DISCOVER DSO

June 2021

DARPA Defense Sciences Office

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From the Director's Desk

Welcome DSO Friends and Colleagues...
...to the "silver linings" edition of the annual Discover DSO Newsletter! This past year has certainly brought many challenges to both our personal and professional lives. But if it's true that hindsight is "2020," then perhaps we can look forward to the future with some degree of optimism, even as a very difficult year is receding in our proverbial rearview mirror. Such optimism is justified knowing that, despite the challenges and personal loss that we've all endured, we have learned a lot (and maybe even surprised ourselves) about our ability to persist and survive under extremely stressing conditions. In this year's Newsletter we highlight some of the many creative ways that DSO has worked to maintain a collaborative, connected, supportive, and productive environment during the COVID-19 pandemic.

Not only did the COVID-19 pandemic fail to deter the passion and commitment of DSO personnel, this past year has been one of our most productive ever. Over the past 12 months, DSO started 7 major new programs as well as several smaller Disruptioneering and AI Exploration programs. Additionally, we have been setting a record pace in terms of placing funds on existing and new efforts. Anyone who has worked with DSO knows how much we value being able to celebrate various holidays and special life events together. Zoom and Microsoft Teams became valuable tools in making sure we were able to maintain some level of connectedness, even as we stayed apart and socially distant. Many thanks to Heather Heigele and Julie Evans in the DSO Front Office for facilitating multiple virtual celebrations and get-togethers. You should read the "DSO Copes with COVID" article inside this year's Newsletter to learn more about the many innovative ways we found to not only persist, but thrive, in an era of forced teleworking!

As our nation continues to work towards a post COVID-19 recovery, there has been much discussion of the need for greater robustness and resiliency in facing future pandemics and other disasters. Considerations of improved resilience and robustness have always been a major influence in shaping DARPA investments and, for this reason, the Agency was able to lean forward in multiple directions towards the development of technology needed to diagnose and treat critical care COVID-19 patients. For example, as COVID-19 related drug shortages brought a focus on vulnerabilities in the U.S. pharmaceutical supply chain, DSO performers on the Make-It and Acceler-

continued

Inside This Issue

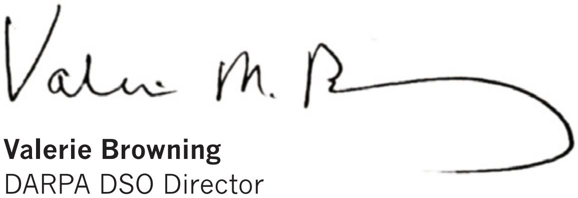
From the Director's Desk (cont'd)

ated Molecular Discovery (AMD) programs were able to quickly pivot their development efforts towards enabling more flexible and robust drug discovery and manufacturing supply chains. Please see our "Combating COVID" article to learn about more ways that DSO innovation is being applied to address current and future pandemic threats.

Beyond COVID related activities, this year's Newsletter also includes multiple articles that highlight how we are planning and investing with a renewed focus and commitment towards a more robust and resilient U.S. defense infrastructure. DSO investments are enabling more capable and survivable structures, platforms, and sensor systems to support DoD missions across multiple domains and environments. In addition, the resilience, robustness, and survivability of our most valuable resource, our people, is a key theme across several of DSO's new and existing programs. Again, descriptions of new DSO programs as well as emerging results from our current portfolio are provided for your review throughout the Newsletter.

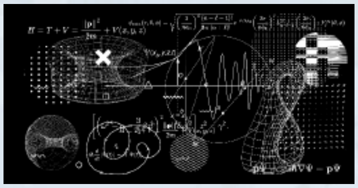
In closing, I hope you will enjoy exploring the 2021 Discover DSO Newsletter. All of us in DSO would like to express our sincere desire that the extended family of DSO friends and colleagues are as excited as we are about the potential for a brighter and more connected future!

Best regards,



Valerie Browning
DARPA DSO Director
June 2021

Current DSO Thrust Areas

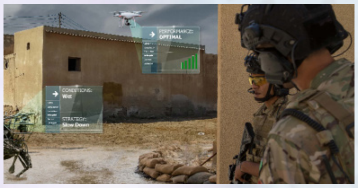


Frontiers in Math, Computation & Design

- Quantum Information Processing
- Alternative Computing
- Foundational AI Science
- Design Tools

Limits of Sensing & Sensors

- Quantum Sensing
- Imaging in Low Resource Environments
- Novel Light Matter Interactions



Complex Social Systems

- New Social Science Tools and Methodologies
- Human-machine Teaming
- Complex Wargaming
- Science of Influence

Anticipating Surprise

- WMD/WMT Detection and Deterrence
- Materials for Harsh Environments
- Advanced Manufacturing
- Resilient Infrastructure and Supply Chains

Program Managers

Our Team

DSO identifies and pursues high-risk, high-payoff research initiatives across a broad spectrum of science and engineering disciplines—sometimes reshaping existing fields or creating entirely new disciplines—and transforms these initiatives into radically new, game-changing technologies for U.S. national security.

Dr. Joe Altepeter

Joe's interests include quantum and quantum-inspired technologies, novel sensors and imaging systems, hyperspectral awareness, and the visualization of useful data from complex physical systems.

Dr. Tatjana Curcic

Tatjana is interested in advancing quantum science and technologies for solving national security problems. Topics of interest include exploration of the utility of Noisy Intermediate-Scale Quantum (NISQ) devices, quantum-enhanced machine learning methods, and novel quantum sensing and metrology approaches.

Dr. Bill Carter

Bill is interested in new materials for extreme environments, including hypersonics, space, arctic and deep ocean. He has additional interests in advancing our ability to field new materials, understanding and preventing material failure, and enhancing human learning.

Dr. Anne Fischer

Anne is interested in pursuing creative applications of molecular approaches, methods, and tools to advance a wide range of technologies.

Dr. Rohith Chandrasekar

Rohith's interests include static and dynamic planar imaging systems, nonlinear optical devices, and radar systems.

Dr. Molly Jahn

Molly is interested in leveraging advances in biochemistry and complexity to improving resiliency in critical U.S. infrastructure and supply chains.

Lt. Col. C. David Lewis

David is interested in applying the forefront of fundamental physics in unique ways to DoD challenges, using the disciplines of quantum mechanics, space and plasmas, and gravitational physics.

Dr. Greg Witkop

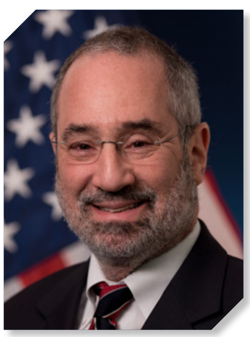
Greg's research interests focus on leveraging advances in neuroscience, non-invasive physiological monitoring, and unsupervised machine learning to enhance credibility assessment, suicide prevention, and high-performance learning.

Dr. Bartlett Russell

Bart is a Cognitive Neuroscientist whose work focuses on understanding the variability of human cognitive and social behavior to enable the decisionmaker, improve analytics, and generate autonomous and AI systems that enable human adaptability.

Dr. Mark Wrobel

Mark is interested in advanced sensing modalities for chemical, biological, radiological, nuclear and explosive threats and their precursors and advanced analytics for both sensor and transactional data.



Mr. Ted Senator

Ted is interested in fundamentals, principles, applications, and methods of AI, including new science needed for classes of problems not yet attempted, applications of existing technologies to new domains, and the system engineering methods needed for developing, integrating, scaling, and sustaining these applications.

Dr. Jiangying Zhou

Jiangying is interested in understanding the foundations of machine intelligence, novel concepts of unconventional computing and human-machine teaming.

Dr. Vishnu Sundaresan

Vishnu is interested in high-energy density energy storage devices, quantum effects in soft matter, structural computing for the next generation of mechatronic systems, materials for storing and transmitting radiant energy, advanced concepts in metrology, and novel chemistries for emerging manufacturing paradigms.

How did these folks end up being DARPA Program Managers?

You may be asking yourself, "How did these folks end up being DARPA Program Managers?" While the journey to DARPA Program Manager (PM) is different for each of them, there are certain common characteristics:

Subject Matter Expertise. Prior to coming to DARPA, DARPA PMs made significant contributions to the advancement of their field and have strong connections to the scientific community. They have key insights into science and technology and a vision for how these insights might be exploited to revolutionize national security, maybe even our day-to-day lives.

Intellectual Curiosity. DARPA PMs don't have tunnel vision. They seek to explore the intersections between disciplines to identify new discoveries to solve intractable national security problems.

Scientific Courage. DARPA PMs are passionate in their pursuit of new science. Armed with their cutting edge insights, they have the courage to question conventional wisdom and turn unproven theory on its head.

National Service. DARPA PMs share a love of country and a strong desire to create technology that will protect the warfighter and defend the homeland.

DARPA PMs typically serve 2–4 years. DARPA is a fast-paced environment where PMs are expected to hit the ground running to make their initial idea a reality as quickly as possible, while simultaneously envisioning their next awesome idea.

If you have the expertise, curiosity, courage, and dedication to country to be a DARPA PM, please reach out to any of us in DSO to start a conversation.

Voices from DARPA

DARPA's podcast series, "Voices from DARPA," offers a revealing and informative window on the minds of the Agency's program managers. In each episode, a program manager from one of DARPA's six technical offices—Biological Technologies, Defense Sciences, Information Innovation, Microsystems Technology, Strategic Technology, and Tactical Technology—will discuss in informal and personal terms why they are at DARPA and what they are up to.

The Hypersonic Materialist

Bill Carter

https://www.youtube.com/watch?v=6ZTh1vE8wQk

The Opportunity Hunter

Lt. Col. C. David Lewis

https://www.youtube.com/watch?v=dpZOjjfHog8

Science 2.0

Dr. Jiangying Zhou

https://www.youtube.com/watch?v=FdDsNqbGpsw

Leadership

Dr. Valerie Browning

DSO Director

Valerie Browning was named director of DARPA's Defense Sciences Office in December 2017.

Dr. Browning has more than 30 years of experience in managing and executing defense-related research and development. Prior to her most recent DARPA appointment, Dr. Browning worked as an independent consultant providing subject matter expertise and strategic planning support to the Department of Defense, Department of Energy, and other government clients in the areas of advanced materials and alternative energy. She also served as chief technology officer for HELM System Solutions, Inc., a woman-owned small research and development (R&D) business.

Dr. Browning was a program manager in DSO from 2000–2007, where she initiated and managed a diverse R&D portfolio in areas that included metamaterials, bio-magnetics, unmanned underwater vehicle energy storage, portable power, thermoelectric materials, and others. Dr. Browning also worked as a research physicist at the Naval Research Laboratory from 1984–2000 where her primary areas of research included thermoelectric materials, superconductors, magnetics, and magnetic oxide materials.

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Dr. Philip Root

DSO Deputy Director

Army Lt. Col. (ret) Philip Root, PhD, was named deputy director of the Defense Sciences Office in June 2019. He continues to manage the Squad-X program in DARPA's Tactical Technology Office (TTO), where he explores the intersection of AI, autonomy, and military operations. His former TTO programs include Urban Reconnaissance through Supervised Autonomy (URSA), ALIAS aircrew autonomy, Mobile Force Protection counter-UAS, Underminer tactical tunneling, and DSO's Fast Lightweight Autonomy (FLA). He maintains responsibility for the legal, moral, and ethical (LME) analysis of the URSA program as an exemplar for in-depth LME analysis of an autonomous system.

Before coming to DARPA, Phil was the director of the Center for Innovation and Engineering at the United States Military Academy at West Point, where he oversaw cadet and faculty research in support of Army operations. Root deployed as a research and development officer to Afghanistan, where he developed and implemented the hardware and software needed to support cloud-based military intelligence analytics. He served two years as an Astronaut Office support engineer at the Johnson Space Center, where he had oversight responsibilities for the booster and launch abort system of the Constellation program intended to return Americans to the Moon. Root spent nearly the first decade of his career as an Apache helicopter pilot in Germany and Korea. He is a graduate of the United States Military Academy, and he received his Master of Science and doctorate from MIT at the Laboratory for Information and Decision Systems (LIDS).

Mr. Scott Wenzel

DSO Assistant Director, Program Management (ADPM)

Scott became DSO's ADPM in September 2018. In this role, Mr. Wenzel is responsible for managing DSO's business processes. He has 7 years of experience at DARPA managing budgets, finance, contracts, acquisition, and policy for multiple technical offices, and 4 years of Army Acquisition Workforce experience as a civilian supporting the Program Manager for DoD Biometrics under Program Executive Office for Enterprise Information Systems. Scott is especially interested in streamlining processes to ensure compliance with regulations without impacting technical execution. He is also actively engaged in managing relationships between DARPA and those military and civilian agencies who do work on its behalf.

Ms. Karen McMullen

DSO Program Analyst

Karen joined DSO in April 2014 as program analyst. Karen brings 34 years of experience supporting various DARPA technical offices to her duties overseeing day-to-day office operations and supporting DSO's ADPM in financial formulation, budget formulation and program management support. A key responsibility is acting as contracting officer's representative for DSO's SETA support contracts. In this role, she ensures DSO program managers get the support they need to create and manage successful programs.

DSO Copes with COVID

It's been more than a year since DARPA, and the rest of the world, began its forced experiment with working from home. DSO, in true DSO spirit, jumped into teleworking, and telepartying, with gusto! Zoom and MS Teams, with their squares of faces reminiscent of the Brady Bunch, became de rigeur to replace in person meetings.

Despite the many challenges that come with teleworking, DSO has been able to maintain the standards of excellence we are known for and to deliver on our mandate to innovate in support of national security. Since transitioning to a maximum telework environment last March, we have initiated 7 new programs, 3 Disruptioneerings and 2 Artificial Intelligence Explorations. In addition, we have been maintaining a record setting pace for Office commitments and obligations.

We also commemorated DSO's 40th Anniversary with a booklet that reflects on some of the most interesting and impactful technologies pioneered within DSO over the past four decades that have changed the way we live today. This booklet can be found on the DARPA website at https://www.darpa.mil/work-with-us/interact-with-DSO. While COVID has prevented us from coming together to celebrate those 40 years of amazing progress in person, we hope to be able to do so before the end of this year.

From the beginning, DSO was using telework platforms for weekly happy hours and lunches. We also hosted our holiday party on Zoom, with ugly sweaters (and other accoutrements) and a wildly competitive household scavenger hunt.

Another way DSO put the pandemonium in pandemic was by recording a vocal track and video of its theme song "Science Is Real" by They Might Be Giants. Everyone in DSO was invited to record themselves singing, playing an instrument, or lip-synching and dancing along. It was a lot of fun to discover all the talent within the office.

Of course, there were downsides, too. A number of us lost loved ones to the disease. DSO came together to offer solace to our friends and colleagues with condolences on Kudoboards. We missed celebrating birthdays and other milestones in person. So again, Kudoboards let people know we remembered.

It gets lonely working from home, but knowing you have a family in DSO makes it a little better. Here's to hoping we regain some semblance of a normal work environment and can make up for not seeing each other over this past year+ before the 2022 issue of the DSO Newsletter goes to press!

Advanced Concept Compact Electron Linear-accelerator (ACCEL)

Dr. Matthew Higgins

Linear accelerators, LINACs for short, are devices that accelerate electrons or other sub-atomic particles along a straight line to generate a beam of high energy. LINACs have a variety of commercial uses such as generating X-rays for cargo inspection, medical diagnostics, food sterilization, and even enabling precise external radiation treatments to destroy cancer cells without damaging surrounding tissue. To generate more powerful electron beams using current technology, however, requires building larger LINACs that can grow to dozens of meters or longer depending on the application. Unfortunately, powerful LINACs are too large and heavy to be practical for military use in the field.

The Advanced Concept Compact Electron Linear-accelerator (ACCEL) program's goal is to develop a powerful, deployable electron LINAC for military applications.

A high-power, compact, rugged accelerator that can be transported by truck or aircraft to austere locations would provide multiple defense and homeland security benefits. It could be used for medical treatments in locales without advanced hospitals, remote detonation of improvised explosive devices (IEDs), and mobile imaging or inspection of shipping containers' contents to counter chem-bio and radiological threats. A deployable LINAC could also enable portable sterilization for foods and surfaces to prevent contamination and infection in deployed environments.

The program seeks to develop a compact LINAC that can create electron beams with energy up to 35 mega-electron volts (MeV) in a package that weighs less than 75 kilograms and can fit in a 1-meter long cylinder with 0.4-meter diameter. The LINAC will need to be ruggedized so that it can be transported by air, rail, or truck and operate in widely varying heat or cold conditions.

Sign up for DSO News Updates
via Constant Contact at
http://www.darpa.mil/work-with-us/interact-with-DSO (Under the Resources link)

Enhancing Design for Graceful Extensibility (EDGE)

Dr. Bartlett Russell

The objective of the EDGE program is to develop the tools necessary to create, measure, and test Human Machine Interfaces (HMI) that provide enough situational awareness (SA) of a system's processes and status, in addition to its operational environment, so the operator can adapt the system in off-nominal situations. EDGE seeks design capabilities that will be fast, quantifiable, and repeatable enough for effective HMI concept design, development, and testing to be integrated into the larger systems design and development process.

HMI design has not matured at the same pace as automated and autonomous machines and, as a result, most current interfaces do a poor job supporting the operator's SA of the machine's processes, status, and/or operational context. An operator with reduced SA may not adapt to unexpected circumstances, risking catastrophic failure.

EDGE aims to create HMI design tools prioritized and oriented toward quantifying, supporting, and testing SA, rather than reducing cognitive load at the expense of SA. EDGE will help designers build HMI systems that allow operators to not just monitor autonomous systems but also adapt their use to meet the needs of unanticipated situations.

An Invitation to Ideate

Human curiosity, the desire to understand how things work, and the persistence to seek answers have led to scientific discoveries that changed how people live, work, socialize, and fight wars. The pace of scientific discovery is constantly accelerating. For example, there are many of us who remember a time without internet, cell phones, and social media, a time our children can't even imagine.

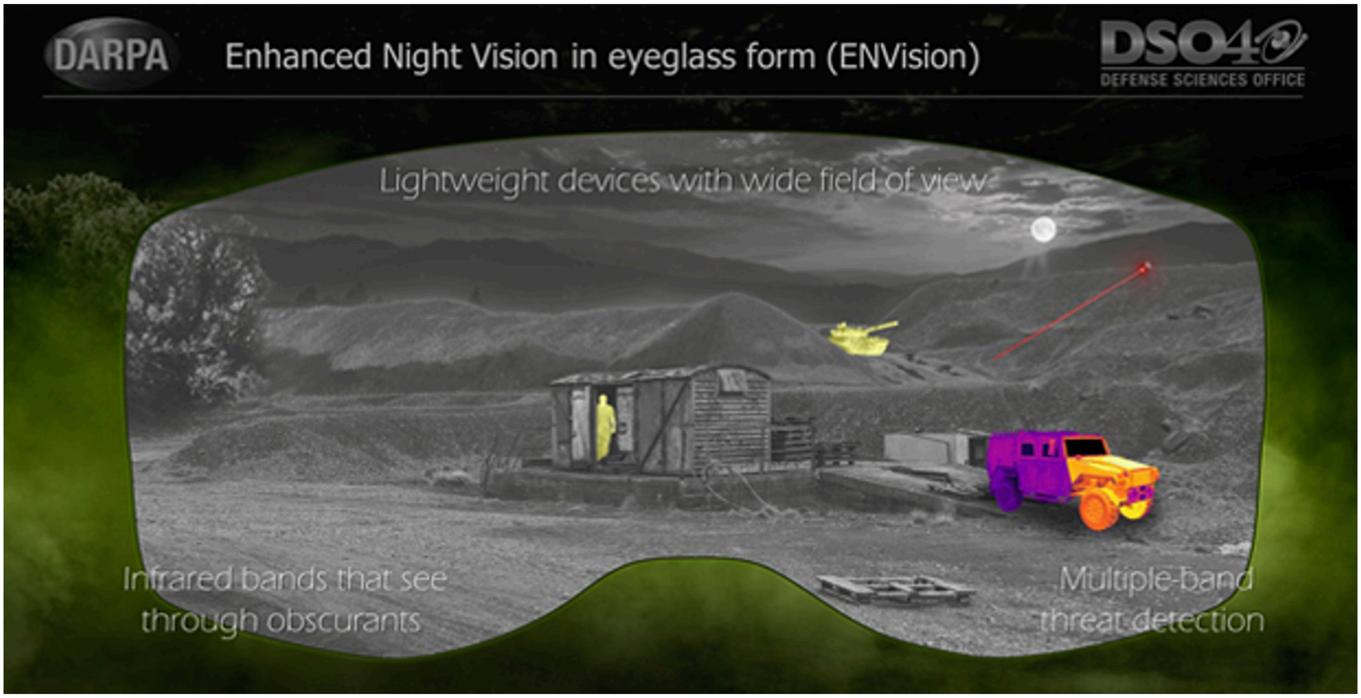
DARPA played a pivotal role in the creation of the internet, stealth technology, and GPS—how will DARPA contribute to the next scientific revolution? DSO is uniquely positioned as DARPA's "far forward scouts" to identify and invest in nascent science and technology that promises to change the DoD and the world.

DSO program managers are constantly looking for new science that will revolutionize our ability to protect the country and support the warfighter. If you have a new idea, approach, or technique that is potentially paradigm-shifting, we want to hear from you. You can contact a DSO Program Manager at http://www.darpa.mil/about-us/people. If your idea is more mature, DSO's office-wide BAA is another great way to present your ideas to a DARPA PM: https://www.darpa.mil/work-with-us/opportunities (filter on DSO).

We look forward to hearing from you!

Enhanced Night Vision in Eyeglass Form (ENVision)

Dr. Rohith Chandrasekar



Despite decades of development, current night vision (NV) systems are bulky and heavy, resulting in a large torque on the wearer's neck. This torque greatly limits the wearer's agility and often leads to chronic injury over prolonged use. Additionally, these systems provide the wearer with a narrow field of view (FOV) and generally have limited spectral access to the near-infrared (NIR), greatly limiting situational awareness.

The DARPA ENVision program will leverage recent advances in planar optics and transduction materials to develop novel direct-view NV systems that demonstrate an increased FOV and enhanced visual access across infrared bands, all contained in a low-torque near-eyeglass form factor.

ENVision will also investigate the fundamental limits of low-input-intensity photon upconversion bandwidth and efficiency. These new insights could potentially lead to further transformative NV systems that require no optics or transduction, but simply directly upconvert ambient infrared light into the visible.

The Knowledge Management at Scale and Speed (KMASS)

Mr. Ted Senator

Organizations, including the military, store massive amounts of knowledge intended for human consumption, e.g., doctrine, policy, procedures, etc. Creating these documents, videos, and other modes is both expensive and time consuming. They are not structured or indexed to support rapid and appropriate application to particular tasks and may be inconsistent or confusing. Further, this knowledge must be augmented by local and timely knowledge appropriate to the particulars of a task, accounting for any unique context or situations. Capturing knowledge along with this context as it is created currently requires a dedicated effort on the part of the person performing the task, which often does not happen. Applying stored knowledge requires a user to know that it exists, where it exists, when it is needed and relevant, how to retrieve it, and how to locate the specifics in what typically is a multipage document or several minute long video with audio. Applying stored knowledge may not always be possible given time constraints.

The Knowledge Management at Scale and Speed (KMASS) program aims to research, develop, integrate, evaluate, and demonstrate underlying technology that will enable effective use of documented knowledge, acquisition of new knowledge as part of regular workflows, and application of useful knowledge when and where it is required and with necessary granularity. KMASS technology seeks to scale to a broad set of tasks and contexts across an organization by collecting and modifying knowledge "in-the-flow" as part of regular task execution and applying the knowledge documented for one purpose to other purposes as appropriate. The goal of the KMASS program is to deliver user specific knowledge "nuggets" that are useful for a current task—whether the knowledge is requested or not by the user—exactly when needed, while avoiding irrelevant or already known information. This concept is a core tenet of KMASS and may be referred to as the "JustINs" — i.e., just in time, just enough, and just for me. KMASS systems also will contain a persistent knowledge store comprising source documents in human understandable form in multiple modalities (e.g., text, videos, presentations, etc.), augmented with appropriate tags and indexed for identification, retrieval, linking, and application that will update at the speed of task performance. KMASS requires advances in three key complementary areas: organizing background knowledge, capturing local knowledge, and disseminating contextualized knowledge usefully, appropriately, and on time.

Morphogenic Interfaces (MINT)

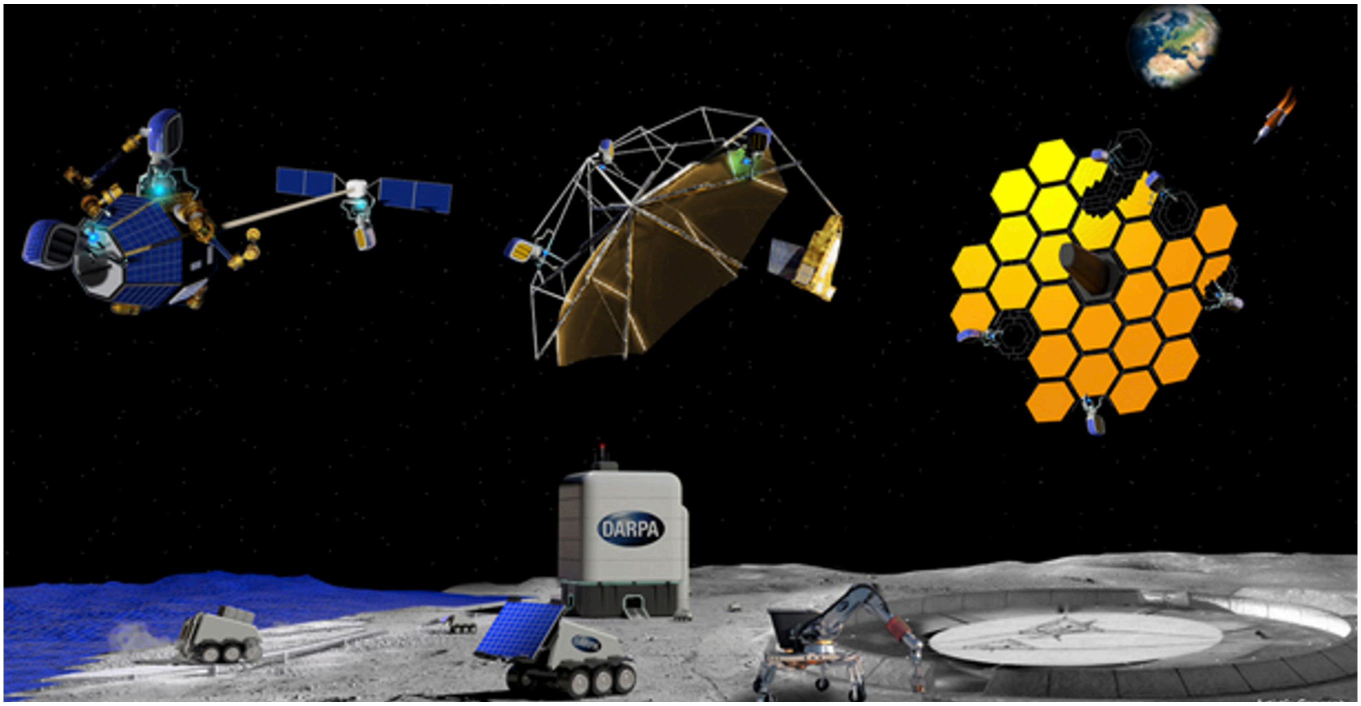
Dr. Vishnu Sundaresan

The Morphogenic Interfaces (MINT) program aims to enable the development of persistent, high-performance, electrochemical systems by addressing the irreversible morphological degradation that occurs at the functional material's interface. The program will investigate innovative approaches to model solid/solid, solid/liquid, and solid/vapor electrochemical interfaces and apply this knowledge to create novel interface materials that can self-regulate their morphology and maintain desired charge transport function at the electrochemical interface.

The MINT program has two application-centric focus areas. The first focus area will develop solid/solid charge transfer interface materials and lead to high specific energy solid-state batteries with long charge/recharge cycles. The second focus area will develop novel alloys or alloy-coatings that can minimize transport (self-passivate) at the solid/liquid and solid/vapor interface and, therefore, exhibit higher fatigue strength in aggressive corrosive environments.

Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D)

Dr. William Carter



The Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D, pronounced NOMAD) program aims to develop the foundations for building robust, precise structures in space or on the moon. In contrast to today's deployable structures that are optimized for ground test and launch survival, structures such as solar arrays, antennas, or optics will be specifically designed for the space or lunar environment. The NOM4D program comprises two technical areas. The first plans to develop and demonstrate foundational materials, manufacturing processes, and designs to enable the on-orbit and on-moon fabrication of robust, resilient, and high-precision structures that will support future off-earth space systems. The second technical area will investigate innovative designs that take advantage of the ability to manufacture in space, yet enable precise, mass-efficient future space structures that withstand maneuvers, eclipses, damage, and thermal cycles inherent to the space and lunar environments. The goal is to do so with mass efficiencies that transcend the limits of today's stiffness-driven designs.

Quantum Benchmarking (QB)

Dr. Joe Altepeter

It has been credibly hypothesized that quantum computers will revolutionize multiple scientific and technical fields within the next few decades. Examples include machine learning, quantum chemistry, materials discovery, molecular simulation, many-body physics, classification, nonlinear dynamics, supply chain optimization, drug discovery, battery catalysis, genomic analysis, fluid dynamics, and protein structure prediction. For many of these examples, like quantum chemistry and protein structure prediction, quantum computers are hypothesized to be useful simulators because the target problem is inherently quantum mechanical. Other examples, like classification and nonlinear dynamics, center around problems that have nothing to do with quantum systems, but involve combinatorial complexity that is intractable for conventional computers.

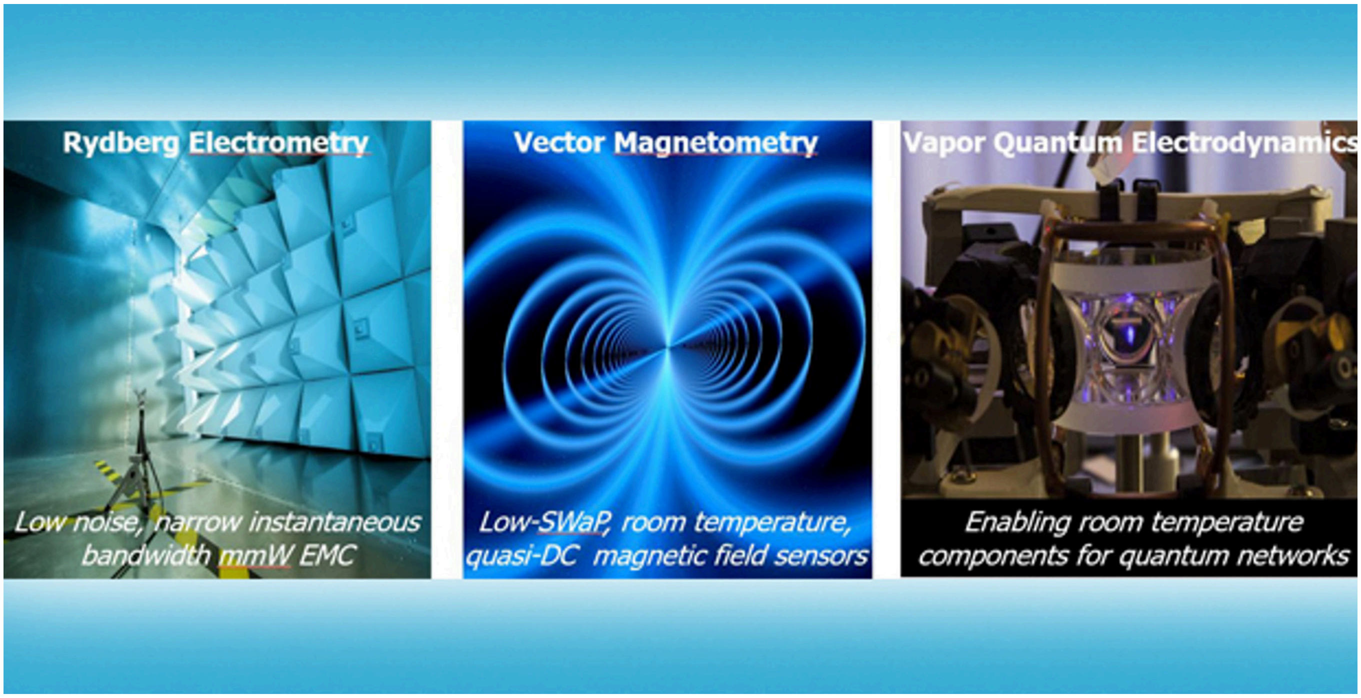
For each of the fields listed above, it is unclear exactly what size, quality, and configuration of quantum computer—if any—will enable the hypothesized revolutionary advances. The Quantum Benchmarking program will estimate the long-term utility of quantum computers by creating new benchmarks that quantitatively measure progress towards specific, transformational computational challenges. In parallel, the program will estimate the hardware-specific resources required to achieve different levels of benchmark performance.

How DSO Develops Programs

DSO typically starts 8–12 programs per year. Some of these may be smaller programs announced via Disruptioneering Special Notices (https://sam.gov/opp/13b47041a06d4820b5ff17e56c46c8cf/view), while others are more traditional DARPA programs solicited by a dedicated Broad Agency Announcement (BAA). The formulation of a program involves a great deal of due diligence and rigor and typically evolves over multiple months. A program manager (PM) may be exploring several concepts at any given time, sometimes using seedlings (small awards, typically 3-to-9 months in duration), to see which of these ideas have the greatest potential for impact as a DARPA program. A PM may also issue a Request for Information (RFI) under a Special Notice at SAM.gov to ask the community what they have been working on relative to an idea. The results of seedlings and RFI submissions don't always indicate that a new program is warranted; however, when they do, PMs will put together a presentation for the DARPA Director and agency leadership. If the DARPA Director agrees the PM's idea should be a DARPA program, funding for the program is provided, and a BAA or other solicitation is issued at SAM.gov to request proposals.

Science of Atomic Vapors for New Technologies (SAVaNT)

Dr. Tatjana Curcic



The "Science of Atomic Vapors for New Technologies" (SAVaNT) program aims to significantly advance the performance of atomic vapors as a room-temperature (RT) platform for enabling new technologies in the areas of electric field sensing and imaging, magnetic field sensing, and quantum information science (QIS).

SAVaNT has three Technical Areas based on the application domains where atomic vapors are expected to have the biggest impact: (1) Rydberg Electrometry, (2) Vector Magnetometry, and (3) Vapor Quantum Electrodynamics (vQED). The common scientific challenge is to improve atomic coherence at room temperature. The associated technical challenges depend somewhat on the specifics of the most dominant decoherence mechanisms in each approach. Program goals include improving sensitivity of Rydberg electrometry, developing vector modality for atomic magnetometry with high sensitivity and accuracy, and demonstrating cavity quantum electrodynamics with atomic vapors.

If successful, SAVaNT advances will lay the foundations for new technologies that address important DoD needs, including applications that require low size, weight, and power (SWaP), high sensitivity electric and magnetic field measurements, and applications that require scalable room-temperature quantum memories and interfaces.

Disruptioneering

Enables DSO to initiate a new investment in fewer than 90 days from idea inception

Investigating Adaptive Modal Bases for Intelligent Classification (IAMBIC) –

Dr. Joe Altepeter

Recent imaging techniques inspired by the mathematics of quantum information claim to enable imaging beyond the traditional Rayleigh resolution limit.

These claims are based on the use of "modal imaging" and are representative of a much broader group of techniques developed over many decades that attempt to efficiently extract information from multi-dimensional systems using non-Fourier measurement bases. In almost all of these cases, prior information enables more efficient or more accurate information recovery from measurement results. More importantly, even without prior information, intelligently and continually adapting the measurement basis in response to earlier measurement results enables superior performance for many information retrieval tasks.

The Investigating Adaptive Modal Bases for Intelligent Classification (IAMBIC) program is an effort to create new frameworks for analyzing when such adaptive measurement bases can provide significant, real-world advantage for important problems.

IAMBIC performers are developing a cohesive and general theoretical framework for adaptively varying measurement bases in response to initial measurement data. They are applying their adaptive measurement framework on two (or more) tasks: The first task is addressing the DARPA-defined Constellation Challenge problem of imaging groups of unresolved sources beyond the Rayleigh resolution limit. The other measurement tasks are performer-defined. The performers will analyze these tasks using their adaptive measurement framework and show that their strategy provides a significant real-world impact.

SenSARS

Dr. Mark Wrobel

Environmental monitoring for airborne pathogens has historically been, and continues to be, an extremely challenging area of investigation. The current pandemic has motivated the ability to sense the SARS-CoV-2 virus in the atmosphere as a new mechanism for public health monitoring, enabling safer conditions for a wide range of basic activities including work, travel, and school. SenSARS aims to identify SARS-CoV-2 signatures suitable for rapid indoor air monitoring and use these signatures to develop and demonstrate prototype sensors that can detect the virus with sufficient sensitivity, specificity, and speed. This would enable practical monitoring of different environments and provide a warning of possible conditions where exposure and infection may be more likely to occur.

Thermal Engineering using Material Physics (TEMP)

Dr. William Carter

The Thermal Engineering using Metamaterial Physics (TEMP) program leverages recent developments in materials and physics to control the direction and wavelength of thermal transport by radiation in the visible spectrum in extreme thermal conditions. Solutions are being developed that can adaptively control the directionality of radiative heat transfer while simultaneously withstanding high-temperature oxidative or corrosive environments.

Applications for TEMP technology include thermophotovoltaic energy conversion and turbine engines. The program will also demonstrate that proposed solutions are manufacturable and scalable to be commercially relevant.

DARPA's Artificial Intelligence Explorations (AIE) Program

DARPA announced in September 2018 a multi-year investment of more than $2 billion in new and existing programs called the "AI Next" campaign. Key areas of the campaign include automating critical DoD business processes, such as security clearance vetting or accrediting software systems for operational deployment; improving the robustness and reliability of AI systems; enhancing the security and resiliency of machine learning and AI technologies; reducing power, data, and performance inefficiencies; and pioneering the next generation of AI algorithms and applications, such as "explainability" and common sense reasoning.

The AIE program, which was first announced in July 2018, constitutes a series of high-risk, high payoff projects where researchers will work to establish the feasibility of new AI concepts within 18 months of award. Leveraging streamlined contracting procedures and funding mechanisms enables these efforts to move from proposal to project kick-off within three months of an opportunity announcement.

Forthcoming AIE Opportunities will be published on the SAM.gov website. Below are DSO's AIE efforts.

Time-Aware Machine Intelligence (TAMI)

Dr. Jiangying Zhou

The Time-Aware Machine Intelligence (TAMI) program is developing new time-aware neural network architectures that introduce a meta-learning capability into machine learning.

This meta-learning is enabling a neural network to capture the time-dependencies of its encoded knowledge. TAMI's vision is for an AI system to develop a detailed self-understanding of the time dimensions of its learned knowledge and eventually be able to "think in and about time" when exercising its learned task knowledge in task performance.

TAMI draws inspiration from ongoing research in time-processing mechanisms in human brains. A large number of computational models have been introduced in computational neuroscience to explain time perception mechanisms in the brain. TAMI will go a step further to develop and prototype concrete computational models. TAMI is leveraging the latest research on meta-learning in neural networks.

Reversible Quantum Machine Learning & Simulation (RQMLS)

Dr. Joe Altepeter

Machine learning and artificial intelligence techniques are currently being applied in a number of diverse fields, including molecular simulation, many-body physics, classification, and computational optimization. However, progress in addressing these types of problems is being slowed or stopped when the problem complexity grows exponentially with size. Moreover, even when these complexity barriers are overcome, the impact of machine learning solutions is often mitigated by the high energy cost of training and operating the machine learning systems.

In principle, both of these fundamental obstacles—exponentially growing complexity and energy inefficiency—might be overcome using high-coherence quantum annealers, which are a specific type of quantum computing technology.

DARPA's Reversible/Quantum Machine Learning and Simulation (RQMLS) AIE opportunity aims to: (1) explore the fundamental limits of reversible quantum annealers; (2) quantitatively predict the computational utility of these systems for machine learning tasks in simulation, many-body physics, classification, optimization, and other fields; and (3) design experimental tests for these predictions that can be carried out on small-scale systems. If successful, these small-scale systems could be scaled to much larger, potentially transformative systems.

Combating COVID

DSO spent the past year making pivotal investments in the fight against COVID-19. Below are a few featured accomplishments made by DSO programs.

SIGMA+

Battelle Memorial Institute developed a unique signature for the SARS-CoV-2 virus using their Resource Effective Bio-identification System (REBS). The REBS platform is designed to monitor the atmosphere for the presence of biological warfare agents and other pathogens using Raman spectroscopy. This signature is currently being evaluated in several trials that utilize the REBS system and newer REBS+ system that provide a range of performance improvements compared to original REBS systems. This includes sampling times reduced from 30 minutes to just seconds.

RTI International with support from Garmin® International, Inc. is evaluating the potential use of wearable technology to detect COVID-19 and other infectious diseases. The effort includes a number of studies on whether wearables can provide indications of infection based on an individual's immune response. One such study will track the health of U.S. Navy sailors living in close quarters aboard a ship via a novel "app" to monitor high quality wearable data. The app allows for continuous data collection in areas with limited or no access to Wi-Fi or cellular networks.

SenSARS

The SenSARS Disruptioneering program seeks to develop high performance, airbreathing pathogen sensors for SARS-CoV-2 and beyond, targeting use in offices, classrooms, and buildings. The effort will examine new high sensitivity and high specificity signatures for SARS-CoV-2 and use those signatures to produce technology readiness level 4 sensor prototypes.

Accelerated Molecular Discovery (AMD)

AMD performers are collaborating with Government labs, including Walter Reed Army Institute of Research (WRAIR) and the National Institutes of Health (NIH) National Center for Advancing Translational Sciences (NCATS), to apply artificial Intelligence (AI) techniques to accelerate the discovery of drugs to combat SARS-CoV-2. Under this effort, NCATS and WRAIR provide medicinal chemistry expertise to Massachusetts Institute of Technology (MIT) and SRI and also conduct in vitro testing of the AI predictions to validate and inform therapeutics models the teams are building.

Researchers at MIT are concentrating efforts on developing new AI algorithms that specifically address the problem of data scarcity inherent in studying a novel virus, while also leveraging FDA-approved drugs to identify synergistic drug combination therapies. They recently released results from their model trained to predict antiviral activity against SARS-CoV-2 and described their efforts developing machine-learning tools to aid in identifying molecules with therapeutic effects against the disease.

SRI International is developing AI tools that incorporate chemists' expert knowledge, in addition to that learned through data, to discover analogs of existing therapeutics with potency against SARS-CoV-2. They have also recently published data on the use of machine learning models to identify inhibitors of the virus.

Make-It

The COVID-19 pandemic has highlighted vulnerabilities in the U.S. pharmaceutical supply chain. Work being done under DARPA's Make-It program furthers development and commercialization of technology that directly addresses these vulnerabilities to enable an end-to-end, deployable and scalable capability for production of medicines made from readily available materials that can be sourced within the U.S.

continued

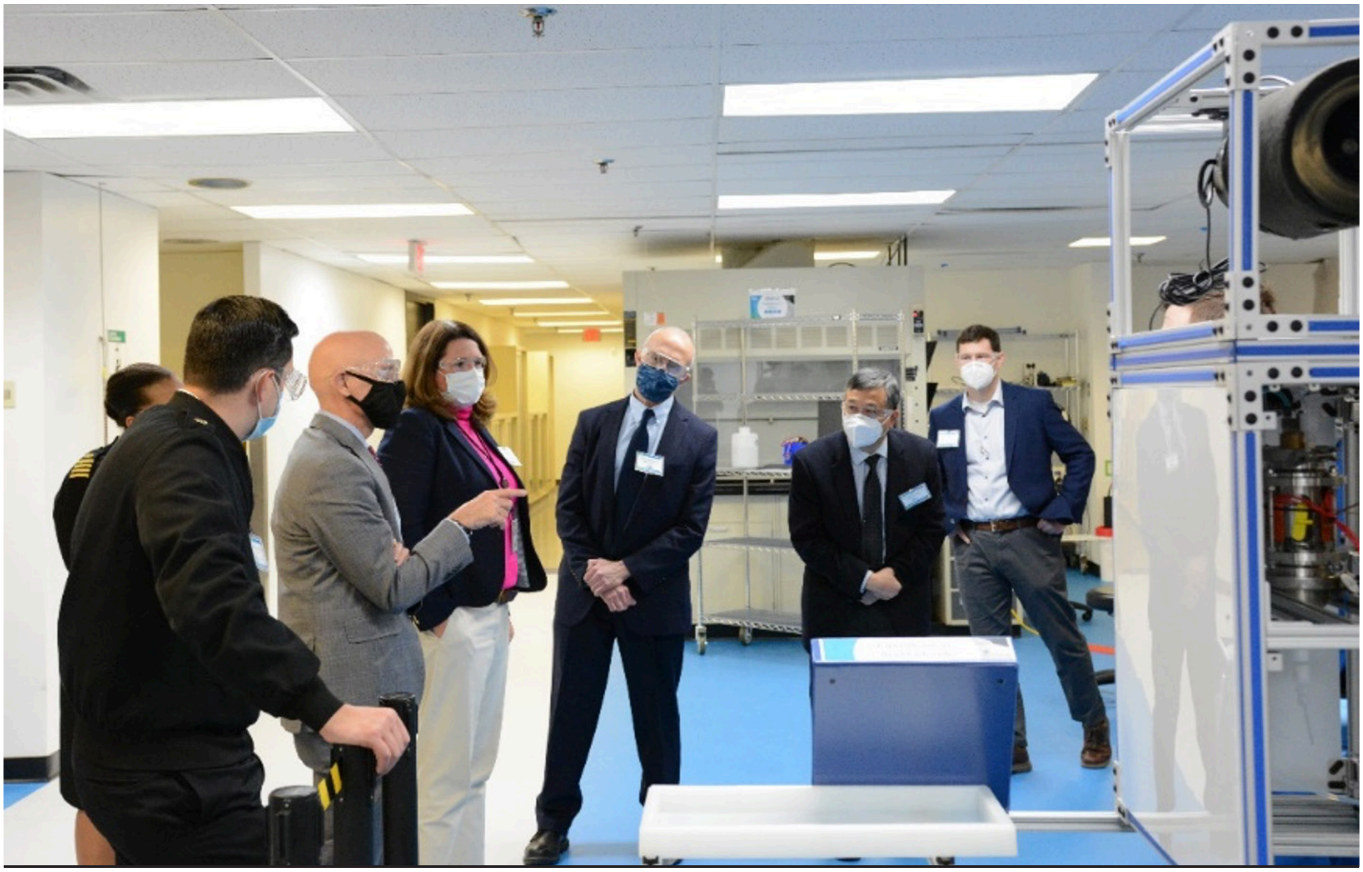
Make-It (cont'd)

Under Make-It, DARPA performers developed automated, continuous, scalable production capabilities for synthesis of Active Pharmaceutical Ingredients (APIs) and final formulated medicines (injectables and pills) toward realizing a suite of flexible manufacturing capabilities for scalable, resilient production of important medicines. Current efforts are focused on addressing regulatory requirements and expanding the capacity to produce not only critical medicines but also precursors necessary to ensure domestic supply of medicines needed to treat critical care COVID-19 patients.

For example, On Demand Pharmaceuticals' (ODP) focus is on the production of fine chemical reagents and active pharmaceutical ingredients (APIs). Their technology is based on small-footprint chemical manufacturing devices that were developed in DARPA's Battlefield Medicine and Make-It programs. Their effort is jointly funded by DARPA and Health and Human Services (HHS) under The Coronavirus Aid, Relief, and Economic Security (CARES) Act. ODP is actively engaged with many Federal stakeholders, including the DHA, JPEO, FDA, ASPR, BARDA and NCATS. For example, the company enjoyed a visit from FDA Commissioner, Dr. Stephen Hahn, as well as DARPA's Deputy Director, Dr. Peter Highnam, on 3 December 2020.

SRI International is developing an approach that enables simple scaling of flow-based pharmaceutical production from bench-top to production scale in a single step.

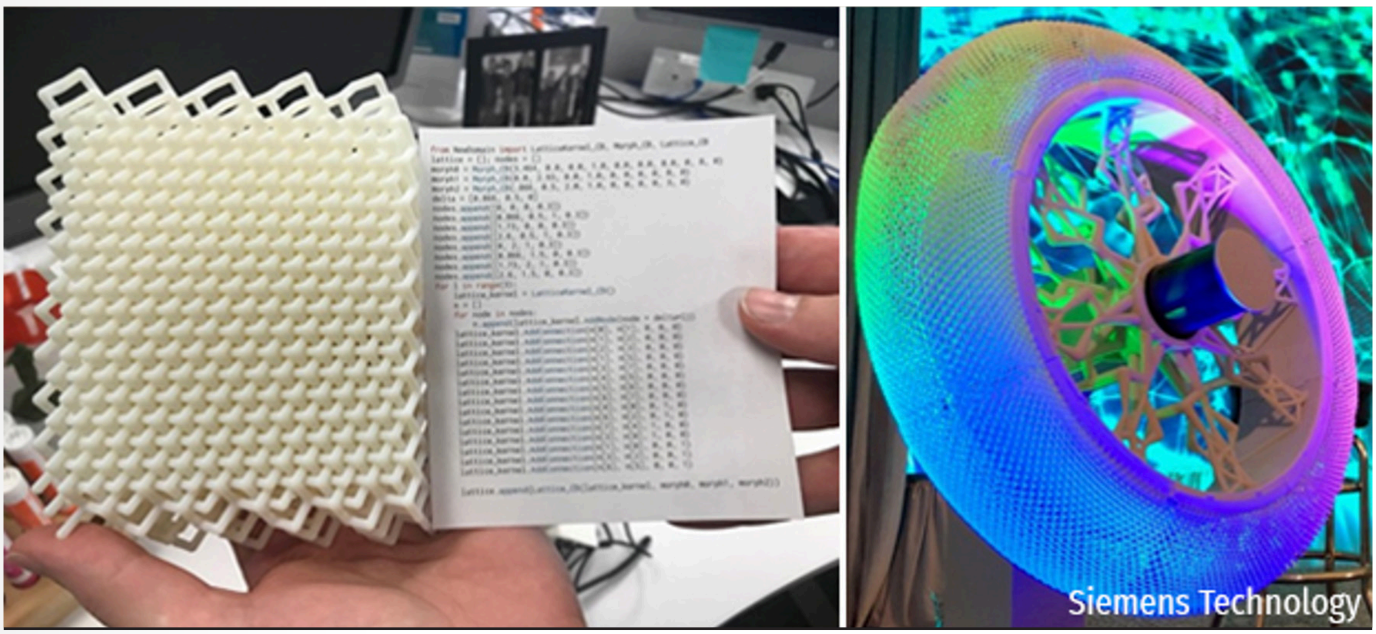
Virginia Commonwealth University is building tools to analyze and optimize U.S. based chemical manufacturing to enable rapid reallocation of existing on-shore process streams to critical APIs in a time of need.



Former FDA Commissioner Hahn visits On Demand Pharmaceuticals on December 3, 2020. DARPA is now engaged with several offices across FDA and continues to discuss regulatory aspects of this new approach to producing small molecule medicines.

DARPA Opens Door to Producing "Unimaginable" Designs for DoD

Program develops new design tools to exploit advanced materials and manufacturing technologies



TRADES tools allow representing designs a million times more complex than state-of-the-art design systems using only a few lines of computer code. Pictured on the left is a complex lattice structure with the code required to generate it. Similar code enabled generation of a lattice tire on the right, inspired by NASA's spring tire. The TRADES tools open up a vast design space for DoD applications (photo credit: Siemens Technology)

DARPA's TRAnsformative DESign (TRADES) program, which began in 2017, set out to develop foundational design tools needed to explore the vast space opened by new materials and additive manufacturing processes commonly called 3D printing. The program recently concluded, having successfully developed new mathematics and computational techniques, including artificial intelligence and machine learning, that will allow future designers to create previously unimaginable shapes and structures of interest to defense and commercial manufacturing.

Manufacturing technology breakthroughs in recent years, such as 3D printing, have allowed precise material placement, new material behaviors, and complex shaping of parts and structures. Design tools, however, have not kept up with the complexity of the design space resulting from these advances.

"In the past four years, TRADES has explored new ideas from mathematics and computer science that have allowed us to now represent things—like parts and components—that are a million times more complex than current state-of-the-art systems can represent," said Jan Vandenbrande, former TRADES program manager.

continued

DARPA Opens Door to Producing "Unimaginable" Designs for DoD (cont'd)

"We can now describe both shape and material in a coordinated way across multiple physics to allow intricate designs and to understand properties at every point on the produced part. The aim is to be able to mimic integrated hierarchical structures found in nature, where different sized structures respond to different types of physics."

TRADES tools are helping overcome what's known as the "analysis interoperability problem." Current processes involve describing a design and then analyzing it subject to multiple physics to answer questions such as: Is it strong enough? What's its drag? What's its thermal response? This process requires manual handling and transfer of data across incompatible systems.

"That manual handling, moving data from design systems to analysis, absorbs 50% of the entire design cycle because the formats are not compatible and current systems can't directly interoperate," Vandenbrande said. "TRADES has developed new concepts that would eliminate that bottleneck and accelerate the design process to include automated synthesis, where a computer explores design alternatives across multiple physics such as thermal, mechanical, electro-optic and the like, without human intervention. This would turn computers into true collaborative partners to help create new designs that are not intuitive to even the best human designers."

TRADES is also enabling design for dynamic problems where structures change as time evolves, such as a solid-rocket engine, which changes its internal shape as the propellant burns.

"The TRADES design tools have made significant headway in addressing the time and cost burdens associated with current design cycles for DoD platforms and should enable rapid and effective response to new and evolving threats and requirements," Vandenbrande said. "This includes generating in-field spares where shaping accommodates some of the discrepancies caused by material substitutions."

The advanced design tools, processes, and algorithms developed in the TRADES program are poised to help increase the performance of DoD platforms; reduce the cost and time associated with materials and geometry selection, optimization, and numerical analysis; and enable exploration of new design concepts that are currently out of reach.

By enforcing generality in the underlying theories, TRADES is positioned to handle future 3D printing capabilities to include biological components such as a femur, including the "spongy" interior structures. Other challenge problems related to TRADES are available on http://solidmodeling.org/trades-cp/ to serve as future benchmarks.

The TRADES program comprised seven university and industry performers who created new design technologies focused on modeling, analysis, and synthesis: University of Colorado Boulder, Columbia University, Etaphase, International Computer Science Institute (ICSI), Palo Alto Research Center (PARC), Siemens, and University of Utah.

Two additional performers provided high-performance software and hardware testbeds on which the design technology teams developed and refined their tools: Sandia National Laboratory and the Texas Advanced Computing Center (TACC).

Although the program has formally wrapped up, a few performers are continuing work on their TRADES tools through 2021.

Indianapolis Testing Advances Capabilities of Chemical, Biological Threat Detection Sensors

DARPA leverages background environmental data in city to refine algorithms for sniffing out threats

DARPA's SIGMA+ program conducted a week-long deployment of advanced chemical and biological sensing systems in the Indianapolis metro region in August, collecting more than 250 hours of daily life background atmospheric data across five neighborhoods that helped train algorithms to more accurately detect chemical and biological threats. The testing marked the first time in the program the advanced laboratory grade instruments for chemical and biological sensing were successfully deployed as mobile sensors, increasing their versatility on the SIGMA+ network.

"Spending a week gathering real-world background data from a major Midwestern metropolitan region was extremely valuable as we further develop our SIGMA+ sensors and networks to provide city and regional-scale coverage for chem and bio threat detection," said Mark Wrobel, SIGMA+ program manager. "Collecting chemical and biological environment data provided an enhanced understanding of the urban environment and is helping us make refinements of the threat-detection algorithms to minimize false positives and false negatives."

SIGMA+ expands on the original SIGMA program's advanced capability to detect illicit radioactive and nuclear materials by developing new sensors and networks that would alert authorities with high sensitivity to chemical, biological, and explosives threats as well. SIGMA, which began in 2014, has demonstrated city-scale capability for detecting radiological threats and is now operationally deployed with the Port Authority of New York and New Jersey, helping protect the greater New York City region.

In addition to collecting more than 250 hours of chemical and biological background environment data, DARPA researchers also evaluated the sensors' performance in detecting benign controlled chemical

continued

Indianapolis Testing Advances Capabilities of Chemical, Biological Threat Detection Sensors (cont'd)

releases that could be representative of threat agent production processes. Five safe chemicals were released and tracked by the sensor platforms during the week.

One such chemical is acetone, which has benign industrial and business uses but can also be used for nefarious purposes.

"We tested the ability of the sensors to distinguish between normal background chemical environment and small traces of specific chemicals such as acetone," Wrobel said. "If a chemical sensor makes an acetone hit near a nail salon, the SIGMA+ data analytics can help authorities make a determination that it's probably a benign use of the chemical. But if an anomalous concentration of acetone is picked up at a location with no logical connection to the chemical, it could indicate something worth investigating, since acetone is also a precursor ingredient for some types of explosives."

DARPA also demonstrated the SIGMA+ network architecture and common operating picture to Indianapolis Metropolitan Police Department officials and other regional stakeholders. The deployed sensors communicated the data they acquired in real-time to a cloud architecture for storage and display at a local command post. Observers received a demonstration of the SIGMA+ user interface, highlighting the functionality and long-term vision to provide law enforcement and first responders new capabilities to detect, localize, and track chemical, biological, and radiological threats in real-time to support situational awareness and decision making. Additionally, the demonstration facilitated discussions with stakeholders to guide future concept of operations (CONOPs) planning and to coordinate follow-on on tests of the SIGMA+ system.

"The outstanding support of the Indianapolis Metropolitan Police Department made the testing possible," Wrobel said. "The continued cooperation with IMPD builds on great support we've also received from the Marion County Health Department and the Indianapolis Motor Speedway, who allowed us to temporarily install threat-detection sensors to enhance security at the 2018 and 2019 Indianapolis 500 and to conduct additional chemical sensor testing at the Speedway in August 2018."

"We recognize the importance of staying a step ahead of our adversaries and to continue to develop the best tools possible for our warfighters and strategic partners," said Sgt. Robert Brown, counter-weapons of mass destruction (WMD/CBRNE) program manager in the Homeland Security Bureau of the Indianapolis Metropolitan Police Department.

The DARPA SIGMA+ chemical sensors were developed by Physical Sciences Inc., Andover, Massachusetts and by Bruker Detection Corp., Billerica, Massachusetts. The biological sensors were developed by Battelle Memorial Institute, Columbus, Ohio.

DID YOU KNOW?

DARPA's Young Faculty Award (YFA) has been ongoing for 15 years, awarding 447 grants to date across 40 States nationwide. DSO administers the YFA program for the Agency, soliciting topics on an annual basis from every DARPA Technology Office.

The objectives of YFA are to identify and engage rising stars in junior research positions inside and outside of academia, expose them to Defense Department needs and DARPA's program development process, and provide high-impact funding to develop new research directions that help to transform national security capabilities.

You can find out more about DARPA's YFA program at https://www.darpa.mil/work-with-us/for-universities/young-faculty-award.

DARPA's SIGMA Program Transitions to Protect Major U.S. Metropolitan Region

Advanced radiation detection system operational with Port Authority of New York & New Jersey

DARPA's SIGMA Program has transitioned to the Port Authority of New York & New Jersey, providing an advanced radiation detection system to help protect the nation's largest metropolitan region.

On a blustery winter day in December 2019, a car carrying radioactive material approached one of the Port Authority of New York and New Jersey's major transportation hubs. As the car got closer, an alarm flashed and sounded on a large monitor in the police operations center, identifying on a digital map the exact location of the vehicle and the specific radioactive isotope radiating from the car—Cesium-137. Within minutes, officers in the Port Authority Police Department—equipped with vehicle-mounted and pocket-sized radiation sensors displaying the same real-time digital map—tracked the vehicle and apprehended the suspects in a parking lot. Thankfully, the potential terrorists and radiation-emitting isotope were not a threat, as the scenario was only a drill.

The December exercise marked the capstone for DARPA's SIGMA program, culminating a five-year effort to develop and deploy an automated, high-performance, networked radiation detection capability for counterterrorism and continuous city-to-region scale radiological and nuclear threat monitoring. The transition of the radiation-detection system took place prior to the coronavirus disease (COVID-19) pandemic. Since the SIGMA transition, DARPA has been developing and testing additional sensors under its SIGMA+ effort to detect chemical, biological and explosive threats as well.

"We want to thank the Port Authority for their outstanding support throughout the SIGMA program and their continued support as we test SIGMA+ sensors," said Mark Wrobel, SIGMA program manager. "Being able to test and refine the system in

continued

DARPA's SIGMA Program Transitions to Protect Major U.S. Metropolitan Region (cont'd)

the country's largest metropolitan region was invaluable in taking SIGMA from a research project to an operationally deployed system in just five years."

SIGMA adds an additional layer of radiation-detection capability for the Port Authority.

"New York City and Northern New Jersey have some of the nation's most critical transportation infrastructure—heavily trafficked tunnels, bridges, airports, train and bus stations, and ferry terminals," said Dave Warrington, senior manager for strategic preparedness in the Port Authority's Office of Emergency Management. "This unique partnership with DARPA was mutually beneficial—DARPA had access to our transportation nodes to collect real background radiological data for developing the system, and the Port Authority now has a network of high-performance stationary, vehicle-mounted, and wearable sensors providing enhanced, 24-hour nuclear and radiological threat detection."

Port Authority Police Department (PAPD) officers commented on the capabilities and improved detection sensitivity SIGMA provides, significantly reducing false-positives.

"Our legacy radiation-detection system takes a lot more time to identify if a radioactive hit is a threat or a non-threatening source, such as construction-site materials," said Lt. Rich Munnelly, emergency management liaison officer at PAPD headquarters. "SIGMA enables much faster reaction time, since you don't need to wait for additional equipment to be brought in to evaluate the radioactive material. With SIGMA, the first responder knows immediately via handheld display what the radioactive isotope is and can quickly determine if it's a threat or not."

Munnelly noted how user friendly the system is. SIGMA uses an app-like Android interface that is easy to train new officers on. He also highlighted how the network allows officials up the chain of command to follow alerts and track potential threats in real-time along with first responders, significantly streamlining the coordination process across various levels of command and with federal agencies in the case of a radiological event.

"The system automatically sends officers alert notifications and texts, which is key," Munnelly said. "Everyone gets all the information at the same time, and because the various sensors are networked it allows for remote monitoring and standoff detection, increasing safety for our officers and the public."

Another benefit of the SIGMA sensors is their reduced size, weight, and power—from the portable sensors first responders wear on their vest to the more powerful sensors carried in police vehicles, to the stationary sensors at key transportation nodes. For example, legacy vehicle-borne sensor packages take up the whole vehicle, Warrington said, whereas SIGMA's vehicle-mounted detectors require significantly less space, allowing vehicles to perform their primary function and have room for additional gear.

Most importantly, SIGMA runs continuously, analyzing background radiological conditions daily to constantly refine threat-detection algorithms.

"It's not a closed-end system," Munnelly said. "Software refreshes are pushed out regularly, updating isotope profiles to improve detection of known threats and to account for potential new ones."

The use of this constantly collected background data also supports reduction in false and nuisance alarm rates, a major operational burden with legacy systems.

The performers who developed the SIGMA radiation detectors and network are Physical Sciences Inc., Kromek Ltd., Silverside Detectors, and Two Six Labs.

Emerging Results

AI Model Predicts Drug Combinations with Synergistic Effect Against SARS-CoV-2

Synergistic drug therapies have been shown to be more effective than single drugs against diseases such as cancer, HIV, and tuberculosis. However, the combinatorial explosion of possibilities, even if limited to known (i.e., FDA-approved) drugs, rapidly makes experimentally testing combination therapies intractable. As such, relatively few have been evaluated, particularly for new diseases and viral threats including SARS-CoV-2. In response to need for effective antiviral drugs during the past year, performers in DSO's Accelerated Molecular Discovery (AMD) program developed an AI model that is able to exploit the large amount of biological target information available for single (FDA-approved) drugs to complement the scarce combination information available for training. In collaboration with the NIH National Center for Advancing Translational Sciences, AMD performers at the Massachusetts Institute of Technology used this model to identify two novel combinations of known drugs that showed strong synergistic antiviral effects against SARS-CoV-2 in vitro[1]. The teams are now working to better understand the mechanisms of action. By enabling rapid and accurate AI-assisted virtual screens of drug combinations with well-understood biological profiles, this approach could significantly reduce the time to clinical adoption compared to designing novel drugs.

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1. Wengong Jin, Regina Barzilay, Tommi Jaakkola. "Discovering Synergistic Drug Combinations for COVID with Biological Bottleneck Models," NeurIPS Machine Learning for Molecules Workshop 2020. https://arxiv.org/pdf/2011.04651.pdf

DSO DRINQS (Driven Non-equilibrium Quantum Systems) Demonstrated Entanglement and Control of Single Nuclear Spins in an Industrially Scalable Material

Nuclear spins are attractive candidates for quantum memory registers as their lifetimes can exceed hours. Recently, commercial silicon carbide (SiC) has been shown to provide a technologically mature semiconductor host for various spin qubits. However, the control of single nuclear spins in SiC has remained an outstanding challenge. DRINQS has demonstrated, for the first time, coherent control of isolated 29Si nuclear spins in commercial SiC to create an entangled state between an electron spin and a strongly coupled nuclear register. This research provides a guide for future materials design of spin-based quantum technologies such as quantum memories in practical substrates.

Miniaturizing Important Photonic Component

DSO's Nature as Computer (NAC) performer University of Rochester developed the world's smallest electro-optical modulator (EOM). The compact, high-speed, and energy-efficient EOM was developed using high-quality lithium niobite photonic crystals fabricated with electron-beam lithography. The modulator is a key component of the team's hardware implementation of their optical Ising machine design, which shows promise for solving problems of interest to DoD such as logistic delivery optimization and communication network resource optimization.

DARPA Performers Break Rayleigh Limit for Optical Imaging

For over a century, scientists believed that imagers were limited to the classical Rayleigh resolution limit, which states that the best possible imaging resolution is inversely proportional to the diameter of a camera's aperture. Independently, two teams, one with a DARPA Young Faculty Award performer and the other comprised of researchers from the DSO Investigating Adaptive Modal Bases for Intelligent Classification (IAMBIC) program, have shown this is not true for important DoD problems in which it is unnecessary to recover the full image. As one example, using analysis, the IAMBIC team showed that the modal imaging approach can accurately, and >200x faster than a traditional camera, read a 2-cm-wide bar-code with four bars from a distance of 1 km when using a 3-mm aperture. A full demonstration device is now being built.

DSO SIGMA+ Demonstrated Detection of Simulated WMD Manufacture, Planning, and Use During Field Trials with the Indianapolis Metropolitan Police Department (IMPD)

Data were acquired and new analytics were tested to detect threat activity in live sensor data fused with contextual and transactional datasets. The SIGMA+ network architecture successfully managed 8 different data sets, collected over 18M sensor readings, and stored over 31M data elements. The analytics detected all of the 126 synthetic "threats" injected into the datasets and triggered by actual chemical alerts from controlled releases over a week-long event with no false alarms. A new situational awareness tool used to display trigger and search results was also demonstrated to IMPD stakeholders.

MACH Demonstrates a Novel Additive Manufacturing Process that Promises Increased Temperature Resistance of Hypersonic Vehicle Leading Edges

The DSO MACH (Materials Architectures and Characterization for Hypersonics) program is investigating approaches to produce aerodynamically sharp, hypersonic vehicle leading edges that combine refractory materials with cooling approaches to achieve unprecedented survivability under extreme heat flux. The MACH program has demonstrated a novel additive manufacturing process that uses high energy lasers and controlled solidification to produce porous, ultrahigh temperature nano-architectures from refractory metals that, when combined with transpiration cooling, can withstand conditions that cause state of the art leading edge materials to rapidly blunt and increase vehicle drag. By keeping an aerodynamically sharp leading edge at higher heat fluxes, future platforms are expected to achieve superior operational capability with increased velocities and extended range.

Building Ultrafast and Dense Computer Memory with Skyrmions

DSO Topological Excitations in Electronics (TEE) for the first time demonstrated skyrmions moving at velocities at least 1000 meters/second (4x faster than reported state-of-the-art research and 100x faster than existing magnetic memories) inside a domain wall by utilizing materials like cobalt gadolinium and rare earth iron garnets. Additionally, using a 100 picosecond probe, TEE succeeded for the first time in observing nucleation and annihilation processes that occur at nanosecond timescales. The combination of low-power consumption with stable and massive storage capacity will, if achieved, enable significant new capabilities available to the warfighter.

EXTREME (Extreme Optics and Imaging) Performer Sandia National Laboratories Releases the World's First Metamaterial Inverse Design Tool, MIRaGE

MIRaGE (http://www.mirage-software.com) is capable of rapidly designing, simulating, and optimizing electromagnetic metamaterial structures from nanometer to centimeter length scales with virtually any desired electromagnetic response. The advantage of metamaterials is that the large number of degrees of freedom (DOF) in the geometry of sub-wavelength scatterers allows trades of sensitivity, dynamic range, and aperture size to be made in a single device, which in turn can greatly reduce the size, weight, and power of such sensor systems while potentially enhancing functionality. MIRaGE overcomes the problem of wading through the large set of DOF options by linking performance directly to structure in a single step, making the rapid design of novel metamaterial sensor technologies for DoD applications a reality. MIRaGE was awarded Laser Focus World magazine's "Innovators Platinum Award," the highest award level in any category throughout optics and photonics.

Design Optimization Program Supports NASA Electric Aircraft Development

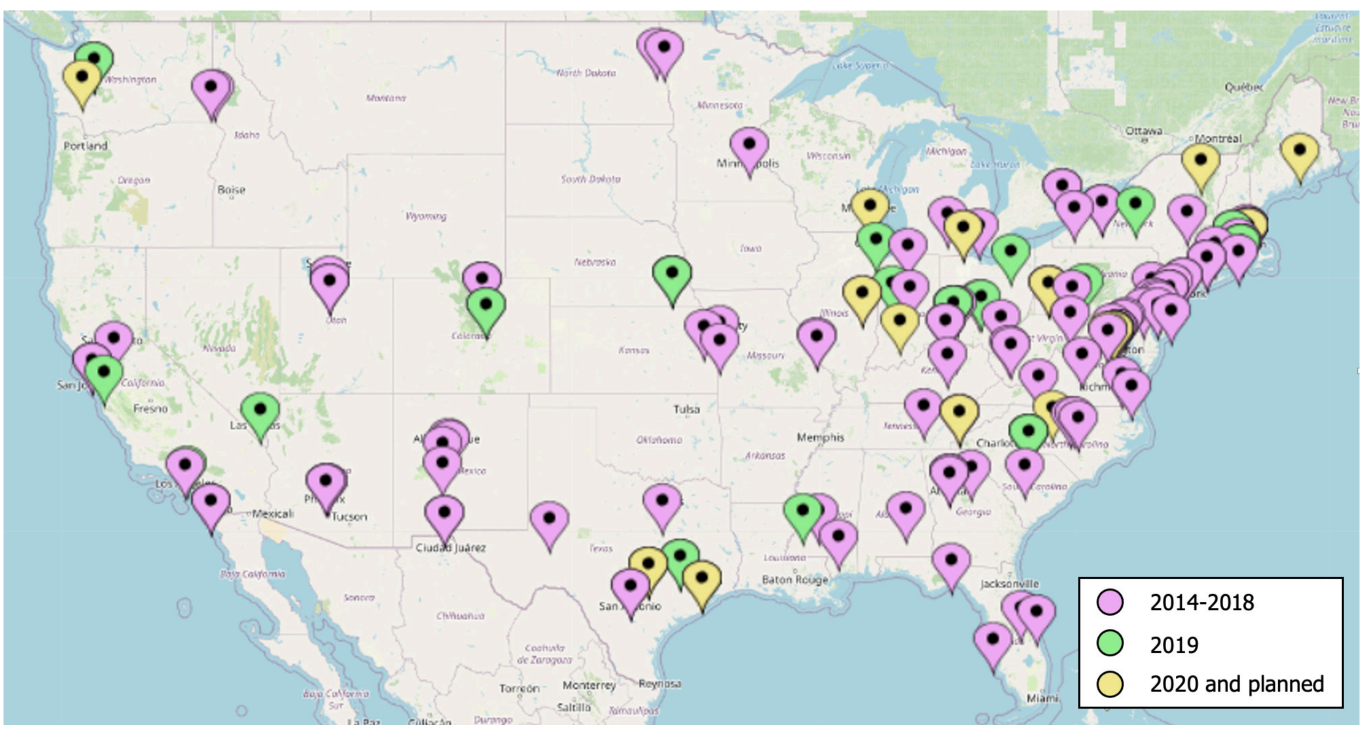
A Transformative Design (TRADES) performer used the OpenVDB computational package originally developed at DreamWorks to represent complex animation scenes to optimize complex, multi-physics, multi-materials designs represented with up to 10 billion voxels without requiring high performance computers. Based on the TRADES results, the performer was awarded a 3-year project under NASA's Transformational Tools and Technologies (TTT) project with the objective of optimizing structural, thermal, and flow physics for thermo-elastic components for load carrying battery designs. Results to date have produced designs that, for the same weight, are 6% stiffer, have a 15% reduction in average battery temperatures, and a 23% reduction in pressure drop, properties that have the potential to increase the viability of electric aircraft (such as NASA's X57).

DARPA Develops a novel spiking neural network (SNN) architecture for power-efficient always-on intelligent function

A Microscale Bio-mimetic Robust Artificial Intelligence Networks (μBrain) performer has demonstrated a SNN prototype in CMOS for key-word spotting (KWS) and other always-on classification tasks. By leveraging signal sparseness, the always-on classifier hardware consumes less-than 220 nW for the KWS task, representing up to a three-order-of-magnitude reduction in power consumption. Such low-power, always-on, event-driven classifiers are critical for computing on the edge to enable persistent sensing capabilities for extended time periods while deployed.

DSO Outreach

Engaging with people and institutions who are unfamiliar with DARPA and DSO is important to identifying new research partners and ideas. The DSO Director and Deputy Director actively communicate and disseminate "How to do Business with DSO" via various outreach efforts to companies, universities, and small businesses. Over the past year, outreach events were held with the University of Chicago, The Ohio State University, University of Maine, and University of Vermont, just to name a few. The map below shows every outreach event conducted by office leadership since 2014.



DSO's Extreme Optics and Imaging (EXTREME) program transitions technology to military partners and commercial marketplace

Materials with novel optical properties developed under DSO's EXTREME program are having an impact on Air Force systems and, potentially, your cell phone.

EXTREME developed new optical components, devices, systems, architectures and design tools using engineered optical materials, or metamaterials, to improve the size, weight, and power (SWaP) characteristics of traditional optical systems. Metamaterials are composed of unit cells that are much smaller than the operating wavelength, allowing for greater manipulation of light. Early examples of metamaterials were used to design and build multifunctional elements that seemingly defied standard "laws" of reflection and refraction. These were limited in efficiencies and in sizes less than a millimeter, prohibiting their integration into optical systems. EXTREME addressed these challenges by improving efficiencies of lenses based on metamaterials, expanded their apertures to cm-scale, looked at methods to reduce the effect of optical aberrations, and explored new optical design space and associated trade-offs in SWaP afforded by such meta-lenses.

Such insights are being leveraged by the Air Force Research Laboratory (AFRL) funded under its Seedlings for Disruptive Capabilites Program (SDCP). Through SDCP, AFRL directorates partner with industry to answer critical needs of the Air Force Futures Strategy. The SDCP project, Integrated Compact EO/IR Systems (ICES), that exploits discoveries made under EXTREME is focused on low cost attritable platforms, such as unmanned aerial systems (UAS) that can be deployed in contested environments. These platforms have more stringent volume constraints and weight restrictions than legacy platforms. Adding another sensor is not an option without removing an existing one. The introduction of metasurfaces and planar optics for EO/IR capabilities disrupts the tradespace, potentially enabling us to keep both sensors and increase platform capability.

AFRL is relying on EXTREME technology to modify the EO/IR systems on developmental platforms under SDCP: the XQ-58 Valkyrie and Air Launched Off-Board Operations (ALOBO) program, which is a tube-launched UAS, are among the platforms that are the focus. For the XQ-58, AFRL is looking to reduce the volume of existing sensors to make room for additional sensors. For the tube-launched UAS in ALOBO, they are modifying the tube launch compatible gimbal system. Advances in optics by EXTREME allow AFRL to realize new tradespace for the gimbal with either 10x reduction in SWaP while maintaining performance or 4x improvement in resolution at current SWaP requirements. 4x improvement in resolution means seeing a person versus seeing if they are holding a shovel or a weapon.

On the commercial front, EXTREME performer, Harvard University, spun out the startup Metalenz. Metalenz is partnering with a cell phone manufacturer to outfit its smartphone with a 3D sensor that uses a single, flat lens system built on a glass wafer. The system is based on optical metasurfaces first developed under EXTREME. This technology is anticipated to provide the same or better image quality as current lenses by collecting more light, while taking less space and power, allowing for smaller phones or the addition of more sensors to existing phones. Metalenz chips are expected to be in mass production by the end of 2021.

EXTREME also led to DSO's Enhanced Night Vision in Eyeglass Form (ENVision) program. ENVision will leverage recent advances in planar optics and transduction materials to develop novel direct-view night vision systems that demonstrate an increased field-of-view and enhanced visual access across infrared bands, all potentially contained in a near-eyeglass form factor.

Spectral Combs from UV to THz (SCOUT) Transition

For more than two decades, DARPA has invested in the scientific and technological underpinnings for high performance RF and optical sources. DARPA investments were built on fundamental, early stage demonstrations with complex, precisely orchestrated laboratory experiments. The demonstrated approaches, however, ultimately suffered from noise and decoherence effects, precluding their use in important DoD applications that require high stability and signal-to-noise ratios. DARPA was interested in further developing these nascent capabilities toward critical defense applications, including ultra-secure communications, high-precision navigation, and chemical sensing, particularly in cluttered (i.e., real life) environments.

Recently, under DSO's Spectral Combs from UV to THz (SCOUT) program, researchers developed and demonstrated the first ever high-speed, high-precision spectroscopy capability to characterize chemical species in complex mixtures, including long-range (10s of kilometers) detection of harmful substances in the air and short-range (centimeter-scale) engine combustion diagnostics.

The groundwork for this revolutionary technique was laid in DSO's Program in Ultrafast Laser Science and Engineering (PULSE), which developed two key advances in optical frequency combs (OFCs). An OFC is a light source with an optical spectrum comprising many discrete, equally spaced frequencies. For a conceptual image, imagine a conventional hair comb that is 23 miles long, with each comb tooth representing a slightly different color of light. While OFCs existed prior to PULSE, generating the combs was a trial-and-error process, and tweaking device parameters to generate a stable comb could take hours or days. DARPA PULSE performers provided a critical advance in OFC technology by developing methods to automatically achieve this mode-locking (i.e., stable comb generation) process, essentially creating a turn-key OFC generator. PULSE also created capabilities to enable system use outside of an ideal laboratory environment (critical for DoD applications in the field), by hardening the system against vibration and temperature fluctuations.

Use in spectroscopic applications to identify chemical species of interest in complex (real life) backgrounds, however, required further advances that included integrating an additional frequency comb to detect the interaction of each color of light with molecules in

University of Colorado and AFRL teams in the control room during the dual-mode ramjet ground test. The modified dual frequency comb system is in the center foreground, and is sending light to the test cell, which is located beyond the control room windows.

LongPath dual frequency comb emissions detection system installed in an oil and gas production field in Oklahoma. This system is continuously monitoring 20 complex multi-well facilities over a 17.5 square mile region.

a system (so-called dual-comb spectroscopy (DCS)), system miniaturization, and other improvements in usability. The DARPA SCOUT program set out to tackle these and other challenges, further developing OFC capabilities for ultrafast, high-precision chemical spectroscopy. Performers in SCOUT developed a number of new materials to generate combs, demonstrated dual-comb operation in real-world environments (outside the laboratory), and, most notably although SCOUT was a basic research program, transitioned compelling capabilities to Government, commercial, and military applications.

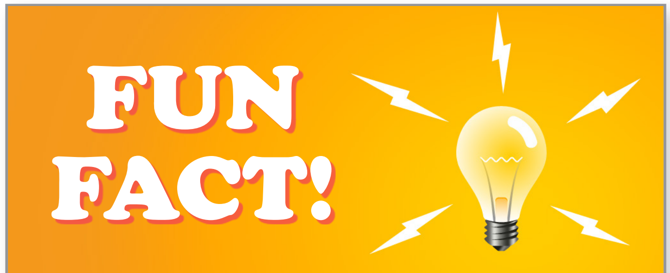
continued

Spectral Combs from UV to THz (SCOUT) Transition (cont'd)

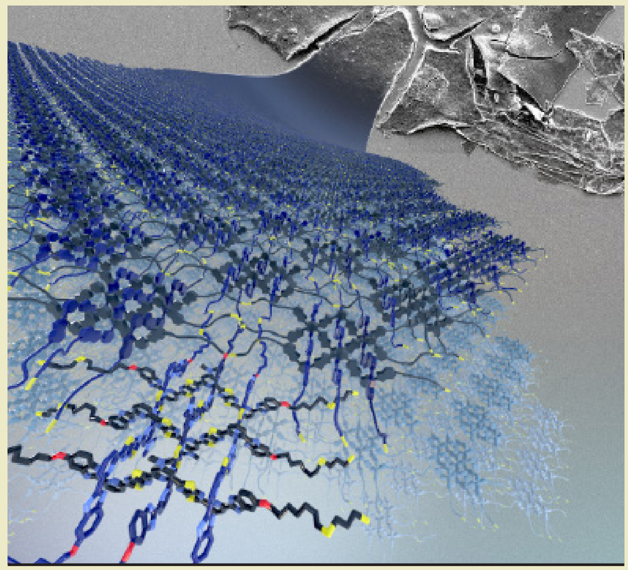
For example, joint work at the University of Colorado (CU), Boulder and National Institute of Standards and Technology (NIST) resulted in a turn-key fieldable DCS system, realized by miniaturizing the electronic components and further maturing the comb-generating capabilities of the device. As a result of their efforts under SCOUT, the team received follow-on funding from the Advanced Research Projects Agency – Energy (ARPA-E) to develop the technology for long-range methane leak detection under the Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) program. The result was a low-cost DCS system that could detect methane leaks equivalent to a quarter of a human exhalation from one mile away.

The team spun out LongPath Technologies (https://www.longpathtech.com) to create the first low-cost commercial DCS platform and further develop the capability toward DoD and commercial applications. LongPath recently received an additional $5M from ARPA-E to scale up its approach for continuous monitoring of methane emissions in oil and gas fields. A recent test of one LongPath system identified methane leaks that mitigated 43 million cubic feet of methane emissions in a six-month period. In the coming years, LongPath will deploy dozens of systems enabling real-time location and sizing of natural gas emissions across more than 600 square miles of the Permian Basin in the southwestern United States. This will be the largest continuous emissions monitoring network for the oil and gas industry and is projected to reduce oil and gas production emissions by 60-80%.

The CU/LongPath DCS capability is also of interest to the DoD. During the SCOUT program, DARPA and the U.S. Air Force Research Laboratory (AFRL) collaborated to evaluate the system in a dual-mode ramjet and better evaluate its performance for critical defense applications. During the first measurement campaign, the CU team correctly identified multiple important engine performance parameters in the ramjet system, at a precision well beyond currently employed technology. These results, coupled with those from a second and more complex test scenario using a modified laser configuration, convinced AFRL to make further investments in the technology. AFRL has characterized LongPath's OFC system as a leap ahead in the state of the art for laser technology and is now funding the former SCOUT team to further develop the technique for additional diagnostic needs.



University of Manchester wins Guinness World Record for finest woven fabric.



'*Self-assembly of a layered two-dimensional molecularly woven fabric*' David P. August, Robert A. W. Dryfe, Sarah J. Haigh, Paige R. C. Kent, David A. Leigh, Jean-François Lemonnier, Zheling Li, Christopher A. Muryn, Leoni I. Palmer, Yiwei Song, George F. S. Whitehead and Robert J. Young, Nature, **588**, 429-435 (2020)

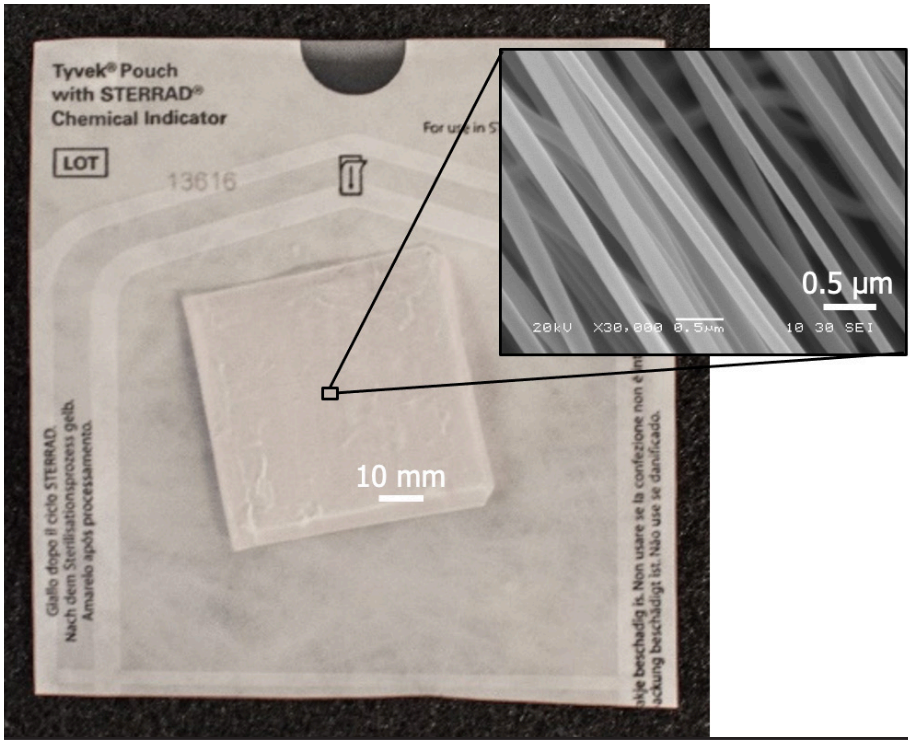
August, D.P. et al. *Nature*, **588**, 429-435 (2020)

DARPA-funded work at the University of Manchester wins Guinness World Record for finest woven fabric, demonstrating for the first time, an approach for weaving polymers at the nanoscale: A DSO seedling performer demonstrated a way to weave polymers together, creating 2-D sheets only 4 nm thick and >0.1 mm long. This "molecularly woven fabric" represents a new class of material that has the strength and flexibility of polymers but the functionality of patterned nanomaterials. The group demonstrated that the material could be used to filter molecules from solution (like a net). These structures may offer new ways to tailor materials for improved sensing, catalytic, electrical, and optical properties. This work was recently published in Nature.

DSO Investment in Nanotechnology Manufacturing Helps Wounded Warriors Return to Peak Performance

An investment made under DSO's Atoms to Products (A2P) program is set to revolutionize how some serious leg and shoulder injuries are treated. Tendon and ligament tears are common injuries experienced by warriors, athletes, and laypeople alike, causing significant pain and downtime as they recover. Sometimes these injuries are severe enough to require surgery. Surgery may involve stitching the end of the ligament or tendon together or reattaching it to the bone, and patients rarely fully recover from this type of surgery. Particularly damaged tendons and ligaments may require an autograft, removing a tendon or ligament from another part of the patient, resulting in a loss of functionality in another part of the body.

The technology developed by Embody LLC (https://embody-inc.com) under A2P is a nanostructured collagen composite that is designed to wrap around the sutured tendon or ligament during surgery to reinforce the area during recovery and provide a scaffold for the growth of new tissue. Embody claims the collagen composite improves handling and suturing over traditional repair methods, while new dense tissue integrates with the implant and native tendon as early as 4 weeks after surgery. This rapid tendon repair promises to restore pre-injury performance. Embody recently received FDA 510K premarket approval for their TAPESTRY Biointegrative Implant device. They are marketing their technology for ligament and rotator cuff tears as well.



Nanostructured collagen composite patch product for connective tissue repair with SEM inset showing aligned fiber structure

Photo courtesy of Embody

Embody received support to bring its technology to market from a DARPA Direct to Phase II Small Business Innovation Research award and via DARPA's Embedded Entrepreneurship Initiative (EEI). EEI provides catalytic funding, mentorship, and investor and corporate connections for select DARPA researchers. Embody's CEO Jeff Conroy said, "Embody's EEI program participation was transformational, allowing us access to market data, business forecast modeling, and our first commercial hire. This was critical to accelerate our evolution into a commercial stage company. The EEI Program is a valuable extension of DARPA's mandate to create disruptive market-focused companies."

TAPESTRY is a significant commercial transition for DSO's A2P program. A2P was conceived to develop and demonstrate scalable technologies that bridged the assembly gap between nanometer- to micron-scale components into larger, human-scale systems. Properties in nanometer- to micron- scale components are often unique and/or superior compared to their bulk counterparts. However, conventional manufacturing technologies have no way of incorporating these small-scale components into larger structures and devices while still preserving the desired properties.

DSO Alumni: Where are they now?

Dr. Larry Dubois

DSO PM: 1993–1995
DSO Deputy: 1995–1996
DSO Director: 1996–2000

In the book *All I Really Need to Know I Learned in Kindergarten*, Robert Fulghum lays out his principles for a good life. I would argue that all I really need to know to be successful, I learned from DSO.

When I first joined the Agency, Lee Buchanan, then the Director of DSO, said that DARPA would be the best job I ever had—and it is all downhill from there! He was right on one front: DARPA *is by far the best place in the world to work*, but there really is life after DARPA. In DSO we shared, we were honest, we hired the best, and trusted each other's knowledge and judgment. We laughed, we argued, we took risks, and sometimes made mistakes, but we worked together as a team (except when we played laser tag, and I seemed to be everyone's target!). As program managers, support contractors, and office staff, we worked hard, took responsibility for our actions, pushed the envelope—and really made a difference in the world. While we laid out what I believe to be the right principles, it is the people of DSO that made it great.

Heilmeier asked great questions—in my view, the key to making a difference is implementing the right solutions—moving beyond invention to true value creation, starting with the end in mind and working backwards to see what really needs to be accomplished. After leaving DARPA, I joined SRI International as Corporate Vice President and Head of the Physical Sciences Division—a group of scientists and engineers that represented the depth and breadth of DSO. We used the principles learned from DARPA and thought bigger, bolder. We hired great new staff, pulled together multidisciplinary teams that had never worked together before, and solved important problems thought to be intractable. We took a Division that had been losing money for decades and made it highly profitable—and along the way we had fun. Similarly, as the Senior Vice President and Chief Technology Officer of Advanced Technology Materials, Inc. (ATMI), we used the same principles to broaden our technology solutions and make a greater impact on the world.

I worked closely with the Defense Sciences Research Council (DSRC) while at DARPA and had the honor of joining the Council after I left. With all of the changes going on in the world and at DARPA, the Council provided a window into the future and into areas of importance to DARPA, DSO, and MTO. The Council brought fresh thinking, an outside perspective, and a place for DARPA staff to be creative and think beyond individual programs. Twenty great years of friendship and fellowship: Two decades of making a difference with the best and the brightest.

As the next chapter of my life unfolds, as the Founder and CEO of NANOIONIX, I am fortunate to work closely with many current and former DARPA staff. At NANOIONIX we are focused on fighting the spread of infectious disease through advances in materials science—combining technologies from disparate fields to address major global challenges. To dream big, to solve important problems, and build on the teams that we started putting together so many years ago. Life comes full circle—and for me and the successes that I have shared—it always seems to revolve around the seven years I spent in DSO.

Dr. Anantha Krishnan

DSO PM: 2002–2005

Looking back, I realize that I was extremely lucky to be a PM at DARPA during the heyday of biological programs in DSO. My particular focus on bio-molecular interfaces, especially in the context of nano-bio-technology, led to the exploration of many novel and innovative device concepts, some of which have been successfully deployed in the medical diagnostics community. I credit these successes to DARPA's non-traditional approach of supporting novel, high risk, and high impact concepts, extending even into the medical domain. More importantly, I also got to see how DARPA brought scientific communities together that otherwise would not have interacted with each other. These multidisciplinary collaborations are key to some of the great breakthroughs that were achieved in DARPA programs, and many of these advances happened long after the programs officially ended.

I joined Lawrence Livermore National Laboratory (LLNL) after leaving DARPA in 2005. I was able to transfer some of the DARPA approach and philosophy to my team at LLNL and was able to help initiate a couple of technology thrusts in Advanced Manufacturing and Neuro-Technology, respectively. Interestingly, both thrusts received significant support from DARPA (DSO and BTO) in the early days and eventually matured into capabilities that are continuing to have a significant impact in the community. The National Nuclear Security Administration (NNSA) now uses advanced components (prototyped and demonstrated by LLNL) in its Stockpile Stewardship mission that can be traced back to DARPA's support of the initial concept. Similarly, LLNL now produces advanced neural implants that are being used widely by the neuroscience community that were prototyped with DARPA funding many years ago. I am thankful that I had the opportunity to apply the DARPA model at a National Laboratory and have it make a significant impact on the Laboratory's missions.

More recently, I have taken on the role of Senior Vice President for Energy at General Atomics (GA). The Energy Group at GA manages two large programs in the areas of Magnetic Fusion Energy and Inertial Confinement Fusion. A recent National Academies report, recommending the deployment of a pilot fusion plant on the energy grid by 2040, has generated immense excitement within the magnetic fusion community. Although scientists have been working on nuclear fusion for decades, the realization of a fusion pilot plant in the next 15 to 20 years has many "DARPA-hard" challenges that need to be addressed. I hope the community adopts a DARPA-like approach to take on this extremely worthy goal of demonstrating an unlimited source of clean energy on Earth.

In closing, I must say that it is a great thing that DARPA asks all its PMs to quantify the potential impacts of any investment that DARPA makes through its programs. However, it is also important to realize that DARPA has an impact well beyond its programs in terms of the communities and collaborations that it creates and enables, the impact produced by the DARPA model being applied at other organizations—especially by former DARPA PMs—and, of course, in the creation of other government organizations modeled after DARPA (IARPA, ARPA-E, etc.). Despite all the great roles that I have had since leaving DARPA, I must say that I still cherish and value the unique DARPA tenure that I was fortunate to experience early in my career.

Former DSO and TTO PM Recognized with DARPA's 2020 Game Changer Award

Dr. Chris Warren

ATO/STO PM: 2006–2007

DSO PM: 2010–2013

TTO PM: 2013–2016

Former DSO and TTO Program Manager Chris Warren was recognized in December 2020 with DARPA's Game Changer award for the significant contributions transitioned from DSO's Hybrid Multi-Material Rotor (HMMR) and TTO's Hybrid Demonstration (HyDem) programs to the U.S. Navy.

A key weapon in the U.S. Navy's arsenal is the attack submarine. The mission of attack submarines is to attack and sink enemy submarines and surface ships, while protecting friendly surface combatants and missile submarines. In order to stay one step ahead of the enemy, attack submarines must run quiet. New propulsor technology enabled by the HMMR program is deployed on the Virginia-class nuclear attack submarine USS South Dakota (SSN-790). Rear Adm. Michael E. Jabaley discussed the Navy's Acoustic Superiority Program at an event sponsored by the Center for Strategic and International Studies in July 2016: "South Dakota will have an improved enhanced hybrid propulsor that we have developed with DARPA. It promises to present a significant acoustic advantage." The new propulsor was successfully demonstrated on South Dakota, and the Navy plans to adopt it for use on future Virginia-class boats as well as the future Ohio Replacement Program (ORP) ballistic missile submarines.

HMMR (2010–2016) developed novel hybrid material systems that allow for tunable stiffness and dampening in large complex structures (in excess of 20ft in diameter) under dynamic loading to significantly improve U.S. submarine propulsor capability, resulting in game-changing improvements with regard to weight and stiffness. The goals of this program were to reduce the weight of individual rotor blades by 50% and increase blade stiffness by a factor of 1.5x over the Nickel/Aluminum/Bronze (NAB) baseline.

The properties of the constituent materials that make-up these hybrid systems are well known -- carbon fiber composites, S-glass/epoxy composites, metals, and polyurethanes. However, determining the dynamic behavior of hybrid material systems (combinations of the constituents) and tuning these systems to have an optimal dynamic response to different operating conditions is extremely difficult. To address this challenge in relationship to a complex submarine propulsor requires examining an overwhelmingly large set of materials solutions across a diverse set of operating conditions. In order to do this quickly, the HMMR program utilized unconventional design approaches to develop an innovative, fast, and efficient set of design and analysis tools that integrated structural, material, hydrodynamic, and performance codes. These tools are now used by the U.S. Navy to reduce computational time for a single analytical estimate from 6 weeks to less than 1 week in support of legacy, current, and future submarine designs.

HMMR not only developed tools to predict the hybrid materials' behavior but also the manufacturing technologies to fabricate complicated rotor geometries. For example, the program developed a family of viscoelastic polyurethanes with tunable anisotropic damping properties.

The follow on HyDem program (2013–2018) rapidly applied these new materials, design tools, and manufacturing technologies to full-scale submarine design and testing, with the christening of South Dakota in 2017.

Congratulations, Chris!

Rethinking Competition

While the U.S. and allies can be expected to compete well head-to-head with resurgent powers in overt conflicts, optimal strategies for less transparent competitions are lacking. Indeed, even defining the nature of the competition within domains as interwoven as economics, information, finance, politics, and cyber can be elusive. How best to respond to covert or proxy military actions such as Russian use of contractors in Syria and Libya or Chinese use of their "maritime militia"? How best to respond to Russian gas embargoes to Europe or Chinese trade embargoes to Australia? How can the U.S. provide solace to Syrian refugees even as Russia leverages them to create instability within Europe and probe Finnish border security? Americans like to win, but is it even right to think about winning within these complex competitions?

The collaborative, interdisciplinary, and often-contrarian nature of DSO makes the office a fertile breeding ground for thoughts on how best to frame the geopolitical challenges our Nation and allies face. We have been *rethinking competition* beginning with game theory and folding in lessons from social science, epistemology, and complex systems engineering. In short, we see two forms of competition with correspondingly different, optimal strategies. Competitions of the first type are "winner takes all," and many technology races fit within this category. For example, the U.S., Chinese, and Russian governments have all declared that AI, biotechnology, and quantum computing are respective national priorities.

Competitions of the second type are marked by long-term campaigns for influence. In these competitions, there is no finish line; rather, these are infinite contests with complex interactions where the players have limited ability to anticipate all of the possible outcomes. Within complex environments, there are no guarantees that the same action will yield the same result, and optimal strategies within these complex environments require different strategies than those appropriate within less dynamic environments. Decision makers must continuously validate their intuition since their past experience may have no relevance to the current environment; rather, decision makers would do well to maintain multiple competing, often orthogonal hypotheses, that possess different degrees of explanatory power. Therefore, the decision maker must adopt a strategy of acting or probing the environment first to characterize it and then rapidly adapt to this new characterization given the short time horizon when this characterization is valid. Key among this strategy is the need to learn and adapt more quickly than our competitors.

Many technical challenges emerge from this perspective of rethinking competition. How do we quantify influence? How do we appropriately consider the variety of populations we seek to influence, ranging from the local population of a destabilized nation to the security apparatus of a resurgent nation? How do we intend to sense the outcome from our probing actions? How do we combine these sensed outputs into a coherent decision despite any remaining uncertainty? What is the time constant associated with strategic adaptation?

Finally, competing in a manner that prioritizes prudent but rapid adaptation, possibly across many domains in a synchronized fashion, is not a strength of liberal democracies and bureaucracies. The U.S., however, does seek to empower those decision makers at the tactical and local level to make the best decisions possible. We see this within the military routinely, but how can we best support this low-level initiative in the face of possible strategic-level outcomes? Such is the nature of this competition, and it is through this lens of competition that we are challenging program managers interested in this area to look for future DSO technical opportunities.

Doing Business with DSO

DARPA's Defense Sciences Office (DSO) identifies and pursues high-risk, high-payoff research initiatives across a broad spectrum of science and engineering disciplines, and transforms them into important, new game-changing technologies for U.S. national security. Current DSO themes include Frontiers in Math, Computation & Design, Limits of Sensing & Sensors, Complex Social Systems, and Anticipating Surprise.

DSO relies on the greater scientific research community to help identify and explore ideas that could potentially revolutionize the state of the art.

Four ways to make DSO aware of your research ideas:

1. Talk to a Program Manager

Program Managers recommend which proposals should receive DSO funding. You may communicate directly with one or more of them (see DSO's website, https://www.darpa.mil/about-us/offices/dso). E-mails, phone calls, or face-to-face meetings allow you to explore concepts and ideas and translate them into a substantive proposal.

2. Submit a proposal to DSO's Office-wide Broad Agency Announcement (BAA), HR001121S0032

The Office-wide BAA is primarily used to fund small, short-duration exploratory projects. These small projects help DSO determine whether "disbelief" in an idea's plausibility can turn into "mere doubt" — and "mere doubt" is often enough to encourage DSO to make a larger investment to determine if a scientific or technology innovation may be possible. These efforts are typically 3–9 month projects that answer a specific question and involve a very limited number of personnel. Knowledge gleaned from these small projects often leads to the next generation of program ideas. See section entitled "DSO's Office-wide Broad Agency Announcement below."

3. Submit a proposal to a program-specific BAA

Exploratory investments that bear fruit and become programs will appear as individual program BAAs throughout the year. You can search for them on SAM.gov, grants.gov, the DSO website, or the DARPA website under "Solicitations."

4. Submit a proposal to DSO's Disruptioneering Program Announcement, DARPA-PA-21-03

See section entitled "DSO's Disruptioneering" below.

DSO's Disruptioneering

The pace of discovery in both science and technology is accelerating worldwide, resulting in new fields of study and the identification of scientific areas ripe for disruption. In order to capitalize on these new opportunities, DARPA's approach to investing must include faster responses with smaller, targeted investments. DSO has successfully addressed this concern through use of its Disruptioneering acquisition technique to make awards in fewer than 90 days after solicitation.

Targeted special notices called Disruption Opportunities (DOs) are issued under the Program Announcement, DARPA-PA-21-03, for each Disruption effort. These DOs focus on small, high risk programs within technical domains important to DSO's mission. Research topics of interest to DSO may be found at https://www.darpa.mil/about-us/offices/dso.

DARPA's mission is to make the pivotal early technology investments that create or prevent technological surprise for U.S. national security

DSO’s Office-wide Broad Agency Announcement

The current DSO Office-wide BAA covers the entire scope of DSO’s technical interests for this year and is open for new ideas through June 10, 2022.

Please note that the Office-wide BAA does not supersede program-specific BAAs. Rather it is intended to fund completely new ideas not connected with programs that are already underway or currently soliciting proposals.

The Office-wide BAA offers three different ways to submit ideas: (i) executive summaries (typically no more than two pages in length), (ii) abstracts (not to exceed five pages), and (iii) full proposals (read the BAA instructions regarding the structure and content of full proposals).

We recommend you start by submitting an executive summary (ES), preferably after discussing your ideas with a Program Manager. Your ES will be circulated among all the Program Managers in DSO, and you will receive feedback letting you know if there is any interest.

If you are not getting a timely response from a Program Manager or have other questions, please contact DSO’s BAA Administrator directly at HR001121S0032@darpa.mil.

General Advice for Submitting New Ideas to DSO

The “Heilmeier Catechism” is helpful for organizing your thoughts. Developed by Dr. George Heilmeier, Director of DARPA from 1975–1977, DARPA has lived by this catechism for decades. It poses the questions we ask ourselves about every new DSO program:

1. What are you trying to do?
2. How is it done today and who does it? What are the limitations of the present approaches?
3. What is new about our approach, and why do we think it will succeed?
4. If we succeed, what difference will it make?
5. How long do we think it will take?
6. What are our mid-term and final exams?
7. How much will it cost?

Initially, we recommend you focus on the first four to help define and scope your proposed research. In addition, we will ask you, “Why DARPA? Why DSO? Why now?” These questions of relevance come up every day in conversations at DARPA.

Above all, please read the BAA. If you have questions about the BAA, contact the Office-wide BAA Administrator at HR001121S0032@darpa.mil.

darpa.mil/about-us/offices/dso

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DARPA Defense Sciences Office