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Brain Machine Interface

Our office director, Michael Goldblatt, briefly touched upon the Agency's bio vision and its four components: enhancing system performance, protecting human assets, enhancing human performance, and developing new tools for biology.

As we bring this brief overview of the Defense Sciences Office to a close, I'm pleased to have the opportunity to describe our newest and boldest initiative in human performance enhancement—the Brain Machine Interface. This program exemplifies how the office coalesces its expertise in materials, biology, and mathematics to create imaginative new opportunities that live at the interface of multiple disciplines.

Picture a time when humans see in the UV and IR portions of the electromagnetic spectrum, or hear speech on the noisy flight deck of an aircraft carrier; or when soldiers communicate by thought alone. Imagine a time when the human brain has its own wireless modem so that instead of acting on thoughts, warfighters have thoughts that act. Later during DARPATech, you will hear from IPTO about efforts to create intelligent machines.

Our Brain Machine Interface Program is about giving machine-like capabilities to intelligence, asking the brain to accommodate synthetic devices, and learning how to control those devices much the way we control our arms and legs today. Our path to realizing this vision is an interdisciplinary one—drawing from DARPA's foundational investments, combining the best of materials science, mathematics and, of course, biology.

The brain's performance is dynamic and amazing. It contains perhaps as many as 100 trillion connections; this is vastly more than the mere 55 million transistors on a Pentium 4 chip. Understanding how these connections are used to process information and control behavior is one of the great challenges of our time. DARPA is exploring the brain from a number of dimensions, from pharmacology and physiology to learning and behavior.

Several efforts are looking at improving the ability of the brain to process and retain data either by improving knowledge visualization or by active feedback and monitoring of the brain's ability to capture information and record data to memory. Other efforts are evaluating target sites and molecules for pharmacological intervention in cognitive processes.

Several programs are drawing on DARPA's strength in material science to develop devices that are orders of magnitude denser than those currently available. And, most important, several initiatives are leveraging DoD's historical ability to locate the data within noisy environments. Our unique signal processing capabilities will be deployed to help us decipher the language of the brain as we learn to record the chatter of millions of neurons communicating with one another in the language of action potentials, local field potentials, and chemical signals.

Beginning almost 2 years ago, *Science and Nature* began featuring articles from a project in Alan Rudolph's Controlled Biological Systems Program that reveal that honeybees translate optical flow data into spatial coordinates as a way to communicate the location of a food source to their hivemates. So insects use optical flow processing strategies in motion detection to navigate with high maneuverability and speed when chasing targets, avoiding collisions, and finding reproductive mates.

We have mimicked this capability in silicon by engineering microchips that control small, unmanned vehicles with the maneuverability of insects. We have demonstrated an autonomous helicopter, which can hover and do terrain following and collision avoidance at high speeds using optical flow. We also plan on using the chip in a 1-centimeter long micromechanical flying insect.

And finally, to get the most bangs for our buck, we have just begun to partner with the Navy at China Lake to place a biomimetic seeker on a hydrorocket. We are betting that a fairly low-resolution rocket using biologically inspired signal processing algorithms on the front end could be used to find and hit a moving target with greater accuracy.

The harbinger of our Brain Machine Interface Program began with our foray into the creation of a wireless brain modem for a freely moving rat. Here, we are able to create, in real-time, at a standoff distance, interactions with the brain to allow us to control the motor behavior of a rat. The objective of this effort is to use remote teleoperation via direct interconnections with the brain. These implants can last in the brain for a year or more and are used to steer the rat by providing positive rewards to the rats (or other animal systems) as they perform in accordance with certain desires. As this movie of Roborat demonstrates, he can be directed to move in unusual and quite capable ways.

Here, Roborat is demonstrating that we can obtain the kind of mobility and dynamic capability in locomotion that could be very useful in search and rescue or other surveillance opportunities. Most roboticists can appreciate that there is nothing in their labs that can move like this.

The next obvious move in this direction is to use higher density interconnects to create and collect information from the brain in other regions associated with sensory input. Why? As just one example, imagine if we could plug into the olfactory cortex region of the brain and interpret from a distance what an animal smells. Is that cocaine? Explosives? A rat-fearing human?

You may have read recently about clinical experiments using a retinal implant that utilized a prosthetic device carrying an array of only 16 elements that enabled blind patients to discriminate light from dark and shadows. But to provide a blind person with the ability to see images, prosthetic vision devices require much higher resolution. We are about to find out what happens when you plug high-density interconnects into the visual sensory system.

Another project in the Controlled Biological System Program—a collaborative effort between investigators at Johns Hopkins University and the Naval Research Laboratory—developed a nanochannel glass array containing 3,200 elements that can communicate with the retina compared to the 16 that were used in the current experimental devices. Images from a digital camera will be transferred via the high-density nanochannel array to the retina and to the brain, where an image will be created. Wires are now used to transport images from the digital camera to the nanoarray. In the future, however, images will be transmitted wirelessly. We anticipate that within a year or so, the new high-resolution device will be in human clinical trials.

These and other projects involving high density interconnects with the brain seduced DARPA to further investigate interactions with other regions of the brain. We are creating new high-density interconnects for brain machine interfaces that will allow us to monitor the brain patterns associated with a wide variety of behaviors and activities relevant to DoD.

And now we are equipped to aggressively begin moving beyond acting on thoughts to having thoughts that act. Hence, the recently initiated Brain Machine Interface Program. This program was launched to demonstrate the use of brain activity to command, control, actuate, and communicate with the world directly through brain interfaces. Initially theses interactions are with peripheral devices, but ultimately it may be interaction with another brain. The first peripheral devices were robotic arms.

Three research groups supported by DARPA recently demonstrated that when a monkey is trained to do a peripheral motor task, such as reaching for a piece of fruit, the executive command activity associated with that behavior can be intercepted and then used to control artificial devices that execute the same movements. In a closed loop, the monkey can learn to drive a peripheral device—or a cursor on a screen—using only its brain's executive motor commands.

We are pushing hard to study how to provide the sensory feedback directly to the brain of the experience of that peripheral device. The Brain Machine Interface Program is asking the brain to accommodate synthetic devices and learn how to control these devices much the way we control our arms and legs.

There are a number of important new materials and signal-processing questions that we will be asking in terms of controlling more complex kinds of DoD-related technologies, such as exoskeletons or airframes. Additionally, even the most aggressive proponents of the brain machine interface vision recognize the long-term need to be able to noninvasively capture the brain's internal communications, to listen and understand without having to implant hardware.

Who knows . . . if we can eavesdrop on the brain,maybe we can sort out deceit from honesty, truth from fiction. What a lie detector that would be!

The skills required to make this happen—math, biology, material science, physics, and imagination—represent many of the strengths of the Defense Sciences Office.

Thank you.