# DARPA

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Creating Technology Breakthroughs and

New Capabilities for National Security

"DARPA does more than plan for and adjust to the future. DARPA aims to drive the technological advances and capabilities that will determine the future, with the nation's security always as the first and foremost goal."

*August 2019*

For more than 60 years the Defense Advanced Research Projects Agency, DARPA, has held to a singular and enduring mission: to make pivotal investments in breakthrough technologies for national security.

The genesis of that mission and of DARPA dates to the 1957 launch of Sputnik and a commitment by the United States that in the future we would be the initiator and not the victim of strategic technological surprises. Working with innovators inside and outside government, DARPA has repeatedly delivered on that mission, transforming revolutionary concepts and seeming impossibilities into practical capabilities. The results have included game-changing military capabilities like precision weapons, stealth technology, and unmanned aerial vehicles, as well as icons of modern civilian society such as the internet, automated voice recognition and language translation, and Global Positioning System receivers small enough to embed in myriad consumer devices.

DARPA explicitly reaches for transformational change instead of incremental advances. Our projects rely on and inspire an innovation ecosystem that includes academic, corporate, and government partners, with a constant focus on the nation's military services, which work with us to create new strategic opportunities and novel tactical options. For decades, this vibrant, interlocking ecosystem of diverse collaborators, including DARPA's own imaginative people who create and imagine programs, has proven to be a nurturing environment for the intense creativity that DARPA is designed to cultivate.

DARPA's role has never been more vital. This document spells out the threat environment and our plans for the next several years that will create new national security capabilities by conceiving and delivering breakthrough technologies. **Boldly imagining what might be possible, daring to set our sights high, and quickly enabling our partners and people – that is how we will win. Ultimately, that is how we will achieve greater peace.**

*Steven H. Walker*
DIRECTOR

*Peter Highnam*
DEPUTY DIRECTOR

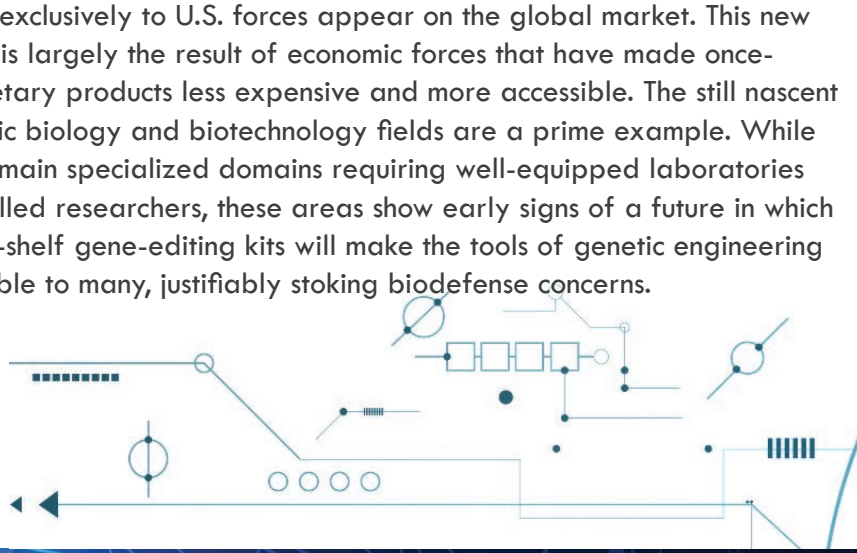
# The Threat Environment: Factors Shaping DARPA's Investments

DARPA's mission and philosophy have held steady and yielded breakthrough technologies for six decades, even as the world has changed dramatically – because the agency always targets the future. Today, the rate at which those changes are arriving and affecting national security has accelerated. What had been a fairly well-defined global order punctuated by occasional surprises has transformed into an ever-shifting, complex, and less certain security picture. We are experiencing multiple disturbing technological, social, economic, and geopolitical movements that pose threats to U.S. preeminence and stability. These trends, and how they may affect U.S. national security needs into the next decade and beyond, inform DARPA's determination of its strategic priorities for the next several years. As those threats change, so too will the agency's priorities, because DARPA does more than plan for and adjust to the future. DARPA aims to drive the technological advances and capabilities that will determine the future, with the nation's security always as the first and foremost goal.

"The United States faces multiple threats to our nation's security and success. These help to determine and drive DARPA's strategic priorities in a global context."

## The Changing Technology Front

Examining our national security landscape, DARPA sees daunting challenges. On the technology front, the nation must maintain domestic superiority even as sophisticated components and systems once available almost exclusively to U.S. forces appear on the global market. This new reality is largely the result of economic forces that have made once-proprietary products less expensive and more accessible. The still nascent synthetic biology and biotechnology fields are a prime example. While they remain specialized domains requiring well-equipped laboratories and skilled researchers, these areas show early signs of a future in which off-the-shelf gene-editing kits will make the tools of genetic engineering accessible to many, justifiably stoking biodefense concerns.



The expanded investments that others are making in developing new technologies is compounding the expanded commercial access to security-related technical advances and enhanced capabilities by a broad set of actors. Related factors include:

- Globalization of science and technology (S&T) development and talent, including the growing number of non-U.S. recipients of advanced science and engineering degrees.
- Emerging and rapidly maturing areas of S&T with the potential to alter the character of warfare, such as hypersonic flight, small satellites, and ubiquitous autonomy and applied artificial intelligence.
- The relative rise of military research and development (R&D) investment and capability advances by near-peer competitors.
- Increased investment by commercial entities in advanced technical capabilities, which state and non-state actors could exploit for military use.
- The diminished ability of the DoD to influence R&D activity because of its declining percentage of total U.S. R&D investment.
- Business practices in DoD and its performer base that are insufficiently agile to adapt to new circumstances, particularly in fast-moving areas of technological innovation.
- DoD system developments that are mostly evolutionary, incremental extensions of warfighting constructs and that rely primarily on monolithic, high-value assets. These ships, aircraft, and space systems, for example, are expensive to design, develop, field, and sustain and may be vulnerable to emerging high-tech countermeasures.

The commodification and off-the-shelf availability of weapons-capable technology and the expanded development of new technologies around the globe are historic shifts, raising the stakes for the United States. Advanced hardware and software alone are no longer a near-guarantee of military and economic success. Increasingly, it is the nation or non-state player that makes the smartest, fastest, and most-strategic use of those technologies that will dominate, or at least be poised to instigate, extreme disruption.

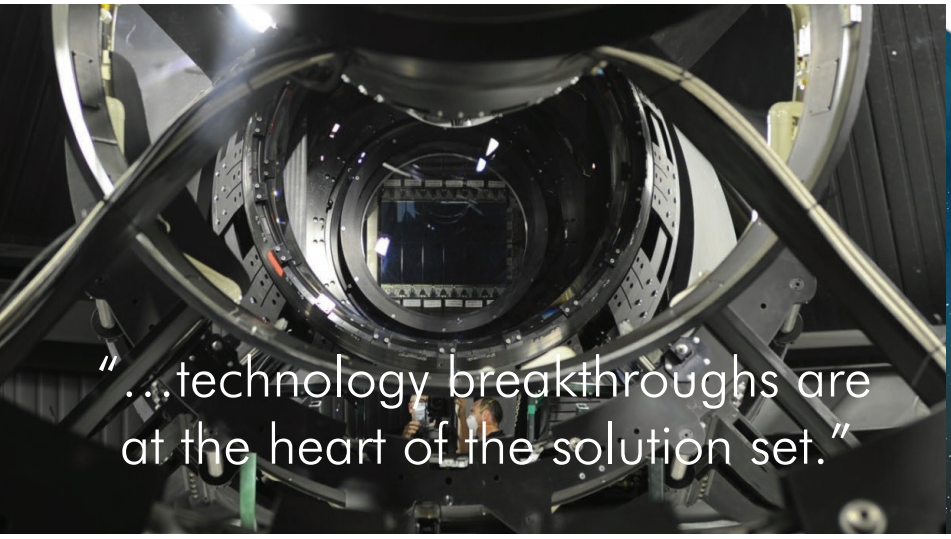
"Our goal is nothing less than to create fundamentally new concepts, technologies, and capabilities for warfare in the ground, maritime, air, space, cyber, and human domains."

**Familiar – and New – Adversaries**

Rather than setting strategies and fighting battles based on traditional and known state actors, the United States today faces multiple, simultaneous challenges not only from long-term state actors, but also from trans-regional networks of sub-state groups and sometimes loosely aligned violent extremist organizations.

With these adversaries showing up as customers in the very global marketplaces that the United States contributes to and frequents, those who present the greatest security threats to our nation now frequently have access to, and are able to take advantage of, rapid technological changes. It seems inevitable that future conflicts will come upon us more swiftly, have the potential to last longer, and take place on much more technically challenging battlefields against more agile adversaries. Given our competitors' focus, level of investment, and determination to close the gap with us, the overwhelming technical dominance we have maintained across operating domains for the past quarter century is eroding. The nation must confront this reality with a sense of great urgency, and technology breakthroughs are at the heart of the solution set.

To address the myriad known and yet-to-emerge threats to national security, DARPA is upping the ante, teaming with new partners and allies to invent unique, revolutionary technologies.




"The United States must develop new concepts and capabilities to protect our homeland, advance our prosperity, ***and preserve peace***."

*National Security Strategy, December 2017*

"This increasingly complex security environment is defined by rapid technological change, challenges from adversaries in every operating domain, and the impact on current readiness from the longest continuous stretch of armed conflict in our nation's history."

*National Defense Strategy, January 2018*

**Technologies, Capabilities, and Speed All Matter**

The challenge is not only about new ideas and novel technologies. Technology breakthroughs can offer enhanced and new capabilities to our defense and national security enterprise that can shape the future of war and lead to greater peace – frequently with an enormous bonus of ***delivering value to our civilian economy and broader society.***

But the current pace at which technology advances and then is incorporated into systems at the disposal of our warfighters will not satisfy our security needs. New and abundant global threats drive home the urgency for fresh, creative, daring approaches to be imagined, developed, and quickly deployed. Whatever new technologies DARPA and others on our national security team imagine, we must dramatically pick up the pace of today's national security enterprise efforts and speed delivery of improved tech-based tools and tactics – capabilities – to our warfighters.

To mitigate the impact of strategic trends on our country's future technical superiority, DARPA is pursuing a strategic vision and strategy based on novel approaches to developing warfighting concepts and capabilities. **Our goal is nothing less than to create fundamentally new and game-changing concepts, technologies, and capabilities for warfare in the ground, maritime, air, space, cyber, and human domains.**

# DARPA's Path Forward: Anticipating and Countering Threats, Advancing Breakthrough Technologies

**Strategic Priorities**

DARPA always has prided itself on creating and capitalizing on the latest advancements. The agency frequently is at the vanguard of science and technology in this nation and around the globe. This is a time when incremental improvements are inadequate to achieve our vision. That is why DARPA solicitations frequently note: "Specifically excluded is research that results in evolutionary improvements to the existing state of practice." The agency knows that it must raise and exceed expectations in delivering technological capabilities that provide surprising advantage for U.S. and Allied warfighters.

"The agency knows that it must raise and exceed expectations for technological capabilities that provide surprising advantage for the U.S. and Allied warfighters."

"To maintain our competitive advantage, the United States will prioritize emerging technologies critical to economic growth and security..."

— *National Security Strategy, December 2017*

**To address that reality and to provide a base for future innovation, DARPA is concentrating on four strategic imperatives:**

1

## Defend the homeland:

Defending the homeland involves an array of completely new capabilities ranging from autonomous cybersecurity, to strategic cyber deterrence, to weapons of mass destruction sensing and defense, to active bio-surveillance and bio threat countermeasures. Because we know peer competitors have been developing hypersonic weapons, near-term development of defenses against these weapons also is paramount.

2

## Deter and prevail against high-end adversaries:

Succeeding against peer competitors in Europe (a stand-in scenario) and in Asia (a standoff scenario) requires new thinking. Realizing new capabilities across the land, sea, and air domains will be important, but space and the electromagnetic spectrum will be just as or more important in deterring conflict away from our shores. New capabilities must be developed, fielded, and operated with speed and adaptability to stay ahead of increasingly capable adversaries.

3

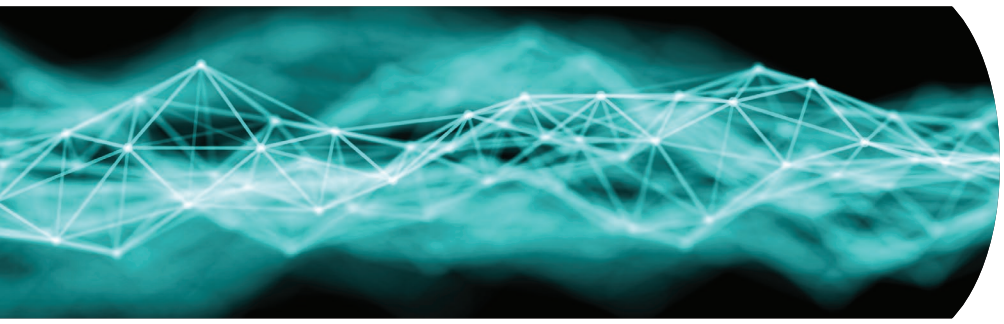
## Prosecute stabilization efforts:

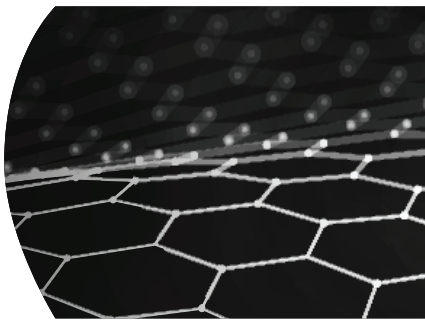
The United States needs to get better at rapidly adapting to different environments. In particular, we need capabilities to address informal, unconventional gray-zone conflicts and city-scale warfare, along with rigorous and reliable models to better understand and predict our adversaries' moves prior to engagement.

4

## Advance foundational research in science and technology:

Basic research underlies all of DARPA's grander pursuits and is what makes possible never-before-seen capabilities. Ultimately, the goal of the agency's fundamental R&D investments is to understand where technology is leading us and to further develop and apply that technology with purpose, solving the nation's toughest security challenges. The best way to prevent technological surprise is to create it, ensuring that U.S. warfighters and our allies have access to the most advanced technologies and capabilities first. Research funded by DARPA in the near term will explore science and technology that leads to "leap ahead" solutions for specific current and future threats across multiple operational domains. Highest priority is assigned to investments that enable the country to maintain a technological advantage over adversaries while ensuring maximum deterrence.

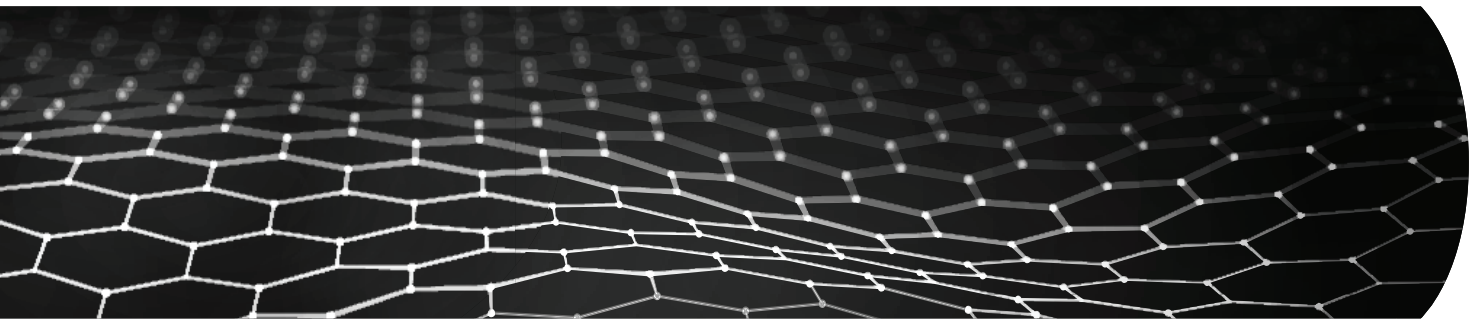




**Aligning with our National Defense and Security Strategies**
DARPA's strategy and these focus areas align closely with the National Defense Strategy (NDS) and the National Security Strategy (NSS). As the NDS states, "The drive to develop new technologies is relentless, expanding to more actors with lower barriers of entry, and moving at accelerating speed."

DARPA both informs and plays an important role in carrying out those defense and security strategies. At the same time, the agency is charged with imagining new threats and new solutions helping DoD to avoid finding itself in a reactive mode. DARPA pursues game-changing technologies and capabilities that address challenges in a way that provides surprising advantage for U.S. and allied warfighters and at a much faster pace than the current acquisition system can handle. The Department readily acknowledges that it is critical to pick up the pace in its acquisition and deployment processes and that it must be more nimble and flexible in order to accommodate promising technological innovations. DARPA's work with the services and other agencies aims to meet known and as-yet-unrecognized needs and move swiftly to deployment. That includes an increased emphasis on prototyping and joint projects – and, especially, a tighter focus on designing, building, and testing aspects of technology innovations as opposed to study and modeling.

Areas targeted for heightened attention and investment by DARPA informed the development of many of the top technologies singled out by the Department of Defense's Under Secretary for Research and Engineering for urgent attention and modernization. These include *hypersonics*, with applications for offense and defense; *microelectronics*; and *artificial intelligence/machine learning*. DARPA already is pursuing, or soon will direct significant attention to, other opportunities in the DoD upper-tier areas, including fully networked command, control, and communications; space; and cybersecurity. Also on the agenda for future investments is quantum science.



# Forging the Next Technological Revolutions

Based on the multi-faceted and multi-sourced threats that the United States faces or may confront in the years ahead, DARPA program managers vigorously pursue new concepts in myriad fields and disciplines to create breakthrough technologies and capabilities. Partners – especially performers across industry, academia, and other agencies and the military services – are key to turning concepts into reality. Following are a few examples of transitions that are poised to yield large national security dividends when deployed. Many programs meet the needs of multiple focus areas, especially those furthering foundational research in science and technology. Together, these advances that are well along, in the works, or targeted by new or prospective DARPA projects, represent a portfolio of progress that will help keep the nation secure.

# 1 Defend the homeland

DoD's principal task is to defend the homeland and our interests around the world. Defense is DARPA's reason for being and why this primary focus on defending the nation is such an important portion of the agency's portfolio. DARPA is focusing on:

- Cyber deterrence and defense
- Defense against weapons of mass terror and destruction
- Bio-surveillance and bio-threat detection and mitigation

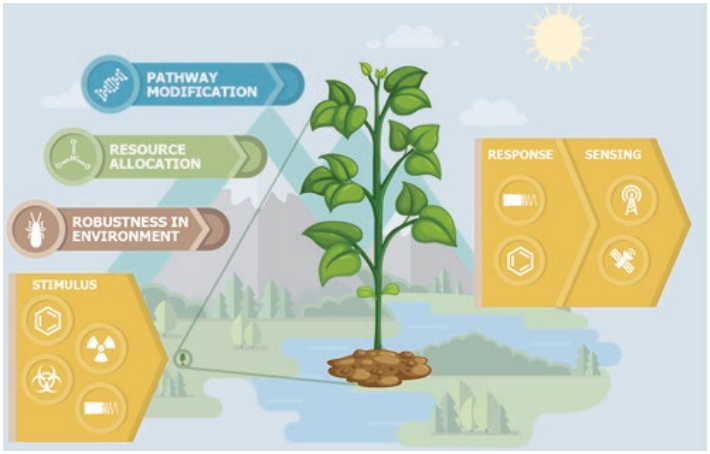
**Safe Genes**

DARPA created the Safe Genes program to gain a basic understanding of how gene editing technologies function; devise means to safely, responsibly, and predictably harness them for beneficial ends; and address potential health and security concerns related to their accidental or intentional misuse. Achieving such ambitious goals requires knowledge about how gene editors, and derivative technologies, including gene drives, function at various physical and temporal scales under different environmental conditions, across multiple generations of an organism. In parallel, demonstrating the ability to precisely control gene edits, turning them on and off under certain conditions or even reversing their effects entirely, will be paramount to the safe translation of these tools to practical applications.

**Advanced Plant Technologies**

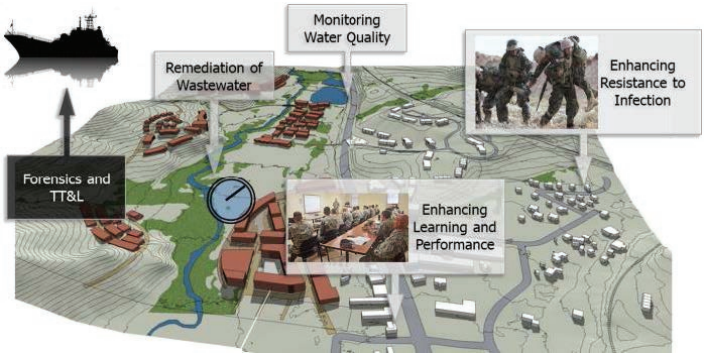
The ambitious goal of DARPA's Advanced Plant Technologies (APT) program is to develop plants capable of serving as next-generation, persistent, ground-based sensors to protect deployed troops and the homeland by detecting and reporting on chemical, biological, radiological, nuclear, and explosive (CBRNE) threats. Plant sensors effectively would be energy-independent, increasing their potential for widespread use, while reducing risks associated with deploying and maintaining traditional sensors. They also could support humanitarian operations by detecting unexploded ordnance in post-conflict settings, for example.

DARPA envisions harnessing plants' innate mechanisms for sensing and responding to environmental stimuli in order to engineer response mechanisms that can be remotely monitored using existing ground-, air-, or space-based hardware. To succeed, modified plants must be safe, robust, and self-sustaining in their environments. Initial research is taking place entirely in contained facilities. If successful, later-phase field trials would take place under the auspices of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service, following all standard protocols for plant biosafety.



**Biological Robustness in Complex Settings**

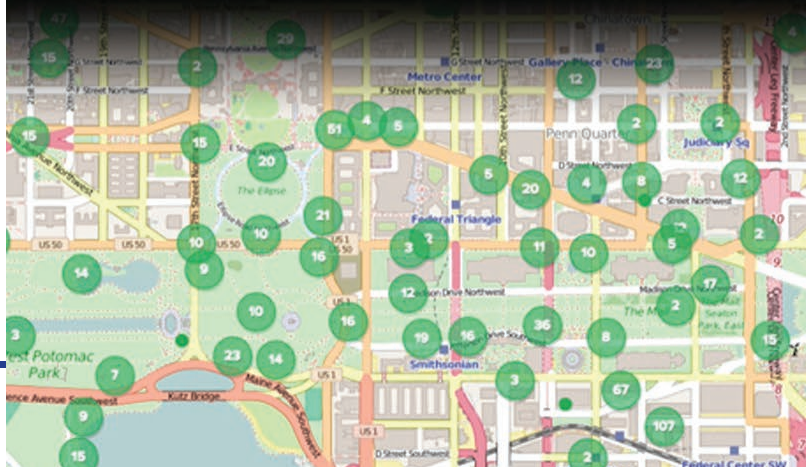
Can engineered microbial bio-systems be transformed into reliable, cost-effective strategic resources for DoD, contributing to intelligence, readiness, and force protection? DARPA aims to find out through the Biological Robustness in Complex Settings (BRICS) program. Examples of applications may include identifying the geographical provenance of objects; protecting critical systems and infrastructure against corrosion, biofouling, and other damage; sensing hazardous compounds; and efficient, on-demand bio-production of novel coatings, fuels, and drugs. BRICS pursues the fundamental understanding, design principles, and component technologies needed to engineer safe, stable bio-systems that function reliably in changing, minimally structured environments. A long-term goal is to enable safe transition of synthetic biological systems from well-defined laboratory environments into the more complex settings typical of DoD operations.




# Detecting Radiological Threats Before It's Too Late

Perhaps no domestic security threat today exceeds that of a nuclear or radiological "dirty bomb" detonation. Current sensors can detect high-emitting radiological materials that could signal such mass-terror devices but are too large and expensive to deploy widely to fully protect an urban area or major transportation hub.

DARPA's SIGMA program has successfully created high quality, handheld radiological sensors – the size of an average smart phone – at a fraction the cost of today's devices. SIGMA developed not only that hardware but also the software to monitor thousands of those mobile detectors in real time – an essential capability to discern the movement of nuclear materials before they can be incorporated into a terrorist's weapon. In collaboration with officials in Washington, D.C., and the Port Authority of New York and New Jersey, DARPA in 2016 tested the devices and networking system at critical transportation hubs and on a citywide scale involving 1,000 detectors. That test showed the system could fuse the data provided by all those sensors to create minute-to-minute situational awareness of nuclear threats. Working in close cooperation with the Department of Homeland Security, DARPA's technology has been on track for deployment in multiple locations. Through the newly created SIGMA+ program, DARPA is expanding SIGMA's capabilities to include threat detection for other harmful elements such as chemicals, explosives, and biological and radiological agents.



# What is Happening in Cyberspace? Plan X

If the cyber domain is to be tractable for military operations, cyber operators need the tools to understand what is happening in their complex, obscure, and fast-morphing world. That was the need identified by DARPA's Plan X foundational cyberwarfare program, generating visual representations of cyberspace to enable DoD to identify threats and better plan for, conduct, and assess cyberwarfare in a way similar to kinetic warfare approaches. The program bridged cyber communities of interest, linking academe, the defense industrial base, commercial interests, and user-experience experts, and results will be of use in national security and private sector applications. Plan X technology recently transitioned to U.S. Army Cyber Command and is actively supporting decision makers and defending networks at the hands of Cyber Protection Teams.


**Enhanced Attribution for Malicious Cyber Acts**

Malicious actors in cyberspace do not fear prosecution because it is extremely difficult to attribute actions to individuals. That is due in part to the lack of end-to-end accountability in the internet's infrastructure. Identifying malicious cyber campaigns based on indicators of compromise, today's approach, too often allows offenders to evade defenders and to resume operations by superficially changing their tools and aspects of their tactics, techniques, and procedures. In turn, that inhibits policymakers from exercising cyber and non-cyber responses.

By providing high-fidelity visibility into all aspects of a malicious cyber operator's actions, DARPA's Enhanced Attribution program aims to make transparent the actions by malicious adversaries that are currently opaque. That would permit attribution to individual cyber operators without damaging sources and methods. The program seeks to develop techniques and tools for generating operationally and tactically relevant information about multiple concurrent independent malicious cyber campaigns, each involving several operators, and offer the means to share such information with interested parties.

**Automating Tools to Detect and Resist Cyber Attacks**

Networks relied upon for U.S. military and commercial purposes face an increasingly broad spectrum of cyber threats from numerous actors and novel attack vectors. The malicious activity crosscuts organizational boundaries, as nefarious actors use networks with less protection to pivot into networks containing key assets. DARPA's Cyber-Hunting at Scale (CHASE) program seeks to counter the problem by adjusting network and host sensors at machine speed. The program is supporting development of automated tools to detect and characterize novel attack vectors, collect the right contextual data, and disseminate protective measures both within and across enterprises. CHASE focuses on protective measures that a network owner has the authority to execute within their own environment, and on measuring the accuracy and efficiency of threat detection techniques. DARPA wants to prototype components that enable network owners to reconfigure sensors and disseminate protective measures at machine speed with appropriate levels of human supervision.

CHASE is one of a series of DARPA programs aimed at automated, scalable, machine-speed vulnerability detection and patching. An earlier effort – the Cyber Grand Challenge – sought to create automatic defensive systems capable of reasoning about flaws, formulating patches, and deploying them on a network in real time. Incentivized competitors created expert-level software security analysis and remediation at machine speeds on enterprise scales, and DARPA further advanced the R&D community for automated cyber defense.

# Defending the World's Largest Network

DARPA'S Network Defense project is already contributing to national security. The program, which launched in 2015, sifts through terabytes and terabytes of Department of Defense Information Network (DODIN) data to sniff out harmful network events. Each month, DODIN users generate an order-of-magnitude more data than existing analysis capabilities can possibly process. To address this deficit, DARPA quickly transitioned elements of its Network Defense program to the United States Cyber Command. Working with members of the Army's Cyber Protection Teams as well as U.S. CYBERCOM, DARPA researchers were able to identify three Advanced Persistent Threats domains within the first few days of operation. As the program progressed, several crime-ware infections were discovered, and several other network anomalies were referred for detailed investigation.

# 2 Deter and prevail against high-end adversaries

To present adversaries with surprising warfighting scenarios that create dilemmas or completely disrupt their decision calculus, we must disrupt our own warfighting enterprises and provide decisive advantage across air, land, and sea, as well as space and the electromagnetic spectrum. Big, monolithic platforms designed, built, and procured to do everything cost too much, take too long to field, and are usually technologically out dated by the time they are available. DARPA seeks a new asymmetric advantage – one that imposes complexity on adversaries by harnessing the power of dynamic, coordinated, highly autonomous, and flexible architectures. Among other things, DARPA is especially interested in:

- Adaptive long-range effects for air, land, and sea
- Robust space
- Control of the electromagnetic spectrum

**Making Hypersonics a Reality**

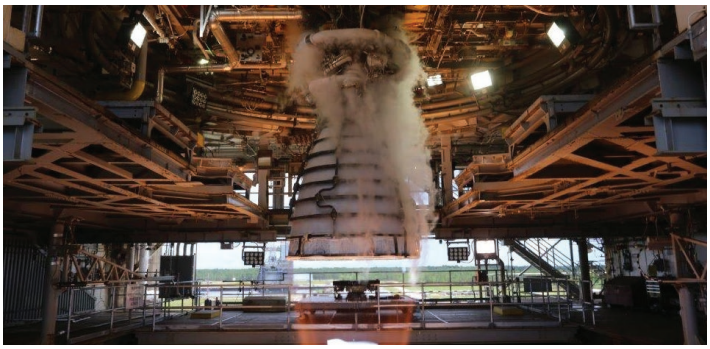
The ability to field hypersonic systems ranks high on the DoD's list of priority technologies that DARPA is pursuing due to the pace of research by peer adversaries. Hypersonic flight at velocities of more than five times the speed of sound offers major strategic advantages, especially for conducting military operations from longer ranges, with shorter response times, and with enhanced effectiveness compared to current military systems.

Looking beyond the early investigative stages of its hypersonics program, DARPA is developing technology demonstrations, on schedule for 2019, for operational capabilities. For example, the Hypersonic Air-breathing Weapon Concept (HAWC) program is a joint effort with the U.S. Air Force (USAF), seeking to develop and demonstrate critical technologies to enable an effective and affordable air-launched hypersonic cruise missile. The program emphasizes efficient, rapid, and affordable flight tests to validate key technologies. HAWC is pursuing flight demonstrations to address three vital technology challenge areas: air vehicle feasibility, effectiveness, and affordability.

The Tactical Boost Glide (TBG) program is another joint DARPA/USAF undertaking, striving to develop and demonstrate technologies to enable future air-launched, tactical-range hypersonic boost glide systems. In such systems, a rocket accelerates its payload to high speeds. The payload then separates from the rocket and glides unpowered to its destination. TBG plans to include ground and flight-testing to mature critical technologies, and demonstrate system performance. The program is exploiting the technical knowledge and lessons derived from development and flight-testing of previous boost glide systems, including the Hypersonic Technology Vehicle 2 (HTV-2). Further leveraging and integrating ongoing investments in hypersonic tactical boost glide vehicles, the Operational Fires (OpFires) program seeks to develop and demonstrate a novel ground-launched system enabling hypersonic boost glide weapons to penetrate modern enemy air defenses and to engage critical time-sensitive targets. Working with the Air Force, the agency has established a "LRASM-like" transition activity for hypersonics programs and is adding more flights and evaluations prior to hand-off to the service.

**Responsive Space: An Experimental Spaceplane**
Demonstration of aircraft-like, on-demand, and routine access to space is important for meeting critical DoD needs and could help open the door to a range of next-generation commercial opportunities. DARPA's Experimental Spaceplane program aims to build and fly the first of an entirely new class of hypersonic aircraft that would bolster national security by providing short-notice, low-cost access to space. The program wants to achieve a capability well out of reach today: launches to low Earth orbit in days, compared to the months or years of preparation currently needed to get a single satellite on orbit. Success depends upon significant advances in both technical capabilities and ground operations but would revolutionize the nation's ability to recover from a catastrophic loss of military or commercial satellites, upon which the United States today is critically dependent.

The spaceplane would dramatically slice costs and wait times with a fully reusable, unmanned vehicle roughly the size of a business jet that would combine a traditional airplane and conventional launch vehicle. In its pursuit of aircraft-like operability, reliability, and cost-efficiency, DARPA and its performer on this program are planning a flight test demonstration of Experimental Spaceplane technology, flying ten times in ten days, with an additional final flight carrying the upper-stage payload delivery system.



If successful, the program would enable a commercial service that could operate at an achievable flight rate and with recurring costs at a small fraction of the cost of launch systems the U.S. military currently uses for similarly sized payloads. Designers plan to take advantage of technologies and support systems that have enhanced the reliability and fast turnaround of military aircraft. They intend to increase efficiencies by integrating numerous state-of-the-art technologies, including some previously developed by DARPA, NASA and USAF – which would be key transition partners, along with the U.S. Navy.

# Delivering Long-Range Anti-Ship Capabilities

One example of a flexible, semi-autonomous capability is the Long Range Anti-Ship Missile (LRASM), developed jointly by DARPA and the Office of Naval Research (ONR). Begun in 2009, LRASM is a precision-guided, survivable standoff missile that protects U.S. Navy surface ships in highly contested environments. After successful initial flight tests carried out with ONR, DARPA stood up a rapid deployment office at the agency's headquarters with the Navy and Air Force to ensure a seamless and speedy leap to operational capability in 2018, an extraordinarily short period for a paradigm-stretching innovation.

**Distributed, Resilient Space: Blackjack**

The growing importance of space for national security is transforming this domain, with technology advancing to the point where U.S. military success may depend upon our ability to place very capable small satellites in low Earth orbit (LEO) and in larger constellations. Right now, satellites critical to our national security and warfighting capabilities traditionally are custom-designed and placed in geosynchronous orbit to deliver persistent overhead access to any point on the globe. In the increasingly contested space environment, these exquisite yet costly and monolithic systems have become vulnerable targets that would take years to replace if degraded or destroyed; their long development schedules preclude orbital systems that are responsive to new threats.

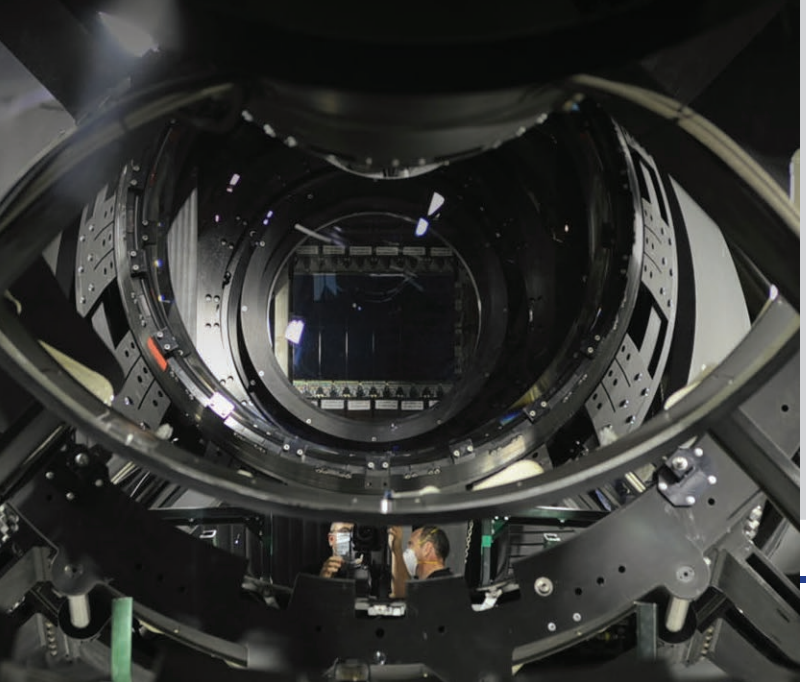
The evolution of commercial space has led to the design and manufacturing of LEO constellations intended for broadband internet service, which could offer previously unavailable economies of scale. DARPA is interested in leveraging these advances and driving them forward in order to demonstrate military utility. Launched in 2017, Blackjack is collaborating with the commercial sector to achieve that goal and meet needs ranging from command and control to Intelligence, Surveillance, and Reconnaissance (ISR). Blackjack aims to develop and demonstrate the critical technical elements for building a global high-speed network backbone in low Earth orbit. That would enable highly networked, resilient, and persistent DoD payloads that provide infinite over-the-horizon sensing, signals, and communication, and hold the ground, surface, and air domains in constant global custody. To do that, researchers will investigate innovative vehicle delivery approaches that enable revolutionary advances in payload size, weight, power, and cost.

## Highly Autonomous Unmanned Ship

The United States took a big step towards long-range, highly autonomous vehicles for maritime operations when, in 2018, DARPA transitioned to the Office of Naval Research the technology demonstration vessel it had developed and built. Known as ACTUV, for Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel, the program created the 132-foot "Sea Hunter." This ship is not remotely piloted but is designed to operate over thousands of kilometers of open ocean with only sparse supervisory oversight, all while adhering to international rules for navigation and collision avoidance. These capabilities mean that future autonomous vessels could patrol large areas at a fraction of the cost of a crewed ship, and, potentially, engage in such dangerous tasks as submarine tracking and mine clearing without posing any risk to sailors.

# Space Situational Awareness: Avoiding Collisions in Orbit

Concerned about traffic volumes and behavior, military and commercial space planners know their domain is increasingly congested and contested. Valuable satellites and manmade and natural orbital debris all trace paths above the Earth. The U.S. Space Surveillance Network, operated by U.S. Air Force Space Command, tracks hundreds of thousands of known objects in Earth orbit to ensure the safety of U.S. assets. The Network is getting help, thanks to the DARPA-developed Space Surveillance Telescope (SST). In 2016, SST transitioned from a DARPA-led design and construction program to ownership and operation by the U.S. Air Force, which plans to operate the telescope in Australia jointly with that country's government. There, SST will provide key space situational awareness from an area of the geosynchronous belt that is currently only sparsely observed. With its numerous breakthroughs in telescope design and camera technology, SST provides unprecedented imaging quality to spot small, faint objects across an extraordinarily wide field of view and the ability to take thousands of pictures per night. It also boasts revolutionary image analysis software that enables much faster discovery and tracking of previously unseen or hard-to-find small space objects.



**Networking Undersea Platforms**

No matter how capable, the most advanced vessel can only be in one place at a time, yet U.S. Navy assets must cover vast regions around the globe. DARPA initiated the Hydra program to help address this challenge. In a series of major technical advances, Hydra is bringing the U.S. Navy much closer to developing a distributed undersea network of unmanned payloads and platforms to supplement manned vessels. The system innovatively integrates existing and emerging technologies to deliver capabilities above, on, and below the ocean's surface. By separating capabilities from the traditional platforms that deliver them, Hydra's communications features would serve as a force multiplier, enabling asset deployment wherever needed, faster, at the needed scale, and more cost effectively. Working synergistically with manned platforms, Hydra's communications suite would increase their effectiveness and significantly extend operational reach by enabling remote control at long range. Moreover, Hydra intends to enable other new capabilities not currently performed by manned platforms, such as allowing for forward-deployed airborne ISR offering expendable platforms or recharging hubs for undersea vehicles.

## Asserting a Robust Capability in Space

While the United States is increasingly reliant on space for virtually every essential security mission, our space capabilities have not kept pace with monumental and rapid global changes. DARPA assigns a high priority to developing new approaches to launching satellites into orbit on short notice and at low cost, including by means of reusable first-stage and space-plane systems, which have the potential to enable launch of satellites from virtually anywhere with just 24 hours-notice and at a fraction of current costs. The agency is also demonstrating technologies to enhance the nation's current limited capabilities relating to space domain awareness.

**Spectrum Collaboration: A Challenge**

Today, access to the spectrum is managed by dividing it into rigid, exclusively licensed bands, limiting exploitation of the full potential capacity of the spectrum – with national security and economic implications. In 2016, DARPA launched a series of competitive events – the Spectrum Collaboration Challenge (SC2), a first-of-its-kind collaborative machine-learning competition to overcome scarcity in the radio frequency spectrum. In SC2, competitors reimagined a new, more efficient wireless paradigm in which radio networks autonomously collaborate to determine efficient spectrum use moment to moment. SC2 teams are taking advantage of recent advances in artificial intelligence (AI) and machine learning with the expanding sophistication of software-defined radios. Through a partnership with the Mobile World Congress, DARPA will host a live SC2 Championship event in late 2019, when finalists will compete for cash prizes and, more importantly, demonstrate that they have devised the best collaborative framework for making sure the spectrum will be able to accommodate ever-growing demand.

**Assault Breaker II**

The Assault Breaker II (ABII) program addresses several challenges posed by our near-peer competitors. Patterned after the original Assault Breaker program in the late 1970's, a memorandum of agreement was signed by DARPA and the vice chiefs of all four services to establish a joint service team creating technology solutions to these critical challenges. Interacting closely with the intelligence, military operator, and technology communities, the team's first objective is to design warfighting operational constructs based on new and emerging technologies and capabilities. The program's second objective is developing an advanced modelling and simulation environment to support analysis of true cross-domain (seafloor to space) cross-service, warfighting constructs. Finally, the program is tying the advanced modelling and simulation environment into an interactive experiment environment to support exploration of highly complex, interdependent approaches that characterize the future of warfighting.

Modern warfare is becoming less about singular platform and weapon capabilities, and more about combinations of systems that can be rapidly developed and composed into more effective warfighting constructs. ABII seeks to organize this evolution and acts as a conduit to both communicate technology solutions to the services as well as articulate critical challenges to the technology development community in a manner where they can appreciate the larger picture. ABII will serve as the technical baseline for multi-domain operations moving forward.

# Communications through Jamming

Our adversaries not only are deploying new radar frequencies and waveforms that challenge U.S. jamming capabilities; they also are improving their own jammers and ability to disrupt U.S. military communications. To address that threat, DARPA's Communications Under Extreme RF Spectrum Conditions (CommEx) program has developed innovative technologies that support air-to-air communication in contested environments.

Building upon technologies investigated under the CommEx program, the agency's Computational Leverage Against Surveillance Systems (CLASS) program is developing new ways to protect U.S. military signals from increasingly sophisticated threats. Collaborating with the U.S. Army's Communications-Electronics Research, Development and Engineering Center (CERDEC), DARPA conducted TRL-6 testing of CLASS in field exercises. The technology is also being integrated into a new CERDEC project aimed at securing Army radios against jamming threats.

# 3 Prosecute stabilization efforts

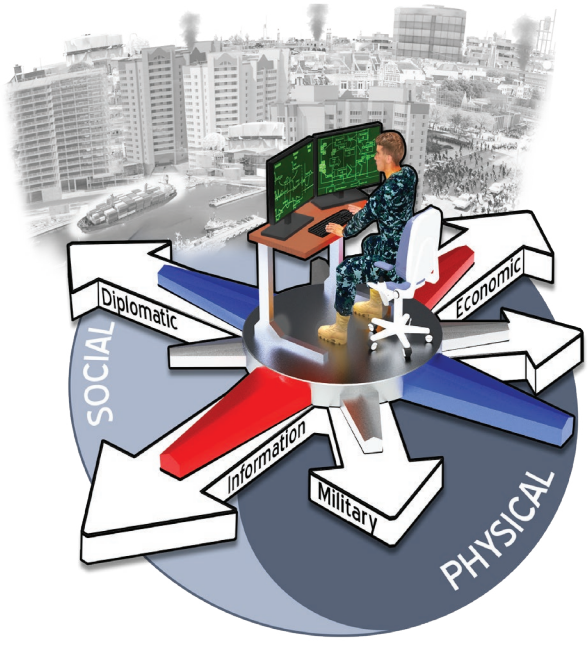
DARPA identifies current or future advances that have the potential to bend today's security trajectories and, years from now, could disrupt the stability the country enjoys with developments that could enhance national and global stability. Invariably, stabilization efforts also require U.S. soldiers to be on the ground to remove threats and project strength, putting lives in danger. Accordingly, DARPA considers it a moral obligation to attend to and roundly improve all aspects of warfighter performance. With this focus on stabilization, DARPA pursues:

- Gray warfare experimentation
- Behavior modeling and influence
- City-scale operations
- Warrior performance

**Making Gray-Zone Activity More Black and White**

As gray-zone activity around the world becomes more sophisticated, the United States needs to leverage artificial intelligence (AI) and other technologies to help commanders make effective decisions to thwart an enemy's disruptive activity. Gray-zone conflicts sit in a nebulous area between peace and conventional warfare. Action is not openly declared or defined, and it is slower and prosecuted more subtly – using social, psychological, religious, information, cyber and other means to achieve objectives with or without violence. The lack of clarity of intent, the grayness, makes it challenging to detect, characterize, and counter an enemy fighting this way.

DARPA's Collection and Monitoring via Planning for Active Situational Scenarios (COMPASS) program seeks to develop software that would clarify enemy intent by gauging an adversary's responses to various stimuli. COMPASS is leveraging AI technologies, game theory, modeling, and estimation to identify stimuli that yield the most information about an adversary's intentions and to provide decision makers with high-fidelity intelligence on positive and negative tradeoffs on potential actions. The ultimate goal: to provide theater-level operations and planning staffs with robust analytics and decision-support tools that reduce the ambiguity about adversarial actors and their objectives.



**Averting Crises by Modeling the World**

DARPA's World Modelers program aims to provide a comprehensive understanding of complicated, dynamic national security questions by using technology that integrates qualitative causal analyses with quantitative models and relevant data. Ideally, DARPA will develop approaches that can accommodate and integrate dozens of contributing models connected by thousands of pathways – orders of magnitude beyond what is possible today. World Modelers analyses intend to be timely enough to recommend specific actions that could avert crises. The program seeks to develop technologies that will enable analysts to build models to provide quantitative projections within weeks or even hours of processing, compared to the months or years it takes today to understand considerably simpler systems.

Questions for analysis typically will be framed at subnational scales and look one to five years into the future, although the factors that influence outcomes of interest might operate on larger and longer scales. The subnational focus reflects the changing nature of conflict and security, which increasingly plays out in cities and districts. The first use case of World Modelers: food insecurity resulting from the interactions of factors including climate, water availability, soil viability, market instability, and physical security.

**Extending Squad Awareness and Capabilities**

To succeed in their missions, military units must have a robust, multi-faceted picture of their operational environments, including the location, nature, and activity of threats and allied forces around them. Technology is making this kind of rich, real-time situational awareness increasingly available to airborne and other vehicle-assigned forces, with a capacity to deploy precision armaments more safely, quickly, and effectively. Dismounted infantry squads, however, have so far been unable to take full advantage of some of these highly effective capabilities because many of the technologies underlying them are too heavy and cumbersome for individual Soldiers and Marines to carry or too difficult to use under demanding field conditions.

DARPA's Squad X program is developing novel technologies for integration into user-friendly systems


that would extend squad awareness and engagement capabilities without imposing physical and cognitive burdens. The goal is to speed the development of new, lightweight, integrated systems that would facilitate infantry squads' unprecedented awareness, adaptability, and flexibility in complex environments, and enable dismounted soldiers to more intuitively understand and control their complex mission requirements.

**Subterranean Challenge: Make the Inaccessible Accessible**

Underground settings are increasingly relevant to global security and safety. Rising populations and urbanization are requiring military and civilian first responders to perform their duties below ground in human-made tunnels, underground urban spaces, and natural cave networks. One of the main limitations they face is a lack of situational awareness; they often do not know what lies beneath. Recognizing that innovative, enhanced technologies could accelerate development of critical lifesaving capabilities, DARPA is running another in a line of challenges: the DARPA Subterranean or "SubT" Challenge, which aims to explore new approaches to rapidly map, navigate, and search underground environments. Teams from around the world are proposing novel methods for tackling time-critical scenarios through unknown courses, mapping subsurface networks and unpredictable conditions too hazardous for human first responders.

The SubT Challenge aims to provide previously unimaginable situational awareness capabilities for operations underground. Advances in robotics, autonomy, and even biological systems could permit us to explore and exploit underground environments too dangerous for humans. Instead of avoiding caves and tunnels, we can use surrogates to map and assess their suitability for use – coming up with new technologies and concepts to make the inaccessible accessible.

**Tapping the Neuroscience of Touch to Improve Prosthetics**

With a focus on wounded warriors and facilitating their return to military service, DARPA's Hand Proprioception and Touch Interfaces (HAPTIX) program is pursuing key technologies to enable precise control of, and sensory feedback from, sensor-equipped upper-limb prosthetic devices. If successful, the resulting system would provide users near-natural control of prosthetic hands and arms via bi-directional peripheral nerve implants. The program aims to create and transition clinically relevant technology in support of wounded warriors suffering from single or multiple limb loss.

HAPTIX builds on prior DARPA investments, which created novel neural interface systems that overcame previous sensor reliability issues. A key focus is on creating new technologies to interface permanently and continuously with the peripheral nerves in humans. With very positive early results, HAPTIX technologies tap into the motor and sensory signals of the arm to allow users to control and sense the prosthesis via the same neural signaling pathways used for intact limbs. If successful, the system will integrate with one of the advanced prosthetics developed under DARPA's Revolutionizing Prosthetics program to create the first dexterous prosthetic limb with full sensory and motor capabilities. DARPA anticipates a 12-month, take-home clinical trial of the complete HAPTIX system as the culmination of the program.

**Slowing Biological Time to Extend the Golden Hour for Lifesaving Treatment**

When a Service member suffers a traumatic injury or acute infection, the time from event to first medical treatment is usually the single most significant factor in determining the outcome between life and death. First responders must act as quickly as possible, first to ensure a patient's survival and then to prevent permanent disability. The Department of Defense refers to this critical, initial window of time as the "golden hour," but in many cases the opportunity to successfully intervene may extend much less than 60 minutes, which is why the military invests so heavily in moving casualties as rapidly as possible from the battlefield to suitable medical facilities. However, due to the realities of combat, there are often hard limits to the availability of rapid medical transport and emergency care.


DARPA created the Biostasis program to develop new possibilities for extending the golden hour, not by improving logistics or battlefield care, but by going after time itself, at least how the body manages it. Biostasis is attempting to address the need for additional time in continuously operating biological systems faced with catastrophic, life-threatening events. The program leverages molecular biology in the development of controlling the speed at which living systems operate, and thus extend the window of time following a damaging event before a system collapses. Essentially, the concept aims to slow life to save life.

Biostasis is generating proof-of-concept, benchtop technologies and testing their application in simple living systems for experimental validation. To support eventual transition to patients, DARPA will work with federal health and regulatory agencies as the program advances to develop a pathway for potential, future human medical use. By the end of the five-year, fundamental research program, DARPA hopes to have multiple tools for reducing the risk of permanent damage or death following acute injury or infection.

# Facilitating Close Air Support

To maintain a decisive tactical advantage in 21st century combat, warfighters need to deploy ordnance against elusive mobile targets. Unfortunately, air-ground fire coordination – referred to as close air support or CAS – has changed little since its emergence in World War I. Pilots and dismounted ground agents can focus on only one target at a time and must ensure they hit it using just voice directions and, if they are lucky, a common paper map. It can take up to an hour to confer, get in position and strike – time in which targets can attack first or move out of reach. DARPA created the Persistent Close Air Support (PCAS) program to help address these challenges.

The agency successfully sought to increase CAS effectiveness by enabling dismounted ground agents and combat aircrews to share real-time situational awareness and weapons systems data. The system enables target controllers on the ground to identify multiple targets simultaneously. They then can jointly select precision-guided ordnance that best fits each target and minimizes collateral damage and friendly fire. Finally, both parties can authorize weapons deployment. DARPA-developed software, coupled with the Android Tactical Assault Kit (ATAK) that transitioned directly to units in Afghanistan, drastically enhancing their ability to coordinate air engagements, improve accuracy, and reduce collateral damage and friendly-fire losses. Later, in advising Iraqi Special Operations Forces, PCAS technology was part of the U.S. Coalition Special Operations Forces' Remote Advise and Assist approach that enabled the Iraqis to battle ISIL. Also, in the United States, emergency responders, including firefighters in the West and Southwest, have tested and adopted these wireless communication and coordination tools.

# 4 Advance foundational research in science and technology

DARPA's job is to change what's possible – to do the fundamental research, the proof of principle, and the early stages of technology development that take "impossible" ideas to the point of "implausible" and then, surprisingly, "possible." No other DoD agency has the mission of working on projects with such a high possibility of producing truly revolutionary new capabilities – or such a high possibility of failure. A big part of DARPA's expertise is seeking high pay off capabilities by managing risk in ways that help keep the innovation pipeline flowing. These are the kinds of foundational-research efforts that promise to impact national security like the ARPAnet, which yielded the internet, and AI research, which is making autonomous self-driving cars a reality. Currently, DARPA is giving special attention to:

- Artificial intelligence and machine learning
- Microsystems assurance and differentiation
- New computing approaches via molecular informatics
- Next-generation social science

**AI Next: Giving Shape to Third Wave AI Science and Technology**

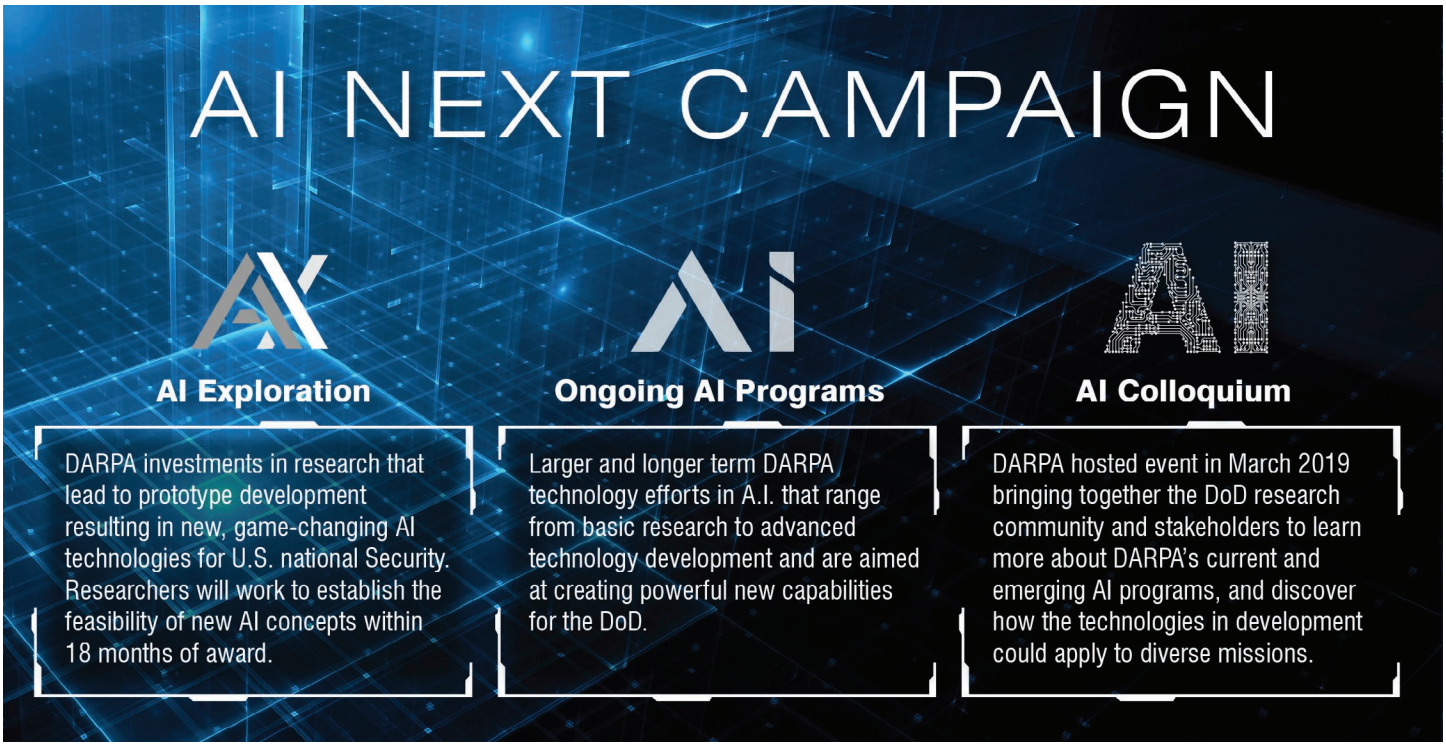
DARPA continues to aggressively pursue artificial intelligence (AI) technologies that create powerful, game-changing capabilities for the Department of Defense. Past DARPA investments facilitated the advancement of "first wave" (rule-based) and "second wave" (statistical-learning-based) AI technologies, enabling some of the first successes in the field, such as expert systems and search, and, more recently, advanced machine-learning algorithms and hardware.

DARPA is interested in researching and developing "third wave" AI theory and applications that address the limitations of first and second wave technologies by making it possible for machines to adapt contextually to changing situations. Similar to ERI, DARPA established in 2018 a multi-year, $2 billion "AI Next" campaign that seeks to give rise to a future in which AI-enabled machines serve as trusted, collaborative partners in solving problems of importance to national security.

AI projects will include proofs of concept, pilots, applications of commercial technologies for defense purposes, as well as the creation, design, development, and demonstration of technical or operational utility or combinations thereof. DARPA's AI investments will also create the deep analysis and theoretical understanding of how and why today's AI technologies work, to enable the robust performance guarantees essential for military and safety-critical systems. Important research and development, specifically, includes:

- **New Capabilities.** AI technologies enable DARPA R&D projects, including the Electronic Resurgence Initiative (ERI), real-time analysis of sophisticated cyberattacks, detection of fraudulent imagery, construction of dynamic kill-chains for all-domain warfare, human language technologies, multi-modality automatic target recognition, biomedical advances, and control of prosthetic limbs. DARPA will explore research to advance AI technologies for enabling automation of critical DoD business processes, such as accreditation of software systems for deployment.

- **Robust AI.** AI technologies have demonstrated great value to missions as diverse as space-based imagery analysis, cyberattack warning, supply chain logistics and analysis of microbiologic systems. At the same time, the failure modes of AI technologies are poorly understood. DARPA is working to address this shortfall, with focused R&D, both analytic and empirical. DARPA's




success is essential for the Department to deploy AI technologies, particularly to the tactical edge, where reliable performance is critical.

- **Adversarial AI:** The most powerful AI technology today is machine learning, but such systems can be easily duped by changes to inputs that would never fool a human. The data used to train such systems can be corrupted and the software is vulnerable to cyber-attack. These areas, and more, must be addressed at scale as more AI-enabled systems are deployed operationally. DARPA is investing in adversarial AI R&D to understand and counter such attacks.

- **High Performance AI:** Computer performance increases over the last decade have enabled the success of machine learning, in combination with large data sets, and software libraries. More powerful performance at lower electrical power consumption rates is essential to allow both data center and tactical deployments. DARPA has demonstrated analog processing of AI algorithms with 1000x speedup and 1000x power efficiency over state-of-the-art digital processors; the agency also is researching AI-specific hardware designs. Moreover, DARPA is attacking the current inefficiency of machine learning by researching ways to reduce requirements for labeled training data.

- **Next Generation AI:** The machine learning algorithms that enable face recognition and self-driving vehicles were invented over 20 years ago. DARPA has taken the lead in pioneering research to develop the next generation of AI algorithms, which will transform computers from tools into problem-solving partners. DARPA research aims to make it possible for AI systems to explain their actions, and to acquire and reason with common sense knowledge. DARPA R&D produced the first AI successes, such as expert systems and search. More recently, the agency has advanced machine learning tools and hardware. DARPA is now creating the next wave of AI technologies that will enable the United States to maintain its technological edge in this critical area.

In addition to new and existing DARPA research, a key component of the AI Next campaign is DARPA's Artificial Intelligence Exploration (AIE) program. AIE 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 is enabling these efforts to move from proposal to project kick-off within three months of an opportunity announcement.

**Explainable Artificial Intelligence**

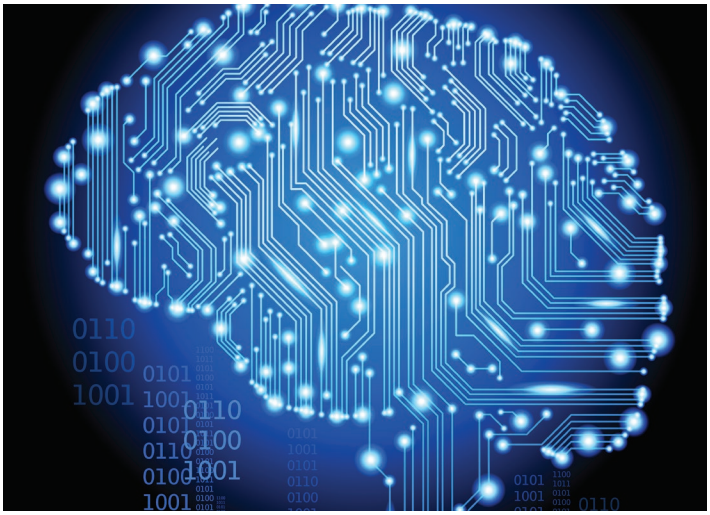
Early "first-wave" AI research by DARPA resulted in expert systems, powerful ways to interact with computers, knowledge representation used in electronic commerce, enhanced operational planning tools, industrial robots, and self-navigating vehicles.

We are now in the midst of the "second wave" in which machine-learning techniques, powered by inexpensive computing, have produced breakthroughs in broad areas of our everyday experience, including interaction with computers, language translation, image and video analysis, and the beginning of autonomous vehicles for consumers. DARPA's vision, focus, and funding played a key role in making this possible.

DARPA is framing and leading the "third-wave" of AI, which is focused on contextual reasoning in order to understand objects within their environment or knowing that an action can have good or bad consequences depending on the situation. Contextual reasoning will be essential for AI-based analysis and for autonomous systems that behave appropriately in complex operational environments. DARPA is also advancing the theory of AI to ensure that systems are robust and efficient as the technology is embedded within critical systems across society. One of the programs at the center of this push is Explainable AI (XAI).

Recognizing that DoD faces challenges that demand more intelligent, autonomous, and symbiotic systems, XAI aims to create a suite of machine learning techniques that produce explainable models – while maintaining a high level of prediction accuracy so human users understand, appropriately trust, and effectively manage the emerging generation of artificially intelligent partners. Enabling computing systems in this manner is critical because sensor, information, and communication systems generate data at rates beyond what humans can assimilate, understand, and act upon. Incorporating these technologies in military systems that collaborate with warfighters will facilitate better decisions in complex, time-critical battlefield environments and empower unmanned systems to perform critical missions safely with high degrees of autonomy.

Through XAI, new machine-learning systems will function more as colleagues than as tools, partnering with humans. DARPA knows that as projects like XAI, advance, it is vital that the agency and others are mindful not only of the promising positive impacts on national security and society in general, but also of the value of participating in early, wider discussions about potential negative impacts. One forum for those discussions is the Select Committee on Artificial Intelligence, a group convened in May 2018 under the auspices of the White House Office of Science and Technology Policy to plan and improve coordination of AI efforts – DARPA's director co-chairs that group.



**Lifelong Machine Learning**

Machine learning and artificial intelligence systems have moved ahead significantly in recent years. Still, despite the increased attention they are receiving from researchers, policy specialists, and the public, these systems are limited to executing those tasks they are specifically designed to perform; they are unable to adapt when encountering situations outside their programming or training. DARPA's Lifelong Learning Machines (L2M) program, drawing inspiration from biological systems, seeks to change that by developing fundamentally new approaches that allow systems to adapt continually to new circumstances without forgetting previous learning and without pre-programming or training sets.

L2M research teams are developing complete systems and their components, as well as exploring learning mechanisms in biological organisms with the goal of translating them into computational processes. Discoveries in both technical areas are expected to generate new methodologies that will allow AI systems to learn and improve during tasks, apply previous skills and knowledge to new situations, incorporate innate system limits, and enhance safety in automated assignments. While the program is still in its early stages, L2M researchers already have identified and solved challenges associated with building and training a self-reproducing neural network. L2M seeks to enable systems to learn from experience and become smarter, safer, and more reliable than existing AI. The task is ambitious; DARPA is pursuing nothing less than paradigm-changing approaches to machine learning that will enable systems to continuously improve based on experience.

# High-Performance RF Arrays

DARPA's earlier development of gallium nitride (GaN) semiconductors catalyzed U.S. development and deployment of the world's most powerful, highest-performing, farthest-sensing, and strongest-jamming radio frequency (RF) arrays. These investments in GaN are enabling a new generation of military systems that can scan space for debris, search the horizon for incoming missiles, and interrupt adversary communications at ranges not possible with conventional electronics. DARPA's foresight to invest in this technology when its value was uncertain is paying off today by delivering unprecedented capabilities for some of the nation's most critical military programs, including Space Fence; the Terminal High Altitude Area Defense (THAAD); the Surface Electronic Warfare Improvement Program's anti-ship missile warning and protection system; and the Next Generation Jammer airborne electronic warfare system. All of these rely on GaN to provide the United States with the tactical and strategic edge required to win tomorrow's battles.

**Electronics Resurgence**

For more than a half century, advanced electronics has been one of the foundational technology areas for national security and economic and social well-being. DARPA long has had an essential role in driving advances in state-of-the-art electronics, especially when it comes to semiconductors. Today, the advanced electronics industry is at an inflection point. Design work and fabrication now required to keep on pace is becoming ever more difficult and expensive, and the pace of homegrown innovation is slowing, while countries like China – which has been significantly behind the United States in semiconductor capability – now invests enormous sums of government-directed private capital to acquire on-shore semiconductor design and manufacturing capabilities.

In 2017, DARPA launched the Electronics Resurgence Initiative (ERI), which aims to create technology that will marginalize traditional circuit technology and create a wave of new U.S. development and economic opportunity. ERI addresses two priorities: assurance and specialization.

- **Assurance.** DoD must be able to manufacture state-of-the-art technologies that keep the warfighter at the cutting edge. That means minimizing intellectual property theft, hardware Trojans, loss of access to manufacturing services, and supply chain disruptions – among other risks.
- **Specialization.** DoD has long-term needs to resolve the skyrocketing cost of circuit design; to manage the slowdown in electronics progress under Moore's Law; and to diminish foreign governments' attempts to distort the global electronics market. Specialization will allow the United States to chart a path away from commercial parts to custom parts that use differentiated technologies optimized for specific applications.

The foundation for ERI has been building for several years via existing programs. A major component of the initiative is an extensive university-based program – the Joint University Microelectronics Program (JUMP) – that DARPA and corporate partners have organized to build up a fundamental research base in fields underlying microelectronic technologies.

ERI ELECTRONICS RESURGENCE INITIATIVE

ERI is composed of many component programs, each of which seeks to answer a critical question. For example:

- **Architectures:** Can we enjoy the benefits of specialized circuitry while still relying on general programming constructs through the proper software/hardware co-design?
  - The goal of the Software Defined Hardware (SDH) program is to build runtime-reconfigurable hardware and software that enables near application-specific integrated circuit (ASIC) performance without sacrificing programmability for data-intensive algorithms. SDH will create a hardware/software system that allows data-intensive algorithms to run at near ASIC efficiency without the cost, development time, or single application limitations associated with ASIC development.
- **Design:** Can we dramatically lower the barriers to modern system-on-chip design and unleash a new era of circuit and system specialization and innovation?
  - The overall goal of the Intelligent Design of Electronic Assets (IDEA) program is to create a "no human in the loop" layout generator that enables users with no electronic design expertise to complete the physical design of electronic hardware within 24 hours. IDEA will develop the algorithms, methodologies, and software required to create an automated, unified layout generator for mixed-signal integrated circuits, systems-in-package, and printed circuit boards.
- **Materials and Integration:** Can the integration of unconventional materials enhance conventional silicon circuits and continue the progress traditionally associated with scaling?
  - The overall goal of the Three Dimensional Monolithic System-on-a-Chip (3DSoC) program is to develop 3D monolithic technology that will enable > 50X improvement in SoC digital performance at power. 3DSoC aims to drive research in process, design tools, and new compute architectures for future designs while utilizing U.S. fabrication capabilities.
  - The goal of the Foundations Required for Novel Compute (FRANC) program is to define the foundations required for assessing and establishing the proof of principle for beyond von Neumann compute architectures. FRANC will seek to demonstrate prototypes that quantify the benefits of such new computing architectures.

# Rapid Diagnosis of Infectious Diseases

Today's diagnostic tests for infectious diseases can take a week or more to provide definitive results from the field – far too long when the disease in question is a fast-moving scourge such as Ebola or Zika. To address this concern, the Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is actively supporting individual troop readiness and total force health protection through the development of technologies to rapidly identify and respond to threats posed by natural and engineered diseases and toxins.

ADEPT has pioneered use of nucleic-acid-based anti-infective technologies, valuable for their efficacy and adaptability. These tools – primarily coded genetic instructions to the body on how to produce its own protective antibodies against a specific threat – have the advantages of being easily manufactured at scale using largely synthetic processes, transported and stored without many of the cold-chain logistics required by traditional medical countermeasures, delivered with near-immediate efficacy, and safely expressed in the body for only a limited duration, causing no permanent alteration to the genome.

In 2018, DARPA developed an Ebola antibody in partnership with National Institutes of Health (NIH), which was protective for non-human primates days after lethal Ebola infection. NIH funded a Phase I clinical trial to test antibody safety in humans and sent more than 100 doses to the Democratic Republic of the Congo for humanitarian use.

**Turning to Chemistry for New Computing Concepts**

As the complexity and volume of global digital data grows, so does the need for more capable and compact means of processing and storing data. To address this challenge, DARPA's Molecular Informatics program seeks a new paradigm: instead of relying on binary digital logic of computers, DARPA wants to exploit the wide range of structural characteristics and properties of molecules to encode and manipulate data. Millions of molecules exist, each with a unique three-dimensional atomic structure as well as variables such as shape, size, or even color. This richness provides a vast design space for exploring novel and multi-value ways to encode and process data beyond the 0s and 1s of current logic-based, digital architectures.

Molecular storage concepts, such as those based on DNA sequences, have advanced in recent years and show promise for archiving digital data in a format that takes up extremely small physical space. DARPA is exploring opportunities in the much broader design and encoding space of millions of molecules, which offers far more opportunity than do the four building-block molecules of DNA. To achieve its goals, the Molecular Informatics program is tapping into a diverse, collaborative community of researchers from fields including chemistry, computer and information science, mathematics, and chemical and electrical engineering. By addressing mathematical and computational problems that challenge our current capabilities, the Molecular Informatics program aims to discover and define opportunities for the use of molecules in information storage and processing.

**Next Generation Social Science**

The explosive growth of global digital connectivity has opened new possibilities for designing and conducting social science research. Once limited by practical constraints to experiments involving just a few dozen participants or to correlational studies of large datasets without any opportunity for determining causation, scientists now can engage thousands of diverse volunteers online and explore an expanded range of important topics and questions. If new tools and methods for harnessing virtual or alternate reality and massively distributed platforms could be developed and validated objectively, many of today's most important and vexing challenges in social science – such as identifying the primary drivers of social cooperation, instability, and resilience – might be more tractable. Benefits would flow to domains as broad as national security, public health, and economics.

To begin to assess the research opportunities provided by today's web-connected world and advanced technologies, DARPA created the Next Generation Social Science (NGS2) program. The agency is working to determine fundamental measures and causal mechanisms that explain and predict the emergence of collective identity, an important and complex challenge as researchers seek to validate tools and methods. While the program will focus on this research question, DARPA anticipates that successful NGS2 capabilities will have benefits for tackling other complex problems and topics, including those with national security implications, such as resilience in social networks and structures, changes in cultural norms or beliefs, emergence of cooperation/competitions, and social influences on preferences and cognition.

## Remaining Creative and Vigilant: One Breakthrough at a Time

Powerful technological trends are fueling many of these and other DARPA programs. In a time of great global uncertainty, one thing that is certain: in the years ahead, even as DARPA is working on these focused initiatives, the agency will be creative and vigilant, on the lookout for new opportunities for technological surprise to support U.S. national security interests – one breakthrough at a time.

# How DARPA Will Succeed

To prevail against the myriad threats and challenges we face, DARPA will build on the principles that have enabled its more than 60-year record of delivering scientific and technological advances that have made a dramatic difference in our nation's security. In short, DARPA will continue to leverage its **projects**, its **partnerships** with others in the technology and national security ecosystem, and its **people**.

First, DARPA is a projects agency that thrives on risk and rewards. DARPA projects address the highest payoff, highest risk, and most forward-looking technology concepts in deciding what investments might have the most significant impact in addressing future national security challenges. The agency's investments seek to hurdle seemingly impossible technical barriers in demonstrating "proof of concept" for solutions to these challenges. This model has produced answers to future questions that span operational environments while sometimes leading to applications in the commercial sector.

The agency starts projects and just as important, when prudent, it also stops projects. It insists on metrics and milestones to measure progress. If DARPA's researchers prove something audacious can be done, then it may have the potential to gird our nation's security position and even change the world. Building on what works, DARPA uses its rigorous, time-tested methods to ensure it initiates and shepherds programs that anticipate future threats and make significant contributions to national security.

DARPA is an organization deeply engaged in, and committed to, partnerships. Strong partnerships with others in the science and technology ecosystem have always been an essential modus operandi for the agency. That includes collaborations with the services, defense companies, small and large commercial entities, startups, allied nations, academics, and stakeholders in the executive and legislative branches of government. DARPA cannot accomplish what it does without support from these elements of the technology and national security ecosystem. Locked in on the need to pioneer breakthrough technologies as part of the enterprise seeking to advance weapons systems and capabilities, DARPA is strengthening relationships with senior military leaders. These are relationships based on trust and performance – with the goal of more effectively and quickly turning ideas perceived to be impossible into weapons and tools in the arsenals of U.S. warfighters. That strengthening includes increasing the emphasis on establishing joint projects offices and aiming for prototypes to forge new pathways for faster transitions. Increasing the number and types of partnerships with international allies is another strategy that DARPA is emphasizing as a way of improving its effectiveness.

DARPA's cadre of extraordinary people is the essential ingredient in its success. The agency comprises approximately 220 government employees, including approximately 100 technical program managers, who together oversee about 250 research and development programs. This small group of imaginative and dedicated people is responsible for maintaining acute awareness of emerging technology trends

"In short, DARPA will continue to leverage its projects, its partnerships with others in the technology and national security ecosystem, and its people."

and capitalizing on them before others do. Technical program managers are at the heart of DARPA's success, and the organization goes to great lengths to identify, recruit, and support extraordinary program managers who are at the top of their fields and are hungry for the opportunity to push the limits of their disciplines. These leaders come from academia, industry, and government agencies for limited stints, on average, designed to last just three to five years. That inherent sense of deadline fuels the signature DARPA urgency to achieve success in less time than might be considered reasonable in a conventional setting. They define their programs, set objectives, meet with their performers, and assiduously track progress. All the while, they are probing for the next big thing in their fields by engaging as peers with leaders in the scientific and engineering community to identify new challenges and potential solutions.

In each new conflict, our warfighters have relied upon scientific and technical advances to provide them with overmatch capability to employ against foes in changing environments. Those creative developments, including game-changing advances imagined and made possible by DARPA projects, partners, and people have made an enormously positive difference in our military security. Today, tomorrow and beyond, the need for DARPA to imagine, invest in, and deliver game-changing advances from our scientific and engineering enterprise is more compelling than ever.

## TRANSITIONS AT DARPA

DARPA's work is not done until the new and extraordinary technologies it develops are making a difference. That is why, even before a program launches, DARPA starts developing strategies for transitioning anticipated results into applicable, real-world domains.

The transition from research to demonstrable impact can take a variety of paths. In some cases, a DARPA program will result in a near-term military capability and move directly to a program of record in one or more of the services. In other cases, new DARPA-enabled technologies will transition first to the civilian sector, where commercial forces and private capital may drive further technical advances and cost efficiencies that can facilitate subsequent incorporation into military systems. In still other cases, DARPA's role may be even more fundamental, proving the realistic potential of a capability previously believed impossible and setting the stage for others to pursue that exciting glimmer of novelty and surprise.

By design, not all DARPA efforts transition upon their conclusion. Some programs simply fail – positive evidence that the agency is staying true to its mission of extreme ambition. Some succeed but the resulting capability is so disruptive that, in the short term at least, it cannot be introduced into existing systems or strategies. In those cases, years may pass before a DARPA-supported advance gets the opportunity to make its mark – perhaps because related technologies have matured or because geopolitical or economic contexts have evolved in ways that have made the advance more practicable or more critically needed. DARPA is committed to ensuring that its achievements are ultimately put to use to keep our nation safe.

## VITAL STATISTICS

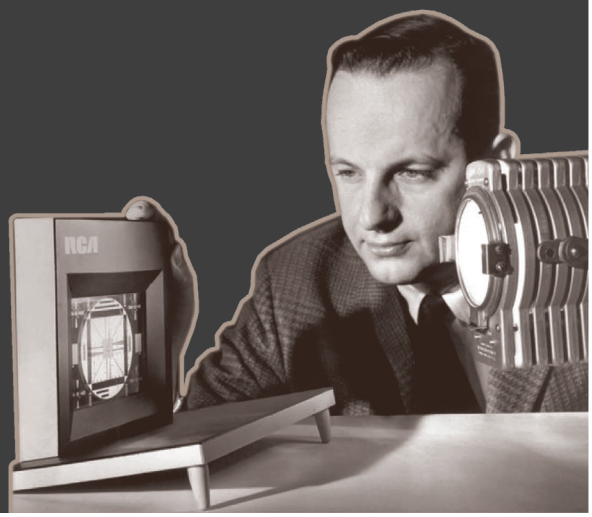
- $3.4 billion budget in FY 2019
- 25% of DoD's total science and technology funding; 2% of all federal research and development funding
- 220 government employees, including 100 technical program managers with limited terms, averaging four years
- One building in Arlington, VA
- 250 programs
- 2000 contracts, grants, and other agreements with companies (67% of funding), universities (17% of funding), DoD, and other labs

# THE HEILMEIER CATECHISM

DARPA operates on the principle that generating big rewards requires taking big risks. But how does the agency determine what risks are worth taking?

George H. Heilmeier, a former DARPA director (1975-1977), crafted a set of questions known as the "Heilmeier Catechism" to help agency officials think through and evaluate proposed research programs.

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

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