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Statement by

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Mr. Chairman, Subcommittee Members and staff: I am pleased to appear before you today to discuss the Defense Advanced Research Projects Agency's (DARPA) on-going Fiscal Year (FY) 2007 activities, and our FY 2008 plans to continue as the engine for radical innovation in the Department of Defense (DoD).

DARPA's original mission, inspired by the Soviet Union beating the United States into space with Sputnik 50 years ago, was to prevent technological surprise. This mission has evolved over time. Today, DARPA's mission is to prevent technological surprise for us *and* to create technological surprise for our adversaries. Stealth is one example of how DARPA created technological surprise.

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

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 transforming 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.

DARPA delivered its updated Strategic Plan to the Congress this February[1]. Our updated plan reflects the continuity in DARPA's recent overall strategy. The new plan looks to the future more than previous ones and provides a list of significant technical research – Future Icons – that we believe will eventually prove to be memorable DARPA accomplishments.

Future Icons

It is often said that past results do not necessarily indicate future performance. Nevertheless, the following is a list of ongoing DARPA research that promises major benefits to DoD, and which

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[1] The Strategic Plan may be downloaded from DARPA's website, www.darpa.mil

may become icons of significant technical achievement by themselves. To be clear, this is basic and applied research and development of technologies that some day may be incorporated into fielded systems – and even prototypes of some of those systems. DARPA rarely engages in the development of full systems to the point that the systems can be used in the field as any other weapon or system might be. However, if we get the concepts right, if we learn the right things from the research, and if the technology proves out, here are some of the results we may get:

- **Networks**: self-forming, robust, self-defending networks at the strategic and tactical level are the key to network-centric warfare.
- **Chip-Scale Atomic Clock**: miniaturizing an atomic clock to fit on a chip to provide very accurate time as required, for example, in assured network communications.
- **Global War on Terrorism**: technologies to identify and defeat terrorist activities such as the manufacture and deployment of improvised explosive devices and other asymmetric activities.
- **Air Vehicles**: manned and unmanned air vehicles that quickly arrive at their mission station and can loiter there for very long periods.
- **Space**: the U.S. military's ability to use space is one of its major strategic advantages, and DARPA is working to ensure the United States maintains that defense advantage.
- **High Productivity Computing Systems**: supercomputers are fundamental to a variety of military operations, from weather forecasting to cryptography to the design of new weapons; DARPA is working to maintain our global lead in this technology.
- **Real-Time Accurate Language Translation**: real-time machine language translation of structured and unstructured text and speech with near-expert human translation accuracy.
- **Biological Warfare Defense**: technologies to dramatically accelerate the development and production of vaccines and other medical therapeutics from 12 years to only 12 weeks.
- **Prosthetics**: developing prosthetics that can be controlled and perceived by the brain, just as with a natural limb.
- **Quantum Information Science**: exploiting quantum phenomena in the fields of computing, cryptography, and communications, with the promise of opening new frontiers in each area.
- **Newton's Laws for Biology**: DARPA's Fundamental Laws of Biology program is working to bring deeper mathematical understanding and accompanying predictive ability to the field of biology, with the goal of discovering fundamental laws of biology that extend across all size scales.
- **Low-Cost Titanium**: a completely revolutionary technology for extracting titanium from the ore and fabricating it promises to dramatically reduce the cost for military-grade titanium alloy, making it practical for many more applications.
- **Alternative Energy**: technologies to help reduce the military's reliance on petroleum.

- **High Energy Liquid Laser Area Defense System**: novel, compact, high power lasers making practical small-size and low-weight speed-of-light weapons for tactical mobile air- and ground-vehicles.

The Future Icons span a huge range of science and technology, from networking to air vehicles to biology to lasers. More importantly, they are tremendously difficult technical challenges that will be hard to solve without fundamentally new approaches – ones which may require bringing multiple disciplines to bear and perhaps even result in entirely new disciplines.

This research is technically bold. Some of it will succeed, some will fail, and some will go in directions we cannot foresee. But because the challenges are so hard, so important, and so fundamental, when we *do* succeed it will yield very high payoffs for our military.

DARPA's Nine Strategic Thrusts

DARPA's strategy for accomplishing its mission is embodied in strategic thrusts. Over time, as national security threats and technical opportunities change, DARPA's strategic thrusts change. The nine strategic research thrusts that DARPA is emphasizing today are:

- 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

Robust, Secure, Self-Forming Networks

The DoD is in the middle of a transformation towards "Network-Centric Operations." The promise of network-centric operations is to turn information superiority into combat power so that the U.S. and its allies have better information and can plan and conduct operations far more quickly and effectively than any adversary.

At the core of this concept are networks – networks that 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 to the right place at the right time.

But for these networks to realize their full military potential, people can no longer be central to establishing, managing, and administering them. The networks must be able to form, manage, defend and heal themselves so they always function at the enormously high speeds that provide their advantages.

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. DoD now has the opportunity to bridge the gap between these two families of networks, allowing the strategic and tactical levels to rapidly and effectively share information and insight.

DARPA is developing technologies for wireless tactical net-centric warfare that will enable reliable, mobile, secure, self-forming, ad hoc networking among the various echelons with the most efficient use of available spectrum.

A seminal DARPA tactical networking program was the Small Unit Operations Situational Awareness System to link together dismounted Soldiers operating in difficult environments such as in cities and forests. This self-forming and self-healing communications network technology transitioned to the Army, where its basic network waveform is being integrated into the Joint Tactical Radio Systems Ground Mobile Radios and the Handheld, Manpack, Small Form Factor Radios.

The next logical step was to move up from connecting individual Soldiers together to connecting tactical ground and airborne vehicles together. Our Future Combat Systems–Communications (FCS-C) program developed a gateway approach that makes a mobile, self-healing ad hoc network for ground maneuver vehicles and unmanned air vehicles operating in cluttered, complex terrain, which includes the urban environment.

One problem that has plagued the DoD for years is radio interoperability. A special feature of FCS-C Gateway is that interoperability is built into the network itself, rather than having to build it into each radio, so any radio can now be interoperable with any other. We showed that it is possible to have previously incompatible tactical radios talk seamlessly among themselves and to more modern systems, including both military and commercial satellite systems. This offers a potentially more affordable route for military communications interoperability in the future. FCS-C Gateway has transitioned to U.S. Special Operations Command for their evaluation and use.

Complementing this is our work to compensate for the difficult physical and frequency environments in which our tactical units may need to communicate. Tactical units sometimes have to work in the uniquely cluttered environments of cities, which creates problems because signals bounce around and take multiple paths that degrade the links. The Mobile Multiple-Input/Multiple-Output Network (MNM) program is turning this problem into an opportunity by actually exploiting the multipath effect to improve communications between vehicles moving in cities without a fixed communications infrastructure. MNM was recently tested using several vehicles operating at speeds up to 45-60 miles per hour in complex terrain, and the technology transferred more data using less bandwidth than the program goals.

The military frequency spectrum is cluttered and limited in extent, with most of the spectrum already allocated to users who may or may not be using it at a given time and place. The neXt Generation (XG) Communications program is developing technology to increase the radio spectrum availability by ten times by taking advantage of spectrum that has been assigned but is not being used at a particular point in time. XG technology assesses the spectrum environment and dynamically uses spectrum across frequency, space and time. XG is designed to be successful in the face of jammers and without harmful interference to commercial, public service, and military communications systems. XG is transitioning to the Army to solve spectrum challenges in-theater.

DARPA is working to bridge strategic and tactical networks with our Optical and Radio Frequency Combined Link Experiment (ORCLE) program. The Department’s strategic, high-speed fiber optic network, called the Global Information Grid (GIG), has an integrated network whose data rate is hundreds to thousands of megabits per second. To reach the theater’s deployed elements, data on the GIG must be converted into a wireless format for reliable transmission to the various elements and echelons within the theater. ORCLE provides the wireless means for distributing GIG information to operational assets that further distribute the information down to tactical forces – even if some high data-rate links are degraded by atmospheric or physical obstructions – by teaming high-speed optical communications with high-reliability radio communications. ORCLE's proof-of-principle was successfully tested at White Sands Missile Range last year.

We also are working on very high-speed optical networks for the global strategic network. Our Dynamic Multi-Terabit Core Optical Networks: Architecture, Protocols, Control and Management program will leverage DARPA's photonics and secure networking research programs to revolutionize the operation, performance, security, and survivability of DoD's long-haul strategic networks.

It is also essential that the tactical and strategic networks are secure. DARPA is developing technologies to make networks not only secure, but also disruption-tolerant and, when attacked, self-reconstituting.

Networks rely on a widely available timing signal, or common clock, to sequence the movement of voice and data traffic. The timing signal is provided by the Global Positioning System (GPS), and we should expect adversaries to attack our networks by denying us use of the GPS signal.

To protect the networks, DARPA has been developing microelectromechanical systems (MEMS) technology to create a miniature atomic clock – measuring approximately one cubic centimeter – to supply the timing signal should the GPS signal be lost. The Chip-Scale Atomic Clock (CSAC) will allow a network node, such as a Soldier using a Single Channel Ground and Airborne Radio System (SINCGARS), to maintain synchronous operation with the network for several days after loss of the GPS signal. Last year we demonstrated the first CSAC the size of a pager that maintains time accurately to within one second over 200 years. We currently have plans to insert a CSAC into an Army SINCGARS radio to demonstrate that it can provide a time signal if GPS is not available.

Finally, as the DoD moves towards development and deployment of true mobile ad hoc networks (MANETS), the ability to defend this type of network becomes more and more important. The Defense Against Cyber Attacks on Mobile Ad Hoc Network Systems program will develop defenses for MANETS, including automatic and dynamic quarantine response and forensics analysis of malicious code, that can sense failures and attacks and recover automatically in real-time.

Detection, Precision ID, Tracking, and Destruction of Elusive Targets

For many years, the Department of Defense has steadily improved its ability to conduct precision strike against both stationary and moving ground targets. America's adversaries have realized that, if they are to survive the United States' superior precision strike capabilities, they either have to move, hide, or "blend-in" in cluttered environments such as urban areas.

DARPA is responding by assembling sensors, exploitation tools, and battle management systems to rapidly find and destroy ground targets in any terrain, in any weather, moving or stopped, with minimum accidental damage or casualties. To do this, we must seamlessly meld sensor tasking with strike operations to use platforms or a network of platforms that carry both capable sensors and effective weapons.

Let me give you some examples of our work and progress in this area.

DARPA's Fast Connectivity for Coalitions and Agents (Fast C2AP) program uses software agents to allow naval watchstanders to automatically monitor vessels and locate, investigate, and intercept vessels engaged in suspicious activity. Last year, Fast C2AP was deployed to both the U.S. Navy's Sixth Fleet and the North Atlantic Treaty Organization's Component Commander-Maritime and was utilized in NATO's Operation Active Endeavor. Fast C2AP increases the number of vessels that watchstanders can monitor from tens to thousands per watch, and reduces the time required to obtain detailed information regarding ships by 30-60 minutes. Fast C2AP is transitioning to the Navy.

To track vessels at sea, DARPA's Predictive Analysis for Naval Deployment Activities (PANDA) program is developing technology to automatically learn the normal behavior of over 100,000 vessels and detect when those vessels deviate from the behavior. PANDA will automatically filter deviation detections to alert on those vessels exhibiting suspicious activity – including activities that have not been previously seen or defined. In so doing, PANDA will allow analysts/operators to focus on those vessels whose current behavior is unusual, rather than relying on a predefined list of behaviors or vessels. In addition, PANDA will provide increased situational awareness by characterizing normal behavior for vessels.

DARPA's Wide Area All Terrain Change Indication Technologies (WATCH-IT) program has developed software to exploit the data collected from foliage penetrating radar. WATCH-IT uses change detection to monitor the arrival and departure of vehicles, interferometry to estimate terrain height, and tomography to construct three-dimensional models of structures hidden under the trees.

DARPA's laser detection and ranging (LADAR) sensors can obtain exquisitely detailed, 3-D imagery through foliage to identify targets in response to these cues. By flying the LADAR over a target, photons can be collected from many different angles. Those that pass through gaps between leaves, however few, can be collated together into a full image. New computational methods can match these data against 3-D geometric models of a variety of target types, even identifying gun barrels, rocket launchers, and other equipment that indicate the military nature of the vehicle.

DARPA is developing software tools to "stitch-together" information obtained from a variety of tactical sensors (e.g., moving target indicator radar, synthetic aperture radar, optical, video, and acoustic sensors), and then cue the sensors to obtain more information. For example, the change detections obtained from radar could cue the LADAR sensor to watch a new arrival. Conversely, if Predator video lost a target because it entered a forest, the radar could be cued to search for the vehicle when it stops.

We are also pursuing intelligence, surveillance, and reconnaissance capabilities in littoral waters. Our Collaborative Networked Autonomous Vehicles (CNAV) program will create a field of dozens or hundreds of networked unmanned undersea vehicles, connected by wireless acoustic communications that will work collaboratively and autonomously. Last November, and again this year, a CNAV network was tested and achieved field-level performance goals.

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

<u>Urban Area Operations</u>

By 2025, nearly 60 percent of the world's population will live in urban areas, so we should assume that U.S. forces will continue to be deployed to urban areas for combat and post-conflict stabilization. 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 (WMD).

Urban area operations can be the most dangerous, costly, and chaotic forms of combat. Cities are filled with buildings, alleys, and interlocking tunnels, which provide practically limitless places to hide, store weapons, and maneuver. They are hubs of transportation, information, and commerce, and they are homes for a nation’s financial, political, and cultural institutions. Cities are densely packed with people and their property, creating an environment in which our adversaries can mix in 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, and even in the rugged natural terrain of the traditional battlefield, is less effective in the urban environment. 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.

Our research seeks new urban warfare concepts and technologies that would make a smaller U.S. force operating in an urban area more effective, suffer fewer casualties, and inflict less collateral damage. If successful, these new urban warfare concepts and technologies would enable U.S forces fighting in or stabilizing an urban area to achieve the same or greater overall effect as a larger force using today’s technology.

This thrust’s research includes: improving urban intelligence; tagging, tracking, and locating targets; improved weapons for congested urban areas; technology to detect, prevent, or mitigate asymmetric attacks, such as suicide bomber attacks; and improved command, control, communications, and intelligence specifically suited for urban operations.

Hundreds of coalition patrols operate each day in Iraq. On patrols, our Soldiers and Marines interact with the local population and build an understanding of the environment and the pattern of life. Each individual on a patrol has a significant role as an information-gatherer, and the information is of critical importance.

DARPA’s Advanced Soldier Sensor Information System and Technology (ASSIST) program will enhance the intelligence gathering capabilities of our ground troops. ASSIST is developing sensors, networks, and databases that allow a patrol leader to directly add to and use the collective experience of previous patrols, including the details about specific neighborhoods. It allows patrol leaders and other officers to build a detailed picture of the area of operations through standardized reports. A Soldier returning from patrol enters ASSIST-collected data, such as the GPS track and photos, and Soldiers preparing for patrols would use the collected data to search for information about people, infrastructure, and past events. Soldiers in Iraq began testing this year, and their initial assessment was overwhelmingly favorable.

A typical urban mission may require a U.S. team to pursue adversaries inside a multi-story building. Defenders have a major advantage because they know the building's interior layout. DARPA's Radar Scope, which weighs less than 1.5 pounds and runs on AA batteries, allows U.S. forces to sense through nonmetallic walls, such as concrete, to determine if someone is hiding inside a building or behind a wall. Recent Army tests showed that Radar Scope was successful at detecting a person hiding behind concrete and adobe walls. DARPA is deploying 50 Radarscopes to the Army, Marines, and others for evaluation in-theater.

Improvised explosive devices (IEDs) remain a significant threat to our forces in Iraq and Afghanistan. Our Hardwire program is developing a novel hybrid armor concept primarily to protect vehicles. Hardwire's unique composition and topology uses conventional, commercially available technology and materials, and has demonstrated outstanding protection against armor piercing rounds, fragments, and IEDs in a test at the U.S. Army Aberdeen Test Center. Hardwire's armor weight is much lower than steel armor, meaning that we can achieve protection equivalent to conventional armor but at much lower weight, or greater protection at the same weight.

Another significant threat is small arms fire. DARPA's low-cost Boomerang shooter detection and location system provides a new force protection tool that warns Soldiers when they are being fired upon and the direction from where the fire is coming.

We used evaluation reports from operations with the first deployed Boomerang units to improve the system. We sent these improved Boomerang units to deployed forces, and the Soldiers tell us the system's performance has been spectacular. Over all, DARPA provided over 60 Boomerang systems to the Army, Marine Corps, Special Forces, and others. Beyond DARPA's systems, hundreds of additional Boomerang systems have been deployed in Iraq and Afghanistan, with both Army and Marine Corps units, and more are on the way.

DARPA's Crosshairs program is extending the success of Boomerang by developing an integrated detection and warning system for our ground forces against a broad range of threats including small arms, rockets, missiles, and mortars. Our Slapshot program is looking at ways of protecting light vehicles like HMMWV's from rocket propelled grenades (RPGs). In October a Slapshot system on a HMMWV defeated two live-fire RPGs without damage beyond minor scratching of the vehicle's armor.

We have also developed a smaller, highly portable, lighter-weight sniper rifle called the DARPA XM-3, which is currently being evaluated in-theater.

In the area of command and control, we need ways to control unmanned aerial vehicles (UAVs) so that they are efficiently deployed and do not aggregate on a single target. Our Heterogeneous Urban Reconnaissance, Surveillance, and Target Acquisition Team (HURT) program simultaneously controls multiple UAVs to conduct autonomous, coordinated area searches. HURT allows warfighters to stay focused on the fight, rather than having to pilot UAVs. HURT will provide on-demand, live video from such synchronized aerial vehicles as DARPA's Wasp micro air vehicle in support of force protection and cordon and search missions.

The Real-time Adversarial Intelligence and Decision-making (RAID) program is developing technologies to help a tactical commander estimate the location, strength, and intent of hostile forces and predict their likely tactical moves. Think of RAID as a computerized tactical advisor. In a recent experiment at Ft. Leavenworth, RAID software helped junior officers best a team of seasoned officers in estimating the location, strength, and intent of hostile forces in a simulated urban combat environment.

Command Post of the Future (CPOF) is a distributed command and control system that provides commanders with planning and mapping tools, and allows command and control centers to be wherever the commanders are – without regard to a fixed geographic location. Deployed forces are currently using over 600 CPOF systems in Iraq. Soldiers say CPOF allows them to share information and respond more quickly, while providing greater flexibility and insight. CPOF has transitioned to an Army Program of Record.

DARPA is adapting commercial computer game technology to train U.S. warfighters in the unique combat skills they need in the urban environment, such as tactical language skills and avoiding ambushes. DARWARS Ambush! is a PC-based trainer that teaches Soldiers how to recognize, manage and recover from convoy attacks. DARWARS Ambush! has spread throughout the Army: Fort Lewis, Washington uses the technology to train up to 400 Soldiers a month; over 300 DARWARS Ambush! systems are in use by the Army in Europe; and, last summer, 800 West Point cadets used the tool to train in dismounted infantry operations. The system is also being delivered to troops in Iraq and Afghanistan.

DARPA's Tactical Language and Culture Training systems are now teaching Soldiers, Marines and Airmen to speak basic Iraqi Arabic or Afghan Pashto through a computer-game-like interface. The tool was created to teach a bit of the culture, gestures and mission-oriented vocabulary. Eight-hundred copies of the tool have been set up at bases everywhere from stateside to Iraq and Afghanistan. Now, anyone with a ".mil" email address can download Tactical Iraqi for use on personal computers.

These digital tutors have proved to be very useful. We are also updating the systems to teach Soldiers how to troubleshoot information technology systems and reduce the need for information technology specialists.

Advanced Manned and Unmanned Systems

Unmanned systems provide autonomous and semiautonomous capabilities that free Soldiers, Sailors, Airmen and Marines from the dull, dirty, and dangerous missions which might now be better executed robotically. And they enable entirely new design concepts unlimited by the endurance and performance of human crews. The unmanned aerial vehicles in Afghanistan and Iraq have been demonstrating their transformational potential.

DARPA's efforts have been focused in two areas. First, DARPA seeks to improve individual platforms so that they provide new or improved capabilities, such as unprecedented endurance or survivability. Second, we are expanding the autonomy and robustness of robotic systems.

Progress is measured in how well unmanned systems can handle increasingly complex missions in ever more complicated environments. Autonomy and robustness are improved by networking manned and unmanned systems into a more tightly coupled combat system that will improve our knowledge of the battlespace, enhance our targeting speed and accuracy, increase survivability, and allow greater mission flexibility.

One miniature airborne sensor ideally suited for small unit operations (both in the open terrain and the urban environment) is the Wasp micro air vehicle, a small, quiet, portable, reliable, and rugged unmanned air platform designed for front-line reconnaissance and surveillance over land or sea.

Wasp is capable of flying in excess of one hour, with a speed range of 20-40 miles per hour, and provides real-time imagery from relatively low altitudes. With only a 16-inch wingspan, weighing about two-thirds of a pound, and fitting in a backpack, Wasp serves as a reconnaissance platform for the company level and below by virtue of its extremely small size and quiet propulsion system. Wasp prototypes are currently under extended evaluation in-theater by the U.S. Marine Corps and the U.S. Navy.

The Oblique Flying Wing program is demonstrating a transformational design concept for a new class of efficient supersonic aircraft. At supersonic speeds, the oblique flying wing flies with one wing swept forward and the other swept backward, and has lower supersonic wave drag than conventional symmetrically swept wings. And at low speeds, the wing (really the entire plane) pivots to an unswept design for better subsonic efficiency, because at low speeds an unswept wing is more efficient than a swept one.

This flexibility will improve range, response time, fuel efficiency, and endurance for supersonic strike, intelligence, surveillance and reconnaissance missions, and transport missions. The goal of the program is to prove out the stability and control technologies required for an oblique flying wing with an X-plane that will demonstrate an asymmetric, variable sweep, tailless, supersonic flying wing. We have completed the baseline X-plane design and conducted initial low-speed wind tunnel testing in January.

One of a pilot's more complex and dangerous tasks is midair refueling. DARPA has developed technologies that can do this for unmanned aircraft and could be applied to manned aircraft to improve safety and efficiency. The Autonomous Airborne Refueling Demonstration program is demonstrating this technology on a modified F-18. During the demonstration, the pilot watched – literally with his hands and feet off the aircraft's controls – the automated system successfully perform rendezvous, station-keeping, separation, emergency override maneuvers, and fully autonomous aerial refueling.

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

From our testimony last year and news reports, you probably are familiar with our successful Grand Challenge, held in October 2005. Five autonomous vehicles completed a 132-mile course across the desert – four of them under the required 10 hours – and the fastest, "Stanley" of Stanford University, was awarded a $2 million prize.

It was an important step to have autonomous ground vehicles that can navigate and drive across open and difficult terrain from city to city. But the next big leap will be an autonomous vehicle that can navigate and operate in traffic, a far more complex challenge for a "robotic" driver. So this November we are very excited to be moving from the desert to the city with our Urban Challenge. The Urban Challenge is designed to accelerate the development of autonomous ground vehicles that can navigate in an urban environment and operate safely among other vehicles. Prizes of $2 million, $1 million, and $500,000 will be awarded to the first, second, and third place teams that complete the Urban Challenge's 60-mile course in six hours or less.

Detection, Characterization, and Assessment of Underground Structures

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

While large, developed facilities have long been recognized as strategic threats, there is increasing need to find and characterize small underground structures. These include caves that serve as hiding places and tunnels for smuggling weapons and infiltrators across borders. Caves and tunnels provide secret entry into sensitive areas, such as Baghdad's International Zone, and might even contain prisons, weapons laboratories, or nuclear power plants.

To meet the challenge posed by the proliferation of these facilities, the Counter-Underground Facility program 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.

Our Low-Altitude Airborne Sensor System (LAASS) is demonstrating the use of airborne electromagnetic, acoustic, and gravity sensors to rapidly find underground facilities and map out their backbone structure. In proof-of-concept testing, LAASS exhibited excellent performance, and DARPA has begun prototype development.

The LAASS unmanned aerial vehicle sensor prototype has undergone successful developmental flight tests on a UAV. We have begun a new effort to specifically address the small tunnel and bunker threat using active electromagnetic and gravity signature sensing. It is likely that these technologies could also help in the battle against improvised explosive devices.

One of our warfighters' unmet needs is knowing their location in underground facilities and tunnels while conducting search, attack, and rescue missions. DARPA's Sub-Surface Navigation program is conducting underground tests of a small, lightweight GPS-like capability that uses very low frequency earth-penetrating signals to provide real-time self-location to our forces on underground missions. Our goal is to make our warfighters as aware of their position while underground as they are on the surface.

<u>Space</u>

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 maintains an ambitious effort to ensure that the U.S. military retains its preeminence in space by maintaining unhindered U.S. access to space and protecting U.S. space capabilities from attack.

There are five elements in DARPA's space strategic thrust:

- *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 that "something else" 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 designed to vastly improve the U.S. capability to promptly reach orbit. It includes developing new, low-cost, small launch systems that could be used to launch hypersonic test vehicles and satellites. These new systems will enable affordable and responsive launch for payloads in the 1000-pound class and reduce launch costs by over 50 percent. One of the systems is designed to bypass bottlenecks at ground launch sites by using a C-17 transport aircraft to carry an air-launched rocket to altitude. Last July we conducted the third successful air drop test of a 72,000 pound, 66 foot-long test article from 29,500 feet, the largest and heaviest object ever dropped from a C-17. By the end of 2009, Falcon will also have conducted flight tests of hypersonic test vehicles, spurring progress in this critical area.

DARPA's Orbital Express program promises to fundamentally change on-orbit satellite operations with technology to refuel satellites and replace their electronics on-orbit. This offers a way to dramatically improve the life span, maneuverability, and self-protection of orbiting satellites. Two satellites, NextSat and ASTRO, are now in orbit to demonstrate such key functions as proximity operations and rendezvous, refueling, and electronics replacement.

The F6 (Future Fast, Flexible, Fractionated, Formation-Flying Spacecraft) program takes a technically aggressive approach to combining separately launched space payloads and spacecraft subsystem elements. F6 will develop methods for satellite payloads and subsystem elements to operate in close formation, dividing mission requirements between nodes of the formation.

Satellite systems could be repaired or upgraded by placing a new, wirelessly connected node into the formation. The systems could be less vulnerable to attack or failure because the components are physically separated. This concept also promises improved reliability and reduced risk from launch failures.

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 optics has passed a significant milestone, separating the primary and secondary mirror blanks from a single 3.6-meter diameter Zerodur blank. SST is the first implementation of recent advances in curved focal plane technology, enabling the design of a novel, wide field of view, rapidly scannable, three-mirror, 3.6-meter telescope.

Our Deep View program is developing a high-power, high-resolution, ground-based radar to image and characterize small objects in both low-Earth (LEO) and geo-stationary (GEO) orbits. Imaging objects in deep-space requires very large antennas and very high radar power, so Deep View is developing transmitters capable of providing the required power to image at deep-space ranges over full bandwidth, using antennas that maintain the necessary shape over a very large aperture. In FY 2008 we will support demonstration of a low-power system to demonstrate a LEO-only imaging capability. Then we will proceed to a full power Deep View system to demonstrate the capability to image objects in both LEO and GEO. Deep View technology, planned for transition to the Air Force in FY 2009, will be used both to classify unknown objects, such as space debris, and to monitor the health and status of our operational satellites.

DARPA's Integrated Sensor Is Structure (ISIS) program is the most capable U.S. moving target indicator radar for air and ground targets ever conceived. Using the enormous platform surface area available on a stratospheric airship, ISIS will incorporate an extremely large antenna (approximately 1600 square meters) directly into the structure of the airship. A single ISIS stationed over Baghdad today would provide total airspace knowledge and unprecedented ground vehicle tactical tracking across more than 80 percent of Iraq. Work is proceeding on ISIS component development, including the solar-regenerative power system, the active electronically scanned aperture X-band radar, and the lightweight hull structural material.

Increasing the Tooth to Tail Ratio

We previously called this thrust "Cognitive Computing," but we have recently brought other research areas under this thrust and renamed it to better communicate its fundamental purpose: getting a larger proportion of our forces into the fight.

Information technology can reduce the need for large numbers of clerical and administrative personnel. By using and improving information technology, we can reduce the layers and numbers of personnel supporting military operations (the "tail") relative to the number of fighting forces in the field (the "tooth"), while enabling warfighters to do new things.

The major themes of this 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 providing local knowledge and interaction with the local population by removing language and culture barriers through superb machine language translation, thereby reducing the need for human translators.

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 operations, they have also become increasingly more complex, fragile, vulnerable to attack, and difficult to maintain. The computing challenges facing the 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.

DARPA has embarked on an ambitious mission to create a new generation of computing systems – cognitive computers – to dramatically reduce military manpower and extend the capabilities of commanders and warfighters. Cognitive computing systems can be thought of as systems that "know what they're doing." DARPA's cognitive computing research is developing technologies that will enable computer systems to learn, reason and apply knowledge gained through experience, and respond intelligently to new and unforeseen events.

Success will have enormous benefits for our military. In the real-time environment of military operations, cognitive systems that can learn, reason, and draw on their experience to assist their user will make a huge difference. Cognitive systems will give military commanders and their staffs better access to a wide array of rapidly changing information, reduce the need for skilled computer system administrators, and dramatically reduce the cost of system maintenance.

For example, 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. The DoD needs computer systems that can behave like experienced executive assistants, while also retaining their ability to process data like today's computational machines.

The Personalized Assistant that Learns (PAL) program is creating revolutionary technology for commanders and warfighters – the first comprehensive system that will enable commanders to understand, at a glance, all aspects of the current military situation. PAL will radically reduce manpower and labor required in command posts and in the field, and will automate the massive number of administrative and analytical tasks of today's command centers. PAL systems will automatically adjust to new environments and users; help commanders adapt to evolving situations and priorities; and enable new command center personnel to become effective more quickly.

PAL combines the efforts of 21 universities and research laboratories across the United States, and has already produced a wide range of research breakthroughs in machine learning, knowledge representation and reasoning, communications and interaction, and computational perception.

Because cognitive assistants must learn in order adapt to new situations without reprogramming, PAL is also driving great improvements in the area of computer learning. Recent formal tests of a fully integrated PAL prototype demonstrated remarkable performance improvements in learning capabilities, doubling the system performance over the previous year.

PAL technology is being transitioned to the U.S. Army's Command Post of the Future (CPOF) system to support shift changes, delegation, and other tasks where the user needs to describe the significant activities to the next shift. Working with CPOF, PAL learns significant battlefield activities, organizes them, and locates them on maps. An officer returning from Iraq remarked, "PAL could be an incredibly powerful tool for Tactical Operations Center operations. It has the potential to save countless man-hours by performing routine, repetitive tasks… Those man-hours could then be reallocated to other tasks … or even free up Soldiers to conduct combat operations." This prototype capability will be ready for evaluation by the Army CPOF program office shortly.

DARPA is fostering the computer science for this century, computer science that will enable computing machines that are much more flexible and useful. These will be computers that can learn and adapt to their situations and think about them analytically with flexibility, adaptability, and insight, while retaining the precision and persistence of current computers. We are striving to achieving computers that have more of the qualities of good staff, while maintaining their traditional virtues of machine precision.

Our drive to build computers that reason and learn is directly tackling the most fundamental problems in computer science.

High Productivity Computing Systems

The High Productivity Computing Systems (HPCS) program is the Federal Government's flagship program in supercomputing. HPCS is pursuing the research, development and demonstration of economically viable, high productivity supercomputing systems for national security and industrial users.

But the story is more than just achieving enormous computing speeds. We are looking into what makes computers *productive*. HPCS emphasizes programmability, portability, scalability, and robustness – as well as high performance goals of achieving multiple petaflops and thousands of global updates of memory per second. We are focusing on issues like how long it takes to develop new software, how easy it is to port legacy codes, can these machines run code correctly in the presence of processor failures, and other usability factors. In November, DARPA announced its two performers for the next phase of HPCS to build prototypes.

The performers will demonstrate substantial improvements in both the time that it takes to write new software and the actual time it takes to run that software on the petascale machines. Specifically, they will demonstrate the capability to reduce the development time of new, large software to one tenth of the time that it takes to develop applications today, with the goal that the applications run in less than one percent of the execution time required on today highest performing machines.

Language Processing

Real-time language translation would help U.S. forces better understand the adversary and the overall social and political context of the operational area. This improved awareness would decrease costly operational mistakes due to misunderstandings, thus improving the chances of operational success.

Today, linguists translate important information, but it is a slow process because we have too much raw data and not enough linguists. We want to dramatically reduce the need for linguists at both the strategic and tactical levels with machine translation capabilities that are revolutionary.

The Global Autonomous Language Exploitation (GALE) program is designed 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 is able to produce high-quality answers to the type of questions that are normally provided by bi-lingual intelligence analysts. GALE is working to achieve this very ambitious goal by 2010. Initial capabilities developed in the program were deployed to two sites in Iraq, where they are translating Arabic speech and text into English.

GALE has dramatically improved the state of the art in machine translation, virtually doubling accuracy rates that were previously thought possible. The translation accuracy of structured Arabic into English increased from an average of 55 percent to a minimum of 75 percent for 90 percent of the documents translated from text, and from an average of 35 percent to a minimum of 65 percent for 80 percent of the documents translated from speech. Just as impressive are the numbers for Chinese, in which the accuracy increased from 35 percent to 65 percent for text, and from 20 percent to 65 percent for speech. The objective translation goal for Arabic or Chinese into English is a minimum accuracy of 95 percent for 95 percent of text and 90 percent of speech for material rated by the Interagency Language Roundtable scale to be of Skill Level 3 to 4. Translation accuracy is measured by editing machine translation to reflect the meaning conveyed by a gold standard translation, which is created by three translators, two quality assurance translators, and an adjudicator. The number of edits divided by the number of words in the English document determines the error rate, and the accuracy is determined by subtracting the error rate from one.

Overall, GALE's translation of structured speech and text (e.g., over broadcast news and newswire) has improved to the point that it produces "edit-worthy" text, where it is more efficient for a translator to edit it directly rather than retranslate the material.

At the tactical level, there are not enough translators for each patrol or vehicle checkpoint. Our warfighters also need automatic, on-the-spot speech translation to work with Iraqi units, or use what they might be told by locals about insurgents or suspicious activities.

DARPA's Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program has successfully demonstrated the first two-way speech translation to translate Baghdadi Arabic, a dialect spoken by most of the population in central Iraq, into English, and vice versa. This technology is now on laptop computers and has a vocabulary of approximately 70,000 words. Accuracy rates achieved are 70-80 percent in a laboratory environment with conversations confined to a specified subject area.

Sixty-five prototype TRANSTAC units are being field-tested in Iraq. Feedback from these tests will be used to improve the performance and usability of the system. The goal is hands- and eyes-free systems that can be used outdoors.

Bio-Revolution

DARPA is mining new and fundamental discoveries in the life sciences for concepts and applications that could enhance U.S. national security in revolutionary ways.

The Bio-Revolution thrust has four broad elements:

- *Protecting Human Assets* refers to DARPA's work in biological warfare defense (BWD) and combat casualty care. Advances in BWD will protect warfighters not only from biological warfare agents, but also from the infectious diseases they regularly encounter overseas. We are also developing advanced combat casualty care technologies to greatly improve the chances of our wounded surviving battlefield injury.

- *Biology to Enhance Military Systems* refers to creating new systems with the autonomy and adaptability of living things by developing materials, processes, and devices inspired by living systems. The idea is to let nature be a guide toward better engineering.
- *Maintaining Human Combat Performance* is aimed at maintaining the warfighter's peak physical and cognitive performance once deployed, despite extreme battlefield stresses such as heat and altitude, prolonged physical exertion, and sleep deprivation.
- *Restoring Combat Capabilities after Severe Injury* describes the revolutionary technology DARPA is developing to restore full function after severe injuries. Examples include techniques to accelerate healing and revolutionary new prostheses for combat amputees.

In the BWD arena, current drug and vaccine development takes years or even decades, requiring the current biodefense strategy of stockpiling therapeutics based on the latest threat projections. One DARPA Future Icon is working to accelerate the development and production of vaccines and other medical therapeutics.

Once a basic vaccine, antibody, or immune enhancer has been identified and has undergone pre-clinical evaluation, our Accelerated Manufacturing of Pharmaceuticals program is looking at ways to manufacture millions of doses in 12 weeks or less – instead of the 12 years (and often much longer) required today – at pennies per gram. We are looking at leveraging the large-scale, mass-production industrial processes used in enzyme manufacturing, as well as other techniques such as bacterial fermentation, and "pharming" mushrooms and shrimp to produce large quantities of specific proteins quickly and cheaply.

Now let me turn to the area of *Protecting Human Assets*.

Our PREventing Violent Explosive Neurological Trauma (PREVENT) program is a basic research program looking for the mechanisms of neurological injury – particularly brain injury – caused by blast, such as from an improvised explosive device.

We do not have a good enough understanding of the mechanisms behind the symptoms we are seeing. It used to be thought that peak overpressure was the primary mechanism for blast injury, but that does not appear to be the case for many of the neurological symptoms in today's wounded. PREVENT is an aggressive program to fully characterize the harmful components of blasts, including the brain effects of repeated small blasts that individually might not seem harmful. Once we better understand the physical mechanisms of neurological injury, we can design specific technologies to protect our warfighters against them.

In the area of *Maintaining Human Combat Performance*, one of the most important things we could do for our troops is reduce their pain when they are injured or wounded. Under our Soldier Self Care program, DARPA is pursing a radically different way of treating acute, severe pain. The current best treatment is morphine, which reduces pain quite well – but because morphine acts on the central nervous system (CNS), it also impairs cognition and can dangerously depress body functions. Instead, DARPA is pursuing capabilities to protect cognition by blocking the pain receptors right at the injury site to prevent them from firing and sending a pain signal to the CNS. This will help a Soldier remain alert in dangerous situations.

This research is progressing well. We've shown the treatment is safe, and, at this point, even more effective than morphine – but without morphine's side effects. The next step is for a pharmaceutical company to fund the trials necessary for FDA approval.

Another program in this area is Preventing Sleep Deprivation. During extended operations, where our warfighters receive limited sleep, they are challenged to remain alert to dangers. The difficulty is that, while one can stay awake, the resultant sleep deprivation degrades cognition and the ability to make good decisions.

We have been looking for ideas to keep the brain functioning at alert levels during periods of sleep deprivation. The research has led to drugs that are used for Alzheimer's disease called "ampakines." Ampakines seem to mitigate the effects of fatigue so that test subjects can stay mentally sharp after an overnight period of work, without using any of the current generation of stimulants.

In the area of *Biology to Enhance Military Systems*, we are researching how to use lessons from biology, or even the power of biological systems themselves, to improve our military systems.

Our brains are the finest processors of visual imagery that we know of. No machine yet devised even comes close to the brain at visual pattern recognition.

Our Neurotechnology for Intelligence Analysts (NIA) program seeks ways to harness the unique capacity of the brain for visual pattern recognition to vastly improve the productivity of our imagery analysts and allow them to spend more time on actual analysis.

Not only is the brain the best visual pattern recognition system that we know of, it turns out that the visual pattern recognition part of the brain actually spots things faster than your consciousness can register it. We can now noninvasively detect that the visual pattern recognition system of your brain has spotted something of interest before you consciously know it. This key scientific fact underpins NIA.

One of the first things that imagery analysts must do is actually spot something interesting among the tremendous amount of largely boring, non-interesting imagery they review. This methodical process of going through large volumes of imagery looking for items of interest is aptly nicknamed "mowing the lawn." Our NIA program has shown that, by noninvasively monitoring the brain's responses, we can detect the images of interest three to five times faster. This reduces significantly the time required to find targets and, thus, provides analysts more time to focus on analyzing the items of interest.

Our flagship programs in *Restoring Combat Capabilities after Severe Injury* are the closely related Human-Assisted Neural Devices (HAND) and Revolutionizing Prosthetics programs.

HAND is a basic research program broadly aimed at understanding how the brain processes motor control and sensory signals from the level of individual nerve cells to the level of local and regional brain networks to the level of the whole brain itself. One important component is deciphering how the brain encodes and decodes information to and from normal human limbs to support our effort in revolutionizing prosthetics. There are two separate problems. The first is decoding motor commands in the brain, so we can get those commands out of the brain to run an external device. The second is getting feedback from the external device back into the brain so the brain can actually sense what the device is doing and exercise what is called "closed-loop control."

While things like improved body armor and medical care are saving more wounded, we have more people surviving that have lost limbs. Current prosthetic leg technology is advancing. However, prosthetic arm technology is much more difficult, since it involves so many more joints and movements, as well as the combined abilities to touch, sense, and manipulate fine objects.

DARPA's goal is to revolutionize upper extremity prosthetics, specifically arms and hands. Today, individuals experience such prosthetics – to the extent they can use them at all – like a *tool*, not like a limb. We are striving for a prosthetic arm that people can control with their brains and use just like they can control and use a natural limb. It is a major scientific and engineering challenge to integrate new science from HAND and many technologies – materials, power, control systems, sensors and actuators – to build a vastly improved upper limb prosthetic.

The program will deliver a prosthetic in about a year for clinical trials that is far more advanced than any currently available. This device will enable many degrees of freedom for grasping and other hand functions, and will be rugged and resilient in all environments. It will enable the amputee to have a three-fold improvement in abilities required for daily independent living. And we are making rapid progress: the performers fitted and attached a prototype arm in January. Within hours and with minimal training, the user was able to control the arm in all seven degrees of freedom, including a powered shoulder.

Program plans are to deliver a prosthetic in three years for clinical trials that has function almost identical to a natural limb in terms of motor control and dexterity, sensory feedback, weight, and environmental resilience. This device will be directly controlled by neural signals. Our goal is to give our warfighters that are upper limb amputees the chance to return to active duty as fast as possible.

Core Technologies

While the eight DARPA strategic thrusts described earlier are influenced by national security threats and opportunities, a major portion of DARPA's research emphasizes areas largely independent of current circumstances. These core technologies are the investments in fundamentally new technologies, at the component level, that historically have been the technological feedstocks that lead to new systems and significant advances in U.S. military capabilities.

Quantum Science and Technology

Until recently, quantum effects in electronic devices did not have overriding significance. However, as device sizes shrink, quantum effects can influence device performance. DARPA is conducting research aimed at technology built around exploiting quantum effects to achieve revolutionary new capabilities.

One example is DARPA's "Slow Light" program. Researchers are using quantum effects that influence the passage of light through materials under special conditions to actually control the speed of light and slow it to a faction of its normal speed. If light can be slowed practically without losing the information it carries, it can be stored and switched, much as we store and switch the electric charges in electronics today. This technology opens the door to a revolution in ultra-high-speed optical information processing.

Bio-Info-Micro

For the past several years, DARPA has been exploiting and developing the synergies among biology, information technology, and micro- and nanotechnology. Advances in one area often benefit the other two, and DARPA has been active in information technology and microelectronics for many years. Bringing together the science and technology from these three areas produces new insights and new capabilities.

The Fundamental Laws of Biology program is working to develop a new basis for doing biological research by bringing an increased mathematical discipline to biology, including creating new mathematics to reveal unanticipated features and relationships. The goal is to discover the fundamental laws of biology that extend across biological scales, and that can be used to make accurate predictions about repeatable performance, just as physics-based theories enable performance predictions. We are making progress developing new and rigorous mathematics to describe such phenomena as evolution of microscopic organisms, the growth of supporting structure within plants and animals, and the behavior of large groups of animals moving in groups, such as schools of fish, and scaling laws that connect microscopic dynamics to macroscopic patterns.

Materials

DARPA continues to maintain a robust and evolving materials program. DARPA's approach is to push new materials opportunities and discoveries that might change how the military operates. In the past, DARPA's work in materials has led to such technology revolutions as high-temperature structural materials for aircraft and aircraft engines, and the building blocks for the world's microelectronics industry. The materials work DARPA is supporting today continues this heritage.

DARPA's current work in materials includes the following areas:

- *Structural Materials and Components*: low-cost and ultra-lightweight materials designed for structures and to accomplish multiple performance objectives in a single system;
- *Functional Materials*: advanced materials for non-structural applications such as electronics, photonics, magnetics, and sensors; and
- *Smart Materials and Structures*: materials that can sense and respond to their environment.

DARPA's Prognosis program has developed physics-based materials damage models that accurately describe damage accumulation from flight operations in both aircraft and engine structures. By combining these models with sensor and usage information, we will have much better predictions of the safety and remaining life of aircraft. This will make operations safer and improve overall readiness by minimizing the groundings needed for inspection. Prognosis models have been shown to be robust and applicable to the Navy's EA-6B and P-3 aircraft, and to the F-100 and F-110 engines. Prognosis also demonstrated the ability to diagnose and predict the progression of previously undetectable damage in gearboxes of Army and Navy helicopters.

Our Evaporative Cooling Turbine Blades program is developing innovative technology to cool gas turbine engine blades, which holds the promise of reducing specific fuel consumption. In an area where efficiency improvements of tenths-of-a-percent are considered dramatic, if our preliminary results are borne out in upcoming engine tests, the fuel savings will be significant.

DARPA has demonstrated a titanium production process that offers the potential for radically reducing the price of titanium to less than four dollars per pound for military-grade quality metal. This program, one of DARPA's Future Icons, is advancing from the feasibility stage to a prototype operation. This technology will create a true paradigm shift in the use of titanium, as occurred once aluminum was no longer a precious metal but could be produced economically.

Power and Energy

Portable sources of electric power are critical to today's military. To Napoleon's dictum that an Army moves on its stomach, today's warfighting forces could add, "…and on energy."

Developing portable, efficient, and compact power supplies has important ramifications for increasing our military's reach, while at the same time decreasing material logistic requirements.

DARPA has been active in this area for several years. The Palm Power program is one example, which, among other things, developed portable solid oxide fuel cell technologies that are now being used in intelligence applications and are being further explored by the Air Force.

The Very High Efficiency Solar Cell program is aimed at developing photovoltaic devices with efficiencies exceeding 50 percent. The program has a novel design architecture that integrates previously incompatible materials technologies to maximize performance across the solar spectrum. The optical system at the heart of this new design has recently achieved breakthrough efficiency – a huge step towards our goal of a solar cell with an overall efficiency of 50 percent.

To help reduce the military's reliance on petroleum-based fuels to power their aircraft, ground vehicles, and ships, DARPA's BioFuels program is working to develop an affordable surrogate for military jet fuel (JP-8) derived from oil-rich crops, such as rapeseed, or produced by either agriculture or aquaculture including, but not limited to, plants, algae, fungi, and bacteria. DARPA recently selected three performers to demonstrate converting these renewably produced oils to JP-8 with a minimum process efficiency of 60 percent, and an ultimate goal of 90 percent.

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 hardware technologies of the information age that some of the greatest challenges and opportunities for DoD arise. The model for this integration is the spectacular reduction in transistor circuit size under Moore's Law: electronics that once occupied entire racks now fit onto a single chip containing millions of transistors. There is also a second law that could be stated: the nonlinear increase in transistors per chip has also led to a nonlinear increase in the capital required to build a plant or set up a production line.

An example of the move to integrated microsystems is the 3-D Electronics program. Conventional 2-D circuits are limited in performance by the long signal interconnects across ever larger circuits and by existing circuit architectures. By moving to three dimensions, we can shorten the signal paths and introduce additional functions in each layer of 3-D stacked circuits that will change the way designers can exploit circuit complexity.

This increasing integration will change system architectures. The Vertically Interconnected Sensor Array program is revolutionizing how focal plane arrays are coupled to their readout electronics by putting the electronics directly behind each pixel. New wafer-level processing technology makes it possible to construct these 3-D stacks, which will dramatically increase the performance and reduce the footprint of the focal plane.

DARPA is tackling one of the most important roadblocks to increasing chip integration: heat dissipation. As both the number of transistors on a chip and their clock frequency increase, the waste heat generated rises sharply. Today, some chips radiate as much heat per square inch as a hotplate, and as a result, faster chip clock speeds can not be used, hence threatening to break Moore's Law of continued performance improvement through transistor scaling and increasing clock speed.

DARPA is pursuing three ways to push through the heat dissipation roadblock.

First, we are looking at an entirely new type of transistor, called a tunneling transistor, that would operate at lower voltages – ¼ volt instead of today's 1 volt – thereby greatly reducing the active heat dissipation, which is proportional to the square of the voltage.

Second, we are working to reduce the standby heat dissipated when a transistor is nominally "off," but still leaks a small amount of current. This problem has increased in recent years as transistors have become smaller. One possible solution is nanoelectromechanical switches that would physically disconnect, or "unplug" a transistor when it is off, preventing leakage current that generates waste heat.

Third, DARPA is working to reduce the heat dissipated by the interconnects, or wires, that connect the active devices within a chip – another important source of heat. The model here is what we have done with our telecommunications systems: for the long-haul circuits we have replaced electric wires with optical fiber. Similarly, to limit the heat from wire interconnects in integrated circuits, DARPA is pursuing replacing some of the longer metal wires with optical interconnects, which will generate far less heat.

DARPA is also working to lower the costs of the integrated circuits and microsystems the DoD needs.

It is very expensive to develop the masks needed for the typical process of printing application specific integrated circuits. This poses a particular problem for the DoD because, while high volume production can amortize the high cost of such masks across many chips, DoD generally needs only low volumes. This means that the upfront costs for a mask can make DoD-specific chips extremely expensive and threaten to limit DoD use of leading-edge microelectronics.

In response, our Maskless Direct-Write Nanolithography for Defense Applications program is developing a maskless, direct-write lithography tool that will address both the DoD's need for affordable, high-performance, low-volume integrated circuits and the commercial market's need for highly customized, application-specific integrated circuits. This program, based on writing circuits versus printing them, will also provide a cost-effective manufacturing technology for low-volume nanoelectromechanical systems and nanophotonics initiatives within the DoD. DARPA has entered into a cofunded joint development agreement with an integrated circuit tool manufacturer to produce a direct-write, maskless lithography tool. When installed in the Trusted Foundry and in commercial foundries, this would enable state-of-the-art microelectronic circuits to be used in new military systems and the cost-effective upgrade of legacy military systems.

More generally, DARPA is working to lower the cost of microsystems by making it possible for more of the elements of such systems to be made much like silicon-based electronic integrated circuits are made. The idea is to integrate more types of devices onto chips so that they can follow the Moore's law curves that have helped make silicon integrated circuits inexpensive. In short, we are getting Moore's law to apply to more things.

Our 3-D Microelectromagnetic Radio Frequency Systems (3-D MERFS) program should decrease the cost of millimeter-wave radar and communications systems by 100-fold. The key to this is that the coaxial connectors, couplers and resonators that link the active radio frequency devices will now be printed along with the devices.

Similarly, our Electronic and Photonic Integrated Circuits on Silicon (EPIC) program has focused on integrating photonics with silicon. Recently, EPIC has found a way to generate laser light on silicon, a profound development which could have a revolutionary impact on microelectronics. By having lasers that are an integral part of the low-cost silicon used in electronic circuits, the laser light can be directly coupled into the silicon – instead of having to build lasers separately and then piping the light onto the silicon. This promises revolutionary benefits from silicon-based, on-chip optical data processing that is ubiquitous, ultra high-speed, and very low-cost. And our wide band gap semiconductor programs have been moving that type of semiconductor toward lower cost production techniques by improving the materials, so they can be processed in economically sized wafers, and improving the processing techniques themselves.

Information Technology

DARPA's work in information technology is integrated with the strategic thrust to increase the Tooth to Tail Ratio. It is a core technology that supports a broad set of opportunities.

A key area in information technology is embedded systems: special purpose computer systems contained in the device they help control, enabling advanced intelligent functionality such as flight controls, radar, and electronic countermeasures. Embedded computing is critical across a broad range of military applications, such as handheld devices used in the field, intelligent weapon systems, and airborne information and command centers.

Current DoD embedded computing systems are point-solutions, tailored to a specific, static, and inflexible set of mission requirements. These implementations lead to one-of-a-kind systems that are costly to develop and unable or extremely expensive to adapt to changing requirements.

DARPA is pursuing technologies to overcome these limitations. This includes technologies for efficiently designing embedded systems for high performance, flexible embedded processing, and for recovering and maintaining investments in software. These technologies are essential to providing embedded systems that can be efficiently implemented and adapt to changing missions. In its Polymorphic Computing Architecture program, DARPA is developing a class of flexible processors which can reconfigure dynamically, as required by the mission.

Mathematics

Our current mathematical 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. Potential Defense applications include signal and image processing, biology, materials, sensing, and design of complex systems.

For example, DARPA's Topological Data Analysis (TDA) program is developing mathematical concepts and techniques to determine the fundamental structure of massive data sets, along with the tools to exploit that knowledge. Just as a set of data points in a plane can be represented by a simple line "fitted" to the data, the vastly more complex, multi-dimensional data that describes real physical systems can also be represented by a fit – not to a line, but to a high-dimensional geometric shape around which the data clusters. The geometry of this shape contains information, and this program's analytic methods tell us how to extract that information from the shape's properties.

Example applications of TDA's tools and techniques include improving predictions of the survivability of critically ill Soldiers; understanding statistical microstructural variations in materials for improved, controlled delivery of therapeutics; and improving image recognition.

Other branches of mathematics are being applied to model electromagnetic propagation and investigate radar cross sections of vessels and planes, and for fluid dynamics, including weather and climate modeling.

Manufacturing Science and Technology

The 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 DoD's needs must be available in the DoD industrial base.

A key program here is our Maskless Direct-Write Nanolithography for Defense Applications program, which I discussed earlier.

Lasers

Lasers have multiple military uses, from sensing to communication to electronic warfare to target designation. And since the technology was first demonstrated, DoD has maintained a steady interest in lasers for a wide range of speed-of-light weapon applications. Starting in the early 1960s, DARPA has been involved in lasers and laser technology development for the DoD, and continues its work today in this crucial area.

For example, DARPA is currently working on lasers to protect platforms. The High Energy Liquid Laser Area Defense System (HELLADS) program is a Future Icon that is developing a 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 five kilograms per kilowatt, HELLADS allows new and innovative capabilities, such as being used on tactical aircraft systems for effective self-defense, against even the most advanced surface-to-air missiles.

This year, the program demonstrated 15 kilowatts of multimode laser output power. If successful, HELLADS will lead to a truly practical, small-size, low-weight tactical laser weapon that will transform operations, and provide a tremendous advantage to U.S. forces.

DARPA has also been working to improve the performance of laser component technology. For example, the Super High Efficiency Diode Sources (SHEDS) program has achieved 70 percent electrical-to-optical efficiency in generating light from stacks of semiconductor diode laser bars, a dramatic improvement over today's 50 percent efficient diode laser technology.

Summary

In closing, I want to return to a subject I mentioned last year – computer science. As you've seen, DARPA has bold goals in information technology and computer science, but we remain concerned about the declining pool of talent and the lack of interest from high school and college students in computer science studies. Between 2000 and 2005, the portion of incoming freshman interested in majoring in computer science dropped by 70 percent; in Fall 2006, only 1.1 percent planned to major in computer science. These are not the signs of a healthy discipline.

We feel that a major reason for this decline is the lack of new, exciting ideas that would attract more bright students into this field.

DARPA recognized this and responded by starting programs whose purpose is to generate new ideas of value to DoD, but which would also attract new students.

Our Computer Science Study Group (CSSG) program is aimed at educating a select group of extremely talented early-career academic computer scientists on DoD's needs, and then asking them to use the knowledge they've gained to propose ideas for basic research that are relevant to DoD. The program plans a three-year cycle for each class of about 12 participants. In the first year, they obtain a Secret clearance and are familiarized with DoD and its challenges through group visits to DoD's labs, bases, defense contractors, and operational settings. The visits occur during two week-long trips in the summer. In the second year, the participants' ideas are competed, and the best proposals may be awarded up to $500K to conduct basic research of interest to DoD. In the third year, they may be awarded an additional $250K for their research, provided they match the funds from another source.

We believe this overall approach to cultivating a focus on DoD problems in academic disciplines will prove so effective that we've just started a similar program in the area of microsystems.

We have now selected two classes for CSSG, and the first class will soon begin their research projects. As an example, one of the research projects will look at novel ways to automatically identify individual speakers within a huge array of communications and other acoustic data, and then use that data to infer information about the networks of people associated with the speakers. This has obvious counterterrorism applications.

Our Computer Science Futures program is another effort aimed at attracting and cultivating talent to computer science, in this case linking up world class computer science researchers and interested high school students. Here we ask a panel of young computer science professors to propose five "Grand Challenges" for computer science – problems that are important, hard, and exciting to tackle. The professors must then brief their ideas to high-school students, where the students are asked which of the Challenges are exciting and would draw their interest to study computer science. This year, the first year of the effort, the high school students ranked three of the five as interesting. We've asked the professors to work on the projects with high school students from their local community.

One of the ideas the students liked is Programmable Matter. It is an important idea that is of significant relevance to DoD. The challenge is to build a solid object out of intelligent parts that could be programmed so that it can transform itself into other physical objects in three dimensions. It would do this by changing its color, shape, or other characteristics. A simple example is an antenna that would change its shape based on the communication system to which it is connected. The computer science challenges are to identify the algorithms that would allow each element of the object to do its job as the object changes, while staying well coordinated with the other elements and functioning as an ensemble.

These two programs by themselves cannot reverse the declining trends in computer science, but we do hope that they will be useful and help make people more aware of the talent problems in computer science, and some of the things that could be done about it.

I hope my remarks today have given you a sense of our programs and our ambitions. Thank you for this opportunity to appear today. I would be pleased to answer your questions.