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The Critical Role of Science and Technology for National Defense.

By Honorable Zachary J. Lemnios and Mr. Alan Shaffer

We are embarking on a new era in Defense research. Over the past decade we have seen remarkable progress from the computer science research community spurring growth in the fields of robotics, learning and reasoning, language understanding, collective intelligence and other related technologies. These advances are beginning to find their way into new products and are redefining the human-machine interface.

At the same time, industry, academia and the federal government need to engage as a "Research Triple" to advance new technical ideas in response to an emerging set of national security challenges. This "Research Triple" is both a challenge and an opportunity for the Computer Science community and is critically important to the Department of Defense.

A New Landscape

The foundation of the defense science and technology (S&T) enterprise was anchored when Vannevar Bush outlined a strategy for using technology research and development as the underpinnings of our national security.1 Since 1945, no country has invested more in basic research than the United States.2 Over the past six decades, this strategy has led to training of generations of scientists, opened new technical fields, launched new business sectors, provided the underpinning of our economic prosperity, and provided critical national security capabilities. Unlike Vannevar Bush's era, our current landscape includes a set of technologically savvy and well-resourced international peers. Research is seldom conducted in isolation and often includes international collaborations and global input. As a result, many countries and individuals now enjoy broad access to nearly all leading-edge technologies. While this model drives the innovation cycle of commercial products at a pace much faster than Moore's Law, it has profound implications for our national security challenges.3

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While the Department of Defense continues to lead the technical agenda in defense-specific technologies, these have become fewer and been replaced by the application of commercial-based technologies. With few exceptions, the Department no longer can assume a preeminent position in driving many leading-edge technologies and no longer enjoys selective access to many of these same leading-edge technologies. That said, the Department continues to maintain superiority through superb system design and integration skills, manufacturing innovations and the unmatched skills of our operators.

The emergence of hybrid and irregular warfare is driving a set of new research directions for the Department of Defense and has placed a premium on rapid innovation and deployment of concepts to counter rapidly emerging threats. New research efforts in human terrain mapping, ubiquitous observation, contextual exploitation and decision support are beginning to demonstrate results and are being transitioned to use. Other capabilities outlined in a recent Defense Science Board Study[4] are needed to operate effectively in this space.

This environment has renewed the focus of our nation's Science, Technology, Engineering and Math foundations.[5] It is also the driver for the Department of Defense Science and Technology Strategy to operate over a new set of coordinates: Innovation, Speed and Agility.

DDR&E Imperatives

With this changing landscape and new technical challenges before us, there are considerable opportunities where computer science research could have a significant and lasting impact on our national security. These research thrusts can be discussed within the context of four imperatives we defined to address the challenges of providing technological solutions to our warfighters today and in the future. These are not lofty vision statements or broad goals and objectives. These are the four tasks that we have to get right and have to act on each and every day. The role of computer science research in achieving these goals is critical. These imperatives, outlined below, are the mantra and marching orders for the organization for which we will apply resources and focus.

Accelerate Delivery of Technical Capabilities to Win the Current Fight.

We must solve the most difficult near-term challenges on the battlefield and expeditiously transition compelling concepts to our forces. This work is focused on rapid prototyping, demonstration and transition of early concepts in days to weeks. It requires innovation and early risk assessment to evaluate and triage for capability impact. It requires intimate connection with the user and builds on the "Research Triple" to pull innovative ideas from the contractor base. And, it requires new contracting and delivery concepts.

Prepare for an Uncertain Future.

The focus of the imperative is to counter and create technological surprise. This has been squarely in the DARPA lane since its inception, but is foundational to the full scope of S&T functions within DDR&E. Countering technological surprise cannot be done in isolation. We have reinvigorated our interaction with the intelligence community in the areas of technical intelligence, horizon scanning, net assessments and red-teaming to further develop a full understanding of both blue and red future capabilities. Creating technological surprise hinges on developing advances in autonomy; specifically, areas like perception, understanding, dynamic re-planning, reasoning and self organization will be critical to creating new defense capabilities. Integrated sensing and decision support remains an elusive but important goal, and will require advances in tasking, object recognition in structured and unstructured data, unsupervised learning, robust signature-level fusion, human-machine interface and open source data mining, just to name a few.

Reduce the Cost, Acquisition Time and Risk of Major Defense Acquisition Programs.

The newly formed Systems Engineering and Developmental Test and Evaluation Directorates will engage alongside our traditional DDR&E Technology Maturity Assessment efforts to provide deep systems analysis and comprehensive technical assessments across the Department. With these new responsibilities, I have a "seat at the table" during the USD(AT&L)-led Defense Acquisition Boards which provide oversight and milestone approval for the approximately 150+ major defense acquisition programs (MDAPs) across the Department. The inputs of the DDR&E team have already proven effective at identifying potential issues and providing technical assistance for many programs early in the acquisition cycle.

Develop World Class Science, Technology, Engineering and Mathematics (STEM) Capability for the DoD and the Nation.

This imperative is foundational to the others. Without a first-rate workforce to innovate and manage the DoD S&T enterprise the other imperatives will be unachievable. STEM leadership for the Department is managed within our Research Directorate and targets middle school through post-doctorate education. Examples of our commitment to this effort include: DoD laboratory scientists spending time at local schools; providing internships for college students at our laboratories; and an array of scholarship opportunities. We recently formed a DoD STEM Board of Directors to align efforts throughout the Department and to oversee this critically important initiative.

These imperatives represent an enterprise effort to include the full resources of our DoD laboratories, agencies, Service S&T organizations as well as our industry partners. Only with full transparency and collaboration can we achieve optimum effectiveness for the warfighters.

Computer Science at the Nexus

As the importance of software in today's defense systems grows, developing new methods that provide advanced techniques for developing, deploying and testing software will become ever more important in accelerating the delivery of technical capabilities. These techniques will provide developmental environments that allow collaboration while protecting IP, provide supply chain and manufacturing models, and include tools for dealing with configuration complexity through advances in autonomous computing. Hybridized environments where mixed virtual and physical systems offer opportunities for spiral development will be important, as well as new approaches that allow small teams of developers to control and develop large programs using new techniques that provide effective code reuse and self-checking to provide functional guarantees. With many rapid capabilities being built on existing platforms the need for legacy system refresh and highly portable systems will also become urgent. Techniques like robust virtual machines, open source chips and automated verification and validation tools are needed. With these advances software-based systems will become more pervasive and will provide a platform for rapidly developing and deploying new capabilities.

To provide a hedge against uncertain futures, advances are needed in many basic research areas like quantum information sciences, computer network defense and computational sustainability. Two enduring problems that help create surprise include the ability to exploit valuable information in large data sets and autonomous systems. A registered spatial, social and economic framework will allow fusion of many data sources, while advances in reasoning and learning will provide automated methods of finding causal relationships. Data storage and retrieval using metadata structures will continue to be an active area of research, as well as structured knowledge spaces in which questions can be quickly answered by trained analysts.

Advances in perception that provide machine situational awareness are critical to truly autonomous systems to allow their operation without GPS guidance. Research in inference, complex environmental representation and intent recognition are necessary, as are advances in reasoning and understanding. Self-organization is another important research area for autonomous systems and includes new techniques for creating dynamic organizational structures and hierarchies for mission success.

As we continue to find ourselves fighting asymmetric threats, future advances in human-social-cultural modeling and interactions will continue to be important. Here, we will need new fundamental advances in mathematical modeling that allow the highly nonlinear models to be developed and tested using real social interactions as datasets. Open source data and the ability to mobilize users we do not control will be instrumental to advances in this area. Media countermeasures and the mathematics of "tipping points" will be central to enlisting the help of local populations to fight extremism and insurgents. Integral to the fielding of these important new capabilities is the issue of Human-Machine Interactions (HMI). Advances in HMI will allow warfighters to interact with machines naturally, using speech and gestures. To accomplish this we will need new advances in techniques for sharing mental models, goals, plans and environmental representations.

With the cost, schedule and performance challenges of many MDAPs, the need for new techniques in complex systems development has never been more important. Complex system development will include new advances in virtual environments that allow government and industry developers to concurrently develop operational concepts and define their physical and information systems. New algorithmic approaches that quantify uncertainty, efficiently scale for multi-grid simulations and provide multi-level and multi-discipline representations are required to further the current state of the art. Not only will we need advances in development environments and new algorithms, but High Performance Computing will have to evolve such that new software approaches can reap the benefits of multiple cores and processors that can self-manage autonomic computing approaches.

Advances like the ones discussed above will require increased enrollments in STEM. Digital education approaches offer the promise of new machine tutors that adapt to the learning styles of students, are proactive in redirecting their misconceptions about physical phenomena, and that can help them learn and retain more effectively using games as a conduit. Many of these same approaches can be used for immersive training of new recruits for both battlefield operations and on the use of technology systems.

A Path Forward: A Vannevar Bush Redux

The innovative engine and expertise in our country have fueled our status as a world leader for the past century. Vannevar Bush's insightful vision after World War II still applies today. We need to invest heavily in science and technology to provide the foundation for our future endeavors in both the civilian and military markets. Computer science expertise will be central to every aspect of our science and technology portfolio. We need to mentor, lead and encourage our youth to contribute to our Science, Technology, Engineering and Mathematics enterprise, and to consider service in our government to support national security. Our investment in Federally Funded Research and Development Centers continues to be vital and an integral part of our overall national security S&T strategy. We need to continue to give these folks meaningful and fulfilling work; they will not let us down.

As we embark on a new era of Defense Research, the computer science research community has the opportunity to bring together all of the elements of the Research Triple and make a significant impact on our success in this new environment.

As Director of Defense Research and Engineering, the Honorable Zachary J. Lemnios serves as the Chief Technology Officer for the Department of Defense. Mr. Alan R. Shaffer is responsible for formulating, planning, and reviewing the DoD Research, Development, Test, and Evaluation (RDT&E) programs, plans, strategy, priorities, and execution of the DoD RDT&E budget.

End Notes

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