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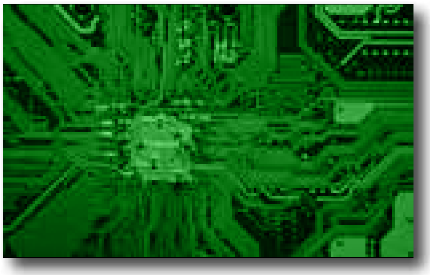

Future Force is a professional magazine of the naval science and technology community. Published quarterly by the Office of Naval Research, its purpose is to inform readers about basic and applied research and advanced technology development efforts funded by the Department of the Navy. The mission of this publication is to enhance awareness of the decisive naval capabilities that are being discovered, developed, and demonstrated by scientists and engineers for the Navy, Marine Corps, and nation.

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Front Cover: *Welcome to the Age of the Geek!,* artwork by Alvin Quiambao

Back Cover: Photo by MC2 Carlos M. Vazquez II

SPEAKING OF S&T

▶▶ By Vice Adm. Ted N. Branch, USN

Photo by OS3 Nicolas Mahone

As the professional magazine of the naval science and technology (S&T) community, the purpose of this aptly named magazine is "to inform readers about basic and applied research and advanced technology development efforts." Its mission is "to enhance awareness of the decisive naval capabilities that are being discovered, developed, and demonstrated by scientists and engineers for the Navy, Marine Corps, and the nation."

I can think of no better topic for Future Force than information dominance, and I'm extremely pleased that it's this issue's featured theme. Information dominance is about delivering warfighting effects where it matters, when it matters, and it relies heavily on continuous, transformational S&T to succeed. Comprised of three interrelated pillars that we call assured command and control, battlespace awareness, and integrated fires, Navy information dominance leverages the asymmetric advantages created through S&T to master the information domain and provide the equipment, systems, and expertise the fleet needs against potential adversaries, now and in the future. It's through dedicated, deliberate S&T and research and development (R&D) that we're able to seamlessly integrate attributes of intelligence, meteorology, oceanography, information technology, space, cyber, and electronic warfare to ensure our freedom of maneuver in all domains, especially in cyberspace and the electromagnetic spectrum.

The range of subjects in this edition largely reflects the scope of our challenge, beginning with a story on Rear Adm. Grace Hopper and spanning features on analytics, sensors, networks, big data, cloud computing, unmanned systems, and warfighter performance. These are not peripheral matters. They are at the very heart of our mission—precisely the things we focus on each and every day.

As you read this edition, I invite you to consider the long-term effects these issues and capabilities will have on the Navy's future force. They represent just the tip of the S&T/R&D iceberg, but they're central to our ability to achieve information dominance through emerging innovations such as electromagnetic maneuver warfare. Help us build on the concepts presented here and identify ways the S&T community can contribute. Warfighting success in the Information Age and our "Future Force" depend on it.

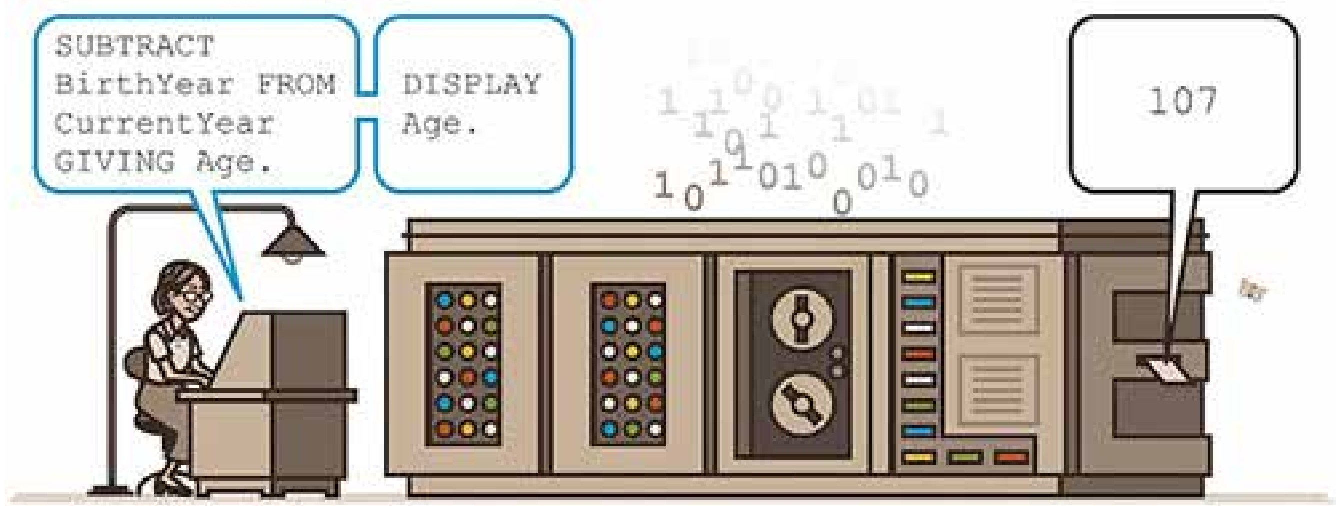
Vice Adm. Branch is the Deputy Chief of Naval Operations for Information Dominance (N2/N6) and the Director of Naval Intelligence.

Navy Information Dominance:

Above, Sailors recieve their warfare specialist pins for the Information Dominance Corps. Information dominance is the operational advantage gained from fully integrating the Navy's information capabilities, systems, and resources to optimize decision-making and maximize warfighting effects in the complex maritime environment of the 21st century.
(Photo by MC1 Eric Dietrich)

►► By Colin E. Babb

GRACE HOPPER AND INFORMATION-AGE INVENTION



Computer pioneer Grace Hopper is famous for what she created—Google honored her achievements in 2013—but she also should be remembered for how she did it.

The terms "Information Age" and "Computer Age" are often conflated, as if both describe adequately the technological, social, economic, and political forces that have driven human societies over the past 70 years toward an interconnected world in which information itself has become a commodity. When the first modern computers were being developed in the 1940s, however, it was not at all clear just what kind of information these new machines ultimately would be able to create. Electromechanical computers such as the Harvard Mark I and even the more sophisticated ENIAC were capable only of doing what Mark I designer and operator Howard Aiken described as "makin' numbers." They were essentially elaborate calculators, the creations of mathematicians to be used for mathematical problems. Had the inputs and outputs of computers remained solely a matter of numbers, it is doubtful that the "Computer Age" would have led as quickly to the "Information Age" that we live in today. A naval officer, Grace Hopper, helped make that transformation a reality by employing a distinctive method of technology development.

For most of the history of computing, which has seen computers do everything from regulate refrigerators to help put men on the moon, the fundamental language of every computer remained simply zeroes and ones (quantum computing—where bits can be both 0 and 1 at the same time—is changing this, but that is another story). Every program is at its lowest level merely a sequence of "off" and "on" commands. It was apparent to some in the first generation of programmers in the 1940s and 1950s that programming in this fashion—writing (or punching) an endless series of zeroes and ones—would be, at best, mind-numbing and, at worst, a constant invitation to the incorporation of errors for anyone but the most expert programmer. The challenge for these earliest programmers was how to create a system that would help humans—who don't naturally communicate in mathematics—to write programs in reasonably understandable script that could be "translated" into the numbers-based language of computers. The problem of compatibility operates in two directions: It is important to facilitate the work of programmers who create inputs in the form of programs, and it is essential to ensure that outputs are understandable to someone who cannot read binary or some other code.

Grace Hopper influenced the decisive first part of this equation by playing a key role in developing one of the first widely used programming languages, COBOL (Common Business-Oriented Language). Her career with computers took her from academia to the military to businesses large and small and back again—a matrix of destinations that would become familiar to many of those who entered the field after her. She often is portrayed as a pioneer for women in mathematics (few women took doctorates in the field when she received hers in 1934) as well as computing. Yet her role as a pioneer transcends gender, and, as Kurt Beyer argues in his *Grace Hopper and the Invention of the Information Age* (2009), a key to her success was her collaborative style of invention (what he terms "distributed invention").

Hopper began her professional life teaching mathematics at Vassar College in Poughkeepsie, N.Y., in the early 1930s. An important part of her experience there, according to Beyer, was her eagerness to take advantage of the faculty's ability to audit classes in other departments. In taking everything from physics to astronomy to economics, Hopper broadened her own intellectual world while also incorporating what she learned back into her teaching. While the experience rubbed some of her colleagues the wrong way—by her own recollection, it was the younger faculty who took the most umbrage at her not concentrating solely on mathematics—it prepared her for working with a wide array of partners in her subsequent career in computing. It also helped her to see the ways in which mathematics could contribute to understanding better other fields and vice versa.

GRACE HOPPER'S CAREER IN THE NAVAL RESERVE SPANNED MORE THAN 40 YEARS. SHE RETIRED IN 1986 WITH THE RANK OF REAR ADMIRAL (LOWER HALF) AT THE AGE OF 79. AT THE TIME, SHE WAS THE OLDEST ACTIVE-DUTY OFFICER IN THE NAVY. (PHOTO COURTESY OF HARVARD UNIVERSITY ARCHIVES)

With the outbreak of World War II, mathematics would be enlisted in the service of every major combatant in ways barely contemplated in previous wars. From building new ships, aircraft, and armored vehicles to creating new weapons and even splitting the atom, mastering the sheer avalanche of numbers necessary for planning and fighting the war became a Herculean task. The first modern computers were developed to tackle these and other complex problems in multiple places, all within a few years of each other, in Germany, the United Kingdom, and the United States. In the latter, the first computers were tasked with solving ballistics problems and creating firing tables for the Army, with its ENIAC (under construction during the war but not completed before its end), and the Navy, with Harvard University's Mark I. The Mark I also would be used for problems associated with the Manhattan Project, but even the computer's operators would be unaware during the war that they were providing help to this top-secret endeavor. It was here, too, that Hopper would enter the world of computing in the summer of 1944 as a newly commissioned lieutenant junior grade in the Naval Reserve, assigned to a small team of operators of the new "calculator."

CMDR. HOWARD AIKEN (LEFT), LT. J.G. GRACE HOPPER, AND ENS. ROBERT CAMPBELL IN FRONT OF THE HARVARD MARK I IN AUGUST 1944, NOT LONG AFTER HOPPER CAME ON TO THE PROJECT. THE JUXTAPOSITION WITH THE SAILORS IN THE BACKGROUND REVEALS THE OPERATING PROCEDURE OF THE MARK I, WHERE ENLISTED PERSONNEL WERE OPERATORS AND OFFICERS WERE PROGRAMMERS. (PHOTO COURTESY OF HARVARD UNIVERSITY ARCHIVES)

The Mark I, designed by professor and naval reservist Howard Aiken and built by IBM, was more than 50 feet long and composed of more than 750,000 parts. A spiritual, if not physical, descendent of Charles Babbage's 19th-century difference engine, the electromechanical Mark I used punched paper tape for its instructions and output. Hopper, who quickly became adept at working with the huge machine, earned Aiken's confidence, such that she soon was asked to write the Mark I's operating manual. This was the first of what would become a long line of publications penned by Hopper that would both document her own education as a computer evangelist and define the nascent field for its first generation of users and programmers. Remaining with the Harvard team even after the end of the war, Hopper became a manager of a data-processing center that operated 24 hours a day, seven days a week.

In 1949, Hopper joined what is widely regarded as the first computer "startup," the Eckert-Mauchly Computer Corporation (EMCC). Run by two of the creators of the ENIAC, J. Presper Eckert and John Mauchly, EMCC sought to build a commercial version of that computer—what would eventually be called the UNIVAC. Although the company's independent existence would be short-lived (it would be purchased in 1950 by Remington Rand after a series of financial difficulties), Hopper would find the experience there memorable. An important relationship there, biographer Kathleen Broome Williams points out, was a friendship with Betty Holberton, whom Hopper believed was the first person to use a computer to write a program.

While working at Remington Rand (later Sperry Rand), Hopper began to confront the formidable and interconnected problems of the time-consuming nature of programming and a still-low number of people entering the highly specialized field of computing. Automating part or all of the programming process by saving or compiling groups of code used over and over by different programs offered a way to reduce the time spent on writing programs and, eventually, to help non-math specialists engage with computers. The first attempts at building these compilers (beginning with A-0 in 1951) put Hopper on the forefront of computing in the early 1950s, but they were difficult to use and still required significant amounts of programming time. In May 1954 at a conference sponsored by the Office of Naval Research (ONR), Charlie Adams, a researcher with MIT's Project Whirlwind, presented the work of several other MIT programmers. Their "algebraic compiler" took standard math symbols and translated them into computer language. Two years later, at a second ONR-sponsored conference, Hopper acknowledged that this work was the most comprehensive language at the time. Beyer argues that MIT's work helped Hopper go in a new direction with her compilers, leading her to believe that the twin goals of opening up who could be a programmer and ending the disconnect with users were within the field's grasp.

By the beginning of 1959, both a widespread need for "automatic" programming as well as the tools required to build it were in place. In April of that year, Hopper met with Robert Bemer of IBM and Howard Bromberg of RCA to discuss the possibility of creating a common business language. The small group found a willing sponsor and partner in Charles Phillips, director of data systems research at the Department of Defense. The group that would create COBOL came to be called the Conference on Data Systems Languages (CODASYL). The group's first meeting in May 1959 consisted of representatives from the Air Force's Air Material Command, the Commerce Department's Bureau of Standards, the Navy's David Taylor Model Basin, Honeywell, Burroughs Corporation, IBM, RCA, Sylvania, and Sperry Rand. As CODASYL's work continued through the 1960s, this list of both industrial and government participants grew greatly in size.

Although Hopper's is the name most often associated with the COBOL, the language's invention was "distributed," which Beyer defines as a style in which prototypes are farmed out to an ever-widening circle of creators. Work on COBOL began with three committees, each with a different task: evaluating current languages (there were others in use, such as FORTRAN), analyzing the syntax of languages, and determining how to build a language useful for both business and science. The group was greatly influenced by one of Hopper's compilers, FLOW-MATIC, in creating COBOL, which would use English-like words and syntax as the fundamental basis for the whole language. What had until then been an experience of writing code in numbers, equations, and symbols became with COBOL a matter of mastering commands such as "GO TO," "DISPLAY," and "STOP RUN." It was not high literature—but it was an enormous step forward when CODASYL submitted its final report on the project in December 1959.

At the time, CODASYL represented a distinctive method of technology invention: using not simply a team, but a team of teams, from multiple organizations. This collaboration of diverse business and government interests brought together potential customers and colleagues—as well as past and future rivals. They all understood, however, that there was an enormous advantage to working together on what promised to be a computer common language that would potentially make everyone's job easier. Programming could now be a job for anyone, not merely for a select few who understood the fine points of mathematical equations. The creation of COBOL and subsequent languages allowed the 1960s, as Beyer points out, to be the first decade in which programmers could finally concentrate on data processing problems rather than on simply mastering the operation of machines.

Interdisciplinary and interagency collaboration and team-oriented management are now ubiquitous in the science and technology community. CODASYL's legacy remains with us today as an exemplary method of invention and research—the Internet itself, for instance, would be "invented" using an industry-academia-government collaboration in 1969, and today's naval science and technology community also remains committed to this kind of approach to managing invention.

The spirit in which CODASYL operated—to provide an open-source code for the benefit of an entire community without regard solely to profit or individual advantage—also remains alive and well. Globally distributed, collaborative projects have built such widely used software programs as Firefox, OpenOffice, and Linux, which are free to all users. Created and maintained by individuals and groups that donate their time and labor, these types of projects are a product of what NYU professor Clay Shirky has called the "cognitive surplus"—the collective potential productive capacity created by modern labor-saving technology that can be applied to social projects. Magnified by the power of global communication networks—themselves enabled by computers—Hopper's method of distributed invention can now be replicated on a massive scale.

Hopper's experience with the creation of COBOL in particular, as well as her career trajectory in general, exemplified another major development of the postwar science and technology community: the rise of what President Dwight Eisenhower termed in 1961 the "military-industrial complex." Indeed, Hopper's work at Harvard, EMCC, and Remington Rand while a naval reservist not only was at the very intersection of this partnership (which also definitively included academia), it demonstrated that the linkages in many respects were already mature when she arrived on the scene. Hopper did not create these connections—she took advantage of and played a role in strengthening them.

Through Grace Hopper, the Navy had an important role in the invention of the first widely used programming language—but the story of COBOL is a modern tale, where collective projects end up being more than the sum of their parts. Ultimately, the creation of viable computer programming languages redefined not only what computers could do, but also who could operate and use them. How information was created and stored—even the very definition of what constituted knowable information itself—was transformed. Computers were no longer machines built only for "makin' numbers."

TO ME, PROGRAMMING IS MORE THAN AN IMPORTANT PRACTICAL ART. IT IS ALSO A GIGANTIC UNDERTAKING IN THE FOUNDATIONS OF KNOWLEDGE.

—GRACE HOPPER

About the author:

Colin Babb is a contractor who serves as the historian for the Office of Naval Research and managing editor of *Future Force.*

Protecting Networks with Statistical Classification

By Mike Reski, Blake Wall, and Ben Greco

Every day within the department of the Navy and Defense (DoD), hundreds of thousands of civilians and service members access the Internet in their daily operations. They do so through encrypted channels to keep personally identifiable information and government communications safe and out of the public domain. This secure transfer of information is paramount to conducting business across an enterprise as wide as DoD.

As one can imagine, the widespread use of unreadable Internet communications creates a natural avenue by which nefarious actors will attempt to compromise a network. Other than dramatically limiting the scope of the connectivity of a network, however, little could be done to stop sensitive information from being sent out or return calls from coming back in—until now.

The Problem

The massive volume of traffic sent by the DoD over the Internet dictates that security must be maintained at a high level. All DoD and U.S. government networks make use of intrusion prevention systems and intrusion detection systems to stop outsiders from accessing their computers and the information within. In order to maintain operational business while upholding the standards of security, the encrypted web traffic and e-mail must be allowed to pass through intrusion prevention and detection systems. This creates holes because encrypted traffic that leaves a computer on the proper port will exit the DoD network. Validation that it is actually the type of traffic meant to be leaving over that port is impossible because of the requisite high-strength encryption.

Such vulnerability makes it possible for essential data to be disseminated to the public by an insider in the DoD community. In addition, if a computer has been infected by an outside actor there is a possibility this actor could control or disable the computer remotely through an encrypted protocol.

The Method

We live in a world filled with metrics and data. The analysis of large data sets predicts elections, generates custom advertisements, and provides insights into the strengths and weaknesses of everything from companies to professional sports teams. New methods for discerning determining factors and classifications through statistical analysis are becoming extremely popular in scientific literature and in corporate practice. The Analytics Research Group at Space and Naval Warfare Systems Center Atlantic has incorporated systematic data analysis and artificial intelligence into its core science and technology vision, and uses these methods every day in practice. Our Statistical Network Analysis project, for example, is currently in its second year of funding through the Naval

Illustration by Alvin Quiambao

COMPUTER NETWORK DEFENSE SERVICE PROVIDER. The computer network defense service provider at Space and Naval Warfare Systems center atlantic offers security services for the department of health affairs. This service provider program received the highest possible accreditation, level 3, in 2012. The persistent penetration force works as an auditor for the services provided. This team mimics real-world threat actors to identify and expose potential threat vectors to the network. Using the same mentality as advanced persistent threats, the team is able to uncover misconfiguration and security threats that normal security technical implement guides fail to protect.

Innovative Science and Engineering program. The project was originally funded at the beginning of fiscal year 2013.

We are studying the use of these statistical and machine-learning methods to discern between the encrypted traffic that should and should not be allowed to exit the network, creating a filter for this exit path where none has existed before. The method works by taking statistics about the raw encrypted traffic moving over the wire. Deep-packet inspection of the traffic is impossible because the traffic cannot be decrypted. Sensitive personal information or even classified data is preserved in a fully encrypted format and can be deleted after statistics are taken. We then use intelligent classification techniques on the statistics generated by each stream to classify if they are or aren't the same as the normal traffic for that specific port.

The technique has a popular Post Office analogy: It is impossible to view the contents of the packages that are being sent through the mail in the same way it is impossible to inspect packets of encrypted traffic. If you had various examples of items and measurements of the packages that came in, however, you would be able to make judgments about parcels without opening them. For example, we could all probably say things like, "That is not long enough to be a surfboard," or "That package is too light to be a new TV." By comparing live traffic to diverse samples from various network operations centers, we hope to be able to develop general baselines for traffic types in this way that could apply to any network enclave, even ones we have never studied.

Our team works with the center's Computer Network Defense Service Provider (CND-SP) to securely take traffic data from DoD health facilities for testing without compromising personal information. We use the full packet capture of these massive networks for training and testing of our models.

The Value

It has been noted that current network and host-based protection security systems have failed to identify sophisticated exploitations. This has left network defense researchers constantly responding to new and complicated "zero-day" type attacks. These advanced persistent threat attackers do not simply generate noisy events on the network. They seek to use common exit points on the network to exfiltrate data and conduct command and control operations with enclaves. A second common tactic of today's advanced attacker is the so-called "script-kiddie" attack, which intentionally generates a huge amount of alerts that can be identified by most security tools today. The amount of incidents generated on an hourly basis is intended to overwhelm computer network defense analysts, who will never be able to review every alert.

We believe our new tool, the Encrypted Protocol Intelligent Classifier, will be able to address these types of attack with a smarter approach to threat analysis. By identifying the common subtle underpinnings of previously indiscernible traffic, we seek to locate the common exit points that are currently vulnerable—without generating the false alarms that would leave users susceptible to intentional script-based attacks. Today's analysts need a tool that can help them identify which streams to investigate soon after an incident without generating many false alarms. We are developing that tool here at Space and Naval Warfare Systems Center Atlantic.

Future Work

Now in its second year of basic and applied research funding, the Statistical Network Analysis team is perfecting its model and working to validate its technique with real-world data from simulated and known threats. Project officials are in talks with the Program Executive Office for Command, Control, Communications, Computers, and Intelligence (PMW 130), Marine Forces Cyber Command, and the Office of Naval Research about transitioning the product in Navy and Marine Corps networks.

About the authors:

Micheal Reski, Blake Wall, and Ben Greco are researchers at the Space and Naval Warfare Systems Center Atlantic.

Data Science to the Rescue

By Robert Beaton

The "fog of war" is an often-used metaphor for the uncertainty, ambiguity, and lack of information that impedes military decision making on the battlefield. Reducing that fog is one of the most significant advantages we can give to warfighters. Over the years, the United States has made huge investments in strategic and tactical systems to overcome the fog of war, but the capabilities of those systems are not adequate to deal with the quantity, quality, and detail of information that will become available in future military conflicts. This is resulting in the rise of "data science," a new way of conceptualizing how we manage information that combines how data are represented, organized, processed, shared, and interpreted under relevant context and with necessary assurance.

The Information Explosion and Big Data

Often described as "the information explosion," the dramatic growth in data available to our forces is truly without parallel. By 2020, the average Navy ship should be able to deploy with the capability to store more than 1,000 terabytes of data. That capacity will be quickly filled up by data collected from the ship's combat and information systems, from a wide range of supporting unmanned vehicles and sensors, and from huge libraries of information brought with the ship when it deploys. All of that will be augmented by vast amounts of data collected and provided by national sources.

Over the past decade, key data technologies have revolutionized access to knowledge and information. These data technologies go by the names of "big data" and "semantic Web." Big data technologies, first popularized by Google's search engine, make it possible to search for information across geographically distributed databases, while leveraging the power of thousands of computers simultaneously analyzing and delivering search results. Through this technology, as most of us commonly experience, Google delivers millions of responses in less than a second.

Recently, the World Wide Web Consortium led the development and standardization of semantic Web technologies to provide a common framework that allows data to be shared and reused across application, enterprise, and community boundaries. Because data have been controlled by applications, sharing and analyzing remain difficult. Anyone with Department of Defense experience will understand the ongoing challenge of correlating data from across military departments or agencies.

These key data technologies are leading to a major paradigm shift when it comes to data. The old paradigm was to figure out how to manage and use internal organizational data to solve problems. The new paradigm involves solving problems by augmenting internal data with the massive amount of data being created by communities throughout the world. In the old paradigm, each community developed its own closed solution and did not put much weight on integrating its data with the wider world. In the new paradigm, communities make their data available so it can become part of a much larger "data ecosystem."

Data Ecosystems

A data ecosystem is a large number of interconnected, distributed data sets provided by a large number of diverse communities interconnected and/or aligned to extend the collective knowledge of all. It includes all the infrastructure, support tools, and processes needed to add data to the ecosystem, align and interconnect it, and support the end user's use of the data. It is important to understand that a data ecosystem has characteristics of both big data (large volumes of heterogeneous data) and semantic Web (large variety of data/communities).

In 2010, the Department of the Army initiated the Unified Cloud Data (UCD) model technology architecture to establish the pilot Army Intelligence Big Data strategy, which, in turn, would inform Army programs of record and the data ecosystem across the service. UCD converges semantic Web big data technologies to improve radically intelligence and analytics and, by extension, cross-service warfighting capability. Through the UCD ecosystem, the Army is correlating all appropriate command-and-control and fire-support data sources to deliver relevant applied information to battle commanders in near real time. The Office of Naval Research's Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance Department is experimenting with the UCD ecosystem data technologies to develop a Naval Tactical Cloud (NTC) ecosystem to support integrated fires.

NTC incorporates software and tools to organize disparate data from many different communities into a single big-data environment, so that the data are fully integrated, accessible, and useful to users. A single big-data environment results in information interoperable across organizations, enabling the sharing of data and analytic tools. As a data ecosystem, NTC consists of a set of representation and semantic tables, plus the software tools, processes, and best practices that have been developed to bring disparate community data into the NTC ecosystem, run analytics on the data to generate extracted knowledge, and provide tools for end users to search, access, and use the data and extracted knowledge.

NTC combines semantic Web technologies with big data technologies while applying data science to ensure operational effectiveness to Army Distributed Common Ground System users. One of the most important concepts in the NTC ecosystem is using semantic Web technology to create data graphs as triple statements to support cross-community data analytics. Representing data in this way creates the flexibility and adaptability required for interconnecting and aligning data sets from widely disparate communities. This is why the NTC ecosystem could help migrate from a world of stove-piped data systems to a world of interconnected data ecosystems.

Naval Data Science Challenges

The evolution of big data and semantic Web technologies has now matured to the point where they are no longer considered major science and technology challenges. From a science and technology perspective, the time has come to move beyond this foundation and begin concentrating on the data science challenges that lie ahead. First and foremost, we must develop the underlying data science constructs that will enable the naval community to pull data out of today's stove-piped systems and integrate them into an ecosystem that will support cross-warfare area data sharing and analytics. There are additional challenges that must be addressed:

Distribution of Data over a Tactical Force: In tactical situations, it is generally not possible to move data to a central site for processing. In a naval task force, most of the data generated and collected by each ship will have to be kept on-site during the ship's deployment. Only when the task force returns to port will there be sufficient network capacity to offload all of the data. Such tactical situations will require data scientists to determine how best to distribute data within a force.

Prioritizing Data Movement in Constrained Network Conditions: Data generated or collected by a tactical unit generally will reside at the tactical unit. There always will be high-value information, however, that is needed by other units in the force. In such cases, it is important that that information be replicated to other tactical units to allow them to have more direct access to the data and ensure it is available to other units when the original unit is disconnected from the network.

Representation of Data for Efficient Movement across Tactical Networks: In many cases, the information content in data isn't a single binary package. Consider a three-minute video of an enemy destroyer that needs to be sent from a collecting unit to an attacking unit. In the best case it would be desirable to send the full video clip. When that is not possible, there are less-costly alternatives, such as selecting the most useful 30-second portion or sending one screen capture taken from the video. An even smaller data set would be to send a chip from the full image. The smallest would be to send only the geospatial coordinates and current heading of the enemy destroyer. Data scientists need to develop data representations that support variable data resolution to account for the variation in network capacity that will occur in tactical environments.

Prioritizing Data Retention in Constrained Storage Conditions: One of the driving assumptions behind traditional big data environments is that storage is infinitely inexpensive and elastic. This assumption is not valid for tactical units operating under constrained space and power conditions. In such situations, there is an upper limit on available storage, and although huge improvements in storage densities and power consumption make that limit extremely high, storage is ultimately a finite resource aboard ships and Marine combat operations centers. Data scientists must now prioritize data retention in constrained conditions. Determining which data to retain and which to discard needs to be driven by operational priorities, but data scientists must organize and structure the data to provide the hooks for making retention decisions.

To fully realize the Navy's information dominance vision requires that significant strides be made in developing a naval data science foundation that enables integrated cross-warfare area operations. Significant challenges lie ahead, but with hard work and creative thinking, we may be able to assist military decision makers in dispersing some of the fog of war that makes their jobs so difficult.

About the author:

Robert Beaton is contractor supporting the Office of Naval Research's Naval Tactical Cloud project and has spent the past 30 years working on information, command and control, and intelligence, surveillance, and reconnaissance systems for the Department of Defense.

TURNING BIG DATA INTO A USABLE CLOUD

By Dr. John R. Callahan

Determining the probability of future events depends on analyzing past trends and patterns. The amount of data currently available to help with this analysis, however, is overwhelming our ability to make any sense of it. Some of the problems of "big data" include:

Velocity: How do we tighten the observe-orient-decide-act loop between data acquisition, warfighters, and decision makers?

Variety: Data from many different sensors help correlate event patterns (or not), but how do we quickly integrate them, in a timely and cost-efficient manner?

Volume: How do we determine what data should be kept, summarized, or discarded?

Veracity: How do we determine the trustworthiness of data in the context of previous information and other data sources?

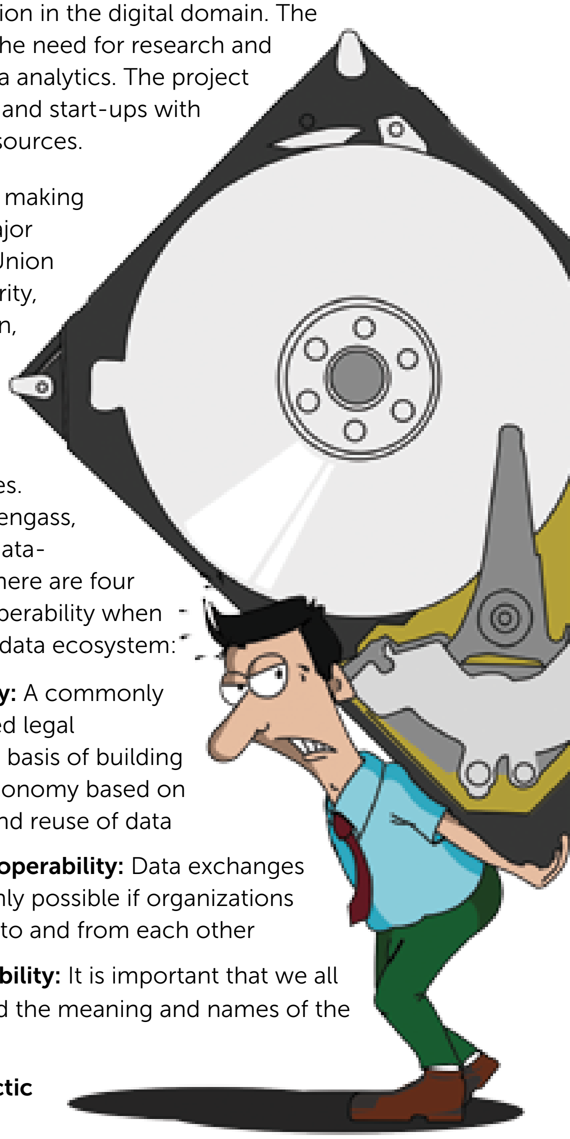
The field of data science recently has been established to address these problems. A merger of statistics and computer science—"data science"—could bring the power of big data to many fields. A key paper, "The Unreasonable Effectiveness of Data," published in 2009 by Google researchers Alon Halevy, Peter Norvig, and Fernando Pereira, found that predictions based on past patterns were increasingly effective and resistant to change if the datasets were of sufficient size and diversity. Such work has led researchers in many fields to apply big data techniques successfully to increasingly large datasets.

The European Union has focused heavily on applications of big data through its past Framework Programme 7 and upcoming Horizon 2020 research investments. The European Data Forum 2014 recently was held in Athens to highlight and review such efforts as:

Open PHACTS: To reduce barriers, accelerate drug discovery, and deliver personalized medicines in industry and academia, the Open PHACTS consortium is building a Discovery Platform. Open PHACTS will be a platform of freely available, integrated pharmacological data from a variety of information resources that provides tools and services to support pharmacological research.

INSIGHT: The goal of the INSIGHT project is to advance our ability to cope with emergency situations in smart cities (e.g., those equipped with closed-circuit TV, traffic sensors, etc.), by developing innovative technologies that will put new capabilities in the hands of disaster planners and city personnel in emergency planning and response. Test beds include Dublin, and flood-prone areas of northern Germany.

Teralab: This is a European Union project to accelerate research and innovation in the digital domain. The project responds to the need for research and innovation in Big Data analytics. The project provides researchers and start-ups with cloud-computing resources.



Data-driven decision making and discovery is a major theme of European Union research across security, energy, transportation, logistics, manufacturing, and healthcare disciplines, and among member states. Dr. Marta Nagy-Rothengass, head of unit for the data-value chain, argues there are four challenges for interoperability when creating an effective data ecosystem:

Legal interoperability: A commonly accepted and adopted legal framework forms the basis of building a functioning data economy based on effective exchange and reuse of data

Organizational interoperability: Data exchanges in value chains are only possible if organizations are able to pass data to and from each other

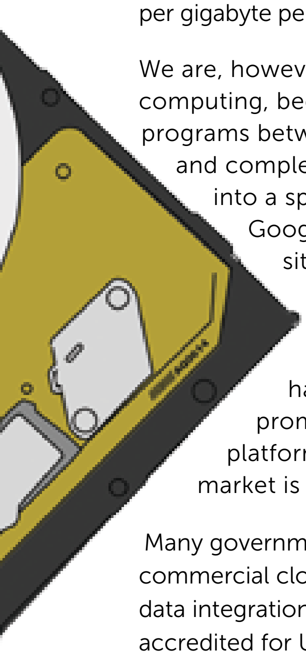
Semantic interoperability: It is important that we all agree and understand the meaning and names of the concepts we use

Technical and syntactic interoperability:

Promote standard data formats and exchange protocols, especially in systems meant to work across national boundaries, and across industry sectors.

The trend toward data-driven decision making and discovery has had another major effect on world markets: cloud computing. Large-scale digital storage and computing platforms as services are needed to store and process the volumes of data we create on a daily basis. In 2013 alone, major cloud vendors such as Google, Amazon, Rackspace, Yahoo, Facebook, IBM, and HP spent more than $150 billion building global data center infrastructure. The global capacity for digital storage and computing power is growing rapidly, and costs are decreasing in a kind of "Cloud Moore's Law" (referring to the principle that the number of transistors on computer circuits doubles every two years) as competition grows. For example, in response to Google's new cloud storage products, Amazon recently reduced its price from $0.085 per gigabyte per month (for the first terabyte with volume discounts for larger amounts) to $0.03 per gigabyte per month.

LARGE-SCALE DIGITAL STORAGE AND COMPUTING PLATFORMS AS SERVICES ARE NEEDED TO STORE AND PROCESS THE VOLUMES OF DATA WE CREATE ON A DAILY BASIS.



We are, however, still in a "mainframe era" of cloud computing, because the ability to move data and programs between cloud vendors is prohibitive in cost and complexity. Most cloud customers are locked into a specific cloud service provider. Vint Cerf, Google's technical evangelist, likens the situation to the early days of the Internet where interoperability between Internet service providers was poor. The Institute of Electrical and Electronics Engineers has initiated an "Intercloud" standard to promote interoperability across vendor cloud platforms, but the effort is nascent because the market is still evolving.

Many governments are mandating migration to commercial cloud platforms to reduce costs and improve data integration. Part of the Amazon cloud was recently accredited for U.S. level 1 and 2 Defense Department applications. This development will accelerate rapidly over the next decade.

Exchanging data using direct transmission over networks slows response time as the size of the dataset grows. Data can be secured and replicated globally in the cloud before any data exchange agreements. After reaching an agreement to share, the data can be unlocked and shared with near-zero latency. Several advanced cloud-based projects at the Office of Naval Research propose to securely share data in the hybrid government and commercial clouds. Using Accumulo, the projects propose to use fine-grain access cloud data guards to share specific pieces of information, instead of whole files or datasets en masse.

The ultimate goal of such projects is to produce better predictions for plans, routes, situational awareness, logistics load allocations, etc. Because of the size of related data sets (e.g., weather, shipping logs, air routes, etc.), the cloud is the platform of choice for integrating big data.

As a global commercial market grows for digital storage and computing, new questions are arising about the security of data. Member states of the European Union, for example, are already reconsidering laws that prohibit movement of data beyond national boundaries.

It is already a grand challenge to protect the security and privacy of data given our current cyber architecture—but the challenge will become more complex once our data are spread across the globe. A worldwide market in cloud computing and storage in which price changes drive data migration and replication instead of backup will be difficult to control through legal and diplomatic means. To help secure cloud platforms, recent advances in encryption, personal cloud computing, commutative replicated data types, and semantic Web technologies will help to secure the data within the cloud with data from other agencies, companies, and even nations. This seems inconceivable today, but the economics of scale, the massive storage requirements, and the ability to integrate datasets with near-zero latency will force many organizations into a global cloud ecosystem.

Typically, advances in technology drive policy changes. We are quickly moving beyond the personal computer, beyond operating your own data center(s) with your own firewalls, and into a new world of virtualized X-as-a-service with dynamic provisioning, spot market pricing, and on-demand storage, networking, and computation. Our reliance on mobile devices and always-on access is driving the need for data science—and the cloud computing platforms to support it.

About the author:

Dr. Callahan is the associate director for information dominance at the Office of Naval Research Global office in London.

From Battlespace on Demand to Decision Superiority

By Scott Livezey, Cmdr. Nick Vincent, USN, and Dr. Daniel P. Eleuterio

To ensure future decision superiority in an operational environment that grows ever more complex, Naval Oceanography and Meteorology Command has undertaken an aggressive, comprehensive science and technology/research and development investment strategy that runs the gamut from leveraging national and international environmental monitoring efforts to groundbreaking work in decision theory. In today's fiscal environment, every dollar counts—and these investments promise to provide decision superiority for Navy and Marine warfighters over the next decade.

The establishment of the Navy's Information Dominance Corps in 2009 brought together key naval information producers to establish decision superiority in an increasingly complex operational environment. The corps joins together the disciplines of intelligence, cyber, networks, space, oceanography, meteorology, precise navigation and timekeeping, and electronic warfare, bringing more value to the U.S. Navy than any one functional capability area can provide alone. The naval oceanography community—responsible for meteorology, oceanography, precise navigation and timing, and space and maritime domain awareness— provides strategic analysis and prediction of environmental impacts on naval operations, weapons, communications, and sensor performance.

Through satellite-based and on-site autonomous environmental sensing, global- and tactical-scale predictive models are being tailored to provide skillful forecasts, even in the data-scarce and data-denied environments likely to be encountered in military operations. In essence, research being done by the many contributors to the Information Dominance Corps brings a "home field advantage to the away games" for improved effectiveness of naval operations worldwide.

The naval oceanography community uses the strategic concept of Battlespace on Demand to add informational value progressively, as data is moved up a four-tiered, pyramid-like process. In Tier 0, environmental data from a variety of sources are collected and fused to describe accurately the current ocean and atmosphere environment, as well as the temporal and geographic reference frames. In Tier 1, high-performance, computing-based numerical environmental models are used to forecast the future battlespace environment based on observations and data fusion in Tier 0.

Tier 2 then takes this Tier 1-predicted environment and assesses its effects on sensors, weapons, platforms, and operations. It then combines the environmental effects with intelligence products, to assess how the weather and ocean conditions will change friendly and enemy order of battle—including targeting constraints, timing, maneuvering, and tactics. The result is a fusion of knowledge that clearly articulates the abilities and liabilities of both friendly and enemy forces with respect to the future physical environment in a 4-dimensional geographic information system format.

In Tier 3, planning and decision processes are applied to the essential knowledge gained in Tier 2, in order to determine opportunities and risks across tactical, operational, and strategic time scales—and to discover potential options for mitigation and maneuver. The result is multiple courses of action that provide actionable recommendations with respect to force allocation and disposition enhancing warfighting effectiveness and safety.

Tier 0: Sensing the Environment

Tier 0 is the foundation on which all other environmental information and knowledge is built. Access to national and international observations through partnership with the National Oceanic and Atmospheric Administration (NOAA), NASA, and the Air Force, as well as collection of environmental data from naval platforms, have been a staple of Tier 0 holdings and investments since Lt. Charles Wilkes, America's first naval hydrographer, collected bathymetric data from sailing vessels in the 1830s. We continue to invest not just in data collection, but in collection of the right data.

For large-scale ocean and weather conditions, satellite sensors (enhanced by surface observations and measurements) provide sufficient data for global numeric models. Future battles, however, will likely be in the global crossroads of straits and chokepoints in littoral zones and shallow marginal seas. In these near-shore conflicts, additional data collected by small unmanned systems, or by sensor packages on aircraft of opportunity, will be critical to capture the strong gradients and rapidly changing conditions typical in these regions.

The Littoral Battlespace Fusion and Integration program is fielding a fleet of hundreds of autonomous underwater sensors in shallow marginal seas worldwide for improved ocean prediction. In addition, new types of space-based sensors—that can sense different wavelengths, narrower frequency bands, weaker signals, or new types of information like polarization of remotely-sensed light or radiation—promise to open a new chapter in environmental remote sensing. An example of this is the Hyperspectral Imaging of the Coastal Oceans sensor. While hyperspectral imaging has been used in the past for very narrow field-of-view targeting to detect camouflaged objects, this prototype sensor on board the International Space Station provides the wide field of view and sensitivity in the blue wavelengths to characterize the depth of the water and bottom type critical for safe navigation, as well as oceanographic and acoustic prediction.

Other sources of Tier 0 data include "through-the-sensor" systems such as the Hazardous Weather Detection and Display Capability (HWDDC) currently installed on aircraft carriers, and the Tactical Environmental Processor targeted for ships with the Aegis combat system. Both of these systems derive environmental data directly from special processing of the radar clutter or noise filtered from air search radars. This ensures safer and more effective air and surface operations in the vicinity of thunderstorms and convective weather. New Tier 0 research projects include a program to assess if improved forecasts of both typhoon strength

and track can be achieved through high altitude (50-65,000 feet) Global Hawk measurements. These measurements can directly observe the outflow area of the storm previously unreachable by most traditional manned flight altitudes and paths. The challenge with these observational "snap shots" of current conditions—whether from assets organic to the strike group such as HWDDC or from satellite or autonomous sensors—then becomes combining these disparate organic and remote data sources into a coherent picture through data assimilation, and to provide this picture to improve the Tier 1 numerical forecast capability for planning the next flight cycle.

TODAY'S FIVE-DAY FORECAST IS AS ACCURATE AS THE ONE-DAY FORECAST WAS 30 YEARS AGO.

Many of today's sensor and weapon systems use fixed environmental databases based on surveyed data over several years (as opposed to time-critical observations and forecasts of current weather and ocean conditions) to optimize performance. As an example, High-Frequency and Low-Frequency Bottom Loss databases are critical components of sonar assessment and prediction capabilities. These databases contain environmental data collected over many years at varying resolutions. As current and future systems become more sensitive to environmental conditions, greater resolution and fidelity are required that can't be effectively collected from traditional survey methods alone. New ways to collect this data from operational platforms in real time, , which can then be passed back to update the observational record, continue to be explored. In the development of acoustic through-the-sensor capabilities, the Navy is determining bottom-loss data through additional processing of signals already collected by current submarine sonar systems. Such techniques that make novel use of existing data sources are critical to future, low-cost, effective Tier 0 data collection.

Tier 1: Characterizing and Predicting the Physical Environment

In Tier 1, super-computer resources at the Fleet Numerical Meteorology and Oceanography Center and the Defense Shared Resource Center located at the Naval Oceanographic Office are used to integrate all of these observations into a consistent global picture of the current environment. Global and regional atmospheric and oceanographic numerical prediction computer models are then used to run the millions of calculations needed to forecast future conditions.

The accuracy of these forecasts has steadily improved over the past decade as larger, faster computers and a better understanding of the underlying physical processes have allowed us to make these calculations more accurately and at finer geographic spacing. Today's five-day forecast is as accurate as the one-day forecast was 30 years ago.

We are beginning to produce actionable decision support at operational timescales that could be achieved only at tactical timescales in the past. For example, in the vicinity of thunderstorms, cyclic flight operations used to be canceled only when the weather got too bad to fly, which impacted readiness and operations in unpredictable ways. We are getting to the point where our skill and reliability is approaching the ability to schedule no-fly days for maintenance in the same window as the highest probability for weather cancellations days in advance, potentially greatly improving efficiency, operational readiness, and safety.

Investments continue in innovative approaches to both atmospheric and oceanographic numerical prediction. The three biggest investments are in the areas of data assimilation, ensemble modeling, and coupled air-ocean-ice modeling. Specific efforts include:

• New mathematical approaches to assimilate nontraditional information sources and new satellite feeds into models

• Numerical ensemble methods that can produce not only the forecast but an objective, quantitative assessment of the confidence level of that forecast

• Coupling techniques to connect weather, surface wave, ocean, and sea ice forecast models to provide a more accurate, consistent, and comprehensive picture of the operational environment.

In addition to a new global atmospheric model in operations, the Navy and NOAA recently began using the Hybrid Coordinate Ocean Model, which will allow for much better accuracy in regions where there are strong vertical salinity and temperature gradients that affect the transmission of sound underwater. This model received an Excellence in Partnering Award because of the effective use of interagency research for common mission needs. In addition, with the recent emphasis on the Arctic by naval strategic planners, these forecasting efforts are being extended to include seasonal ice-coverage predictions in the Arctic. This effort to create a better integrated and more consistent numerical representation across the air-ocean-land environment, and extend forecasting skill to longer lead times globally, is called the Navy's Earth System Prediction Capability—and is part of a national effort with the Air Force and NOAA to extend environmental predictions from the current standard of five to seven days to seasonal timescales for global forces deployment planning.

Tier 2: Assessing Impacts of the Physical Environment

An example of successful Tier 2 investment is the evolution and update of the Scalable Tactical Acoustic Prediction Loss Engine, and its associated tool kit. This engine provides a predictive foundation for many current fleet sonar systems, and includes the Navy standard Tier 0 databases, Tier 1 acoustic models (such as the Navy Standard Parabolic Equation and the Comprehensive Acoustic Simulation System), and Tier 2 capabilities to display the acoustic predictions in user-friendly way. Research continues to support the evolution of these models, both to improve their physics as well as the computational efficiencies that allow predictions that once took hours to be calculated and rendered in mere minutes.

In Tier 2, the goal of research is to assess the impact of the current and future environment developed in Tier 1, on systems and operations. Today's research is focused not only on improving individual predictions, but also on quantifying uncertainty. New probability maps, called "performance surfaces," help identify areas to search for the highest probability of detection—and determine how to optimize sensor placement. An example of this is the anti-submarine warfare performance surface, which provides a probability "heat map" of best search areas for detection, as well optimum sensor selection given the environment. This quickly provides a recommendation of where to search, and with what sensor. The development of these performance surfaces potentially provide the on-scene commander with an intuitive, understandable graphic in four dimensions (3-D space plus forecast time) for potential courses of action and maneuver warfare options that the traditional sensor-threat, point-to-point pairings did not.

Tier 2 capabilities include not only modeling for fleet weapon and sensor systems, but also support for Tier 0 collection capabilities. Unmanned systems that collect environmental data are subject to environmental effects themselves. Modeling efforts to support mission planning are critical to the collection of the right data at the right time to support Tier 1 models.

Additional research is building on a decade of previous experience in command and control of unmanned systems and focuses on optimizing and expanding control of multiple platforms simultaneously. The Glider Monitoring, Piloting, and Communications command and control suite, originally intended for buoyancy-driven ocean gliders used by the Naval Oceanographic Office, has been expanded to control other unmanned systems such as ocean profiling drifting floats, and wave glider unmanned surface vehicles. Recent advances in data compression and processing onboard the platforms have also led to large gains in transmitting relevant data in an efficient, effective, and information-assured way even when limited communications capabilities exist.

Tier 3: Achieving Decision Superiority

Research in the Tier 3 arena is continuing the pursuit of decision superiority. Leveraging ongoing work in data fusion, exploration is ongoing in behavior analysis and decision theory, for use with the performance maps from Tier 2, in order to develop multiple courses of action that quantify uncertainty and potential risk. This suite of processes and products is highly dependent on unique-force operational data for asset availability and all source intelligence for target location and possible future behaviors. It brings together the best information across the Information Dominance Corps to provide decision superiority over adversaries.

The future force structure of the Navy is still being determined as our nation is faced with continued budget pressures, military force drawdown after a decade of war, and an ever- increasing number of political, social, and environmental challenges around the world. The corps, while relatively young, is finding new synergy using existing and new information capabilities that help it "punch above its weight" in support of naval operations and planning.

In naval oceanography, continued modest investments in foundational environmental assessment and prediction capabilities, as well as new investments in the areas of information management and decision theory, promise significant dividends in support of decision superiority for warfighters.

About the authors:

Scott Livezey is the technical and executive director at the Office of the Oceanographer of the Navy.

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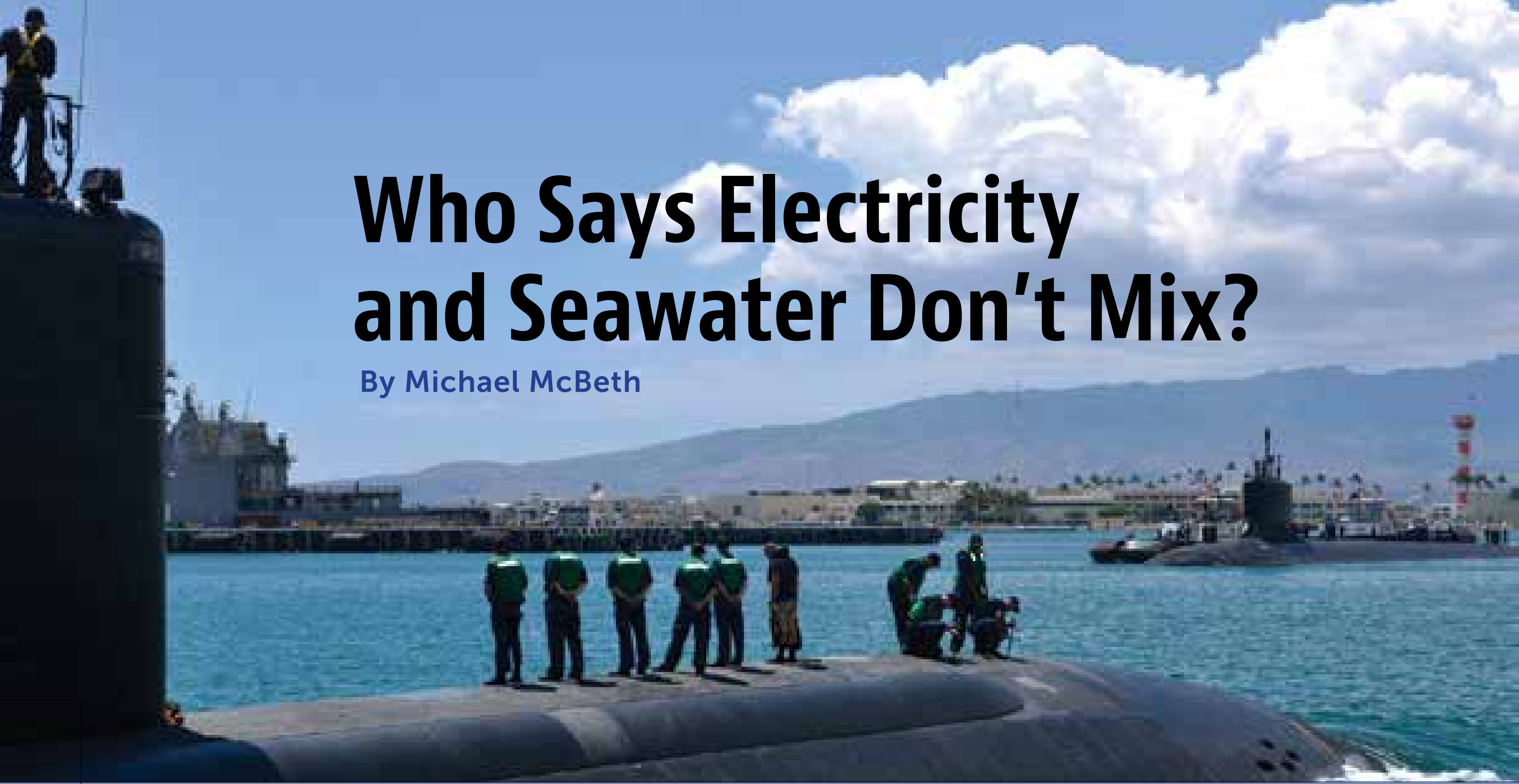
Dr. Eleuterio is a program officer in the Ocean Battlespace Sensing Department with the Office of Naval Research.



Who Says Electricity and Seawater Don't Mix?

By Michael McBeth

New research may help submarines and other underwater craft reach higher speeds without sacrificing situational awareness.

Since seawater is a good conductor, it makes sense to avoid using electric hair dryers or power tools when in contact with it. Mixing electricity and seawater, however, might be just what's needed to allow submarines to detect low-frequency sound pressure signals while traveling at high speeds. If research in this area is successful, submarines and unmanned underwater vehicles of the future will be able to cruise at higher speeds submerged while maintaining acoustic situational awareness.

Currently, the performance of hull-mounted sonar is severely degraded from the flow noise generated by a submarine (or other vehicle) moving at high speed underwater. Submarine commanders must make a choice: travel at high speed, or listen. They cannot do both. To see how mixing electricity and seawater might overcome this problem, we first need to understand how electricity and sound interact in seawater.

"Electrokinetic sonic amplitude"—this strange-sounding term refers to an effect where an electric field in seawater gives rise to a sound pressure wave.

In 1933, Dutch physicist Peter Debye put forward a theory that said when a sound pressure wave passes through an electrolytic solution, such as seawater, it leads to the generation of an electric field. Seawater is primarily composed of water and salt. A water molecule is electrically neutral, but one side is negatively charged while the other is positively charged. Dissolved salt in seawater consists of chlorine ions that are larger and carry a negative charge, and sodium ions that are smaller and carry a positive charge.

At equilibrium, the water molecules and charged ions in seawater arrange themselves so you cannot observe any net charge separation or electric field. Debye reasoned, however, that as a sound pressure wave passes, it exerts a force on the molecules and ions that accelerates them. Since the water molecules and ions have different sizes and masses, their resulting displacements are unequal—resulting in momentary net charge separations that you can observe as an electric field. The frictional forces and ionic mobilities in electrolytic solutions, including seawater, make this effect more pronounced at ultrasonic frequencies. This is why Debye chose to call this effect the "ultrasonic vibration potential."

This potential, however, is normally small and hard to measure. In fact, while Debye predicted the effect in 1933, it was only confirmed by experimental measurements in 1949.

Two Sides of the Same Coin

The ultrasonic vibration potential and the electrokinetic sonic amplitude are two sides of the same coin. With the first effect, the mechanical motion of a sound wave passing through the water gives rise to an electrical potential or voltage. In the second effect, an alternating

Photo by MC1 Jason Swink

electric voltage moves the seawater in a way that gives rise to a mechanical sound pressure wave. So we see that a sound wave passing through seawater gives rise to an electric potential, while an alternating electric field in seawater gives rise to a sound wave.

Fast-forward to the early 1980s. Researchers at the Matec Company in Warwick, R.I., invented an instrument to measure the properties of liquids. This measurement technology saw wide application, particularly in the pulp and paper industry. Matec used the electronic sonic amplitude to measure electrical charge on particles in liquids. The company's innovation was to apply bursts of several cycles of ultrasonic frequency at a constant voltage across the electrodes. This generates sound pressure bursts that propagate through the fluid to a conventional piezoelectric transducer or hydrophone (the main listening component of a sonar). By measuring phase and amplitude changes in the received ultrasound pulses, the amount of charge, and polarity of the charge on the particles in a liquid can be determined.

Operational Relevance

Today, researchers at the Space and Naval Warfare Systems Center Atlantic are working to apply the electrokinetic sonic amplitude effect to solve problems and create new capabilities for the Navy. One potential application involves sensing beyond the turbulent boundary layer to provide submarines with the capability to mitigate flow noise, so that subs can sense low-frequency sound pressure signals while traveling submerged at high speeds. Conventional hull mounted hydrophones become useless because of flow noise generated at high speeds.

Another potential application involves sensing the charge on suspended sediments in rivers, estuaries, and littoral environments. Knowledge of sediment transport behaviors is critical in understanding and characterizing marine environments. Currently, these types of measurements involve cumbersome laboratory experiments with prepared samples that are difficult to work with in the field. The idea is to develop an instrument to measure these properties that can be lowered into the water from a research vessel or integrated into unmanned underwater vehicles.

These capabilities contribute to achieving information dominance by using advanced sensor technology to enhance acoustical situational awareness while a submerged submarine maneuvers at high speeds.

Space and Naval Warfare Systems Technology

While neither of these applications has been fully proven, a Naval Innovative Science and Engineering basic and applied research project is developing and experimenting with the building blocks to make them a reality. At the Seawater Remote Sensing Laboratory located on the NASA Langley Research Center in Hampton, Va., the research team has:

- Evolved a series of seawater electrode designs to achieve desired electrical and acoustic properties in an adjustable acoustic dipole wire electrode assembly
- Developed high-voltage and high-frequency signal generation and measurement capability
- Collaborated with researchers from the Virginia Institute of Marine Sciences in Gloucester, Va., to develop an in-situ measurement capability for suspended sediments.

The team's initial seawater electrode design was based on some electrode assemblies that other researchers had used to test underwater electrical communication signals. Strange effects take place as the voltage to the electrodes is increased. At the lowest levels there is no observable effect. Then gas bubbles began to appear from the action of electrolysis. At higher voltage levels, acoustic tones begin to be produced. Finally, at even higher voltage levels the sound becomes quite chaotic and filled with harmonics as nonlinear dynamic behavior takes over.

In an experimental setup using a seawater test bath, bursts of high-voltage, high-frequency energy are applied to the seawater electrodes. This produces acoustic tone bursts in the water surrounding the electrodes that travel through the water to the acoustic hydrophone at the other end of the bath. We made our initial measurements in the seawater test bath before moving to the larger and longer 100-gallon seawater tank.

The Way Forward

Submarines and other underwater vehicles of the future that can maintain acoustic situational awareness while cruising at high speeds submerged could prove to be a decisive element in the underwater game of cat and mouse. In addition, sensors mounted on underwater vehicles will be able to measure and characterize the sedimentation dynamics critical to understanding marine in-shore environments. Researchers at Space and Naval Warfare Systems Center Atlantic will have gained hands-on knowledge and expertise that can be reapplied to solve the Navy's next generation of problems and challenges.

About the author:

Michael McBeth is the Navy-NASA science and technology collaboration lead assigned to NASA Langley Research Center in Hampton, Va. His research interests include underwater acoustics, interferometry, electromagnetics, photonics, and space radiation shielding.

BUILDING THE NAVY'S TACTICAL CLOUD

By Wayne Perras

The Office of Naval Research's (ONR's) Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance Department is leading a collaborative effort to develop a Naval Tactical Cloud (NTC) that leverages significant investments in Army and Marine Corps cloud-related science and technology investments. As conceived, NTC will help Sailors and Marines deal better with the huge increase in data available for warfighting planning and execution decisions to naval and joint forces.

This effort is focused on extending and enhancing an existing data processing framework to ingest all maritime warfighting and fleet decision support data (e.g., combat, command and control, surveillance and reconnaissance, and logistics data) into the NTC architecture on all naval platforms. The NTC infrastructure and data science work involves developing and refining complex models to achieve data interoperability and near-real-time analytics. This will improve combat identification, indications and warnings, and enemy intentions/locations prediction, as well as enhance tactical cyber defense.

The Office of Naval Research also is developing NTC capabilities to support ship-to-ship and ship-to-shore NTC connections during disconnected, interrupted, and limited-bandwidth communications and networking tactical warfighting conditions. NTC-developed capabilities will be rigorously assessed through a series of experiments to enable partners from the Navy, Army, and Defense Department to field prototypes for fleet/joint force use in mid- to late 2015. NTC will transition to the fleet in fiscal year 2016, relying on previous deeply analytic experiments and prototyping to reduce the risk for rapid fleet-wide NTC introduction.

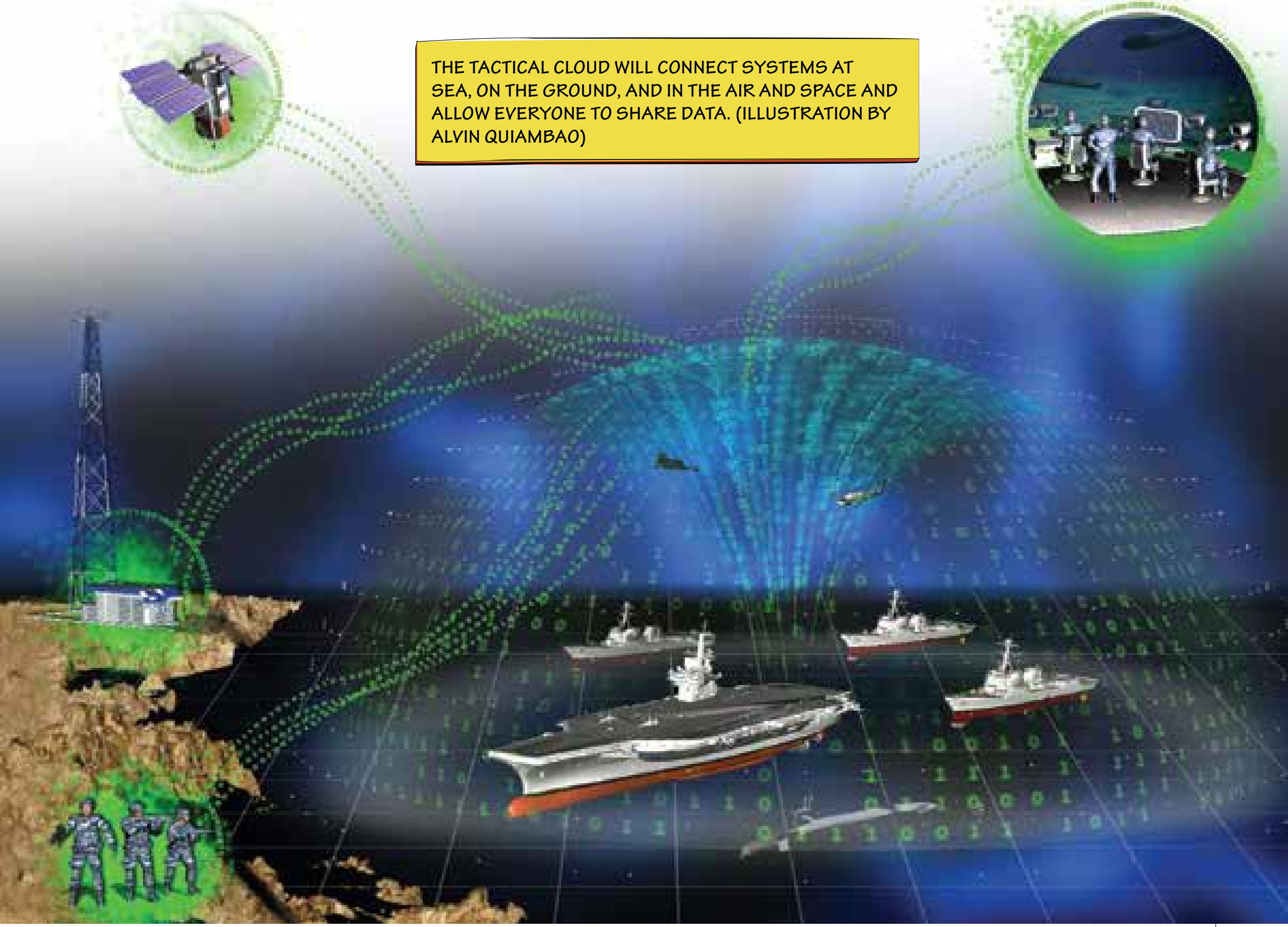
Multiple partnerships are helping to bring NTC capabilities to the fleet and force:

Army Communications-Electronics Research, Development, and Engineering Center Intelligence and Information Warfare Directorate: ONR is collaborating closely with the Army to prepare the Quick Reaction Capability Intelligence Community Information Technology Enterprise pilot for transition to the Army's and Navy's Distributed Common Ground Systems. This partnership is focused on aligning the NTC data science associated with the universal cloud data ecosystem with evolving Army and Marine tactical cloud activities. It will promote intelligence, surveillance, and reconnaissance interoperability across Navy, Army, and Marine Corps forces and eventually extend to command and control, combat systems, and mission command tactical interoperability across the joint force.

Navy Tactical Exploitation of National Capabilities: NTC will support a critical cloud-based suite of analytic tools, leveraging all intelligence collection systems afloat (such as ships' signal exploitation equipment and full-motion video) with the ability to fuse tactical data with off-board national system sources in near real time. Prototype capabilities will be deployed to fleet units as early as this fall to enable ship signals intelligence collection and analysis at the tactical edge. This pathfinder activity ultimately will provide technology improvements for fleet maritime operations centers to store, process, exploit, and disseminate an exponential increase in data available to fleet units.

Air Force and Navy Tactical Exploitation of National Capabilities: NTC will be the foundational infrastructure to develop a Pacific Command prototype that will perform mission-critical modernization of joint information systems as part of an initial Defense Tactical Cloud. This cloud will support all-source, enhanced air and maritime situational awareness with signature- and behavior-based identification and intent, leading to improved intelligence, surveillance, and reconnaissance and targeting kill chains. The prototype will be deployed to the command in mid-2015. This also is the transition path for NTC-employed cyber security products that ONR will begin developing later this year.

Commander, 10th Fleet: This initiative provides a Navy cyber situational awareness prototype for fielding at cyber facilities ashore in fiscal year 2015 that will use



THE TACTICAL CLOUD WILL CONNECT SYSTEMS AT SEA, ON THE GROUND, AND IN THE AIR AND SPACE AND ALLOW EVERYONE TO SHARE DATA. (ILLUSTRATION BY ALVIN QUIAMBAO)

NTC infrastructure and data services to support mission-critical cyber data alignment and real-time analytics. The prototype will support improved cyber situational awareness across Navy enterprises for spectrum, transport, information assurance, and computer network defense. This will improve near-term mission readiness assessments and affect mitigations for Fleet Cyber Command and Commander, Pacific Fleet.

Deputy Chief of Naval Operations for Information Dominance: ONR will deliver NTC capabilities by the end of fiscal year 2015 to support a prototype from this command to the fleet by fiscal year 2016 as the pathfinder for advanced Navy's Distributed Common Ground Systems Increment 2, Maritime Tactical Command and Control, and the Navy Integrated Tactical Environmental System Next programs. This sponsored prototyping effort will parallel previous efforts with Commander, Pacific Fleet, that accelerated enhanced command-and-control capabilities to the fleet.

Office of Naval Intelligence/National Maritime Intelligence Center: NTC data services provide the foundational infrastructure for the center developing a cloud prototype in fiscal year 2015. This will improve maritime domain awareness through automated vessel alerting, including event, cargo, people, and equipment data relationship creation. This also will create real-time analytics that augment indications and warning, battlespace awareness, and support to other naval intelligence missions.

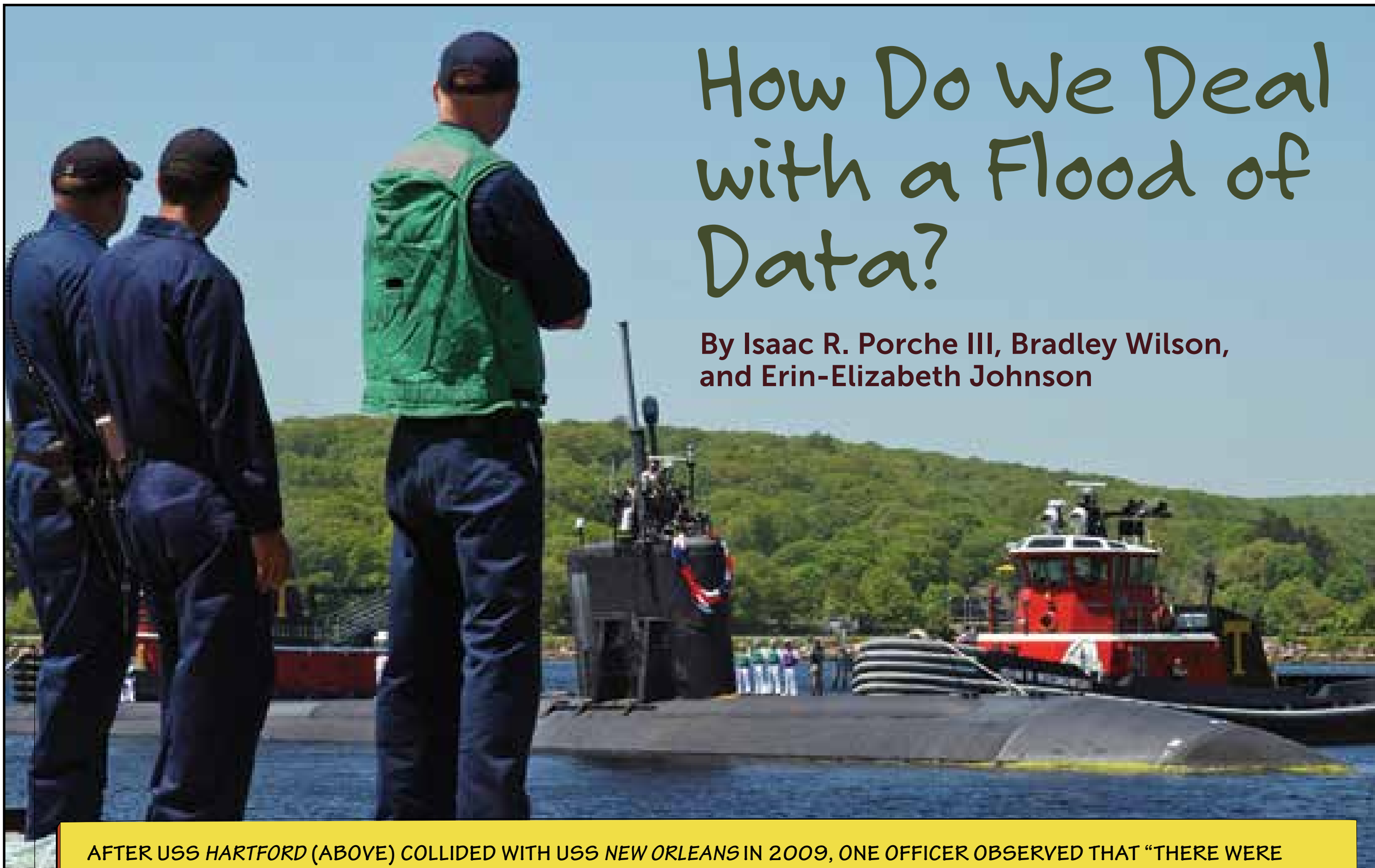
ONR's science and technology effort will provide unprecedented data access, analytics, and interoperability that will help build advanced warfighting concepts such as air-sea battle, cyber defense, and integrated fires for the fleet and joint forces. This effort relies on efforts by ONR in collaboration with its many partners to realize risk reduction, rapid prototype capability fielding, and experimentation to transition NTC into programs of record.

About the author:

Wayne Perras is a senior advisor for experimentation for the Office of Naval Research.

How Do We Deal with a Flood of Data?

By Isaac R. Porche III, Bradley Wilson, and Erin-Elizabeth Johnson



AFTER USS *HARTFORD* (ABOVE) COLLIDED WITH USS *NEW ORLEANS* IN 2009, ONE OFFICER OBSERVED THAT "THERE WERE A WHOLE LOT OF WATCHSTANDERS THAT FAILED TO RECOGNIZE THE SENSOR DATA PRESENTED TO THEM." (PHOTO BY MC2 PETER D. BLAIR)

U.S. Navy intelligence, surveillance, and reconnaissance (ISR) functions have become critical to national security over the past two decades. Within the Navy, there is a growing demand for ISR data from drones and other sources that provide situational awareness, which helps Navy vessels avoid collisions, pinpoint targets, and perform a host of other mission-critical tasks.

Despite the battle-tested value of ISR systems, however, the large amount of data they generate has become overwhelming to Navy analysts. As the Intelligence Science Board wrote in 2008, referring to the entire Department of Defense, "the number of images and signal intercepts are well beyond the capacity of the existing analyst community, so there are huge backlogs for translators and image interpreters, and much of the collected data are never reviewed."

In the coming years, as the Navy acquires and fields new sensors for collecting data, this "big data challenge" will continue to grow. Indeed, if the Navy continues to field sensors as planned but does not change the way it processes, exploits, and disseminates information, it will reach an ISR "tipping point"—the moment at which intelligence analysts are no longer able to complete a minimum number of exploitation tasks within given time constraints—as soon as 2016.

How Big Is Big?

To understand how big "big data" is, think about the volume of information contained in the Library of Congress, the world's largest library. All of the information in the Library of Congress could be digitized into 200 terabytes, or 200 trillion bytes. Now consider the fact that the Navy currently collects the equivalent of a Library of Congress' worth of data almost every other day.

Technically, the amount of data that can be stored by traditional databases is unlimited. The more data being collected and shared, however, the more difficult mining, fusing, and effectively using the data in a timely manner becomes. In the Navy, where analysts use data to create information that informs decision making, this challenge is particularly troublesome. All data and information collected by the Navy is potentially useful, but processing this information and deriving useful knowledge from it is severely taxing the analytical capabilities of the Navy's personnel and networks. As the Navy acquires and fields new sensors for collecting data, this difficulty will grow.

Increasingly unable to process all of its own data, the Navy has little hope—if nothing changes—of exploiting all of the potentially useful data in the greater digital universe, which is billions of terabytes large and constantly growing. Commercial, government, and other sources, such as Twitter, GeoEye, and the National Oceanic and Atmospheric Administration, to name but a few, create hundreds of terabytes of potentially useful data every day. But how much of it can be made useful to the Navy?

A Big Data Opportunity

ISR systems are highly valued in the Navy—and across the military—for good reason. The data collected provide commanders with information on enemy positions and activities. They enable warfighters to locate targets with precision. They provide vital information about the location of friendly forces. Former Air Force Deputy Chief of Staff for ISR Lt. Gen. David A. Deptula (Ret.) has predicted that ISR will "lead in the fight" in 2020. He also has suggested that "ISR is currently moving from a supporting capability to the leading edge of national security operations."

Like other services, the Navy sees data collected through ISR as essential to situational awareness—a vital technological advantage. The Navy hopes to realize the Office of the Director of National Intelligence's definition of big data: the enabling of "mass analytics within and across data...to enable information integration."

among a number of radar contacts: "There were a whole lot of watchstanders that failed to recognize the sensor data presented to them."

As this example demonstrates, situational awareness is critical to naval operations, and the Navy needs to improve its ability to make sense of the data that growing numbers, and growing varieties, of sensors provide. Indeed, as the Intelligence Science Board reported in 2008, "integrating data from different sensors and platforms" could "dramatically enhance" geolocation and other important tasks. So what, exactly, is preventing the Navy from reaping the benefits of ISR-provided data?

Barriers to Benefitting from Big Data

Today, as little as 5 percent of the data collected by ISR platforms actually reaches the Navy analysts who need to see it. In the case of analysts working afloat on ships, a large part of the problem is attributable to extremely slow download times caused by bandwidth and connectivity limitations. Analysts face other challenges to the timely consumption of data, including having to share access to communications pipelines with other organizations and having to download multiple pieces of large data (such as high-resolution images) to find exactly what they need. Most of the time, analysts do not have the luxury of receiving the "right" data in a timely fashion.

> WE'RE GOING TO FIND OURSELVES IN THE NOT TOO DISTANT FUTURE SWIMMING IN SENSORS AND DROWNING IN DATA.
>
> —RETIRED AIR FORCE LT. GEN. DAVID A. DEPTULA

The Navy's ISR cycle (consisting of tasking, collection, processing, exploitation, and dissemination) is not undertaken for its own sake but with a clear, vital objective: providing the fleet with situational awareness. In military operations, knowledge is power. In the Navy, it is situational awareness—derived, in part, from ISR data—that gives commanders that power by helping them answer four critical questions: Where am I? Where are my friends? Where is the enemy? Where is everyone else?

An inability to answer any of these four questions can be disastrous. Consider the case of USS Hartford (SSN 768), a submarine that collided with USS New Orleans (LPD 18), an amphibious transport ship, in the Strait of Hormuz in 2009. The accident left 15 Sailors injured, thousands of gallons of diesel spilled, and $100 million in damage. In a Navy Times report on the incident, a senior Navy officer attributed part of the blame to analysts' inability to discern

Today's analysts also face a wide variety of data streaming in from different platforms and sensors—data they must integrate (or fuse) to ensure accurate, comprehensive situational awareness. Their workstations comprise multiple screens, each showing different streams of data and each loaded with different suites of tools. In many cases, the applications, databases, and operating systems underlying these tools are produced by different vendors and are not interoperable. Sailors told us they are overwhelmed as they struggle to master the functions provided by each tool in the suite at their workstations.

Another challenge is the existence of multiple and often mutually exclusive security domains (different classification levels). Some ISR platforms are designed to feed all of their data into a specific database that resides in a specific, isolated security domain, regardless of whether all the individual pieces of data collected by that platform really need to be classified at that particular level. For analysts, this means that searching for a single piece of data can require multiple networks to access multiple databases—a dampener on productivity and a dangerous situation, given that achieving accurate situational awareness requires integrating data from multiple sources in a timely fashion. Common wisdom among analysts is that they spend 80 percent of their time looking for the right data and only 20 percent of their time looking at the right data.

One Option: Dynamically Managing Workloads

Despite the anticipated growth in incoming data, the Navy has no plans to increase the number of analysts it employs. One option for ensuring that Navy analysts are better able to cope with big data is dynamically managing their workloads. Today, the Navy's intelligence specialists are, for the most part, working on "local tasks," since task allocation tends to be based on which analysts are nearby, or statically assigned, rather than on who is available to accept new tasking. The main disadvantage of today's fixed, geographically based tasking arrangements is that intelligence specialists in one location can become quickly overwhelmed with tasks that need not necessarily be assigned to them but that, because of the local tasking model, come their way by default.

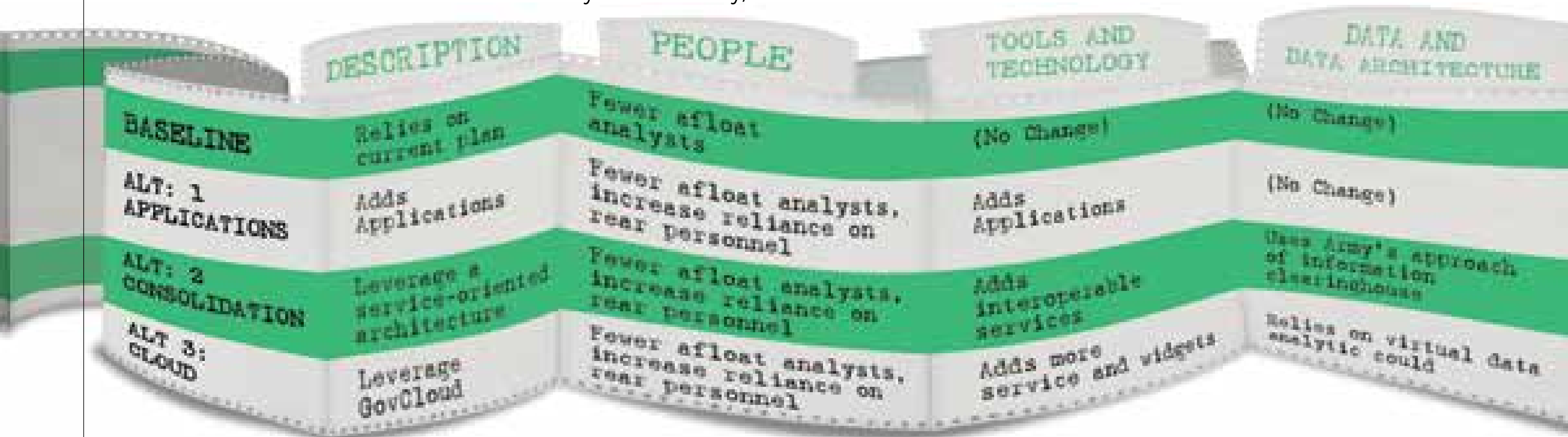
What if the Navy were to consider implementing a regional or even global tasking model instead? In these models, tasks would be automatically shared and allocated within regions, or globally in the latter case, based on who is available to accept new tasking.

RAND researchers developed a model of intelligence specialist productivity and, using a year of operational data, found that the regional and global tasking models improve intelligence specialist productivity. However, this is true only to a certain extent. As the number of ISR sensors and platforms increases, all three models eventually dip down, revealing that imagery analysts simply will not be able to keep up with all of the imagery coming their way, no matter how we balance their workloads.

Implementing a regional or global tasking model may buy the Navy a short-term improvement in analyst productivity, but, clearly, changes to how workloads are managed are not, on their own, a viable long-term solution. More comprehensive alternatives to solving the big data challenge are therefore required.

Alternatives for Dealing with Big Data

To be complete, a solution to the Navy's big data challenge must involve changes along all of the following four dimensions: people; tools and technology; data and data architectures; and demand and demand management. In conducting an analysis of alternatives for the Distributed Common Ground System–Navy Increment 2 (a system intended to help the Navy address the influx of data), we developed three potential alternatives (described above in Figure 1). Relative to the baseline, each increases the Navy's ability to better manage and use the rising flood of ISR data. All three alternatives assume that the Navy begins to dynamically manage analysts' workloads and that sensors are cued smartly.



How Well Do the Alternatives Perform?

Modeling and simulation reveal that all three alternatives outperform the baseline when it comes to finding the greatest number of targets in the smallest amount of time—a performance metric that indicates how quickly a commander can be made aware of the targets around his or her area of command. The baseline results in the lowest percentage of targets found when using data of a single intelligence type. Alternatives 1, 2, and 3 outperform the baseline, with alternative 3 (cloud) resulting in the greatest number of targets found most quickly.

A similar result is found when looking at the percentage of targets found across time given data of multiple intelligence types. In this case, analysts are fusing data from two or more intelligence sources—a process that improves the accuracy or "veracity" of a commander's situational awareness. Once again, alternatives 1, 2, and 3 outperform the baseline, but alternatives 2 and 3 offer significant improvements over both the baseline and alternative 1.

Recommendations

A solution to the Navy's big data challenge must involve changes along all four dimensions. This means that the Navy needs more than just new tools—it needs an approach to integrate them and make them more interoperable. The Navy also needs more than an adjustment in the number of analysts at each site—it needs to manage analyst workload dynamically. And the Navy should do more than just increase the number of distinct intelligence sources that are available—it needs a means to make them easy to find.

We recommend that the Navy pursue alternative 3—a cloud strategy similar to those adopted by Google, the intelligence community, and other large organizations grappling with big data's challenges and opportunities. This alternative offers significant potential performance improvements despite some technical and schedule risk. It is also (arguably) the alternative most amenable to future changes in information technology tools and applications.

We also recommend that the Navy adopt the intelligence community's cloud approach, designing its next generation of ISR tools and systems to work with the National Security Agency's distributed cloud concept (i.e., the Intelligence Community GovCloud). This information architecture should be sufficient to meet the growing volumes of data and thus enable viable tasking, collection, processing, exploitation, and dissemination operations in the future—even in a disconnected, interrupted, and low-bandwidth environment. Integrating and leveraging a distributed cloud architecture will enable some reachback for analysis and help analysts cope with the increasing variety and volume of data, thereby improving their ability to help commanders make better decisions. Although alternative 3 involves an increased reliance on personnel and analytic capability "from the rear," the Navy should embrace this dependency in order to reap the full benefits of the cloud solution.

THIS STUDY LOOKED AT A BASELINE AND THREE ALTERNATIVES FOR HANDLING ISR DATA (ABOVE): THE ADDITION OF APPLICATIONS; CONSOLIDATION USING AN EXISTING ARMY ARCHITECTURE; AND A CLOUD-BASED SOLUTION THAT LEVERAGES GOVCLOUD.

Note: This article is adapted from Isaac R. Porche III, Bradley Wilson, Erin-Elizabeth Johnson, Shane Tierney, and Evan Saltzman, *Data Flood: Helping the Navy Address the Rising Tide of Sensor Information* (Santa Monica, Calif.: RAND Corporation, 2014). It contains copyrighted material. The full report can be accessed at www.rand.org/t/RR315.

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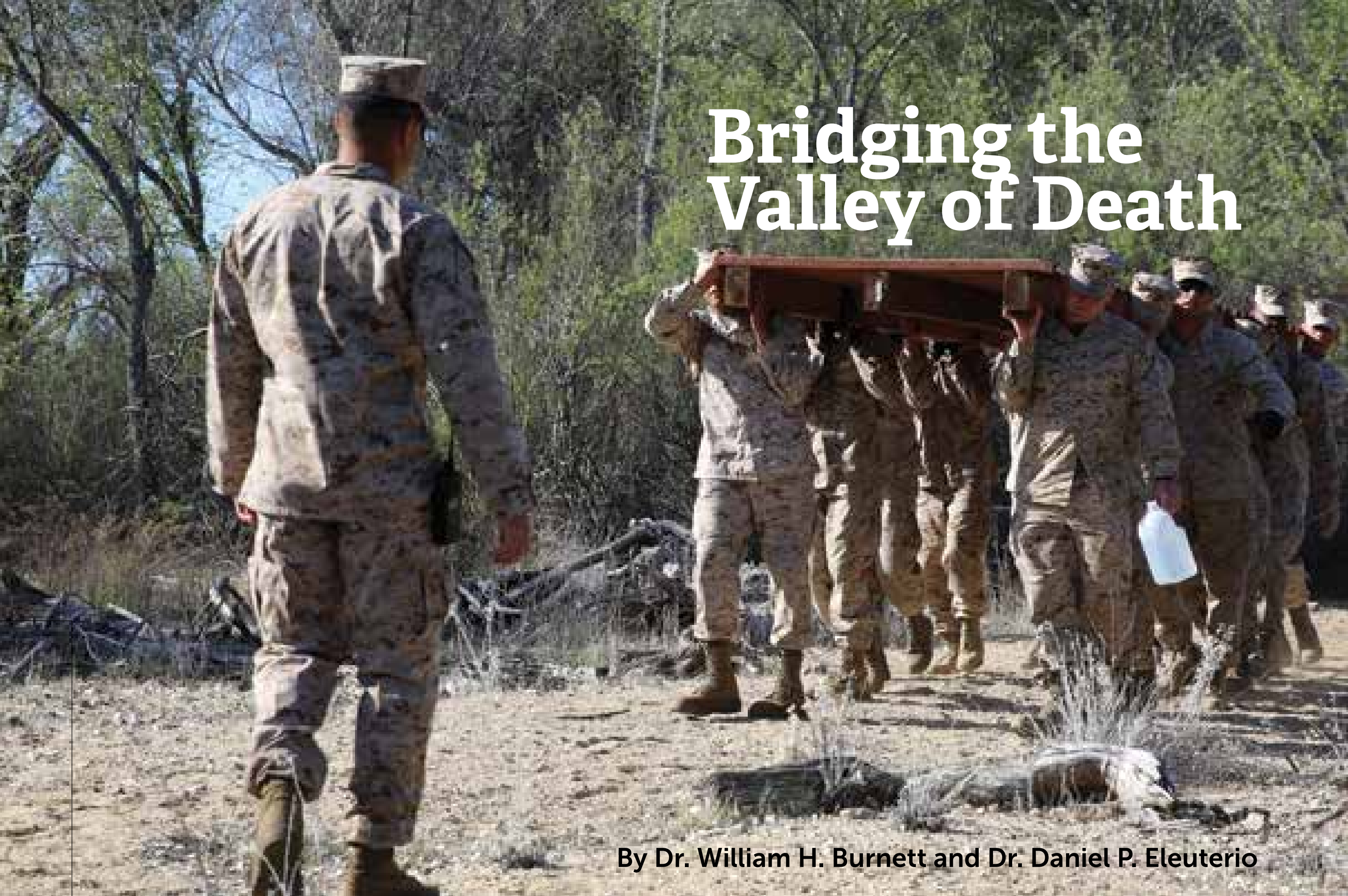


Bridging the Valley of Death

By Dr. William H. Burnett and Dr. Daniel P. Eleuterio

Getting new information dominance projects across the acquisition pipeline's valley of death can be as daunting as any new technology—but it can be done.

The Navy's Information Dominance Corps (IDC) can prepare now for successful transitions of research to operational use in the fleet by utilizing a coordinated, cross-enterprise, team-based strategy developed by the Naval Oceanography Program—and avoiding the long and often painful transitional period known as the "valley of death." The rapid changes in software technologies make these kinds of bridging governance structures and accelerated acquisition especially important to the IDC relative to other warfare enterprises. Just as a game of baseball requires equipment and players, effective transitions from science and technology to research and development (and ultimately to operations) need flexible budgets (the equipment) and integrated government support (the players) for a successful enterprise solution.

Study after study has documented the painful reality of the valley of death. In 2004, the Department of Defense asked the National Research Council to investigate the reasons behind the painfully long transition times to move technologies from research into operations, many of which have taken 10 years or more. "Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems" made three key recommendations: create a culture for innovation and rapid technology transition; establish methodologies and approaches to adjust the risk/reward relationship of the military customer and its suppliers to work toward the desired operational capability; and develop innovative, enabling design tools, software, and standardized databases.

Lack of coordination between the developer and the operator, different funding lines and governance of research and development, and changing operational needs and priorities are just some of the causes for the valley of death. As members of the Naval Oceanography

Photo by Sgt. Melissa Wenger

Program have learned, however, all of these factors can be mitigated through an aligned, clearly defined transition process that involves all the stakeholders and meets fleet needs and requirements.

Figure 1 illustrates the valley created by funding, programmatic, and schedule shortfalls across the research, development, testing and evaluation (RDT&E) spectrum and into operations because of a lack of coordination between various developmental organizations (such as the RDT&E sponsors at the Office of Naval Research and the Office of the Chief of Naval Operations, and the execution agents at the program executive offices) and the type commanders. Part of the valley is caused by a lack of coordination between the developer and the operator (i.e., the pitcher and the catcher in our baseball analogy), different funding lines and governance structures, and changing operational needs and priorities. Everyone knows that for a team to win a baseball game, the pitcher and catcher must communicate and stay on the same game plan. The same is true for the Information Dominance Corps and the transfer of technologies to operations. To extend the analogy a bit further, it is important that the catcher wear the correct mitt to catch the ball. Too often, developers launch into a new technology that addresses a fleet operator's requirement, only to find out that the technology is outdated or is unsupportable once it is ready to be tested and fielded. And so the ball gets dropped.

For example, 20 years ago the Naval Oceanographic Office (NAVOCEANO) had a requirement to analyze ocean surface fronts and eddies in the Gulf of Mexico and the North Atlantic to support anti-submarine warfare operations. At the time, NAVOCEANO analysts used a cumbersome in-house software package to extract sea-surface temperature gradients from satellite images and digitize them. Researchers worked on a new software analysis package to make the digitization process more effective and efficient. After several years, they were ready to test the software with the ocean analysts. Unfortunately, because they developed the software without including the scientific analysts from the beginning, it did not operate properly on the new computer equipment installed to support the analysts. The testing failed after six months. In this case, the developers understood the requirement but failed to keep operators informed of their progress. The result was a "dropped ball."

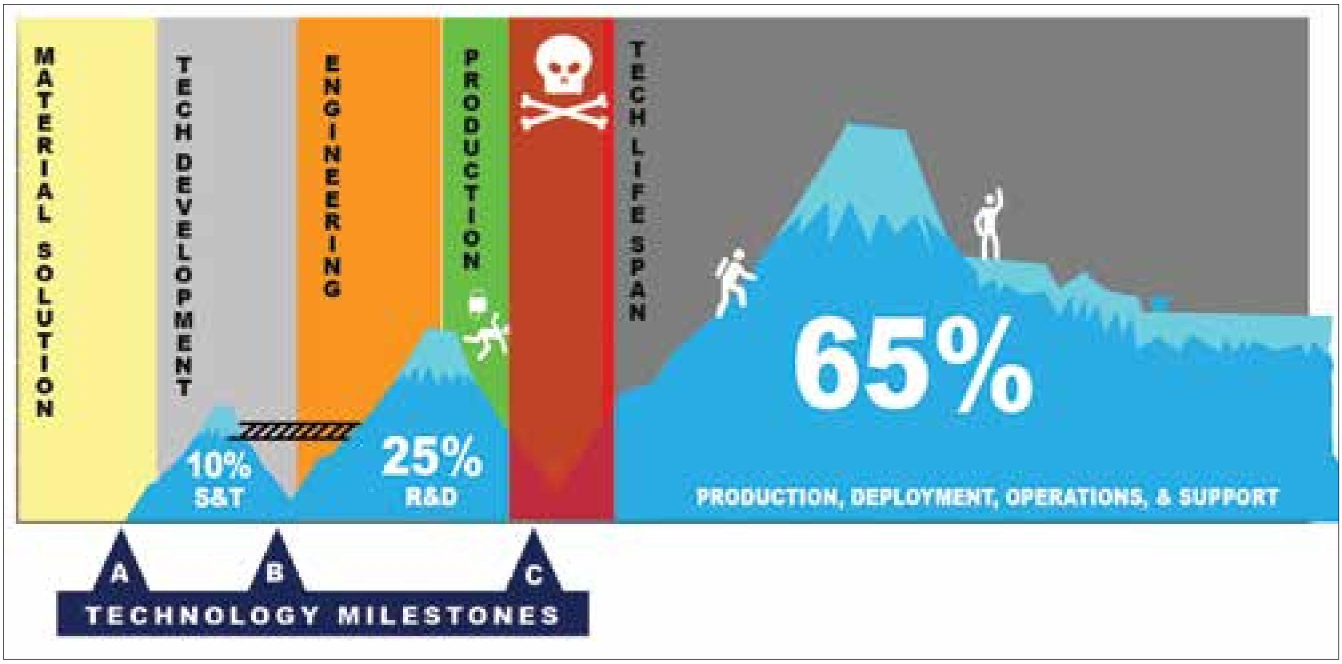
In the late 1990s, the Naval Oceanography program had a much more successful transition when advancing high-performance computing methods at Fleet Numerical Meteorology and Oceanography Center. A change in computing framework, or architecture, was required to increase scientific computing capabilities for atmospheric modeling to meet fleet requirements under a reduced operating (and flat-lined procurement) budget.

To ensure all atmospheric and oceanographic models were quickly, but carefully, transitioned to the new architecture, close coordination was necessary among the Office of Naval Research; the Naval Research Laboratory; Fleet Numerical Meteorology and Oceanography Center; Commander, Naval Meteorology and Oceanography Command; and the Oceanographer of the Navy resource sponsor. This partnership and coordination was important because numerical environmental prediction programs are extremely large and complex software systems—so it is somewhat analogous to a mid-life or extended service life upgrade for a major warfighting platform.

One difficulty in coordinating the different stakeholders was determining which group was responsible for paying for which part of the code update. Enhanced code for existing architecture was already funded by research and development dollars. Funding for a "scalable" code conversion was not clear-cut, and various members disagreed about which group should be responsible for funding that part of the program. The transition was falling quickly into a valley of death that would cause catastrophic failure for the Naval Oceanography Program.

Fortunately, the Department of Defense had the High Performance Computing Modernization Office (HPCMO) available to help out in circumstances such as these. The HPMCO is a technology-led, innovation-focused program committed to extending high-performance computing to address the most significant challenges in computational resources, software application support, and nationwide research and engineering networks. HPCMO officials understood the difficulties many high-performance computing agencies experience while transitioning software use and design, so they funded the development of code with an emphasis on reusability, scalability, portability, and maintainability. The HPCMO also trained scientists and engineers to understand and use scalable software techniques to reduce future costs of doing business and increase future defense capabilities. Through this team effort and targeted funding, the Fleet Numerical Meteorology and Oceanography Center converted all of their atmospheric and oceanographic models to the new scalable architecture on schedule and under budget.

FIGURE 1: THIS GRAPHIC DEPICTS ONE VIEW OF THE CATEGORIES OF RESEARCH, DEVELOPMENT, TESTING, AND EVALUATION (RDT&E) FUNDING AND THE VALLEY OF DEATH. THE VALLEY IS THE SEAM BETWEEN RDT&E TECHNOLOGY MATURATION AND TRANSITION. THIS MOST OFTEN OCCURS AT MILESTONE C IN FIGURE 1 WHEN THE CAPABILITY BEGINS TO IMPACT PROCURE-MENT FUNDING AND PERSONNEL, BUT CAN ALSO OCCUR AT MILESTONE B IN THE TRANSITION FROM SCIENCE AND TECHNOLOGY (S&T) TO RESEARCH AND DEVELOPMENT (R&D).



The Naval Oceanography Program's leadership institutionalized new processes from this successful team approach, and created a Standing Acquisition and Coordinating Team (SACT) composed of members from the various sponsors and execution agents, and chaired by the Oceanographer of the Navy.

The SACT conducts a deliberate, continuous assessment and coordination process. The team advises the Naval Oceanography Program on efforts pertaining to the effectiveness of coordinated science and technology, research and development, programs of record, and development activities in meeting warfighter and fleet needs and requirements. This team effort facilitates the effective and application of resources through cross-program communication and coordination.

Within information dominance's battlespace awareness pillar, the SACT ensures all parties work together using agreed-upon roadmaps aligned to the Naval Oceanography Program's Battlespace on Demand and its four tiers. The roadmaps within each tier will support both the Chief of Naval Operations' sailing directions and navigation plans—warfighting first, operate forward and be ready—and address all three information dominance pillars for operational advantage: assured command and control, battlespace awareness, and integrated fires.

A thorough transition plan ensures both research and development and operations are aligned. Principal investigators develop plans while collaborating with operational technical points of contact to specify key components. The principal investigators or software developers are obligated to note what requirement is addressed by the transferred technology, the acceptance criteria between the two organizations (developer and operator), types of computing resources needed, anticipated training requirements, quality-assurance plans, and predicted follow-on upgrades. The plan also provides a work breakdown structure with actions and milestones to track work completed during the transition. All stakeholders—developer, operator, resource sponsor, and operational agency lead—sign the transition plan.

Accelerated acquisition has been used in various cases across the Navy with excellent results, and is especially applicable in the information dominance domain because of both the rapid evolution of computing environments and the significantly lower material and logistics costs after Milestone C for software-only and less-hardware-focused technologies. A cross-enterprise governance and coordination practice such as the SACT should be considered by other components of Program Executive Office Command, Control, Communications, Computers, and Intelligence. There is a similar and relevant structure for rapid technology insertion for acoustic signal processing called the Advanced Processor Build process in Program Executive Office Integrated Warfare Systems. Accelerated acquisition with fleet user assessment also has been used to great effect in command and control (C2) systems under the C2 Rapid Prototyping Capability program, where the dissemination and visualization of environmental forecasts were among the first successful segments and the systems was evaluated in stride by Pacific Fleet watchstanders while the software engineers and developers could still make significant changes to the prototype architecture.

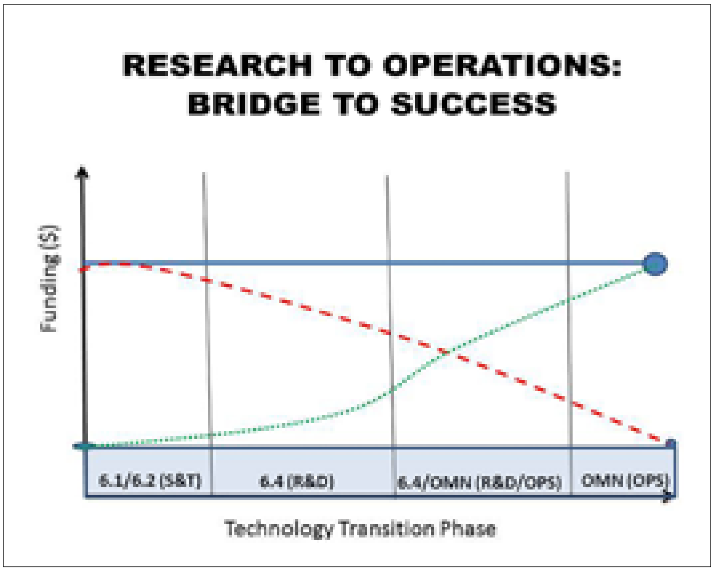


FIGURE 2: TO AVOID THE VALLEY OF DEATH, THERE MUST BE A STABLE FUNDING PROFILE. THE BLUE SOLID LINE SHOWS THE OVERALL FUNDING PROFILE, THE RED DASH LINE IS THE RESEARCH AND DEVELOPMENT FUNDING LINE, AND THE GREEN DOTTED LINE IS THE OPERATIONS AND MAINTENANCE LINE.

There are several transition programs for the interface between science and technology and research and development—such as the Future Naval Capabilities, Rapid Technology Transition, Speed to Fleet, and even the Naval Oceanography Program's internal Rapid Transition Program— but funding for the transition from research and development to operations seems to be the most problematic. As identified in Figure 1, research and development resources taper off toward the end of a transition project, just as operations and maintenance funding starts at a minimum level. Figure 2 depicts a more realistic and executable funding profile.

The Office of Naval Research, Naval Research Laboratory, and the Office of the Chief of Naval Operations represent the majority of Naval Oceanography and Meteorology Command's funding sponsors for new and improved capabilities, but other possible sponsors exist within the information dominance community and at outside agencies (e.g., HPCMO, National Geospatial Intelligence Agency, National Oceanographic and Atmospheric Administration, and Defense Advanced Research Projects Agency) in our high-performance computing architecture example. These groups must communicate, responsibilities must be clearly delineated, and funding resources identified.

As information dominance matures and manages new technologies, resource sponsors from basic research to operations and maintenance must work through the requirements process to develop a transition vision that is effective, efficient, and responsible toward fleet needs. The Naval Oceanography Program's model of a successful transition strategy can be adapted to the entire Information Dominance Corps.

In baseball, when the pitcher and catcher are on the same page and have the right equipment, the thrown ball is caught properly. In information dominance technology transitions, the right communication, plans, and funding ensure that the right technology gets to the right operators on time and budget to meet fleet needs and requirements and enable decision superiority. And that's a winning formula in any league.

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Cool Runnings: New Sensors Take the Cold Road

By Dr. Benjamin Taylor and Elisha Gamboa

Making information dominance a reality requires advanced technology that will enhance existing signal intelligence (SIGINT) capabilities and give operational forces a strategic communications advantage on the battlefield.

Over the years, the number of topside antennas aboard U.S. Navy ships has grown significantly, even though the space available has not. The abundance of topside antennas interferes with receiving critical data, creating problems such as antenna blockage, electromagnetic interference, and increased enemy awareness of Navy combat ships.

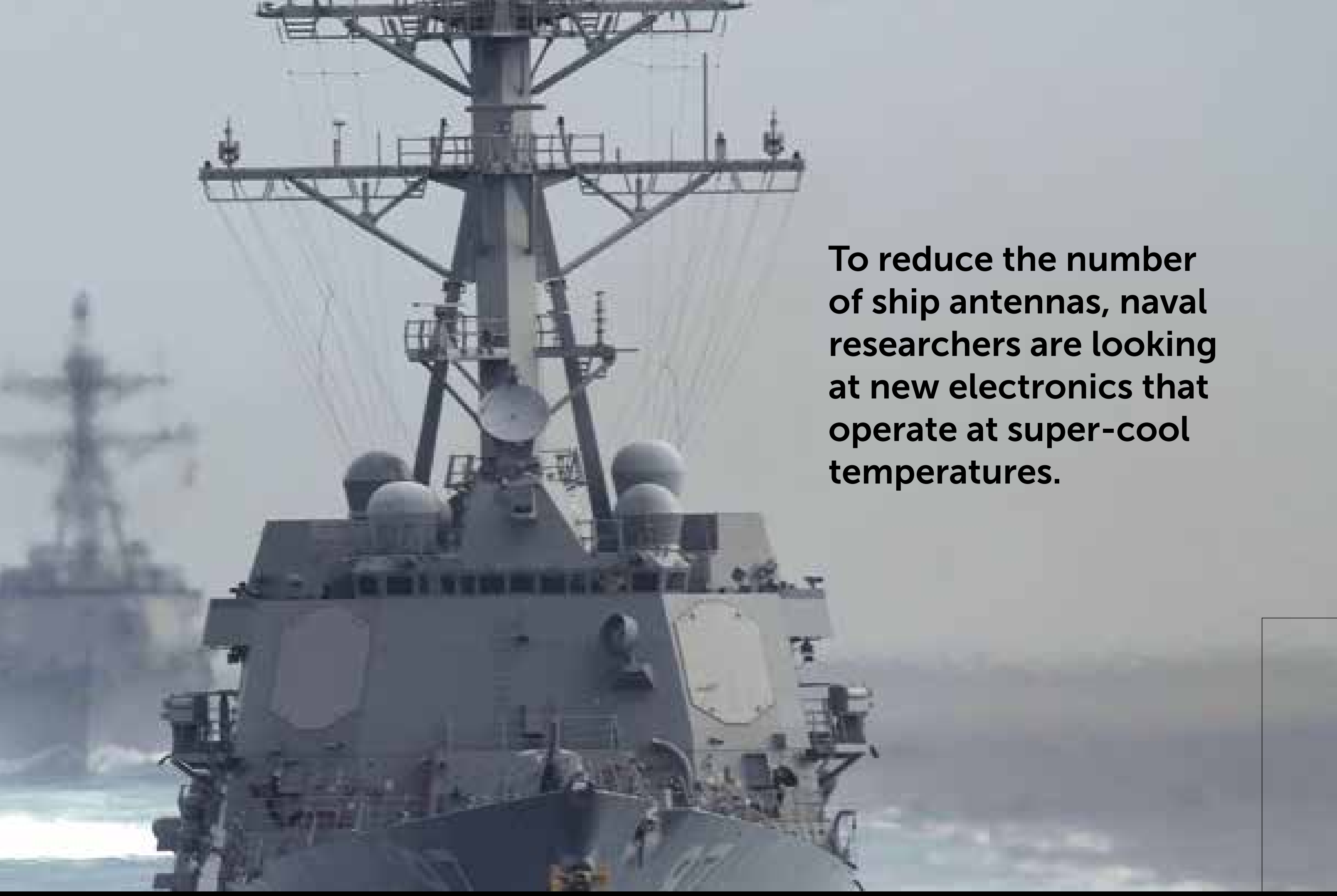
Space and Naval Warfare Systems Center (SSC)Pacific is working to develop a sensor that will aid in reducing a ship's topside antenna profile, enhance existing battlefield information capabilities, and extend the SIGINT domain. The compact, highly sensitive broadband radio frequency (RF) sensor offers frequency-selective capabilities for Navy ships and other key platforms.

Over the past few years, the SSC Pacific Cryogenic Exploitation of Radio Frequency (CERF) lab, with support from the center's Tactical SIGINT Technology program, has been building a full-spectrum, state-of-the-art electronics and experimental device test facility. The lab characterizes and certifies in-house and external RF devices and electronics.

In addition, the lab conducts research and development of advanced RF sensors, devices, and electronics that exploit the properties of superconducting (and other novel) materials that must be operated at cryogenic temperatures.

The CERF lab has collaborated with the University of California, San Diego, in research to develop a superconducting quantum interference device (SQUID)-based RF sensor. The sensor consists of arrays of interconnected SQUIDs that perform together as an interference device, often called a SQIF (superconducting quantum interference filter) RF sensor.

These sensors are low-power receivers that are highly compact and lightweight. They are sensitive and have a noise floor far below conventional state-of-the-art electronics. They also can detect almost the entire RF spectrum. The sensor's true broadband nature and high sensitivity deliver a more complete picture of events and increase warfighter awareness, significantly enhancing command and control capabilities and SIGINT performance.



To reduce the number of ship antennas, naval researchers are looking at new electronics that operate at super-cool temperatures.

FOR MILITARY PLANNERS, THE MOST CRITICAL ELEMENT OF INFORMATION DOMINANCE IS INFORMATION CONTROL.

Supported by SSC Pacific's Naval Innovative Science and Engineering basic and applied research program, the project is now at the proof-of-concept stage. The goal is to field the SQIF RF sensor to provide the Navy with an improved and highly advanced intelligence, surveillance, and reconnaissance capability in the maritime domain.

The compact size of the complete SQUID array sensor package makes it suitable for use as SIGINT, communication, targeting, position, navigation, and timing systems on platforms including submarines, surface ships, aircraft, unmanned aircraft, and high-altitude craft. As an example, a SIGINT operator/platform would be able to extend the standoff distance for interception of signals from a region of interest, making detection of the Navy asset less likely.

The broadband nature of the sensors brings benefits to the warfighter across a wide range of RF spectrum-defined scenarios. Through increased area of coverage, number of signals detected, probability of signal detection, and a reduced time to search and target a source, vital battlefield awareness and control is extended for the warfighter.

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Elisha Gamboa is a staff writer for Space and Naval warfare Systems Center Pacific's Public Affairs Branch, and a technical writer for the Publications Branch.

►► By Michael August, Darren Powell, Chris Raney, and Charles Yetman

CONNECTING UNMANNED VEHICLES TO THE CLOUD

Photo illustration by Alvin quiambao

A team of scientists and engineers at Space and Naval Warfare Center Systems Center (SSC) Pacific in San Diego is developing unmanned vehicle control systems that could revolutionize warfighters' battlespace awareness capabilities—an important asset in the Navy's goal for information dominance.

"To the Cloud"

"UxV to the Cloud via Widgets" is a science and technology research effort established to demonstrate distributed control of unmanned systems. *UxV* stands for any one of the four categories of unmanned vehicle: ground, air, surface, or undersea. Humans operate these vehicles from remote locations. *Widgets* are user-configured Web applications that provide a limited view into a larger application, similar to windows within a Web browser that display interactive Web applications. The *cloud* is the collective computer power of remotely accessed networked servers and computers—very much like the networks that you access on your cell phone or laptop.

Synthesizing these three distinct technologies presents a novel approach to unmanned vehicle control.

Currently, unmanned vehicles are commanded by dedicated control systems with proprietary hardware, and system software components must be custom-built for each platform. The UxV project challenges that practice by allowing an operator to control multiple vehicles simultaneously within a Web browser.

This project began in 2012 under the direction of SSC Pacific Executive Director Carmela Keeney, with funding from the Naval Innovative Science & Engineering (NISE) program. The NISE program was established in 2009 in legislation passed through the National Defense Authorization Act to fund efforts in basic and applied research, technology transition, workforce development, and capital equipment investment.

Cloud, widget, and unmanned vehicles team members joined forces to design and develop a prototype system using open-source components. The system has a realistic unmanned surface vehicle (USV) simulator, a software interface for controlling the vehicles in the simulator, widgets that provide human operators with a graphical user interface for controlling the vehicles, and a data cloud for storing all of the data received from the vehicles.

The team developed the widgets using the Ozone Widget Framework, an open-source Web application originally developed by the National Security Agency. The cloud implementation is based on Apache Accumulo, an open-source data cloud software bundle with security features. Government employees at SSC Pacific developed all software components of the system.

Capabilities

Multiple personnel can use the system to control an unmanned vehicle and record data in the cloud, and individuals not in control of the vehicle can view the unmanned vehicles' observations. For example, an operator on ship A uses widgets on a control dashboard to send commands to the unmanned vehicle. An operator on ship B can request control of the vehicle from the operator on ship A. If the operator on ship A agrees with the request, then control is passed to the operator on ship B. As the vehicle is in transit, its sensor data and camera feeds are ingested into the cloud in near real time. An analyst on shore can monitor the archived historical data as well as the live data stream.

Connecting a data cloud to the system to archive the incoming data will allow sharing among operators and analysts, enabling them to pass control from one operator to another and access the vehicle's historical inputs through the cloud.

Software and a set of widgets must reside both ashore and on each ship, and each ship can control a USV directly. The control widgets send commands directly to the USV without going through the cloud, as the time lag of the cloud is too long to perform real-time operations through it. As the operator on board the ship is controlling the USV, its position information, sensor data, and camera imagery are pushed into the cloud stack. These data points in the ship-based cloud stack are shared with other ships and the shore. From these other locations, analysts can open up analysis widgets and inspect the imagery taken from the USV as well as track the USV's position over time. Operators and analysts on board other ships also can launch control and analysis widgets to access this information.

An operator managing the control dashboard within his or her Web browser can see the live feed from the USV's camera. In addition to viewing the feed from the front-facing camera, the operator can see the video feeds from the rear- and side-facing cameras, known as the "quad view," all within a single window. A recent innovation of the control widget features a 3-D "can view," which studies suggest is more intuitive than the 2-D or "quad view."

The operator can use a gamepad controller plugged into the computer to control the vehicle, another modification made from usability studies at the Office of Naval Research. A unified map widget also combines the tactical map and the analysis map into one widget. This map has multiple zoom levels and different layers that operators can toggle on or off, including digital nautical charts for navigation. When in vector mode, the operator controls the vehicle using the gamepad. When in waypoint mode, the operator controls the vehicle by setting waypoints on the map. The operator can click and drag these waypoints around the map, enabling the vehicle to be redirected while in transit.

A single operator can control multiple vehicles displayed on the map with a circle that annotates the vehicle currently under control. Many digital nautical chart features and multiple layers can be toggled on or off. Three types of data—historical, near-real-time, and live—can be displayed on the map simultaneously. The historical data is retrieved from the cloud and displayed alongside the live data on the map. When the mouse is hovered over the vehicle track, a thumbnail of the vehicle's camera feed pops up. The waypoints representing the autonomous route for the USV are displayed on the map as lines.

A controlled vehicle simultaneously places data into the cloud. The data consists of geospatial location and various sensor readings, as well as video feeds from the cameras located on the vehicle. This data is ingested into the cloud and indexed for quick retrieval. As the number of data files ingested into the cloud increases, the size of the cloud grows to accommodate the larger data set. With the appropriate permissions, an analyst in a remote location with network connectivity can access the analysis dashboard. This dashboard consists of various widgets for investigating previous positions of USVs within the analyst's area of responsibility. These include the unified map, data viewer, image viewer, and video widgets. The analyst can click on a point in the map for a particular USV, and the

other widgets automatically display the data associated with that point.

The data viewer widget shows the coordinates and heading of the vehicle, as well as other relevant data. The image viewer widget displays the image taken from the forward-looking camera on the USV at that point in time. The video widget plays the full-motion video captured by the forward-looking camera starting at the point in time at which the analyst clicked on the track. If operators or analysts notice something they would like to analyze in detail later on, they can always come back and view the captured video and imagery and the associated position of the vehicle.

Multiple Applications

Currently in its third year of funding, the team is leveraging existing architecture and components to integrate control of an unmanned aerial vehicle (UAV) with minimal software changes required. Operating multiple UAVs from a Web browser will provide the air community with a flexible architecture for UAV control, and provide a mechanism for sharing

Illustration by Alvin quiambao

both surface and air data among operators and analysts. The team also is extending its full-motion video architecture to generate 3-D models of objects of interest within the camera's field of view, an experimental technology referred to as "Structure from Motion." In addition, social and collaboration widgets are being developed to enable operators and analysts aboard different platforms to communicate with one another directly using widgets within the dashboard.

Some of the technology developed within this project already has been applied successfully to a different domain: the management of logistics data from aircraft. As part of the Comprehensive Automated Maintenance Environment-Optimized project at SSC Pacific, an effort that uses widgets and the cloud is being developed to provide maintenance personnel with a true condition-based-maintenance-plus capability. Condition-based maintenance enables fault patterns in aircraft components to be discovered before a problem arises within the aircraft. This Readiness Integration Center stores sensor data in the cloud for display within widgets. A suite of services that provides visualization and analytics capabilities is currently being built into the system.

The "UxV to the Cloud via Widgets" prototype has successfully demonstrated a novel approach for operating the Navy's growing number of unmanned systems, and for managing and sharing the sensor data generated by those systems. As a NISE technology transition project, "UxV to the Cloud via Widgets" has secured agreements to transition its technology into multiple Navy programs of record for current and future technologies. Transitioning technology into Navy programs in support of the warfighter is the ultimate barometer of success for the NISE program. "UxV to the Cloud via Widgets" combines command, control, communications, computers, intelligence, surveillance, and reconnaissance assets to reduce manning of unmanned systems while enhancing battlespace awareness—a solution for reducing costs while providing superior information dominance capabilities to warfighters.

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A LOOK AHEAD
WARFIGHTER PERFORMANCE

►► Dr. Terry Allard

People are the critical element in complex systems. They provide the ingenuity, collaboration, and determination necessary for operational effectiveness and resilience. The next issue of *Future Force* will address a broad range of research questions and technology transitions that support Sailors and Marines afloat and ashore. These topics include manpower, personnel, training, and design approaches to enhance performance while reducing costs.

Advances in behavioral sciences, medical technologies, and modeling and simulation techniques are enabling new approaches to mission-critical questions such as: How do we train effectively and efficiently, reducing the time and cost of predeployment training? How do we design intuitive systems that are easy to use, reducing the requirement for on-the-job training? How do we support decision making in distributed teams of people and autonomous agents? How do we mitigate the risks of putting our warfighters in harm's way, keeping them healthy and ready to fight? Can we avoid costs by looking at the trade space between people and technology in acquisition and operations?

Manpower and personnel simulations can help us design crew complements for new ships across a range of missions. Artificially intelligent tutoring systems can help new recruits learn basic skills, while adaptive simulation-based training systems tailor training to the needs of individual Sailors and Marines. Immersive and augmented reality displays provide experiential learning opportunities using simulation to train as we fight. Automated performance assessment techniques enable instructors to evaluate readiness at the individual and team levels and to focus their efforts effectively on the knowledge and skill gaps of the individual warfighters where it's needed.

Mission scenario generation, distributed network simulations, and the advent of artificially intelligent forces can provide the capability for integrated fleet training exercises that extend the training ranges virtually and let students take risks not possible with live assets, while reducing the logistical costs of large training exercises. Live, virtual, and constructive training exploits the benefits of real-world platforms and operators interacting with networked simulators and computer-synthesized forces to train on multiple platforms on multiple simultaneous missions. Scenario generation capabilities are becoming so realistic that planners can develop and evaluate new tactics, techniques, procedures, and concepts in simulation.

Intuitive, decision-centric, and user-friendly interfaces and decision support displays can reduce training requirements and associated costs while enabling more effective operational capability. Human-centered design enhances tactical, operational, and strategic decision making and planning. A deeper understanding of human intelligence, communication, and collaboration will enable better team performance and, ultimately, support peer-to-peer collaboration between human and artificially intelligent machines. Models of human social and cultural behavior will help defeat our adversaries and set the stage for more effective humanitarian assistance and disaster relief.

Medical technologies are needed to mitigate warfighter risk at sea, in the air, and in austere isolated environments. Medical modeling and simulation enables improvements in personal protective equipment such as body armor and hearing protection. Closed-loop medical monitoring and control systems can be a force multiplier for the hospital corpsman and field surgeons who may be treating multiple casualties or evacuating Sailors and Marines long distances from the field to a seabase.

Looking ahead, we hope to gather success stories and articulate the enduring challenges facing our Sailors and Marines today and in the future. Contributions to *Future Force* will help the Office of Naval Research shape its November 2014 Focus Area Forum on warfighter performance, one of several gatherings this year that brings the research community together with naval leaders to discuss and find solutions for science and technology challenges. We look forward to hearing your ideas as we formulate our future science and technology investment strategy.

Dr. Allard is the head of the Office of Naval Research's Warfighter Performance Department.

Artwork by Alvin Quiambao

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