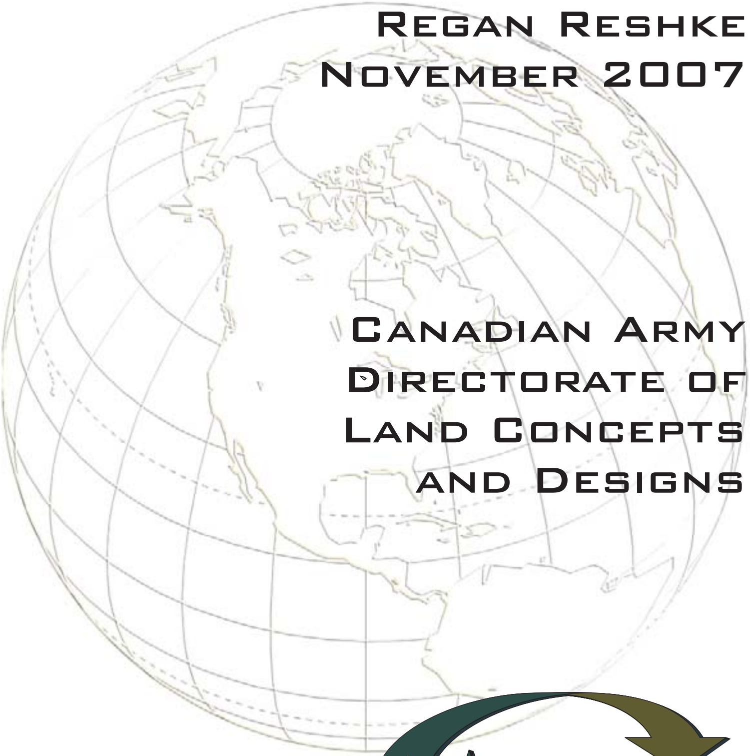
JADEX PAPERS 1

BRAVE NEW CONFLICTS: EMERGING GLOBAL TECHNOLOGIES AND TRENDS



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NOVEMBER 2007

CANADIAN ARMY
DIRECTORATE OF
LAND CONCEPTS
AND DESIGNS

Future

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“JADEX”

General Jacques Alfred Dextraze

These occasional papers are named in honour of the legendary Canadian Army General Jacques Alfred Dextraze, CC, CMM, CBE, DSO, CD, LL.D., affectionately known to his soldiers first as ‘Mad Jimmy’ and then later simply, ‘JADEX’. Born 15 August 1919, he joined the Canadian Army in 1940 as a private soldier. He would end his military career 37 years later as a full general and the Chief of Defence Staff (CDS).

Jacques Dextraze received his early education at St. Joseph’s College in Berthierville before joining the Dominion Rubber Company as a salesman. During the Second World War, he left his civilian employment and enlisted as a private soldier with the Fusiliers de Mont Royal (FMR) in July 1940, shortly after the fall of France. Showing leadership potential during training was promoted to acting Sergeant, but his first attempt to gain a commission in early 1941 was refused by the regiment. Nevertheless, he continued to display good natured leadership and great skill, especially in instructing other soldiers. He was eventually commissioned in early 1942, and applied for active service overseas as soon as his officer training was complete.

Lieutenant Dextraze arrived in England just after the Dieppe Raid in August. With his unit decimated in that attack, it fell on him and other new junior officers to rebuild the unit and make it combat ready once more. The resourceful and dedicated young Dextraze applied himself completely to the task, showing great leadership at all times. By June 1944, Dextraze and the FMR were ready for combat.

The FMR landed in France in the first week of July as part of the 6th Canadian Infantry Brigade, 2nd Canadian Infantry Division. It immediately went into action as the 1st Canadian Army was ordered to attack and destroy the remaining German resistance in Normandy and secure positions for the breakout battle that would follow.

On 1 August 1944, Major Dextraze commanded D Company in an attack to capture the church of St.Martin de Fontenay. The church, which was used as an observation post by the enemy, commanded the whole area and threatened the success of further operations of 6th brigade as it dominated a feature that had to be captured to secure the front. D Company took heavy losses in the assault from enemy machine gun and mortar fire which swept the open streets. Realizing that it was vital to keep up the momentum of the attack, Major Dextraze rushed forward and with no regard for his own safety he personally led the assault into the church yard through enemy grenades, rifle, and machinegun fire. A sharp hand-to-hand fight took place, Major Dextraze "setting the example", overwhelmed the enemy and captured the position. Almost immediately the enemy counter-attacked, but Major Dextraze quickly organized the remainder of his men and defeated all efforts against his position. For his tremendous personal leadership and bravery in combat, the army awarded Major Dextraze the Distinguished Service Order (DSO).[1] His men awarded him the title, "Mad Jimmy".

In December 1944 Major Dextraze was promoted to Lieutenant Colonel and command of his regiment. He led the FMR through the remainder of the war, earning a second DSO for his leadership in the liberation of the City of Groningen, the Netherlands, on 15 April 1945. The 6th Canadian Infantry Brigade was given the task of clearing the enemy from the centre of Groningen, and the FMR were ordered to clear the eastern half of the city. This involved house to house fighting, as the enemy was determined to hold the position at all costs.

During the early stage of the battle the leading troops were held up by heavy machine gun fire coming from well sited posts. Lieutenant-Colonel Dextraze quickly appreciated that if this condition was allowed to continue the whole plan might well collapse. He went forward immediately to the leading company, formulated a plan to clear the machine gun posts, and personally directed their final destruction. When the right flank company commander was killed, Dextraze raced through enemy fire to reach it, reorganized its attack, and personally led it forward to its objective. Despite intense enemy fire, he forced the Germans from their defenses and forced the surrender of the garrison. Throughout the entire action, Lieutenant-Colonel Dextraze led his battalion forward, and when they were held up, he assisted and encouraged them onto their objective. His resourcefulness, superb courage, and devotion to duty was not only a great inspiration to his men, but the contributing factor to the final surrender of the enemy garrison of Groningen and the completion of the divisional plan.[2]

It was during Lieutenant Colonel Dextraze commanded his unit until the final surrender of Germany, after which he volunteered to lead a battalion in the Canadian infantry division then formed for active service in the Pacific. Japan surrendered in August before Canadians units were deployed, and Dextraze 'retired' to the general reserve officer's list and re-entered to civilian life. His tenure out of uniform was short, however, and in 1950 he returned to active duty as the officer commanding 2nd Battalion, Royal 22^{e} Regiment. Dextraze again displayed his tenacious character and leadership at the defence of Hill 355, when his unit was surrounded by the enemy but held off all attacks and refused to surrender the position. In 1952, Lieutenant Colonel Dextraze was made an officer of the Order of the British Empire (OBE) for his service in Korea.

After returning from Korea, Dextraze was briefly appointed to the Army Staff College and then to the Land Forces Eastern Area Headquarters. In 1954 he promoted full colonel and made the Chief of Staff of Quebec Command in Montreal. He subsequently served at the Infantry Schools in both Borden and Valcartier, until he returned to command the Quebec Region as a Brigadier in 1962. His tenure there was short, however, as the following year he deployed as the commander of the Canadian contingent as well as the Chief of Staff for the United Nations Operation in the Congo. In early 1964 he organized, coordinated, and led a series of missions under the operational codename 'JADEX' to rescue non-combatants from zones of conflict in theatre, actions which earned him a promotion within the Order of the British Empire to the rank of Commander as well as the award of an oak leaf for gallant conduct.[3]

Upon returning to Canada Dextraze was appointed to command of the 2nd Canadian Infantry Brigade where his traditional signature of 'Jadex' on all official correspondence stuck with him as a nickname. In 1966, he was again promoted to Major-General and the position of Deputy Commander of Mobile Command. In 1970, Dextraze was promoted to Lieutenant-General and made Chief of Personnel at National Defence Headquarters. In 1972, Lieutenant-General Jacques Alfred Dextraze was appointed to Chief of the Defence Staff with the rank of full General and made the Commander of the Order of Military Merit. He served as Canada's top soldier until his retirement in 1977, nearly four decades after he joined as a private in the infantry. For his tremendous service to the armed forces and the country he was admitted to the Order of Canada in 1978. When Jacques Alfred Dextraze passed away peacefully on 9 May 1993, the country said a sad goodbye to one of the army's most legendary and outstanding soldiers in its history.

Endnotes

1. Recommended for immediate DSO, 5 September 1944, endorsed by Lieutenant-General H.D.G. Crerar, Acting General Officer Commanding-in-Chief, First Canadian Army on 4 November 1944.
2. Recommended for immediate Bar to DSO on 17 April 1945; supported by Headquarters, 6 Canadian Infantry Brigade on 2 May 1945 and passed forward on 30 May 1945.
3. Awarded Commander, Order of the British Empire (CBE) with gallantry oak leaf as per Canada Gazette of 3 October 1964 "For Services with the UN Forces in the Congo" as Commander of the Canadian contingent with the United Nations in the Congo (UNUC).

ABOUT THE AUTHOR

Mr. Regan Reshke enrolled in the Canadian Forces in June 1980 and graduated in 1985 from the Royal Military College (RMC) of Kingston with a Bachelor of Engineering Degree in Civil Engineering.

Upon completion of Military Engineering training in Chilliwack, he was posted to the Construction Engineering section at CFB Edmonton where he served as Operations Officer, Utilities Officer, Contracts Officer and Engineering Officer. During this time, he completed the requirements for membership in the Association of Professional Engineers, Geologists and Geophysicists of Alberta (APEGGA) and was granted membership as a Professional Engineer in 1988.

Selected to attend occupation specialty training at the University of New Brunswick (UNB) in 1989, he received a Graduate Diploma in Mapping, Charting and Geodesy in 1991. Upon graduation, he was posted to the Mapping and Charting Establishment in Ottawa where he served as Operations Officer and Officer Commanding the Cartographic Squadron, and Officer Commanding the newly formed Digital Production Squadron. In 1993, he was posted to the project management staff of the newly formed Land Force Command System project where he served as the project's Geographic Information System Engineer for four years.

Selected to undertake sponsored graduate studies in civil engineering at RMC in 1997, he received a Master of Engineering Degree in Structural Engineering in 1999. Upon graduation, he joined the Civil Engineering Department at RMC as a lecturer. During this time, he successfully completed the requirements for registration as an Ontario Land Surveyor/Ontario Land Information Professional and was granted professional membership in 2001. He was posted in 2001 to the J2 branch of the CF Joint Headquarters in Kingston where he served as J2 Environment until his retirement from the CF in 2002.

Regan joined Defence Research and Development Canada in March of 2002, where he is currently Director Science & Technology Land 7, serving as Scientific Advisor to the Chief of Staff Strategy (formerly DGLCD) in Kingston. Serving a liaison function between the Land Staff's Capability Developers and DRDC, Regan researches and advises on Science and Technology trends and their implications for Army Capability Development.

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Disclaimer

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DIRECTORATE OF LAND CONCEPTS AND DESIGNS

The Directorate of Land Concepts and Designs (DLCD) evolved out of the original Directorate of Land Strategic Concepts (1997-2006) as part of the ongoing army transformation and maturation of capability development in the land force. As the primary ‘think tank’ for the Canadian Army, its mission is to advise the Chief of Land Staff on the Future Security Environment (FSE), the capabilities that will be required to operate in that environment, and alternative concepts and technologies to achieve those required capabilities. DLCD provides a focal point within the Army to identify, examine, and assess factors and developments that will have an impact on the Army of Tomorrow (AoT) and the Future Army (FA), or more concretely, from 2016 and beyond. In meeting its mandate, the Directorate examines a wide range of issues covering the global and domestic environments, emerging technologies and human factors, as well as allied and foreign force developments.

ABSTRACT

Throughout history, warfare has been profoundly altered by science and technology. Radar, radios, computers, lasers, GPS satellites, rifles, artillery, tanks—all these 20th-century military technologies and many others can trace their origins at least in part to science, technology and engineering research. Investments in science and technology have served the Army well and will continue to be the essential underpinning for maintaining superior Land Force warfighting capabilities. Science and technology research will be even more influential in the 21st century than it has been throughout the 20th century.

While it is impossible to predict the future, studying the primary factors contributing to change does allow for identification of some of the broad possibilities that lie ahead. Negative possibilities constitute a warning, while positive possibilities can reveal opportunities that should be actively pursued—thus shaping the future. Although opinions vary as to the key drivers of change for the future, there is broad consensus amongst those who study the future, that technology is the primary enabler of social change. It is imperative, therefore, to monitor and understand ongoing and emerging trends in science and technology given their acknowledged status as key drivers of change.

Ironically, despite the broad parallels between the study of the future and military planning, military professionals dedicate very little effort towards the study of the future. As a small step towards ameliorating this situation, and in keeping with the diversity of global change in the 21st century, the drivers, trends and technologies considered in this paper are wide-ranging, covering both military and commercial systems and their potential impact on society and the military. The paper will demonstrate that failure to hedge development activities to cover the potential threats offered by the onslaught of advanced commercially available technologies represents a serious risk to tomorrow's land operations.

BRAVE NEW CONFLICTS
EMERGING GLOBAL TECHNOLOGIES AND TRENDS

By Regan Reshke

> *Science and Technology can effectively support the Canadian Forces transformation by contributing directly to the advancement of Canadian military capabilities.*
>
> R.J. Hillier, General, Chief of the Defence Staff and Ward P.D. Elcock, Deputy Minister, in a foreword introducing the Defence S&T Strategy, released in December 2006.

Introduction

Throughout history, warfare has been profoundly altered by science and technology. In his analysis of the effect of industrialization and technology on warfare, Patrick Murphy[1] reveals that Europe after 1850 experienced a surge in weapon development. Science, technology and engineering contributed to the improvement of most weaponry including small arms (the breech-loading rifle), and artillery (rifling) yielding vast increases in accuracy and lethality. Such developments altered the way wars were fought thereafter as troop dispersal increased and communications technology (the telegraph) was introduced to facilitate command and control of dispersed forces. Due to their high cost however, only wealthy nations could afford to implement the newest capability developments, thus creating technological disparities between rich and poor. Despite the intervening century and a half since industrialization first began to transform warfare, the very same trends are recognizable today—increasing weapon accuracy, range, firepower, lethality, troop dispersal, information technology enabled command and control and technological disparities between states.

Science and technology are also the primary drivers of the economies of developed and to some extent developing countries. Indeed, fifty-eight percent of executives surveyed in the 2005 Economist Intelligence Unit CEO Briefing[2] cited advances in technology as the most critical driver of change in the global marketplace. Furthermore, science and technology shape all other driving forces (from demographics to globalization[3]), thus their impact is central, albeit difficult to anticipate due to the vast array of innovation that characterizes the early 21st century. While some technologies can be anticipated, especially those that are improvements or new application of old technologies, there is such rapid change in fundamentally new areas that it is hard to foresee their consequences.

Science, as defined in the Encyclopaedia Britannica Online, is any system of knowledge that is concerned with the physical world and its phenomena and that entails unbiased observations and systematic experimentation.[4] In general, a science involves a pursuit of knowledge covering general truths or the operations of fundamental laws. Scientific knowledge is a fundamental enabler for the development of new or improved technologies. Thus, the major innovations of future technology, those that will shape society, will require a foundation of strong basic research. Hence innovation is the key to the future, whereas basic research is the key to future innovation.[5]

Technology is the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment.[6] Technology thus comprises machinery and equipment based on scientific knowledge. Tools and machines, however, need not be material. Virtual technology, such as software, also falls under this definition of technology. Military technology comprises the range of weapons, equipment, structures, and vehicles used specifically for the purpose of fighting. It includes the knowledge required to construct such technology, to employ it in combat, and to repair and replenish it.[7]

Although the broad definition of technology in the preceding paragraph applies to every man-made implement, from boots to nuclear weapons, there is an apparent tendency among military professionals to only regard new and evolving developments as technology. Mature equipment, tools and techniques that have become an integral part of well-developed doctrine are less likely to be seen as technology, but rather as part of the cultural fabric—thus becoming superior to technology. As a result, the term technology is incorrectly becoming synonymous, for example, with the latest developments in information and communications technology (ICT)—so called high technology or high-tech. This belief however, can lead to a tendency to eschew evolving technology solutions in favour of mature technologies such as tanks or artillery. While there continues to be some merit in this approach, it cannot remain the default reaction to new developments, particularly as they mature at an increasingly rapid pace.

Technology has been an important catalyst of change throughout history. While there are varying opinions as to which are the key drivers of change, there is broad consensus amongst those who study the future, that technology is the primary enabler of social change. Though the importance of science and technology is clear, its value and function in society remains a matter of debate since it is hard to anticipate the effects of these changes, and it is not clear whether technology drives a societal change or if it is the other way around. Increasingly it seems that it is neither one nor the other, but rather a symbiotic connection—technology and society influencing each other's development in incremental steps, sometimes one leading, and sometimes the other—but both ultimately progressing.

It is important to monitor and understand trends since this helps organizations think about adapting to the inevitable change that will occur in the future, which is the sum of the outcomes of trends, chance events, and human choices. Moreover, it is imperative that trends pertaining to science and technology be analysed due to their acknowledged status as key drivers. While it is impossible to predict the future, studying the primary factors contributing to change makes it possible to identify broad possibilities that lie ahead. Negative possibilities constitute a warning, while positive possibilities can reveal opportunities that should be actively pursued—thus shaping the future.

In his landmark text, Futuring: The Exploration of the Future[8], Edward Cornish compares the study of the future with the grand expeditions of the great European explorers. Military professionals will readily identify with the great explorer's meticulous preparations; their success depending upon having the right equipment, the right supplies, the right team mates, and the right training at the moment of need.[9] In addition, Cornish identifies seven lessons from these great expeditions that are applicable to the study of the future,[10] and these lessons will also be familiar to military planners: prepare for what you will face in the future; anticipate future needs; use poor information when necessary; expect the unexpected; think long term (strategically) as well as short term (tactically); dream productively (creatively innovate); and learn from your predecessors. Ironically, despite the broad parallels between the study of the future and military planning, military professionals dedicate very little effort towards the study of the future. As a small step towards ameliorating this situation, and in keeping with the vast diversity of global change in the 21st century, the drivers, trends and technologies considered in this paper will be wide-ranging, covering both military and commercial systems and their potential impact on society and the military.

Mega-Trends

In order to understand the complexity of the rapid change that is unfolding today, Cornish[11] proposes a simplifying set of super- or mega-trends, which are shaping the future. He acknowledges technological progress as the main engine driving rapid cultural evolution.[12] He suggests however, that technological progress is more than a super-trend; it is a super-force, one that gives rise to other super-trends. Discussed in more detail below, economic growth is the first super-trend that is being driven directly by technological progress. New technologies have, and continue to be developed that make it possible to design, produce and deliver better goods and services that drives a continual demand cycle. Combined, this technologically driven economic growth has undeniably created a startling amount of societal change over the past century and a half. Together, techno-economic growth, in Cornish's opinion, is another super-force, because it causes many other changes including four additional super-trends: improving human health, increasing mobility, environmental decline, and increasing deculturation or culture shock.

Techno-economic growth has lead to improving human health through the production and distribution of more food, better medical intervention, health services and improved sanitation, for example. Healthier societies have experienced increasing longevity resulting in several important sub-trends: population growth and age related demographic shifts. The increasing mobility super-trend results from the fact that collectively, technological progress, economic growth and global population rise, leads to an increased movement of people, goods and information at rates and in quantities greater than ever experienced before. This rise in global mobility, according to Cornish,[13] appears to be the principle cause of globalization—the increasing integration of human activities on a global scale.

Regarding the environmental decline mega-trend, recent WMO and UNEP Intergovernmental Panel on Climate Change (IPCC) reports[14] offer compelling arguments that global economic growth and population increases are key contributing drivers. Finally, Cornish attributes deculturation or culture shock, to increasing global mobility, rapid technological change, economic growth, globalization and urbanization among other factors.

With these mega-trends as a broad framework for simplifying the massive scale of change that characterizes the 21st century, the following sections will examine many of the underlying trends that contribute to these major currents of our time.

Innovation

Progress, whether technological or otherwise, is the result of innovation. A hallmark of innovation is that it builds on the work of others; scientific and technological breakthroughs do not occur in a vacuum. Today's scientists and engineers can trace their work back to an extensive lineage of innovators. Innovation is further strengthened through high-profile competitions such as the Ansari X-Prize for space flight,[15] Archon X-Prize for Genomics,[16] automotive X-Prize,[17] DARPA Grand Challenge for urban autonomous vehicles,[18] or Robo Cup Challenge for autonomous humanoid robotics.[19] These competitions attract and motivate an enormous amount of human intellectual capital. Moreover, several web based open collaboration initiatives such as ThinkCycle,[20] are attempting to create a culture of open source design innovation, with ongoing collaboration among individuals, communities and organizations around the world. Another web service founded in 1999, yet2.com,[21] focuses on bringing buyers and sellers of technologies together so that all parties maximize the return on their investments. The yet2.com service excels at locating unrealized IP value potential, especially in situations where IP and technology offer substantial market opportunities for products, services or cooperative relationships with third parties.

In addition to a foundation of basic scientific research, innovation requires creativity. Science fiction has often been the creative inspiration for many technological developments that ultimately transform fiction into reality. After all, science fiction writers foreshadowed wireless communication, flight, nuclear weapons, cyberspace, computer viruses, and space travel among many other developments. Paul Saffo, a Silicon Valley technology forecaster advises senior leaders to stay abreast of the science fiction that new recruits are reading in order to get a sense of what they will want to build or implement when they become middle managers.[22] Increasingly, the source of creativity for today's youth can be found in computer games and virtual worlds.[23] These varied sources of creative stimulation will continue to drive innovative scientific and technological advancements.

Ray Kurzweil was one of the first to provide a label for the continuous onslaught of technological innovation, which he calls the law of accelerating returns.[24] This law describes technological innovation and development as a positive feedback loop whereby each cycle of innovation yields an improved set of tools, which are in turn used to invent newer and better tools. Kurzweil and now others[25] identify the continuous shortening of time between innovation cycles (i.e. accelerated change) as a hallmark characteristic of technological development. A good example of Kurzweil's law in action is within the automation industry, where higher fidelity and more flexible automation are used to fabricate parts for still-better automated systems. Now, a new innovation tool is available in the designer's toolbox: digital manufacturing, which creates a fully digital product lifecycle management (PLM) environment. This capability allowed Boeing to completely "manufacture" its 787 "Dreamliner" digitally before a single tool was cut.[26] This capability is turning innovative designs into reality with less risk of wasting time on a design that cannot be easily manufactured. More rapid design-manufacturing cycles will obviously contribute to the accelerating pace of change in technological developments.

Rapid prototyping, a common name given to a variety of related technologies that are used to fabricate physical objects directly from digital CAD data sources, is also contributing to accelerating change. These methods are unique in that they add and bond materials in layers to form objects. Such systems are also known by a variety of names including: additive fabrication; three-dimensional printing; solid freeform fabrication (SFF); and, layered manufacturing. These technologies offer many advantages over traditional milling or turning fabrication. For example, objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly. While the material options are not as broad as that for traditional fabrication techniques, there is a growing list of materials that can be used in rapid prototyping systems, such as: numerous plastics, ceramics, metals ranging from stainless steel to titanium, and wood-like paper. Two new materials have recently been added; silver nitrate solution as a "metal ink" and ascorbic acid (vitamin C) as a reducing agent. When loaded into a modified desktop inkjet printer, researchers have been able to print electronic circuits.[27] This experimental device could lead to safer, greener and cheaper electronics manufacturing.

Furthermore, the availability of global communication and advanced Internet-based search tools is creating a thriving innovation environment resulting in improved interaction of researchers and research ideas that tend to multiply their impact and acceleration. Indeed, this environment is undergoing continuous active improvement through such initiatives as the National Academies Keck Futures Initiative,[28] which seeks to catalyze interdisciplinary inquiry and to enhance communication among researchers, funding organizations, universities, and the general public. The Initiative's objective is to enhance the climate for conducting interdisciplinary research, and to break down related institutional and systemic barriers. Technology itself is becoming the single most important facilitator of globalized research. It can, for example, give a research organisation a 16- or even a 24-hour day in R&D, as research activity passes through time zone after time zone to make a global circuit. Round the clock research accelerates the productive outcomes of a project and thereby offers the sponsor a potential advantage in meeting competitive goals.[29]

Significantly, globalization of R&D is changing the global balance of technological strength. For example, according to a recent report by the World Economic Forum[30], the US has lost its position as the world's primary engine of technology innovation. The report indicates that the top innovators are Denmark followed by Sweden whereas the US is now ranked seventh in the body's league table measuring the impact of technology on the development of nations.

Technological Drivers

According to a 2005 study by the Canadian National Research Council (NRC) Renewal Futures Team entitled Looking Forward: S&T for the 21st Century,[31] three primary transformative technologies will drive global change out to 2020: Information and communication technologies (ICTs), biotechnologies, and energy and environmental technologies. The report indicates that the transformative power of information and communication technologies is already under way and is apt to be even more profound by 2020. It is expected that computing power will become ubiquitous and part of the fabric of daily living. The transformative nature of Biotechnology, according to the report's authors, will eventually impact most sectors of the global economy. It is suggested that biotechnologies are becoming the most significant S&T area of the current century, with impacts that are expected to exceed even those of information and communications technologies. Energy and environmental technologies are rapidly gaining prominence globally, spurred by recent global climate change studies, suggesting that this innovation wave will have a growing impact over the next few years.

In addition to the broad transformative technologies noted above, the NRC report identifies a series of primary enabling sciences and technologies. It is acknowledged though, that due to their complexity, most significant advances are only made possible by complementary advances in other enabling sciences and technologies. Indeed the report reveals that increasingly, themes of "convergence" will dominate S&T development, whereby new technologies will often be a blend of two or more disciplines and advances in one field will enable advances in another (e.g. the influence of informatics on genomics research). The convergence of nano-bio-info-cogno-technologies (sometimes referred to as NBIC technologies)[32] is expected to produce significant advances in human health, security and industrial applications to name a few. An example of nano-bio-info technology convergence was recently announced by IBM,[33] wherein they describe the first-ever application of a breakthrough self-assembling nanotechnology to conventional microprocessor chip manufacturing, borrowing a process from nature to build the next generation computer chips. The announcement claims that chips manufactured using this technique demonstrate a 35 percent increase in electrical signal speed and can consume 15 percent less energy compared to the most advanced chips using conventional techniques.

Repeated below is the NRC Renewal Futures Team report listing of important sciences and technologies that are expected to see significant advancement out to 2020:

❖ Nanoscience and Nanoengineering: The prospective impact of nanoscience and nanoengineering technologies is expected to be the most profound of all. Nanoscience—materials science on the scale of the atom and molecule—will change the very fabric of society in the long term.

❖ Materials Science: Materials science is a multidisciplinary field focusing on functional solids, whether the function served is structural, electronic, thermal, chemical, magnetic, optical or some combination of these.

❖ Photonics: Photonics refers to science and technology based on and concerned with the controlled flow of photons, or light particles. As a tool, optics is making its way into virtually every field of science and technology.

❖ Microfluidics: Microfluidics is perhaps the future of the wet lab. It may be thought of as the miniaturization of the cell culture laboratory, with the ability to control complex combinations of interactions between test molecules and individual sites on individual cells.

❖ Quantum Information: Quantum information has the potential to revolutionize many areas of science and technology. It exploits fundamentally new modes of computation and communication because it is based on the physical laws of quantum mechanics instead of classical physics.

In addition to the drivers that will lead to continuous and significant science and technology developments, the Renewal Futures Team Report cautions that there are also points of friction that may slow or change the course of developments: first, is the challenge for regulators to keep pace with the rate of change in S&T development and secondly, is a growing sense of over-reliance on S&T, which is leading to a degree of fear of technology. A dramatic example is provided in a recent Pew Internet & American Life Project poll of 742 tech experts on the question: Will we be able to control our technologies in the future?[34] An unexpected 42% of survey respondents were pessimistic about humans' ability to control technology in the future, implying that the dangers and dependencies will grow beyond our ability to stay in charge of technology.

A 2006 survey of more than 700 IEEE Fellows by the Institute for the Future (IFTF) and *IEEE Spectrum*[35] revealed similar drivers to those of the NRC report. The IFTF and IEEE survey was conducted to learn what developments IEEE Fellows expected in science and technology over the course of the next 10 to 50 years. The survey's authors felt that this group was particularly well situated to foresee S&T developments given that they have so much to do with delivering them—exemplifying Alan Kay's quote: "The best way to predict the future is to invent it."

The survey identified five themes that are believed to be the main arteries of science and technology over the next 50 years: "Computation and Bandwidth to Burn" involving the shift of computing power and network connectivity from scarcity to utter abundance; "Sensory Transformation" the result of 'things' beginning to think; "Lightweight Infrastructure" seen as the exact opposite of the railways, fiber-optic networks, centralized power distribution, and other massively expensive and complicated projects of the 20th century; "Small World" described as what happens when nanotechnology starts to get real and is integrated with microelectromechanical systems (MEMS) and biosystems; and finally, "Extending Biology" resulting from a broad array of technologies, from genetic engineering to bioinformatics being applied to create new life forms and reshape existing ones.

Contemplating, evaluating, understanding and responding to the inevitable rapid change that these broad drivers will generate, will be an ongoing challenge for large organizations, particularly those with significant institutional inertia. The CF in general, and Army in particular, are susceptible to this risk. Subsequent sections will examine many of the key technological enablers that are continuing to fuel the race for ever-more sophisticated technologies. This will be followed by an introduction to many of the change trends that are becoming evident, which will undoubtedly continue to shape the future.

Significant Technology Trend Areas

For more than 40 years, escalating computing power has driven the growth of the information age. This has had a profound impact on information and communications technology (ICT), which comprises computers, networking devices and infrastructure, both hardwired and wireless. Mounting computing power available at decreasing prices has become synonymous with IBM's Gordon Moore and his 1965 prediction that the number of components that could be squeezed on to a silicon chip would double every year or two. The result of this remarkably consistent exponential growth trend is that a multi-core desktop computer can be purchased today for one ten-thousandth of the price but with the equivalent performance of the number one ranked supercomputer from 1991.[36] Coupled with this extraordinary price performance improvement has been an equally astonishing reduction in the physical volume and power consumption of computing devices. The result of these trends are seen in the portable music players of today that pack as much computing resources as yesteryear's mainframe computers; cell phones (essentially portable mini-computers) that have become ubiquitous the world over, and the demise of film-based cameras.

With the increase in computing power made possible through the exponential increase in the number of components being placed on microchips, known as Moore's Law, plus exponential increases in sensor technology and software algorithms (also made possible by the proliferation of our computing resources), completely new and previously unimagined capabilities are emerging in laboratories around the world. From a security perspective, for example, computer scientists at the University of California, Berkeley, have devised a means to analyse the audio recording of keyboard clicks to determine what was being typed. Referred to as "acoustical spying", the researchers were able to take several 10-minute sound recordings of users typing at a keyboard, feed the audio into a computer, and use an algorithm to recover up to 96 percent of the characters entered.[37] Combine this capability with ubiquitous small portable digital recording devices such as MP3 players, phonecams or Personal Digital Assistants, and the challenges to privacy and security become evident.

Although the eventual demise of Moore's law has been predicted for some time now, recent announcements suggest that innovative techniques will continue the doubling of processor power well into the early part of this century. For example, another massive leap in consumer computing power is expected when Intel's 45 nanometre breakthrough chips[38] begin hitting the market in 2007. IBM recently announced[39] that it has plans to move Moore's law into the third dimension with a new chip layering technology called "through-silicon vias", which allows different chip components to be packaged much closer together for faster, smaller, and lower-power consumption systems. The announcement indicates that IBM plans to target wireless communications chips, power processors, Blue Gene supercomputer chips, and high-bandwidth memory applications.[40] It can be expected that each of these areas will continue to experience exponential growth in performance over the next several decades.

While the miniaturization and power of devices has been aided by Moore's Law, often integrated circuits only deal with about 10 percent of any given system. The other 90 percent is still there, in the form of an array of bulky discrete passive components such as resistors, capacitors, inductors, antennas, filters, and switches, and these are typically interconnected over one or more printed-circuit boards. Real miniaturization, which will likely give rise to mega-function devices, is nearing reality as researchers continue to make progress on an approach called the system-on-package (SOP). The Microsystems Packaging Research Center at the Georgia Institute of Technology, in Atlanta claims that their SOP approach will greatly surpass Moore's Law when it comes to convergence and miniaturization of devices.[41] It combines integrated circuits with micrometer-scale thin-film versions of discrete components, and it embeds everything in a new type of package so small that eventually handhelds will become anything from multi- to mega-function devices.[42] SOP products will be developed not just for wireless communications, computing, and entertainment; when outfitted with sensors, SOPs could be used to detect all manner of substances, toxic and benign, including chemicals in the environment, in food, and in the human body. The level of system integration using system-on-package (SOP) technology proposed by the researches will see an exponential growth from about 50 components per square centimetre in 2004 to a component density of about a million per square centimetre by 2020. A spin-off benefit of this magnitude of size reduction is that it allows for much faster chip-to-chip signals at lower currents and voltages, which cuts power dissipation. The ultimate in system miniaturization will be the creation of smart dust particles comprising sensors, power sources, digital communications and processing circuitry in a volume of one cubic millimetre.

On the data storage front, recently, Caltech and UCLA researchers announced[43] the creation of a memory circuit the size of a human white blood cell, able to store 160 kilobits of data—the equivalent of 100 billion bits (100 gigabits) per square centimetre. This memory storage density, the highest ever produced, has been achieved about 13 years earlier than anticipated by Moore's Law. Disk storage is also undergoing dramatic improvement. While high-definition disks and players based on blue lasers have only just arrived on the market, already a new generation is in development, promising another fivefold increase in storage density. First-generation discs relying on red lasers could store about 5 gigabytes of data, and blue lasers have increased that to 50 GB. New systems utilizing ultraviolet lasers could raise disk densities to 250 GB.[44] Similarly, new advances are arriving in hard disk storage. While traditional spinning hard disk drive (HDD) capacities have reached the terabyte[45] range, 2007 saw the introduction of solid-state hard drives.[46] Though not competitive on a cost per Gigabyte basis, solid-state drives (SSD) offer many advantages: they are lighter, faster, quieter and less power-hungry than conventional hard drives and they are more resistant to rough handling in portable applications and generate less heat. Recent reports have indicated that solid-state hard drives are being built with data throughput capacity of up to 62MB/sec—about 100 times faster than conventional hard drives. This level of performance will likely lead to cell phones that can record several hours of video, or alternatively smaller notebooks with greatly improved battery life. As with most other information technologies before it, costs are coming down as capacities are heading up. Indeed some reports[47] suggest that the technology is improving a little faster than Moore's Law, doubling in memory density every year. This is due in part to the fact that a few years ago, NAND technology was being produced on trailing-edge manufacturing lines. Now manufacturers are putting it on their leading-edge facilities, thus accelerating product development.

The "computation to burn" prediction made by IEEE Fellows, as noted earlier, appears to be a highly plausible outcome from these technological developments. As computing power increases, but with lower power consumption and smaller sizes, it can be expected that computational abilities will be increasingly integrated into all manner of devices—turning them into smart devices—enabling the possibility of ubiquitous computing.[48] Already, the latest cell phones are being referred to as smart phones.

Advances in data transmission speeds, battery life, and storage capacity are changing cell phones, or smart phones into multipurpose tools. The ability to use a phone as a television, credit card, or GPS locator, is taking the device to new usability levels. The newest generation of phones will enable mobile web surfing able to seamlessly roam across Wi-Fi hot spots, cellular networks and new high-speed data networks. Many now expect that within ten years the cell phone—or its evolutionary heir—will replace the laptop as the dominant Internet tool.[49] Already, some cell phone manufacturers are facilitating this trend. For example, LG Electronics, the world's fifth-largest mobile handset maker, announced recently that it will ship 10 new phones in 2007 that will come pre-installed with Google Maps, Gmail and other Google products and services.[50]

These continuing trends in ICT led the International Telecommunications Union (ITU) to foresee the possibility of creating 'The Internet of Things".[51] In a 2005 report with this title, the ITU noted that the developed world is on the brink of a new ubiquitous computing and communication era, one that has the potential to radically transform our corporate, community, and personal spheres. As the ICT trends continue, radio frequency identification (RFID) tags, sensors, robotics and nanotechnology will make processing power increasingly available in smaller and smaller packages so that networked computing dissolves into the fabric of things around us. The report suggests that early indicators of this ubiquitous information and communications environment are already evident in the proliferation of ever more powerful and numerous cell phones. The authors suggest that the existing ability for "any time" and "any place" connections provided by current ICT will be expanded to include connections to "any thing". This development is in essence, the meaning of the IEEE Fellow's vision of 'Sensory Transformation', as introduced earlier.

Digital data proliferation is, and will continue to be a by-product of ICT proliferation. In an IDC white paper sponsored by EMC Corporation titled "The Expanding Digital Universe: A Forecast of Worldwide Information Growth Through 2010", the authors describe the alarming magnitude of this situation.[52] According to this report, between 2006 and 2010, the information added annually to the digital universe will increase from 161 exabytes to 988 exabytes[53] due in large measure to three major analog to digital conversions: film to digital image capture; analog to digital voice; and, analog to digital TV. IDC predicts that by 2010 organizations including businesses, corporations, governments, etc. will be responsible for the security, privacy, reliability, and compliance of at least 85% of the digital universe despite the fact that individuals will have created nearly 70% of it. This incredible growth of the digital universe has implications for individuals and organizations concerning privacy, security, intellectual property protection, content management, technology adoption, information management, and data center architecture. Given this situation, it cannot be mere coincidence that data management companies such as Google are gaining global Internet prominence. CF and Army digitization initiatives will lead to similar data management issues. A paradox of the digital universe, due to rapidly changing technology however, is that even as our ability to store digital information increases, our ability to store it over time decreases. The life-span of digital recording media is much shorter than stone or paper; the media degrades but more importantly the playback mechanisms become obsolete. The design life of a standard hard drive can be as short as 5 years and the usable lifespan of magnetic tape has been estimated to be as little as 10 years. While the life expectancy of CDs and DVDs is still unknown, it may not be much longer than 20 years. Data archival practices will need to be cognizant of this situation, and ensure that data stored on old media are continuously transferred to new media standards as they mature.

Beyond consumer computing devices, supercomputer technology is also continuing to improve exponentially.[54] Supercomputers are used to solve complex problems including the simulation and modeling of physical phenomena such as climate change, explosions, or the behaviour of molecules, the analysis of data from sources such as national security intelligence, genome sequencing, or astronomical observations; or the intricate design of engineered products.[55] Their use is important for national security and defence, as well as for research and development in science and engineering. The importance of supercomputer development is reflected in the US response to the Japanese, Earth Simulator supercomputer that took over the top global supercomputing spot in 2002 (and held it for 2 years). The US responded with significant funding and since 2004 have regained the lead, with not one, but three (and now four) faster machines.[56] Still faster machines can be expected as next generation supercomputers relying on NEC's laser diode called a Vertical-Cavity Surface Emitting Laser (VCSEL)[57] are developed with the potential to reach petaflop[58] performance levels.

For those of us who use our desktop computing power for little other than the creation of documents and e-mail, a faster supercomputer may seem rather irrelevant. Nothing could be further from the truth. The computing power of these machines makes it possible to conduct such high fidelity simulations, that they approach real-world fidelity (and indeed they permit the simulation of events or phenomenon that we could not even begin to attempt in the real 'physical' world). This in turn means that new innovations can be simulated on a supercomputer before any manufacturing or tooling takes place and coupled with rapid prototyping tools such as 3D printers, means that new innovations can reach the market at an ever increasing rate. Exponential technological growth therefore will almost certainly continue (barring any major catastrophes).

It is interesting to note that while the US dedicates a significant portion of its supercomputer resources for military purposes, other countries (which now includes China) are increasingly using their supercomputer facilities for commercial innovation purposes. It is unlikely to be mere coincidence that the G8 countries combined possess 417 of the world's top 500 supercomputers. It is also worth noting that China and India, which are both experiencing significant economic growth, each have more top 500 supercomputers than Canada and Russia combined. If supercomputing prowess is indeed an indicator of economic growth potential, then it can be expected that China and India will continue their recent growth trajectories.

Turning now to bandwidth enabling technologies, we see very similar trends for both wired and wireless domains. Regarding the fibre optic network infrastructure, Alcatel-Lucent Bell Labs recently announced the creation of a new optical filter on a chip[59] that promises to deliver the integration of silicon electronics and fibre optics. This integration will remove current bottlenecks caused by current network filters that must convert optical signals into an electrical one to clean it up, and then convert it back into an optical signal before retransmission. Similarly, IBM researchers recently announced[60] a new optical transceiver chipset that can move data at speeds up to 160 GB per second, which is eight times faster than previous optical components.

To promote further bandwidth innovation within the fixed network infrastructure, The Internet2 Consortium[61] sponsors The Internet2 Land Speed Record (I2-LSR) competition for the highest end-to-end network bandwidth—an open and ongoing contest. The current record holder within the IPv6[62] Category—Single Stream Class is a team consisting of members from the University of Tokyo, the WIDE Project, Microsoft Corporation, and others. This team reached a data rate of 272,400 terabit-meters per second by transferring 585 gigabytes of data across 30,000 kilometres of network in about 30 minutes—an equivalent average rate of 9.08 gigabits per second.[63]

Regarding wireless networking, the use of multiple antennas at transmitter and receiver, popularly known as multiple-input multiple-output (MIMO) wireless is an emerging cost-effective technology that promises to make 1Gbps wireless links a reality. Another common term for this technology is smart antennas.[64] MIMO technology has attracted attention in wireless communications, since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per Hertz of bandwidth) and link reliability or diversity (reduced fading).

Several technologies promise to deliver true broadband speeds that will push pervasive connectivity closer to reality. Three technologies have emerged to span short through extended distances: Ultra-Wideband (UWB), Wireless Fidelity (Wi-Fi), and World Interoperability for Microwave Access (WiMAX). UWB systems are suitable for ranges up to 10 metres, whereas Wi-Fi typically reaches ranges of up to 100 metres and WiMax is projected to reach ranges up to 50 kilometres.

UWB technology is based on the WiMedia standard and will deliver the convenience and mobility of wireless communications to high-speed interconnects in devices throughout a digital home or office. It is designed for low-power, short-range, wireless personal area networks (WPANs) and is the leading technology for freeing people from wires, enabling wireless connection of multiple devices for transmission of video, audio and other high-bandwidth data. UWB technology provides data transmission over radio in the 3.1- to 10.6-GHz range, capable of generating data transfer rates approaching 500Mbit/sec with low interference.

Wi-Fi networks use radio technologies called IEEE 802.11a, 802.11b or 802.11g to provide secure, reliable, fast wireless connectivity. A Wi-Fi network can be used to connect computers to each other, to the Internet, and to wired networks (which use IEEE 802.3 or Ethernet). Wi-Fi networks operate in the unlicensed 2.4 and 5 GHz radio bands, with an 11 Mbps (802.11b) or 54 Mbps (802.11a) data rate[65] or with products that contain both bands (dual band). They can provide real-world performance similar to the basic 10BaseT wired Ethernet networks.[66]

WiMAX technology is based on the IEEE 802.16 standard and is expected to enable true broadband speeds over wireless networks at a cost point that will enable mass-market adoption. Two main applications are envisioned for WiMAX: fixed WiMAX applications enabling point-to-multipoint broadband access to homes and businesses; and mobile WiMAX, which offers the full mobility of cellular networks at true broadband speeds. Both fixed and mobile applications of WiMAX are engineered to help deliver ubiquitous, high-throughput broadband wireless services at a low cost. Some researchers expect next generation 4G wireless technologies to evolve towards the WiMAX standard thus employing all-IP-based networks, which are seen as an ideal means for delivering cost-effective wireless data services.[67] The importance of all-IP-based Internet routing is reflected in a recently announced[68] US DoD Joint Capability Technology Demonstration (JCTD) project to test Internet routing in space (IRIS). Intelsat General Corp., a wholly owned subsidiary of Intelsat Ltd, has been selected to demonstrate the viability of conducting military communications through an Internet router in space, which will revert to commercial use once testing has been completed. If successful, IRIS will extend the Internet into space, integrating satellite systems with the ground infrastructure thus improving bandwidth for US warfighters, first responders and others who need seamless and instant communications.[69]

Satellite communication, an important capability for military operations, is also experiencing great change. For example, new satellites forming part of the Skynet 5 programme recently became operational thus doubling the bandwidth available to UK forces in theatre within Afghanistan and Iraq.[70] Remarkably, this communications system is not owned by the military but rather by Paradigm Secure Communications, a consortium of defence contractors led by EADS Astrium, Europe's leading space company. Although Paradigm is under contract to the UK MOD (under a Private Finance Initiative) for the delivery of assured bandwidth, the arrangement allows for spare bandwidth on the new satellites to be sold to "friendly" forces, thus earning money not just for Paradigm but for the defence department as well. Canada is among the forces that buys bandwidth from Paradigm.

As noted above there are a variety of new radio technologies being developed, including Bluetooth, ZigBee, a growing number of cellular voice and digital services, and broadcast satellite. In order for this proliferation of wireless technologies to function with minimal interference, each is restricted to specific bands of the electromagnetic spectrum. Traditional spectrum management in this fashion, however, is limited in the way it divides that spectrum into channels and in the encoding and modulation schemes it can use.[71] An emerging technology is on the horizon, called cognitive radio that promises to redefine spectrum management. A cognitive radio will be a wireless device that is smart enough to analyze the radio environment and to decide for itself the best spectral band and protocol to reach whatever base station it needs to communicate with, at the lowest level of power consumption.[72]

Although computer hardware and networking continues to experience exponential growth, thus enabling unprecedented data transfer rates and storage capacities, user interfaces that provide effective and efficient user access to ever growing amounts of digitized data have not been keeping pace. This will likely change within the next few years as new modes of data manipulation are enabled though multi-touch interfaces, haptic devices and motion sensing controllers. An early example of multi-touch functionality has been developed and demonstrated by Jeff Han at the Department of Computer Science Courant Institute of Mathematical Sciences New York University.[73] Multi-touch sensing enables users to interact with a system with more than one finger at a time. Such sensing devices are also inherently able to accommodate multiple simultaneous users, which is especially useful for larger interaction scenarios such as interactive walls and tabletops—thus, ideally suited to command and control information system displays in formation and unit headquarters. Conversely, haptic devices will enable users to touch or "feel" digitized data. A haptic interface is a device, which allows users to interact with a computer by receiving tactile feedback. This feedback is achieved by applying a degree of opposing force to the user[74] using a variety of techniques including magnetic levitation.[75] Another form of feedback interface is the motion-sensing controller, made popular by the Nintendo Wii game system.[76] Coupled with the exponential advances in computer graphics quality that is increasingly delivering lifelike displays of 3-D virtual worlds, these interface devices will lead to compelling and realistic virtual environments.

Software design and development, like interface technology, is also beginning to experience significant change. Development is moving away from the sequential model, in which progress is a steady flow through the phases of requirements analysis, design, implementation, testing (validation), integration, and maintenance. New methodologies will undoubtedly see greater agility,[77] enabled through ICT, becoming interactive, cooperative and often real-time. Capitalizing on these advances within the defence community will not be without significant challenge. Sue Payton, the US DoD Deputy Undersecretary of Defense (Advanced Systems and Concepts), highlights the challenges in an on-line edition of the Military Information Technology periodical. She notes that defence software is often still acquired with the same industrial-age business processes used to acquire ships, tanks and other physical machinery.[78] In her opinion, in order to wage information-age warfare, new business processes will be required that allow more rapid evolution of capabilities. Unlike planes or tanks, which require factories to make multiple copies, software can be copied perfectly, from practically any location and modified on the fly to change its characteristics.

Emerging development environments such as Ajax as well as presentation layer technologies will make it possible to combine data sets on demand with a minimum amount of programming. Another growing trend is the delivery of software as a web service—epitomized by Google's Docs & Spreadsheets, which allows users to create MS Office compatible documents and spreadsheets without installing any software (beyond a standard web browser). Documents can be edited (even collaboratively) from any web-enabled computer and shared with ease. There is a growing number of web based software services. The Office 2.0 Database[79] for example, lists over 250 web based services grouped within a variety of application areas including: bookmarks, business intelligence, calculators, calendars, clipboards, contacts, CRM, databases, desktop publishing, development tools, document managers, drawing, email, event managers, expense trackers, fax, feed processors and readers, file managers, file senders, and file servers. New web services, such as iUpload[80] and Knownow,[81] are also promising to provide the tools that will allow organizations to build organic, self-managed knowledge management systems, especially when coupled with enterprise search and business intelligence applications.

Combined, the innovations noted above in computer processing, memory capacity, disk storage, bandwidth, interfaces and software development will continue to drive information and communications technology (ICT) innovation. The importance of ICT for national development and economic growth must not be underestimated. Indeed, the World Economic Forum's benchmark Global Information Technology Report, which assesses national ICT strengths and weaknesses, highlights the continuing importance of ICT.[82] The strong correlation between those nations with poor performance on the World Economic Forum's Network Readiness Index[83] and the Failed States Index[84] provided by Foreign Policy.com reinforces the importance of global ICT for not only economic development, but also global security. Similarly, in its Information Economy Report 2006, the United Nations Conference of Trade and Development (UNCTAD) indicates that global economic processes, including international trade, are increasingly influenced by the creation, dissemination, accumulation and application of information and knowledge.[85] Furthermore, they conclude that development can no longer be understood without full consideration of the widespread effects of information and communication technologies (ICTs). The report estimates that broadband networking could contribute hundreds of billions of dollars a year to the GDP of developed countries in the next few years. Though perhaps surprising to some, within the report, broadband networking has been compared in importance to utilities such as water and electricity. The UNCTAD warns that the growing importance of high-speed Internet access is "disturbing news" for the developing world where broadband access is scarce, because technology is exerting an ever greater influence on global business trends.[86]

The global proliferation of Information and communications technologies noted above, is enabling revolutionary capabilities. Supercomputing, as discussed earlier, is no longer the sole purview of wealthy nations. Broadband networks coupled with the proliferation of increasingly powerful and Internet connected personal computers has delivered supercomputing to the masses. Large technology players such as IBM, Sun Microsystems Inc. and Hewlett-Packard Co. already sell computing power, on a grand scale, to large corporations. New services, however, from Amazon.com Inc. and 3tera Inc. for example, are bringing on-demand computing to midsize and small businesses. This concept is known as hosted hardware or grid computing and relies on a technique called virtualization. Amazon, for example, provides virtual servers that have the equivalent power of a machine with a 1.7-GHz Xeon processor, almost 2GB of RAM, a 160GB hard drive and a high-speed Internet connection. Users pay on demand at a rate of 10 cents per virtual server per hour for access to spawned instances of virtual servers.[87] Numerous scientific research projects utilize this technique in reverse, providing home computer users with an application that automatically ties their computer into a distributed supercomputer configuration, which utilizes the surplus processing capacity of their home computers. Recently, this technique has also been extended to high-end gaming consoles, with the announcement by Sony[88] that their latest console, the PS3 will be able to participate in the folding@home project run by Stanford University.[89] Remarkable levels of processing power have been harnessed using this technique. The Berkeley Open Infrastructure for Network Computing (BOINC) application, for example, links nearly 2 million computers into 41 different research projects. The climate prediction project alone achieves on average the equivalent of 43,183 billion calculations per second.[90] Since the BOINC application is open source, it is reasonable to predict that there will be more projects added over time. It may be difficult however, to ensure that new projects are not designed for malicious purposes but disguised as benevolent research.

Yet another ICT enabled trend is the proliferation of Internet hosted storage. Recently, Yahoo! announced that it would offer unlimited email storage space for its users.[91] Google's Gmail on the other hand, provides its users with nearly 3 Gigabytes of file storage. Each of these offerings would undoubtedly not have been possible without the cost performance increases in data storage noted earlier. Another entry in this field, Amazon S3 (Simple Storage Service), is an Internet storage scheme that is designed to make web-scale computing easier for developers. Amazon S3 provides a simple web services interface that can be used to store and retrieve any amount of data, at any time, from anywhere on the web. It gives any developer access to the same highly scalable, reliable, fast, inexpensive data storage infrastructure that Amazon uses to run its own global network of web sites. There is no minimum fee, and no start-up cost. As an example of the cost effectiveness of this offering, a monthly investment of $200.00 would provide 667 Gigabytes of storage and allow for 500 Gigabytes of data transfer.[92] Combined with Amazon's Elastic Compute Cloud (Amazon EC2) and developers have access to web-scale computing from practically anywhere in the world, simplifying their development activities. Given this level of computing resources that is available to anyone who has Internet access, it would be a mistake to assume that insurgent groups or criminal organizations are not technology enabled.

The "computation and bandwidth to burn" projection by the IEEE Fellows, and equally the NRC ICT forecast, is the result of the confluence of ongoing exponential growth trends in information technology and high-speed broadband network communications as shown above. Microchips are becoming more energy efficient, smaller and ever more powerful. Computational competence, and network bandwidth, whether it is by fibre-optic cable or wireless, is continuing to proliferate and grow in importance as a vital national capability.

Within military environments, the importance of information technologies and networking has been acknowledged for many years. Indeed, the success of the Adaptive Dispersed Operations concept for the Army of Tomorrow hinges on adequate distribution of ICT to the lowest levels, including individual dismounted soldiers. The premise here follows the logic that networking everyone and everything will empower the edges of the network[93] to take independent decisions. The parallels to mission command philosophy within current Army doctrine should be evident. Ubiquitous networking also fits well with James Surowiecki's 'Wisdom of Crowds' idea[94] that large groups of people are smarter than an elite few, no matter how brilliant they may be. Networked crowds according to Surowiecki are better at solving problems, fostering innovation, coming to wise decisions, even predicting the future. Many questions remain unanswered though, particularly with respect to the impact that this will have on human resources decisions. For example, what will be the most important selection criteria for leaders in the future? What will be the measure of a good commander in this era? Should it be previous operational experience or maybe it will be human resource management skills? Perhaps trends that are now becoming visible within commercial sectors provide insight; the most successful CEO's today are those who nurture, develop and create an environment that empowers the edges—embracing and encouraging the innovative potential of the 'crowd'. While mission command may be a step in this direction, perhaps it is merely a small step compared to the potential for empowering 'everyone and everything' on the battlefield.

One of the key benefits of the increasingly ubiquitous ICT environment that has been presented thus far has been the manner in which it has enabled people to network with each other. A key by-product of this situation has been a dramatic increase in collaboration, often on a global scale. An area that has benefited greatly from this 'wisdom of crowds' type of collaboration has been the open source software movement. Though not a new development, the open source initiative[95] has produced robust applications that today have become a globally significant challenge to conventional proprietary software. The sheer scale of global network collaboration has led to the development of open software in practically every application domain; software and source code that is free to download, use and modify.

Proponents of the open source software philosophy claim that given the fact that open source code is transparent and freely available helps to make open source more secure than commercial software. Conversely, others suggest that the lack of contractual agreements between vendor and purchaser in the open source world makes open source deployments less secure. While it is unlikely that this debate will be settled any time soon, it is very likely that open source software adoption will flourish in developing nations due to the prohibitive cost barriers presented by the commercial software alternatives. Given the high quality of many open source offerings, combined with numerous global users who contribute patches, fixes and upgrades, there is very little disadvantage to developing nations following this approach. The costs of sharing code are low while the benefits are high. The One Laptop Per Child (OLPC) project[96] (which utilizes exclusively open applications) will only serve to strengthen the open source movement within developing nations. It is possible that the open source initiative coupled with the OLPC could be the impetus behind Microsoft's recent announcement to slash software prices for students in developing nations.[97] Microsoft plans to offer a limited version of its Office software suite to schoolchildren in developing countries for the price of three dollars per copy. Regardless of the motivations behind this initiative, when combined with open source offerings, there is a potential to narrow the existing digital divide.[98] It is clear that open source software is a growing trend. It is a trend that empowers individuals with advanced ICT tools and capabilities, regardless of their location or financial means.

The open source movement is also dramatically changing the face of education. The Massachusetts Institute of Technology (MIT), for example, initiated its groundbreaking OpenCourseWare (OCW) program six years ago.[99] OCW is a free and open educational resource (OER) for educators, students, and self-learners around the world. The OCW currently provides open access to course materials for up to 1,550 MIT courses, representing 34 departments and all five MIT schools.[100] The goal is to include materials from all MIT courses by 2008. Since MIT's pioneering efforts, eleven other U.S.

colleges have indicated plans to offer similar OCW, and five of these already have an online presence.[101]

Another rapidly evolving human networking trend is the social networking phenomenon, including wiki's, blogs, social bookmarking and tagging. Each of these areas shares similarities with the open software initiative noted above; their strength lies in maximum participation and collaboration of the user community. The changes being wrought due to the social phenomenon of human networking, will be addressed in more detail in a later section on the social impact of technology. The remainder of this section will deal with advances in other technology areas that have ridden the wave of progress within ICT.

Artificial intelligence research is an area that has seen resurgence in activity due to the progress made in ICT and other fundamental scientific research areas. Some experts believe the arrival of autonomous technological intelligence to be inevitable, but propose that the manner and timing of the transition remain key choices under the influence of human beings.[102] What is most notable about current Artificial Intelligence (AI) predictions, however, is the fact that experts are once again daring to make predictions about the future of AI. Failure to deliver on the AI hype of the late 80's and early 90's lead to the evaporation of AI research funds. It now appears that a critical mass of research aimed at creating true Artificial Intelligence, (and other advanced technologies including robotics), is rapidly converging.

Already, there are numerous examples of niche areas where machine intelligence surpasses human level abilities. For example, Wallace Forbes, President, Forbes Investors Advisory Institute claims that their proprietary computer software program, the "Quant Model", is outperforming most human portfolio managers at stock picking. Forbes claims that more than 75% of portfolio managers under-perform the market, whereas over a 10-year period the Quant Model outperformed the S&P 500 by a staggering 362%.[103] Some have compared these niche area intelligent applications to autistic savants—highly gifted in very narrow domains, but severely handicapped in most others. While this may be a reasonable comparison today, the fact remains that there are a growing number of these niche domains where AI performs as well as, or better than humans. Though there is no clear consensus among AI researchers, these narrow areas could eventually converge, yielding increasingly capable AI systems that cover broad domains—possibly achieving human-level intelligence.

One of the successful areas of AI implementation is Intelligent Agents. An agent is a program (often web based) that runs automatically without a user needing to start it once it has been configured. For example, the online job service Monster Board (www.monster.com) allows users to enter the types of jobs they are looking for. Even when users are offline, the agent scans the Monster Board job database daily and sends an e-mail when it finds a job matching the user's criteria. The ongoing development and improvement of the semantic web[104] promises to establish a data and knowledge framework that will allow more sophisticated information and knowledge automation through intelligent agents. The US Defense Advanced Research Projects Agency (DARPA) is funding an intelligent agent program called the Personalized Assistant that Learns, or PAL, that aims to radically improve the way computers support humans by enabling systems that are cognitive, i.e., computer systems that can reason, learn from experience, be told what to do, explain what they are doing, reflect on their experience, and respond robustly to surprise.[105] More specifically, PAL will develop a series of prototype cognitive systems that can act as an assistant for commanders and staff. Such AI developments are now also entering the commercial domain. One example is Proto-Mind Machines' (PMM) MATY—a computer model of human brain neural networks.[106] PMM markets MATY as part of a wearable system complete with microphones and an experimental computer vision system, claiming that the system will learn and become strongly connected to the wearer's intellect.

Artificial Intelligence technologies also promise to enable and enhance smart devices. A product from Intelli-Vision[107] for example, enables 'smart cameras', which are able to pick out suspicious events and activities.[108] Such applications promise to ameliorate manpower intense functions such as perimeter security monitoring. Manpower that would have been required for the tedious and error prone video monitor over-watch task can be reallocated for more demanding activities. Smart devices are likely to proliferate at a greater rate as new artificial intelligence techniques such as evolutionary algorithms[109] mature and enable previously unattainable solutions.

Announcements of progress in various AI related fields appear on a regular basis. Researchers are abandoning the older AI approach that attempted to mimic human behaviour using hard-coded rules, an approach which proved inadequate in situations where the AI systems were faced with situations that fell outside the scope of the pre-established rules.[110] Many of the greatest strides in AI research have been achieved by implementing algorithms that learn through observation and mimicry similar to the approach utilized by humans. Some researchers are now anticipating that the web will be the source of the raw knowledge necessary to seed future AI with the common-sense knowledge necessary to give them human levels of intelligence.[111]

Though there appears to be growing consensus that human-level machine intelligence will be achieved, there is wildly varying opinion as to when this could happen. Some speculate that this could occur as early as 2029.[112] It is likely that AI development will follow the same trends as practically all other technologies—it will progress in incremental steps, each one building on previous successes. This 'accelerating returns' development methodology suggests that there will not be a catastrophic over-night development that catches humanity unaware, despite this popular theme within Hollywood. Rather, it will be a series of deliberate choices made along the way, where each incremental step serves to address some immediate human need. Many historical examples already exist, such as code breaking, aircraft auto-pilot systems, unmanned aircraft or cruise missiles. Today, significant research effort, both military and commercial, is being devoted to autonomous ground vehicle technologies.[113]

As AI systems achieve greater levels of ability, they will increasingly replace functions that traditionally were the sole purview of humans. As noted above, our machines are already exceeding humans in the performance of more and more tasks, for example, managing the power grid[114] or guiding objects like missiles or satellites and assembling other machines.[115] It will be important for Army capability development efforts to remain aware, indeed to ride the wave of AI developments as they continue to accelerate along with the other exponential growth areas such as cybernetics, mechatronics and robotics.

At some point in the future, it can be expected that military related AI will reach a threshold of ability that threatens to cross moral, ethical and/or legal boundaries. For example, an autonomous system that is able to make life and death decisions within chaotic or dynamic environments. While the standard approach today is to limit these complications by ensuring that there is a human-in-the-loop to make such decisions, this may not be a suitable solution in the future. It is possible that there will be situations wherein events transpire so rapidly that typical human response times would be wholly inadequate. Already we are seeing the beginning of this trend. For example, automated countermeasures such as active armour must deploy in milliseconds, well before human operators would be able to sense and respond to an incoming threat.

Given the recent progress in AI and the likelihood that it will reach a point of sophistication that challenges human abilities in broad areas, it would be prudent for those within capability development organizations to be mindful of the moral, ethical and legal ramifications of AI related development decisions. Compounding this situation is the fact that automation is currently seen as a force multiplier. Perhaps these issues need to be debated today in order to determine what the moral and ethical boundaries for AI systems should be. As history will show however, moral and ethical boundaries continue to shift as societies change and adapt to new technologies.

Closely related to the AI domain, cybernetic systems technology is another area that is rapidly developing due to the exponential growth of many of the enabling technologies. Cybernetics pertains to the integration of mechanics, electronics, bionics and robotics. A prime example of a cybernetic system is an exoskeleton.[116] A more dramatic example is the bionic arm developed at the Rehabilitation Institute of Chicago, developed within the Neural Engineering Center for Artificial Limbs (NECAL) utilizing a pioneering muscle reinnervation procedure which takes an amputee's own nerves and connects them to a healthy muscle.[117] This technique allows a user to move a prosthetic arm as if it were a real limb—by simply thinking about what they want the arm to do.

Aside from the obvious benefits for the disabled community, this rapidly evolving technology holds potential for the development of new capabilities such as tele-presence, for example. Imagine being able to control the functions of a humanoid robot[118] simply by thinking about it. Then combine an intelligent humanoid robot[119] with a network based interface and it is feasible that an operator will be able to think about what the tele-robot should do—its own intelligence functions compensating whenever there was a network lag or interruption. Then imagine the feedback from the robot returning directly to your brain[120] providing tactile sensation[121] as well as visual[122] and auditory information.[123] These trends suggest that it may soon be possible to 'be there' without ever leaving home. Potentially, if the sensory feedback information achieves a sufficiently high resolution, in your mind, you would actually be there. While this level of capability is unlikely to be achieved within the timeframe covered by this paper, this type of cybernetic system is likely to become a factor in the future—perhaps as a means to mitigate the moral and ethical issues surrounding AI decision making noted earlier.

Exponential growth is also evident in the Robotics domain, due to many of the same growth trends attributable to Moore's Law. New development tools such as Microsoft's Robotics Studio[124] should serve to continue this trend. Some researchers believe that robotics is on the verge of becoming the next major commodity technology, perhaps surpassing the computer in importance.[125] The US DoD appears to think so as well: despite the obstacles, US Congress ordered in 2000 that a third of the ground vehicles and a third of deep-strike aircraft in the military must become robotic within a decade. The United States has already spent many billions of dollars on military robotics attempting to meet this mandate. Technological breakthroughs have undoubtedly been achieved, though the detailed results of this program are not public knowledge.

A 2006 Australian Defence Science and Technology Organization (DSTO) study[126] that examined issues of situational awareness generation within autonomous systems, concluded that in strategic terms, given the precedents in concept development, and the known bottlenecks and progress in technology, robotics has passed the point of being a new strategic threat, to one that broadens the threat at the operational and tactical level. The key feature is commoditization, enabling different actors to utilise formerly specialised technology. The threat space from autonomous systems thus builds on advances and commoditisation of enabling technologies, notably including: insertion into space/orbit, civilian communication networks, and computer hardware and software.

The DSTO report also touches on similar moral and ethical debates as those noted earlier regarding AI systems and notes that options for robot use will be shaped by social background (casualty aversion), expected environment (expeditionary forces) and tempo of decisions (combat intensity). Decisions will also centre on the issue of autonomy and awareness—not whether a system "is" autonomous or "has" awareness, but whether the system has *sufficient* awareness to be *sufficiently* autonomous for the situation at hand. The report's historical review showed cases where "dumb" technologies with low awareness had been deployed at high autonomy (land mines for example), while "smart" technologies (the Aegis air warfare system for example) with high awareness had been held at low autonomy due to situational constraints.

The advances in enabling technologies, point towards increasing levels of machine awareness and autonomy, which will require careful consideration by capability developers as to acceptable modes of operation given societal expectations and constraints.

While there has been a surge recently in humanoid robotics,[127] as evident in military 'smart' munitions, it is likely that robots will continue to take a variety of shapes and forms. Indeed the first commercially available home service robots[128] or tactical robots[129] from iRobot do not resemble our historical science fiction depiction. Many future robots will likely have no definite shape, but can be an assembly of components that reconfigure themselves to suit the task at hand. The robot might consist of a series of articulated units that can link into extendable chains, allowing the structure to adapt for motion over a wide range of terrains: walking, writhing like a snake, swimming like a fish or even flying.[130] These devices are known as self-reconfigurable or polymorphic robots, and they might be well suited to conducting a range of tasks in inhospitable environments, such as clean up of toxic waste or repairs to spacecraft.[131]

Reconfigurable robots have emerged from the field of swarm robotics: the notion that a collection of many small, and cheap, robotic units can act as an autonomous entity. Ant colonies have provided biological inspiration in that they exhibit a kind of 'swarm intelligence' that enables the ants to forage far more effectively as a collective than if they were each to act independently. Importantly, there is no central 'control centre' directing the activities, but instead the collective behaviour emerges spontaneously, which can make it adaptive and efficient without the need for sophisticated decision-making software. An extension of this idea is to reduce the size of the components so that they become autonomous 'atoms' that can build structures with a wide range of functions and properties. Such miniaturised swarm robots have been dubbed 'smart dust'[132] and now an emerging concept called 'claytronics'.[133] Swarm robotics might provide a better way of monitoring remote environments on earth and on other planets than does a single complex device, or indeed they may enable compelling synthetic realities. Not only can robot swarms search more efficiently, but they also are potentially more robust against failures.[134]

Other biologically inspired robots include mechanical insects, which some researchers suggest could prove far more manoeuvrable than micro-sized versions of conventional aircraft or helicopters.[135] Such insect-like craft could fly unobtrusively around buildings, moving into open windows, for example. When equipped with different sensor types, they could be used as miniature hazard monitors. DARPA is developing four flying "robobugs", weighing up to 10 grams each and with wingspans of up to 7.5 centimetres. Aerovironment, one of the companies developing the craft for DARPA aims to have a "rough demonstrator" flying by the middle of 2008.[136] It is expected that these robotic insects will quickly become cheap and commonplace due to their size and weight (less than a tenth of a gram) and could sell for less than a dollar.

Yet another class of robots is being studied. It uses a network of cultured animal neurons to control its functions.[137] The researchers have shown that the cultured "brain" grows more complex as it learns and interacts with the outside world through the robot's actions. Combined with new forms of robot power, such as artificial muscles[138] made from electo- or chemically-active polymers, and it can be expected that there will be significant progress in robot mobility, control and self awareness. For example a star-shaped robot developed by researchers at Cornell University is able to sense and respond to changes in the environment and damage to its own body by continuously refining its built in software.[139]

Overall, robotic technologies are maturing at an accelerating pace, due largely to the exponential growth trends in the enabling technologies. New commercially available unmanned aerial vehicles (UAVs) are reaching the market with increasing frequency and with impressive performance specifications—achieving about 50% of the speed, range and endurance of much more expensive military UAVs.[140] More significantly, some models can be purchased in a fully autonomous version for under $25k. With a quiet electric drive and onboard video, it is fully feasible for belligerents to use such a system for covert surveillance and target detection inside coalition camps. As a more sinister prospect, it could be used as a cheap cruise missile—perhaps to deliver biological agents. Increasingly, as these cheap but capable systems proliferate, current concepts that imply or rely upon information superiority may prove flawed. Moreover, without remaining near the leading edge of commercial technology, information inferiority is possible. Criminal and terrorist groups continue to generate billions of dollars through Internet crime—thereby making it feasible that they will be able to buy state-of-the art commercial technology whenever they wish, with delivery the next day through UPS. The same certainly cannot be said for the CF procurement system.

Compounding the problem of commercially available robotics is a growing interest in hacking their capabilities.[141] There is a growing list of Internet sites that offer hacking ideas as well as software code.[142] A roomba vacuum for example, costs a few hundred dollars and contains sophisticated electronics making it a candidate for use as a fully autonomous IED—able to identify and attack intended targets without human over-watch. While our troops today are facing fairly low tech enemies, this is likely to change. Already, trends in Iraq and Afghanistan reveal the ingenious abilities of adversaries to integrate various commercial technologies into increasingly sophisticated improvised explosive devices. Indeed, the 9/11 attack on the US was a crafted combination of low tech (box cutters) and high tech (Boeing 767 aircraft).

Given the magnitude of global research activities, it is reasonable to expect that by 2025, robots could look, act, think and feel like humans in almost every way.[143] Although there are many technical problems that need to be overcome in order to achieve this, they are being overcome one by one. The ability of robots to engage humans emotionally is prompting researchers to reflect on the human-robot interaction, questioning whether the relationship should evolve from a simple human-tool perspective to a more complex team-mate relationship. Other researchers caution that it is unlikely that machines will have the ability to engender an emotional level of trust—a prerequisite for a team.[144] Still other researchers believe that by 2015 robotic vehicles will be employed on the battlefield for convoy operations or in areas where there is extreme danger to personnel. Stanford University researcher, Sebasian Thrun, expects that by 2030 robotic vehicles will have driving reliability that will exceed humans by orders of magnitude. Autonomous systems will likely begin to be used to a greater extent by adversaries. No suicide bomber required, but equally deadly.

Within the commercial automotive industry, design methodologies are well established that will facilitate this transition to robotic vehicles. For example, there are more and more electronic and electromechanical components and systems in vehicles today—from simple solenoids and motors to embedded microprocessors that control braking, steering and engine operations.[145] Combined with a well-developed network of sensors and electronically controlled actuators for practically every vehicle system and it would appear reasonable to anticipate the emergence of commercial robotic vehicles. Micro-electromechanical systems (MEMS) miniaturized self-contained systems (on the order of the width of a human hair—micron scale), that integrate electrical and mechanical functionality to sense, process and act upon information in their environment will further advance automotive and robotic technologies. MEMS are batch fabricated using techniques similar to those used in the integrated circuit industry. The autonomous, miniaturized nature of MEMS decreases the cost and increases the functionality of the products into which they are integrated. MEMS will have a significant effect on the development of ‘intelligent’ products in a wide range of industries including aerospace, healthcare, automotive, healthcare and consumer goods. This integration of electronics, mechanics, software and controls within the automotive industry is called mechatronics, which will clearly drive further advancement of robotics technologies.

According to a recent study by the US Board on Army Science and Technology, robots, including unmanned ground vehicles (UGVs), have many valuable attributes that will aid and complement soldiers on the battlefield. They are well suited to perform routine and boring tasks. They are fearless and tireless. They do repetitive tasks with speed and precision. They can be designed to avoid or withstand enemy armaments and to perform specific military functions. Most importantly, robots can reduce casualties by increasing the combat effectiveness of soldiers on the battlefield.[146]

The study went on to evaluate the technologies that would be required in order to realize various levels of autonomy. For the least complex systems, mature technologies already exist to facilitate their implementation. In contrast, technologies for the most advanced systems, such as autonomous hunter-killer systems, are not anticipated to be sufficiently mature before 2016 and more likely 2025.

It is probable that early autonomous UGV and UAV implementations will target mapping tasks within urban settings. Engineers at the University of California, Berkeley, have developed a technique, called “virtualised reality” that could be used to map unknown city areas, building accurate three-dimensional maps street by street, recording every window and doorway of the urban battlefield.[147] This automated technique employs lasers to measure distances to objects and building facades, while a digital camera takes 2D photos. Following a short period of data processing, the system creates a photo-realistic virtual 3D model of the area that could be used for training and mission rehearsal.

Significant progress continues to be made in the area of 3D modelling and virtual reality. These technologies have the potential to radically alter military training techniques. Some researchers for example, propose that by 2020 real and virtual environments will become practically indistinguishable. Already, digital clones of people have been created using 3D scanners and high resolution cameras with enough resolution to capture skin pores and wrinkles. In less than a minute a system of scanners and cameras can capture enough data to create a 3D digital double that can be aged, given a sun tan or realistically illuminated to fit into almost any situation.[148] Combining these realistic 3D virtual models and characters with sophisticated AI algorithms within first-person video environments will provide compelling training environments. Adding haptic resistance feedback interfaces will further enhance the experience by introducing a means to induce fatigue. Current video gaming environments already combine many of these techniques to create very compelling environments with impressive artificial-intelligence algorithms that endow fellow ‘digital’ soldiers with the ability to follow and sometimes lead, providing covering fire and warnings about snipers and grenades.[149]

Trends within the commercial sector will further enhance the development of virtual reality environments. Numerous companies, including Dell, IBM, Toyota, Sony BMG, Telstra, the ABC, adidas and the US retailer American Apparel have purchased digital territory within one of today's leading online virtual environments, Second Life.[150] The number of virtual avatars within this virtual world has continued to grow exponentially since its introduction in 2003. Recently, IBM has recommended more integration between the various online virtual worlds where avatars meet.[151] IBM will be attempting to make it possible for a user in one virtual world to take the assets created in that environment and move them to other worlds, which IBM executives have described as a "virtual planet". This concept appears similar to the immersive virtual world imagined by Neal Stephenson in his visionary novel, Snow Crash. Indeed the Metaverse Roadmap (MVR) project[152] describes the metaverse as the result of the convergence and merger of existing evolving technologies: when video games meet Web 2.0; when virtual worlds meet geospatial maps of the planet; when simulations get real and life and business go virtual; when you use a virtual Earth to navigate the physical Earth; and when your avatar becomes your online agent.

At the opposite end of the same technological spectrum lies "embodied virtuality" which has been described as the process of drawing computers out of their electronic shells, miniaturizing them, and placing them in everything—cars, buildings, appliances and human bodies. The likely outcome of this pervasive or ubiquitous computing environment is the ability to create augmented reality. These emerging technologies make it possible to deliver immersive education and training to anyone, regardless of time or location. Already, augmented reality gamers are turning the real world into virtual battle zones using existing technologies such as GPS and web enabled cell phones.[153] These examples reveal the powerful potential of a fully network enabled force—i.e. one that has communications, computation and location based services.

Commercially, an early implementation of ubiquitous computing is already underway in South Korea's Songdo City, which is projected to be an international commercial center and the first true U-city ("U" being the shorthand for ubiquitous computing).[154] The city's infrastructure will allow all IT systems, whether belonging to government agencies, corporations, healthcare providers, or private citizens, to share data. Every street, every house, every office will be wirelessly networked, demonstrating the benefits (or pitfalls) of living a digital lifestyle. An underpinning technology will be an array of new RFID-based services, which will be introduced, tested, and refined before being unleashed on the rest of the world.

Turning to biology, we see many of the same growth trends that were evident in the ICT domain. Indeed, ICT has revolutionized the study of biology—it has in essence become an information technology, subject to the exponential growth and accelerating returns discussed earlier. According to well known inventor Ray Kurzweil, bio-related technologies continue to double their price performance and capacity every year.[155] At this rate, Kurzweil projects that biotechnologies will experience an increase in capability by a factor of one thousand within a decade and by a factor of one billion by 2030.

The magnitude of biotechnology development has profound implications, leading to the potential to fundamentally alter life on earth. Signs of the power and potential of biotechnologies are evident in the initial steps towards developing a malaria-resistant mosquito, a measure that could potentially reduce the spread of malaria.[156] Bio-related developments will likely continue to face some resistance due to the real or perceived consequences to ecological and human health made possible by genetic modification of organisms.[157]

Despite the early resistance, some researchers foresee a rapidly approaching era where biology hacking becomes commonplace thus potentially amplifying beyond recognition any existing bio hazard situations. What makes this opinion plausible and worrisome is the fact that the pace of technological development in biotechnology and genetics is progressing at an exponential rate. New generations of sophisticated tools are being developed continuously[158]—resulting in research labs upgrading their equipment, and selling their ‘old’ equipment at discount rates. Equipment availability is easily determined by anyone owing to used scientific equipment and laboratory instrument sales web sites such as LabX.[159] Although this equipment is not state of the art, it remains remarkably sophisticated from the point of view of what was available 5 years ago. This discount equipment is more than adequate for conducting the research and thereby enabling a proliferation of bio-related threats.

Open access databases and knowledge warehouses add to the potential risk. It remains a matter of debate as to whether scientific information should be published for the public good or whether it should be safeguarded because that information and knowledge represents an enormous amount of power—and thereby a threat if used as a weapon. This information is accelerating scientists’ ability to fight disease and make other medical advances, but policymakers must consider the possibility that the information could also be used for destructive purposes in acts of bioterrorism or war.

Despite this tension between open access and security constraints, current policies allow scientists and the public unrestricted access to genome data on microbial pathogens. The US National Research Council Committee on Genomics Databases for Bioterrorism Threat Agents, concluded in their report that open access improves our ability to fight both bioterrorism and naturally occurring infectious diseases, and security against bioterrorism is better served by policies that facilitate, not limit, the free flow of this information.[160] The report also notes that the database of available information is significant, comprising the entire genomes of many hundreds of organisms, from viruses to bacteria to humans and partial sequences from many thousands more organisms. Complete genomes of more than 100 microbial pathogens—including those for smallpox, anthrax, Ebola hemorrhagic fever, botulism, and plague—are already in Internet-accessible databases freely open to all and the genomes of hundreds more pathogens will be sequenced with the support of government funds in the next few years.

It is evident from these risks that the pace of scientific progress creates a need for continuous and thorough evaluation of scientific technology as it affects national security and the health and welfare of all the inhabitants of this planet.[161] Despite the “dual-use” dilemma of bioterrorism, modern biological research is a thriving international enterprise with enormous potential to benefit society. The synergy created by increasing knowledge and open exchange of ideas and information is accelerating the advance of medicine, industry, and agriculture. Emerging details about the interplay between pathogenic micro-organisms and their hosts will allow scientists to continue to develop and deliver new and improved vaccines, stronger infection-fighting drugs, and more-precise diagnostic tools.[162]

The promising potential of biological research was discussed at an Accelerating Change Conference held at Stanford University in 2005. Several well respected members of the scientific community outlined the impact that bio-related technologies and research were having on our understanding of life and death. Some researchers are beginning to view aging as a disease that could one day be curable. Even if this is a bridge too far, an inevitable result of the rapid pace of biotechnology development will be increased human life-spans and ultimately ageing populations within developing nations. Indeed this trend is already evident. According to statistics published by the Municipal Research and Services Centre of Washington, the United States is on the brink of a longevity revolution.[163] By 2030, the number of older Americans will have more than doubled to 70 million, or one in every five Americans. The growing number and proportion of older adults places increasing demands on the public health system and on medical and social services. Canada will undoubtedly face similar pressures that will change society in ways that are still uncertain. There is potential for there to be human resource shortages in the future. Indeed there may be a reduction in the pool of available recruits for the future armed forces. Japan, for example, has already recognized this aging trend within its society, and has begun huge investments in robotic technology that will offset the smaller labour force available to care for its increasing number of elderly.[164] Moreover, aging populations will have an impact on future military budgets. Military retirement pensions will become more costly every year as people live longer and the cost of new health care technology and drugs needed to keep the elderly alive rises. Recruits who join the military today at age 18 and retire at age 38 will receive retirement pay on average for another 40+ years—effectively collecting retirement benefits for twice as long as active duty pay.

Aside from the negative consequences possible due to the advances in biotechnology areas noted above, there are equally important foreseeable impacts on the human dimension. Since the unlocking of the human genome, the scientific community's ability to tinker with the code of life has expanded enormously, leading to discoveries that, only a few short years ago, were possible only within the realm of science fiction. For example, progress is being made towards understanding, but more significantly, manipulating the genetic basis of the fear response. While it is not unreasonable to think that such genetic manipulation can only be undertaken within a laboratory environment, recent advances point to the potential for manipulating the manner in which genes are expressed by modifying the food we eat.[165] Notwithstanding the moral, ethical and legal resistance and constraints that are obvious, there is growing evidence that points to the potential for radical human enhancement. The developing areas of nutrigenomics[166] and personalised nutrition for example, promise to offer products that are tailored to exactly suit disease prevention based on one's individual genetic make-up.[167]

These capabilities clearly have offensive and defensive implications for the Army of Tomorrow and the future. For example, will the CF harness this capability to make its soldiers truly fearless warriors in the face of the enemy? Could this ultimately mitigate the effects of posttraumatic stress? While this may remain too radical for western democracies for some time, it may not be so for a well-funded terrorist cell or crime network. Perhaps by eliminating their fear, terrorist groups could 'recruit' an infinite number of future suicide bombers.

The science-fiction-like abilities being developed though genetic engineering are likely to become increasingly disruptive over the course of the next decades. Force development activities will need to remain aware of the developments and potentially feature scenarios that include such radical capabilities if indeed we are to be prepared for the defence and security threats that lie ahead.

Complicating this situation is the evolving research area of synthetic biology. Synthetic biology is described as: the design and construction of new biological parts, devices, and systems; and, the re-design of existing, natural biological systems for useful purposes. This domain of research will undoubtedly see dramatic increase in capability as vendors such as Microsoft Research (MSR) continue to offer grants targeting research projects aimed at tackling the computational challenges of synthetic biology.[168] According to an article in PLoS Biology, the peer-reviewed, open-access journal published by the Public Library of Science, synthetic biologists aim to make biology a true engineering discipline, rather than simply transferring a pre-existing gene from one species to another.[169]

In much the same ways that electrical engineers rely on standard capacitors and resistors, or computer programmers rely on modular blocks of software code, synthetic biologists are attempting to develop an array of modular biological parts that can be readily synthesized and mixed together in different combinations. Already, the Massachusetts Institute of Technology (MIT) has a Registry of Standard Biological Parts, or BioBricks, that supports this goal by indexing biological parts that have been built, and offers assembly services to construct new parts, devices, and systems.[170] In essence, synthetic biology is an attempt to construct life starting at the genetic level. Remarkable and occasionally alarming results have been achieved. For example, a live polio virus was created from scratch using mail-order segments of DNA and a viral genome map that is freely available on the Internet.[171] Experts worry that synthetic biology may spawn bio-hackers. One expert in the field, Harvard University genetics professor George Church, compared the potential misuse of synthetic biological designs with the danger posed by nuclear weapons. However, there is one important difference, in his view it is much harder to build a fusion device than to genetically engineer a pathogen. Furthermore, the complexity of biological processes increases the danger of accidents.[172]

Our present capability development efforts for the interim army and army of tomorrow, which in large measure rely upon kinetic energy weapons, will become irrelevant if insurgent groups succeed in harnessing the full disruptive potential of synthetic biology. As this technology matures, there will likely be a need to reassess the balance of investment amongst the operational functions—with sense and shield capabilities rising in importance. Perhaps the sensor to shooter link of the future, instead of delivering a kinetic energy round, will need to deliver a synthetic biological entity antidote.

Apart from the real potential for biotechnologies to fundamentally alter and potentially radically enhance human performance at the genetic level, growing understanding of the function of the human brain is leading to less invasive but nonetheless dramatic improvement in human performance potential. For example, the US DARPA is seeking to combine several technologies into a system that literally taps the wearer's prefrontal cortex to warn of furtive threats detected by the soldier's subconscious.[173] This system will integrate technologies that have been available in laboratories for years, ranging from flat-field, wide-angle optics, to the use of advanced electroencephalograms, or EEGs, to rapidly recognize brainwave signatures. Commercial developments promise to expand this capability well beyond the defence sector. For example, San Jose, California-based NeuroSky[174] recently announced the development of a cost effective biosensor and signal processing system for the consumer market.

Researchers are now suggesting that within the timeframe 2015 to 2020 the first physical neural interface between a computer and a human brain (probably serving a prosthetic function) may be demonstrated.[175] It is envisioned that such neural interfaces will provide a direct connection between a human or animal brain and nervous system and a computer or computer network. With the advent of such interfaces, humans will be able to interact directly with computers by merely thinking. As noted earlier, the successful implementation of a neural interface may come from researchers working on human perception and prosthetic engineering at the intersections of medical and computer science, neural signalling, electronics, and signal processing. Increasingly however, progress in the domains of molecular biology, nanotechnology and bionanotechnology[176] are offering promising results towards the realization of a neural interface.

Today, nanotechnology is at a formative stage, similar to the condition of computer science in the 1960s or biotechnology in the 1980s. It is maturing rapidly, however. According to a 2006 study, investment in nanotech research between 1997 and 2005 by governments around the world soared from $432 million to about $4.1 billion, and corresponding industry investment exceeded that of governments by 2005.[177] More recent information presented by Luxresearch at the 2007 Nano and Giga Challenges in Electronics and Photonics conference, indicates that the total investment in nanotechnologies in 2005 reached $9.6 billion.[178] Luxresearch estimates that the market for products based on nanotechnology will reach $3.7 trillion by 2014.

Nanomaterials, a subset of the nanotechnology market presents tremendous opportunities to introduce a wealth of new products that could revitalize existing markets or in fact solve major societal problems such as plentiful cheap clean drinking water and energy.[179] In the near term, nanotechnology will result in materials that are lighter and stronger and will feature different properties than materials available today. The potential economic and societal contributions of nanomaterials has prompted U.S. Federal agencies participating in the Nanoscale Science, Engineering, and Technology Subcommittee (NSET) and U.S. chemical companies of all sizes to commit significant resources to nanotechnology research and development (R&D).[180] The race to research, develop, and commercialize nanomaterials is global. Advances in nanomaterials promise to revolutionize broad domains such as high-performance materials, coatings, energy conversion and storage, sensors, electronics, pharmaceuticals, and diagnostics.

Other governments are also seeking to become major players in the nanotechnology domain. The Taiwanese government for example, plans to invest NT$20 billion between 2006 and 2010 in industries that apply nanotechnology to daily life, reflecting the expectation that Taiwan will develop into a global nanotechnology R&D center.[181] Nanotechnology in Taiwan is one of six strategic daily-life S&T industries. The others include soft electronics, RFID (Radio Frequency Identification), intelligent robots, intelligent vehicles, and intelligent accommodation. It is estimated that by 2013, the manufacturing value of Taiwanese intelligent robots will hit NT$90 billion, and that of RFID will hit NT$70 billion.

According to an article in AFCEA's International Journal, Signal Magazine, nanotechnology has vast military, economic and security implications for the future.[182] The potential capabilities that nanotechnology will enable, still appear to many, as science fiction. Daily breakthroughs in almost every aspect of nanotechnology, however, are bringing these capabilities closer to reality. While nanotechnology may or may not turn out to be a disruptive force, it is without a doubt, an enabler that the CF capability development community cannot afford to ignore or marginalize.

The US Army, recognizing the importance and potential impact of nanotechnologies on future capabilities has provided $50 million to stand up the Institute for Soldier Nanotechnologies at the Massachusetts Institute of Technology (MIT) in Cambridge in order to develop technologies to improve warfighter protection. The institute's director, Dr. E.L. Thomas, predicts that within the next 5 to 15 years, new capabilities such as battlesuit systems architectures and ultralightweight nanorelief networks, self-assembled microtrusses and photopatterned nanocomposites will be possible.[183] While these developments will enable the development of new uniforms, better armour and improved sensors, beyond 2020, it is expected that nanotechnology will have a significant impact on all types of weaponry, including smart chemical weapons—offering a unique combination of lethality and precision. It is expected that in this timeframe, conventional and nuclear weapon production will also benefit from nanotechnology. For example, the potential to produce nuclear weapons much more rapidly with a much lower detection threshold is possible.[184] This has caused some experts in the US to see global nanotechnology superiority as a race that is on par with, and perhaps exceeding that of nuclear weapons.

An important area of research at MIT is mechanically active materials and devices based on reconfigurable materials. This research promises to deliver smart materials that change shape when flexed. They will offer such capabilities as clothing that becomes armour or transforms into a reconfigurable cast that stabilizes an injury such as a broken leg. Yet, a more remarkable shape shifting material—intelligent nanodust or Claytronics—is at early stages of development at Carnegie Mellon University.[185] The goal of the claytronics project is to understand and develop the hardware and software necessary to create a material, which can be programmed to form dynamic three-dimensional shapes, which can interact in the physical world and visually take on an arbitrary appearance. Claytronics refers to an ensemble of individual components, called catoms (claytronic atoms). Each catom contains a CPU, an energy store, a network device, a video output device, one or more sensors, a means of locomotion, and a mechanism for adhering to other catoms. If successful, when combined with the 3D digital scanning noted earlier, then it could be possible to recreate a replica of anything or anyone, wherever there happens to be sufficient catoms available.

Another science fiction-like capability, invisibility, is being touted as a future possibility based on nanomaterial research into an area referred to as metamaterials.[186] Several researchers have already developed metamaterials with remarkable properties. For example, Canadian researchers have succeeded in creating metamaterials that have a negative index of refraction, able to focus electromagnetic waves with unparalleled precision.[187]

It is expected that within the energy sector, nanotechnology will offer significant breakthroughs. All areas of the energy market stand to benefit from new nano approaches. For example, new nanomaterials promise to enable the production of cheap and increasingly efficient solar panels that will rival conventional electricity production sources. New bio-nano techniques will offer significant improvement in biomass conversion to energy and potentially for direct hydrogen production. Even wind energy will benefit from nanotechnologies as lightweight structural materials created with nano carbon fibres (carbon nanotubes) are integrated into the components of wind turbines.

Beyond the applications noted above, nanotechnology researchers envision ultra-miniature robotic systems and nano-mechanical devices that have applications in manufacturing and in life sciences. These areas are likely to develop more slowly than some others as concerns over safety will raise policy issues. Canada's own National Institute for Nanotechnology (NINT)[188] will undoubtedly play a lead role in establishing national policies. From a defence perspective, given the significant disruptive potential offered by new nanotechnology developments, it will be important for the defence community to remain connected with policy decisions, particularly with respect to commercial technology transfer issues.

The convergence of all these technology areas is revolutionizing many existing technology dependant endeavours. Access to space, for example has become a commercial venture that is increasingly becoming available to the public.[189] Due to the current excessive fees for space tourism, but an acknowledged demand, Buzz Aldrin, the second NASA astronaut to walk on the moon, recently announced plans to conduct a space tourism lottery. It would send the winner into space in a bid to spread the dream of extraterrestrial travel beyond the super-wealthy.[190] Moreover, Virgin Galactic's Richard Branson is on pace to develop a six passenger craft that will offer sub-orbital space tourist travel this decade.[191] The offshoot of this renewed interest in space is a growing ability for individuals to access space. While space tourism is hardly a national security threat, there is potential for any well-funded group to gain access to space with a commercial launch of a micro surveillance satellite system for example. It appears that there is a new space race taking shape that will drive renewed innovation in space technologies. An increasing number of global players are targeting major space initiatives. Russia and China, for example, recently announced a joint mission to Mars.[192] It is possible that space could become a new battlefield in the future.

Technologically Induced Societal Change

As identified in the introduction to this chapter, technology is a key driver of societal change. Moreover, the pace of change is leading to societal disruptions, which in many cases are manifest in reactionary changes in laws and policies. For example, disputes are arising as a result of small groups using, or desiring to use new technologies, which are beginning to appear in the courts before the public is generally aware of them, and thus before any elected body has considered the public policies surrounding them. In this era of Blogs and other social networking tools such as MySpace, which offer platforms for individuals to openly and globally criticize governments and other officials, there will likely be growing tensions between freedom of speech and State censorship of these capabilities. The courts will therefore need to deal with situations that appear from our current frame of reference as outrageous and immoral,[193] perhaps on an increasingly frequent basis, and often before a suitable regularity environment is in place. For this, if for no other reason, future-oriented exercises are of great practical importance. Systematic study of futures issues should become a routine part of all developmental activities as a means to avoid being taken by surprise and thus having to make rash judgments that often result in unintended consequences.

The ongoing ethical debate over human embryo stem cell research in the US is a characteristic example of ongoing technology induced policy disruption. Proponents point to the great promise that stem cell research has for curing juvenile diabetes, Parkinson‘s, cancer, spinal cord injuries and many other diseases and conditions. Conversely, US President George Bush, citing concerns over the moral implications, has indicated that he would veto recently introduced legislation[194] that loosens restrictions on the use of embryonic stem cells if it advances all the way through Congress.[195]

An equally disruptive development enabled by our globally connected society is the power the internet affords individuals and social groups in their fight against corruption[196] or even state or national level policies or activities. For example, the US Navy was recently sued over its use of sonar technology and the environmental harm that it causes.[197] Moreover, misinformation that is easily spread using new social network tools[198] such as YouTube, can easily incite international tensions. For example, a Greek user recently posted a video on the YouTube site portraying Mustafa Kemal Ataturk, the founder of modern Turkey, and all Turkish citizens as homosexual, prompting the Turkish government to ban this site.[199]

All parts of society will undergo transformation due to the introduction of new technologies. The legal system, for example, is beginning to adapt to the impact of neuroimaging and neuroscientific evidence in criminal law proceedings. Proponents foresee a significant impact not only on questions of guilt and punishment, but also on the detection of lies and hidden bias, and on the prediction of future criminal behaviour. Sceptics however, fear that the use of brain-scanning technology as a mind-reading device will threaten privacy and mental freedom. Some have suggested that a new concept of cognitive liberty will be required to mitigate these concerns.[200] Genetic liberty is also becoming an issue as advancements in biotechnologies and genetics offer an ability to identify genetic predisposition to specific diseases. This prompted the U.S. House of Representatives to pass the Genetic Information Non-discrimination Act,[201] which prohibits improper use of genetic information in hiring and health insurance decisions.

Virtual reality developments will eventually lead to virtual economies and increasing segments of society that spend more and more time online. An emerging capability that is rapidly maturing because of the growing online community and automation tools is an ability to create increasingly customized worlds around us. A more significant outcome of the increasing numbers of people online is the generation of stigmergic behaviours.[202] Tools such as e-mail and web logs or blogs for example, enable people to work together no matter where they are located. Furthermore, time-separated collaboration (stigmergy) is possible, as evidenced by the growing use of wiki tools.

Digital security however will become an increasing area of concern as more personal and private information is digitized. Recently the US Transportation Security Administration (TSA) discovered that an external hard drive containing personnel data (including name, Social Security number, date of birth, payroll information, financial allotments, and bank account and routing information) was missing from a controlled area at the Headquarters Office of Human Capital.[203] The implications for institutions are significant. Failure to safeguard digital information in addition to the security implications, could also lead to financial penalty. The TSA for example has had to provide one year of free credit monitoring and identity theft insurance up to $25,000 to assist employees in the event they are a victim of identity theft. Military systems will not be immune to these same risks and challenges.

Another area that will continue to challenge societies is the ease with which digital data can be copied, shared and manipulated. Before the advent of digital cameras and sophisticated image manipulation software such as Photoshop or the freely available open alternative—GIMP, adjusting images in a darkroom required concerted effort, skill and considerable time. Today, image and video manipulation is possible with a few keystrokes or clicks of a mouse and is available to practically anyone. These inexpensive capabilities, combined with near instantaneous world-wide dissemination over the Internet offer opportunities for misinformation, deception and fraud—intentional or otherwise. The ability to access this information via the web, complicated by e-mail traffic from colleagues, will increase the need for due diligence in verifying sources. It will become impossible to believe anything seen, heard, or read in the popular media or online unless it is corroborated by numerous unique, distinct and trusted sources. Unfortunately, it is becoming all too easy for legitimate sources to 'lift' content (accurate, misleading or just plain wrong) in an instant in our web-connected world. Even scientific journals are not immune to deception as the growing 'publish-or-perish' paradigm forces failing programs to take drastic measures.[204] Web logs or blogs will only serve to aggravate the situation as laypeople pontificate about the things they have heard, seen or read about in the popular media or on some other blog.

Despite the negative aspects of inappropriate data and information manipulation noted above, network enabled social collaboration through tools such as Wikis, remains a powerful and beneficial capability that will most likely continue to grow in popularity and importance. Many large government organizations will likely attempt to tap into this social phenomenon. NASA for example, has already announced a new open-source project called CosmosCode, which aims to recruit volunteers to write code for future space missions.[205] Interestingly, participants can meet other members of the volunteer community at CosmosCode's weekly Tuesday meetings which are conducted in the virtual world of Second Life—all without leaving their home or office.[206] This level of openness and transparency within a defence environment is likely to face security constraints, however there is no reason why similar social collaboration tools could not be implemented to tap into the collective wisdom of current serving members of the CF. Failure to implement such social collaborative tools could result in security disruption as private sector mass collaboration may well out-compete traditional institutional bureaucracies.[207] The potential power of social collaboration was demonstrated recently when a fifteen-year-old high school student created a sophisticated fusion device with some online collaborative assistance.[208] Recognition of the power afforded by network collaboration has led some corporations to develop applications that enable 'crowd sourcing'[209]. Furthermore, the net has even become the new political battlefield[210] for the upcoming US presidential election.[211]

Network based collaboration is hardly a new phenomenon, however momentum is gaining as new so-called Web 2.0 applications proliferate. These applications start with very little information, but they provide easy to use tools that encourage users to contribute material and expand the content. Over time, a Web 2.0 application evolves—the users essentially becoming the administrators, thus establishing a self-organizing site. A 2006 Booz Allen Hamilton study revealed that the use of social networking sites, wikis, and other Web 2.0 technologies is a growing mass phenomenon. The study found that social networking was a massive phenomenon applicable to all users regardless of age, social class, gender, or education. Furthermore the survey revealed that more than half of all Internet users already rely on advice from a massive worldwide user community, indicating a wide acceptance of new ways to form opinions and make buying decisions. Privacy concerns have also diminished; 70% of MySpace users in the U.K. create their own content to share, but only 39% restrict public access to materials intended only for themselves or their acquaintances.[212]

While there may be some resistance to implementing open collaborative initiatives, it may become necessary for government organizations to provide open access to their publicly funded research. Several organizations such as the Alliance for Taxpayer Access are actively seeking this access claiming that public money should result in public benefit.[213] The scientific community has to some degree, already begun to provide open access to their information—at least to other scientific professionals through the wiki for professionals. This wiki is described as a workspace on the semantic web that will enable real-time knowledge exchange and exploration by combining information in databases with literature so that it all appears to be a single database from a user's perspective.[214] Open access to all this information, coupled with the addition of text mining software will allow users to probe links within the data thus facilitating detailed analysis. The liberation of information in this manner will empower individuals while at the same time reducing the monopoly on information that governments have enjoyed in the past. Indeed, it may become a necessity for organizations to provide social networking tools to their personnel. Failure to do so may increasingly be seen by in-house staff as an attempt to censor their activities. To some degree, this situation is being played out in the US Military, as access to social networking tools has been restricted due to bandwidth and security concerns.[215]

While bandwidth and security concerns may be legitimate concerns in a military context that necessitate restrictions, such measures may become increasingly intolerable to individuals who expect social collaboration and communication tools to be made available to them. The recent response by users of the social news portal Digg.com to perceived bullying authority may become more prevalent in the future. Recently Digg.com users posted links to a code that allows software developers to copy encrypted content from HD-DVD discs. The code's creators, Advanced Access Content Systems, demanded that the Digg.com administrators remove the links. While the site's administrators cooperated with the request, the site's users rebelled.[216] Digg's site was covered with thousands of links to the code and free speech protest statements. Ironically, millions have now seen the HD-DVD code and a Google search of the first few digits of the code results in links to over 1.6 million copies of the complete code. This social rebellion has forced Digg's administrators to abandon its attempts to remove the code and instead to develop a legal position in preparation for inevitable litigation by the code's creators. In the future, any attempt by authority to stifle user communication within these emerging Web 2.0 collaborative environments may ironically lead to greater proliferation of the information that they initially attempted to restrict. This phenomenon is becoming known as viral marketing,[217] which clearly can have positive advertising benefits but negative consequences if attempting to protect sensitive information. There are growing opportunities, however, to data-mine these flourishing connections. Intelligence agencies are seeking to track insurgent groups with social network mapping tools[218] for example. While this raises privacy issues, it is likely that the convenience afforded by social networking will trump these concerns. However, with the proliferation of camera and videophones, the biggest threat to privacy in the future may not be the government, but rather your next-door neighbour. The potential implications for social disruption seem profound.[219]

The proliferation of these open social collaborative network platforms will thus enable the small to become powerful. Access to the growing collection of comprehensive and searchable information on the web may also change society's definition of intelligence. Whereas in the past, intelligence was largely determined by how much an individual could remember, in the future, one's intelligence may be measured by an ability to quickly locate, organize and understand information gleaned from global information sources such as the Internet. Therefore, a person who knows very little about a subject but who can quickly find and organize relevant information on that subject will be far more productive than someone unfamiliar with information search and retrieval technologies, regardless of their mental capacity. Increasingly, this skill will grow in importance as societies become more complex and access to the global web of information becomes available 24/7 from any location because of proliferating cell phone coverage and Mobile Social Software (MoSoSo) applications.[220]

Commercial MoSoSo applications provide the civilian equivalent of blue force tracking, situational awareness and command on the move. It is likely that these civilian network enabled operations capabilities will grow in sophistication and power, rivalling anything that can be implemented by large institutional armies due to their bureaucracies. This condition of continuously available computing will undoubtedly cause societies to morph in unexpected directions as people find innovative ways to put these commercial and open-source technologies to use in their social lives. At some point in the near future, the underlying hardware and software that enables this ubiquitous mobile[221] social networking will become so unobtrusive and commonplace that it will become part of the fabric of society, and it will thus cease to be viewed as high-tech. At this point, being cut off from the network will be a traumatic event. While this situation may be a few years away, and some may argue that it is already here for many individuals, the Army's capability development community will need to be aware of this issue and its human resources impact. Potential recruits in the year 2021, which is projected as the date for AoT full operating capability, are presently four to eight years old. They will undoubtedly have well developed expectations of continuous ubiquitous network enabled social collaboration availability. Capability development will therefore need to cater to this expectation. Moreover, an ability to operate in this environment will be a trait in high demand amongst recruits since the AoT ADO concept envisions a ubiquitous network environment. Balancing security requirements with availability demands will likely continue to be a challenge for military system implementation, however. One piece of mobile spyware for example, known as SymbOS/Flexispy.B, is able to remotely activate the microphone on a mobile device, allowing someone to eavesdrop on that person.[222] Others can activate cameras.

While developed nations will lead in the development of ubiquitous networking, the importance and proliferation of networking in developing countries cannot be underestimated. For example, the United Villages project uses buses and motorcycles equipped with wi-fi to deliver web content to remote rural villages in the developing world.[223] In rural India and parts of Rwanda, Cambodia and Paraguay, the vehicles offer web content to computers with no Internet connection. Already, significant portions of the developed world are seeking to make network access mandatory. For example, the 25 European Commission member states and nine accession countries have all signed up for a plan that could make accessibility in e-procurement mandatory.[224]

Military Technology Change

The changes wrought to global societies due to the proliferation of networking within the commercial sector are also influencing the interface between Canadian society and the military. Communication between deployed personnel and their families, and society in general, has been improved significantly through initiatives such as DNDTALK[225], which is promoted as a place were family members can post messages to deployed personnel. It features blog capabilities and will soon provide podcasting tools that will allow audio messages in mp3 format to be posted.

Military blogging is a rapidly developing trend. Milblogging.com for example, provides a global index of military blogs. The site also tracks Milblogs by country. The United States and Iraq top the list of countries with Milblogs with 1123 and 386 sites respectively. Canada has 18 Milblogs[226] listed on the site. One example, the Canadian-Forces blog[227], serves as a reservist recruiting site. Others provide blogging tools for military families.[228] While these sites offer tremendous support for families and may enhance troop morale, they are not without their challenges. Providing access to these and other services for deployed troops requires significant communications bandwidth. Operational imperatives obviously will demand that available bandwidth be prioritized for mission specific use. Insufficient reach-back bandwidth therefore, could jeopardize troop morale in the future as more and more individuals become used to being in constant contact—often in real time.

While the continuing development and expansion of the Internet characterizes and defines the 21st century information age, from a military capability perspective, the basic tools of warfare remain remarkably similar to their industrial age predecessors—tanks, trucks, direct fire systems and missiles for example. Though the integration of 21st century information technology into vehicle systems is notable, their basic physical performance characteristics are only marginally better than those of their cold war predecessors. Propulsion systems and other mechanical components that define their physical performance characteristics are progressing at much slower rates than information technology or its uptake. Therefore it will be primarily within the realm of information technology, where exponential improvements in rapid computation, simulation, situational awareness, targeting, surveillance, and precision will serve to increase vehicle effectiveness.

Advanced ICT networking technologies are increasingly being applied to extend the useful life of legacy systems by allowing them to be used in new and innovative ways—including dispersal with greater situational awareness and superior cooperative engagement potential. Newly integrated ICT also provides better engagement capabilities. For example, new ICT based fire control systems comprising computers, sensors and software, can offset a deficiency in armour protection with improved first hit/kill probability. Furthermore, as robotic vehicles enter service by 2021, they could draw fire or spot targets allowing legacy systems to engage and dominate even though they do not posses superior firepower or armour. New materials research may offer opportunities to increase the service life of the main chassis of major weapons platforms; however, it would be unreasonable to expect the integrated ICT components to have a service life greater than several years. This is not because they would fail, but rather that they would become obsolete due the exponential pace of development of the technologies. This situation demands a modular plug and play upgradeability path that allows new ICT to be easily incorporated without major retrofit into legacy systems.

Technology is currently being leveraged to gain the full strategic and tactical advantage of a mobile, agile, and flexible force. This has led many armies to focus much of their development effort on fleets of lighter armoured vehicles that provide a credible and effective fighting force. While recent experience in the Current Operating Environment has emphasized the shift to increased emphasis on protection with regard to the firepower, mobility, protection triangle and the need for heavy armour levels of protection in countering the IED threat, advances in materiel design and manufacture and information technology will be leveraged to enhance the protection of lighter weight forces. In this sense, survivability encompasses all successive layers of protection, from mobility and stealth, to signature reduction and soft-kill Defensive Aids Suites (DAS), to hard kill DAS, to improved armour, to spall suppression systems.

According to a 2004 report by the Center for Strategic and Budgetary Assessments, a revolution in war has been underway for nearly three decades.[229] Western allies have sought to offset the numerical superiority of Warsaw Pact forces during this period by seeking to develop asymmetric technological advantages. Despite the end of the Cold War, the report's authors suggest that the revolution resulting from these initiatives continues and can be characterized by: the emergence of all-weather precision war; the advent of stealth; the rise of unmanned systems; the tactical and operational exploitation of space; and the emergence of early forms of network-based warfare and joint force integration. Furthermore, the authors suggest that the rate of change in military capabilities will likely increase substantially over the next couple of decades. Precision-strike capabilities will continue to increase in reach, scale and sophistication. More advanced forms of stealth are in development. Sensors and battle networks will continue to increase in capacity and sophistication. Unmanned systems will become an increasingly important component of force structures. It appears unclear however whether or not a critical mass of these capabilities will diffuse to potential competitors or whether the United States will remain the dominant military technological power.

The continuing utility of legacy systems much beyond the 2010 timeframe, however, has been called into question. Defence analysts Michael Vickers and Robert Martinage, contend that the power of smart munitions (which can be fired remotely or shoulder launched) is outstripping the protection afforded by speed or armour.[230] Similarly, George and Meredith Friedman contend that conventional weapons platforms such as tanks will have difficulty surviving in a world of precision-guided munitions.[231] This uncertainty is underscored by trends within the protective armour R&D community, which is turning to explosive reactive armour as a potential means to defeat smart munitions.

Commercial technologies are increasingly becoming available at much lower costs and often with greater operational functionality than currently fielded militarized equivalents. While these commercial systems sometimes lack security features, they are being purchased by troops before they deploy to theatre. For example, the CFLO ARDEC Feb/March 2007 update noted that US units and/or soldiers were purchasing commercial Garmin GPS products for use while in theatre. Doing so ensured that at least one person per patrol and sometimes everyone had GPS capability. This situation will likely continue as commercial innovation provides increased capabilities more frequently than military procurement programs can respond. More significantly, newer navigation devices have become inexpensive commodities that anyone, including adversaries, can obtain. These sophisticated compact personal devices offer advanced functions including point-to-point navigation with turn-by-turn directions, all displayed on a three to four inch touch map screen complete with voice instructions.[232] These rugged commercial systems are designed to be portable and rugged with extended battery operations. They could even be integrated into a variety of cheap off-the-shelf commercial products thus facilitating the creation of inexpensive precision weapons. When combined with commercially available communications technologies, they offer situational awareness capabilities rivalling those available to current deployed military systems. Though facing some funding challenges, the European Union commercial satellite navigation system, Galileo, will add to the robustness of commercial navigation offerings. Galileo, however, will offer advantages over its contemporary military counterparts (the US Global Positioning System (GPS) and the Soviet GLONASS); it should provide significant performance improvement given what has been learned from thirty years of experience with GPS technology.

China is also actively seeking to enter the satellite navigation sector. On April 14, 2007, China launched a COMPASS navigation satellite, which follows a February 3, 2007 launch, the fourth since 2000. China reportedly plans to provide national coverage and coverage for some neighbouring countries in 2008.[233] It is expected that this will be expanded to global coverage.

Commercial innovation is providing other advanced capabilities to the public that were previously only available to advanced militaries. The Israeli-owned ImageSat International, for example, offers customers the opportunity to task its EROS-A imaging satellite and download its data in total secrecy with few if any restrictions.[234] This service essentially provides private customers with their own reconnaissance satellite, but at a fraction of the cost. Now the freely available Google Earth[235] and Map applications provide anyone with an Internet connection and a contemporary computer with powerful free geographic tools and global satellite mapping coverage. The private satellite industry is becoming so advanced and pervasive that many advanced militaries, including the U.S. military, now rely upon it to provide some of its imaging and much of its communications needs.

Another dramatic shift towards commercial innovation is evident in the robotics sector. In a recent fastcompany magazine interview, Rodney Brooks, director of a large scale US computer science and artificial intelligence lab, indicates that ten years ago 90% of his group's funding was provided by the Defense Department whereas today it is less than 25%.[236] Thus, sophisticated robotic technology will proliferate commercially, not just within the military domain.

The confluence of all these trends could lead to new forms of war within the dimensions of space, information and biology. The conduct of land warfare could shift from a regime dominated by mobile, combined-arms, and armoured forces to one that is dominated by much lighter, stealthier and information-intensive forces that make heavy use of robotics. Increased commercial and military use of space could lead to the emergence of a wide range of offensive and defensive space control capabilities. Computer network attack tools and radio frequency weapons could be widely used to attack information infrastructures and information-intensive forces. Designer biological weapons and the emergence of biological operations could also figure prominently in the future. Failure to hedge capability development efforts to deal with these possibilities represents a significant future risk.

Human Factors Implications

As society changes, the skills that citizens need to address challenges also change. In the early 1900s, a person who had acquired simple reading, writing, and calculating skills was considered literate. Today, it is expected that all students must read critically, write persuasively, think and reason logically, and solve complex problems in mathematics and science. According to an enGauge 21st Century Skills study[237], the driving force for the 21st century will be the intellectual capital of citizens. On the military front, soldiers will need digital age proficiencies in order to thrive on a digital battlefield. And, the military training system must make parallel changes to prepare soldiers for this environment. In particular, the training system must understand and embrace the skills demanded by changing technology in the 21st century: These skills include:[238]

- **Visual and Information Literacy**: The graphic user interface of the World Wide Web and the convergence of voice, video, and data into a digital format have increased the use of visual imagery dramatically. Advances such as digital cameras, graphics packages, streaming video, and common imagery standards, allow for the use of visual imagery to communicate ideas. Good visualization skills are required to be able to decipher, interpret, detect patterns, and communicate using imagery. Information literacy includes accessing information efficiently and effectively, evaluating it critically and competently, and using it accurately and creatively.

- **Cultural Literacy and Global Awareness**: As the world becomes increasingly wired and interconnected, the resulting globalization of commerce, trade and conflict increases the need for cultural literacy. In such a global economy, with interactions, partnerships and competition from around the world, there is a greater necessity for knowing, understanding and appreciating other cultures, including the cultural norms of a technological society.

- **Adaptability/Managing Complexity and Self-Direction**: Today's interconnected world generates unprecedented complexity. Globalization and the Web are inherently complex, accelerating the pace of change in today's world. Interaction in such an environment requires individuals capable of identifying and reacting to changing conditions independently. Indeed, individuals must be self-directed learners who are able to analyze new conditions as they arise, identify the new skills that will be required to deal with these conditions and independently chart a course that responds to such changes. They must be able to take into account contingencies, anticipate change, and understand interdependencies within systems.

- **Curiosity, Creativity and Risk-taking**: Individuals today are expected to adjust and adapt to changing environments. Inherent in such situations is a curiosity about the world and how it works. Researchers now understand how the very structure of the brain can be changed through intellectual pursuits. Curiosity fuels lifelong learning as it contributes to the quality of life, and to the intellectual capital of the country. Equally important is risk taking—without which there would be few quantum leaps in discoveries, inventions, and learning.

- **Higher Order Thinking and Sound Reasoning**: For decades reports have been calling for higher order thinking and sound reasoning in school curricula. This includes thinking creatively, making decisions, solving problems, seeing things in the mind's eye, knowing how to learn and how to reason. Sound reasoning enables individuals to plan, design, execute, and evaluate solutions— processes that are often carried out more efficiently and effectively using technological tools.

- **Teaming and Collaboration**: The rapid pace of today's society and communications networks has caused, and enabled, a shift in the level of decision-making down to the individual. At the same time, the complexity of today's world requires a high degree of specialization by decision makers. This demands the teaming of specialists to accomplish complex tasks in ways that are efficient, effective and timely. Information technology plays a key role in the ease with which individuals and groups collaborate. Email, faxes, voice mail, audio and video conferencing, chat rooms, shared documents, and virtual workspaces can provide timelier, iterative collaborations.

- **Personal and Social Responsibility**: Emerging technologies often pose ethical and values dilemmas. As technical complexity increases, ethics and values must guide the application of science and technology at the personal, community, and governmental levels. Individuals must grasp this responsibility and contribute as informed citizens at all levels.

- **Interactive Communication**: In our wired, networked society it is imperative that individuals understand how to communicate using technology. This includes asynchronous and synchronous communication such as person-to-person email, blog and wiki interactions, group interactions in virtual environments, chat rooms, multi-user gaming environments, interactive videoconferencing, phone/audio interactions, and interactions through simulations and models. Such interactions require knowledge of etiquette often unique to that particular environment. Information technologies do not change what is required for high quality interactive communications. Yet they do add new dimensions that need to be mastered so they become transparent (e.g. scheduling over time zones, cultural diversity, and language issues). Otherwise, such technologies may interfere with rather than enhance communication.

- **Prioritizing, Planning, and Managing Results**: High levels of complexity require careful planning, managing, and an ability to anticipate contingencies. This means more than simply concentrating on reaching the main goals of the mission or monitoring for expected outcomes. It also requires the flexibility and creativity to anticipate unexpected outcomes as well.

Conclusion

Leadership in the 21st century will belong to those nations that can capitalize best on change. Science, Technology and engineering research has become the most powerful force for change in our society. A strong and forward-looking defence research capacity will allow the Army to deal with a large variety of future challenges, whether national-security threats, environmental problems, public emergencies, or crises that we cannot yet predict. Solutions to pressing problems will continue to emerge in unexpected ways from new science and technology knowledge.

Military technologies will undoubtedly continue to be augmented with improved intelligence, speed, range, stealth, lethality and autonomy in what amounts to a continuous race to outpace perceived threats. Indeed, despite the inherent inability to predict the future, there is sufficient trend data to suggest that technology (primarily commercial) will continue to advance exponentially and converge (barring an unforeseen catastrophe). This offers the potential for small, well-funded groups to achieve asymmetric technological advantage in niche areas, thus threatening current western military superiority.

Foreseeable advances in artificial intelligence, computation, simulation, communication, sensors, robotics and portable power are just beginning to influence today's land force capability development thinking. Unfortunately, given the snail's pace at which major new system capabilities are delivered, complicated by a procurement pipeline that is fully subscribed with mainly traditional equipment and platforms, it will be difficult to respond in a timely manner to the continuing rapid technological change, let alone to a potential (perhaps looming) security disruption caused by new commercial technological breakthroughs. Moreover, militaries are loosing market leverage due to reduced defense spending. Nevertheless, commercial innovation is proceeding apace, which leads to rapid military technology obsolescence due to the reduced cost and cycle time of commercial technology development.

It is still unclear whether failed and failing states, or terrorist groups and organized crime syndicates will successfully incorporate these new high-tech capabilities into their operations in sufficient quantity to threaten western military superiority. Already though, Al Qaeda has proven proficient at harnessing the power of networking technologies and adapting commercial technology for use as weapons (such as the 9/11 use of commercial jet liners as cruise missiles). Furthermore, knowledge of what commercial technology is able to do, and where to obtain it, is public domain on the Internet. And, it is easily ordered over the Internet with next day delivery by one of many international courier services. Indeed, asymmetric attacks using simple commercial technology, such as cell phones or IR remote controls, have already occurred. Furthermore, as recent experience with suicide bombers shows, these ad hoc technological threats need only be designed to work once in order to be an effective weapon.

The key issue for force development however, is to determine to what extent the potential offered by rapidly changing technological developments will influence capability requirements in 5 to 10 years. These time frames are particularly important since the capital procurement history of DND suggests that many procurement decisions made today, are unlikely to be fielded much before 2015 and in some cases not until 2020 and beyond.

Future-focused projects such as autonomous systems (robotics) need to be entered into the procurement pipeline as soon as possible. It is imperative that the capability development priorities stemming from Army of Tomorrow work remain informed by the pace of technological change in the broad domains outlined above. Indeed, failure to hedge development activities to cover the potential threats offered by the onslaught of advanced commercially available technologies represents a serious risk to tomorrow's land operations.

Endnotes

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15. http://www.xprize.org/xprizes/ansari_x_prize.html
16. http://www.xprize.org/xprizes/genomics_x_prize.html
17. http://www.xprize.org/xprizes/automotive_x_prize.html
18. http://www.darpa.mil/grandchallenge/index.asp
19. http://www.robocup.org/
20. http://www.thinkcycle.org/ ThinkCycle is an academic, non-profit initiative engaged in supporting distributed collaboration towards design challenges facing underserved communities and the environment.
21. http://www.yet2.com/app/about/about
22. http://www.cio.com/archive/100106/essential_tech.html
23. http://www.technewsworld.com/story/57224.html
24. http://www.kurzweilai.net/articles/art0134.html?printable=1
25. http://www.accelerationwatch.com/degree.html
26. http://designnews.com/article/CA6435790.html?nid=2332&rid=2052535400
27. http://www.newscientisttech.com/article/dn11632?DCMP=NLC-nletter&nsref=dn11632
28. http://www.keckfutures.org/site/PageServer?pagename=home
29. Where Science is Headed—Sixteen Trends The Journal of the Washington Academy of Sciences (Fall-Winter 2003) Page 1, Joseph Coates Consulting Futurist, Inc.
30. http://www.weforum.org/en/initiatives/gcp/Global%20Competitiveness%20Report/index.htm
31. http://www.nrc-cnrc.gc.ca/aboutUs/ren/nrc-foresight_e.html
32. http://wtec.org/ConvergingTechnologies/
33. http://www-03.ibm.com/press/us/en/pressrelease/21473.wss
34. http://www.pewInternet.org/PPF/r/188/report_display.asp
35. http://www.spectrum.ieee.org/sep06/4435
36. http://www.openfabrics.org/archives/aug2005datacenter/W8.pdf (slide 7)

37. http://www.berkeley.edu/news/media/releases/2005/09/14_key.shtml
38. http://www.intel.com/pressroom/archive/releases/20070416supp.htm Also included in this announcement is Intel’s project Larrabee, which promises easily programmable parallel chip architectures designed to scale to trillions of floating point operations per second (Teraflops) of performance. This performance level will lead to acceleration in applications such as scientific computing, recognition, mining, synthesis, visualization, financial analytics and health applications. Intel also has specific goals to drive down power-consumption and manufacturing die-size to get to processors for ultra mobile computer usage, aiming for a 10x reduction in power-consumption in its processor portfolio by 2010.
39. http://domino.research.ibm.com/comm/pr.nsf/pages/news.20070412_3dchip.html
40. Other than the supercomputer application, these chips are all utilized in cell phone development. If these advances deliver on the performance claims, it can be expected that cell phone performance will hit new levels. It would be reasonable to expect that cell phones will soon reach the level of performance of laptop computers.
41. http://www.prc.gatech.edu/
42. Recently, Intel introduced their Intel® CE 2110 Media Processor, a complete system-on-a-chip (SoC) architecture that combines a 1GHz processing core with powerful A/V processing and graphics, and I/O components, onto a single chip intended for use in consumer electronics.
43. http://mr.caltech.edu/media/Press_Releases/PR12942.html
44. http://spectrum.ieee.org/mar07/4946
45. Equal to a capacity of 1024 Gigabytes.
46. http://www.sandisk.com/Oem/Default.aspx?CatID=1477
47. http://news.com.com/Bye-bye+hard+drive,+hello+flash/2100-1006_3-6005849.html
48. According to Xerox, ubiquitous computing is invisible, everywhere computing that does not exist on a personal device of any sort, but is in the woodwork everywhere. http://sandbox.xerox.com/ubicomp/
49. http://www.ipsos-na.com/news/pressrelease.cfm?id=3049
50. http://www.technewsworld.com/story/56567.html
51. http://www.itu.int/osg/spu/publications/Internetofthings/
52. http://www.emc.com/about/destination/digital_universe/
53. An exabyte is equivalent to one billion gigabytes.
54. http://www.top500.org/lists/2006/11/performance_development
55. http://books.nap.edu/openbook.php?record_id=10784&page=1
56. In addition to the top four supercomputers in the world, the US has seven in the top ten and 309 in the top 500.The US therefore has more supercomputers in the top 500 than the combined total of the other 30 countries on the list. http://www.top500.org/list/2006/11/100
57. http://www.newscientist.com/article.ns?id=dn8876&print=true
58. A petaflop is a computer processor performance measurement representing a thousand trillion floating point operations per second.
59. http://www.technewsworld.com/story/56545.html
60. http://www-03.ibm.com/press/us/en/pressrelease/21278.wss
61. Internet2 is a not-for-profit advanced networking consortium comprising more than 200 U.S. universities in cooperation with 70 leading corporations, 45 government agencies, laboratories and other institutions of higher learning as well as over 50 international partner organizations.
62. IPv6 is the Internet protocol address scheme that will replace the existing IPv4 implementation. IPv6 will offer 5x1028 addresses for each of the world’s 6.5 billion people. IPv4, on the other hand, only supports about 4.3 billion addresses.
63. http://www.Internet2.edu/lsr/
64. http://www.nari.ee.ethz.ch/commth/pubs/p/proc03
65. The IEEE 802.11n Working Group recently approved draft 2.0 of the standard, paving the way for 100+Mbps wireless LAN products. The IEEE standard originally called for a minimum of 100+Mbps throughput, however several “draft 1” or “pre-11n” products already on the market are delivering 140 to 160Mbps. With more antennas, more power and other tweaks, many vendors say they expect to achieve over 200Mbps, sometimes much more. http://www.ieee802.org/11/
66. http://www.wi-fi.org/OpenSection/why_Wi-Fi.asp
67. http://www.intel.com/netcomms/technologies/wimax/index.htm
68. http://www.intelsatgeneral.com/pdf/en/aboutus/releases/2007-4-11-IRIS.pdf
69. Ibid.
70. http://news.bbc.co.uk/2/hi/science/nature/6645987.stm
71. http://www.spectrum.ieee.org/feb07/4892
72. Ibid.
73. http://cs.nyu.edu/~jhan/ftirtouch/
74. http://www.utoronto.ca/atrc/reference/tech/haptic.html
75. http://www.msl.ri.cmu.edu/projects/haptic/
76. http://wii.nintendo.com/controller.jsp
77. http://www.agilealliance.org/
78. http://www.military-information-technology.com/article.cfm?DocID=1589
79. http://itredux.com/office-20/database/
80. http://www.iupload.com/
81. http://www.knownow.com/

82. http://www.weforum.org/en/initiatives/gcp/Global Information Technology Report
83. http://www.weforum.org/pdf/gitr/rankings2007.pdf
84. http://www.foreignpolicy.com/story/cms.php?story_id=3420&page=1
85. http://www.unctad.org/Templates/WebFlyer.asp?intItemID=3991&lang=1
86. http://www.itu.int/ITU-D/ict/statistics/
87. http://computerworld.com
88. www.scei.co.jp/folding/en/
89. http://folding.stanford.edu/
90. http://www.boincstats.com/stats/project_graph.php?pr=cpdn&view=hosts
91. http://yodel.yahoo.com/2007/03/27/yahoo-mail-goes-to-infinity-and-beyond
92. http://www.amazon.com/gp/browse.html?node=16427261
93. www.dodccrp.org/publications/pdf/Alberts_Power.pdf
94. This idea of tapping into the collective intelligence of opinion of a broad audience is now often referred to as ‘crowdsourcing’—a play on the term outsourcing. A typical application for crowdsourcing, is citizen journalism, in which the public participates in the reporting process. New applications are arriving on a regular basis such as CrowdSpirit—http://www.crowdspirit.org/how-it-works. Many large vendors are also tapping into this phenomenon such as Dell Computers with their Idea Storm site—http://www.ideastorm.com/.
95. http://www.opensource.org/
96. http://www.laptop.org/en/vision/index.shtml
97. http://www.microsoft.com/middleeast/press/presspage.aspx?id=200718
98. http://www.developmentgateway.org/?goo=147
99. http://web.mit.edu/newsoffice/2001/ocw.html
100. http://ocw.mit.edu/OcwWeb/Global/all-courses.htm
101. http://oedb.org/library/features/how-the-open-source-movement-has-changed-education-10-success-stories
102. http://www.accelerationwatch.com/singtimingpredictions.html
103. http://www.forbesinc.com/newsletters/fgi/
104. The semantic web is an extension of the current web in which information is given well-defined and structured meaning, better enabling computers and people to work in cooperation. http://www.w3.org/RDF/Metalog/docs/sw-easy.html
105. http://www.darpa.mil/ipto/programs/pal/index.htm
106. http://www.proto-mind.com/
107. http://www.intelli-vision.com/
108. http://www.vigilos.com/article_04032006.html
109. http://www.newscientisttech.com/channel/tech/mg19526146.000?DCMP=NLC-nletter&nsref=mg19526146.000
110. http://www.newscientist.com/article.ns?id=dn6914
111. http://www.newscientist.com/article.ns?id=dn6924
112. http://www.kurzweilai.net/meme/frame.html?main=/articles/art0655.html
113. http://www.darpa.mil/grandchallenge/index.asp
114. http://www.scientificcomputing.com
115. http://www.kurzweilai.net/meme/frame.html?main=/articles/art0637.html
116. http://www.newscientist.com/article.ns?id=mg18624945.800
117. http://www.ric.org/bionic/
118. http://www.sony.net/SonyInfo/QRIO/top_nf.html
119. http://robots.stanford.edu/papers/thrun.icra_minerva.html
120. http://www.sciencedaily.com/releases/2004/03/040324071203.htm
121. http://motorcortex.huji.ac.il/research.asp#4
122. http://www.mdsupport.org/library/chip.html
123. http://www.nidcd.nih.gov/health/hearing/coch.asp
124. http://www.machinebrain.com/
125. http://www.sciam.com
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127. http://www.nasa.gov/vision/universe/roboticexplorers/robots_human_coop.html
128. http://www.irobot.com/sp.cfm?pageid=95
129. http://www.irobot.com/sp.cfm?pageid=109
130. http://www.isi.edu/robots/
131. http://www.sigmascan.org//ViewIssue.aspx?IssueId=302
132. http://www-bsac.eecs.berkeley.edu/archive/users/warneke-brett/SmartDust/index.html
133. http://www.cs.cmu.edu/~claytronics/
134. http://www.sigmascan.org//ViewIssue.aspx?IssueId=302
135. http://www.newscientisttech.com
136. Ibid.
137. http://www.gatech.edu/news-room/release.php?id=125
138. http://sbir.nasa.gov/SBIR/successes/ss/9-066text.html

139. http://www.news.cornell.edu/stories/Nov06/ResilientRobot.ws.html
140. http://www.rctoys.com/rc-toys-and-parts/DF-TANGORC/INDUSTRIAL.html
141. http://todbot.com/blog/category/roomba/
142. http://www.botmag.com/
143. http://www.newscientisttech.com/article/mg19325966.500?DCMP=NLC-nletter&nsref=mg19325966.500
144. Ibid.
145. http://www.designnews.com/article/CA6424936.html?nid=3198&rid=2052535400
146. Technology Development for Army Unmanned Ground Vehicles, Committee on Army Unmanned Ground Vehicle Technology, Board on Army Science and Technology, Division on Engineering and Physical Sciences, NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES, THE NATIONAL ACADEMIES PRESS, Washington, D.C. Copyright 2002 by the National Academies Press, http://books.nap.edu/openbook.php?record_id=10592&page=13
147. http://www.newscientist.com/article.ns?id=mg18624985.800
148. http://www.newscientisttech.com/article/mg19426006.800
149. http://www.technologyreview.com/InfoTech/wtr_16479,294,p1.html
150. http://www.smh.com.au/articles/2007/04/23/1177180526985.html
151. http://www.cio.com/article/107551?source=nlt_cioinsider
152. MVR is the first public ten-year forecast and visioning survey of 3D Web technologies, applications, markets, and potential social impacts. http://metaverseroadmap.org/
153. http://www.newscientist.com/article.ns?id=mg18625036.200
154. http://www.songdo.com/default.aspx
155. http://www.sciam.com/print_version.cfm?
156. http://www.jhsph.edu/publichealthnews/articles/2007/jacobs_lorena_mosquito.html
157. http://www.ornl.gov/sci/techresources/Human_Genome/elsi/gmfood.shtml

158 New lab tools, such as microfluidic lab-on-a-chip technology are maturing rapidly and promise to further accelerate existing biology fields and spawn entirely new subjects of study. For example, the study of biology is now subdivided into such areas as genomics (the study of genes and their functions) and proteomics (the study of proteins that genes encode).

159. http://www.labx.com/
160. http://www.nap.edu/catalog.php?record_id=11087#description
161. The CBRNE Research and Technology Initiative lead by DRDC is an excellent example of the proactive approach being taken by Canada. http://www.crti.drdc-rddc.gc.ca/en/default.asp
162. Ibid.
163. http://www.mrsc.org/Subjects/Governance/DemogOver.aspx
164. http://www.globalaging.org/health/world/2005/robot.htm
165. http://www.newscientist.com/channel/health/mg18825264.800.html
166. Nutrigenomics is the science of how food and ingested nutrients affect genes—particularly those related to disease prevention.
167. http://www.newscientist.com/channel/health/mg18825264.800.html
168. http://research.microsoft.com/ur/us/fundingopps/RFPs/eScience_RFP_2006.aspx
169. http://biology.plosjournals.org/perlserv/?request=get-document
170. http://parts.mit.edu/registry/index.php/Main_Page
171. http://www.nature.com/doifinder/10.1038/431624a
172. http://www.eetimes.com/news/latest/showArticle.jhtml
173. http://www.darpa.mil/sto/solicitations/SN07-20/index.html
174. http://www.neurosky.com/
175. http://humanitieslab.stanford.edu/2/290
176. http://www.biomed.drexel.edu/BioNano/
177. http://www.sciam.com/article.cfm
178. http://asdn.net/ngc2007/presentations/mamikunian.pdf
179. http://www.nano.gov/
180. http://chemicalvision2020.org/nanomaterialsroadmap.html
181. http://english.www.gov.tw/TaiwanHeadlines/index.jsp?categid=9&recordid=91955
182. http://www.afcea.org/signal/articles/templates
183. http://web.mit.edu/ISN/
184. http://www.afcea.org/signal/articles
185. http://www.cs.cmu.edu/~claytronics/
186. http://www.photonics.com/content/spectra/2006/July/tech/83278.aspx
187. http://www.nserc.ca/news/2004/p040311_bio3.htm
188. http://nint-innt.proteus.cisti.nrc.ca/main_e.html
189. Presently, while space tourism is a commercial reality, it is only within reach of the wealthy. Like most technology dependant endeavours however, it is only a matter of time before the costs reduce to a point where they begin to be within the reach of the middle class.
190. http://www.reuters.com/article/scienceNews/idUSN1742589120070417
191. http://www.virgingalactic.com/htmlsite/index.htm
192. http://www.technewsworld.com/story/57383.html

193. For example, researchers in California injected embryonic human cells into two-week-old fetal mice as they developed in the womb. When the mice matured, some human stem cells survived and became functional components of the mice's brains and nervous systems. http://news.nationalgeographic.com/news/2005/12/1214_051214_stem_cell.html

194. http://thomas.loc.gov/cgi-bin/bdquery/z?d110:SN00005:@@@L&summ2=m&

195. http://www.technewsworld.com/story/56853.html

196. http://www.transparency.org/global_priorities

197. http://www.nrdc.org/media/pressreleases/051019.asp

198. http://www.technewsworld.com/story/56458.html

199. http://www.technewsworld.com/story/56184.html

200. http://www.nytimes.com/2007/03/11/magazine/11Neurolaw.t.html

201. http://thomas.loc.gov/cgi-bin/bdquery/z?d108:s.01053:

202. Pierre-Paul Grasse introduced the concept of stigmergy in the 1950's to describe the indirect communication among individuals in social insect societies.

203. http://www.tsa.gov/datasecurity/b

204. http://blog.sciam.com/index.php?title=journals

205. http://colab.arc.nasa.gov/

206. http://colab.arc.nasa.gov/virtual

207. http://www.cio.com/article/107253/Why_You_Should_Collaborate

208. http://discovermagazine.com/2007/mar/radioactive-boy-scout

209. http://www.businessweek.com/innovate/content/jul2006/id20060713_755844.htm

210. http://www.technewsworld.com/edpick/56424.html

211. http://www.technewsworld.com/story/57041.html

212. http://www.boozallen.com/publications/article/29354647

213. http://www.taxpayeraccess.org/

214. http://www.popsci.com/popsci/how20/58c7db3c57f61110vgnvcm1000004eecbccdrcrd.html

215. http://www.technewsworld.com/edpick/57400.html .

216. http://blog.digg.com/?p=74

217. http://www.marketingterms.com/dictionary/viral_marketing/

218. http://drupal.org/node/60614

219. http://www.washingtonpost.com/wp-dyn/content/article/2005/07/06/AR2005070601953.html

220. http://m-trends.org/2005/11/mososo-wi-fi.html

221. Speaking at a conference in 2006, Sir David Brown, Chairman of Motorola, indicated that the mobile industry had no idea how successful they would become. He admitted that in the mid-1980s the mobile phone industry estimated that by the year 2000, there would be a market for about 900,000 mobile phones worldwide. At the turn of the millennium, he said, 900,000 phones were being sold every 19 hours.

222. http://www.darkreading.com/document.asp?doc_id=111595

223. http://www.unitedvillages.com/

224. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/769&format=HTML&aged=0

225. http://dndtalk.com/Joomla/

226. http://www.milblogging.com/result.php?country=Canada&mode=advance

227. http://canadian-forces.blogspot.com/

228. http://military.families.com/blog/category/357

229. http://www.csbaonline.org/4Publications/PubLibrary/R.20041201.RevInWar

230. http://www.csbaonline.org/4Publications/PubLibrary/R.20041201.RevInWar , P80.

231. http://www.holtzbrinckpublishers.com/academic/Book/BookDisplay.asp?BookKey=566248

232. http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=300303

233. http://www.spacedaily.com/reports/China_Launches_Compass_Navigation_Satellite_999.html

234. http://imagesat.pionet.com/?catid={38D9FD69-CE40-4E27-8F6D-85D35E50AFEF}

235. http://earth.google.com/

236. http://www.fastcompany.com/magazine/104/open-debate-extra.html

237. The enGauge 21st Century Skills were developed through a process that included literature reviews, research on emerging characteristics of the Net-Generation, a review of current reports on workforce trends from business and industry, analysis of nationally recognized skill sets, input from educators, data from educator surveys, and reactions from constituent groups. (http://www.metiri.com/features.html)

238. This list of 21st century skills is adapted from the enGauge 21st Century Skills study. http://www.ncrel.org/engauge/skills/skills.htm

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