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Statement by

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Mr. Chairman, Subcommittee Members and staff: I am Bob Leheny, Acting Director of the Defense Advanced Research Projects Agency (DARPA). I am pleased to appear before you today to discuss DARPA's ongoing activities and our plans to continue as the engine for radical innovation in the Department of Defense (DoD).

With the change in Administration, our long-time Director, Dr. Tony Tether, left DARPA in late February. As the Deputy Director, I have been asked to serve as DARPA's Acting Director until a permanent Director is appointed. You may naturally wonder what changes are in store for DARPA. We are essentially continuing on the path we were on before Dr. Tether left. When the new Director arrives, he or she will, of course, make changes; that is, after all, a big part of the job. But one of the pleasures of working at DARPA is the strong support we have enjoyed over the years from successive administrations, this subcommittee, and other committees in Congress. So while there will be changes at DARPA, I'm confident that we will continue the mission we began more than 50 years ago.

DARPA's original mission, established in response to the Soviet Union beating the United States into space with Sputnik in October 1957, was to prevent technological surprise. This mission has expanded from preventing technological surprise for us to creating technological surprise for our adversaries. Stealth aircraft, developed at DARPA more than 25 years ago, is one among many important examples of how we create technological surprise.

DARPA conducts its mission by searching worldwide for revolutionary high-payoff ideas and then sponsoring research projects that bridge the gap between these fundamental discoveries and their military application.

DARPA is the Department of Defense's only research agency not tied to a specific operational mission: DARPA supplies technological options for the entire Department and is designed to be a specialized "technological engine" for DoD.

This is a unique role within DoD. The Department's operational components naturally tend to focus on the near-term because they must meet urgent needs and requirements. Consequently, a large organization like DoD needs a place like DARPA whose only charter is radical innovation.

Secretary Gates' Announcement and DARPA Priorities

Mr. Chairman, you asked that I address DARPA's S&T priorities in light of Secretary Gates' budget announcements on April 6th, and his objective to "reshape the priorities of America's Defense establishment." I believe the portfolio of nine strategic research thrusts DARPA is emphasizing today, which I will describe in greater detail later in my testimony, are in strong accord with the Secretary's goals:

- Robust, Secure, Self-Forming Networks
- Detection, Precision ID, Tracking, and Destruction of Elusive Targets
- Urban Area Operations
- Advanced Manned and Unmanned Systems
- Detection, Characterization, and Assessment of Underground Structures
- Space
- Increasing the Tooth-to-Tail Ratio
- Bio-Revolution
- Core Technologies

One of the first things the Secretary mentioned in his announcement was keeping our commitments to our all-volunteer force, including their medical care. For several years, our Bio-Revolution strategic thrust has included important research aimed at keeping our warfighters healthy, fit, and protected in the field; caring for them when they are wounded; and rehabilitating our wounded over the long-term. More specifically, these are:

- Protecting human assets through advanced technologies to provide combat casualty care to greatly improve the chances of our wounded surviving battlefield injury.
- Maintaining combat performance by innovative approaches to sustain the warfighter's peak physical and cognitive performance when deployed, despite the challenges of extreme battlefield stresses such as heat and altitude, prolonged physical exertion, and sleep deprivation.
- Restoring capabilities after severe injury by developing technologies to restore full function, including techniques to accelerate healing and revolutionary new prostheses for combat amputees.

For example, last month, DARPA's program to revolutionize upper extremity prosthetics was highlighted in a story on "60 Minutes" and as part of the Veterans Affairs' Research Week.

While there are many exciting things happening at DARPA, we are proudest of this work that aids our wounded men and women in uniform.

The Secretary also emphasized rebalancing DoD's programs to enhance our ability to fight the kind of wars we are in today, and will most likely continue to face in the years to come. Much of the fighting in Iraq has happened in cities, which can be one of the most dangerous, costly, and chaotic forms of combat. And our adversaries have realized that, if they are to survive the United States' superior precision strike capabilities, they either have to move, hide, or blend into cluttered environments. DARPA is responding by developing sensors, exploitation tools, and battle management systems to rapidly find, track, and destroy forces that operate in difficult terrain such as mountains, forests, and swamps, as well as those ground troops and other insurgents that abandon open country for urban terrain where whole organizations are often embedded in civilian activities. Since before the current conflicts began, DARPA has been addressing these issues in programs aimed at:

- Improved Intelligence, Surveillance, and Reconnaissance (ISR) capabilities to vastly improve understanding of what is going on throughout complex environments.
- Tagging, tracking and locating capabilities to persistently monitor targets or equipment of interest; tag, track and locate enemy activities; track and detect weapons fabrication and movement; and precisely discriminate threat from non-threat entities against severe background clutter.
- Asymmetric warfare countermeasures to develop technology to detect, prevent, or mitigate asymmetric attacks, such as suicide bomber attacks, improvised explosive device attacks, and WMD attacks – including radiological dispersal devices.
- Pre- and post-conflict capabilities to model and understand social indicators that precede the onset of hostility and conflict.
- Command, Control, Communications, and Intelligence (C3I) for irregular warfighting to develop new approaches to all-echelon C3 and new intelligence analysis tools specifically suited for irregular operations that allow warfighters to see and understand what is happening throughout the urban battlespace in real time.

A great deal of our effort is focused on improving our ISR capabilities. Our programs include developments in three general areas; sensors to find targets; sensor exploitation tools to identify and track targets; and battle management systems to plan and manage the use of sensors, platforms, and weapons throughout the battlespace. Our goal is to seamlessly layer surveillance and battle management systems using a network of platforms that includes radars and electrooptical sensors that can scan wide areas of open or forested terrain and laser detection and ranging (ladar) sensors to obtain high-resolution, three dimensional imagery that is particularly useful in urban terrain. We are developing tools to exploit video, in all regions of the spectrum, to track elusive targets as they move around. By networking sensors together, and coordinating sensor movement and tasking, we aim to achieve wide area coverage, high resolution, high frame rates and high revisit rates.

One of the lessons of today's wars is the importance of prompt language translation at both the strategic and tactical levels to understand what is being reported and to allow our troops to work with the people they encounter. Efficient language processing with superb machine language translation technologies can remove barriers to interaction with the local population. For many years, DARPA has pursued better automated language translation, and it remains a crucial part of our strategic thrust in Increasing the Tooth to Tail Ratio. This long-term effort is yielding fruit for our warfighters today, with DARPA translation devices being used and evaluated in the field.

On the other side of rebalancing, the Secretary also pointed to the continuing need for conventional and strategic modernization to contend with possible security challenges from the militaries of other nations, including better cyberspace capabilities. While few DARPA programs could be characterized as "conventional," our strategic thrusts in Space, Advanced Manned and Unmanned Systems, and Robust, Secure, Self-Forming Networks are focused on keeping our conventional force-on-force capabilities unsurpassed.

In particular, our Robust, Secure, Self-Forming Networks thrust contains our work in cyber security, a threat area that has been receiving increasing attention. U.S. tactical and strategic networks must be reliable in any environment for extended periods and must be protected against cyber threats. DARPA has increased its efforts to develop technologies that make computers and their networks secure against the spectrum of information operations attacks, including the capability to be disruption-tolerant and to quickly self-reconstitute after attack.

As technologies are developed and deployed to successfully block overt cyber attacks, adversaries will likely attempt to insert malicious code in our networks to impede our ability to fight. The ever-growing sophistication of this threat has surpassed the ability of current commercial markets to provide DoD with rapid and robust solutions, particularly at the hardware and component levels.

The microelectronics used in DoD systems are purchased from multiple vendors, including foreign sources. DARPA's TRUST program seeks ways to determine whether malicious features were inserted during the design or fabrication of application-specific integrated circuits or during the loading of field programmable gate arrays. DARPA is at the forefront of research in this area, addressing many of these issues in a comprehensive manner for the first time.

Cyber security threats will continue to increase in scope and sophistication. Rapid experimentation of new defensive capabilities is needed to stay ahead of cyber threat advances. In the belief that you can only truly understand what you can measure, DARPA is taking an unusual position by leading the development of a cyber test and evaluation facility. The National Cyber Range will allow realistic, quantifiable tests and assessments of cyber security scenarios and defensive technologies. The range, which DARPA will not operate in the long run, will contain thousands of real and virtual nodes to provide realistic, tailored simulations of large-scale military and Government networks, all coupled with state-of-the-art forensic tools to analyze exactly what happens. We believe rapid technical progress requires precise tools for rigorous experiments, and the National Cyber Range will provide these tools. The revolution in large-scale cyber testing created by the National Cyber Range will spur tremendous progress in making networks more secure and reliable in the face of a wide range of challenges.

Given our mission, DARPA must remain focused on the technologies of the future – both threats and opportunities. The best way to prepare for the future is to create it yourself, so that is where our Core Technologies thrust comes in. These are the technologies that will make the military systems of the future possible. They are often our most long term investments and will have payoffs against both conventional and asymmetric threats.

DARPA continues to enjoy strong support in the DoD for our mission and our current portfolio of programs. While there will always be adjustments and changes at DARPA – that's part of who we are – I believe we currently are on the right track and aligned with DoD's overall direction.

You also asked for our views on acquisition reform. As a purely S&T organization, DARPA doesn't manage any acquisition programs, so we are not well-positioned to comment on what exactly should be done and how. But, as an organization upstream of acquisition programs, reforms that make the system faster and more agile can only help us more quickly and effectively transition new technologies to the warfighter.

DARPA's Strategic Thrusts

I would now like to update you on our work in more detail by describing the strategic thrusts that currently embody our mission, and providing you with examples of what DARPA has been doing in each.

<u>Robust, Secure, Self-Forming Networks</u>

DoD is in the middle of a transformation to "network-centric operations" with the promise of turning information superiority into combat power so the United States and its allies have better information and can operate far more quickly and effectively than any adversary. Network-centric operations offers the prospect of fusing the typically separate functions of intelligence and operations to dramatically speed up our OODA – "observe-orient-decide-act" – loops.

At the core of this concept are robust, secure, self-forming networks. These networks must be at least as reliable, available, secure, and survivable as the weapons and forces they connect. They must distribute huge amounts of data quickly and precisely across a battlefield, a theater, or the globe, delivering the right information at the right place at the right time. They must form, manage, defend, and heal themselves so they always work at the enormously high speeds that provide their advantages, which means that people can no longer be central to establishing, managing, and administering them.

Tactical networks must locally link effects to targets and be agile, adaptive and versatile. Strategic and operational networks must globally link air, ground, and naval forces for operational maneuver and strategic strike and enable knowledge, understanding, and supply throughout the force. And there is now the opportunity to bridge the gap between these two families of networks so strategic and tactical echelons can share information and insight rapidly and effectively.

To connect tactical ground, airborne, and satellite communications platforms and terminals together, our Network-Centric Radio System (NCRS) program has developed a mobile, self-healing, ad hoc network gateway that provides total radio/network interoperability among these platforms moving in any terrain. Limited radio interoperability has plagued the DoD for decades. NCRS builds interoperability into the network itself, rather than building it into each radio–so now, any radio can talk to any other radio. Previously incompatible tactical radios can talk seamlessly among themselves and to more modern systems, including both military and commercial satellite systems. We are now taking this technology and working on commercial components and practices to make NCRS more affordable at low rate initial production quantities. Specifically, the follow-on program, Mobile Ad hoc Information Network GATEway (MAINGATE), is focused on providing this capability and more at a low unit cost ($60,000 each) in small volumes (1,000 units).

Frequency spectrum is scarce and valuable. DARPA's neXt Generation (XG) Communications technology will effectively make up to 10 times more spectrum available by taking advantage of spectrum assigned to other users, but not being used at a particular place and time. XG technology senses the actual spectrum being used and dynamically uses the spectrum that is not busy at that moment. Recently, XG conducted a series of successful experiments and demonstrations at several military locations, and various organizations within DoD are planning to transition XG technology broadly into current and existing wireless communication systems.

DARPA has been developing communication networks for cities. Urban clutter can create multiple signals from diverse reflections of the initial signal (multipath), and the result is weak or fading communications. Turning this problem into an opportunity, our Mobile Networked Multiple-Input/Multiple-Output (MNM) program is actually exploiting multipath phenomena to improve communications between moving vehicles in cities without using a fixed communications infrastructure.

MNM has demonstrated reliable non-line-of-sight communications during on-the-move field trials in urban environments. MNM successfully exploited multipath to increase information throughput and reliability while maintaining high data rates. The program also demonstrated reliable communications in the face of interference by enabling multiple signals to simultaneously occupy the same frequency band, resulting in increased capacity of that channel.

Building on XG and other technologies, the Wireless Network after Next (WNaN) program is developing an affordable communication system for the "tactical edge." The low-cost, highly capable radio developed by WNaN will allow the military to communicate with every warfighter and every device at all operational levels. WNaN networking technology will exploit high-volume, commercial components and manufacturing so DoD can affordably evolve the capability. This means the radio cost will be so low that we could throw them away after a few years of use and issue newer, more capable radios at the time of deployment – like we use cell phones in civilian life. We are working with the Army to make a "low cost handheld networking radio" for about $500 apiece a reality. In fact, we recently signed a memorandum of agreement that could lead to the Army buying large numbers of units for military use.

DARPA is bridging strategic and tactical operations with high-speed, high-capacity communications networks. The DoD's strategic, high-speed fiber optic network—the Global Information Grid (GIG)—has an integrated network whose data rate is hundreds to thousands of megabits per second. To reach deployed elements, data on the GIG must be converted into a wireless format for reliable transmission to the various units within theater. This creates problems in the timely delivery of information.

How can we connect the tactical warrior to the GIG? We need a high-speed network that robustly disseminates voice, video, text, and situation awareness information among the various military echelons and coalition forces. DARPA is combining the high data-rate capability of laser communications with the high reliability and adverse-weather performance of radio frequency communications to make such a network possible.

The goal of our Optical RF[1] Communications Adjunct (ORCA) program is to create a high data-rate backbone network, via several airborne assets that nominally fly at 25,000 feet and up to 200 kilometers apart, which provides GIG services to ground elements up 50 kilometers away from any one node.

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[1] Radio frequency

Recent ORCA tests demonstrated billions of information bits per second communicated error-free across 147 kilometers on an optical link between two mountains in Hawaii under high turbulence conditions. Moreover, the radio frequency technology maintained communications at hundreds of millions of information bits per second when clouds blocked the optical link. ORCA will perform a more complex set of air-to-air, air-to-mountaintop, and air-to-ground field trials to assess our progress.

At sea, we are working to bridge strategic and tactical maritime operations with a revolutionary new capability for submarine communications. The Navy has long sought two-way communications with submarines traveling at speed and depth. Current technology offers only one-way communications to deeply submerged boats at low data rates by using towed antennas that significantly constrain maneuvers. However, laser-based communications with submarines offers the promise of two-way communications at speed and depth without maneuver restrictions.

We are striving toward a blue laser efficient enough to make submarine laser communications at depth and speed a near-term reality. This laser will be matched with a special optical filter to form the core of a communications system that could enable a signal-to-noise ratio thousands of times better than other proposed laser systems. If successful, it will meet all the Navy's requirements for submarine communications at depth and speed, dramatically change how submarines communicate, and greatly improve their operations and effectiveness. Submarines could become truly persistent nodes for Network-Centric Operations at sea.

DARPA is building the components needed for the laboratory tests to show that an operational system is worth building. If the components prove out, the next step would be to build an actual prototype system and test it as a joint program with the U.S. Navy.

This thrust also contains our work in cyber security, which I discussed earlier.

<u>Detection, Precision ID, Tracking, and Destruction of Elusive Targets</u>

For many years, the DoD has steadily improved its ability to conduct precision strike against both stationary and moving ground targets. In response, America's adversaries realized that if they are to survive, they have to move, hide, or blend into cluttered environments. U.S.

combatant commanders consistently cite the need for an improved ability to find and track these elusive targets.

To provide a focused response to these challenges, DARPA is assembling sensors, exploitation tools, and battle management systems to rapidly find, track, and destroy irregular forces that operate in difficult terrain. This strategy includes small units operating in mountains, forests, and swamps; ground troops that abandon open country for cities; and insurgents whose whole organization – finance, logistics, weapon fabrication, attack – is embedded in civilian activities.

We must seamlessly layer surveillance and battle management systems using a network of platforms with capable sensors and effective weapons. For example, changes detected between images generated by DARPA's foliage-penetrating radar can be used to engage elusive targets. The radar operates at frequencies that penetrate forest canopy. Algorithms, running either on an aircraft or on the ground, compare images taken at different times to detect changes. Because radars operate in all weather and at long ranges, this technique can discover the location of potential targets over very wide areas.

We successfully demonstrated a foliage penetrating radar that detects vehicles and dismounted troops moving under heavy forest canopy. The radar, called FORESTER, was most recently installed on an A160, DARPA's revolutionary high-altitude, long-endurance, unmanned helicopter. In the initial safety test, the A160 was flown with the FORESTER antenna over various altitudes at various air speeds and antenna orientations, including with the antenna deployed at right angles to the helicopter. Significantly, no degradation in aircraft performance and handling was noted. Further testing shows the electromagnetic compatibility of FORESTER with A160. The development of the A160/FORESTER system is continuing, and we expect to transition the system to USSOCOM during this fiscal year.

To identify targets in response to these cues, DARPA developed ladar sensors that can obtain exquisitely detailed, 3-D imagery. By flying the ladar over a potential target, photons can be collected from many different angles. For example, in our Jigsaw program, photons that pass through gaps between leaves and branches can even be assembled into a composite image. The fully integrated Jigsaw 3-D laser radar system was placed on the nose of a UH-1 helicopter and used to collect 3-D imagery of a wide range of obscured targets. Based on these successful demonstrations, the Jigsaw technology has been transitioned to the Army for continued evaluations, further development, and transition to the warfighter.

For longer distances, DARPA's Standoff Precision Identification in 3-Dimensions (SPI-3D) program is developing a 3-D ladar system to allow commanders to quickly and accurately identify and locate targets at standoff ranges. Flight tests were conducted last June using improved miniaturized components integrated into a Twin Otter airborne testbed. Test sites included both rugged terrain and urban facilities, and the flight data confirmed achievement of the 3-D imaging and location goals.

The Vehicle and Dismount Exploitation Radar (VADER) is a program with the Joint IED Defeat Organization to rapidly create a radar for surveillance and tracking of ground vehicles and dismounts from a Warrior, or similar unmanned aerial vehicle. VADER will provide all-weather detection and localization of vehicles and dismounts at high area coverage rates and will be suitable for urban operations.

VADER conducted its first test flight in April 2008 and successfully produced real-time, high-quality synthetic-aperture radar images and ground moving target indicator data. An exploitation ground system is being developed that will provide state-of-the-art vehicle tracking capabilities, automated intelligent sensor resource management, motion pattern analysis, automated change detection, and advanced dismount signature analysis. Later this year, VADER plans to deliver a radar system suitable for installation and fielding on the Warrior.

This strategic thrust also includes some of our most ambitious work to defeat the threat from improvised explosive devices (IEDs). I cannot say more about this in an open forum.

Urban Area Operations

By 2025, nearly 60 percent of the world's population will live in urban areas, so we must assume that U.S. forces will continue to be deployed to cities. Unstable and lawless urban areas give terrorists sanctuary to recruit, train, and develop asymmetric capabilities, possibly including chemical, biological, and radiological weapons of mass destruction.

Urban area operations can be the most dangerous, costly, and chaotic forms of combat. Cities are filled with buildings, alleys, and interlocking tunnels that provide practically limitless places to hide, store weapons, and maneuver. They are hubs of transportation, information, and commerce, and homes for a nation's financial, political, and cultural institutions. Cities are densely packed with people and their property, creating an environment in which adversaries can mix and use civilians as shields to limit our military options. And insurgents don't just mix in, they *blend* in.

Warfighting technology that works superbly in the open or in the rugged natural terrain of the traditional battlefield is often less effective in cities. By moving into cities, our adversaries hope to limit our advantages, draw more of our troops into combat, inflict greater U.S. casualties, and cause us to make mistakes that harm civilians and neutrals.

The Urban Area Operations thrust is aimed at creating technology to help make U.S. operations in cities as effective as operations elsewhere by seeking new warfare concepts and technologies that would make a smaller U.S. force conducting operations in an urban area more effective, suffer fewer casualties, and inflict less collateral damage.

DARPA has several programs to vastly improve U.S. capabilities to understand what is going on throughout a complex urban environment.

Threats in urban environments pose unique challenges for the warfighter because the most common objects can have tactical significance: trashcans can contain IEDs, doors can conceal snipers, jersey barriers can block troops, rooftops can become landing zones, and so on. The sheer number of potential threats in a city means that a human geospatial analyst cannot possibly examine city-wide imagery and identify all of them in a meaningful time interval.

This is the background to DARPA's Tactical Ground Reporting (TIGR) system, a multimedia information capture/sharing system first used in Iraq in January 2007; it was so successful in Operation Iraqi Freedom, it was requested by brigades going to Afghanistan. TIGR allows small units, like patrols, to easily collect and quickly share "cop-on-the-beat" information about operations, neighborhoods, people, and civil affairs. This highly detailed patrol-level information is crucial to today's fight. Recent tests have shown that TIGR requires very little bandwidth and operates robustly even when there are frequent network disruptions, important considerations for small units operating in remote outposts in Afghanistan.

DARPA's Urban Reasoning and Geospatial Exploitation Technology (URGENT) program has developed a suite of 3-D urban object recognition algorithms to improve situational awareness for the warfighter in urban environments. URGENT algorithms were evaluated by an independent Government team in December and successfully demonstrated fully automated location and labeling of objects in urban scenes. Further, the algorithms' accuracy was equal to human geospatial analysts and more than 10 times faster. URGENT algorithms will be integrated into operational environments starting later this year.

Our UrbanScape system rapidly creates a 3-dimensional model of an urban area that allows the user to navigate and move around in a computer environment much like a video game – but one based on real data. This capability will allow troops to become very familiar with the urban terrain before beginning a mission.

In 2008, DARPA worked with the Army to evaluate and assess the prototype UrbanScape system in a complex operational training environment. Results of the evaluation concluded that the system met or exceeded all the technical objectives. The system successfully collected data for seven continuous hours, automatically processed all the raw collected data, and converted it to fully fused 3-D models that were of exceptional quality and very accurate. As a result, the system was transitioned to the Army.

Moving up from ground level, DARPA is developing ARGUS-IS, a new wide-field-of-view video sensor that significantly increases the number of targets that can be tracked. The sensor will provide more than 65 real-time, high-resolution video windows, *each one* providing motion video comparable to Predator imagery. Each video window is electronically steerable and independent and can either provide continuous imagery of a fixed area on the ground or automatically track a specified target. From a platform at an altitude of 6,000 meters, the system will be capable of imaging an area of greater than 40 square kilometers with a pixel size on the ground of 15 centimeters. Flight testing of ARGUS-IS on a manned helicopter, followed by flight testing on an MQ-9 Unmanned Aerial System, is planned for early 2010.

In the area of command and control, we need ways to control unmanned aerial vehicles (UAVs) so they are efficiently deployed and do not bunch up on one target. Technology from our Heterogeneous Airborne Reconnaissance Team (HART) program simultaneously controls multiple UAVs to conduct autonomous, coordinated area searches, allowing warfighters to stay focused on the fight rather than having to pilot UAVs.

In November 2008, HART controlled multiple platforms performing simultaneous tasks over an infantry brigade combat team-sized area of operations. HART autonomously and simultaneously flew more than 50 UAVs and demonstrated the system's ability to reconnoiter hundreds of kilometers of roadway, support convoys and explosive ordnance disposal teams; provide persistent perimeter surveillance for forward operating bases; and rapidly provide multiplatform, multi-echelon "eyes on" support to troops. The Army is preparing portions of HART's capabilities for use in-theater.

Protecting our warfighters from asymmetric attacks is an ever-present challenge – especially in the close-quarters and congestion of cities. DARPA is developing technologies to counter asymmetric attacks, including suicide bombers and IEDs.

IEDs remain a significant threat to our forces in Iraq and Afghanistan. The jointly-funded DARPA/Army Hardwire program has developed and demonstrated several novel hybrid armor concepts aimed at protecting troops in ground tactical vehicles against armor piercing threats, fragments, IEDs, and explosively formed projectiles. All of these armor systems exploit the high-performance characteristics of low-cost, commercially-available materials, and exceed the performance of currently fielded armor at lighter weights.

One Hardwire composite armor system was integrated and tested on a prototype Family of Medium Tactical Vehicles truck cab. The integrated armor provided modular vehicle protection and saved approximately 20 percent of the armor weight on the vehicle, while significantly increasing the protection.

The DARPA Hardwire initiative provides an industrial infrastructure for development of advanced composite armors, under which Hardwire has successfully responded to a critical surge demand for armor materials. Specifically, working closely with the Army and vehicle manufacturers has resulted in rapid transition and armor procurement contracts for both the Navistar MaxxPro-Plus Mine Resistant Ambushed Protected (MRAP) vehicle and the MaxxPro-DASH MRAP vehicle: 2,243 MaxxPro-Plus vehicles up-armored with Hardwire materials are in theater in Iraq just over two years after the start of the program, and Hardwire is currently producing armor panels for 1,222 advanced IED kits for the MaxxPro-DASH MRAP.

For several years, DARPA's Boomerang system has helped alert ground forces that they are being shot at and from where. On the strength of Boomerang's success, we turned our attention to the air.

Our Helicopter ALert and Threat Termination - Acoustic (HALTT-A) program is developing a system to alert an aircrew of hostile gunfire, and provide the location of the shooter, a caliber estimate, and the trajectories of passing bullets in real time. To-date, five complete live-fire tests have been conducted using different caliber threats in multiple flight regimes and flight profiles including hover and straight and turning flight at speeds between 30 and 150 knots. The most recent test series, conducted in February 2009, included multiple simultaneous shooters and burst fire; the test included over 1600 shots. The HALTT-A system detected 100 percent of the bullets that passed within 100 meters of the test helicopter. One false alarm was experienced. Significantly, no false alarms have been generated by outgoing fire.

There are many dimensions to operating in the complex urban theater that make training very difficult. To improve that training, DARPA's RealWorld program will let U.S. troops rehearse missions using a laptop on which they can build their own mission simulations quickly and easily. They will be able to build simulations, without programmers, saving a tremendous amount of time, money, and manpower while getting better tailored simulations.

Hundreds of beta copies of RealWorld have been distributed within DoD and to other Federal agencies. It is being widely evaluated, including in theater, and is being used to train all U.S. Air Force electronic warfare officers and A-10C pilots. RealWorld is used in the Marine Corps' Infantry Immersion Trainer, by the Defense Threat Reduction Agency for chem-bio dispersion simulation, and by the Air Force for UAV simulations. RealWorld technology is being used in a SEAL Delivery Vehicle trainer and an AC-130 sensor operator station trainer.

Advanced Manned and Unmanned Systems

DARPA has worked for many years toward a vision of a strategic and tactical battlespace filled with networked manned and unmanned air, ground, and maritime systems. Unmanned systems provide capabilities that free Soldiers, Sailors, Airmen, and Marines from the dull, dirty, and dangerous missions that might be better done robotically, and they enable entirely new design concepts unlimited by human crews.

Our efforts have been focused in two areas: DARPA seeks to improve individual platforms so they provide new or improved capabilities, such as unprecedented endurance or survivability. In addition, DARPA is expanding the autonomy and robustness of robotic systems by more tightly networking manned and unmanned systems to improve our knowledge of the battlespace, enhance our targeting speed and accuracy, increase survivability, and allow greater mission flexibility.

Our A160 program has been developing an unmanned helicopter for intelligence, surveillance, and reconnaissance (ISR) missions, with long endurance – up to 20 hours – and the ability to hover at high altitudes. In 2008, the A160 set a world record for UAV endurance when it completed an 18.7-hour endurance flight, carrying a 300-pound payload, much of the time at 15,000 feet. The A160 will eventually fly at speeds up to 165 knots with a ceiling of 20,000 to 30,000 feet altitude for more than 20 hours, and a high hover capability of up to 15,000 feet altitude. The altitude and endurance of this UAV, combined with the ability to hover at altitude and take off and land vertically with a significant payload, will give our military a set of capabilities not currently found in any other operational aircraft.

In the past, we described the Wasp micro air vehicle, a squad-level surveillance and reconnaissance asset that enables small units to quickly see their local terrain from above. Wasp gained the distinction of being the first micro air vehicle (MAV) to be adopted by our forces in an acquisition program, the Air Force's Battlefield Air Targeting Micro Air Vehicle. Based on Wasp, DARPA's Stealthy, Persistent, Perch and Stare program is creating an entirely new generation of perch-and-stare MAVs that can fly to difficult targets, land, perch, conduct sustained surveillance, and return home.

The Micro Air Vehicle (MAV) Advanced Concept Technology Demonstration (ACTD) program developed a back-packable, easy-to-operate, affordable reconnaissance and surveillance system organic to and operated by platoon-sized units. The MAV is capable of vertical takeoff and landing, allowing it to be deployed from nearly anywhere. It provides hover-and-stare capability and can effectively monitor a 10-kilometer area, remaining in the air for approximately 40 minutes at density altitudes in excess of 7,000 feet. The system provides still images and full motion video from a gimbaled camera in either visible band or infrared for day and night. As part of the Joint Explosive Ordnance Disposal Taskforce (J-EOD), the Navy has been testing 10 MAV systems (20 aircraft) in theater since 2007. Based on the success of that testing, the Navy recently issued a contract to procure 90 systems for use by EOD teams in theater. Delivery of these units is expected later this year.

Just as air vehicles have moved toward increased mission complexity and increased environmental complexity, DARPA is trying to increase both the mission and environmental complexity for autonomous ground vehicles.

The Unmanned Ground Combat Vehicle – Perception for Off-Road Robotics (PerceptOR) – Integration (UPI) program demonstrated an unmanned ground vehicle (UGV) capability by putting perception and the use of terrain data for path planning on an extremely capable robotic vehicle. DARPA has begun to transition this technology to the Army and provided a prototype ground vehicle with PerceptOR vehicle control algorithms and software to the Army Tank-Automotive Research, Development and Engineering Center to use in developing a UGV control architecture and conducting vehicle design and control risk mitigation activities for Future Combat Systems (FCS) UGVs. UPI's perception and planning control and sensor algorithm suite has been transitioned to the FCS Autonomous Navigation Sensor program, the technology has been used in NASA's Mars Rover, and is being integrated into mining trucks.

DARPA held a series of prize competitions in 2004-2007 to promote the development of autonomous ground vehicles. The final event, the Urban Challenge, used what we had learned in the two open desert Grand Challenges to lay out a far more difficult challenge: autonomous ground vehicles driving at-speed in urban traffic, obeying driving rules and regulations, and interacting with other manned and unmanned vehicles, maneuvering in a mock city on simulated military supply missions.

Last November, the National Museum of American History added a display on autonomous ground vehicles, one that features the winner of our 2005 Grand Challenge, "Stanley," and one of the most innovative entrants we had, an unmanned motorcycle called "Ghostrider." The display is well done, and I encourage you to visit it and see what this committee and others in Congress helped make happen. Getting an achievement into the Smithsonian is a signature achievement for any scientist or engineer, and we are very proud to have it there.

Detection, Characterization, and Assessment of Underground Structures

Our adversaries are well aware of the U.S. military's sophisticated intelligence, surveillance, and reconnaissance and global strike capabilities. In response, they have been building deeply buried underground facilities to hide and protect various activities.

These facilities range from caves to complex and carefully engineered bunkers in both rural and urban environments. They can be used for a variety of purposes, including protecting leadership, command and control, hiding artillery and ballistic missiles launchers, and possibly producing and storing weapons of mass destruction.

To meet the challenge posed by these facilities, DARPA is developing a variety of sensor technologies and systems – seismic, acoustic, electromagnetic, optical, and chemical – to find, characterize, and conduct post-strike assessments of underground facilities.

Our program is working on tools to answer the questions, "Where is the facility? What is this facility's function? What is the pace and schedule of its activities? What are its layout, construction, and vulnerabilities? How might it be attacked? Did an attack destroy or disable the facility?"

To answer these and other questions, DARPA is developing ground and airborne sensor systems with two-orders-of-magnitude improvement in sensor system performance, with emphasis on advanced signal processing for clutter rejection in complex environments.

Space

DARPA began as a space agency, when the shock of Sputnik caused Americans to believe the Soviet Union had seized "the ultimate high ground." DARPA's ambitious efforts are aimed at ensuring the U.S. military stays preeminent in space.

DARPA's space strategic thrust has five elements:

- Access and Infrastructure: technology to provide rapid, affordable access to space and efficient on-orbit operations;
- Situational Awareness: the means for knowing what else is in space and what it is doing;
- Space Mission Protection: methods for protecting U.S. space assets from harm;
- Space Mission Denial: technologies that will prevent our adversaries from using space to harm the U.S. or its allies; and
- Space-Based Support to the Warfighter: reconnaissance, surveillance, communications, and navigation to support military operations down on earth – extending what the United States does so well today.

The Falcon program is working to vastly improve the our capability to promptly reach other points on the globe by developing technologies for long-duration hypersonic flight. The program recently fabricated and tested a prototype carbon-carbon aeroshell, a key technology for future hypersonic vehicles. Falcon's aeroshell is both the thickest carbon-carbon laminate and the largest complex carbon-carbon shape ever made, an achievement that required breakthroughs in carbon-carbon processes and advanced nondestructive evaluation and inspection techniques.

The Space Surveillance Telescope (SST) program will demonstrate rapid, uncued search, detection and tracking of faint, deep-space objects, such as small, potentially hazardous debris objects and future generations of small satellites. SST's novel wide-field-of-view, rapidly scannable, three-mirror, 3.6-meter telescope design is the first to make use of recent advances in curved focal plane technology. The program is completing final assembly, polishing, and testing of subsystems, and components. Onsite integration of subsystems and components will begin this summer, with "first light" expected next year.

The Integrated Sensor is Structure (ISIS) program is developing a stratospheric, airship-based, autonomous, unmanned sensor offering years of persistence in surveillance and tracking of air and ground targets. ISIS will have the capability to track the most advanced cruise missiles at 600 kilometers and dismounts at 300 kilometers. It uses a large aperture instead of high power to meet radar performance requirements, making it the most powerful moving target indicator radar ever conceived.

The enormous size of ISIS requires that we develop an advanced, ultra-low-weight hull material that is flexible and structural and can incorporate the platform's electronic sensors. DARPA's researchers began with ultra high molecular weight polyethylene fibers and overcame materials and fabrication limitations to produce a breakthrough composite laminate hull material that is robust and significantly lighter than materials currently used in lighter-than-air vehicles.

Combined with other key advances in the airship power system and radar antenna and components, the stage is now set for building a scaled demonstrator of ISIS. DARPA has signed a memorandum of agreement with the Air Force to jointly fund the demonstration phase of the program, which will culminate in a year-long flight of a one-third scale ISIS system.

Increasing the Tooth-to-Tail Ratio

Today's forces require an extensive support infrastructure that is growing even larger. The military sometimes describes the proportion of forces in actual contact with the enemy to the supporting forces as the tooth-to-tail ratio. Improved information technology can reduce the layers and amount of infrastructure (the "tail") needed to operate the computers, software applications, and networks that support fighting forces (the "tooth"). The fundamental goal of this thrust is to get more of our forces into the fight.

The major themes of this strategic thrust are:

- Cognitive Computing – reducing manpower by providing information systems that "know what they are doing" and whose functionality improves through user interactions;
- High Productivity Computing Systems – speeding up the development and deployment of new weapon systems by more complete and rapid design and testing; and
- Language Processing – improving our global operations by removing language and cultural barriers through superb machine language translation, thereby reducing the need for human translators and improving our local knowledge and interactions with the local population.

Cognitive Computing

Computer systems are essential to military logistics and planning, command and control, and battlefield operations. However, as computing systems have become pervasive in DoD, they have also become increasingly more complex, fragile, vulnerable to attack, and difficult to maintain. The computing challenges facing DoD in the future – autonomous platforms that behave reliably without constant human intervention, intelligence systems that effectively integrate and interpret massive sensor streams, and decision support systems that can adapt rapidly – will depend on creating more flexible, competent, and autonomous software.

Today's computers handle low-level processing of large amounts of raw data and numeric computations extremely well. However, they perform poorly when trying to turn raw data into high-level actionable information because they lack the capabilities we call "reasoning," "interpretation," and "judgment." Without learning through experience or instruction, our systems will remain manpower-intensive and prone to repeat mistakes, and their performance will not improve. DoD needs computer systems that can behave like experienced executive assistants, while retain their ability to process data like today's computational machines.

The Personalized Assistant that Learns (PAL) program is developing integrated cognitive systems to act as personalized, executive-style assistants to military commanders and decision-makers. PAL is creating a new generation of machine-learning technology so information systems automatically adjust to new environments and users, help commanders maintain battle rhythm, and adapt to new enemy tactics, evolving situations and priorities. The program will help new personnel be effective more quickly in command operations, while making more effective use of resources.

PAL technologies are being used by the Army's Command Post of the Future (CPOF) to amplify the capabilities of overworked combat command and control staffs. Working with CPOF, PAL learns significant battlefield activities; organizes and locates them on maps, and helps users collect information, plan, and execute operations. Evaluations at the Army Battle Command Battle Lab (BCBL) were highly successful: In a head-to-head evaluation, a PAL-enhanced CPOF prototype strongly outperformed the existing manually controlled CPOF.

PAL technology has been integrated and deployed on the situational awareness network of a unified command to facilitate the sharing of intelligence, enabling analysts and decision-makers to stay abreast of events unfolding throughout the world in real time. PAL technology is also helping get the right information to the right people at three military websites – one for platoons, one for companies, and one for military families.

PAL technology is used at a major military hospital center to automate and streamline patient booking. Hospital receptionists, not programmers, will teach PAL tasks such as finding appointments, making referrals, booking appointments with doctors based on referrals, adding notes, and sending reminder notices by demonstrating how to perform each task. By combining new information with prior knowledge and a concrete demonstration by the user, PAL will "learn" complex tasks in a single brief training session.

High Productivity Computing Systems

The High Productivity Computing Systems program is pursuing economically viable, high productivity supercomputing systems. The major goal is to produce extremely high performance computing systems that can be easily programmed and used by experts and nonexperts alike. These innovative systems will emphasize programmability, portability, scalability, and robustness as well as high performance goals of achieving multiple petaflops and thousands of global updates of memory per second.

The program continues to make progress. Key hardware components are fabricated and being tested, and software from the program is beginning to make its way into some of the latest, most high performance products. The program will culminate in prototype demonstrations that will begin at the end of 2010.

Language Processing

Real-time language translation technology will help U.S. forces better understand adversaries and the overall social and political contexts of the operational areas. This enhanced awareness will decrease costly mistakes due to misunderstandings and improve our chances of success.

Today, linguists translate important information, but it is a slow and arduous process. Massive amounts of raw data are collected, but there are not enough linguists to handle it. To deal with the volume of data, we must dramatically reduce the reliance on linguists at both the strategic and tactical levels by using revolutionary machine translation capabilities.

At the strategic level, the goal of the Global Autonomous Language Exploitation (GALE) program is to translate and distill foreign language material (e.g., television shows and newspapers) in near-real-time, highlight the salient information, and store the results in a searchable database. Through this process, GALE will produce high-quality answers to the questions that are normally provided by bilingual intelligence analysts. GALE is making progress toward achieving this very ambitious goal by 2011.

Currently, GALE performance for newswire is 90 percent of the documents exceed 87 percent accuracy, while for web logs and news groups, 85 percent of the documents exceed 84 percent accuracy. For broadcast news, 85 percent of the documents exceed 85.6 percent accuracy, and for broadcast talk shows 75 percent of the documents exceed 84 percent accuracy.

But the real proof of GALE's value is that it is being used today. A Special Forces unit is using GALE technology to translate Arabic television broadcasts and other sources in Iraq. Users watch Arabic television while GALE provides synchronous English translation. They then search through transcripts and translations of video from multiple channels. Synchronization among the video, Arabic text, and highlighted English translation allows for easier and more timely identification of relevant information.

At the tactical level, there are not enough translators for each patrol or checkpoint. Our warfighters need automatic, on-the-spot speech translation to take advantage of what they may be told by locals and to train or conduct missions with Iraqi units. DARPA's Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program is working on two-way speech translation to convert spoken foreign language input to English output and vice versa. TRANSTAC works on basic questions and answers about people, medical screening, civil affairs, and force protection.

DARPA's first Iraqi Arabic speech translation system was prototyped in 2006 and has undergone rapid enhancements. In March 2008, the Marines successfully trained with TRANSTAC prototypes during exercises with Iraqi Arabic speakers covering such scenarios as vehicle check points, census collections, home searches, and civil affairs meetings.

Bio-Revolution

DARPA's strategic thrust in the life sciences, called Bio-Revolution, is a comprehensive effort to harness the insights and advances of modern biology to make U.S. warfighters and their equipment safer and more effective.

The Bio-Revolution thrust has four broad elements.

Protecting Human Assets

Advances in biological warfare defense (BWD) should protect warfighters not only from traditional and modern biowarfare agents, but also from the infectious diseases they regularly encounter overseas.

Developing defenses against biological attack poses daunting problems. Strategies using today's technologies to counter future biological threats are seriously limited. From the moment a new pathogen is first identified, today's technology requires at least 15 years to discover, develop, and manufacture large quantities of an effective therapy. Since it is nearly impossible to predict what threats might emerge in 2 decades, particularly engineered threats, it would be exorbitantly costly to attempt to "cover the bases" with the research and development required to deal with a wide range of potential threats, and then stockpile, maintain, and indefinitely renew population-significant quantities of vaccines or other therapeutics just in case one or more of those threats might emerge. And if, in spite of all this, a previously unknown or unpredicted pathogen does appear, there may well be no effective therapeutics available.

DARPA has been seeking to change the stockpiling paradigm by creating technologies to shrink the time from when a pathogen first appears to the production of millions of doses of effective therapeutics from today's 15 years to *16 weeks or less*. This plan includes work to identify and characterize pathogens, boost the effectiveness of vaccines, and find and design new therapeutics that are effective against an extremely broad array of pathogens.

Central to this vision, DARPA's Accelerated Manufacturing of Pharmaceuticals (AMP) program is producing technology for large-scale, rapid manufacturing of therapeutics and vaccines. Instead of the years required to ramp up today's manufacturing practices, AMP technologies will combine high-speed, natural biological production systems, such as fungi, plants, and mushrooms, with powerful enabling technologies such as flexible bioreactor systems and automated growth processes and enable rapid and inexpensive manufacture of millions of doses of life-saving drugs or vaccines, at unprecedented scale, in a matter of weeks.

The AMP program advanced the fungal approach to demonstrate an emergency capability for production of monoclonal antibodies at less than $10 per dose, approximately 1/100 the cost of current production methods.

In the case of plants, DARPA demonstrated that a hydroponic growth rack, roughly 14 feet by 10 feet by 10 feet tall, can yield sufficient protein for at least 1 million vaccine doses – replacing 3 million chicken eggs as a growth medium. This technology is readily scalable to 3+million dose capacity: the seed stocks are easily stored and, within 6 weeks of seeding, the plant-generated vaccine materials can be harvested for purification. This approach has also demonstrated the capability to produce vaccines that cannot be produced using current egg-based methods, such as a vaccine against a strain of avian flu that cannot be produced by traditional means because, not surprisingly, it kills the eggs. Work has begun on a large-scale, automated Good Manufacturing Practice vaccine production facility based on this technology.

We also made great progress in demonstrating that a third approach based on the common button mushroom, like the ones you buy in the grocery store, could be used to produce viable proteins, such as human monoclonal antibodies and vaccines. This approach offers the prospect that today's automated commercial mushroom farming practices can be combined with current protein expression technologies to produce massive doses of protein therapies and vaccines at comparatively low cost.

"Protecting human assets" also means doing everything we can to greatly improve the chances of our wounded forces surviving battlefield injury. Hemorrhage continues to be the leading cause of death from combat injuries on the battlefield, accounting for about 50 percent of fatalities. To extend the time available for evacuation, triage, and supportive therapies, DARPA's Surviving Blood Loss (SBL) program is developing novel strategies to delay the onset of hemorrhagic shock due to blood loss by extending the "golden hour" after severe trauma, during which successful treatment is possible, to 6-10 hours, or more. SBL is working to understand how the body's energy production, metabolism, and oxygen use is controlled and to identify protective mechanisms to preserve cellular function despite low oxygen caused by blood loss.

SBL identified two very promising therapeutics -- hydrogen sulfide and estrogen -- that, in large animal tests, extended survival from potentially lethal hemorrhage to more than 3 hours without requiring resuscitative fluids. Human safety trials for the hydrogen sulfide treatment are proceeding: one clinical study on the toxicology has been completed, and a second clinical study on dosing is underway. Our commercial partners in the estrogen-based countermeasures are preparing designs for clinical trials.

DARPA's PREventing Violent Explosive Neurological Trauma (PREVENT) program seeks to analyze and build understanding of blast-induced traumatic brain injury (TBI) so as to be able to better treat and prevent TBI. PREVENT's systematic study evaluated the nature of physiological injury on animal surrogates exposed to increasing blast levels both in the open and in confined spaces that mimic conditions in an armored vehicle. Early evidence shows that low level of blast in animals does not lead to TBI. At the other end, very high blast levels can directly cause severe TBI including gross tissue damage, vasospasm and death.

At moderate blast levels, however, the results appear more important. At those levels, there is little evidence of direct blast-induced destruction of brain neurons. But in the acute phase, there is significant inflammation of intercellular tissue around the neurons, which persists for days to weeks. When untreated, this inflammation is found to eventually lead to degeneration of brain fiber tracts. The mechanism for this degeneration appears to be disruption of the extracellular matrix and not the brain cells themselves. This discovery, if confirmed, suggests the possibility that by treating people for inflammation after moderate blasts, perhaps even with over-the-counter medicines, we may be able to prevent long-term TBI in some cases. At this point in our investigations this is just a possibility, not a known solution, but our discovery of the potential role of inflammation in TBI could be very important if confirmed.

PREVENT has also sponsored studies of Marine breachers in training. It was found through brain imaging scans (MRI) and neurobehavior testing that, even though these Marines are exposed to up to 70 explosive blasts over a two week training period, there was no evidence of brain injury. However, one surprising finding was elevated levels of lead in their blood, although still within OSHA approved levels. While the levels alone were not high enough to cause neurological damage, other tests suggest that when an electromagnetic burst, such as can be caused by some IEDs, occurs in the presence elevated levels of lead, neurons can function abnormally and degenerate. It should be noted that in training, the breachers do not use explosives that emit electromagnetic bursts. These investigations suggest there could be multiple and synergistic factors in the creation of TBI.

In Phase 2 of PREVENT, treatment and mitigation strategies will be developed based on these new insights.

Biology to Enhance Military Systems

DARPA is creating new systems by developing materials, processes, and devices inspired by living systems. The idea is to let nature be a guide toward better engineering.

For example, our brain is among the finest processors of visual imagery of which we are aware. No inanimate machine yet devised comes close to the brain at visual pattern recognition. DARPA's Neurotechnology for Intelligence Analysts (NIA) program seeks ways to harness this unique capability of the brain to vastly improve the productivity of our imagery analysts so they can spend more time on actual analysis.

In the current phase of NIA, researchers are testing increasingly complex imagery in a variety of modalities. Additional tests with imagery analysts confirmed findings from the initial observations, and pilot experiments investigating differences associated with target complexity and alternative chip presentations are underway to further improve this technology.

On the ground, today's U.S. infantry squads must carry large loads, in many cases more than 100 pounds per soldier, into remote areas inaccessible to traditional wheeled or tracked vehicles. DARPA's Big Dog program developed a walking robotic "mule" to travel with dismounted infantry carrying supplies. Big Dog proved the basics of quadruped control and terrain negotiation, culminating in two 250-pound prototypes. In joint DARPA-Marine Corps experiments, Big Dog repeatedly negotiated a difficult 200-meter section of a Marine infantry training course carrying an 80-pound mortar system. The robot demonstrated its endurance by autonomously following Marines on a trail for 7.8 miles in 3 hours and autonomously navigating along waypoints provided by a mission planning unit.

Maintaining Human Combat Performance

We train our warfighters to be in peak condition when deployed, despite extreme battlefield environmental stresses such as heat and altitude acclimatization, prolonged physical exertion, and sleep deprivation. DARPA is working to maintain the warfighter's physical and cognitive performance once they are deployed.

The Peak Soldier Performance program is developing technologies to maintain optimal warfighter performance, despite the stressors of combat. This program's past achievements include the simple, novel "cooling glove" technology that can both cool troops who have become overheated and warm those who have become chilled.

In 2008, Peak Soldier Performance researchers identified that calcium leaking into muscle cells was a major cause of muscle fatigue, contributing to muscle damage and inflammation – negative effects that can last for weeks. This research also demonstrated that a novel drug, S107, which prevents calcium leakage, limits muscle fatigue in mice. S107 may enable the warfighter to perform at peak levels without the fatigue related muscle damage normally associated with extended missions.

Restoring Combat Capabilities after Severe Injury

Beyond the obligation to care for our troops when they are injured, a longer-term obligation is to do the best we can to rehabilitate them. DARPA's goal is to return wounded warriors, as best we can, to who they were before they were injured.

Improvements in body armor and medical care increase the chances of survival, but also lead to more limb amputations. While current prosthetic leg technology is good and is advancing, prosthetic arm technology, involving so many more joints and complex movements, as well as the combined abilities to touch, sense, and manipulate fine objects, is much more challenging.

The ultimate vision of our flagship program, Revolutionizing Prosthetics, is to utterly transform upper extremity prosthetics, specifically arms and hands. Our goal is to develop a prosthetic arm that can be controlled directly by the brain and provide the manual dexterity and sensation feedback approaching that of a natural hand or arm.

We are making rapid progress. Clinical and home trials will soon begin at two Veterans Affairs clinics with an intermediate-stage prototype arm. While not neurally controlled and having less capability than the ultimate goal, this prototype is already the best in the world and, because of its modular design and flexible control, is meeting the needs for a variety of amputees. After only a few hours of training, patients display a range of function far beyond that of even the best conventional prosthetics, including field stripping, reassembly, and firing an M16; opening doors; eating soup; and even reaching above their head, grabbing a bottle, and opening it with a bottle opener. This prototype weighs only 8 pounds, has 10 powered degrees of freedom, and nearly 11 hours of battery life. The device can provide afferent feedback so the amputee can sense pressure applied to an object.

For patients who do not need or want a neurally controlled prosthetic, this prototype could provide a significant improvement in function over currently available commercial devices. The prototype has been evaluated in six patients with more than 500 hours of use and is entering advanced clinical trials with anticipation of full manufacture, marketing, and delivery to combat amputees.

The next phase of the program will demonstrate the use of an implanted wireless chip to enable full brain or peripheral control of the prosthetic. By comparison, these chips are smaller and use less power than the implanted heart pacemakers in use by millions of people around the world. Early investigations with wired devices and ongoing experiments with wireless devices demonstrate the feasibility of using wireless signals from the brain and peripheral nerve to control a prosthetic arm. If the goals of the program are fully achieved, the prosthetic arm will mimic the response of the original natural arm. DARPA expects submission for FDA approval of this prosthetic in early 2010.

Core Technologies

While our strategic thrusts are strongly driven by national security threats and opportunities, a major portion of our research is largely independent of current circumstances. These investments in fundamentally new core technologies historically have been the technological feedstocks for new systems.

Quantum Science and Technology

Until recently, quantum effects in electronic devices have not had overriding significance. As devices shrink to near atomic dimensions, quantum effects not only have to be taken into account, but can dominate device performance. DARPA is sponsoring research aimed at technology that actually exploits these quantum effects to achieve revolutionary new capabilities.

The Quantum Entanglement Science and Technology (QuEST) program is (1) creating new quantum information science technologies, focusing on overcoming the loss of information due to quantum decoherence and limited communication distance due to signal attenuation, and (2) developing protocols and techniques for exploiting larger numbers of quantum bits (qubits) and their entanglement.

Bio-Info-Micro

For the past several years, DARPA has exploited and developed the synergies among biology, information technology, and micro- and nanotechnology. Advances in one area often benefit the others, and bringing together the science and technology from these three areas produces new insights and new capabilities.

The Fundamental Laws of Biology (FunBio) program is working to discover the fundamental laws that govern biological behavior on multiple, interconnected scales – from molecule to cell to organism to population – and to show that such laws can be used to make accurate predictions about biological processes, just as physical theory enables predictions about processes in the inanimate world.

The program has delivered results of enormous potential benefit. New models of viral and bacterial evolution are providing insight into how those organisms leverage genetic variation to escape the body's immune system and will guide the development of new treatments for disease. Other models explain how cyclic growth patterns in plants and animals link gene expression with structural development and provide a deeper understanding of tissue generation. Novel analytical techniques provide insight into new ways of diagnosing congestive heart failure. Underlying all these discoveries is an emerging picture: Environmental pressure, under the right set of biological conditions, forces a spontaneous and quantifiable change in biological organization. The mathematical expression of this principle will be a key insight toward unlocking a unified, predictive, theoretical foundation for biology.

Materials

DARPA continues to maintain a robust materials research program. Its approach is to push new materials opportunities and discoveries that might change how the military operates. DARPA's current programs in material science are focused on the following areas:

- Structural Materials and Components: low-cost and ultra-lightweight materials designed for structures or to accomplish multiple performance objectives in a single system;

- Functional Materials: advanced materials for nonstructural applications such as electronics, photonics, magnetics, and sensors; and
- Smart Materials and Structures: materials that can sense and respond to their environment.

The Prognosis program is developing the science and technology to revolutionize the maintenance of turbine engines and aircraft. The idea is to perform preventive maintenance when physics predicts it is actually required, rather than according to a schedule. The program recently completed tests on a retired outer wing panel from an EA-6B naval aircraft. Predictions made by Prognosis technology correctly identified the actual crack sizes found during post-test teardown. The test validated Prognosis as a management tool for both legacy and new aircraft. Prognosis technology shows that, using the same risk criteria, the aircraft's flight capability was more than 60 percent longer than prescribed by the Navy's original Fatigue Life Expended retirement strategy.

Power and Energy

Developing portable, efficient, and compact power supplies has important ramifications for increasing our military's reach, decreasing our logistics burden, and improving the overall efficiency of our warfighting forces – especially for distributed and net-centric operations.

Our BioFuels program is developing an affordable surrogate for military jet fuel (JP-8) derived from oil-rich crops, such as canola, to reduce the military's reliance on petroleum-based fuels to power aircraft, ground vehicles, and ships. A modified version of the process has been successfully scaled up and produced more than 6,000 gallons of fuel for engine certification for aircraft. Eventually much larger capacity facilities will be needed.

The Bio-Fuels program also is investigating using short chain oils, say from biomass waste, that must be "stitched up" to create JP-8. Having an efficient process for doing so is a key technical challenge. We have made progress here as well, producing small quantities of fuel that meet some of the most important JP-8 requirements like energy content, flash point, and freeze point.

The newest development in the program is a concerted look at algae-based ("algal") fuels. Nonedible feedstocks like algae promise to reduce biofuel's price pressure on food by using nonagricultural land. The great advantage of algal fuels for JP-8 is the extremely large potential yield per acre. This work is in its early stages.

As electronic devices continue to shrink in size, their application in small autonomous networks and miniature robotics become limited by the size of the power source. Conventional batteries lose energy density as they lose volume due to the current packaging schemes. The Micro Power Sources program is working to overcome this constraint to produce cubic-millimeter-sized batteries by exploiting advances in battery chemistries and new architectures to maintain and increase energy densities. DARPA researchers demonstrated a 0.77-cubic millimeter microbattery with an integrated silicon photovoltaic having an energy density greater than 300 watt-hours per liter, compared to conventional batteries with approximately 350 watt-hours per liter packaged in cells many orders of magnitude larger, and a power density greater than 200 watts per liter. Our goal is to produce a battery more than 1,000 times smaller than today's lithium-ion cells – less than one cubic millimeter – with comparable energy density.

Microsystems

DARPA is shrinking ever-more-complex systems into chip-scale packages, integrating microelectronics, photonics, and microelectromechanical systems (MEMS) into "systems-on-a-chip" that have new capabilities. It is at the intersection of these three core information age hardware technologies where some of the greatest opportunities for DoD applications arise. By integrating elements from these core technologies with advanced architectures and algorithms, bulky existing systems can be reduced to sugar-cube size, and completely new capabilities can be developed.

DARPA is also exploiting advances in nanoscience and nanotechnology, where matter is manipulated at the atomic scale to enable still-more-complex capabilities in ever smaller and lower-power packages. The vision includes adaptable microsystems for enhanced radio frequency and optical sensing; more versatile signal processors for extracting minute signals in the presence of overwhelming noise and intense enemy jamming; high-performance communication links with assured bandwidth; and intelligent chips that allow a user to convert data into actionable information in near-real-time.

Together, these capabilities will create information superiority for our forces by improving their ability to collect, process, manage, and act on information – with the ultimate goal of enabling U.S. forces to think and react more quickly than the enemy in a rapidly changing battlespace.

Microelectronics

DARPA is tackling one of the most important roadblocks to increasing chip performance: heat dissipation. As transistor size decreases, their number and chip-clock frequency increases, causing waste heat generation to rise sharply. Today, some chips dissipate as much heat per square inch as a hotplate, with the result that chip-clock speeds cannot increase further. The long-term consequences threaten to break Moore's Law of continued performance improvement through transistor scaling and increasing clock speed.

DARPA is pursuing ways to push through the heat dissipation roadblock. An entirely new type of transistor, called a "tunneling transistor," is being investigated. This approach would operate devices at lower voltages – ¼ volt instead of today's 1 volt – and thereby greatly reduce heat generation, which is proportional to the square of the voltage. Efforts are underway to further reduce the heat dissipated in standby mode – when a transistor is nominally "off" – by using nanoelectromechanical switches to physically disconnect, or unplug a transistor when it is turned off, preventing leakage current that generates waste heat. Researchers also are working to reduce the heat generated in the wires connecting active devices within a chip by replacing longer metal wires with optical interconnects, which generate far less heat and greatly improve data transfer speed.

In addition to our work to reduce the amount of heat produced, we are working on new ways to better manage the heat that is produced. To that end, we have programs to better extract the heat, starting at the scale of individual devices, extending to transporting heat out of the chip with improved substrates, and even improving air cooling of systems.

In the longer term, nonsilicon electronics will play an increasing role in the advance of microelectronics. Alternatives to traditional silicon chips can provide key advantages to military systems, including greatly enhanced operating speeds, the ability to handle enormous power loads, or dramatically reducing power consumption.

DARPA's wide bandgap semiconductor research demonstrated transistors that offer speed and power performance far exceeding silicon devices. Gallium nitride devices promise much greater performance for radars. However, up to now, difficulty in producing high quality material has caused major reliability problems. Three years ago, gallium nitride-based microwave power transistors had lifetimes measured in minutes. Today, thanks to advances in our Wide Band Gap Semiconductors for Radio Frequency Applications program, transistor lifetimes have been extended to more than 100,000 hours. The program's dramatic success in meeting its reliability goals in a manufacturable process paved the way to rapidly transition the technology to multiple military systems, including electronic warfare/electronic attack transmitters, missile defense sensors, and Navy radars.

Photonics

Increasingly, light is used to move vast amounts of information between computers. DARPA has pioneered development of photonic components, such as optical wavelength converters, optical switches, optical waveform generators, and optical buffers, under the Data in the Optical Domain Network (DOD-N) program. DOD-N has, for the first time, shown a path to an optical network that eliminates electrical-to-optical-to-electrical data conversion at each data router, increasing the projected network data throughput by over a factor of 10.

DOD-N has had many successes, including the world's first optical random access memory that enables random access storage of optical data packets; highly scalable, multiple wavelength lasers with fast tuning speeds and small footprints; mode-locked lasers that enable retiming, reshaping, and reamplification of optical signals; and the world's highest functional component count photonic integrated circuit (PIC) – a monolithically integrated CMOS/photonic chip that realizes a compact, low-power, tunable optical router with 640 gigabits per second throughput. Combined with new network management strategies that dramatically reduce the amount of buffer memory required at each network node, DOD-N will enable new optical networks that can meet the growing DoD need for bandwidth, while minimizing latency.

Analog to digital (A/D) conversion technology has been around for a long time, but is bandwidth-limited and consumes large amounts of power. Defense applications demanding higher A/D bandwidth include signals intelligence, the need to capture and study large bandwidths of communications and radar signals, and the growing bottleneck in high bit-rate communications networks at the interface between radio frequency (RF) broadcasts and Internet optical digital signals. Our Photonic Bandwidth Compression for Instantaneous Wideband A/D Conversion (PHOBIAC) program uses a novel, efficient mode-locked laser with ultra-low jitter to advance A/D conversion technology with high capture quality and large bandwidth. PHOBIAC promises to meet the power consumption requirements of many users, while providing 40 times greater bandwidth than today's A/D converters.

Advanced photonic technology is also having a dramatic impact on meeting the low-noise and high dynamic range demands of RF signal processing. Our Linear Photonic RF Front-End Technology (PHOR-FRONT) program is developing the critical, high-fidelity components for a universal photonic RF front end module: a highly stable, high power, low noise, and narrow linewidth laser used to convert the RF signal to a phase-modulated optical signal; and a highly linear, optical phase demodulator that converts the optical signal back to RF. PHOR-FRONT pursued two independent laser designs, resulting in dramatic progress in the laser module development. Both designs show great promise for a wide range of Defense applications that have stringent laser requirements, such as RF photonic links, coherent ladar, acoustic sensors, and advanced optical communications.

Microelectromechanical Systems (MEMS)

Miniaturizing mechanical, thermal, and chemical devices can yield dramatic increases in performance versus their conventional, bulky counterparts. Microscale chemical and biological sensors are being developed that yield higher performance at lower power, as seen in faster response times, lower false alarm rates, and higher probability of detection. The Micro Gas Analyzer program is shrinking a lab bench of equipment for analysis of toxic chemicals down to a few cubic centimeters, allowing for person- or UAV-carried systems that will revolutionize our awareness of the chemical and biological battlespaces.

Combined Systems-on-a-Chip

The Navigation-Grade MEMS Inertial Measurement Unit program is developing tiny, low-power, navigation sensors capable of achieving performance comparable to Global Positioning Satellite (GPS) in settings where GPS is unavailable (e.g., caves and underwater) or denied by an enemy. This capability will enable precision navigation of small platforms, including individual troops, unmanned air vehicles, unmanned underwater vehicles, and even tiny robots. The program will revolutionize our ability to navigate in places we never could before and in places where adversaries would deny GPS, bringing the equivalent of hundreds of pounds of precision equipment down to systems that fit in a wristwatch.

Information Technology

DARPA's work in information technology is closely intertwined with its strategic thrust in Increasing the Tooth-to-Tail Ratio. It is a core technology that supports advanced military capabilities in the post-2010 timeframe with processing performance in excess of 1 quintillion (10^{18}) operations per second. A challenge we face is creating the tools needed to write applications (software) more quickly and effectively for these extremely high performance machines.

DARPA's Computer Science Study Group (CSSG) program selects a group of extremely talented early-career academic computer scientists for a program that combines support for their current innovative research with educating them on DoD's needs. CSSG challenges them to use the knowledge gained to compete for grants of up to $500,000 to conduct basic research of interest to DoD. Each group is typically about a dozen academics who obtain Secret security clearances and learn about DoD and its challenges.

CSSG performers interact with several military organizations in such diverse areas as analyzing and modeling speech and audio signals for military communications; efficient construction of networks of military sensors and detection devices; dynamic updating of mission-critical software; designing advanced prosthetic limbs with sensory feedback; cost control via improved software dependability; and ensuring secure information flow.

Mathematics

Current program themes include topological and geometric methods, inverse methods, multiresolution analysis, representations, and computation that are applied to design and control complex systems, extract knowledge from data, forecast and assess risk, develop algorithms, and perform efficient computations. These techniques underlay key Defense applications such as signal and image processing; understanding biology, materials, and sensor data, design, and deployment; and design of complex systems. Inspired by the famous 23 problems posed in 1900 by mathematician David Hilbert, DARPA issued its own 23 mathematical challenges. Hilbert's challenges drove much of mathematics over the next 100 years, and we hope to have at least a fraction of that impact.

Specifically, our Topological Data Analysis (TDA) program is developing mathematical concepts and techniques to determine the fundamental structure of massive data sets with the tools to exploit that knowledge. The result will be easy-to-use algorithms that find and display hidden properties of massive data sets and allow greater and faster understanding of the phenomena they represent. Recent program results include key insights in such diverse fields as images, material science, cancer biology, virus evolution, and medical diagnostics.

Distinguishing high-dimensional patterns in the statistics of natural images is leading toward a novel, nonlinear compression scheme that will revolutionize the way images are analyzed. For example, TDA researchers developed the Mapper tool, which automatically reduces a data set containing millions of points into a mathematical space with far fewer points, based on how a data set fits around a particular geometric shape or topology. These tools successfully demonstrated these principles on a variety of data sets – including natural images and compression, epidemiology, cardiology, and breast cancer – by unraveling distinct features and unique patterns in the data not obtainable using standard statistical tools.

Manufacturing Science and Technology

DoD requires a continuous supply of critical, defense-specific materiel and systems. To ensure reliable, robust, and cost-effective access to these items, manufacturing technologies that can meet those needs must be available in the DoD industrial base.

DARPA's Disruptive Manufacturing Technologies (DMT) program is developing manufacturing technologies and processes that can provide significant and pervasive cost savings for multiple platforms or systems, and/or decreases in manufacturing cycle time for components for existing and future military procurements. A new process pioneered under DMT offers the potential of quickly fabricating armor parts in any shape. Boron carbide nanopowder was plasma-synthesized with trace amounts of titanium, magnesium, tungsten, and aluminum, resulting in a powder sample that sintered without pressure to greater than 93 percent of theoretical density, and sintered to full density with hot pressing. DMT is currently manufacturing low-cost boron carbide (B4C) armor, with the ultimate goal of demonstrating densification sufficient for hardness and ballistic performance equivalent to conventional hot-pressed B4C used in today's body armor – but at one-third the cost.

Lasers

Lasers have multiple military uses, from sensing to communication to electronic warfare to target designation. DARPA has been involved in lasers since the early 1960's, and continues its work today.

The High Energy Liquid Laser Area Defense System (HELLADS) program is developing a practical, compact, high-energy laser weapon system (~150 kilowatt) with an order-of-magnitude reduction in weight compared to existing laser systems. With a weight goal of less than 5 kilograms per kilowatt, HELLADS would transform operations and provide a tremendous advantage to U.S. forces, such as use on tactical aircraft systems for effective self-defense against even the most advanced surface-to-air missiles.

The program has completed tests of a laser module that demonstrated high laser power output and outstanding optical wavefront quality in a compact package. Two competing contractor teams are developing full-scale laser modules that would be replicated and assembled to produce a continuously operating 150-kilowatt laser with near diffraction limited beam quality that weighs 5 kilograms per kilowatt – the program goal – in a volume of 3 cubic meters.

DARPA's Adaptive Photonic Phased Locked Elements (APPLE) program extends our vision for high energy laser programs. Imagine a laser system with multiple beams that can be independently electronically steered, eliminating electromechanical complexity. Moreover, imagine such beams coming from an aperture that conform to the shape of the aircraft, eliminating a pod that might stick into the airstream and create drag. Finally, imagine that these multiple beams could be used for low-power applications like communications, sensing and tracking—and could be brought together coherently as a high power weapon. That is what we are trying to do with APPLE.

APPLE is ultimately projected to deliver up to 300 kilowatts to a small spot on a distant target. APPLE succeeded, for the first time, in coherently combining a seven-element optical phased array, while utilizing an adaptive optic in each array element to correct for phase distortions introduced by turbulence in the atmosphere.

As I noted above, these systems rest on new core technologies. DARPA is working to develop higher performance components for electric laser systems in the relentless pursuit of ultra-compact, high power laser systems that fit on small platforms such as aircraft pods and UAVs. Over the past several years, the Super High Efficiency Diode Sources (SHEDS) program succeeded in improving the efficiency of diode lasers systems by nearly a factor of 1.5, from 50 percent to 72 percent. SHEDS laser diode bars now produce 120 watts. These advances in laser diode efficiency and power are not only reducing the size and weight of the laser electrical power supply, but also the size and weight of the laser thermal management system.

As many of you know, last year DARPA celebrated its 50th Anniversary. I hope what I have told you today shows that even though are now over 50, we remain bold in our pursuit of our mission.