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Defense Sciences Office (DSO)
Office Overview

Good morning, and welcome to the meeting that turns the tables, when the grantors entertain the grantees, so what better way to start the day than with additional fantasies.

Imagine soldiers having no physical limitations . . . water and power being available whenever and wherever they are needed . . . mechanical systems as autonomous and adaptable as living things.

What if, instead of acting on thoughts, we had thoughts that could act? Indeed, imagine if soldiers could communicate by thought alone . . . or communications so secure there is zero probability of intercept. Imagine the threat of biological attack being inconsequential. And contemplate, for a moment, a world in which learning is as easy as eating, and the replacement of damaged body parts as convenient as a fast food drive-thru.

As impossible as these visions sound or as difficult you might think the task would be, these visions are the everyday work of the Defense Sciences Office.

The Defense Sciences Office is about making dreams into reality. Today, we will share with you some of these bold visions and amazing achievements that have the potential to profoundly alter our world.

During my presentation, I will provide you with an overview of the Defense Sciences Office, a road map for this morning's speeches, and an illustration of some of the richness the office endows. Throughout the morning's presentations, it is important to remember we are talking about science *action*, not science *fiction*.

The program managers of the Defense Sciences Office vigorously pursue the most promising discoveries and imaginative innovations in science and engineering. All are connected by common threads. They are DARPA hard driven by an inspired interdisciplinary staff and consistent with the office's long-term vision of creating paradigm shifts in defense capabilities. Hence, "imagineering" is a natural activity at DSO.

Our work is purposefully broad. We place no boundaries on the technical fields we might pursue. Many of my predecessors have said that DSO will explore any opportunity that does not claim to violate more than one law of physics. However, in these more contemporary times, we have chosen several endeavors that aggressively challenge our understanding of those laws, including sonoluminescence, the generation of mysterious bursts of high energy from the collapse of bubbles generated via sound waves.

Like Jason and the Argonauts, we do not fear the unknown and we relish exploring the unknowable, even if it means traveling to the outer limits of space.

For the foreseeable future, DSO is putting special emphasis on four distinct areas of exploration.

- The Brain Machine Interface, a small part of which directly addresses the challenge of moving beyond acting on thoughts to having thoughts that act

- Logistics technologies that create a world where self-sustaining replaces just-in-time provisioning

- Enhancing human performance where the slogan "Be all You Can Be” takes on a new dimension

- Exploiting complex systems where we move beyond accepting intractability to discovering and exploiting mathematical structure.

Immediately following me, Steve Wax, Joe Bielitzki, Doug Cochran, Valerie Browning, and Eric Eisenstadt will describe some of the approaches we will be taking in transforming these four initiatives into tangible opportunities. Their presentations will illustrate how DSO harvests science and engineering for developing paradigm-shifting technologies.

Historically, DSO has reaped huge returns from the areas of material science and mathematics. However, biology, also an exciting platform, is pregnant with potential for developing revolutionary change. We will make biology DARPA's future historical strength. DARPA's biology vision currently has four broad themes:

- Protecting human assets
- Enhanced system performance
- Enhanced human performance
- Creation of the tools for enabling new capabilities in the life sciences arena

Protecting human assets is about making the effects of a biological attack inconsequential. Success requires the design and fabrication of material, diagnostics, sensors, and therapeutics that address current and future threats posed by biological and chemical warfare agents. This initiative will continue to concentrate on next-generation threats, both known and unknowable. In the future, protecting human assets will include an overlay with computational models that predict and describe biological structure, function, and consequence.

Enhancing system performance, as Steve Wax will elaborate, is, in part, about making mechanical systems as autonomous and adaptable as living things. This work is not just for the Wizard of Oz, but for everyone who dares to leverage biology to provide enhanced warfighting capabilities. Solutions for hard defense problems such as denial-of-area access and signal extraction in cluttered backgrounds can be found in nature.

Eric Eisenstadt will elaborate on approaches to enhancing system performance that include using animal sentinels for sensing, identifying, and eliminating targets. He will discuss how we are exploiting neuro- and behavioral sciences to build intelligent machines and mechanical biomimicry for fault-tolerant mobile robotic systems.

Enhanced human performance, as Joe Bielitzki will explain, is born from the realization that with the emphasis on technology in the battle space the human is rapidly becoming "the weakest link." Soldiers having no physical, physiological, or cognitive limitations will be key to survival and operational dominance in the future.

The exoskeleton initiative will provide mechanical augmentation extending individual performance. Metabolically dominant warfighters of the future will be able to keep their cognitive abilities intact, while not sleeping for weeks. They will be able to endure constant, extreme exertion and take it in stride. Success in metabolic engineering will be visible, because I will be the first volunteer to be transformed. The Biovision's tools are the enabling technologies necessary to make the revolution real.

This emphasis on Biovision does not mean that DSO is becoming a bio-office. Quite the contrary. Our strength lies in the culture of cooperation that exists among multiple disciplines enabling us to work at the interface. Just consider what happens when physicists interact with biologists. The physicists I know often imagine measuring and controlling individual atoms or spins as the ultimate nanoscale switch for interrogating biological systems. Because the DSO menagerie houses two active physicists, it is only fitting that each has a unique and compelling path to fulfilling the ultimate nanoswitch dream, as embodied by the MOSAIC and BioMagnetICs programs.

The MOSAIC Program combines atomic force microscopy with nuclear magnetic resonance imaging to develop new instrumentation, computational tools, and algorithms for real-time static and dynamic three-dimensional atomic-level resolution of molecules and nanostructures in both living and inanimate things. The mathematical challenge of signal processing in MOSAIC, as Doug Cochran will discuss, is immense. Will we even recognize a single electron spin when we see it amongst all of the clutter?

The BioMagnetICs Program, as Valerie Browning will explain, is taking a different path. It will explore and demonstrate the utility of high-moment, nanoscale magnetics as a portable, robust, and highly sensitive transduction mechanism for monitoring and controlling biological activity at the cellular and, ultimately, single molecule level.

Imagine if, in spite of everything you know about the periodic table, you could create properties never known to exist . . . if design engineers, as they conceptualize a product, could be as unconstrained as chefs, by the performance limits of materials. For example, imagine magnets powerful enough to enable compact, light motors capable of propelling the navy ships and army tanks of the future. Imagine a material with a negative index of refraction that can focus and direct electromagnetic energy in ways never before dreamed possible.

The MetaMaterials initiative will accomplish this goal by engineering materials at sufficiently small-length scales so the physics of conventional materials—the very physics that limit their performance—no longer applies. MetaMaterials is demonstrating new understandings of small-scale physics and new process developments to design and assemble novel, bulk materials that defy the limitations of conventional materials. The more we learn about the physics of small scale, the more we see that revolutionary improvements in material performance are achievable. The generation once enthralled by MEMS has been replaced by one excited by nanotechnology.

However, for those of you who are tiring of both, we have something else to offer the imagination: engineering atoms beyond the nanoscale. Imagine a metal that forms without crystals, not even a mere nanocrystal! Such material depends upon special, short-range, atomic clusters arranged in a glass-like structure that yields the benefits of both metals and glasses: ultra-high strength, hardness, toughness, wear and corrosion resistance, and excellent blast and ballistic performance. These materials exist and are affectionately called structural amorphous metals. Not only do they exhibit self-sharpening behavior, which is important in the performance of ruthlessly efficient penetrators, but they also enable noncorrosive, nonmagnetic ship hull materials with substantially increased blast resistance. Materials such as these could mitigate the amount of damage sustained from incidents such as that encountered by the USS Cole.

Sometimes you have to be careful for what you wish—it might come true.

In preparing for the inevitable success of the Structural Amorphous Metals Program, we have to anticipate the challenge of fabricating such materials into useful devices and components without destroying their unique structure and properties. New machining technologies that allow the material to be processed while preserving its desired crystalless attributes are required. One approach to joining these metals is to develop friction stir processing for easily directed, localized modification of microstructure. In addition to joining local metals, friction stir processing can also increase strength and ductility by 100 percent and generate a 10-fold increase in fatigue resistance.

As for machining the incredibly tough new materials, why not imagine, as Flash Gordon did, a handheld, non-thermal molecular disintegrator. Or, as Dr. Evil contemplates, a waterproof laser.

The Femtosecond Laser (FLAME) initiative is taking laser diodes to extraordinary new levels of performance. This program will deliver such a device in time to begin machining the plates of amorphous metal as they roll out of the mills. In fact, the program has broken the previous world record for laser diode system energy output by nearly 100,000-fold, which means this laser diode will be able to ablate amorphous metals with ease.

Now that is DARPAESQUE!

Imagine if electrical circuits were printed on the frames of eyeglasses or interwoven with clothing. The Mesoscopic Integrated Conformal Electronics (MICE) Program will do this and more, including the ability to print ruggedized electronics and/or antennas on conformal surfaces, such as helmets and other wearable gear. MICE technologies will eliminate the need for solder, thereby greatly increasing the robustness of electronic circuitry, and eliminate the need for printed wiring boards, enabling significant weight savings for a number of military electronic platforms.

The program is developing manufacturing tools that directly write electronic components, such as resistors, capacitors, antennas, fuel cells, and zinc-air batteries that, by the way, have four times more volumetric power density than commercial batteries. MICE write speeds approach or exceed commercial printing technologies with significantly decreased processing complexity and cost. And you can play with these devices by depositing the appropriate number of quarters when you visit the DSO display booth in the adjacent hall. (All proceeds, minus a 10 percent office tax, go directly to funding new programs.)

If you have pet rocks and jumping beans, what is next? Well, just imagine—jumping rocks! The Piezoelectric Single Crystals Program exploits the discovery of a class of materials that provide a revolutionary improvement in converting an electrical signal into a mechanical motion. These rock-hard materials are able to change their shape under electric stimulus over 10 times more than conventional materials.

But why bother? In the Defense sector, these materials will lead to revolutionary advances in Navy sonar systems, Army helicopter rotor blade control, Air Force airfoil shape control, and Navy acoustic stealth applications.

For example, an innovative torpedo homing transducer element, which is three-tenths the size of present devices, has shown, in the laboratory, more than three times the bandwidth and a sound source level four times greater than the conventional device it will replace. In civilian markets, major impacts will be made in medical ultrasonic diagnostics imaging, optical switches in telecommunications, and precision machine tool control.

Did you know that a 5-person reconnaissance team packs 225 pounds of batteries? The Palm Power initiative is promising to deliver the equivalent power and energy in a mere 25-pound package by converting high-energy content fuels into electricity. For lower power requirements, we are busy tapping the redox potential of bacteria to power small electronic payloads.

Imagine if electronics were no longer about moving electron charge, but about moving electron spin. If you could do this, storage densities and processing speeds would increase by at least two to three orders of magnitude. Such is the mission of the Spins in Semiconductors Program. The SPINS Program has demonstrated long-lived electron spin coherence in semiconductors, which translates to very long spin-propagation distances. The project has also demonstrated that spin information can be programmed in femtoseconds and then can easily propagate across boundaries between very different semiconductors in a complex heterostructure without any loss of spin information. Furthermore, the program has demonstrated a light-emitting diode controlled by spin that emitted more than 85 percent circularly polarized light, and also discovered several new and technologically important ferromagnetic semiconductors with transition temperatures above room temperature.

However, nuclear and electron spin have another amazing property: they strictly obey the laws of quantum mechanics. Spins combined with quanta of light can be used to beam information ultrasecurely, by teleportation—just like Scotty beaming Kirk on Star Trek.

DARPA's QuIST project is developing not only a quantum internet, but a quantum computer that can solve in a matter of minutes problems that would take the best conventional computer billions of years to complete.

This is not science fiction, but science action.

And to finish where we started—imagine if nuclear fusion could be a tabletop experiment. Take one flask, add deuterated acetone, bombard with neutrons, and shock with sound waves. For sure you get sonoluminescence, but will you also get tritium and high-energy neutrons; it is imaginable, but currently in hot dispute.

However, by the next DARPATech, we will share the results at Sea World, where fantasies sometimes become wet.

And now, please help me welcome from the primordial waters, Steve Wax, our second metabolically dominant warrior!