NOT FOR PUBLICATION UNTIL RELEASED BY THE SUBCOMMITTEE

Statement by Dr. Stefanie Tompkins

Director, Defense Advanced Research Projects Agency (DARPA)

Submitted to the
U.S. Senate Armed Services Committee –
Subcommittee on Emerging Threats and Capabilities

Accelerating Innovation for the Warfighter

April 6, 2022

NOT FOR PUBLICATION UNTIL RELEASED BY THE SUBCOMMITTEE

Chairman Kelly, Ranking Member Ernst and Members of the Subcommittee, thank you for the opportunity to testify before you today. I am Stefanie Tompkins, Director of the Defense Advanced Research Projects Agency, DARPA. It is a pleasure to be here with my colleagues, Ms. Heidi Shyu, from the office of the Undersecretary for Research and Engineering (USD(R&E)), and Mr. Michael Brown, Director of the Defense Innovation Unit (DIU). Our organizations work together every day to advance national security through new technology. DARPA plays a particular role in both the DOD and the broader U.S. technology ecosystem. That role is to anticipate, create, and demonstrate breakthrough technologies that are outside and beyond conventional approaches – technologies that hold the potential for extraordinary advances in national security capabilities.

For more than 60 years, DARPA has held to a singular and enduring mission: to create technological surprise. We do this by making pivotal investments in breakthrough technologies for national security. Working with innovators inside and outside government, DARPA has repeatedly delivered on our 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, miniaturized GPS receivers, and, just a decade ago, mRNA-based vaccines. Today, DARPA's role has never been more vital. From being front and center in our Nation's fight against the COVID-19 virus, to defensive as well as offensive hypersonics technologies, state of-the-art artificial intelligence, quantum technologies, and directed energy solutions, DARPA is delivering on our most pressing security needs.

DARPA creates and executes programs that rely on and inspire an innovation ecosystem of academic, industry, and government partners. Efforts to strengthen the U.S. technological ecosystem as a whole, such as the Bipartisan Innovation Act, would therefore significantly enable DARPA's efforts to provide game-

changing technical solutions. We work with national security leaders and the Nation's military services to understand today's hardest challenges and anticipate tomorrow's, and demonstrate transformational technology solutions for both.

We work quickly, embrace risk, and seek what we call "DARPA-scale impact". One of our program managers once joked, "if you didn't invent the internet, you get a B". In recent years, with the democratization and acceleration of technological advances around the world, we have increased our emphasis on rapid prototyping and on faster and lower-cost methods of designing, building, and testing technology not just in controlled settings but in the complex, dynamic, messy real-world environments in which they must ultimately succeed. Today, I will focus my testimony on examples of DARPA portfolios and programs in various stages of development and transition. Please remember: some of these may fail. But some will succeed, and in doing so may fundamentally transform our ability to defend the homeland, deter adversaries, increase global stability, and lay the foundations for continued technological surprise.

"AI Next" Campaign

DARPA has been a leader in artificial intelligence since the 1960s. The agency played key roles in realizing the first and second waves of AI (first rule-based, then statistical-learning-based), and now we are working to realize the third wave, which can be described as contextual adaptation. To better define a path forward, DARPA announced in September 2018 a multi-year investment of over $2 billion in new and existing programs called the "AI Next" campaign.

Currently, DARPA is pursuing more than 39 programs that are exploring ways to advance the state-of-the-art in AI, pushing towards third wave contextual reasoning capabilities. In addition, more than 60 active

programs are applying AI in some capacity, from sharing electromagnetic spectrum bandwidth to detecting and patching cyber vulnerabilities.

Under the AI Next campaign, key areas being explored include improving the robustness and reliability of AI systems; enhancing the security and resiliency of machine learning and AI technologies; reducing power, data, and performance inefficiencies; and pioneering the next generation of AI algorithms and applications, such as "explainability" and commonsense reasoning.

DARPA also has a quick-turn funding mechanism called Artificial Intelligence Exploration (AIE) that allows the agency to test the feasibility of AI concepts by rapidly developing prototypes. AIE opportunities are released on a rolling basis from across DARPA's portfolio, providing awards within 90 days of up to $1 million each for 18-month periods of performance. During these periods of performance, we investigate very high-risk, high-reward topics to assess feasibility and clarify whether the area is ready for increased investment. To date, we have made 244 contract awards for more than 37 AIE topics, and launched at least 2 significant research investments based on the AIE research results.

Applying AI (example): CBRNE Detection

A representative example of our AI Next campaign is the SIGMA+ program, which seeks to alert authorities when there is a chemical, biological, radiological, nuclear, or explosive (CBRNE) attack in a US city or on a military base. Last year, in collaboration with the Indianapolis Metropolitan Police Department (IMPD), we concluded a three-month pilot study focused on early detection and interdiction of CBRNE threats. For the pilot, researchers integrated highly sensitive chemical and biological sensors into several IMPD vehicles and characterized the real-world environmental background data over a large part of the Indianapolis

metropolitan region. Researchersthen used AI-supported algorithms to detect chemical simulants against that background.

Knowing the naturally occurring chemical and biological backgrounds in an area allows customization of both sensors and algorithms to minimize false positives and maximize detections of threats. During the Indianapolis pilot study, nuisance alarms were suppressed by 75%.

The Indianapolis pilot study and field testing marked the first time DARPA was able to demonstrate comprehensive SIGMA+ sensor technology in a law-enforcement vehicle, including air sampling, power, and a user interface that provided real-time analysis of potential threats via a tablet. The ultimate goal is to outfit a citywide fleet of law enforcement and other public service vehicles to enable a continuously refreshed mobile network that can detect CBRN threats with low false-alarm rates across a city and region. Next steps for SIGMA+ include testing in other metropolitan regions and developing operational procedures to integrate sensors into real-world use.

Advancing AI (example): Machine Learning with Limited Data

Much has been written about how the commercial world has harvested and created large sets of labeled data for training machine learning (ML) models. Unfortunately, when we try to use these models on DoD and Intelligence Community alert problems, they fail. This is because military-relevant data collections are often degraded and noisy – we are collecting images and audio non-cooperatively, we are processing seized/degraded media, or our sensors are different than commercial sensors. DARPA's Learning With Less Labeling program is developing new learning algorithms that require much less information to train or update ML models with increased accuracy.

The approach we take in Learning with Less Labeling (LwLL) is to generalize the machine learning objective. It turns out that many machine learning algorithms boil down to an optimization problem. The research goal is to use a million times fewer images than today's standard practice to train a system, and require roughly 100 labeled examples to adapt a system instead of the millions needed today.

In the context of identifying objects in images, LwLL researchers have already demonstrated and benchmarked, using real-world examples, a new technique that requires 1000x less labeled data than conventional ML with only 10% degradation in accuracy. This early breakthrough is promising and is already being shared with DoD transition partners, while the program continues to advance towards its ultimate goal of demonstrating a 1,000,000x reduction in labeled data required.

Assault Breaker II

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. DARPA's Assault Breaker II (ABII) initiative seeks to change fundamentally the way the military thinks about designing, buying, and deploying future systems.

First, the ABII program addresses several challenges posed by our strategic 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 five Services to establish a joint service team creating technology solutions for 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 to develop an advanced modeling and simulation environment to support analysis of true cross-domain, cross-service warfighting constructs. Finally, the program is tying modeling and simulation into an interactive experiment environment to support exploration of highly complex, interdependent approaches that characterize the future of warfighting.

ABII seeks to organize this evolution in warfighting and act as a conduit both to 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 a technical baseline for multi-domain operations moving forward.

Electronics Resurgence Initiative

In June 2017, DARPA announced the Electronics Resurgence Initiative (ERI) as a bold response to several technical and economic trends in the microelectronics sector. Among these trends, the rapid increase in the cost and complexity of advanced microelectronics design and manufacture is challenging a half-century of progress under Moore's Law, which holds that the number of transistors per silicon chip doubles every year. Meanwhile, non-market foreign forces are working to shift the electronics innovation engine overseas, while cost-driven foundry consolidation has limited DoD access to leading-edge electronics, challenging U.S. economic and security advantages. Moreover, highly publicized challenges to the Nation's digital backbone are fostering a new appreciation for electronics security – a longtime defense concern.

Building on the tradition of other successful government-industry partnerships, ERI is forging forward-looking collaborations among the commercial electronics community, defense industrial base, university researchers, and the DoD to address these challenges. There is significant historical precedent to suggest

the viability of this approach, as each wave of modern electronics development has benefitted from the combination of defense-funded academic research and commercial sector investment.

Given today's cost, complexity, and security challenges, it is critical that the nation collaboratively innovate on the next generation of electronics advancement. DARPA is advancing research in four key areas – 3D heterogeneous integration, new materials and devices, specialized functions, and design and security – each of which have been central to ERI since its inception. Leveraging 3D heterogeneous integration, the next wave should support continuing electronics progress despite challenges to traditional silicon scaling. This integration will enable innovators both to add new materials and devices to the silicon foundation and create specialized functions precisely designed to meet the diverse needs of the commercial and defense sectors. To manage the complexity of working in three dimensions, the next wave will also demand new architectures and design tools that address rising design costs, enable rapid system upgrades, and make security integration a primary design concern.

A major component of ERI is the JUMP Initiative. In late December 2021, DARPA announced its participation in a new public-private partnership with the Semiconductor Research Corporation (SRC) and a consortium of companies in the commercial semiconductor industry and the defense industrial base called the Joint University Microelectronics Program 2.0 (JUMP 2.0). The program supports high-risk, high-payoff university research that addresses existing and emerging challenges in information and communication technologies. JUMP 2.0 builds off an earlier iteration of the SRC-led collaboration that was formed in 2018 to support university research centers focused on maintaining U.S. microelectronics innovation. The targeted efforts of ERI play a critical role in the U.S. microelectronics ecosystem and support the whole-of-government efforts underway to ensure continued leadership in this important area.

Cyber

In addition to addressing threats in the physical world, DARPA is also intensely focused on threats in the virtual world. To further this area of research, last year, DARPA conducted its first bug bounty program – the Finding Exploits to Thwart Tampering (FETT) Bug Bounty – to evaluate hardware protections in development on the System Security Integration Through Hardware and firmware (SSITH) program. SSITH explored hardware security architectures and tools that protect electronic systems against common classes of hardware vulnerabilities exploited through software, with the goal of breaking the endless cycle of software patch-and-pray.

Through FETT, hundreds of cybersecurity researchers and reverse engineers had virtual access to secure SSITH processors in order to detect weaknesses and vulnerabilities. Key to this effort was the development of a scalable, virtualized platform for remotely testing and evaluating the processor prototypes. The platform is a first-of-its-kind infrastructure that provides a means of virtually crowdsourcing the analysis of future processor technologies.

After rigorous testing and evaluation, researchers have proven that SSITH concepts provide robust hardware safeguards against known common weakness enumeration (CWE) classes of hardware vulnerabilities. The program is now focused on transitioning and converting the proven concepts from lab discoveries to practical application. For instance, SSITH successfully worked with Arm Ltd to incorporate SSITH protections into Arm's microcontroller-class and high-performance processor product lines. Over 20 billion Arm processors are made each year, and are used widely within DoD weapon systems.

Long Range Effects

The ability to field hypersonic systems ranks high on the DoD's list of priority technologies, due in part 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 enhanced effectiveness compared to current military systems.

Last year, DARPA, in partnership with the U.S. Air Force, completed a free flight test of its Hypersonic Air-breathing Weapon Concept (HAWC). The missile was released from an aircraft seconds before its scramjet (supersonic combustion ramjet) engine kicked on.

The HAWC vehicle operates best in the lower atmosphere, where speed and maneuverability make it difficult to detect in a timely way. It could strike targets much more quickly than subsonic missiles and has significant kinetic energy even without high explosives. The test brings us one step closer to transitioning HAWC to a program of record that offers next generation capability to the U.S military.

Distributed Complex Systems

For several years now, DARPA has been spearheading the "Mosaic" construct of future warfare. The Mosaic concept posits that using less expensive systems brought together on demand as the conflict unfolds could facilitate the creation of "effects webs," enabling diverse, agile applications – from a kinetic engagement in a remote desert setting, to multiple small strike teams operating in a bustling megacity, or an information operation to counter an adversary spreading false information in a population threatening friendly forces and strategic objectives. Mosaics, therefore, can be rapidly tailored to accommodate available resources, adapt to dynamic threats, and be resilient to losses and attrition.

One program resulting from the Mosaic concept is STITCHES, or System of Systems (SoS) Technology Integration Tool Chain for Heterogeneous Electronic Systems. STITCHES is an open-source approach to allowing interoperability between systems that have complimentary functions but were not designed to be implemented together. Recently, the DOD evaluated STITCHES, determining it enables Joint All Domain Command and Control (JADC2) interoperability. By pushing message translation to the edge, joint interoperability could be achieved via a federated point-to-point solution that scales linearly vice the traditional quadratic complexity scaling. As the number of systems and domains increases, this linear scaling offers a dramatic decrease in complexity and cost while increasing speed of interpretation and adaptability. STITCHES enables not just data translation but also in-line synchronization, and functions that are traditionally achieved by changing system software or physical gateways.

Warfighter Protection and Performance

Spinal cord injury disrupts the connection between brain and body, causing devastating loss of physiological function to the wounded warfighter. In addition to paralysis, service members living with these injuries exhibit increased long-term morbidity due to factors such as respiratory and cardiovascular complications. Bridging the Gap Plus (BG+), a new DARPA program that combines neurotechnology, artificial intelligence, and biological sensors, opens the possibility of overcoming the worst effects of spinal cord injuries by promoting healing at the wound site and interfacing with the nervous system at points around the body to restore natural functions such as breathing, bowel and bladder control, movement, touch, and proprioception that can be lost when the spinal cord is damaged.

BG+ encompasses two research thrusts aimed at developing and integrating technologies for injury stabilization, regenerative therapy, and functional restoration to support patients during all phases of spinal cord injury — acute, sub-acute, and chronic. DARPA's focus is on improving healing outcomes during the

acute and sub-acute phases of injury (approximately the first 2 days to two weeks after injury), and on restoring lost function in the chronic phase of injury.

DARPA created BG+ as a five-year program, scheduled to conclude with clinical demonstrations in human patients. Just this February, BG+ researchers demonstrated a minimally invasive approach to restore bowel function in cats, which avoids the pitfalls of traditional surgical approaches that can leave patients with irreversible nerve damage. This functionality will be incorporated into a user-controlled, integrated visceral function restoration system to give veterans and others with paralysis a useable long-term solution.

Gray Warfare

The U.S. is engaged with its adversaries in an asymmetric, continual, war of weaponized influence narratives. Adversaries exploit misinformation delivered via influence messaging: blogs, tweets, and other online multimedia content. Analysts require effective tools for continual sensemaking of the vast, noisy, adaptive information environment to identify geopolitical influence campaigns.

Today, detection and sensemaking of adversary influence campaigns is largely manual and ad hoc. With current tools, it is difficult to connect messages over time and across multiple platforms to track evolving campaigns, and analysts must manually sift through a high volume of messages to find those with relevant influence agenda and then gauge which ones are gaining traction and with whom.

The INCAS program began in 2021 to address these challenges. If successful, INCAS will provide analysts with the ability to detect, characterize, and track geopolitical influence campaigns across multiple languages and platforms with confidence. INCAS addresses the increasingly complex world of information

warfare, building upon and adding to previous DARPA successes with our programs in Media Forensics and Semantic Forensics, which detect manipulated imagery and information.

Climate and Environment

Sea level rise and wave-induced flooding during storm events threaten sustainability of the more than 1,700 Department of Defense (DoD) managed military installations in coastal areas worldwide. Despite previous efforts to implement storm mitigation solutions, damage due to storm surge and flooding continues to impact military infrastructure. Current DoD coastal protection measures, including bulkhead and coastal seawalls, may reflect wave energy, exacerbate flooding, create downstream sediment loss, and restrict water exchange. To protect DoD personnel and infrastructure, DARPA has established the Reefense program, which aims to develop novel hybrid biological and engineered reef-mimicking structures to mitigate wave and storm damage and reduce the ecological impact of current coastal protection measures.

As part of the Reefense program, custom wave-attenuating base structures will promote coral or oyster settlement and growth, which will enable the structures to be self-sustaining and address the infrastructure-related impacts of sea level rise over time. Program performers are employing recent innovations in materials science, hydrodynamic modeling, and adaptive biology to optimize these structures for responding to a changing environment.

Reefense takes the novel approach of integrating structural engineering, reef health, and adaptive biology to create reef-like ecological systems. These structures will help significantly reduce infrastructure maintenance costs, promote ecosystem health, and strengthen DoD's ability to maintain its infrastructure and military readiness.

Modeling, Simulation, and Experimentation

Following recent successful experimentation with Marines at Camp Lejeune, North Carolina, DARPA's Prototype Resilient Operations Testbed for Expeditionary Urban Scenarios (PROTEUS) program will transition to the Marine Corps Warfighting Laboratory (MCWL) in Quantico, Virginia.

PROTEUS comprises a suite of visual software training and experimentation tools that enables Marines from squad to battalion level to explore and develop novel multidomain fighting concepts. The tools allow Marines to integrate emerging capabilities and learn how to effectively employ them in realistic expeditionary combat scenarios.

DARPA launched PROTEUS in 2017 and recently completed a five-day capstone demonstration with 1st Battalion, 2nd Marines at Camp Lejeune, where Marines rapidly explored and assessed future infantry battalion task organizations, force packages, and tactics. PROTEUS provided unique insights in support of the Marine Corps' Force Design 2030, the Service's plan for organizing, training, and equipping Marines for future challenges.

Using the PROTEUS software, Marines were able to visualize and manipulate their electromagnetic footprint, apply logistics support automation, and obtain quantitative analytics on the effectiveness of force packages and tactics in real time. PROTEUS brings the power of multi-domain force package and CONOPS (concept of operations) development to the platoon, company, and battalion.

Transition and Business/Countering Foreign Influence

Over the past two years, DARPA's Embedded Entrepreneurship Initiative (EEI) has helped more than 50 pre-seed stage research teams raise over $275M in U.S. investment, spin out a dozen new companies, establish numerous joint development agreements with corporate partners, and commission multiple manufacturing facilities. In early 2021, DARPA launched an expansion of EEI with the goal of accelerating 150 DARPA-backed technologies out of the lab and into products that promise to fundamentally change the way we live, work, and fight. EEI augments technical research teams with critical entrepreneurial expertise, top-tier commercialization mentors, and connections to investors, effectively countering aggressive adversary-nation investors by building stronger companies that have the ability to attract U.S. capital.

EEI provides catalytic funding, mentorship, and investor and corporate connections for select DARPA researchers. Resources include: an average of $250,000 in non-dilutive funding to hire a seasoned entrepreneur or business executive for one to two years with the goal of developing a robust go-to-market strategy for both defense and commercial markets; dedicated commercialization mentors with extensive private sector experience; and engagement with DARPA's private sector Transition Working Group comprising over 100 top-tier U.S. investors and corporations key to scaling and supply chain development.

DARPA-funded scientists and engineers are an invaluable resource for national competitiveness. Supporting these researchers with tailored business expertise to advance their innovations for public and military use is critical to obtaining the full benefit from taxpayer funded R&D investments.

Foundations of Technological Surprise

One of the classic models of technology development begins with basic or early-stage applied research that uncovers a new principle or phenomenon, which innovators then apply and develop into a new capability. This model cannot account for the origin of all of the technologies DARPA has had a hand in, but it applies

to many of them. 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 through "implausible" and then to, surprisingly, "possible" or even "likely." 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 particularly timely and relevant example has to do with quantum computing. Several DARPA programs explore aspects of quantum computation to determine which approach offers the most promise for substantial practical advantage. Of note, the Quantum Benchmarking (QB) program seeks to bring rigor to the fledgling quantum computing marketplace with the introduction of insightful benchmarking. There is much potential that quantum computing may make possible -- in diverse markets such as pharmaceuticals, battery catalysis, and machine learning -- but it is also possible that there is limited value of any sort in quantum computing beyond the commonly discussed application of unlocking encrypted data.

QB was started in 2021 with the goal of developing key quantum computing metrics, making those metrics testable, and estimating the required quantum and classical resources needed to reach critical performance thresholds. Coming up with effective metrics for large quantum computers is no simple task. Current quantum computing research is heavily siloed in companies and institutions, who often keep their work confidential, and existing metrics (such as the number of interacting qubits in a system) may not be relevant to actual computing performance on many applications. If successful, QB will accelerate the development of quantum computing across multiple domains, or illuminate its lack of utility in those same domains.

Conclusion

From DARPA's perspective, the technological future is enormously attractive, bright with opportunities, but also fraught with the potential for technological surprise from our adversaries. For more than 60 years, the men and women of DARPA have taken very seriously our unique mission to prevent such surprises by creating our own.

One year after returning to DARPA, it is clear to me that we are stronger and more committed to that mission than ever. I look forward to working with the members of this subcommittee and others in the Legislative and Executive branches to ensure that the United States maintains its lead in the investigation and development of powerful technologies, in addition to their safe and responsible application in support of a more stable, secure, and sustainable world.