. Bad weather and cloud cover hampers the utility of both. Many portions of the oceans remain remote and hostile. Despite the limits of traditional approaches, the past four decades have fostered major discoveries in ocean and earth sciences. These include a newly discovered microbial biosphere in the rocks beneath the seafloor, life forms that thrive without sunlight under high pressure, high temperature, and low pH. Some estimate that this biosphere may rival that found at the ocean's sunlit surface, yet it was unknown until only a few years ago.

We now recognize that there are complex and extensive interactions among the atmosphere, the ocean, and the underlying seafloor. The global ocean may be viewed as the environmental "flywheel" of the planet in that it plays a major role in modulating long- and short-term climate change. Production of food on continents is directly linked to fluctuations within the oceans. As the world's population continues to increase, improving our ability to detect and forecast changes in oceanic processes may be the key to our survival.

The University of Washington is leading an international program that is developing and building NEPTUNE (North East Pacific Time-Series Undersea Networked Experiments), the world's first Regional Cabled Ocean Observatory. To be located off the coasts of Washington, Oregon, and British Columbia, NEPTUNE's 3,000-km network of fiber-optic/power cables will encircle and cross the Juan de Fuca tectonic plate in the northeast Pacific Ocean.



PROPOSED NEPTUNE NETWORK IN THE JUAN DE FUCA AREA.



AN ARTISTIC VIEW OF A SMALL PART OF THE NEPTUNE SYSTEM.

Ultimately, NEPTUNE cables will deliver up to 100 kW power to nearly 20 seafloor nodes (~5 kW each) and provide greater than 10 GB/sec bandwidth connectivity between land and thousands of sensor packages distributed across the seafloor, below the seafloor (in drill holes) or in the overlying water column. Entirely new approaches to oceanography will evolve based on the power-bandwidth availability in situ. The network will enable regional-scale, real-time, interactive observations and experiments with the ocean, the seafloor, and the biological communities that thrive in these environments. Hardwired to the Internet, NEPTUNE will provide scientists, students, educators, and the public with virtual access to remarkable parts of our planet, rarely visited by humans.

NEPTUNE will also provide a unique facility for improving our understanding of potential earthquake and tsunami hazards along our coastline. The ocean sciences are now in a transformational period leading to entirely new ways of accessing the oceans. Scientists, educators, decision makers, and the general public will soon reap the benefits of new approaches that provide interactive and continuous access to the oceans, the seafloor, and the sub seafloor.

The NEPTUNE infrastructure, and the science that it enables, offer tremendous opportunities for interdisciplinary research at UW and beyond, including robotics; telemanipulation; automation; controls; power; chemical, biological, and physical sensors; radar; acoustics; photonics; imaging; data compression; biomaterials and biofouling; self-assembly; computing and communication systems; network security; genomics and proteomics; ecogenomics; nanotechnology; microbiology; chemistry; ecology; and geology.

NEPTUNE will have profound ramifications for the manner in which scientists, engineers, and educators conduct their professional activities. However, the most far-reaching effects may well be a significant shift in public attitudes toward the oceans and the scientific process. The real-time data and high-speed communications inherent in remote observing systems will open entirely new avenues for the public to interact with the natural world. Public access to science will be transformed by enabling participation in the journey of scientific exploration and discovery. EK2005



HARDWIRED TO THE INTERNET, NEPTUNE WILL PROVIDE SCIENTISTS, STUDENTS, EDUCATORS, AND THE PUBLIC WITH VIRTUAL ACCESS TO REMARKABLE PARTS OF OUR PLANET, RARELY VISITED BY HUMANS.

## NEPTUNE POWER AND CYBERINFRASTRUCTURE

PROFESSORS MOHAMED A. EL-SHARKAWI AND JOHN R. DELANEY

We can install permanent observatories in outer space where energy is continuously available from the sun. But in the deep ocean, technology has not matured enough to provide the continuous electric energy needed for permanent observatories. Present technology allows the deployment of battery-operated instruments, or instruments powered from shore or ship. Carrying out scientific experiments on the ocean floor for an extended time will require a permanent source of energy. NEPTUNE will involve a network of about 3,000-km of fiber-optic/power cables covering an area of roughly 500 km by 1,000 km. Submarine cable will be used to serve two purposes; its hollow core will carry fiber optics for communications, and its copper sheath will be used to transmit electric power. The ocean provides the return path for the current, so only a single conductor cable is needed.

NEPTUNE's power system is significantly different from terrestrial power systems. It requires completely different switching, protection and control strategies. The network is composed of approximately 30-40 evenly distributed branching units (BU), which are like the switching yards in terrestrial systems. The branching circuits are cables connecting the BUs to "science nodes" on the seafloor. The length of the branching cables can be as long as 100 km. Each node provides standard power to scientific equipment, and Internet communication interfaces between this equipment and the shore. The communication network has a capacity of about 10 gigabits per second, and the power network will deliver 200 kW with a design life of 30 years. Two shore stations will provide the energy of the network; one is located on Vancouver Island, Canada, and the other on the Oregon coast. Each of these stations is capable of providing 100 kW. A redundant power supply will be located at each of the shore stations.

The engineering power system prototype is a parallel power system utilizing flexible DC/DC power supplies that auto adjust to changing load conditions with a multi-layered, reliable protection system. The backbone voltage is 10kV DC, and the cable will have a current rating of 10 A. The anode of

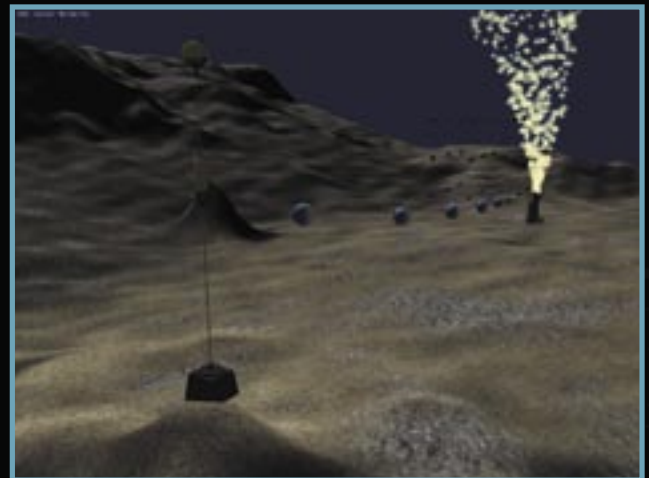
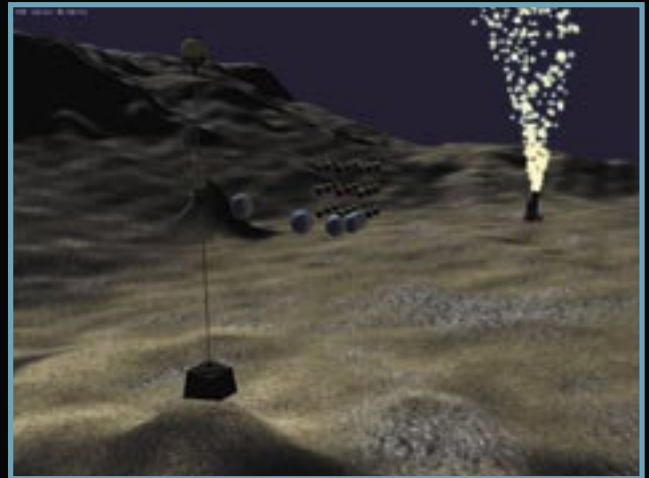
the system is at the shore station, to limit the corrosion of the equipment in deep water. Hence the voltage of the shore station is negative with respect to ground. At each science node (30+ locations), a DC/DC converter will be used to reduce the incoming voltage from ten kV to a more conventional level of 400V (and 48 V). In the event of component failures or cable fault, a protection system inside the BU isolates the fault as soon as possible and minimizes the loss of load. This is done without any communication from the shore station or coordination between the BUs. Furthermore, if a fault occurs, its location can be identified to within one km to minimize the cost of search and repair in deep water.

The goals of NEPTUNE can be achieved only if the at-sea portion is complemented by an information technology cyberinfrastructure that can fully utilize and ultimately automate interactive ocean observatories. This will involve a strong collaborative effort between computer and ocean scientists. A working prototype will be built linking, via experimental wireless, optical networks, and grid technology, a series of facilities located off the Pacific coasts of Mexico, the United States, and Canada. The prototype will allow development of essential middleware to facilitate and enable instrument and infrastructure control, data generation and distributed storage, data assimilation and ocean simulation, analysis, visualization, and collaboration. The prototype infrastructure will be a large distributed data grid, driven by a variety of instruments, and will be capable of interactively analyzing and collaboratively visualizing multiple data objects. [EEK2005](#)

## NEPTUNE SENSORBOTS

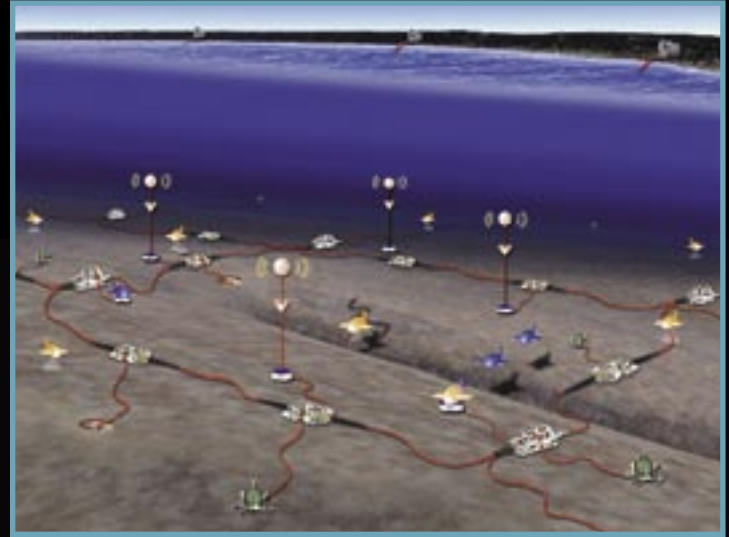
PROFESSORS JOHN R. DELANEY AND DEIRDRE R. MELDRUM

The power and bandwidth that NEPTUNE can deliver would enable the deployment of an adaptable array of small, semi-autonomous sensor-robots or "sensorbots" capable of moving, either independently or under remote control, in a 3-D geometric formation through precisely controlled volumes of seawater. In such a system, the operator (on land) might specify the spacing of the sensorbots, the rate of movement through the water, the types of sensors that are activated and the repetitive patterns of flight that would be utilized. Swarms of sensorbots could be used to record spatial and temporal variations in aquatic environmental parameters, permitting effective monitoring of changes in controlled ocean volumes near volcanic or seismic activity, near mass-wasting events, within primary-secondary plankton blooms, or associated with any other dynamic process operating within the ocean. When programmed to operate in an autonomous mode, these sensor swarms would have the ability to function in complex, harsh, and remote environments. For example, spatially and temporally indexed genomic analysis of microbial communities may be possible with the appropriate micro-analytical systems mounted on the sensorbot platforms in the swarm mode.



SENSORBOT ARRAYS TO MONITOR SPATIAL AND TEMPORAL VARIATIONS IN AQUATIC ENVIRONMENTS: SENSOR-ROBOT SWARM INTENDED FOR USE IN THE DEEP OCEAN. THE SCENE IS AT THE FLOOR OF AN ACTIVE SUBMARINE VOLCANO (2000 M DEEP) SHOWING AN ACTIVE HYDROTHERMAL VENT. THE YELLOW MOORING (FOREGROUND) IS HARDWIRED TO A BURIED ELECTRO-OPTICAL CABLE CONNECTED DELIVERING POWER AND COMMUNICATIONS TO SHORE. THE MOORING COMMUNICATES WITH THE YELLOW SENSOR-ROBOT SWARM BY OPTICAL MODEM, WITH ACOUSTIC BACKUP, THROUGH THE SINGLE CHAIN OF BLUE COMMUNICATION-NAVIGATION MODULES. FIGURE A SHOWS THE TIGHTLY CLUSTERED SENSORBOT SWARM NEAR THE MOORING. FIGURE B SHOWS THE EXPANDED SENSOR SWARM DOWNRANGE. THE SENSORBOT SWARM MAKES SELECTED MEASUREMENTS IN TIME AND SPACE AS IT MOVES, USING TONS OF DIFFERENT MICRO-SENSORS. POWER IS FROM RECHARGEABLE BATTERIES SERVICED ROUTINELY AT CHARGING STATIONS NEAR THE BASE OF THE MOORING.

If the position, control, and mobility parameters on these sensorbots can be designed to be sufficiently precise and accurate, as a swarm they would have the ability to detect and respond to specific stimuli such as motion, turbulence, thermal variations and other physical processes operating in the deep ocean. These robots might be programmed to respond to events such as submarine volcanic eruptions and earthquakes. Bioluminescence will be tested as a biological (non-electrical) medium for intercommunication between adjacent sensorbots, which does not require high-speed communication or high optical intensity. Once in full operational mode, all data would be continuously downloaded to the NEPTUNE network and data archiving and analysis system. These capabilities will allow oceanographic and geophysical phenomena to be explored with entirely new research strategies. [EEK2005](#)



THE MAIN DESIGN FEATURES OF NEPTUNE POWER SYSTEM.

## THE NSF OCEAN OBSERVATORIES INITIATIVE

As a result of recent discoveries about the ocean, scientists are asking new questions that cannot be answered using only traditional approaches. To address the next generation of questions and problems, the National Science Foundation's Ocean Observatories Initiative (OOI) will support the development of novel strategies to allow for remote, routine, and continuous operation within the oceans. These will enable better understanding of our planet's crucial fluid engine of global change and moderation, and will help us to eventually learn to manage major components of our ocean space.

The OOI merges technological advancements in sensor technologies, robotic systems, high-speed communication, ecogenomics, and nanotechnology with ocean observatory infrastructures that will meet the needs of both science and society. One of these next-generation facilities, a regional cabled observatory, will provide instantaneous and remote surveillance of thousands of square kilometers of seafloor and the overlying volume of ocean. Vast sensing arrays, coupled with new classes of robots and autonomous vehicles, will respond to unexpected events as well as continuously collect information from microbial to global scales. High-bandwidth communications will transmit data directly from instruments the oceans to any user with an Internet connection.

## THE PEOPLE OF NEPTUNE

Members of the multi-institutional NEPTUNE consortium are the University of Washington, the University of Victoria, the Woods Hole Oceanographic Institution, the Monterey Bay Aquarium Research Institute, and the California Institute of Technology's Jet Propulsion Laboratory (JPL).

The University of Washington's Applied Physics Laboratory and the department of Electrical Engineering are teaming with the Jet Propulsion Laboratory of California Institute of Technology to design the NEPTUNE power network. The first prototype, named MARS is scheduled for deployment during the second half of 2005. It is a scaled down version of NEPTUNE, which will be installed at Monterey Bay Aquarium Research Institute in California.

Canada has begun work on the northern portion of the NEPTUNE network, led by the University of Victoria, with support (\$62.4M Can) from federal and provincial governments. In the US, the National Science Foundation has formed the Ocean Research Interactive Observatory Networks program to oversee the comprehensive national development of the Ocean Observatories Initiative (OOI). The OOI is slated to begin in FY2007 with a 6-year budget of \$268M US, to be funded through NSF's Major Research Equipment and Facilities Construction Account. The NEPTUNE consortium will compete for participation in that program.

The NEPTUNE Power System is being developed by an engineering research team led by Bruce Howe and Tim McGinnis from the UW Applied Physics Laboratory, Harold Kirkham and Vatche Vorperian from JPL, and UW EE Professors Mohamed El-Sharkawi and Chen-Ching Liu.

UW Oceanography (Professor John Delaney), Computer Science and Engineering (Professor Ed Lazowska), and UW Computing and Communications (Dr. Ron Johnson) have teamed with Oregon State University (Professor Mark Abbott), and the University of California, San Diego (Professors John Orcutt and Larry Smarr) to initiate the design of the NEPTUNE cyberinfrastructure.

The "sensorbot swarm" concept is being developed by Professor John Delaney of UW Oceanography, Professors Deirdre Meldrum, Mani Soma, and Lih Lin of UWEE, and Professor Mary Lidstrom of UW Microbiology and Chemical Engineering.

For further information on this project, please visit the following sites:  
<http://www.neptune.ocean.washington.edu>  
<http://www.neptunecanada.ca>  
<http://www.neptune.washington.edu/>  
[http://neptunepower.apl.washington.edu/np\\_home.html](http://neptunepower.apl.washington.edu/np_home.html)  
<http://cialab.ee.washington.edu>