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Before the

Subcommittee on Emerging Threats and Capabilities,
Armed Services Committee, U.S. House of Representatives

Department of Defense Fiscal Year 2017 Science and Technology Programs: Defense Innovation to Create the Future Military Force

February 24, 2016

NOT FOR PUBLICATION UNTIL RELEASED BY THE SUBCOMMITTEE

Chairman Wilson, Ranking Member Langevin and Members of the Subcommittee, thank you for the opportunity to testify before you today. I am Arati Prabhakar, Director of the Defense Advanced Research Projects Agency, better known as DARPA. It is a pleasure to be here with my colleagues from across the Department of Defense (DoD) Science and Technology (S&T) community, with whom we work closely throughout the year.

For nearly six decades, DARPA has played a particular role in this community of government innovators, and in the larger U.S. technology ecosystem: to pursue extremely challenging but potentially paradigm-shifting technologies in support of national security. In my testimony today I will describe a number of DARPA programs at various stages of maturity, including some whose products are already being adopted by the military Services and are already making a difference for our warfighters; some that are advancing through the challenging technological frontier that separates the seemingly impossible from the doable—a stage of work that in many ways is the heart and soul of DARPA; and some that are in their earliest phases of development but whose potential to radically change the technological and security landscape is so great that they are already influencing the Department's strategic thinking.

But before I dive into those details, I would like to briefly convey a more personal sense of what is going on at DARPA—an agency that is, after all, not just a collection of programs but a team of about 200 extraordinary individuals. It is a team whose collective energy not only propels DARPA but also invigorates people across the wide community with which we work—defense companies large and small, commercial startups and major firms, universities, government agencies and labs, and our close partners across DoD. It is a team that revels in the opportunity to attack pressing, nearly intractable problems—all in the context of public service.

So let me say in advance, rather than waiting until my closing as is traditionally the case, how much I and my colleagues at DARPA appreciate the ongoing support and trust that this committee and subcommittee have bestowed upon DARPA. I am fully committed to ensuring that, just as past investments in DARPA helped secure our Nation by repeatedly bending the arc of technological history, so today's investments will give rise to capabilities that will protect our Nation and project our interests for many decades to come.

A CHANGING WORLD

Our senior military and civilian leaders face a world of kaleidoscopic uncertainty today and into any foreseeable future. The daily fare is a noxious stew of violent extremism, terrorism and cross-border criminal activity. At the same time, the actions and the intentions of nation states in every region also demand our focus and attention. The Department has embarked on an important shift in recent years to reenergize its ability to invent, experiment with and operationalize advanced military capabilities that will be critical to deter and defeat if necessary the emerging great powers of this century. DoD's Third Offset Strategy and its Long Range Research and Development Plan (LRRDP) embody this important shift. DARPA has participated by sharing its future perspectives on technology, and many programs across the DARPA portfolio will demonstrate the critical core technologies for these new strategies. I will discuss a number of these programs today.

In addition to the geopolitical landscape, the other global context for our work is what's happening in the world of technology itself. The United States is still the largest investor in R&D around the world today. But unlike past decades, we are not alone in our excellent scientific and technical capabilities. With their rising investments, several other nations have first-rate people, labs and industries in various fields. Within the United States, the private sector currently spends $2 for each $1 the Federal Government spends on R&D, and of that federal share, a declining percentage is for defense. It is easy to mourn the passing of an era—now many decades ago—when these trends were reversed. But in fact, they reflect vitally important economic progress both within our Nation and around the world.

Our challenge at DARPA and in DoD is to create a significant advantage for military and national security purposes against this competitive, shifting backdrop. Two principles guide our thinking at DARPA in this regard. One key concept is that the most powerful defense systems will come from the tight integration of the leading edge of commercial technology with highly specialized military technologies. You will see this approach in many of our programs, from tablets with added encryption for close air support, to state-of-the-art digital electronics with added DoD-unique radio chips for leapfrog radio frequency (RF) systems. The second is the understanding that U.S. military success will lie in building systems that are designed to evolve, grow and adapt, rather than counting on technologies that other actors can't get for decades, as in the past. This compels us not just to design a new point of capability, but to design new curves of expanding capability over time. And again, you will see this theme throughout our programs.

The agency's current strategic framework and descriptions of our major areas of investment are outlined in "Breakthrough Technologies for National Security," which also describes DARPA's approaches to ensuring that advances are successfully transitioned to the military Services, commercial enterprises or other research entities for further development in ways that best serve U.S. national interests. Rather than restating those basics, I'd like to focus my testimony today on a number of individual endeavors within DARPA's portfolio of more than 200 active programs. What follows are brief descriptions and progress reports for programs within each of DARPA's three major investment areas—Rethinking Complex Military Systems, Mastering the Information Explosion, and Nurturing the Seeds of Technological Surprise—broken into groups representing each of the three degrees of maturity I mentioned earlier: already being piloted or used ("Adoption and Impact"), currently in development ("Technical Progress") and fresh investment directions ("New Opportunities").

DARPA'S INVESTMENT PORTFOLIO

Rethinking Complex Military Systems

The unparalleled technological capability that has enabled U.S. military and security superiority comes with a price: spiraling increases in complexity. Today, many high-end military platforms are so complex they take decades to produce and years to upgrade. In a world in which pace is inexorably increasing, and in which other economic and manufacturing sectors have recognized the benefits of systems modularity, rapid-fire iterative improvements and faster hardware- and software-system upgrades, the military's current approach to managing complexity is inadequate. It risks leaving the Nation vulnerable to adversaries developing more nimble means of adopting technology.

Today DARPA is turning the tables on complexity, creating engineering architectures and approaches that deliver significantly greater combat power, but with a technical elegance that also allows for flexibility in the field and fast upgrades.

Adoption and Impact

Communications Under Extreme RF Spectrum Conditions (CommEx)
DARPA's CommEx program is developing technologies that can characterize the jamming environment and then actively suppress enemy jamming, so aircraft can still communicate with each other in a highly contested RF environment. Initial components of CommEx technology are part of a planned upgrade to the widely used Link 16 air-to-air data network.

Cognitive Electronic Warfare (EW)
DARPA's Advanced RF Countermeasures (ARC) and Behavioral Learning for Adaptive Electronic Warfare (BLADE) programs are investing in the technologies needed to rapidly react to dynamic electromagnetic spectrum signals from adversary radar and communications systems. These programs are applying machine learning—computer algorithms that can learn from and make predictions from data—to react in real time and jam signals, including new signals that have not yet been cataloged. DARPA is working with the Services to transition technologies derived from the field of cognitive electronic warfare into the F-18, F-35, Army Multi-Function EW program, and Next Generation Jammer.

Power Efficiency Revolution for Embedded Computing Technologies (PERFECT)
DARPA's PERFECT program is developing revolutionary approaches to improving the energy efficiency of DoD computational systems, an improvement that will embed significantly increased computing capabilities including modern learning algorithms on power-limited platforms such as UAVs. Resulting technologies are transitioning to both commercial and government users, with the National Reconnaissance Office adopting them for new, radiation-hardened circuit architectures that enable extremely high data-throughput next-generation space systems. A consortium of companies including Google, HP and Oracle, is pursuing power-efficient open-source hardware, such as RISC-V open-source cores developed in part with PERFECT funding.

Aircrew Labor In-Cockpit Automation System (ALIAS)
DARPA's ALIAS program is developing a tailorable drop-in kit that would add high levels of automation into existing aircraft and reduce the demand for onboard crew. The program is leveraging the considerable advances that have been made in aircraft automation systems over the past 50 years, as well as the advances that have been made in remotely piloted aircraft technologies, to help shift and refocus pilot workloads, augment mission performance and improve aircraft safety.

DARPA will be working with the U.S. Army Utility Helicopters Project Office to test ALIAS technologies on the Blackhawk platform for potential transition of enhanced automation capabilities to the Army utility helicopter fleet. Among the project's goals are improved handling qualities, improved safety and system reliability and the ability to add apps to introduce new functionality and capabilities into the fleet.

Persistent Close Air Support (PCAS)

Close air support (CAS) has long been delivered to warfighters on the ground by those in the air through coordinating strike details with paper maps and voice communications over a radio. The PCAS program set out to bring the power of digital technology to dramatically improve CAS, starting by adding encryption and military radios to commercial Android tablets and designing easy, nonintrusive upgrades for aircraft. Today, simple versions have been adopted and used in theater, and more fully integrated versions have been demonstrated with Service partners.

The ground component of the PCAS system was first put through its paces by Marines in combat in Afghanistan, with DARPA providing more than 500 systems for testing. Marines in theater subsequently adopted the tablets in the thousands, and field reports documented dramatically improved navigation, situational awareness, fire coordination and communications. Marines are currently using this technology in operations in the U.S. Central Command Area of Responsibility. DARPA has also successfully tested the full PCAS prototype system in a U.S. Marine Corps infantry/aviation training exercise. That demonstration marked the first successful integration of automated, digital, real-time coordination capability into a military aircraft system, including tube-launched munitions, digital data links and advanced software in support of ground forces. Ground forces requested a strike with a few taps on a tablet, and the aircrew delivered digitally confirmed strike four minutes later.

This past summer, DARPA demonstrated its PCAS system on an A-10 Thunderbolt II attack aircraft, marking the system's debut on a U.S. Air Force platform. The tests, which involved 50 successful sorties near Nellis Air Force Base in Nevada, showed that a warfighter serving as a joint terminal attack controller (JTAC) on the ground could, in seamless coordination with a pilot, conduct a CAS operation with each party seeing exactly the same information about the target. The system also featured collateral damage calculation and friendly force location information that could enable improved safety in CAS operations. In addition, to test the portability of the aircraft component of PCAS, DARPA worked with Army and Army Special Operations partners to perform ground-based demonstrations of the PCAS system on both a helicopter and unmanned aircraft. Army Special Operations Aviation Command is evaluating PCAS for adoption in air-ground capabilities.

Long Range Anti-Ship Missile (LRASM)
DARPA and the Office of Naval Research (ONR) collaborated to develop the Long Range Anti-Ship Missile (LRASM), an advanced anti-ship missile capable of operating at extended ranges with reduced dependency on intelligence, surveillance and reconnaissance (ISR). The collaboration began as a technology demonstration effort in early 2009. The first two flight tests were conducted in the fall of 2013, during which all demonstration objectives were met. To ensure speedy and seamless development and deployment of this new capability, DARPA created and at first led a LRASM Deployment Office (LDO) with the Navy and Air Force, as LRASM transitioned to a Navy Program of Record. A third flight test, conducted in February 2015, further assessed technical maturity. This past December the Navy took over the LDO directorship, marking the successful transition of a model collaborative effort to address a pressing strategic need.

Technical Progress

Unmanned Surface Vessel for Long-Duration Missions
The Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) program has designed, developed and constructed an entirely new class of ocean-going vessel—one able to traverse the open seas for months and over thousands of kilometers without a single crew member aboard. The 130-foot ship is designed to robustly track quiet diesel electric submarines. But of broader technical significance, it embodies breakthroughs in autonomous navigational capabilities with the potential to change the nature of U.S. maritime operations. Specifically, ACTUV is endowed with advanced software and hardware that enables full compliance with maritime laws and conventions for safe navigation—including international regulations for preventing collisions at sea, or COLREGS—while operating at a fraction of the cost of manned vessels that are today deployed for similar missions. ACTUV was recently transferred to water at its construction site in Portland, Ore. It is scheduled to be christened on April 7, with open-water testing to begin this summer off the California coast.

Space Robotics and Modular Systems at Geosynchronous Orbit

DARPA's Phoenix program is developing innovative technologies and systems that will make it possible to reimagine operations in geosynchronous Earth orbit (GEO), 35,000 kilometers above the Earth. This is the orbit where the highest priority military satellites operate, and commercial satellites there generate over $100 billion annually in revenue. DARPA is developing a variety of space robotics technologies, including assembly, repair, asset life extension and refueling in the harsh GEO environment; low-cost modular satellite architectures that can scale almost infinitely; and a standardized payload orbital delivery (POD) mechanism designed to safely carry a wide variety of separable mass elements to orbit—including payloads, satlets and electronics—aboard commercial communications satellites. Phoenix has now ground tested the world's first modular satellite, called eXCITe, and prepared it for launch in 2016. In addition, a prototype of a POD mechanism to deliver low-cost rideshare to GEO has also been constructed and is being readied for launch in mid-2017.

High-Capacity Wireless Communications for Remote Environments

Troops in remote forward operating locations typically lack the benefit of a reliable communications infrastructure. And while satellite communications services can provide some capacity to remote areas, they cannot provide the high-bandwidth communications needed to support the amount of data generated by emerging ISR systems. DARPA's Mobile Hotspots program is developing a scalable gigabit-per-second (Gb/s) communications backbone that can be carried on UAVs to connect dismounted warfighters with forward operating bases, tactical operations centers, ISR assets and fixed communications infrastructure. This past year the program made significant progress by building low-power millimeter-wave radios small enough to be carried on UAVs, and demonstrating that these can communicate at tactically relevant ranges at Gb/s rates. We expect to demonstrate a full network built upon these radios later this year in a major Marine Corps exercise.

In related work, DARPA's 100G program is developing the technologies and system concepts to project fiber-optic-class 100 Gb/s airborne data links at ranges of 200 kilometers air-to-air and 100 kilometers air-to-ground from high-altitude long-endurance aerial platforms. Computationally efficient signal processing algorithms are also being developed to meet size, weight and power limitations of host platforms. Recent progress included a demonstration of key components performing to levels suitable to meet overall 100G system goals, during which

DARPA performers set several millimeter-wave modulation and transmission records. The technologies are currently being integrated into a full 100 Gb/s system, to be followed by flight testing.

City-Scale Nuclear and Radiological Monitoring

Terrorist attacks involving dirty bombs or nuclear devices remain a potentially catastrophic threat to security, both at home and abroad. Today, we lack a continuous, wide-area ability to detect such dangers. To that end, DARPA's SIGMA program is developing a networked detection capability that combines sensors and fusion algorithms to enable continuous monitoring of radioactive sources of interest at city-wide scales. The sensors are the size of a smart phone, inexpensive (less than $400 apiece, which is 10 to 20 times less than equivalent sensors today), and can detect both gamma and neutron radiation, the unique signatures of radiological and nuclear weapons. A network of such sensors deployed across multiple locations could quickly determine if an anomalous reading indicated a potential threat and provide the foundation for a critical layer of defense against weapons of mass terror.

System of Systems for Air Superiority

In recent years, DARPA has started a collection of programs that aims to develop and demonstrate technologies that together can dramatically advance air combat capabilities against sophisticated adversaries by coordinated deployment of distributed assets with diverse capabilities rather than reliance on densely consolidated capabilities on large, expensive and unwieldy platforms. Key to these efforts is the approach of integrating new capabilities with existing systems to achieve cost leverage against near-peer adversaries and to continuously progress faster and at lower cost than traditional monolithic platform-based approaches.

DARPA's System of Systems (SoS) Integration Technology and Experimentation (SoSITE) program is developing novel architectures—combinations of different types of aircraft, weapons, sensors and mission systems—that distribute air warfare capabilities across a large number of interoperable manned and unmanned platforms. In the last year, we developed an analytical capability to compare the mission performance and cost leverage of alternative architectures and found several promising approaches to achieving air dominance in highly contested environments. The technical and operational risks associated with these approaches are being analyzed this year to provide the basis for our flight experimentation program in the next phase of the program.

The Distributed Battle Management (DBM) program is one key component of the Agency's system-of-systems vision. Current battle management systems offer only limited automated aids to help warfighters comprehend and adapt to dynamic situations. Adding more elements to the SoS architecture—more unmanned aircraft, missiles and mission systems—will exacerbate the battle management challenge, as will the degraded communications of a highly contested environment. The DBM program seeks to develop appropriately automated decision aids to assist airborne battle managers and pilots manage air-to-air and air-to-ground combat. In the initial phase of the program, we developed algorithms to disseminate hostile track data using limited communications across tactical data links. These algorithms achieved high accuracy while requiring less communications capacity then standard approaches. We also developed algorithms for automatic control of UAVs in conducting air-to-air and air-to-surface engagements. In the next phase of the program, these algorithms will be integrated with appropriate human-computer interfaces. The resulting capability will be evaluated by pilots and operators in a virtual simulation environment.

New Opportunities

Maritime System of Systems

DARPA has made important technical progress towards future air dominance through the development of a systems-of-systems approach. Now, through its Cross Domain Maritime Surveillance and Targeting (CDMaST) program, DARPA is extending this model into the maritime domain. The program will be developing technologies to disaggregate various functions across multiple lower cost, upgradable and in many cases unmanned platforms on the sea surface and underwater. By distributing the functions of position, navigation and timing; communications; command and control; and networking and logistics across large expanses, this architecture will force the adversary to defend a very wide area at high cost, inverting the cost curve for securing the maritime environment.

Leading-edge Electronics with Built-in Trust

Under the hood of every military system are the electronic components that are its brains, eyes and ears, but DoD has struggled for decades with contradictory demands in designing, sourcing and maintaining these vital components. Military systems need the most capable integrated circuit (IC) technology to do their phenomenally difficult computational or signal-processing tasks with the limited power available on a missile or aircraft. Yet designing custom ICs continues to grow more complex, and fewer teams are able to commit the time and money for custom design, even in the commercial world. At the same time, security is essential for military applications but semiconductor production has globalized, with diminishing U.S.-owned, U.S.-sited production capacity at the leading edge of technology, and supply chains now crossing multiple national borders. And while IC technology progresses at a pace set by the commercial sector, DoD needs access to components for decades. To address this group of challenges, DARPA is building a cluster of programs aimed at creating new options for DoD.

DARPA's Trusted Integrated Circuits (TRUST) program is developing technologies that will ensure the trustworthiness of ICs used in military systems, even when those components have been designed and fabricated under untrusted conditions. TRUST makes a radical departure from conventional verification approaches, using advanced metrics to identify with increasing efficiency ICs that have been maliciously attacked while reducing the incidence of declaring good circuits to be bad.

The Supply Chain Hardware Integrity of Electronics Defense (SHIELD) program aims to eliminate counterfeit ICs from the electronics supply chain by inserting into the packaging of these components minuscule "dielets"—chips tinier than a grain of salt, with embedded encryption, sensors, near-field power and communications capabilities—to detect any attempt to tamper with the relevant electronics. Dielets are being designed to incorporate passive, unpowered sensors capable of capturing attempts to image, de-solder, de-lid or image the IC; mechanical processes that make the dielet fragile and prevent intact removal from its package; and a full encryption engine and advanced near-field technology to power the dielet and provide communications, to make counterfeiting too complex and time-consuming to be cost effective.

DARPA's Integrity and Reliability of Integrated Circuits (IRIS) program is developing techniques to provide system developers the ability to derive the function of digital, analog and mixed-signal ICs non-destructively, given limited operational specifications. These techniques include advanced imaging and device recognition of deep-sub-micron circuits, as well as computational methods to determine device connectivity. The program is also working to better understand circuit aging systems and to produce innovative methods of device modeling and analytic processes to determine the reliability of integrated circuits by testing a limited number of samples. Resulting technologies will help ensure that DoD microelectronics reliably perform as expected and only as expected by revealing potential compromises due to manufacturing defects, counterfeiting or the addition of malicious components.

The Circuit Realization at Faster Timescales (CRAFT) program seeks to develop new fast-track circuit-design methods, multiple sources for IC fabrication and a technology repository that will facilitate reuse of proven solutions. To achieve its goals, CRAFT seeks to shorten the design cycle for custom integrated circuits by a factor of 10 (on the order of months rather than years); devise design frameworks that can be readily recast when next-generation fabrication plants come on line; and create a repository so that methods, documentation and intellectual property need not be reinvented with each design and fabrication cycle.

Mastering the Information Explosion

The accelerating growth of digital data, and the Nation's increasing reliance on information systems in every sector of society, present a challenge and an opportunity. The opportunity is to derive from this massive trove the myriad associations and causalities that, once unveiled, can provide insights into everything from the predicted arrival of a new strain of influenza to the plans for a terror attack halfway around the globe. The challenge is how to separate these valuable signals from noise, and how to be able to trust the information and information systems upon which we now rely for virtually every function.

DARPA is developing novel approaches to deriving insights from a wide variety of datasets, and is developing technologies to ensure that the data and systems with which critical decisions are made are trustworthy.

Adoption and impact

Research on Fresh Approaches for Computer Security

DARPA's Clean-slate design of Resilient, Adaptive, Secure Hosts (CRASH) program was a basic research effort that designed new computer systems that are highly resistant to cyber attack. The technology development has recently concluded, and CRASH-developed software is now being incorporated in the commercial and military arenas. One university performer started a company based on CRASH research; this led to an announcement from HP in September 2015 that its new line of printers would feature this software to enhance their security. DARPA is coordinating transitions to the Navy and the Defense Information Systems Agency (DISA). For example, the aforementioned software is now being transitioned to the Naval Surface Warfare Center to protect shipboard control systems from cyber attack, and other CRASH software is being transitioned to offer similar protection for DoD command and control servers. Additionally, the Department of Homeland Security and the Air Force Research Laboratory have been working together to test and evaluate CRASH technology in multiple devices. Because the cyber-attack surface is vast and diverse, each of these transitions makes a contribution to the Nation's cybersecurity by taking a class of threats off the table.

Active Authentication

Passwords are cumbersome and imperfect authentication systems for use on information systems, and most systems have no way of verifying that the user who was originally authenticated is the user still in control of the keyboard. DARPA's Active Authentication program is addressing this problem by developing novel ways of validating identity—ways that focus on unique aspects of the individual through the use of software-based biometrics, including behavioral traits such as subtleties in keystroke style or screen-swipe patterns. Although these biometrics may never completely replace passwords, they can provide an added layer of assurance of a user's identity—and DARPA-developed systems have begun to make their way into commercial products, where they are already in use by millions of users. One version, for example, has been incorporated into Google's new Android behavioral authentication system announced last June; others are being piloted by several banks in the United States and Europe, where they have helped secure more than 1.5 million transactions; and yet others are being explored by the National Institute of Standards and Technology for possible use within the National Strategy for Trusted Identities in Cyberspace (NSTIC).

Language Translation and Analysis

DARPA has a long and storied history of breakthroughs in voice recognition, translation and language processing, including seminal contributions to the technology that eventually became Siri. More recently, a number of DARPA's language programs have transitioned to the military Services and other outlets where they are making a difference, including:

The Broad Operational Language Translation (BOLT) program aimed to enable communication with non-English-speaking populations and identify important foreign-language information by allowing English-speakers to understand foreign-language sources of all genres, including chat, messaging and informal conversation and providing English-speakers the ability to quickly identify targeted information in foreign-language sources using natural-language queries. U.S. Special Operations Command and U.S. Central Command have both actively been using BOLT since some of the program's earliest iterations several years ago. It has also been used extensively in theater, including by U.S. forces in South Korea and by DoD, the National Security Agency and other U.S. Government agencies. Currently, U.S. Army Africa is using it as well.

DARPA's Multilingual Automatic Document Classification, Analysis and Translation (MADCAT) program was launched to develop technologies that can automatically convert foreign language text images into English transcripts, eliminating the need for linguists and analysts while automatically providing relevant, distilled, actionable information to military command and personnel in a timely fashion. It is currently in use by the Defense Language Institute and with U.S. Forces Korea.

The Rapid Automatic Transcription of Speech (RATS) program was designed to create algorithms and software for determining whether a communications signal includes speech or is just background noise or music, identifying the language being spoken and whether the speaker is an individual on a list of known speakers, and recognizing specific words or phrases from a list of terms of interest—even when communication channels are extremely noisy and/or highly distorted. RATS is at various stages of testing and transition by the U.S. Air Force, U.S. Navy, Special Operations Command, National Security Agency, Central Intelligence Agency, Federal Bureau of Investigation and Joint Interagency Task Force South.

DARPA's Deep Exploration and Filtering of Text (DEFT) program was designed to use artificial intelligence to enable defense analysts to more efficiently find actionable information in large volumes of documents and to help analysts move from limited, linear processing of huge sets of data to a nuanced, strategic exploration of available information. DEFT technology capable of interpreting human language and converting it to machine-readable knowledge-base entries has been transitioned to the Defense Threat Reduction Agency, the Air Force Research Laboratory, and other activities.

Technical progress

<u>High-Assurance Cyber Military Systems (HACMS)</u>
Embedded processors are the ubiquitous computational brains in DoD systems, but along with their valuable capabilities comes an ever-growing attack surface for

cyber malfeasance. DARPA's HACMS program is developing tools and methods for the design and construction of high-assurance cyber-physical systems—scaling the mathematics of formal methods to create devices effectively "unhackable" for specified properties. DARPA has applied these techniques initially to a Little Bird helicopter, using a HACMS microkernel to give the mission computer a cyber retrofit. In a flight test, a red team was unable to attack the helicopter's controls, despite the fact that the team was given access to the platform and its software, including its source code.

Cyber Grand Challenge (CGC)

It typically takes months or years for a software bug to be identified and patched—a period of time increasingly being taken advantage of by digital miscreants, and a vulnerability window not likely to shrink as long as the process for identifying and repairing such flaws remains mostly manual and artisanal as it is today. CGC is a DARPA-sponsored competition that aims to accelerate the development of automatic defensive systems capable of reasoning about flaws, formulating patches and deploying them on a network in real time. By acting at machine speed and scale, these technologies may someday overturn today's attacker-dominated status quo. Seven teams from across the United States qualified last year to compete in the CGC final event, which will take place August 4, 2016, live on stage, co-located with the DEF CON 24 conference in Las Vegas.

Mining and Understanding Software Enclaves (MUSE)

DARPA's MUSE program seeks a radical rethinking of the way we conceive and maintain software, by integrating foundational ideas from formal methods and machine learning to an ever-growing corpus of open-source software. The techniques being developed under MUSE are intended to discover deep semantic properties from the programs found in its corpus. These properties drive two distinct analytic tasks. The first enables automatic identification and repair of software bugs by recognizing anomalous structure based on properties found in similar previously analyzed programs; the second synthesizes new software behavior from existing corpus elements based on formal specifications. To date, DARPA has assembled a software corpus of more than 20 terabytes and has successfully applied its technologies to automatically synthesize a provably correct implementation of sophisticated cryptographic protocols such as Advanced Encryption Standard (AES), and repair well-known security vulnerabilities such as Heartbleed.

New opportunities

Cybersecurity for the Grid

Across the United States, some 3,200 separate organizations own and operate electrical infrastructure. The widely dispersed nature of the Nation's electrical grid and associated control systems has a number of advantages, including a reduced risk that any single accident or attack could create a widespread failure from which it might take weeks to recover. Since the late 1990s, however, cost pressures have driven the integration of conventional information technologies into these independent industrial control systems, resulting in a grid that is increasingly vulnerable to cyber attack, either through direct connection to the Internet or via direct interfaces to utility information technology systems. DARPA's recently launched Rapid Attack Detection, Isolation and Characterization Systems (RADICS) was created to develop automated systems that would help cyber and utilities engineers restore power within seven days of an attack that overwhelms the recovery capabilities of power providers. RADICS's goals include the development of advanced anomaly-detection systems with high sensitivity and low false-positive rates, based on analyses of the power grid's dynamics; the development of systems that can localize and characterize malicious software that has gained access to critical utility systems; and the design of a secure emergency network that could connect power suppliers in the critical period after an attack.

Changing the Security-Privacy Trade-off

DARPA's Brandeis program will explore technologies that could help break the tension between maintaining privacy and being able to tap into the huge value of data. Rather than having to trade off between these important goals, Brandeis aims to build a third option, enabling safe and predictable sharing of data while reliably preserving privacy. Assured data privacy could help open the doors to a number of security-relevant goals, from collections of publicly available data that can help predict military movements or emergency situations to early evidence of cyber attacks on shared networks—applications that in some environments could be difficult to fully implement without assurances of privacy.

Communicating with Computers

A new and powerful wave of artificial intelligence (AI) is sweeping commercial and military applications today. Based on recent major advances in machine learning—research that was sponsored in part by DARPA—this generation of AI is fueling fields as disparate as search, self-driving cars and financial trading in the commercial world and battle management, electronic warfare, cybersecurity and information operations in the national security realm. I have touched on some of these examples in my testimony today.

Despite this significant technical progress, however, the ways in which we humans interact with machine systems are still quite limited compared to human-to-human interactions. DARPA's Communicating with Computers (CwC) program is a basic research effort to explore how to facilitate faster, more seamless and intuitive communication between people and computers—including how computers endowed with visual or other sensory systems might learn to take better advantage of the myriad ways in which humans use contextual knowledge (gestures and facial expressions or other syntactical clues, for example) to enrich communication. Ultimately, advances from this program could allow warfighters, analysts, logistics personnel and others in the national security community to take fuller advantage of the enormous opportunities for human-machine collaboration that are emerging today.

Nurturing the Seeds of Technological Surprise

From its earliest days, DARPA has scoured the research community for new science and engineering insights and invested in programs to reveal radically advanced technological capabilities from those fertile research areas. That tradition holds true today.

Adoption and impact

Additive Manufacturing for Performance Applications

Despite its revolutionary promise, additive manufacturing is still in its infancy when it comes to understanding the impact of subtle differences in manufacturing methods on the properties and capabilities of resulting materials. Those uncertainties have slowed the reliable mass production of additively manufactured structures with demanding specification requirements, such as structural components for aircraft and other military systems. To overcome this problem, DARPA's Open Manufacturing (OM) program is building and demonstrating rapid qualification technologies that comprehensively capture, analyze and control variability in the manufacturing process to predict the properties of resulting products. Success could help unleash the potential time- and cost-saving benefits of advanced manufacturing methods for a broad range of defense and national security needs.

DARPA’s OM framework and data schema are already being used by the Navy in their efforts to produce flight-critical metallic components with an additive-manufacturing-certified Technical Data Package, with plans to field a set of flight-critical metallic components for the V-22, H-1, and CH-53K platforms by 2017. Manufacturing pedigree considerations, such as a baseline set of standards and schema for additive manufacturing data collection, are being provided by the OM Manufacturing Demonstration facilities at Penn State and the Army Research Laboratory. In another application, advanced manufacturing approaches for bonded composites could enable aircraft wings and fuselages, for example, to be built and joined together without the thousands of rivets and fasteners currently required, significantly reducing manufacturing costs and time and lowering operating costs by making aircraft lighter.

Accurate, Specific Disease Diagnostics on the Spot

The challenge of tracking the spread of infectious disease is exacerbated by the fact that the only way to know precisely which pathogen ails a patient is to draw blood, send it to a lab, and often wait days to hear the result. The Mobile Analysis Platform (MAP) point-of-care diagnostic device is a simple, rugged, handheld, battery-operated instrument that rapidly identifies a range of infectious diseases. Developed under DARPA's Prophecy program, it enables low-cost and robust molecular diagnostics within 30-45 minutes in areas where neither a laboratory nor a secure cold chain is available. And because the device provides instant wireless transmission of test results and location data, it can provide invaluable real-time epidemiological data during outbreaks of fast-moving diseases such as Ebola. DARPA is already engaged in clinical testing of the device with the Naval Health Research Center and the U.S. Military HIV Research Program, and will conduct testing with the Marine Corps Warfighting Laboratory this year during military exercises in the United States and West Africa. In addition, DARPA recently initiated development of a MAP assay for Zika virus.

Biologists, Start Your Startups!

For many of the technologies driven by DARPA’s Biological Technologies Office, the path to impact runs through commercialization. Several recent examples point to early progress in this regard.

DARPA’s Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is creating a new technology base to outpace the spread of natural or engineered diseases and toxins through the development of rapid diagnostics, novel vaccines, new methods for drug delivery and entirely new approaches to providing populations with antibody-derived immunity. Among other technology and business successes resulting from ADEPT are a DARPA-enabled spin-off that has since received more than $25 million in venture funding for further development of a novel diagnostic platform and another small biotech company for which DARPA provided the initial research funding that went on to receive venture funding to continue development of tissue-integrated biocompatible sensors.

DARPA's Microphysiological Systems (MPS) program—better known as the Agency's foray into "organs-on-a-chip" technology—is developing a platform that uses engineered human tissue to mimic human physiological systems as a means of testing the safety and effectiveness of candidate drugs, vaccines or other biomedical countermeasures. In one of many applications, two DARPA performers are collaborating to understand the liver toxicity that can be caused by biological therapeutics—a common reason why otherwise promising drug candidates fail in clinical trials. Among the program's business successes are a start-up microfluidics company spun off from the research that DARPA had funded, which has since gone on to raise more than $10 million in venture funding.

DARPA's Dialysis-Like Therapeutics (DLT) program is developing a portable device that separates harmful agents from human blood and then returns the cleansed blood to the body in a manner similar to dialysis treatment for kidney failure. The resulting device could remove pathogens from the bloodstream, thereby reducing the morbidity and mortality from infection. DARPA invested in a promising core technology and supported studies that proved its feasibility, which led to the spin-off of a new biotechnology company that is now using venture funding to scale up and file for FDA medical device approval.

Technical progress

<u>Revolutionizing Prosthetics</u>

Over the past year, DARPA has built on previous work in its Revolutionizing Prosthetics program to achieve several new and groundbreaking advances that promise to make a difference for wounded warriors and for countless other people with disabilities. Earlier work developed a sophisticated, modular prosthetic arm that could be easily controlled by the user—a prosthetic that earned Food and Drug Administration approval—and demonstrated the first direct, real-time decoding of neural motor control signals from patients to operate such an arm with near-natural control. A newer focus has been on providing users of prosthetics limbs with a sense of touch by sending tactile information from mechanical fingertips to the brain. In September, DARPA reported its first success in this domain, when a 28-year-old man who had been paralyzed for more than a decade as a result of a spinal cord injury became the first person to “feel” physical sensations through a prosthetic hand directly connected to his brain. The advance points to a future in which people living with paralysis or missing limbs will not only be able to manipulate objects by sending signals from their brain to robotic devices, but will also be able to sense precisely what those devices are touching.

New Tools to Fight Ebola

The FY 2015 Consolidated and Further Continuing Appropriations Act provided funds for DARPA to pursue technologies relevant to the Ebola outbreak, leveraging platform capabilities in the ADEPT program that aims to outpace infectious diseases. As a result of that additional support, DARPA was able to achieve a number of milestones in quick order, including completion of a study showing that a novel DNA-based vaccine could protect non-human primates against a lethal Ebola challenge, completion of a Phase I human safety trial for a DNA-based vaccine, identification of highly protective antibodies retrieved from U.S. Ebola survivors, commencement of manufacture of a protective Ebola antibody, and successful demonstration of potentially therapeutic levels of DNA-encoded Ebola antibodies in small animals.

Harnessing Extreme Physics

Through a number of ambitious basic science programs, DARPA is pushing the limits of the physical sciences, opening new possibilities for ultra-precise measurements and unprecedented control over fundamental phenomena. Among them:

The science of quantum communications—in which single photons from entangled photon pairs are transmitted over a distance—offers the possibility of unconditionally secure communication because the act of measuring a quantum object necessarily changes it. For quantum communications to be practical, however, several technological barriers must be overcome. DARPA created the Quiness program to investigate novel technologies capable of high-rate, long-distance quantum communications. Recent demonstrations through Quiness of technologies to capture, manipulate and re-transmit photons without in effect measuring them are truly significant. This is because theorists in Quiness were able to prove from fundamental quantum principles that such "quantum repeater" technologies are the only way to achieve quantum communications over trans-continental distances.

Many defense-critical applications—the Global Positioning System (GPS) and the Internet, for example—demand exceptionally precise time and frequency standards. Today's systems, however, rely on 1950s atomic physics technologies. Recent advances in optical atomic systems give promise to a new generation of optical atomic clocks and quantum metrology that stands to transform numerous DoD applications. The Quantum-Assisted Sensing and Readout (QuASAR) program is developing new quantum control and readout techniques to provide a suite of measurement tools that will be broadly applicable across disciplines, with likely applications relating to biological imaging, inertial navigation and robust global positioning systems. Recently the program demonstrated the world's most accurate clock with a total uncertainty of 2 parts in 10^{18}, or about 10,000 times better than GPS clocks. This means that if the clock began ticking at the Big Bang nearly 14 billion years ago it would be accurate to better than one second today. Clocks of this caliber could lead to improved positioning and navigation, and enable novel imaging and geological sensing techniques.

DARPA's Ultrafast Laser Science and Engineering (PULSE) program is developing the technological means for engineering improved spectral sources, such as ultra-fast optical lasers—advances that in turn could facilitate more efficient and agile use of the entire electromagnetic spectrum and generate improvements in existing capabilities such as geolocation, navigation, communication, coherent imaging and radar, and perhaps give rise to entirely new spectrum-dependent capabilities. Recent PULSE demonstrations include synchronization of clocks with femtosecond precision across kilometers of turbulent atmosphere, corresponding to a 1,000-fold improvement over what is possible using conventional radio-frequency techniques.

New opportunities

<u>Neural Engineering Systems Design</u>

The science fiction dream of linking the brain directly to the outside world has in recent years started becoming a reality—initially through the development of implantable medical devices such as deep brain stimulators used today to treat Parkinson's disease and other conditions and, more recently, through work by DARPA and others to develop brain-machine interfaces that allow amputees and people living with paralysis to operate robotic prosthetic arms and hands with their thoughts. Even state-of-the-art brain-machine interfaces, however, have relatively small capacities compared to the enormous computing power of today’s digital systems and of the brain itself—a situation that has been likened to two supercomputers trying to talk to each other through an old 300-baud modem.

DARPA’s Neural Engineering System Design (NESD) program stands to dramatically enhance research capabilities in neurotechnology and provide a foundation for new therapies and other capabilities by developing small, implantable systems that can communicate clearly and individually with any of up to one million neurons in a given region of the brain. In addition to that hardware challenge, NESD aims to develop the advanced mathematical and neuro-computation techniques to transcode high-definition sensory information between two contrasting languages—the brain’s cortical neuronal representations and the ones and zeros of electronic systems—and then compress and represent those data with minimal loss of fidelity and functionality.

<u>All the Light We Cannot See</u>

Light that enters the eye or the lens of a camera carries much more information than is typically retrieved by viewers, including numerous details about where it has been and what it has experienced. DARPA’s Revolutionary Enhancement of Visibility by Exploiting Active Light-fields (REVEAL) program seeks to unlock information in photons that current imaging systems discard. The program is first developing a comprehensive theoretical framework to enable maximum information extraction from complex scenes by using all the photon pathways of captured light and leveraging light’s multiple degrees of freedom. This framework will then be used to guide the development of new imaging hardware and software technologies. Those technologies will be tested against a challenge problem that calls for full 3D scene reconstruction from a single viewpoint—a rendering that today requires inputs from multiple viewpoints. Such an ability could enhance situational awareness for troops, potentially allowing them to reconstruct, from a single vantage point, a complex scene including objects or people not visible by line-of-sight viewing.

<u>Designing Complex, Dynamic Systems</u>

DARPA’s Complex Adaptive System Composition and Design Environment (CASCADE) program has a seemingly esoteric but ultimately practical goal: to advance and exploit novel mathematical techniques to gain a deeper understanding of system component interactions, a unified view of system behaviors and a formal language for composing and designing complex adaptive systems. Conventional modeling and design tools invoke static ‘playbook’ concepts that do not adequately represent the complexity of, say, an airborne system of systems with its constantly changing variables, such as enemy jamming, bad weather or loss of one or more aircraft. CASCADE aims to fundamentally change how systems are designed to enable real-time resilient response within dynamic, unexpected environments.

KEEPING DARPA VIGOROUS

DARPA’s leadership takes seriously its responsibility to encourage the Agency’s culture of high-risk, high-reward innovation and its ability to execute rapidly and effectively. Toward that end, we continue to experiment with better ways to reach new performers through, for example, the “EZ BAA” process launched by our Biological Technologies Office last year, which greatly simplifies the process by which performers can get on contract with DARPA for efforts of up to $750,000. The EZ BAA is especially helpful in reaching those unfamiliar with defense procurement.

We also continue to use our prize authorities. Prize authorities were crucial to the success of the DARPA Robotics Challenge, our three-year push to accelerate progress in ground robotics for humanitarian assistance and disaster relief, which held its finals in California last summer. We are also using our prize authorities to run DARPA’s Cyber Grand Challenge, which has been working to speed the development of automated cyber defense capabilities and will hold its final competition in August, when seven extremely talented teams will have their computers face off against one another at an event that is expected to draw thousands of spectators. In addition, we continue to use the prize mechanism for smaller efforts, such as last year’s competition to model the spread of Chikungunya, a mosquito-borne infectious disease.

Of course, at the center of DARPA’s success is an abiding commitment to identify, recruit and support excellent program managers—extraordinary individuals who are at the top of their fields and who are hungry for the opportunity to push the limits of their disciplines during their limited terms at DARPA. I am most grateful for the critical support this Subcommittee provided in authorizing the 1101 hiring mechanism, extending it, and in FY 2015 expanding DARPA’s ability to use it. That authority has proven invaluable to our ability to attract some of the finest scientists, engineers and mathematicians to the important work of public service and national security. The 1101 experiment has now been running since 1999 and has clearly proven its benefits to DARPA and the Nation.

After 16 years of annual uncertainty about its ongoing availability, we would appreciate your support to make this authority permanent.

DARPA'S BUDGET

The President's FY 2017 budget request for DARPA is $2.973 billion. This amount is the same as that requested for FY 2016 and $105 million more than the $2.868 billion appropriated for FY 2016. To put these numbers in context, from FY 2009 to FY 2013 DARPA's budget eroded significantly through a series of reductions, including the 8 percent across-the-board sequestration cut in FY 2013. The total reduction to DARPA's budget from FY 2009 to FY 2013 was 20 percent in real terms. With modest increases in FY 2014 and 2015 and a slight decrease for FY 2016, DARPA's budget has not fully recovered, but it has been more stable.

I ask for your full support of the President's budget request for FY 2017 so that DARPA can continue to deliver on its vital mission.

CONCLUSION

As the programs I have highlighted today illustrate, DARPA's commitment to bolstering national security encompasses an extraordinary range of technologies and scientific domains, spanning dimensional scales from the atomic to the celestial, time scales from attoseconds to decades, spectral scales from radio waves to infrared to gamma rays, and—in its most recently created technical office—biological scales from genes and proteins to neurons and organs to infectious diseases and global health. Every day, the people of DARPA come to work to probe and push on those various frontiers. And despite the daunting security challenges around the globe that spur our work, the atmosphere within our agency is persistently one of excitement and even joy—a reflection of the fact that DARPA is obsessed not with problems but with solutions.

A highly functional, effective and spirited organization does not happen by accident. We within DARPA work at it constantly, drawing our inspiration from the amazing, ever-evolving world of technology and from a deep desire to serve our Nation. So I will close this testimony where I started, thanking you for your support and your trust. Both are vital to achieving our mission. I will be pleased to respond to your questions.