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Future Warfare and the Decline of Human Decisionmaking

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To date, most warfare has taken place within what Robert J. Bunker terms “human space,” meaning the traditional four-dimensional battlespace that is discernible to the human senses.¹ In essence, war has always consisted of human beings running, dodging, and hurling things at each other, lately with the help of machinery. Even such revolutionary developments as gunpowder only enhanced our ability to throw things at enemies we could see and hear.

The first crude examples of autonomous weapons were probably the early experiments by the US Navy and Sperry Gyroscope Company on un-piloted aircraft during the last years of the First World War. Then came the advent of electronics, especially radar, and warfare began to leave the realm of human senses. Ships and planes could fire on enemies that were no more than ghostly green images on a cathode ray tube. Later came military robots such as cruise missiles that were able to autonomously execute missions formerly requiring manned systems. Advanced radar engagement systems enabled pilots to locate, identify, and destroy enemy aircraft without ever seeing them. Some robotic systems became even more independent, such as the Navy’s Phalanx close-in air defense weapon, which is “capable of autonomously performing its own search, detect, evaluation, track, engage, and kill assessment functions.”² Thanks to advanced sensors and information processing, target recognition and identification methods are being developed to permit truly autonomous guided munitions. This includes munitions capable of autonomously engaging fixed and mobile ground targets, as well as targets in air and space.³ Warfare has begun to leave “human space.”

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A long step in this direction was taken in mid-2000 when the US Senate Armed Services Committee added \$246.3 million to its version of the 2001 defense authorization bill to speed development of unmanned combat systems. The committee set two ambitious goals--within ten years, one third of all deep-strike aircraft would be unmanned; and within 15 years, one third of ground combat vehicles would operate without human beings on board.⁴ At about the same time, the Defense Advanced Research Projects Agency (DARPA) and the US Army selected initial contractors for the Army's planned Objective Force. The concept calls for "a network-centric, distributed force that will include a manned command and control element/personnel carrier, a robotic direct-fire system, a robotic non-line of sight system, an all-weather robotic sensor system, coupled with other layered sensors."⁵ According to Lieutenant Colonel John Blitch, program manager for DARPA's Tactical Mobile Robotics Program, "We have spent a lot of time and energy analyzing employment concepts for portable robotic platforms over the last few years and are convinced of their revolutionary impact on dismounted warfare."⁶ These initiatives and others are rapidly taking us to a place where we may not want to go, but probably are unable to avoid.

Once this progression of ever more capable machines began, the US armed forces, and those of other advanced countries, started down a road that will probably remove warfare almost entirely from human hands. Several trends are contributing to this unsettling development, but the most important one is the rise of computer-driven information systems coupled with the proliferation of mobile autonomous and semi-autonomous systems (i.e. "robots"). The devices created by this coupling greatly increase the speed at which things happen, especially weapon effects and information processing. A much less noticed trend, the development of very cheap and very small military systems, will also help to move warfare even further out of "human space." In combination, these advances have a synergistic effect. More and more aspects of warfighting are not only leaving the realm of human senses, but also crossing outside the limits of human reaction times. The effect of these trends is already being enhanced by the emergence of directed energy weapons (DEWs) with their capacity for engagement at the speed of light.

In short, the military systems (including weapons) now on the horizon will be too fast, too small, too numerous, and will create an environment too complex for humans to direct. Furthermore, the proliferation of information-based systems will produce a data overload that will make it difficult or impossible for humans to directly intervene in decisionmaking. This is not a consideration for the remote science-fiction future. Weapons and other military systems already under development will function at increasingly higher levels of complexity and responsibility--and increasingly without meaningful human intervention.

According to the US Army Infantry School, "We intend to transform the Army, all components, into a standard design with internettted C4ISR."⁷ And, it is well known that various "digital army" initiatives such as the Land Warrior system and the Force XXI Battle Command Brigade and Below are

under way.⁸ Likewise, a number of unmanned and semi-autonomous systems are already in wide use, and autonomous systems are in prototype or development.⁹ The first operational light-speed weapon, the US Air Force's Yal-1a Attack Laser (also known as ABL or Airborne Laser), is slated for operational readiness by 2003. Others, such as high-power microwave and particle-beam devices, are under development.¹⁰ At Sandia National Laboratories, tiny MEMS (Micro-Electro-Mechanical Systems) already exist in prototype form.¹¹

None of this is accidental. For one thing, it is national policy, articulated by former President Bill Clinton as a critical part of the national security strategy.¹² Second, it has been pursued tenaciously by the military despite expense, setbacks, and criticism. Knowledge is seen as the key to "battlefield dominance," and speed is seen as the key to exploiting that knowledge. We have made these two qualities--knowledge (information) and speed--the keystones of planning for the future Army and the other services as well. Army After Next (AAN) forces are expected to need both "linear speed" (speed across the ground) and "angular speed" (the ability to out-think and anticipate) in order to survive and win on future battlefields.¹³ Like the chiefs of the other services, General Eric Shinseki, the Army Chief of Staff, has clearly stated that he endorses this concept.¹⁴ It is believed that these qualities--information dominance, combined with speed and agility--will lead to military dominance at all levels of warfare: strategic, operational, and tactical.¹⁵

Military discussions of advanced warfighting (as opposed to scientific or technical ones) occasionally include the reassurance that there will always be an immediate, direct, and intimate connection between human beings and warfighting. According to the Joint Chiefs of Staff, "The purpose of technology is to equip the man. We must not fall prey to the mistaken notion technology can reduce warfare to simply manning the equipment."¹⁶ As a white paper from the US Army's Training and Doctrine Command (TRADOC) put it, "Autonomous unmanned systems will be fully adaptive to unforeseen changes while remaining completely predictable in mission performance."¹⁷

We are faced with the prospect of equipment that not only does not require soldiers to operate it, but may be defeated if humans do attempt to exert control in any direct way. It is easy to see a steadily decreasing role for humans in direct combat as the 21st century progresses.

Information Systems

The fundamental development underlying the loss of human control is that of automated information systems. Furthermore, the impressive current capabilities of such systems may only hint at their future capacity. Quoting again from the TRADOC white paper:

Advances in computer architecture and machine intelligence will have reached the point where intelligent agents can analyze the environment and current battle situation, search likely target areas, detect and analyze targets, assist in attack decisions, select and dispense munitions, and report results. These unmanned systems will augment

manned platforms in every facet of operations on the ground, sea, air, and space, including information dominance and manipulation.¹⁸

The difference between a machine that can do all these things and “assist in attack decisions” and one that makes its own “attack decisions” is a matter of programming. This is a description of machines that can function autonomously to conduct warfare at the tactical level. If anything, this description is probably a gross understatement.

Current computers have not even begun to approach their theoretical limits, and those limits continue to recede. In 1998, scientists at the Los Alamos National Laboratory in New Mexico announced that they had been able to consistently manipulate subatomic particles, thus opening to the way for computation and communication systems orders of magnitude smaller and faster than the ones now in existence.¹⁹ In 1999 researchers at UCLA and Hewlett-Packard succeeded in constructing microscopic integrated circuits using single molecules as building blocks. James Heath, the UCLA professor leading the project, suggested that a molecular computer with the processing power of 100 conventional personal computers would be about the size of a grain of salt. The implications are almost unimaginable--cheap, ubiquitous supercomputing, and unlimited memory capacity in devices so small that they are on the scale of insects.²⁰

This is not to suggest that there will ever be an overriding decision to exclude humans from decisionmaking. Instead, we will continue to pretend to be in complete control while leading ourselves gradually and incrementally toward systems whose logic demands that human control become more abstract with less and less direct participation.

Mastering the OODA Loop

The entry point for automated systems to join the military decision-making process is described in abstract form by the so-called “OODA” Loop: observe, orient, decide, and act.²¹ For purposes of this discussion, the loop can be seen as beginning with “observation,” and indeed there will be a great deal of observation connected with future military organizations.

An enormous amount of attention (and money) has been invested in observation in the form of new surveillance and reconnaissance technology. Development of these capabilities has become increasingly vital with the Army Chief of Staff’s 1999 announcement that he plans to field units whose very survival is largely dependent on information collection and advanced information systems.²² This meshes nicely with the TRADOC view of the future: “The use of multiple, inexpensive unmanned platforms with modular sensor and information-gathering devices provide for an almost unlimited ability to analyze the battlespace. These sensor platforms will be land-based (both mobile and stationary), airborne, and space-based.”²³ As explained by Major General John Thomas, commander of the US Army Intelligence Center at Ft. Huachuca, Arizona, this kind of information saturation is essential. The Army’s new lightly armored “medium brigades” will have intelligence and sensor assets equivalent to those of a full division. These new brigades are

expected to survive by using these assets to avoid the enemy, using superior knowledge, terrain, and agility to remain out of enemy fields of fire. According to General Thomas, “Probably the largest and most exciting area is in robotics so that many of these sensors can be automatically emplaced and maybe even autonomously emplaced.”²⁴

But victory does not always go the commander with the best observation. It goes to the one that can best process observation into data, data into information, information into orders, and then orders into action. The process is continuous--the results of action are observed, starting the process all over again. The individual functions involved have been enshrined in military jargon as the OODA Loop mentioned above.²⁵ The notion of mastering this process, “getting inside the enemy’s decision loop” (i.e. execute the OODA process more quickly than the enemy) is at the heart of the digital Army and the information warfare concept.

By 2025, speed-of-light engagement will be a common feature of military conflict. Future architectures envision a new array of ground- and space-based sensors, uninhabited combat aerial vehicles (UCAV), and missile defense technologies that will take advantage of directed energy weapons. Air, sea, land, and space forces will be both faster and more agile. Adversaries will take advantage of these characteristics to operate faster than a defender can observe the activity, orient himself, decide how to respond, and act on that decision. The attacker thus places himself “inside” the defender’s OODA Loop, destroying an adversary’s ability to conduct an active defense.²⁶

To master the OODA Loop in this demanding environment, military leaders are pushing hard for the technology to obtain and process more information more rapidly. This push attempts to achieve the core capability of information dominance, “the ability to collect, control, exploit, and defend information while denying an adversary the ability to do the same.”²⁷ From the perspective of an Army organized around automated information systems, the struggle to get inside the enemy decision loop is one of processing power, the ability to move through the loop ever more rapidly.

When improved sensors are coupled with extensive communications links and advanced data-processing, the result is an ever-increasing flow of detailed information. Unfortunately, the explosion of available information inevitably results in information overload and flawed decisionmaking. Human beings commonly deal with this by ignoring much of the inflow, thus negating the purpose of the information systems in the first place. Recent exercises reveal an alarming number of unread messages because of information overload. As the quantity of data rises, the difficulty of preparing and interpreting it for decisionmaking grows. Furthermore, more information, flowing more efficiently, can easily give the commander conflicting perspectives of the battlespace. Soon it becomes obvious that the slowest element in the process is the human decisionmaker. By reducing the human role, the entire system is enhanced.

Automated systems, using some form of artificial intelligence, may be the solution to this difficulty. As an Air Force document asserts: “Unmanned

systems will capitalize on artificial intelligence technology gains to be able to assess operational and tactical situations and determine an appropriate course of action. The key to the success of command and control is information. Some of these systems will not only collect data but also have the ability to analyze data and provide recommendations to the commander.”²⁸ Operationally, the difference between “providing” a recommendation and “acting” on a recommendation is merely a software tweak.

Automated systems can certainly reduce the pressure of information saturation and eliminate conflicts, but at a price. Essentially, they do so by creating a series of information “filters” that establish priorities and eliminate marginal data, reconcile the remaining information conflicts, and present a consensus picture of the situation. All of this is invisible to the ultimate consumer, out of his or her control and very likely not well understood. This means that the commander is receiving a picture of the battlefield that is designed to emphasize certain things while de-emphasizing others. Still other factors are omitted entirely.

Autonomy

STAR 21, an Army study of 21st-century needs, concluded that unmanned systems will become prevalent on the land battlefield.²⁹ The rise of unmanned ground systems is the most important step toward autonomous systems for land warfare, a rise that is already in full progress. As envisioned by the Army Training and Doctrine Command:

Unmanned systems will operate throughout the depth, width, and breadth of the battlespace, providing both the real-time intelligence necessary for the commander to locate and identify key targets, as well as the means to destroy them. . . . [A]utonomous convoys loaded with the necessary supplies to replenish expenditures can be dispatched from ports or airheads to central logistics bases. From there, the unmanned systems can transport the supplies further forward. . . .

Future battles will have unmanned systems as forward sensor/observers detecting and identifying high-value targets and calling for fires.³⁰

Unmanned systems have been around for a long time in the form of multimillion-dollar cruise missiles and the like. After all, the long-range cruise missile is nothing more than an unmanned bomber, an autonomous aerial vehicle or, simply put, a robot.³¹ But now such systems are cheaper, smaller, and more capable than seemed possible even a few years ago. In 1998, for example, an autonomous aircraft no bigger than a large model airplane and weighing just 29 pounds flew across the Atlantic Ocean, successfully arriving at a predetermined destination.³² The US Department of Defense has an extensive military robotics program, and by 2005 DOD is expected to spend \$72 million on unmanned ground vehicles alone.³³ Unmanned systems have supported the Bosnia mission in the areas of reconnaissance (with Unmanned Aerial Vehicles) and mine-clearing using Standardized Robotic System kits on

manned platforms.³⁴The DARPA Unmanned Ground Vehicle Demo 11 program has fielded four HMMWVs reconfigured as unmanned scout vehicles.³⁵

The difference between a truly autonomous system and one that is merely unmanned is another question of processing power. As mentioned earlier, the coming micro-miniaturization of computer systems will eventually make it possible to pack computing power greater than a year 2001 mainframe system into a device that is barely visible.³⁶ The immediate prospect is for cheap computers small enough to be used in almost any device, followed at some point in the more distant future by ubiquitous supercomputing and unlimited memory capacity in devices that are literally microscopic. These developments are important for their own sake, but also in the present context because they set the stage for autonomy.

As the TRADOC white paper put it, “Unmanned systems may have the ability to learn. The concept of collective leadership and subordination will then permit systems working under human supervision to assist the warfighter in the accomplishment of his mission.”³⁷ As this quote suggests, TRADOC publications in particular are careful to specify that human decisionmaking will be involved at some level in the operation of these systems. However, there is no a priori reason why this should be so. Inevitably, some adversary will decide that eliminating humans from the military decision cycle at the tactical level will confer a significant advantage, forcing others to follow suit.

The logic leading to fully autonomous systems seems inescapable. Clearly, the armed forces will want a “person in the loop” no matter how capable the automated system may become. However, if this person has a meaningful role in the operation of the system (for example, a tank, fighting ship, or warplane), then he or she will obviously be the most critical (and probably the most vulnerable) component of the system as well as the most difficult to replace. The obvious course for an adversary attacking the tank, ship, or plane is to concentrate on attacking the human component. This probability creates serious design restraints and restrictions in performance since protecting the human becomes critically important and imposes a burden in armor, life support, sustainable g-forces, and so forth. This provides a strong incentive not to include humans in the systems at all.

The obvious response to this threat is that favored by the Air Force for some applications, “fly-by-wire.” This means simply that a human located safely away from the battle scene remotely pilots the aircraft by radio control. In principle, there is no reason this solution could not be applied to ground vehicles and ships, or at least to surface vessels (submarines present a different problem). Unfortunately this solution has its own vulnerabilities--the enemy’s priority then becomes to attack the remote control links electromagnetically by jamming or physically by attacking the transmitter.³⁸ This becomes all the more troublesome when cross-continental control is required. Having extended links gives the enemy a logical place to attack that is hard to defend. Systems will need at least some measure of local autonomy in order to survive. Fully autonomous

systems avoid all these difficulties while allowing a less vulnerable, higher performance system.

But even if full autonomy is rejected, the presence of humans making critical decisions still does not avoid the issue. Given that such persons have a real, rather than merely symbolic, role in the command and control of the fighting system, consideration must be given to the possibility that they will be injured or killed and cannot carry out their duties. It seems unreasonable that the highly trained crew and their multimillion-dollar ship or aircraft would simply be written off as a casualty. It is far more sensible to design the system so as to continue to operate the plane or vessel and, if necessary, continue the fight. This is nothing more than autonomy arrived at by a slightly different route.

The trend toward reliance on automation and artificial intelligence can be seen in the Navy's Smart Ship Program, which is spending millions of dollars to replace personnel with technology. By 2005, this program is expected to reduce the number of sailors on the Navy's 27 CG 47 Ticonderoga-class cruisers by replacing them with new control, automation, damage control, and information technologies. Shortly afterward, 57 of the DDG 51 Arleigh Burke-class destroyers will be likewise refitted. According to Navy plans, the crew of the new DD-21 "land attack" destroyers could number as few as 95. Current destroyers and cruisers carry more than 300 sailors on board.³⁹ These improvements aren't cheap. Refitting the 27 Ticonderoga-class cruisers alone will cost \$124 million. But according to a Navy assessment, lower manpower costs, less maintenance, and fewer support costs will save nearly \$3 million a year per ship.⁴⁰ Another example is the "arsenal ship" proposal in which a stealthy, unmanned vessel would loiter off an enemy shore and fire guns or missiles at the command of air or ground forces located elsewhere.⁴¹

In sum, this approach results in the development of systems that take the operator "out of the loop," shifting the role of the human operator from that of an active controller to that of a supervisor who serves in a fail-safe capacity in the event of system malfunction. Unfortunately, the role of passive monitor seems to be a task for which humans are poorly suited.⁴²

Speed

Directed Energy Weapons (DEWs), including laser, microwave, and charged particle or neutral particle beam devices, are a major emerging military technology that enormously increases the speed with which weapon effects occur. All are based on the emission of electromagnetic energy at different frequencies, usually in focused beams. They can be vastly more accurate than conventional weapons because they follow line-of-sight rather than ballistic trajectories, thus eliminating all the problems of ballistics.⁴³ Researchers and engineers are now developing a wide range of these devices.⁴⁴ The first operational laser weapon, the US Air Force's Yal-1a Attack Laser, will be followed by Army and Navy systems. One of these, the Army's Tactical High Energy Laser Demonstrator, scored a first on 28 August 2000 by using a deployable laser system to successfully track and destroy a salvo of two Katyusha artillery

rockets in flight. Other applications are being examined through the Army's "virtual test bed" for vehicle-mounted directed energy weapons.⁴⁵

One advantage of such weapons is that missing the target is less important, since the system will be able to cycle quickly and fire off another speed-of-light burst, this time having corrected its aim. With DEWs, active countermeasures (dodging, throwing chaff, deploying decoys, returning fire) become enormously more difficult and in many cases impossible. It is hard to see many roles for humans in this kind of lightning duel. Human perceptions and motor coordination skills are simply not capable of intervening usefully. Defense then relies on instantaneous, automated responses and passive measures, of which the best are probably speed and size. Small, agile, very fast-moving targets, other things being equal, are harder to detect and much harder to hit.⁴⁶ This will place a premium on micro-systems, to be discussed later. The same qualities that make such systems harder to target and strike also make them much more difficult to control in anything approaching human "real-time."⁴⁷

As indicated by the Army's tactical laser systems, DEWs are not limited to strategic weapon systems.⁴⁸ A variety of threats--short-range rockets and artillery, UAVs, cruise missiles, pop-up helicopters--can appear quickly and without warning. When a threat is not detected until late or its unmasked time is short, there is no second chance. Countering these threats requires a weapon that is fast, accurate, and close-in. On 22 April 1999, Boeing completed proof-of-concept testing of a new tactical high-energy chemical laser. As described by Boeing, this technology "permits . . . highly mobile, self-contained laser weapons with significant lethality at engagement ranges up to 10 km for ground-to-air defensive systems, and over 20 km for air-to-ground or air-to-air systems." The company's plans include "complete weapon systems in roll-on, roll-off installations for rotorcraft (V-22, CH-47), aircraft (AC-130), and ground vehicles." Boeing says that such a system could be ready in about two years.⁴⁹ With different sensors and fire control it also offers a unique ultra-precise strike capability for operations other than war, where pinpoint accuracy, tactical stand-off, and no collateral damage are dominant considerations.⁵⁰

Perhaps the extreme example of warfare outside "human space" is that of "netwar"--electronic conflict within and among computer systems attacking the full spectrum of opposing military and civilian information systems (including computer-controlled networks such as communications, logistics, and transportation). By its nature, the speed of such conflict is limited only by the speed of the electronic circuits in which it occurs. This is another example of conflict that will quickly escalate out of human control due to its complexity and rapidity. Netwar attacks may be too pervasive and rapid for human intervention, adapting instantly to responses. Both attack and defense will be completely automated, because humans are far too slow to participate.⁵¹

Smaller and Smaller

Small systems are highly desirable for military purposes, especially in a force-projection Army. Smaller systems require less space, thus fewer airframes to transport, and they use less fuel in operation. They are more difficult for the enemy to detect and, once detected, harder to hit. The viability of such “small, smart, systems” was demonstrated on 11 January 1999, when Lockheed Martin began DOD-sponsored flight tests on an aircraft with a wingspan of six inches--about the size of an outstretched hand. The aircraft, which weighs only three ounces, is one of the smallest man-made flying objects.⁵²

It is (once again) the presence of micro-electronics that makes the difference between the Lockheed Martin device and an ordinary model airplane. Miniaturized electronic circuits have revolutionized military electronics. Similarly, the miniaturization of mechanical systems is expected to launch another revolution. Military commanders will have very small, very smart machines to more effectively collect target and damage assessment information with reduced risk to personnel and decreased probability of discovery. Swarms (hundreds or thousands) of miniature autonomous vehicles will be capable of performing tasks that are difficult or impossible today, such as locating and disabling land mines, detecting chemical, biological, or nuclear weapons, and verifying treaties.

During the 1990s, Sandia National Laboratories produced an early example of a microsystem, the Miniature Autonomous Robotic Vehicle (MARV). MARV is one cubic inch in size and is made primarily from commercial parts using ordinary machining techniques. Despite its small size, it contains all its needed power, sensors, computers, and controls. MARV is severely limited in its operation, but it is leading to even smaller autonomous vehicles with greatly enhanced mobility, more intelligence, on-board navigation and communication, as well as the ability to act cooperatively with other robots.⁵³ Sandia is also developing technologies to rapidly machine, fixture, and assemble Small Smart Machine devices, including automated assembly of parts down to 100 microns in size.⁵⁴

At the Massachusetts Institute of Technology (MIT), researchers have devised much tinier robots, similar to ants, which exhibit certain limited aspects of intelligence and differentiated specialization, such as avoiding shadows and staying away from each other. They are cheap and easy to reprogram. According to researchers, “Thirty-five years from now, analogous small, lethal, sensing, emitting, flying, crawling, exploding, and thinking objects may make the battlefield highly lethal.”⁵⁵

Very small systems have several advantages. As noted earlier, it is easier to quickly transport huge numbers of them, both sensors and fighting systems. They also can be moved at speeds, accelerations, decelerations, and in intricate maneuvers that human beings could never withstand. It is conceivable to move enormous numbers of these devices at ballistic missile speeds, having them in action half a world away in minutes. In such circumstances, operating according to preset instructions may not provide the necessary flexibility in

operation, and remote control is probably impractical. Once again, this leads us back to autonomy.

The nature of small systems is such that they are more difficult to hit with conventional projectile weapons due to their small size and large numbers. This applies even to some DEWs, such as lasers. The logical countermeasure for very small, smart systems deployed in large numbers is probably an energy weapon with an area effect such as an electromagnetic pulse (EMP) device. Once again this is likely to lead to the play and counterplay of extremely rapid autonomous systems functioning far too quickly for human intervention.

Solutions

If the problem is how to maintain meaningful human control of autonomous warfighting systems, no good solution presents itself. One answer, of course, is to simply accept a slower information-processing rate as the price of keeping humans in the military decision business. The problem is that some adversary will inevitably decide that the way to defeat the human-centric systems is to attack it with systems that are not so limited.

A longer-range solution is to integrate humans and machines in a far more intimate fashion. One form of this concept is that of the Air Force's Information Integration Center (IIC). In this scheme, all-source information collectors would transmit raw data to an IIC. Archival databases linked to the center would be used for historical analyses to fill information gaps. The IIC, housed in an integrated and interconnected constellation of "smart" satellites, will analyze, correlate, fuse, and "deconflict" all relayed data. The refined data would be relayed to human users through implanted microscopic chips, providing users with computer-generated mental visualizations. This would allow the user to place himself or herself into the selected battlespace.⁵⁶ It would avoid the need for clumsy interfaces by making humans a part of the information system in a way very similar to that in which the computers are connected. But, like "fly-by-wire" systems, it does depend on broadcast information at radio frequencies, raising the serious possibility of jamming or other forms of interference.

In the further future, the arrival of very advanced, microscopic information systems may allow extremely sophisticated data processing capacities to be made an integral part of the human brain. However, assuming this proves to be possible, such a step may raise objections from those who object on moral and ethical grounds to blurring the distinction between humans and machines. It also does not address the relative fragility of human beings in combat situations.

Conclusions

The evolution and adaptation of the systems and processes described here are not as simple nor as straightforward as it might seem. The effective use of such technologies will require rapid, effective, and close interaction between many different systems. It will involve sophisticated command and control links as well as a variety of technical means, including reconnaissance sensors,

communication links, computers, display systems, and weapon platforms. This kind of new and subtle interaction will require radical changes in the architecture and integration of these interconnected and widespread intelligence absorbing, processing, and application systems. Right now, the architectures for this kind of “system of systems” are barely in the developmental stages. The actual achievement of solutions for the integration of such large, complex systems will be a long process involving extensive experimentation. At least another decade, probably two, will be required.

This leaves us in something like the position of monarchies witnessing the democratic revolution at the beginning of the 19th century. Something profound and far-reaching is going on all around us, even within our own societies. But the advisers, courtiers, and generals that surround the throne are at a loss to determine what it means, much less what to do about it.

Humans may retain symbolic authority, but automated systems move too fast and the factors involved are too complex for real human comprehension. When computers are designed and programmed by other computers, the situation will be even further from anything humans can reasonably expect to understand, much less intervene in successfully. At the same time, loud denials can be expected from some quarters, angrily claiming that humans are as much, if not more, in charge than ever. In a sense this will be true--the new systems will enable people to accomplish far more in war and peace than was even conceivable before their development, or, rather, is even conceivable now. But the simple fact remains, the farther we extend our reach outside “human space,” the more we require the assistance of machines.

Future generations may come to regard tactical warfare as properly the business of machines and not appropriate for people at all. Humans may retain control at the highest levels, making strategic decisions about where and when to strike and, most important, the overall objectives of a conflict. But even these will increasingly be informed by automated information systems. Direct human participation in warfare is likely to be rare. Instead, the human role will take other forms--strategic direction perhaps, or at the very extreme, perhaps no more than the policy decision whether to enter hostilities or not. Nevertheless, wars are a human phenomenon, arising from human needs for human purposes. This makes intimate human participation at some level critical, or the entire exercise becomes pointless.

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24. Quoted in *Jane's Defense Weekly*, 21 June 2000, internet, http://www.janes.com/defence/interviews/dw000621_i.shtml, accessed 18 June 2001.
25. See, for example, Fadok, et al., p. 16.
26. William B. Osborne, "Information Operations: A New War-Fighting Capability," Air Force 2025 Research Paper (Maxwell AFB, Ala.: August 1996).
27. Sheila E. Widnall, and Ronald R. Fogelman, "Air Force Executive Guidance" (Washington: US Air Force, December 1995), pp. 2, 17.
28. *Ibid.*
29. US Department of the Army, *STAR 21: Strategic Technologies for the Army of the 21st Century* (Washington: National Academy Press, 1996), Introduction.

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31. At one point, devices similar to the cruise missile were referred to as "robot bombers" rather than the now fashionable term Autonomous Aerial Vehicle (AAV).

32. The flight was sponsored, in part, by the Department of the Navy. Tad McGeer and Juris Vagners, "An Unmanned Aircraft's Atlantic Flight," *GPS World Magazine*, June 1999, internet, <http://www.gpsworld.com/0699/0699feat.html>, accessed 2 March 2000. In 1995 students from the University of Texas at Arlington demonstrated an AAV that was able to autonomously takeoff from a designated area, locate and identify radioactive and biohazardous material represented by labeled barrels, map the location of each barrel, and return to its start point.

33. Michael Toscano, "Joint Robotics Program," slide presentation, Office of the Under Secretary of Defense (Acquisition & Technology), Strategic & Tactical Systems, Land Warfare, 24 August 1999, slide 13.

34. *Ibid.*, p. 7.

35. Ronald C. Arkin and Tucker Balch, "Cooperative Multiagent Robotic Systems," Office of Mobile Robot Technology, Georgia Institute of Technology, Atlanta, Ga., undated, received March 2000.

36. "Just Right for Mini-Me: the Mini-Micro-PC," *TIME Digital*.

37. US Army Training and Doctrine Command, "Concept of Employment for Unmanned Systems," p. 12.

38. This problem is mentioned, almost in passing, on the web page for the Advanced Guidance Division of the Air Force Research Laboratory at Wright Patterson Air Force Base, Ohio, <http://www.mn.af.mil/public/advguid.html>, accessed 1 January 2001.

39. Susan I. Erwin, "Running Ships with Fewer Sailors," *National Defense*, March 2000, p. 16.

40. US Navy, "Smart Ship Project Assessment Report," Commander, Naval Surface Force, US Atlantic Fleet, Norfolk, Va., 9 September 1997. See also, "Smart Ship' Program Advances," *MarineTalk* website, 20 December 1999, internet, <http://www.marinetalk.com/article/xxx-00012222TU/>, accessed 6 March 2001.

41. Charles Aldinger, "Remote-Control Warship Planned," *Philadelphia Inquirer*, 16 July 1996, p. 5.

42. See, for example, Raja Parasuraman, "Human-Computer Monitoring," *Human Factors*, 29 (1987), 695-706, and earlier (1981) work by C. D. Wickens and C. Kessel, "Failure Detection in Dynamic Systems," in *Human Detection and Diagnosis of System Failures*, ed. J. Rasmussen and W. B. Rouse (New York: Plenum, 1983).

43. Bill Hillaby, "Directed Energy Weapons Development and Potential," *National Network News*, 4 (July, 1997), 1, published by The Defense Associations National Network, Ottawa, Canada, internet, http://www.sfu.ca/~dann/nn4-3_12.htm, accessed 2 March 2001.

44. Jeffrey E. Thieret, et al., "Strategic Attack Systems Description," in *Strategic Attack in 2025*, Air Force 2025 Project (Maxwell AFB, Ala.: Air University, 1996) ch. 3, internet, [http://www.au.af.mil/au/2025/volume3/chap06/v3c6-3.htm#Target Engagement System](http://www.au.af.mil/au/2025/volume3/chap06/v3c6-3.htm#Target%20Engagement%20System), accessed 9 March 2001.

45. "Tactical High Energy Laser (THEL)," news release BW0064, TRW Inc., Redondo Beach, Calif., 9 November 2000, internet, <http://www.trw.com/thel/>, accessed 12 December 2000. The US Army is also considering a Directed Energy Warfare Vehicle (DEW-V) concept. The DEW-V is a "virtual test bed" to determine the operational effectiveness of vehicle-mounted directed energy weapons for battle scenarios in 2015 and beyond. See Hillaby.

46. John T. Tatum, "A New Threat to Aircraft Survivability: Radio Frequency Directed Energy Weapons," *Aircraft Survivability*, Fall 1995, p. 11.

47. Although no one expects these devices to completely replace conventional weapons, they have at least three advantages over conventional systems in addition to those already cited. First, some DEWs, especially the radio frequency type, have a higher probability of hit than projectiles.

The spreading beam can irradiate the entire target, making accurate pointing and tracking much simpler. Second, the “ammunition” supply for these weapons is large compared to a typical store of conventional projectiles and missiles. This is especially true of aircraft, where weight is a critical consideration. Finally, DEWs are potentially much cheaper to support than conventional explosives. The traditional ammunition loading, fusing, and storage facility could be replaced by the “fuel” required to source the DEW. Additionally, some forms of DEWs, such as lasers and radio frequency weapons, can be used to produce nonlethal effects. See Tatum, p. 11.

48. The US Army and TRW Corporation have been using the High Energy Laser System Test Facility (HELSTF) for a joint tactical program with Israel called “Nautilus.” The joint effort is evaluating lasers for use against short-range rockets, including the kind used with great effect against Israeli troops in South Lebanon and Russian forces in Chechnya. On 9 February 1996, lasers at HELSTF shot down their first armed and operational short-range rocket at White Sands Missile Range, N.M. In 1997, HELSTF conducted a successful live-fire test including the detection, tracking, and destruction of a short-range missile. The demonstration paved the way for further development in the form of the planned Tactical High-Energy Laser (THEL) system, a mobile ground-based air defense system for the US Army Space and Missile Defense Command. “Nautilus Fact Sheet,” US Army Space and Missile Defense Command, Huntsville, Ala., 1996. “Tactical High Energy Laser (THEL)” information sheet, TRW Corporation, Cleveland, Ohio. The same material may be found on the internet at <http://www.trw.co.il/seg/sats/THEL.html>, accessed 29 June 2000.

49. “Boeing Completes Testing of Tactical High Energy Laser,” Defense Systems Daily, internet, <http://defence-data.com/archive/page4222.htm>, accessed 26 June 2000.

50. Ibid.

51. For a full discussion of netwar, see Stefan Eisen, Jr., “Netwar, It’s Not Just for Hackers Anymore,” document number ADA297897, Defense Technical Information Center, Ft. Belvoir, Va., 22 June 1995.

52. “Micro Air Vehicles,” *UK Defence Forum*, March 1999, internet, <http://www.ukdf.org.uk/ts6.html>, accessed 13 March 2000.

53. Sandia National Laboratories, Intelligent Systems and Robotics Center, Miniature Autonomous Robotic Vehicle (MARV) webpage, http://www.sandia.gov/isrc/Capabilities/Prototyping/Small_Smart_Machines/MARV/marv.html, accessed 2 March 2000.

54. Ibid.

55. Institute for National Strategic Studies (INSS), *Project 2025* (Norfolk, Va.: National Defense University, 6 May 1992), p. 36.

56. 2025 Concept, No. 900702, “Implanted Tactical Information Display,” 2025 Concepts Database (Maxwell AFB, Ala.: Air War College, 1996).