DARPA calls for innovative research concepts and Breakthrough Technologies for National Security Vision 2045

DARPA has identified some of the technical, economic and geopolitical shifts that are posing potential threats to U.S. preeminence and stability. On the technical front is increasing availability on the global market the weapons technology, biological and chemical threat capabilities, advanced microelectronics and cyber- and space-related technologies, the capability of social media to spread misinformation and blossom into deadly crises. In the future off-the-shelf gene-screening and -splicing kits will make the tools of genetic engineering accessible to many.

Geopolitical challenges involve peer adversaries and other nation states and encompass conventional-weapon threats as well as concerns about nuclear proliferation. Other challenges stem from terrorist groups and other non-nation-state actors.

Global social, economic and environmental trends are affecting governments and populations. worldwide. These include demographic shifts, such as population growth and urbanization in developing countries and the aging of populations in developed countries; religious and cultural shifts, including the rise of violent extremism; resource imbalances and shortages, including especially those involving energy sources and fresh water; stresses related to climate change, including sea-level rise, drought and flooding, with special concerns about potential impacts on infrastructure and agriculture; and the growing potential for fast-moving human and animal pandemics and other health threats, with their associated risks of economic depletion, loss of trust in leadership, and

social unrest.

“The pace at which we can develop and field new military systems is really important for who wins the next war,” Steven Walker, deputy director for the agency said. “We’re focused here at DARPA on rethinking how we develop new military systems. Some of our systems today are extremely capable, the most capable in the world, but they are very complex, they’re costly and they take a long time to develop and field. So at DARPA we’re spending a lot of time rethinking how we might develop these systems.

Breakthrough Technologies for National Security

The biennial report, dubbed “Breakthrough Technologies for National Security”, outlines the agency’s priorities for dealing with these challenges over the next several years.

Some of the main areas that DARPA plans to focus its strategic investments are maintaining Assuring dominance in the electromagnetic spectrum, Maintaining air superiority in contested environments, improving weapons that can operate in a GPS-denied environment, leading development on hypersonics, mastering the so-called “information explosion,” cheaper launch solutions for space assets, harnessing biology as technology, maritime agility, new ground vehicles, counter-terrorism technologies, and rethinking military systems,

1. It’s Assuring Dominance of the Electromagnetic Spectrum by developing a family of highly precise and accurate navigation and timing technologies that can function in GPS-denied environments, advanced algorithms, fully configurable RF systems and new electronic platforms.

2. Maintaining Air Superiority in Contested Environments through development of air platforms with greater range,

survivability and payload capacity and through Integrated system of intelligence, surveillance and reconnaissance (ISR), weapons, communications, electronic warfare, cyber and other advanced technologies. Leading the World in Advanced Hypersonics for delivering precise warhead at hypersonic velocities.

3. Asserting a Robust Capability in Space by enhancing the capabilities of space domain awareness and capability to launch satellites from virtually anywhere with just 24 hours' notice and at a fraction of current costs by means of reusable first-stage and space-plane systems.

4. Enhancing Maritime Agility by developing an unmanned maritime surface vessel to chase submarines; and novel technologies to enable take-off and landing of long-endurance unmanned aerial vehicles aboard smaller ships.

5. Exerting Control on the Ground against terrorists and insurgents by helping ground forces expand their reach, situational awareness and maneuverability and a new-generation combat vehicle with enhanced mobility and survivability.

6. Counter CBRNE threats by developing and testing networked, mobile and cost-effective nuclear- and radiological-weapons detectors that can easily be deployed to provide real-time surveillance over city-scale areas.

7. The agency is mastering the information explosion by developing novel approaches to derive insights from massive datasets and powerful big-data tools for mapping behavior patterns at scale, including algorithms to quickly identify anomalous threat-related behaviors of systems, individuals and groups.

8. The Agency is also developing technologies to provide **comprehensive awareness and understanding of the cyber battlespace and automated computational capabilities** to detect hidden causal relationships; Search technologies for

discovery, organization and presentation of domain-specific content; software to detect, classify, measure and track the spread of ideas and concepts on social media; and methods for automating the analysis of photos and videos.

9. DARPA is Building Trust In Information Systems by developing technologies for more effective and user-friendly user identification and authentication technologies; secure mobile operating systems, automated cyber defense capabilities and new approaches to building trusted systems from an inherently untrustworthy global supply chain.

10. Harness biology as technology by accelerating progress in Synthetic Biology , developing technologies to harness biological systems for synthesizing compounds, and create materials with novel properties.

11. It is outpacing the spread of infectious diseases like Ebola, through development of genetic and immunological technologies to detect, diagnose and treat infectious diseases with unprecedented precision and rapidity,

12. Mastering New Neurotechnologies like implantable neural interfaces for human clinical use to bridge gaps in the injured brain, help overcome memory deficits and precisely deliver therapeutic stimuli in patients with neuropsychiatric and neurological disease; and systems to provide sensor-enabled feedback from prosthetic hands to the nervous system to provide enhanced dexterity and even the sense of touch for amputees.

13. DARPA is also providing thrust to core competencies like Applying Deep Mathematics for developing new mathematical approaches and mathematical tools for representing, designing, and testing extremely complex systems.

14. Inventing New Chemistries, Processes and Materials facilitate the assessment and adoption of novel materials in practical settings, new modeling and measurement tools for

evaluating and predicting functional reliability and is developing low-cost fabrication methods to allow customized and small-volume production of materials.

15. Harnessing Quantum Physics to bring about new capabilities in navigation and timing, chem-bio detection, communication and information processing, and metrology, and unprecedented degrees of control over the electromagnetic spectrum, critical for electronic warfare and other applications.

Forward to the Future: Visions of 2045

A big part of DARPA's mission is to envision the future and make the impossible possible. In Oct 2015 as the "Back to the Future" day approached, DARPA turned to social media and asked the world to predict: What technologies might actually surround us 30 years from now? Some of the highlights from the responses were:

• **Space:** Interplanetary and interstellar travel, including faster-than-light travel; missions and permanent settlements on the Moon, Mars and the asteroid belt; space elevators

• **Transportation & Energy:** Self-driving and electric vehicles; improved mass transit systems and intercontinental travel; flying cars and hoverboards; high-efficiency solar and other sustainable energy sources

• **Medicine & Health:** Neurological devices for memory augmentation, storage and transfer, and perhaps to read people's thoughts; life extension, including virtual immortality via uploading brains into computers; artificial cells and organs; "Star Trek"-style tricorder for home diagnostics and treatment; wearable technology, such as exoskeletons and augmented-reality glasses and contact lenses

• **Materials & Robotics:** Ubiquitous nanotechnology, 3-D printing and robotics; invisibility and cloaking devices; energy shields; anti-gravity devices

• **Cyber & Big Data:** Improved artificial intelligence; optical and quantum computing; faster, more secure Internet; better use of data analytics to improve use of resources

DARPA researchers from various fields shared their visions of 2045, and why getting there will require a group effort with players not only from academia and industry but from forward-looking government laboratories and agencies:

• **Pam Melroy,** an aerospace engineer, former astronaut and current deputy director of DARPA's Tactical Technologies Office (TTO), foresees technologies that would enable machines to collaborate with humans as partners on tasks far more complex than those we can tackle today.

• **Justin Sanchez,** a neuroscientist and program manager in DARPA's Biological Technologies Office (BTO), imagines a world where neurotechnologies could enable users to interact with their environment and other people by thought alone.

• **Stefanie Tompkins,** a geologist and director of DARPA's Defense Sciences Office (DSO), envisions building substances from the atomic or molecular level up to create "impossible" materials with previously unattainable capabilities.

DARPA BAA for innovative basic and applied research

DSO Office has inviteed proposers to submit innovative basic or applied research concepts that explore Physical and Natural Systems, Human-Machine and Social Systems, and/or

Math and Computational Systems through the lens of one or more of the following technical domains: Complexity Engineering, Science of Design, Noosphere, Fundamental Limits, and New Foundations.

Technical Domains and Research Topics of Interest

Complexity Engineering: Understanding the principles of organization and control, the transformation or harnessing of complexity, and the implications of such methods. Example topics of interest relate to

(1) complex sensing networks to protect cities and surrounding metropolitan areas from chemical and biological threats;

(2) new strategies to protect natural resources;

(3) new concepts in war-gaming and conflict simulation; and

(4) design, synthesis and characterization of materials trapped in non-equilibrium states.

Science of Design: The study of processes and methods of design, i.e., ways in which we transform a given state of the world into a preferred one using tools and technologies. Example topics of interest relate to

(1) the creation of novel optics with metamaterials;

(2) strategies for building microscopic, distributable cameras;

(3) design concepts in synthesis and use of nonlinear materials;

(4) digital representations of engineering information that can anticipate failure, evolve, and merge with other designs; and

(5) mathematical optimization and its use in design.

Noosphere : Creating, measuring, and modeling foundational questions regarding humans, human-machine interactions, and society.

Example topics of interest include:

(1) understanding the limits of human perception;

(2) developing a more detailed understanding of human variability; and

(3) implications and applications of virtual reality and augmented reality technologies.

Fundamental Limits: Creating, measuring, and modeling the boundaries of our current understanding of the natural, physical, mathematical, and computational sciences using rigorous and reproducible, hypothesis-driven, scientific methods.

Example topics of interest include:

(1) understanding the limits of natural intelligence and boundaries of machine intelligence,

(2) establishing the limits of quantum effects, and

(3) determining the limits of chemical-based propulsion.

New Foundations: Discovering new natural phenomena or developing entirely new approaches to address scientific or technical challenges. Topics in this area will uncover new scientific or engineering principles. This area of interest differs from Fundamental Limits in that Fundamental Limits seeks to define the boundary conditions of known phenomena, whereas New Foundations is focused on uncovering the unknown.

Topics of interest are expected to evolve quickly, but current examples include:

(1) correlating effects of uncertainties in materials,

(2) development of knowledge and tools associated with designer metals,

(3) new human-computer interaction concepts that enable improved human-machine symbiotic decision-making,

(4) exploring alternative models to computation,

(5) strategies to leverage the Earth's magnetic field, and

(6) new concepts in ultra-rapid and high magnitude energy transduction.

DARPA Tech Forum Previews National Security Future

In Sep 2015, More than 1,400 scientists and engineers engaged Defense Advanced Research Projects Agency's "Wait, What?" , a forum on future technologies … on their potential to radically change how we live and work, and on the opportunities and challenges these technologies will raise within the broadly

defined domain of national security.

DARPA Director Arati Prabhakar told the audience that the ultimate goal of the forum – in line with the agency's mission –, "is to make the pivotal early investments in breakthrough technologies to create huge new possibilities for national security."

MIT Lincoln Laboratory demonstrates novel laser at technology expo

Researchers from MIT Lincoln Laboratory's Laser Technology and Applications Group were invited by DARPA to Wait, What? to demonstrate the advanced, 101-element optical phased array that they had developed under the agency's sponsorship. At the Laboratory's booth, the engineers conducted demonstrations to highlight the capability of this unique fiber laser that coherently combines an array of 101 optical emitters to produce a powerfully bright single beam.

A high-brightness, concentrated beam can enhance various applications; for example, metal can be cut or welded with a laser if the beam intensity is high, and a high-energy beam that can propagate over longer distances than can a diffuse array of beams could improve the range of laser communication systems.

The researchers explained to visitors that the challenge in developing this laser is to have the individual beams from all 101 emitters arrive at precisely the same time to a designated point in the far-field plane. To achieve this simultaneous arrival, all the path lengths of the 101 emitters need to be matched to much less than a 1 μm wavelength (less than 1/50th the diameter of a hair). The research team solved the synchronization of the beams by maneuvering a set of phase modulators, which sped up or slowed down the beams such that they all arrived together to create a bright central spot at a

target.

The team also demonstrated phase-control algorithm that enabled the phased-array beam to track the moving target. After they showed visitors how to steer a beam and how to compensate for the random fiber path-length variations in an environment that does not have turbulence and atmospheric disturbances, the Lincoln Laboratory team demonstrated beam propagation in a more challenging environment.

They injected hot air into a segment of a beam path so viewers could watch on a monitor how the beam degraded because of the disturbance to it caused by the air's motion. "Our control algorithm compensated for the disturbance by iteratively applying a correction to all 101 emitters in order to optimize the central intensity of the beam," said Montoya, who further explained that the algorithm predistorts the 101-element beam before it propagates through an atmospheric disturbance.

Neuroscience Milestones

DARPA program manager Justin Sanchez presented preliminary findings from the RAM program at a DARPA-sponsored event in St. Louis called "Wait, What? A Future Technology Forum. " Initial results indicate that it is indeed possible to capture and interpret neural codes coming from the brain during memory encoding and retrieval, and improve recall using targeted electrical stimulation of the brain.

DARPA reports that a 28-year-old paralyzed for more than a decade from a spinal cord injury is the first person to be able to "feel" physical sensations through a prosthetic hand connected directly to his brain. He also could identify which of his mechanical fingers was being touched.

In the second milestone, scientists from DARPA's Restoring Active Memory program have found that targeted electrical

brain stimulation can improve memory.

Electrical arrays implanted in the brain's memory centers show promise for helping patients improve scores on memory tests. The research, DARPA says, could lead to therapies for wounded warriors and others with memory deficits caused by traumatic brain injury or disease.

The research is addressing the important issue of the ideal timing of electrical stimuli involved in the neural codes. "Should we provide electrical inputs when the lists are first being taught and memorized, or should we stimulate when the person is working to recall those items? We still have a lot to learn about how the human brain encodes declarative memory, but these early experiments are clarifying issues such as these and suggest there is great potential to help people with certain kinds of memory deficits," Sanchez said.

Space Robotics

Pamela Melroy, deputy director of DARPA's Tactical Technology Office and a former astronaut, discussed a DARPA project called Phoenix that involves building space robotics in geosynchronous Earth orbit, or GEO.
GEO is a stable region of space 36,000 kilometers, or 22,370 miles, from Earth. Because the orbital period matches almost exactly the time it takes for Earth to rotate on its axis in a day, Melroy said, objects in GEO seem to be hovering directly over one place on the planet.

Because GEO is a stable environment for machines – but hostile for people because of high radiation levels – DARPA thinks the key technology there is space robotics.
As part of Phoenix, DARPA is building a robotic arm like the one that helped build the International Space Station but with greater levels of automation and safety, Melroy said. It has, for example, robot reflexes and compliance control to minimize

the risk of debris from collisions.

Port of Call

“We think this is a critical capability to building a transportation hub that allows transportation to and from Earth’s surface, from low Earth orbit to GEO, and even beyond Earth orbit,” she added.

Space capabilities are not about a single monolithic satellite with a few capabilities, Melroy said. DARPA sees them as creating a vibrant, robust ecosystem that involves transportation, repair, refueling, upgrading and on-site construction.

“So look at the great seafaring port cities in the world for inspiration,” the former astronaut said, “and imagine a port of call at 36,000 kilometers.”

Autonomous AI?

Another presenter was Tom Dietterich, professor of computer science at Oregon State University and president of the Association for the Advancement of Artificial Intelligence.

During a talk on artificial intelligence, he discussed autonomous AI systems like those that operate some hedge funds, and like the fully autonomous financial systems that run Wall Street trading. Other examples are self-driving cars and automated surgical assistants. AI is enabling technology for such applications, all of which involve high-stakes decision-making about matters of life and death, severe injury or huge amounts of money, Dieterrich said.

Some people are afraid of the technology, he added, as indicated by Stephen Hawking’s recent warning that robotic AI

could end mankind and Elon Musk's statement that AI is civilization's biggest existential threat.

Dieterrich says such fears are fed by misconceptions, one of which is that someday computers will become smarter than people and then one day they achieve self-awareness and turn against humanity, as did the AI network Skynet in James Cameron's 1984 film "The Terminator."

Smarter than People

"In fact, our tool AI systems [for example, personal assistants such as Apple's Siri or Microsoft's Cortana] are already much smarter than we are," he said. "We wouldn't use them if they weren't superior to people."

But AI systems won't be fully autonomous unless people design them to be that way, Dieterrich said, and give the systems access to resources like money, electrical power or materials.

"When we give them control over those resources, that's when we face a challenge," he added. "So I think the danger of AI is not so much in artificial intelligence itself … but in the autonomy. What should we give computers control over?"

Dieterrich himself doesn't think people should create fully autonomous systems — those over which they have no control. And when people do need the faster-than-human speed and autonomy of computer systems to trade hedge funds or respond to cyber attacks, he says, they should always leave themselves the option of pulling the plug.

Are We Alone?

Near the end of the forum, the founding Director of DARPA's Biological Technologies Office Geoff Ling moderated a panel

titled “Are We Alone and Have We Been?” During the discussion, a paleontologist-molecular geneticist, a biophysicist and an astronomer discussed the likelihood and implications of finding other life in the universe.

As the session wrapped up, Ling observed that some in the audience might wonder why a national security research and development organization like DARPA would focus on extraterrestrial life.

“DARPA has a unique mandate,” he explained. “We need to think about things that others really don’t. Where is the next surprise that will come our way? Where’s the next surprise that we can generate? You don’t know unless you ask, and you won’t find unless you explore.”

The world of biology is young relative to the fields of physics, mathematics and chemistry, but biology is a rich discipline and a place, Ling said, “where surprise is waiting for us.”

Not to engage the science and engineering community in such discussions, he added, “is not in DARPA’s best interest – not in the nation’s best interest. So if somebody’s going to do it, let it be DARPA.”

References and resources also include:

https://www.fbo.gov/index?s=opportunity&mode=form&id=bd42f6bf1369fa510ba083988f42ca61&tab=core&_cview=0