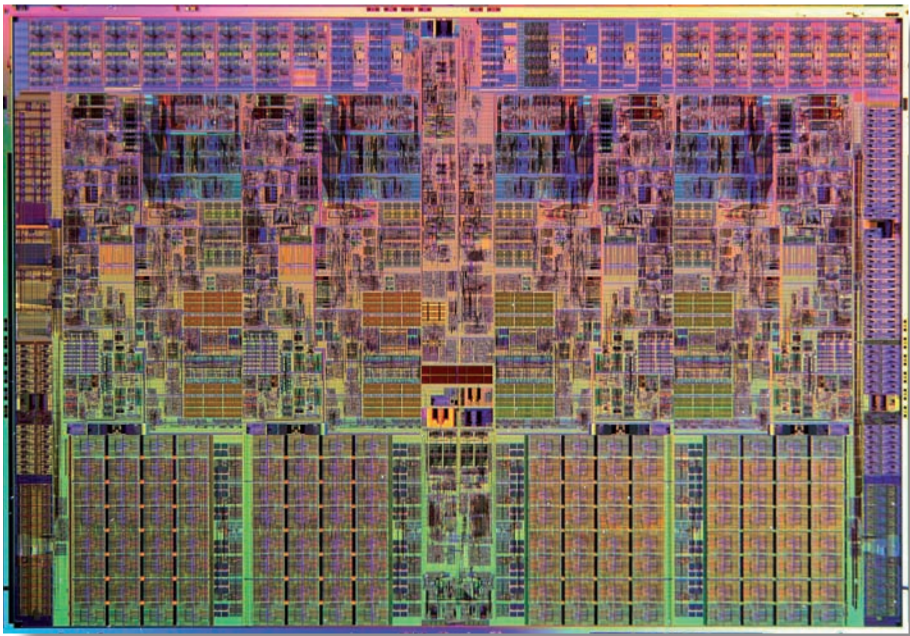
Impact of exponential growth laws in military systems

Dr Carlo Kopp

> An arguably bizarre situation has arisen through an irrational belief in the management circles of many organisations that exponentially growing IT/ICT obviates the need for smart, well educated and trained personnel.



Intel Core i7 Nehalem quad core processor chip die.

A DEFINING feature of the contemporary military computing environment is the direct and indirect impact of exponential growth laws, the best known of which is Moore's Law. Defined by Intel co-founder Gordon Moore in a 1965 paper, this law predicts that the density of computer chips will double every 18 to 24 months. Despite repeated predictions that Moore's Law would fail sooner or later, nearly a half century later it continues to hold. Whenever a technological obstacle appeared, engineers devised a way around it.

Positive Impacts of Exponential Growth Laws

There's no doubt exponential growth laws have produced valuable gains in military information processing and collection applications, also in military networking and sensor technologies. A contemporary radar system, electro-optical system or networking terminal will be more reliable, more sophisticated functionally, and often much more capable than its predecessors of one, two or more decades ago.

Abundant computing power has been especially valuable in military applications such as sensors, networking, navigation, embedded system management processing, weapon guidance, mission planning systems, simulators and databases. The declining cost of computing power has been a major enabler in many key areas, putting computationally demanding problems within easy reach.

Two good examples are Space Time Adaptive Processing (STAP) in radar, used to reject ground clutter, and Orthogonal Frequency Division Multiplexing (OFDM) used in commercial and military digital communications. STAP is now being deployed in a number of radar designs, Western and Russian, to improve the capability to detect small low flying targets, yet the technique was understood but out of reach for well over a decade, as computers of the time were not powerful enough to perform the computations in real time. OFDM is now the mainstay of broadband and digital television modulation, yet when it was devised four decades ago, only the fastest supercomputers of the day could perform the necessary calculations in real time.

Exponential growth in the performance of optical fibre communications has produced important gains in fixed military infrastructure bandwidth, but also internal cabling bandwidth in platforms such as aircraft or warships, where internal copper cabling historically often set hard performance limits on bandwidth between avionic or combat system components.

Vastly improved density and reliability in hard disks is seeing increasingly their use in embedded applications, but has also been of pivotal importance as an enabling technology in areas such as GIS, simulations and data mining. Petabyte databases for storing digital imagery, 3D GIS mapping data, publications and other high value data are now sufficiently affordable to permit much wider use of these valuable technologies.

Improvements in digital imaging chips have enabled important growth in imaging sensors where these operate in the visible colour bands, and can thus exploit exponential growth in commercial imaging products. Recent technology demonstrations such as the DARPA 1.8 Gigapixel ARGUS-IS imaging sensor would be simply infeasible without current commodity commercial digital imaging chips. Commercial high definition CCD or CMOS imaging chips have been used in reconnaissance and surveillance imaging products for almost a decade. Where an exponential growth law applies to a basic technology used or usable in a military system, as long the growth law holds, there will be a sustained period of improvement in the resulting capability. How useful that improvement is depends critically upon the capability in question, and what other factors influence or limit capability growth.

Negative impacts of exponential growth laws

While exponential growth laws have produced enormously valuable gains in many military applications, they have also produced numerous undesirable negative impacts, often producing disproportionate damage. A philosophical observation is that the technology itself knows nor cares about how it is used or abused. A related observation is that this reality has become the basis upon which anti-technology Luddites most typically argue against new technology.

The most widely accepted negative impact of exponential growth laws is early obsolescence of those technologies growing exponentially, as production life becomes ever shorter. This results in many military systems being in a permanent state of being upgraded, as components become unsupportable due to obsolescence of parts used to build them. While this can be planned for, the human dimension of the problem frequently results in a failure to do so, with resulting life cycle cost blowouts.

More importantly, the single biggest negative impact produced as a byproduct of exponential growths laws is a completely irrational and widely held belief amongst technologically illiterate managers, bureaucrats and planners that exponential growth laws apply universally to all technologies, and especially all military technologies. As a result, there has been a widespread abandonment of traditional physics and operational analysis based military and strategic planning in Western nations, as it is somehow believed that exponential growth laws will overcome the laws of physics and basic mathematics in all other areas.

Yet the material reality is that exponential growth laws cannot apply to any technologies in the ‘kinetic domain’ involving mechanical forces and physical mass in objects, and in the ‘information domain’ exponential growth laws simply do not apply to radio-frequency or optical apertures, as they do not apply to software algorithms.

The irrational belief in the ‘universality’ of exponential growth laws is paralleled by a related and no less irrational belief that the ever declining cost of exponentially growing basic technologies must be paralleled by an ever declining cost in all other technologies. Yet as empirically observable reality shows, the declining cost rule does not and indeed cannot apply either to ‘kinetic domain’ technologies, or non-exponential ‘information domain’ technologies such as radio frequency or optical apertures, or software algorithms.

One might argue that this negative impact is indeed not the fault of the technology but of the organisations that choose to employ technologically illiterate personnel in jobs demanding high levels of technological literacy. This argument inevitably leads to a chicken versus egg polemic over advanced IT/ICT equipment enabling the replacement of technologically literate personnel with illiterate personnel.

Technologically highly literate personnel are today much less employable than a decade ago, yet are far more needed now than ever before. An arguably bizarre situation has arisen through an irrational belief in the management circles of many organisations that exponentially growing IT/ICT obviates the need for smart, well educated and trained personnel.

A closely related problem is ‘information overload’ or ‘Information Fatigue Syndrome’, a now pandemic problem in developed nations characterised by management personnel at all levels being unable to make rational decisions as they try to cope with incessant bombardment with erroneous, deceptive or simply irrelevant data.

The latter itself is another most interesting and both unexpected/unintended consequence of an exponentially growing ability to digitally collect, store, process and rapidly disseminate vast volumes of data across military and civilian organisations and communities, nations and indeed the international community. The technology is transparent to the data being distributed, so fact or fiction, the latter intended or unintended, can be propagated at unprecedented speeds. The sad reality is that far more fiction is propagated than fact across the global IT/ICT infrastructure, evidenced by the less than palatable reality that often more than 90 per cent of electronic mail traffic entering mail server computers is unwanted spam.

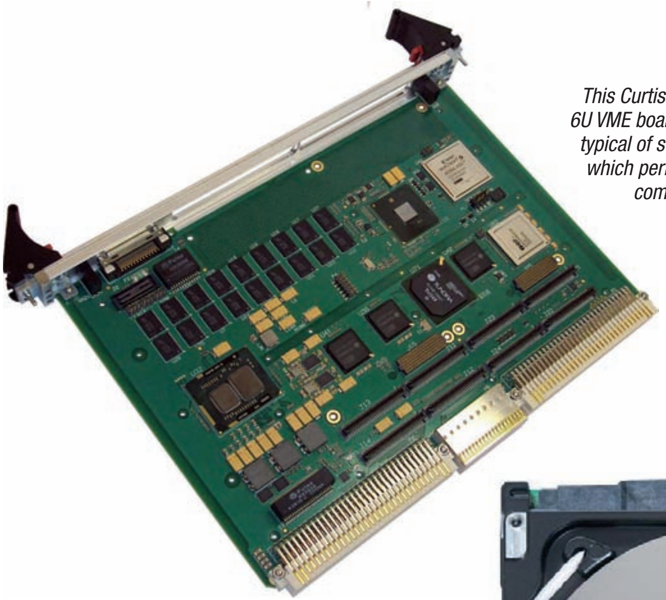
The increasing dependency of developed nations upon pervasive digital technology creates in itself a single point of failure vulnerability, as traditional human processing and handling of information and data is abandoned, and skills to do so lost and no longer taught. Whether damage is inflicted by human driven effects such as cyber warfare or electro-magnetic weapons or by ‘Mother Nature’ solar flares, the material reality is that exponential growth is creating in turn a growing vulnerability to the loss of the IT/ICT infrastructure, regardless of the cause of the loss.

Exponential Growth Laws and their Limitations

In assessing the impact of exponential laws on military and commercially developed systems an understanding of the relative exponential laws and their historical impact on technological capability and performance is essential.

Moore’s Law is one of a family of growth laws identified in recent decades, which define performance, capability in a range of different technologies.

Exponential growth laws are now producing pronounced effects, especially in any technologies where a large consumer market can support the research and development costs. Computer hardware of all persuasions, digital networking running over optical fibres and digital camera chips, have advanced dramatically in performance



This Curtiss-Wright Controls SVME/DMV-1905 6U VME board with an Intel Core i7 processor is typical of state of the art embedded hardware, which permits the insertion of unprecedented computing power into military systems.

This state of the art Seagate Momentus XT hybrid hard disk drive is an interesting example of Kryder’s exponential growth law in its 500 Gigabyte magnetic disk technology, Moore’s exponential growth law in its 4 Gigabyte DRAM cache, and mechanically limited head technology with a 4 millisecond access time, not significantly better than a 3.5 inch drive of a decade ago.

and capability over the past decade, a trend set to continue.

But many other technologies are not advancing exponentially even if there is a widely held expectation outside the science and engineering communities that these somehow should do so. Nature being what it is, some things can happen and others cannot.

Computer software is an area where the opposite trend has emerged, where ever increasing complexity of software systems often exceeds the gains of Moore's Law, resulting in a nett decrease in the performance of an application running on a piece of computing hardware. This observation was first attributed to famous computer scientist Niklaus Wirth, which essentially says that "software is getting slower more rapidly than hardware becomes faster."

A major limitation arising in computer systems is Amdahl's Law of parallel processing. Increasingly, we see a drift from computer chips with single processors (CPU) to multiple core designs, with two, four, six or more 'cores' on a single chip. Recent prototype chips have run to dozens or more cores. The idea is that many computing problems can be partitioned into multiple parallel problems, which can be then computed independently on multiple cores. Double the number of cores, double the speed, quadruple the number of cores, and quadruple the speed. While multiplying the number of cores can indeed produce a proportionate increase in computational speed for many problems, this is not generally true. Amdahl's Law states that speed-up depends more critically on what parts of the software have mutual dependencies that preclude concurrent computation than it does on the number of processing cores. For many basic computing problems, having a hundred processing cores may yield little speed advantage over the use of a single core.

The growth law for hard disks expresses limitations in exponential performance improvement. While the density of information storage on hard disks has increased markedly over the past decade the access time for data on hard disks has only improved two to three-fold in 20 years. Access time is determined by the mechanical rotational velocity of the disk and the time to mechanically move the magnetic transducer head over the rotating disk platter. So the time it takes to find a block of data on a current Terabyte disk drive may be 50 per cent shorter than what it took fifteen years ago to locate a block on a 300 Megabyte period disk.

Wireless radio frequency link performance is driven by the Friis Inverse Square Law, and by antenna performance by the ratio of antenna size to operating wavelength, both as a result producing little if any evolution in many respects since radio technology was introduced a century ago. A 10 GigaHertz band antenna dish with a gain of 20 deciBels will be no different in size today than it was 50 years ago. This hard physics limit in antenna technology is thus a hard constraint not only on radio networks but also on radars, radio-frequency and laser beam weapons, and any other technology which relies upon the transmission of a signal or power over a free space or an atmospheric path.

Another hard limit on achievable bandwidth in wireless radiofrequency channels, whether datalinks or radar, is spectral congestion, arising from ever increasing demands for spectrum used in mostly consumer applications. This has reached the point of forcing early obsolescence of military equipment such as radar and satellite links, where new equipment operating in different bands must be deployed. A more insidious problem is interference from adjacent bands, where cheap commercial equipment leaks transmissions into frequencies in which they do not belong. The latter is beginning to impact satellite navigation systems, and is a well established problem in shared consumer radio frequency bands.

Exponential density increases in monolithic microwave chips have not resulted in exponential growth in the performance or other capabilities of microwave electronics, although reliability has improved vastly, and cost has declined dramatically. This is because such chips handle microwave signals, and propagation physics in internal and external interconnections become a major limitation to performance growth. Power handling capability, i.e. on-chip cooling, has limited performance growth in computer chips, and also often sets hard limits on performance in microwave chips.

Limitations to exponential growth also apply to the performance of digital imaging systems, using an optical lens or mirror to focus an image on to a CCD or CMOS technology imaging chip, as observed in digital cameras, webcams, camcorders and cellular phones. We are now at the point where the spatial bandwidth, a measure of how much information such a system can capture in an image, is mostly limited by the sharpness of the lens or mirror optics, not the number of Megapixels in the imaging chip. While professional camera lenses are still ahead of imaging chips in bandwidth performance, in consumer devices the imaging chip bandwidth outstripped lens performance some years ago, with consumers paying for Megapixels that are effectively unused. A 10 Megapixel imaging chip with a suitable digital processor can today outperform all but the largest format wet film imaging technologies, in dynamic range, colour accuracy, and noise (grain) impairments.

The vast improvements seen in visible band imaging chips have not been observed in military thermal imaging chips, in part due to the difficulties in manufacturing with exotic materials, and in part due to the high development costs during a period of collapsing military research and development budgets.

Conclusion

The pervasive nature of modern digital technology has produced some genuine and deep problems at the human end of the equation, mostly as byproducts of a prior failure to properly educate, train and staff organisations, itself a result of a failure to understand or anticipate the impact of exponential growth laws. Clearly most of these problems can be corrected by properly staffing organisations with personnel who are trained to think critically and understand the limitations of exponentially growing technologies. The biggest challenge is not however in the implementation of corrective action, but in gaining acceptance that action is even required!

Optical imaging chips may well be growing in resolution exponentially, but the optical apertures used, such as lenses, do not. While the professional lens on this digital camera outperforms the 12.3 Megapixel camera body, it would be inadequate in sharpness for a future 120 Megapixel camera body.

Antennas, whether used for radar or communications, neither shrink nor improve in performance exponentially, as they are limited in performance growth by radio physics and the cooling capability of the carrying platform.