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FROM THE EDITORS

Welcome to the November 2017 edition of the *Defense Dossier*, the e-journal of the American Foreign Policy Council. In this issue we focus on the intersection of high technology and national security, and on the potential emerging technologies that will have an impact on military affairs over the course of the next few decades.

For the past several years, the U.S. military has operated under significant fiscal constraints – a state of affairs that has limited the investments made on promising new technologies with applications for the national defense. Such technologies are proliferating, however, and the United States must move quickly and resolutely to capitalize on them, lest its technological edge erode further. The articles in this issue discuss the potential role and impact that several new technologies can have on national security – including directed energy weapons, drones, human enhancement projects and artificial intelligence. They provide a glimpse into the changing nature of today's battlefield, and into what the United States must do in order to persevere on it.

Sincerely,

Ilan Berman
Chief Editor

Richard Harrison
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Emerging Technology and Security—Looking to the Future

Richard Van Atta

Over the past 75 years, an explosion of innovation on a global scale has increasingly challenged America's traditional domination of emerging technologies. This shift has been driven by emerging technologies themselves—particularly those in information processing and communications. In the past, what could be fostered and brought to fruition in one country took considerable time and effort to be realized in others. Today, by contrast, technologies rapidly disperse by way of the internet, and can be replicated quickly using advanced computing capabilities.

Major advances in technology have transformed human affairs and had concomitant impact on how nations have engaged one another. However, the full implications of emerging technologies for national economies and warfare usually manifest themselves over time. Exactly how long is unclear; the time from the initial concept and early prototypes of a new technology until its impacts are felt on the economy, society, and security vary greatly, and depend on which technologies are developed and by whom. Moreover, those who initially conceive of the technology are not always those that ultimately benefit from it. Nations have competed with others over the development of technologies, and governments have formulated policies and made investments in order to achieve a competitive posture in emerging technologies.

The Arc of American Superiority

None of this is new. During World War II, the race for superiority in new weapons became central to the Allied and German strategies. Germany initially aimed to fight a short war, and thus did not give priority to developing new weapons. The Third Reich underestimated the ability of the Allies to innovate and introduce new weapons. The openness and partnership among scientists, technologists, military, and industry in and between the U.S. and UK gave them a key advantage relative to Germany and Japan, who were unable to use science and technology effectively.

The United States met its World War II enemies with prodigious production of war materiel, but also technological innovations from the concerted and coordinated efforts of thousands of scientists, engineers, and technicians, with such developments as radar, nascent information technologies, and the invention of the atomic bomb. These technologies provided a crucial advantage. After a post-war respite, the conflict with the Soviet Union led the United States to again invest heavily in basic and applied research, as well as in advanced military systems in which emerging electronics, materials, propulsion, and other technologies could be utilized by a robust and diverse domestic industrial base. In response to the Soviet Union's launch of the Sputnik satellite in 1957, a new organization, the Defense Advanced Research Projects Agency (DARPA) was created explicitly to pursue emerging technologies for national security—the first organization with such a charter.

In the 1960s, Warsaw Pact offensive forces and integrated anti-aircraft defenses in Europe substantially increased and improved, and the Soviet Union achieved rough parity with the United States in nuclear weapons. President Richard Nixon and National Security Advisor

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> Secretary of Defense Harold Brown and Under Secretary of Defense for Research and Engineering William Perry conceived and implemented "the Offset Strategy." The purpose was to leverage U.S. leadership in advanced technologies to create qualitatively superior military equipment.

Henry Kissinger were concerned that these advances undermined the credibility of NATO's defensive plans. In this context, technological superiority became an explicit, fundamental precept of U.S. national security posture. Subsequently, Secretary of Defense Harold Brown and Under Secretary of Defense for Research and Engineering William Perry conceived and implemented "the Offset Strategy."[1] The purpose was to leverage U.S. leadership in advanced technologies to create qualitatively superior military equipment, offsetting the Warsaw Pact's far greater numbers of troops and heavy weapon systems. This technology-based national security strategy guided the Department of Defense's (DoD) technology and weapons systems investments until the fall of the Soviet Union in 1989, and positioned the United States as the unquestioned leader in military capabilities.

Through a set of focused technology thrusts initiated by the Defense Advanced research Agency (DARPA), starting in the mid-1970s, the United States disrupted the military capability equation by fielding transformative capabilities, such as stealth, standoff precision strike, and unmanned aviation systems. These "change-state" systems emerged from proof-of-concept experiments driven by DARPA and were implemented with hands-on support and encouragement from the Office of Secretary of Defense (OSD). In the 1970s, DoD, again largely through DARPA, also pioneered the development of advanced "dual use" information technologies (ARPANET, artificial intelligence, augmented reality), sensors (distributed sensor networks), and materials (super alloys, carbon fiber and metal matrix composites, electronics materials) that transformed the economy and society, as well as defense.[2]

In 1991, Operation Desert Storm in Iraq dramatically demonstrated the combined effects of stealth; standoff precision strike; and advanced intelligence, surveillance, and reconnaissance. These were exactly the kind of capabilities envisioned in the Offset Strategy: replacing the "fog of war" with "situation awareness"; enabling weaponry to be smaller, lighter, and more accurately delivered from long distances; and employing new weapons concepts and operational approaches that could more easily overcome traditional defenses. Taken together, they represented a "Revolution in Military Affairs" (RMA), providing a fundamental shift in the ability to exercise military control with better information and greater ability to plan quickly, coordinate effectively, and attack accurately.[3]

An Eroding Edge

With the collapse of the Soviet Union, policymakers began to understand that the Pentagon needed to adjust to the discontinuity of the end of the Cold War, as well as to "a profound change (that) has taken place in the global technology base."[4] By the 1990s, commercial research and development (R&D) had outstripped U.S. defense R&D in most of the technology areas that underlay the RMA, and these commercial technology capabilities were growing rapidly worldwide. This combination of changes demanded new thinking in defense policy focusing on improving the linkage between DoD and commercial industry.

A global technology challenge began to emerge as other countries implemented policies seeking technological parity with the United States. They were aided by advances in information and communications technologies, as well as transportation, which have helped to make the world substantially more accessible by dramatically reducing the costs and the time associated with human interaction and commerce over long distances, thereby facilitating unprecedented collaborations and partnerships.

The results have been profound. Although the U.S. advantage in employing such technology remains

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impressive, America's edge in the development of new military technologies has declined. As one report notes, the "…once dominant competitive advantage has been eroding" and now presents serious operational challenges for U.S. military forces.[5]

Grappling with Parity

The rise of global competitors and the vanishing American lead in emerging technologies is a pressing security challenge for the U.S. Related to this is the issue of the DoD's increasing reliance on global commercial technology. A third concern is the growing concentration of technology development in the hands of a few companies (such as Amazon, Apple, IBM, Samsung, and Google) that are using their market power to capture leading technologies, while Chinese companies are aggressively acquiring Western tech companies and developing their own advanced technologies, including artificial intelligence, robotics, unmanned autonomous systems, nanotronics, bioengineering, and human enhancement. Underlying most of these are "enabling" technologies, such as advanced materials.

Many of these raise fundamental implementation and ethical issues, ranging from questions about who will manufacture the products and systems to whether it matters for U.S. security if these are not manufactured in America.

At the core of these and other questions is a more fundamental query: does the globalization of military innovation require a new American approach? The U.S. defense enterprise has become more and more cumbersome, and key elements of innovation—balanced approaches to radical and sustaining innovation, focused technology development, and experimentation employing operational lessons learned, linked to requirements setting and acquisition—have grown apart. This has contributed to escalating costs, long timelines, and notable failures to field major systems. The challenge in innovating in the compressed cycles of globalized innovation is to draw these component parts closer together into an integrated, coherent enterprise. For this to occur, however, the current unwieldy bureaucratic process needs to be simplified and restructured around clear lines of authority and responsibility.[6]

Can we Maintain Technological Superiority?

Globalization and commercialization of science and technology (S&T) is a crucial security issue. To maintain a security advantage in the emerging global environment, new policy mechanisms are needed to help America's defense establishment to support S&T. Currently, DoD's S&T investments are small compared to those of commercial industry, which accesses the best of U.S.-fostered technology through multiple means. Moreover, most advanced science is globally dispersed, so the U.S. will need to consider how to best access and employ it.

During the Obama administration, then-Deputy Secretary of Defense Robert Work emphasized a renewed drive for innovation to maintain technological superiority—a paradigm that he and others dubbed the "Third Offset Strategy." But is this approach realistic and still pertinent today? The answer lies in three fundamental areas:

Issue 1: Understanding the Strategic Priorities

Military needs for war are constantly changing and warfare continues to evolve, requiring new capabilities. As an example, in today's wars the military may require new or better capabilities for "attacking elusive targets in complex terrain," establishing a quick reaction stabilization force, or countering WMD capabilities. Defense planners have a difficult job forecasting how wartime needs will change and what our adversaries will do to exploit weaknesses in traditional U.S. military advantages. It's important to understand U.S. vulnerabilities and make adjustments before enemies can exploit them. Table 1 presents the operational military challenges that the U.S. military will need to address in the coming years.

The strategic priorities summarized below outline concerns for the U.S. military in each domain (sea, land, air, space, and cyber). However, security issues that defense planners must consider also exist outside the military realm. Examples include the vulnerabilities of industrial, information, and energy infrastructures to cyberattack. Mechanisms for making technological investments in these areas should also be considered by defense planners, since damage to these private sector industries can significantly impact overall national security.

"It's important to understand U.S. vulnerabilities and make adjustments before enemies can exploit them.

Issue 2: Navigating Economic Uncertainties

One of the most scrutinized areas in the U.S. budget is the defense sector, which has long had programs that cost too much, take too long to deliver, and often arrive with less capability than originally planned. As mentioned in Table 1, the Army's Future Combat Systems program is a prime example of a poorly conceived defense program—one which may not even have been needed to begin with. Moving forward, it will be important for the DoD to develop the ability to properly identify and support essential defense technology needs.

Table 1: Strategic Priorities for the U.S. Military

Strategic Priority	Challenge potentially requiring S&T innovation
Fleet Protection	There is vulnerability to standoff attack—especially Carrier Task Groups.
Technology for Ground Forces	After the disastrous and costly failure of the Army's Future Combat System (FCS) in implementing ground force robotics, stronger consideration about the real technology needs for ground forces is necessary. In future wars, the military will need to forecast what type of ground forces are needed and how can technology support them effectively.
Air defense vs. Strike	With counter-stealth and increased air defense capabilities, air superiority and dominance may no longer be assured. The U.S. can consider instantaneous precision global strike as an option.
Space-asset defense	The U.S. must consider options to protect space assets given demonstrated capabilities by others, particularly China.
Cyber warfare and cyber defense	The emerging technologies of information and communications gave the U.S. fundamental advantage for decades, but this now raises the prospect of being an Achilles heel, and portends potential security disaster.

Once important capabilities or systems are identified, the military must adopt a more effective and affordable acquisition processes capable of delivering items in a reasonable time frame. A key issue is "time to product"; since DoD weapon systems can take more than a decade from conception to first deployment, identifying a solution to accelerate this timeframe is critical to mission success. A first step to altering the defense acquisition process may be revaluating how the U.S. Defense Industrial Base is utilized and determining what capabilities need to be assured. Moreover, a broad assessment of the role manufacturing plays in defense and security is needed to better understand what policies can help develop and implement the next generation of manufacturing in the United States.

Issue 3: Prioritizing Promising Emerging Technologies
While several emerging technologies have major implications for security, uncertainty exists over which variant will ultimately come to fruition. Additionally, many of the technologies now under development raise daunting ethical and technical questions. Some of the most promising but most concerning are displayed in Table 2.

Beyond these, many others have the potential to impact on national security. They include advanced manufacturing

Table 2: Promising Emerging Technologies [7] [8]

Emerging Technology	State of Maturity/Security Implication	Vulnerability/Area of Concern/Investment
Advanced Microchips	It is generally recognized that Moore's Law is no longer being achieved in the advancement of integrated circuits and that other technologies will be needed. May need to be considered a national security issue.[7]	Other countries may be developing spintronics, quantum computing, and neuro-synaptic biocomputing. Microelectronics purchased overseas may contain security flaws. Investments may be needed to counter these concerns.
Artificial Intelligence (AI)	AI is steadily penetrating both defense and civilian applications. This portends to reshape how decisions are made—perhaps raising the question of whether and when AI will overtake humans in making decisions. Commercial and military needs for accessing and using massive amounts of data for nearly instantaneous assessment and decisions is becoming a reality (see the article by Lemnios, et al, in this volume).	Today AI is weak compared to what some see as possible, Yet, controlling such advanced AI-based systems raises fundamental ethical questions. It is unclear how ethics should be addressed and by whom, and the U.S. should prepare to confront adversaries who may neglect the ethics entirely.
Robotics and Autonomous Systems	While the "rise of robots" has been projected by futurists for many years, the reality of such capabilities appears to be on the cusp. Yet, robotics in military systems have been rudimentary to date—essentially human-operated or simple autonomy. The value of "real robots"—including autonomous air weapons—in military applications is currently undetermined.	The defense sector will need to determine to what extent should military capabilities be turned over to collaborative cognitive systems, and redlines for how far should autonomy be allowed to go. The risk of not pursuing full autonomous systems will have to be weighed as U.S. adversaries move forward with them.[8]
Human Augmentation and Biologics	Understanding of biology at the micro and macro levels has increased exponentially over the past decade. Daunting questions are being raised regarding how far to pursue and implement biological modifications. Genetic modification using CRISPR offers the prospects of overcoming genetic defects, but also the ability to improve human capabilities.	U.S. defense planners will need to determine how far human augmentation should be allowed to go, with the understanding that adversaries are/will likely pursue these activities. It will be important to discern if there are any realistic mechanisms that can be developed to govern such possibilities.

Table continues on page 8.

Emerging Technology	State of Maturity/Security Implication	Vulnerability/Area of Concern/Investment
Nano-MEMSification and Nanobiomechatonics	Micro-electrical mechanical systems (MEMS) are miniature devices based on semiconductor production processes that perform a wide range of physical functions. These have become ubiquitous, but there is a prospect that developing these at the nano-level and integrating them with biological systems could have huge impacts—ranging from bio-sensors for health monitoring, to "Internet of Things," to enabling highly sophisticated robotics with human-like dexterity. Many of these will combine miniaturized sensors with processing and activation capabilities.	The potential impacts of this group of technologies may warrant the focus of a major "enabling technology" investment.

technologies, such as additive manufacturing (3-D print-ing), atomically precise manufacturing, and metamaterials; a broad range of energy technologies for powering systems more effectively and efficiently (all robotics and autonomous systems will require power); and directed energy weapons. Advanced nations are exploring a vast range of emerging technologies, and gauging how to develop and use them in order to gain advantages for their economies and national security.

> Once important capabilities or systems are identified, the military must adopt a more effective and affordable acquisition processes capable of delivering items in a reasonable time frame.

Grave New World

When the U.S. first focused on discovering, developing, and implementing emerging technologies 75 years ago, it had a fundamental lead that allowed it to attain a position of technological superiority. This is not the case today. U.S. security requires well-focused investments in both developing and implementing these technologies. Nevertheless, we cannot go it alone, and we will have to make difficult choices. Simply put, the world of innovation has changed; DoD's management of innovation to sustain U.S. technological capabilities for the future must change as well. ■

Endnotes

[1] See Richard Van Atta, Michael Lippitz, et al., "Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs," Institute for Defense Analyses IDA Paper P-3698, April 2003, for a discussion of the technological and operational innovations for over a decade that preceded and precipitated into the "Offset Strategy."

[2] Richard Van Atta, "Fifty Years of Innovation and Discovery," in DARPA 50 Years of Bridging the Gap (Washington, DC: Defense Advanced Research Projects Agency, April 2008).

[3] Michael Vickers and Robert Martinage, The Revolution in War (Washington, DC: Center for Strategic and Budgetary Assessments, 2004).

[4] William J . Perry,"National Security: New Thinking and American Defense Technology," in Science, Technology, and Government for a Changing World: The Concluding Report of the Carnegie Commission on Science, Technology, and Government, Carnegie Commission on Science, Technology, and Government, New York: Carnegie Commission on Science, Technology, and Government, April 1993.

[5] William J. Perry and John P. Abizaid, Ensuring a Strong U.S. Defense for the Future, 2014 Quadrennial Defense Review, July 31, 2014, 20-23.

[6] This was emphasized by Perry and Abizaid in their 2014 QDR review, cited above.

[7] Richard Van Atta and Marko Slusarczuk, "Tunnel at the End of the Light: The Future of the U.S. Semiconductor Industry," Issues in Science and Technology, Spring 2012.

[8] See Peter Singer, "Robots at War: The New Battlefield," Wilson Quarterly, Winter, 2009. See also Sydney Freedberg, Jr., "Should

Pentagon Let Robots Kill Humans? Maybe," Breaking Defense, July 10, 2017.

Beyond Super Soldiers and Battle Suits

Richard M. Harrison

Science fiction is always fascinating to follow, because at least some of the ideas presented in the genre do become reality over time. The concept of "super soldiers" is a case in point. Although the protagonists in Marvel's iconic Avengers comic books (and now movies) are still a long way from being realistic, we are unquestionably trending in that direction. Thus, the character of Captain America is a soldier enhanced by the government using a special serum to make him stronger, faster and more resilient, while Iron Man is an operator encased in full body armor that affords him super human strength, advanced weapons, and extrasensory systems. Even though such enhancements are still a stretch, performance drugs, exoskeletons, and other new technologies are increasingly augmenting—and expanding—the capabilities of today's warfighters.

The concept of human enhancement for military applications dates back more than two centuries. During the American Revolutionary war, doctors used vaccinations to enhance the immune systems of soldiers against smallpox in an effort to make fighting forces more resilient.[1] Fast forward to the present day, and the U.S. military is developing strategies to help make humans better through "combined collaborative human-machine battle networks" that use artificial intelligence to speed human decision-making, through wearable electronics, or via "human-machine combat teaming with unmanned systems" such as controlling drones using only the mind.[2] Other methods to enhance humans in the near term include drugs, meditation, and electrical stimulation of the brain. And in the long term, whether we like it or not, genetics may play a role in developing humans for military applications.

Looking ahead, all of these enhancement options—along with their myriad ethical implications—must be considered, both in order to optimize the U.S. military and so we can defend against similar advances that are now being explored by our adversaries.

Enhancements Through Exoskeletons

The Iron Man suit shown in the movies regularly defies the laws of physics, but the concept of exoskeletons and technologically advanced full body armor has been under development by the U.S. military and its defense contractors, as well as by potential adversaries of the United States, for some time now. There are several exoskeleton projects funded by the Department of Defense (DoD) that have already demonstrated significant potential.

One such effort is a system dubbed "Air Legs." Funded by the Defense Advanced Research Project Agency (DARPA) and developed by Arizona State University, the system consists of a leg-based exoskeleton with air cylinders that move rapidly, allowing test subjects to run approximately 12 miles per hour.[3] "Air Legs," moreover, is not alone. The Lockheed-Martin Corporation has designed another leg-based exoskeleton, known as the FORTIS Knee-Stress Relief Device (K-SRD), which incorporates artificial intelligence and actuators that understand human movement, allowing users to significantly increase the amount of weight a user can lift. A subject typically capable of squat lifting 185 lbs. for a total of 20-25 repetitions can double the amount of repetitions while wearing an K-SRD unit.[4]

In addition to leg-based exoskeletons, contractors have made major strides in development of full body suits.

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Raytheon has constructed the XOS2 robotic suit, which allows users to remain nimble while capable of lifting 200 lbs. and punching through walls (although the suit still needs to be tethered to a power supply, which represents a major impediment).[5] Arguably the most advanced full suit program is the Tactical Assault Light Operator Suit (TALOS) program. Researchers from the Special Operations Command and the Army have teamed to develop a TALOS capable of breaking into a building, enduring heavy enemy fire, and remaining in a combat zone for long periods of time.[6]

Despite the potential military applications for exoskeletons and full body robotic suits, the advantages must be weighed against existing shortcomings. Non-combat military applications and soldiers recovering from injury may stand the most to benefit from some of these technologies, particularly the leg-based exoskeletons. For combat missions, while formidable, robotic suits have serious limitations currently due to power constraints. Moreover, even when longer lasting battery options become available, it may still be more practical to have a semi- or fully autonomous robot carry out the mission.[7] However, at least in the immediate near term, further development of the helmets in robotic suits and those already worn by aviators holds definite potential for increased situational awareness through better digital displays that overlay information about the surrounding environment in real-time.[8]

Augmentation Through Human Machine Interfaces

Headsets and other brain computer interfaces (BCI) are an area of human enhancement that is being employed in the civilian sector, particularly by elite athletes, to assist in attaining peak performance. Through a process called transcranial direct-current stimulation (tDCS), a device transmits a small amount of electricity across the skull to specific areas of the brain, which may allow the organ to enter "a state of hyper-elasticity, allowing users to learn better and more efficiently."[9] Some headsets used for tDCS look nearly identical to a set of Beats brand over-the-ear headphones.

Applications of tDCS are already gaining prevalence, and the results are noteworthy. Athletes are able to train longer at high levels and develop more power and explosiveness in their movements—attributes which would work well for soldiers in the context of national security.[10] DARPA has funded these types of electrical stimulation technologies to enhance the ability to "speak foreign languages, [as well as for] analyzing surveillance images, and marksmanship."[11] Impressively, U.S. Air Force studies have showing elongated performance times for tasks carried out through tDCS, with no measurable side effects.[12] The tDCS devices developed to date have been external, but there is also the possibility of placing small devices inside the brain to specifically target and amplify certain brain functions through electric stimulation.[13]

The concept of using a human brain to remotely control something, a procedure known as telepresence, is not too far fetched. Indeed, humans will likely be able to control drones with their minds.

Brain machine interfaces can also be used for more involved applications. James Cameron's box office hit Avatar showcased the idea of connecting a human brain to a machine that remotely controls a genetically engineered body in real-time. The concept of using a human brain to remotely control something, a procedure known as telepresence, is not too far fetched. Indeed, humans will likely be able to control drones with their minds.[14] The U.S. Army has worked with researchers from Arizona State University to fund technology "that lets a human control multiple drones using their brain waves, and the group is now working on squadrons of drones that could perform complex operations," which they estimate could be ready in 5-10 years.[15]

Another nascent but potentially game changing application of BCI technology is improved communications. DARPA has committed funding to a project called Silent Talk, which allows soldiers in combat zones to communicate seemingly telepathically, by "allow[ing] user-to-user communication on the battlefield without the use of vocalized speech through analysis of neural signals."[16] The technology is far from mature, but could pay major dividends if allowed to develop. Even further down the line, it may become possible to have memory storage devices implanted in the brain that allow for the ability to transfer information as a download for instant information sharing with another person (similar to the title character's abilities in the 1995 Keanu Reeves movie *Johnny Mnemonic*).[17]

Technology interfacing with other parts of the body, especially through sensor systems, is also under development to enhance humans. The Army Research Laboratory (ARL) has launched a Human Variability Project that outfits soldiers with sensors throughout their bodies designed to measure "biophysical data"—essentially cataloging everything that occurs in the body, as well as its interactions with the environment, down to the genetic level in machine-readable signals aimed at helping improve individual performance.[18] This and other large human variability data collection programs, in turn, may be able to help dictate which individuals are best suited for specific jobs, missions, or to use specific weapons.[19]

Biological Enhancement and Degradation

While exoskeletons and neural interfaces showcase important human enhancing possibilities, some of the more readily available performance aids can also provide U.S. soldiers with significant gains. According to human enhancement specialist Andrew Herr, "When properly applied, performance nutrition, supplements, legal stimulants such as caffeine, and meditation can provide huge benefits to focus, attention, and performance when sleep deprived."

Brain stimulants in particular are ubiquitous in civilian life, with many students using Ritalin or Modafinil to increase their scholastic performance.[21] In the military, pilots have historically relied on prescription dextroamphetamine, colloquially known as "Go Pills," to maintain alertness on long missions, despite known side effects that include "confusion, delusions, auditory hallucinations, aggression and, in extreme cases, psychotic behavior."[22] More recently, the U.S. Air Force has switched to modafinil, a newer generation prescription drug used by doctors to treat narcolepsy but which has cognitive benefits for healthy, sleep-deprived individuals. Large segments of the U.S. Army are likewise known to rely on supplements for self-enhancement. Unfortunately, the military does not currently provide guidance on which supplements to use, so the vast majority of the substances soldiers take are ineffective or could actually have adverse effects.[23]

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Just as it is possible to build people up with drugs, it is also possible to degrade humans using bioweapons or even neuroweapons by "modify[ing] opponents' thoughts, feelings, senses, actions, health or — in some cases — to incur lethal consequences."[24] A specific application could be to target an adversarial "political or military leader to evoke a change in his or her ideas, emotions and behavior. This could exert effects on those they lead, influencing their views and actions toward either conformity or dissonance."[25]

At the cellular level, there have been interesting developments for enhancement. Researchers on multiple continents have prototyped ways to create artificial or "smart" blood that can increase the amount of oxygen carried in the bloodstream, allowing athletes or soldiers increased energy.[26] There is also future potential for programmable "synthetic white blood cells that could receive software updates" to fight diseases or infections.[27] And, while not yet ready for remote control, the newest generation of cancer treatments already is using genetically engineered white blood cells tailored to attack specific targets.

Enhancement at the genetic level is where the technology for military applications becomes both impressive and potentially frightening. There have been significant strides made over the past two decades in understanding the human genome, and as a result there now exists the potential to better plot where someone's optimal career trajectory should lead. Although not currently employed by the military, it is now possible to use genetic variants to determine a range of performance-relevant factors. For example, some genetic variants predispose an individual to have difficulty learning tonal languages, such as Chinese. However, this would not be a problem if the same individual were to learn Russian. These same variants also can suggest the probability of cognitive decline, or indicate the type of physical activity for which an individual is best suited.[28] This technique could reduce costs for the military and lead to a more effective fighting force. Yet, although the military regularly relies on aptitude tests to disqualify or qualify candidates for special operations, there is still extreme hesitancy toward the use of biotechnology for such assessments.

Gene modification is the likely future that we will live in, thanks to CRISPR-Cas9, "a new gene editing technology that offers the potential for substantial improvement over other gene editing technologies in ease of use, speed, efficacy, and cost."[29] Using CRISPR, researchers in China have already conducted trials on embryos to correct for blood disorders, sparking a major backlash from the scientific community.[30] Engineering embryos to receive desirable traits has the potential to be abused, and could truly lead to the creation of super soldiers. And while there is worldwide caution relating to the technology, due to its ethical and moral implications, there is ultimately no way to limit its spread, given its accessibility.[31]

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Former U.S. Deputy Secretary of Defense Bob Work has made it clear that our adversaries 'are pursuing enhanced human operations, and [that] it scares the crap out of us.'

Are U.S. Adversaries Enhancing Humans for War?

Former U.S. Deputy Secretary of Defense Bob Work has made it clear that our adversaries "are pursuing enhanced human operations, and [that] it scares the crap out of us."[32] He has also stated that "[a]ltering human beings from the inside to more effectively fight in combat presents ethical dilemmas for American scientists and military planners."[33] Indeed, the U.S. may never want to pursue some types of human enhancement. But it nevertheless must be prepared to deal with adversaries who have no similar compunctions about moving ahead in this realm.

Russia is a case in point. One need look no further than the country's civilian sector to see how lax the Russian government truly is about human enhancement initiatives. The use of performance-enhancing drugs by Russian Olympic athletes before and during the 2012 Games was well-known, state sanctioned and institutionally abetted by the Russian government.[34] The implications are ominous; concrete evidence of human enhancement in the Russian military is not readily available, but if the Kremlin is covertly providing performance-enhancing drugs to the country's athletes it is reasonable to conclude that it is doing far more for its warfighters.

There is more overt evidence of human enhancement in China. Genetic enhancements are known to have been conducted on dogs and, as mentioned above, Chinese scientists have already experimented with gene editing on human embryos for health applications. Reportedly,

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in their efforts to combat human diseases including Parkinson's and muscular dystrophy, researchers in China have successfully suppressed the myostatin gene, which regulates muscle growth in both dogs and humans. In experiments with the embryos of two beagles, the dogs were born with significantly increased muscle mass.[35]

As a thought experiment, imagine that an adversary finds a way to engineer soldiers with increased cognitive abilities that provide them with a material advantage on the battlefield. If the U.S. were to ignore such developments, by the time this new generation of soldiers demonstrated its true prowess as adults, we could find ourselves two decades behind the development curve.[36]

Preparing for An Enhanced Future

The potential for human enhancement is immeasurable. However, ethical considerations will need to be weighed when the U.S. military evaluates which forms of enhancements to pursue. The Department of Defense has demonstrated a propensity to fund research that enhances humans through exoskeletons and human-machine interfaces, and it should continue to fund such worthy initiatives. However, the hesitancy now visible within the U.S. military to pursue some of the more low-tech forms of biological human enhancements is less advisable. A concerted effort should be made to pursue research on subjects such as performance-enhancing drugs, cognitive enhancements and bio-technology that hold the potential to increase the operational effectiveness of the military.

As for genetic modification, the U.S. military has wisely steered clear of eugenics to date. However, some of America's adversaries might not prove to be so scrupulous. As a result, the U.S. military needs to begin planning now to counter such initiatives. If it does not, we may wake up two decades hence wholly unprepared for the battlefield of the future. ■

Endnotes

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Directed Energy Weapons and Modern Warfare

Howard R. Meyer, Jr.

In a 2009 article entitled "Technology and Warfare," Professor Alex Roland of Duke University wrote that "…technology, more than any other outside force, shapes warfare."[1] In his article, Roland went on to explain how military technologies, while not being deterministic, open doors and provide opportunities—often referred to as 'opportunity space' in current military parlance—for the nations employing them.

The history of warfare is replete with examples of military technological advancements. Some of the most notable of these innovations, including ancient trebuchets and catapults, medieval longbows, artillery, and machine guns, provided immediate and decided advantage to their developers. Others—like submarines, military aircraft, and tanks—had less significant immediate impacts and required decades of evolution, if not longer, to achieve the potential possessed by these systems today. Precision guided munitions (PGMs) and military drones are two of the most recent technology-driven innovations that have reshaped the conduct of warfare.

As it has been with all military technological innovations, gaining "opportunity space" is the reason why numerous nations are currently pursuing the promise of directed energy weapons (DEWs). DEWs, specifically high energy lasers (HELs) and high-power radiofrequency (HPRF, generally referred to as high power microwave, or HPM) weapons, emit very high power, focused beams of electromagnetic radiation to affect their targets. High power is emphasized because low power radiofrequency (RF) and laser devices have been in use for several decades by militaries worldwide. Radars that can find targets at great distances and radar and communications jammers that confuse their targets with, for example, RF noise, have been in use since World War II. Similarly, lasers have been used to designate and guide munitions to their intended targets since the early 1970s and to dazzle or confuse an adversary's optical sensors and combatants for more than a decade.

Beams of the Future

The current emphasis on the development of DEWs and the pace of these developments is accelerating for a variety of reasons. These reasons include the speed of the weapons, their potential range, their potential magazine (that is, the number of potential shots that can be fired before "reloading"), their potential to impact targets at very low costs as compared to traditional kinetic weapons, and the significant amount of research that has been done on DEWs and their component technologies over the past six decades. (Because the physics governing DEWs is quite complex, broad generalizations will be made here, and the reader is referred to the significant volume of nontechnical and technical publications for more information on this topic.[2])

Since electromagnetic radiation travels at the speed of light (186,000 miles per second), DEWs can potentially induce effects upon their targets very rapidly.[3] In the case of HELs, damage to a target is thermally induced by heating or burning through a target's control surfaces or

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> Since the vast majority of DEWs are electrically-powered, they could potentially have unlimited magazines.

outer skin to damage internal components, or by directly damaging its optical imaging or guidance sensors. In the case of HPRF weapons, the effects upon targets range from short-duration upsets to disruption or damage of electronic components.

To effectively employ DEWs, militaries generally need at least a basic knowledge of an intended target's design, materials, and internal components. Open-source and clandestine intelligence, modelling and simulation, and testing against surrogate targets can, however, provide sufficient information to enable DEWs to be effectively used against a wide variety of modern military targets including PGMs, drones, and critical components of air and missile defense systems.

HELs can potentially affect targets at significant ranges. The Airborne Laser (ABL) developed by the U.S. Air Force and successfully demonstrated by the Pentagon's Missile Defense Agency illustrates this well: the ABL was designed to destroy ballistic missiles while they were in their boost phase (powered flight), even though they might be hundreds of miles away. While the range of HPRF weapons is generally far less than that of laser weapons,[4] given the vast numbers of potential targets (any system or facility employing devices or equipment containing electronic components) and the potential impact of these weapons (from temporary upsets to permanent damage), their military value may be considerable. Since HEL and HPM beams are invisible and highly directional, it may also be possible to employ DEWs without an adversary's knowledge.

Since the vast majority of DEWs are electrically-powered,[5] they could potentially have unlimited magazines. The advantage here is two-fold. First, the number of targets that HEL and HPRF weapons could potentially engage is dramatically increased. This is especially important when militaries must defend against large numbers of low cost drones, rockets, artillery, and mortars, and, in the case of some advanced nations, cruise missiles. Additionally, since DEWs do not have to be "reloaded" the way ships, aircraft, and ground forces employing missiles, bombs, and artillery do, DEWs can potentially serve as a significant force multiplier, since combatants would not have to be resupplied or reequipped as often.

The potential to achieve very low cost-exchange ratios with DEWs offers significant advantages to their developers. As Mark Gunzinger, a Senior Fellow at the Center for Strategic and Budgetary Assessments, pointed out in two recent works, the ability to destroy or damage a cruise missile costing hundreds of thousands of dollars with a HEL or HPRF weapon that only costs a couple of dollars to use (the cost of the fuel used to power the electric generators powering the weapon) is a true game changer. By contrast, the missiles the U. S. Navy currently uses to engage an adversary's cruise missiles can cost a million dollars or more each, and two or more of these interceptor missiles may be launched to ensure the incoming cruise missile is defeated.[6] Since inflicting unacceptable costs on an adversary is clearly an objective of war, the combatant that can inflict the most damage upon his adversary at the lowest cost is decisively advantaged.

> The ability to destroy or damage a cruise missile costing hundreds of thousands of dollars with a HEL or HPRF weapon that only costs a couple of dollars to use (the cost of the fuel used to power the electric generators powering the weapon) is a true game changer.

While there are significant technological challenges that must be overcome before DEWs can be deployed,[7] the state of the art in the requisite technologies has advanced to the point where the first operational DEWs could be fielded within a couple of years. The significant increase in the number of conferences, articles, news stories, and press releases addressing DEWs over the past five to ten years attests to this, as do major demonstrations conducted by several nations. That several major defense contractors are developing and actively marketing DEWs also points to this fact.

> Directed Energy Weapons are neither universally applicable nor single-point solutions for military missions... Directed Energy applications complement kinetic systems and can significantly increase their effectiveness, rather than obviate the need for them.

Combat Roles of DEWs

There are a wide variety of potential offensive and defensive combat roles for DEWs. The first combat role envisioned for HELs was ballistic missile defense in nuclear weapons exchange scenarios. Both ground and space-based HELs for terminal-phase, point defense were envisioned, but for a variety of reasons these applications proved to be extremely difficult (if not impossible) and excessively expensive. Some of the most discussed potential DEW applications are summarized below.

As a several authors have pointed out recently, DEWs are neither universally applicable nor single-point solutions for military missions.[9] As Mark Gunzinger has noted, "Although the advent of mature DE capabilities could significantly change the way the U.S. military conducts future operations, it is unlikely that DE alone will underpin a new military revolution that renders obsolete or subordinate existing means for conducting war."[10]

Table 1. Potential DEW Uses in Combat

Defensive Applications	Type	Offensive Applications	Type
Negate rockets, artillery, mortars (RAM)	HEL	Long range strikes against high value targets*	HEL
Negate drones	Both	Short range strikes against high value targets*	HPRF
Cruise missile defense (for ships, bases, ports)	HPRF	Vehicle stopping (e.g., to capture leaders)	HEL
Aircraft self-protection against missiles	HEL		
Negate guidance of precision guided munitions	HPRF		
Vehicle and vessel stopping	HPRF		
Negate improvised explosive devices (IEDs) and unexploded ordnance	HPRF		
Negate ballistic missiles in the boost phase[8]	HEL		

** High value targets include facilities for, e.g., command/control/communications, integrated air defense systems, chemical and biological agent production, munition production and storage, petroleum production and storage, etc.*

One of the most significant insights of his assessment is that DE applications complement kinetic systems and can significantly increase their effectiveness, rather than obviate the need for them.

DEW Development Efforts

Numerous nations are currently developing DEWs. While the following list is not meant to be comprehensive, care has been taken to ensure most of the major development efforts have been captured to give a good idea of both the breadth and scope of DEW development efforts globally. Several other nations have openly stated their desire to develop and field DEWs. Given the potential impact of these weapons, it can be surmised that unreported programs also exist.

Innovate, or Perish

The maturity and number of DEW development efforts underway and the significant volume of both technical and nontechnical reports on the topic of directed energy make it clear that these weapons will be employed in warfare in the future. As General Guilio Douhet, the

Table 2. Some Current HEL Development Efforts[11]

HEL Systems	Potential Targets	Nation	Company
HEL Mobile Test Truck	Rockets, artillery, mortars (RAM), drones	U.S.	Lockheed Martin (LM)
Surface Navy Laser Weapon Demonstrator	Cruise missiles, drones, small vessels	U.S.	Northrop Grumman / DRS
Self-Protect HEL Demo	Aircraft self-defense	U.S.	Air Force Research Lab
Low Power Laser Demo	Ballistic missiles in boost phase	U.S.	Missile Defense Agency
C-130 Laser Gunship	Ground targets	U.S.	USAF Special Operations Command
HEL Reaper	Ground targets, missiles, aircraft defense	U.S., Australia	General Atomics
Excalibur	Aircraft self-defense	U.S.	Defense Advanced Research Projects Agency
Dragonfire	Ship-based self-defense HEL	U.K.	MBDA, Qinetiq
HEL Defense Laser	RAM, drones	Germany	MBDA
Skyshield	RAM, drones	Germany	Rheinmetall
Iron Beam	RAM, drones	Israel	Rafael
Silent Hunter	Drones, lightly armored vehicles, etc.	China	Poly Technologies
Anti-satellite weapon	Satellites	China	?
HEL weapons	Unknown	Russia	?

Table 3. Some Current High Power RF Weapon Development Efforts[12]

HPRF Systems	Potential Targets	Nation	Company
Counter-Electronics HPM Missile Project (CHAMP)	Command & control facilities, chemical / biological agent production facilities, etc.	U.S.	Raytheon
Active Denial System	Personnel (deter hostile forces)	U.S.	Raytheon
RF Vehicle Stopper	Ground vehicles and vessels	U.S.	Naval Surface Warfare Center, Dahlgren, VA
Counter-IED Systems	IEDs	U.S.	Polarix Corp.
RANETS HPRF weapon	Cruise missiles, drones, aircraft	Russia	?
HPRF weapons	Convoy/object protection, car stopping, countering small unmanned aerial vehicles	Germany	Diehl Defence
HPRF defensive weapons	Motors of small vessels	U.S.	BAE
Anti-PGM HPRF weapon	Precision guided munitions	China	?
Recovery of Airbase Denied by Ordnance	Unexploded ordnance	U.S.	Parsons
HPRF weapons	GPS navigation signals, radio communications equipment, satellites	Russia	Radio-Electronic Tech Group, Moscow
Iron Beam	RAM, drones	Israel	Rafael
Silent Hunter	Drones, lightly armored vehicles, etc.	China	Poly Technologies
Anti-satellite weapon	Satellites	China	?
HEL weapons	Unknown	Russia	?

father of strategic airpower noted, "Victory smiles upon those who anticipate the changes in the character of war, not on those who wait to adapt after the changes occur."[13] Given this prospect, nations possessing "first capabilities" will have advantages over their adversaries that may potentially be very significant. As General Robert Cone, past Commander of the U.S. Army's Training and Doctrine Command remarked, "What keeps me awake at night is, are we going to miss the next big technological advance? And perhaps an enemy will have that."[14] ■

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[4] HPM weapons have much shorter ranges than HELs because the divergence of their longer wavelength beams significantly reduces the amount of energy deposited on a target. Additionally, HPM radiation must, in many cases, traverse circuitous routes (through power cords, joints and cracks in component cases, attached cables, etc.) to get into electronic components to upset or damage the components.

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The Advent of the UAV Era

Chloe Thompson

Though Unmanned Aerial Vehicles (UAVs, or drones) are now an essential part of the U.S. national security toolkit, military views of UAVs were less than enthusiastic when the technology first emerged. In the early days of drones, the most prominent roadblocks to widespread adoption by the armed forces were inconsistency in performance, spiking costs, and, perhaps more importantly, a significant lack of interest on the part of military leaders, who could not quite envision a tactical use for the technology and thus had little incentive to push for the investment that such systems required. Today, by contrast, UAVs are an accepted, even vital, part of military and intelligence operations.

Rise of the Drones

UAVs were first utilized during the Second World War, when the Third Reich employed "Buzz Bombs" in 1944 over Belgium, England, and France, killing 10,000 civilians.[1] Thereafter, in 1952, the U.S. Army built its first reconnaissance drone, and by the 1960s the United States was flying "Firebees" over North Vietnam, China, and the Soviet Union.[2] Yet, despite these early instances, widespread UAV use came about only slowly, and with great difficulty.

The Defense Advanced Research Projects Agency (DARPA) was an early pioneer in the development of UAVs. Its interests initially focused on small tactical drones.[3] Once the technology developed enough to be reliable, however, companies faced ever-increasing "requirements creep," in which the army tried to apply manned aircraft requirements to UAVs, thus leading to an ongoing need to improve the technology.[4] But, because no single military branch was solely interested in or responsible for the development of UAV technology, attempts to innovate with UAVs were diffuse and disorganized. This changed in 1988, when Congress consolidated the UAV programs of the various military services into a joint project office, which eventually led to steadier progress in drone technology.[5]

In addition, a novel development process called the Advanced Concept Technology Demonstration (ACTD) was created within the Office of Secretary of Defense to take prototype UAV systems from initial implementation and testing to operational use in actual combat.[6] The goal was to speed up the development process of new military technologies and to involve military leaders more fully in the construction of weapons before the technology was finalized. This was a necessary development, because to many policymakers and military leaders UAVs seemed an expensive "unknown" that did not fit neatly into the military's complex and often rigid structures for procurement and operations. As a result, UAVs did not have committed advocates within the bureaucracy.[7] The ACTD process proved vital for the integration of UAVs into military operations, because it helped military leaders to see for themselves the potential benefits of remotely piloted aircraft for both combat situations and reconnaissance.

The first use of UAVs in a combat situation under the ACTD program occurred in Bosnia in 1995.[8] Subsequently, during President George W. Bush's administration, the use of drones expanded dramatically. During his time in office, President Bush authorized 48 strikes in Pakistan and one strike in Yemen as part of the global war on terrorism.[9] President Obama, who made UAV technology a cornerstone of his national security policy,[10] expanded the covert use of armed drones still further, authorizing over 500 drone strikes throughout his two terms in office.[11]

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> The Islamic State terrorist group has adopted the use of 'suicide drones' in place of actual suicide bombers as a means of conserving manpower, as well as utilizing UAVs to drop explosives on enemy troops.

The Logic of Drone Warfare

The rise of UAV technology has had significant impact on U.S. strategic thinking. Over time, the American military—propelled in part by the premium placed by Americans on the value of individual lives—has gravitated to a strategy that focuses on winning wars through greater technical prowess and better-trained troops.[12] UAVs fit this American way of war well; they are cost-effective and easy to produce, and can in many circumstances take the place of human soldiers altogether.

Of course, the United States is not the only actor to embrace the use of drones in military conflict. Countries such as Russia, China and Iran[13] continue to develop UAV programs of their own, ensuring that U.S. strategic thinking will need to include defenses against such capabilities. Even the Islamic State terrorist group has adopted the use of "suicide drones" in place of actual suicide bombers as a means of conserving manpower, as well as utilizing UAVs to drop explosives on enemy troops.[14] And as commercially available drones become more and more advanced, such actors can be expected to find even greater uses for them.[15]

For America, meanwhile, the use of drones carries with it moral, legal and psychological challenges. President Obama indicated during his time in office that his administration authorized drone strikes "only when we face a continuing, imminent threat, and only where there is … near certainty of no civilian casualties.'"[16] Doubts as to the veracity of that claim persist, in part because independent estimates suggest civilian deaths are far from uncommon in drone strikes.[17]

Today, drone strikes are carried out in one of two broad programs. The first involves strikes on high-value targets, i.e., specific known individuals. The second type of strike is called a signature strike, in which people are targeted not because they are known threats, but rather because they exhibit a set of behaviors that seem to indicate affiliation with a terrorist group.[18] This second type of strike has been criticized by human rights groups because it is much more likely to lead to civilian casualties, although drone strikes on average cause fewer casualties than strikes by manned aircraft.[19]

Future Fight

The success of these efforts, and the growing acceptance of drone warfare among military leaders, suggests an expanded role for UAVs in the future. Currently, the capabilities of most significant interest and study are increased independence (automation), and increased intelligence capabilities.

Scientists are now pursuing autonomy along two separate tracks: independence of action, and complexity of action. Independence of action is the degree to which a drone can behave on its own without oversight from a handler. Complexity of action is the level of difficulty in completing a task. For example, a UAV that can fly in a circle for hours with no input would be entirely autonomous, but of relatively limited utility.[20]

> the Naval Research Laboratory (NRL), in concert with the Air Force Research Laboratory, is now working on battle management software that relies on a human pilot controlling a lead vehicle while systems using artificial intelligence control secondary vehicles.

Former Secretary of Defense Ashton Carter favored near-total automation for UAVs, although stopping shy of permitting the ability to independently launch lethal strikes.[21] These capabilities have progressed; in a concrete example of the current, advanced state of UAV automation, in 2016 an F-16 drone demonstrated autonomous evasive maneuvers during an exercise.[22] Furthermore, the Naval Research Laboratory (NRL), in concert with the Air Force Research Laboratory, is now working on battle management software that relies on a human pilot controlling a lead vehicle while systems using artificial intelligence control secondary vehicles. These artificially intelligent systems are expected to be able to act according to mission priorities in the absence of direct human supervision.[23]

Some potential drone innovations on the horizon seem to come straight from science fiction. For example, at Arizona State University, the Human-Oriented Robotics and Control lab is attempting to harness brain waves, enabling a single pilot to control multiple UAVs at one time. BAE Systems, meanwhile, is exploring development of a "chemputer" that functions a bit like a 3-D printer, and is intended to grow drones or other military hardware at the molecular level.[24] If such an innovation were to succeed, UAVs could be made more cheaply and more quickly, and could possibly speed research on new systems.

Other initiatives show similar promise. Scientists at the University of California Berkeley and at Singapore's Nanyang University have developed a process to control the motor functions of large beetles through the provision of electric current to their brains.[25] Such technology may provide a partially organic alternative to small spy UAVs. The beetles, which are more nimble than their wholly mechanical counterparts, could be used in reconnaissance and intelligence operations.

Finally, the continually expanding capabilities of artificial intelligence could lead to the development of true Unmanned Combat Aerial Vehicles (UCAVs) that do not require a human operator at all.

While it's difficult to predict exactly what UAVs will be capable of in the decades ahead, current research is trending in the direction of greater autonomy and more comprehensive surveillance capabilities. One thing, however, already seems certain; once an obscure technology, UAVs are now a cornerstone of U.S. defense capabilities, and will remain so for the foreseeable future. ■

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Future Thinking: the Role of Artificial Intelligence

Zachary Lemnios and Michael Perrone

The past several years have seen a remarkable transition of Artificial Intelligence (AI) from academia to practical use. This shift is beginning to transform every industry, is fundamentally changing many consumer services, and will have a profound impact on national security.

The current transformation is a half-century in the making. The 1956 Dartmouth Summer Research Project on Artificial Intelligence is properly credited with launching the field of AI.[1] However, it was the insightful 1960 publication by J.C.R. Licklider that outlined the prospect for computers to "facilitate formulative thinking as they now facilitate the solution of formulated problems, and to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs."[2] This symbiotic interaction between humans and computers is a foundational principle of the new ubiquity of AI.

In the decades after the Dartmouth study, the Department of Defense sponsored key work in many AI disciplines—among them speech recognition, natural language understanding and neural networks. These investments have borne profoundly transformational fruit in recent years, and promise to do so for years to come. In tandem, parallel investments by government, industry and academia in high performance computing, machine learning and more recently cloud services have provided the key technical foundation to integrate and apply AI to real-world systems. It is now our task to decide how to bring the next phase of this technology forward for the benefit of national security.

Brave New World

Two seminal events of recent years marked the beginning of the AI-race to commercialization that is underway today.

In 2011, the IBM open-domain question-answering system known as Watson beat the two highest ranked quiz show players in a nationally televised two-match *Jeopardy!* contest.[3] This was the first live demonstration of integrated computational linguistics, information retrieval, knowledge representation and reasoning, and machine learning in an unstructured environment: questions and answers in the language of *Jeopardy!*

The following year, the field of Deep Learning was launched with the publication of a seminal paper from the University of Toronto that used convolutional nets to demonstrate almost half the error rate for object recognition, and precipitated the rapid adoption of deep learning by the computer vision community.[4]

These developments, coupled with the availability of massive data, embedded analytics and wide availability of GPUs that make parallel processing ever faster, cheaper, and more powerful, are today propelling AI into almost every industry. AI is now being used to derive insight from

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> AI is now being used to derive insight from massive data sets that are dynamic, cluttered and in many cases ambiguous. The ability of AI to identify emerging trends and forecast potential courses of action is bound to have a similarly profound impact on national security.

massive data sets that are dynamic, cluttered and in many cases ambiguous. And while these trends are, to a large extent, confined to the commercial and scientific space, the ability of AI to identify emerging trends and forecast potential courses of action is bound to have a similarly profound impact on national security.

The Importance of Industrial AI

McKinsey & Co. recently reported[5] that between $26 and $39 billion was invested in AI by companies in 2016 alone. Sixty-six percent of that investment was made in the United States. Industrial AI, in other words, is undoubtedly a growth industry; venture funding in this space alone has been growing at an average of 40 percent annually for the past 3 years; and 61 percent of the 3,000 companies interviewed by the consultancy group said that they are either AI adopters or partial adopters. This rapid growth in investment and adoption, in turn, has been driven by a number of recent machine learning success stories, such as the estimates of online movie site Netflix[6] that it now saves some $1 billion annually thanks to its AI-based video recommendation system.

Industrial AI solutions vary greatly because of the differing needs of customers. But they all share several features: the ability to ingest vast amounts of data from varied sources; the ability to curate that data for reliability, provenance, value, shelf-life, etc.; the ability to extract meaningful, relevant information; and the ability to covey this information to a user for decision making or to another device for action. For example, IBM's Watson Health system[7] integrates these features to provide improved healthcare outcomes by analyzing volumes of data that no human could possibly read, and digesting and prioritizing situationally relevant information to healthcare professions which can then use it to make treatment decisions.

For the Pentagon, in turn, leveraging this market momentum should be a top priority.

Toward a Preemptive National Security Intelligence Environment

A new approach is likewise needed to address increasingly complex nation-state threats and an emerging era of decentralized dangers that have blended into society and are evolving faster than our current ability to collect, model, understand and interdict them. Responding to these threats has pushed the U.S. into a more reactive posture—one in which we are responding to events after they happen. This new landscape poses great danger to U.S. national security and American interests abroad.

> Between $26 and $39 billion was invested in AI by companies in 2016 alone. Sixty-six percent of that investment was made in the United States.

AI technology offers the American military an opportunity to enable the next era of national security by building a preemptive national security intelligence environment that is centered on forecasting, shaping and disrupting national security threats well before they fully present themselves.[8] These advanced services will give our nation the ability to detect the emergence of threats by modeling the processes that build adversarial capability "maturity" over time and by tracking their progress even where the telltale signs may be only partially visible or deliberately obfuscated. This approach could help inform the following new capabilities.

1) **Persistent Over-Watch (moving analytics from off-line to in-line):** Automated data analytics, machine

learning, and composable cognitive environments that constantly monitor and extract *real-time insight from live data* to detect emerging scenarios *as they are beginning to form*, project how those scenarios could evolve and recommend *the most effective preemptive near-term courses of action.*

2) **Simulation-Based Forecasting (preemptively shaping the threat)**: A set of simulation and game-theory services with integrated military, political, economic and social models that forecast how to best shape an adversary's calculus and recommend *preemptive long-term courses of action* to shape the outcome.

3) **Immersive Data Environments (visualizing the threat)**: Immersive environments that allow analysts and leaders to *visualize*, *interact with and understand* complex intelligence data, evolving scenarios, live metrics and evolving courses of action. This environment will enable analysts and operators to collaborate and evaluate "what if" scenarios and shape the environment by observing new data relationships.

4) **Accelerated DevOps (Innovation, speed & agility)**: A development environment that allows the DoD and the intelligence community (IC) to develop, onboard, provision and utilize new capabilities faster than the adversary with a scaled network effect. This composable environment will be key to protecting the technological gains made by the DoD.

5) **Distributed Decision Making**: By embedding machine learning decision-support systems alongside sensors, future intelligence, surveillance and reconnaissance (ISR) systems will support distributed decision-making for theater commanders requiring more rapid responses to threat signatures.

Challenges Ahead

Although we have recently seen dramatic improvement in AI capabilities in recent times, as well as a rapid growth in the adoption of applications that use them, exploiting AI to its full potential still faces numerous difficult challenges. Today, AI can, with high reliability, identify dogs and cats in images, and it is beginning to be able to identify multiple general objects in an image. But it is still very far from converting a picture into a story, or predicting from an image of a falling coffee mug that something is about to break. These kinds of tasks, known as Artificial General Intelligence[9], involve being able to understand and reason about the real world, and are still stubbornly beyond our grasp. Similarly, for natural language understanding, AI can reliably convert between speech and text, and is beginning to reliably translate between languages. But deeply understanding and reasoning about, for example, the nuances of a legal document is still an unsolved problem.

In military applications, the mistakes of an AI system could have extremely dire outcomes. Satisfactory methods for ensuring AI system reliability in mission critical situations do not exist today.

Trust is another major challenge for AI systems, whose learning algorithms typically do not yield interpretable models and therefore make it very difficult to verify that they always do what is expected of them. For example, it is impossible to test every possible driving situation for a self-driving car, so how does one know the system will respond appropriately to every new situation? To develop trust, practitioners rely on statistical evaluations of AI systems with millions of test cases, or more. However, the complexity of these systems and the sheer volume of data can thwart the best of intentions. Consider the case of the Google Photos application which erroneously classified images of people as gorillas and which led to serious public relations problems for Google.[10] In military applications, the mistakes of an AI system could have extremely dire outcomes. Satisfactory methods for ensuring AI system reliability in mission critical situations do not exist today.

Related to this is the recently identified weakness for "adversarial examples" exhibited by Deep Learning.[11]

Methods exist to easily create data that makes deep learning systems do the wrong things, even without knowledge of the details of the system in question. In one specific example, it is possible to modify a picture of a bus such that it gets recognized as an ostrich, even though the modification is so slight that a human cannot visually detect the change, and certainly cannot see an ostrich in the image. Worryingly, adversarial examples are not limited to buses and ostriches; they can be demonstrated much more generally. This known weakness leaves AI systems open to an array of attacks by malicious actors. Countering this vulnerability is an active field of research.

The Way Forward

Even with its faults, AI technology holds tremendous promise for extending U.S. military effectiveness, for acting as a force multiplier, and for providing a third offset mechanism that will move us to a more proactive posture, allowing us to shape threats before they fully manifest. This capability is especially important as the nature of the military's challenges continues to evolve, and we continually strive to improve in the most cost-effective manner possible. It is imperative that we take full advantage of these opportunities.

Moving forward on this path requires us to provide sufficient investment to advance the core AI technologies required, many of which are still active areas of research. We also must carefully think through how these technologies will be integrated with existing systems and operational methods so they will provide maximal benefit and not detract from what already works well. Finally, we must develop rigorous methods for validating the effectiveness, reliability and vulnerabilities of AI systems in order to prevent unintended consequences.

Despite the significant challenges that lie ahead, AI's potential to change the military landscape presents the U.S. with a unique opportunity. We ought to take advantage while the time is right. ■

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