INFOTRONICS IN A GLOBAL KNOWLEDGE-BASED ECONOMY

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"*It is now taken to be self-evident that a world-class society of the new millennium must have as its underpinning a world-class computing and network infrastructure.*"

Congressman Curt Weldon
Chairman, House Armed Services Committee Subcommittee on Military Research and Development, United States Congress, 1996

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1. INTRODUCTION

While scientific/technological research and development (R&D) are often lumped together, they are actually quite different. Research makes basic knowledge breakthroughs, and deepens it. Development expands existing technological knowledge, and widens knowledge. Between "R" and "D", there is applied research, where basic science is in place but some engineering breakthroughs have to take place to implement empirically what is already known.

One of the greatest scientific discoveries in the 17th century, which received relatively little public attention for about two hundred years, was the finiteness of the speed of light. The person who made this discovery was a Danish astronomer Olaf Roemer,[1] a contemporary of the great Sir Isaac Newton, who discovered the universal law of gravitation. One can easily reason that this discovery and measurement of the speed of light, unlike the universal gravitation law,

[1] Philosophical Transactions, June 25, 1677.

received little attention among the non-scientific community because scientists for the following two hundred years could find little or no use of this information for the betterment of mankind. This is basic research.

This situation changed between the middle and late 19th century when mankind began to understand electromagnetic behavior. The entire body of the knowledge of electromagnetism (a unification of electric and magnetic fields) was elegantly and succinctly embodied in Maxwell's equations. After electromagnetic theory had been further developed and breakthroughs in applied research accomplished, new devices such as telegram and telephone were invented. For the first time, mankind was able to transform the abstract concept of the speed of light to enhance communications and fundamentally influenced the style and living standards of humans.

Scientists in the 20th century made two startling understandings of nature: one is the world of ordinary matter at extremely high speed: the Einstein's theory of relativity, and the other the dynamical laws governing the behavior of the extremely small world, the quantum theory. Once again, while the theory of relativity was an unparalleled intellectual feat, its full utilization in assisting mankind to enhance communication and computer speeds has thus far not been fully realized. In contrast, quantum theory, together with advances in electromagnetic theory, has sparked one of the greatest technological advances.

At the beginning of the 21st century, mankind witnessed a technological revolution in information technology. For example, What computers can do today in one second is equivalent to what the first computer could compute, merely five decades ago, in more than a thousand years. It is not within the realm of possibilities for medical experts in a big city, such as Philadelphia, to diagnose patients in a rural district, such as the remote areas of Pennsylvania. And for the children of herdsmen in the plains of Inner Mongolia to be able to attend "on-line" schools with their teachers via satellite in another continent.

In the new millenium, one cannot help but to recognize that computer and telecommunication, which have permeated all aspects of our lives, will bring in many other new gizmos. Concurrent developments in other areas such as biotechnology and healthcare will also benefit from these technological breakthroughs.

This article intends to discuss this revolution and the economical impact. We shall begin with forms and functions, the elements of the architecture of information.

2. FORMS, FUNCTIONS AND INFRASTRUCTURE

Form and function are the essentials of information architecture. Form is the information shape and structure, and function refers to activities performed. Most information in our knowledge-based economy can be classified into four different forms and four distinct functions, as shown in Table 1. The terms are self-explanatory, and there is a strong overlap from one form (function) to another. This table displays the interplay between the forms and functions.

This simple information matrix provides entrepreneurs and managers a roadmap to the information technology. Indeed, many successful businesses which use this as a navigation compass.

Table 1. Form and function are the essentials of information architecture.[2]

FUNCTIONS FORMS	Generation (G)	Processing (P)	Storage (S)	Transmission (T)
Data (D)	(D,G)	(D,P) Computers started here	(D,S)	(D,T)
Text (T)	(T,G)	(T,P)	(T,S)	(T,T)
Sound (S)	(S,G)	(S,P)	(S,S)	(S,T) Telephones started here
Image (I)	(I,G)	(I,P)	(I,S)	(I,T)

2.1. TYPES OF FORMS

The forms: data, text, sound, and image, are all mental impressions that we perceive through the senses. To date, in our current knowledge-based economy, sight (video) and hearing (audio) or combinations thereof (television, movies) are the most dominant.

2.1.1. Data

The term data used here connotes a wider sense than its usual meaning. Data are any or all the facts, numbers, letters, symbols, and the like, that can be processed or produced by a "processor". Data existed before processors, but it is the ability of processors to handle data that led to the information economy. When text, sound, and images are reduced to binary codes of "0" and "1" in a machine, they become data.

2.1.2. Text

Text is any written language, to distinguish it from spoken language (dialect) which technology simply treats as a form of sound. Though text is normally referred to as machine-printed language exclusively, our current technology has made it possible for machines to recognize hand-written text (for example, signatures and hand written notes). Thus, the term text used here includes text written by hand, or printed by machines.

2.1.3. Sound

Sound is what we hear. We basically hear voice and music. Radio, telephone, records and tape recorders are inventions we use to handle this information. For some time, these inventions were

[2] Stan Davis, and Bill Davidson, "2020 Vision", Simon & Schuster, New York, 1991.

in separate sectors. In our current economy, they merge. For example, we have DVD (digital video device) or we can digitize audio messages for transmission over the Internet.

2.1.4. Images

Images are visual forms. They can be photographs or paintings, artistic or practical, realistic or interpretive, presentations or representations, impressions or expressions. Scanned text or data are treated as images. Thus, fax, copier, printer and scanner are four separate machines performing essentially the same task. These days we see that they are merged in 5-in-1 multifunctional center (MFC) or fax/printer/copier/scanner/pc fax.

2.2. TYPES OF FUNCTION

Basically, we do four things with information: generate, process, store and disseminate. The way is now paved for discussions of the four distinct functions:

2.2.1. Generation

This function takes information (data) that exists in the environment and captures it for presentation in one of the four forms. For example, an abacus captures numbers of an accountant and generates a ledger (data or text). A typewriter captures the words (or thoughts) of an author and generates a book (text). A recording device captures singer's voice and generates a record, tape or CD. And a camera captures the image of a landscape to generate a photograph. Essentially, generation means digitization, or rearranging into "bits". Once digitized, all forms can be handled in subsequent functions as though they are the same. We shall return to digitization in a following subsection.

2.2.2. Processing

Our current computer technology started in data and word processing to cover all forms of processing including audio and image processing. The processing function converts, edits, analyzes, computes, and synthesizes. In this respect, computer hardware is a processor, and software is the set of rules by which gathered information is to be processed.

2.2.3. Storage

The third function takes information in one of the forms, and keeps it for later use. In the time of the Pharaohs, text and data were stored on tablets (e.g. Rosetta Tablet). The Chinese invented paper for the purpose of storing. In today's acronymic, these storage processes are very static, or ROM (read-only-memory). Storage in the electronic age not only covers sound and images, but is also dynamic. We can retrieve a word document and make changes. Thus, storage today is not only about space, but it can also be interactive.

2.2.4. Dissemination or Transmission

Simply put, the fourth function is sending and retrieving all forms of information from one point to another. Whereas storage transfers information across time, transmission moves it across space. This fourth function is "distribution", which includes broadcasting, switching, networking, reception, signal processing, collection, and display. While computers dominate the first three functions - generation, processing and storage- telecommunications excel in transmission.

Simple transmissions, such as books, telephone and TV, convey voices and message as is. Modern telecommunications networks, however, "value add" by combining the other functions with transmission capabilities. These are the fundamentals of a communications network: many computers all linked together, from high performance computers, through desktop workstations and personal and laptop computers, down to the smallest, dumbest terminals or hand-held palm pilots. They are LANs (Local Area Networks) or WANs (Wide Area Networks). When values are added, they are VANs (value-added networks).

2.3. DIGITIZATION

The important thing to note is that linkages are constantly emerging between and across forms. In our current technology, the linkages arise from digitization.

Recording technology provides us with a very straightforward example. In 1877 Thomas Edison pioneered a form of analog sound recording. To record a sound, a membrane in a microphone is used to copy that wave onto some surface. To replay the sound, a needle is forced through the groove created by the recording process. This needle is attached to another membrane in a speaker. When the speaker membrane vibrates, the membrane sets nearby air molecules into oscillations and the original sound wave is recreated. The process is entirely analog. No numbers are involved, the process is completely mechanical, and there is infinite precision, but very limited accuracy and much room for error in the sound recording and reproduction process. Compact disk technology uses digital means to record and play sounds. The sound waves are read by a computer which analyzes each instance of the sound, and assigns it a numerical value. When the music is played back, it goes through another computer, which retranslates the numbers into the sounds that the numbers represent. Since they are recorded at such frequent tiny intervals, the lack of precision is not a problem, and we find digitally recorded music more accurate.

The above is, but one example. Because of digitization, linkages across forms emerge constantly. Industries for decades not related to each other suddenly find themselves in the same sector, and with it comes a redefinition of competitors. Thus we see Silicon Graphics Computer Systems (started as a graphics computer company) swallowing up Cray Computers (a number crunching supercomputer company), AT&T acquiring Digital Cable Network, Napster Inc. using MP3 technology to change the landscape of music industry, and other examples.

2.4. INFORMATION INFRASTRUCTURE

Before forms and functions can interact, we need another element - infrastructure - the scaffold of information technology.

Infrastructures in any economy are the elementary network that are put in place first, and upon which all subsequent economic activities depend. Real estate developers, for example, first put in infrastructure of roads, dams, sewage, electricity, and the like so the communities of homes and businesses can follow. Each economy in history has relied heavily on a particular type of infrastructure, one that is peculiar to the technology of the era.[3] The railroad, for example, was critical for the development of America in the 19th century. The spectacular growth of automobile industry between 1920s and 1940s prompted the building of interstate highways of the 1950s. The info-structure (such as satellites) is now driving our current information-based economy.

We will now take a *tour de horizon* of the development of the current computer and telecommunications technologies, using Table 1 as a tour guide. We shall begin with the development of computers and networks.

3. SCIENCE AND COMMUNICATIONS

The computers and networks have had their effects on all forms of human activities, from the most basic to the most advanced forms of education, in commerce and industries, in medicine and hospitals; from small to mega-scale engineering projects. Referring to this fact, one of the prime movers of science and technology in the US Congress, Congressman Curt Weldon, said in 1996 that "it is now taken to be self-evident that a world-class society of the new millenium must have as its underpinning computing and network infrastructure."

3.1. COMPUTERS

To appreciate the extraordinary developments of computers and networks in the past century, one needs only to examine the short history of computers. Mankind has used mechanical means to assist in computations, from the early Chinese abacus to the more recent mechanical calculators. The very first electronic computer, with vacuum tube technology, was invented by a group of dedicated engineers from Ursinus College from suburbia Pennsylvania and the University of Pennsylvania.[4] The machine, operational in 1946, was named ENIAC (Electronic Numerical Integrator and Computer) by its inventors. As we can see from Table 2, ENIAC was bulky, pitifully slow by today's standard (340 floating points operation per second, or flops) and has exceedingly limited storage space (approximately 3000 bytes). However, it is generally hailed as the machine which ushered mankind into the wondrous world of modern electronic computations.

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[3] Lester C. Thurow, "Building Wealth: The new rules for individuals, companies, and nations in a knowledge-based economy", HarperCollins Publishers, New York, 1999.
[4] Dilys Winegrad, and Atsushi Akera, "A short history of the Second American Revolution", http://www.upenn.edu/almanac/v42/n18/eniac.html

The ENIAC Project is at the top of the applied research totem pole as the Manhattan Project.

Table 2. A brief history of computer speeds.

Machine	Year	Speed (flops)	Memory (bytes)
ENIAC	1946	0.36K	3K
IBM704	1954	12K	32K
CDC6600	1966	4,600K (4.6M)	
CRAY-1	1976	50,000K (50M)	8,000K
CRAY X/MP	1983	166,000K (166M)	32,000K
ETA-10	1990	1,000,000K	
CM2 (64K nodes)	1991	1,000,000K (1G)	
Intel Paragon (128 nodes)	1991	10,000,000K (10G)	
IBM Sp-2 (64 nodes)	1994	17,000,000K (17G)	
P6/Sandia (9072 nodes)	1996	1,200,000,000K (1.2T)	

1 K (Kilo) = 10^{3}, 1 M (Mega) = 10^{6}, 1 G (Giga) = 10^{9}, 1 T (Tera) = 10^{12}.

Also evident in Table 2 is that both the speed and storage space, the two benchmarking parameters of computers, increased rapidly since 1946. Indeed, in the late 80's, the pace further accelerated when computer architecture went from a single central processing unit (CPU), or a node, to the massively parallel multi-nodes. In fact, the very latest P6/Sandia is designed to have the peak speed of about 1.2 Tflops.[5] This means that an ENIAC has to run continuously for nearly a millennium (1000 years) before it can produce what the P6/Sandia can compute in a mere second! In fact, development is now well underway to increase the speed to peta-flops (10^{15}). Never before in human history has the power of computations increased by 10 to 13 orders of magnitude in such a short time. It is no wonder that computers have utterly transformed the way humans operate within the society.

In the form-function matrix, the development of early computers will correspond to the entry (D,P). The computers were primarily for number crunching.

3.2. NETWORKS

As seen in Table 2, around the late 80s, there was a transition of computer architecture: from single node machines, such as the CDC6600 to the massively parallel machines such as the P6/Sandia with 9000 nodes. A salient feature of parallel architecture is the use of fast internal switch, which is technically a link, or network, between processors. As a rule of thumb, the

[5] For the world's top 500 supercomputers as of June 2000, please see http://www.netlib.org/benchmark/top500/top500.list.html

bottleneck of speed of computation is I/O (input/output) of the internal links between nodes, since however fast each node can be, the ultimate result depends on the rate of data transfer between nodes. Internal links thus by necessity have to be exceedingly fast, usually of the order of transferring data at the rate of 900,000,000 bit/second. Since they are embedded in commercial machines, its design is usually proprietary.

Table 3. Network hardware and speeds.

Hardware	Transmission Rate
Modem	14.4 or 28.8 Kb/s
T1	1.5Mb/s
OC3	155Mb/s
OC12	622Mb/s
Fast Internal Switch	900Mb/s
OC48	2.5Gb/s
ATM	5Gb/s

The early network development was primarily for transmitting data, or the development corresponds to entity (D,T) in the form-function matrix.

Concurrently, in the past decade, long distance network has also been developed rather rapidly. For example, the standard modem used everyday in many homes can transfer data at the rate of 14.4, 28.8, 33.6 or 56 Kb/s. While these may be slow compare to the fast internal switch, it has certainly been the workhorse in proliferating electronic mail of everyday life. Recently, commercial networks are now using the more advanced OC3 and OC12 lines, which can transfer data up to 155 to 622 Mb/s, respectively.

Development of network will surely have profound impact on global economy and education. For example, teleconferencing is now gaining momentum in industries, universities, and health care facilities. Already it is quite common for large multi-national corporations to conduct intercontinental business meetings via teleconferencing. By the same token, a number of universities on both sides of the Pacific Ocean, such as MIT and the National University of Singapore are offering mutual courses via this teaching mode. It is not inconceivable that in the near future, this mode of communication may just induce fundamental infra-structural reorganization of universities of today. In fact, it is obvious that universities which do not keep abreast with technological advances will not be able to compete in the long run. A reason why University of Phoenix,[6] the largest private university, is growing so rapidly is because it does not maintain a regular teaching staff, nor does it maintain libraries. All reference materials are online.

3.3. DATA STORAGE

Another important aspect of computer and network infrastructure is the storage of data. We see from Table 4 that there are great differences in storage capacity for various types of storage infrastructure.

[6] http://www.apollogrp.com. University of Phoenix is now a publicly-traded enterprise and has now expanded overseas, including China.

Table 4. Data storage capacity.

Hardware	**Storage Capacity**
Standard Floppy diskette	1.44Mb
Iomega Zip disk	100Mb
Standard CD-ROM	600Mb
2 GB Disk	2Gb
Pittsburgh Supercomputing Center	200 Tb

By way of comparison, the latest so-called data engine, which is designed to store up to 30 terabytes of data, is equivalent to having FIFTY THOUSAND 600-Megabytes CD-ROMs.

With the rapid improvement in data storage capacity, we have moved from a data-restricted environment into one overloaded with data. In this environment, information is limiting and often obscured by the vastness of the data.[7] We can see this by comparing and contrasting data with information:

Table 5. Data versus information.[8]

Data are…	**Information is…**
Stored facts	Presented facts
Inactive (they exist)	Active (enable doing)
Technology-based	Business-based
Gathered from various sources	Transformed from data

It is derived information and knowledge that are of commercial value. In analogy to real mining, in which miners are usually required to sift through a large amount of dirt to extract the metals of interest, the same is true with data. The extraction process, is appropriately called "data-mining".

Data storage capacity has already had profound effects in our daily lives. For example, one of the largest department stores in the United States, Wal-Mart, spends up to 50 million dollars per year for storing, updating and retrieving its vast amount information of its inventories in all its outlets throughout the country.

4. MARKET DICTATE VERSUS SCIENTIFIC LAWS

We took a tour de force of the development of computer and ended with the microchips in the computers. We see that in "supercomputers", the workhorse is a cluster of microchips. These microchips are the same microchips that we find in many of the gizmos and gadgets we are using.

Advances in computing would not have been possible without the concurrent advances in the chip technology. In 1965, the world's most complex chip had 64 transistors. In October 1999,

[7] Hwa A. Lim, "Bioinformatics and Cheminformatics in the Drug Discovery Cycle", In: Lecture Notes in Computer Science, Bioinformatics, R. Hofestaedt, T. Lengauer, M. Loffler and D. Schomburg (eds.), (Springer, Heidelberg, 1997), pp. 30--43..

[8] Bernard H. Boar, "The Art of Strategic Planning for Information Technology", John Wiley & Sons, New York, 1993.

Pentium III has 28 million transistors. This sustained explosion of microchip complexity has no parallel or analogue in other human experience. It does, however, seemed to obey one empirical law.

4.1. MOORE'S LAW

Everyone in the computer industry has heard of Moore's Law. In contrast to the form-function matrix, Moore's Law is a daunting dictate to which engineers and marketers have rigidly adhered for decades. It states that microchips will double in power and complexity and half in size at roughly eighteen-month intervals.[9] As can be seen in Figure 1, it has been an uncannily accurate prediction. The effect of Moore's Law is also obvious: it explains why today's $3,000 PC will cost roughly $1,500 next year and be obsolete soon afterwards.

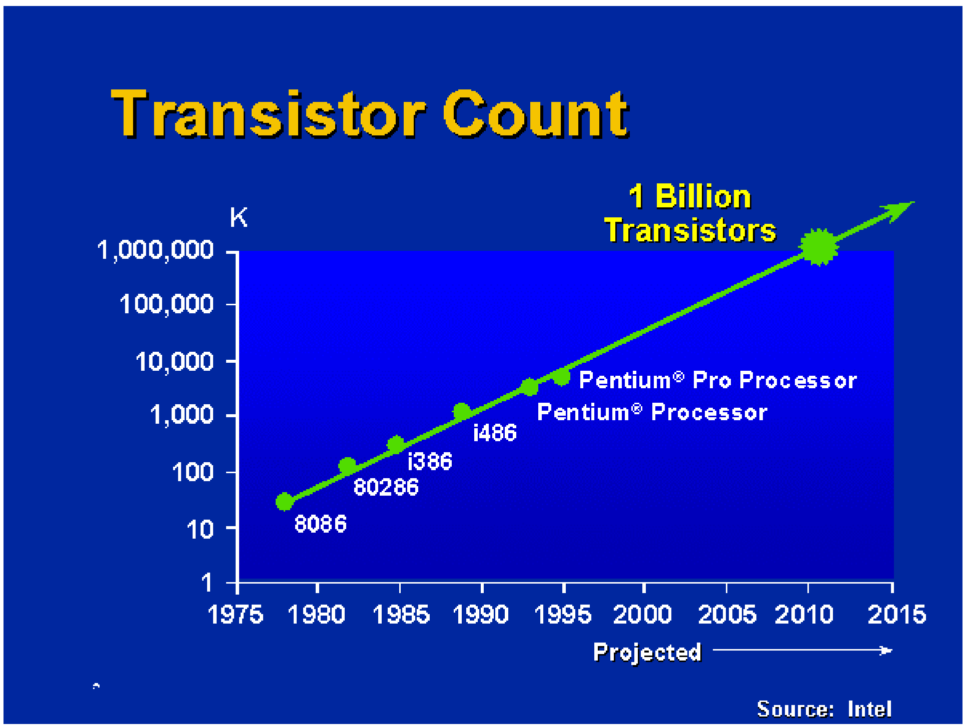

Figure 1. Verification of Moore's Law. It is interesting to note that Moore was one of the founders of Intel, from which the data for this chart was obtained.

Put in another form, in terms of natural occurring living CPU, Moore's Law is as shown in Figure 2.

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[9] Charles C. Mann, "The end of Moore's Law?", Technology Review, May/June, 2000.

4.2. THE FALL OF MOORE'S LAW

As we see above, in the microchip industry, if one thinks big, one is doomed. Size does matter, and miniaturization is the rule of the game!

As a market-based order to a manufacturing team, a business cliché, Moore's Law is not a scientific law. As such, it can only function until a certain point of limited return is reached. The limits are based on the fundamental realities of the nature of matter and energy, over which engineers and marketers have no control. As circuits are reduced in size, the wires carrying electrons get more closely packed, and insulation become an issue because electrons and their associated magnetic fields begin to mutually interfere with each other. This causes low conductance, signal noise, and lower efficiency, while increasing the power needed to send an appreciable signal. If signal integrity and amperage are to be maintained, soon the half/double innovations will come to a halt. How soon we will hit this wall, the belief is anywhere from 5-15 years.

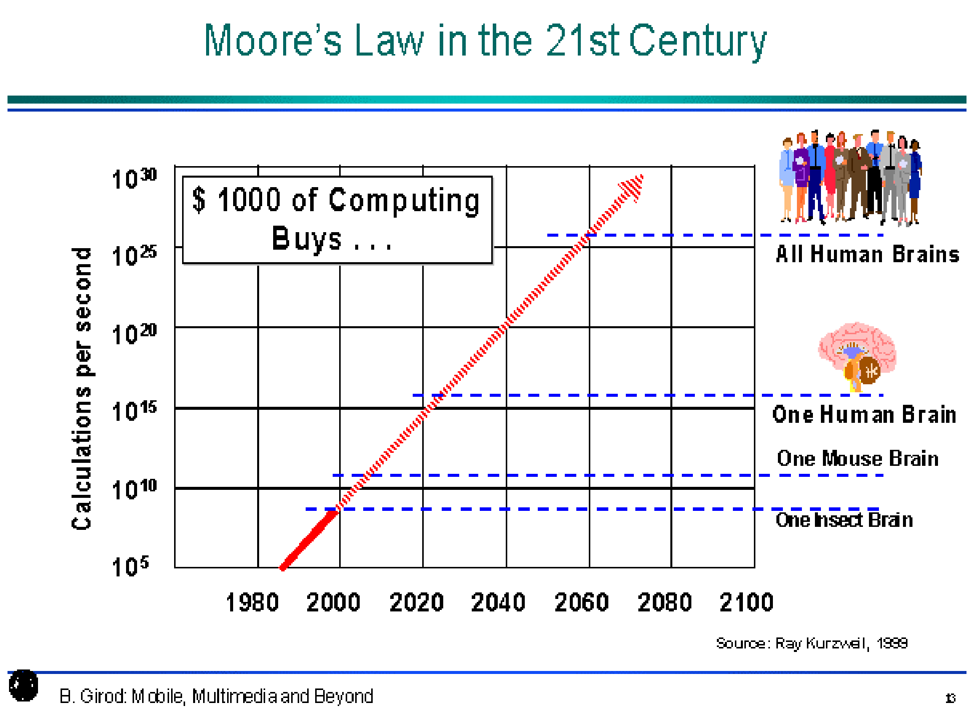

Figure 2. Moore's Law in terms of brains CPUs.

The end of Moore's Law has been predicted so many times that it has become an industry joke. The current alarm, as stated above, is different. Squeezing more and more devices onto a chip means fabricating features that are smaller and smaller. The industry's newest chips have pitches as small as 0.2 micron, or about 400 times thinner than a human hair.[10] At this level, there are three main challenges. First, the use of dopant impurities mixed into silicon to increase its

[10] Joshua C. Ramo, "Two dazzling technical advances promise to fuel the computer revolution", Time, Vol. 150, No. 14, October 6, 1997.

stability to hold areas of localized electric charge can be an issue. Although transistors can shrink in size, the smaller devices still need to maintain the same charge. To achieve that, the silicon has to have a higher concentration of dopant atoms. Unfortunately, beyond a certain limit, dopant atoms begin to clump together, forming clusters that are electrically inactive. Today's chips are very close to the limit.

The second challenge is related to the first. When microchip components were larger, fluctuations in dopant concentration had little effect. In the newest chips transistors are so small that they can end up in dopant-rich or dopant-poor areas. These fluctuations can cause undesirable effects.

Third, the gates controlling the flow of electrons in chips become so small that they are affected by quantum effects. Chip gates are now smaller than 2 nanometers, small enough for quantum tunneling to occur. Gates are supposed to block electrons, and if tunneling occurs, it renders the gates useless.

These are physical limits and roadblocks at the most fundamental level. Ultimately, engineering and processing have to save the day.

4.3. DEFYING MOORE'S LAW

Aluminum has been the material of choice in chip circuitry for more than 30 years although copper is known to be a superior conductor. Most chips of today contain transistors of 0.3 microns. But as transistors get smaller in size, to 0.2 microns, the inefficiency of aluminum at conducting electricity inhibits a chip's circuit from moving fast enough.

Experiments using copper has been unsuccessful because copper bleed into the silicon, contaminating the chip. Another problem is more subtle: a wire that is 0.2 micron wide is so thin that once manufactured, one cannot touch it. So instead of trying to roll tiny wires onto silicon chips, engineers lay down a thin sheet of metal and etch away everything they do not need. What is left are microscopic paths of metal just wide enough to conduct a current. While chipmakers have developed ways to etch aluminum, no one had yet figured out a way to etch copper.

After a decade of experimenting with copper, IBM has perfected a way of using copper without having it bleed into silicon.[11] They have invented a special coating that rests between the copper and the silicon. They also perfected an etching technique that will not only work with copper, but will take chipmakers all the way down to 0.05 microns! Smaller chip sizes means that IBM's advances will bring copper-based chips to such devices as handheld computers, cellular phones and the process for all kinds of semiconductors.

Concurrently, Intel has developed a breakthrough technology in memory chip that will double the data storage capacity of each memory cell in a flash memory chip. This advance will affect

[11] "Defying Moore's Law", PC Magazine Online, September 22, 1997.
http://www.zdnet.com/pcmag/news/trends/t970922a.htm

all flash-memory-based devices such as portable computers, video games, cellular phones. Because of the increased memory, these smart devices will be smarter.

5. THE WEBOLUTION

In a sense, the Web has its origin all the way back in medieval times when a rich system of cross-referencing and marginalia was developed.[12] The most basic model was to set text and graphics on a page and cross-references are made to other works, like the footnotes we use in this article.

In the 1940s, Vannevar Bush described a computer aided hypertext system he named the *memex*. His vivid description of browsing the Web of linked information includes the ability to easily insert new information to add to the growing web. Bush was then Director of the US Office of Scientific Research and Development, and coordinated wartime research in the application of science to war.

After the war, the Web further developed. Douglas Engelbart, who founded the Augmentation Research Center at the Stanford Research Institute (SRI) in 1963 is widely credited with helping develop the computer mouse, hypertext, groupware and many other seminal technologies. Ted Nelson has spent his life promoting a global hypertext system called *Xanadu*. He coined the term *hypertext* and is well known for the books *Literary Machines* and *Dream Machines*, which describe hypermedia including branching movies. Following a workshop on hypertext held in 1987 in Chapel Hill, North Carolina, SIGLINK was formed in 1989. The ACM SIGWEB, successor of SIGLINK, has for many years been the center for academic research into hypertext systems by sponsoring annual conferences.

In 1985, Xerox released *NoteCards*, a Lisp-based hypertext system. This was followed by the OWL Guide, the first professional hypertext system for large-scale applications, in 1986. Bill Atkinson, best known for *MacPaint* (the first bitmap painting program), gave the world its first popular hypertext system *HyperCard* in 1987. HyperCard made it easy for anyone to create graphical hypertext applications. It features bitmapped graphics, form fields, scripting and fast full text search. HyperCard is based on a stack-of-cards metaphor with shared backgrounds. It spawned imitators such as Asymmetrix Toolbook which used drawn graphics and ran on the PC.

In 1989, Tim Berners-Lee and Robert Caillau at CERN, an international high energy physics research center near Geneva, collaborated on ideas for a linked information system that would be accessible across the wide range of different computer systems in use at CERN. At that time many people were using *TeX* and *Postscript* for their documents. A few were using *SGML*. Tim realized that something simpler was needed that would cope with dumb terminals through high-end graphical X Windows workstations. HTML was conceived as a very simple solution, and matched with a very simple network protocol HTTP. CERN launched the Web in 1991 along with a mailing list called www-talk. Other people thinking along the same lines soon joined and helped to grow the web by setting up Web sites and implementing browsers, such as, Cello, Viola, and MidasWWW. The breakthrough came when the National Center for Supercomputer

[12] Shahrooz Feizabadi, "History of the World Wide Web", http://ei.cs.vt.edu/~wwwbtb/book/chap1/index.html

Applications (NCSA) at Urbana-Champaign encouraged Marc Andersen and Eric Bina to develop the X Windows *Mosaic* browser. It was later ported to PCs and Macs and became a run-away success story. The Web grew exponentially eclipsing other Internet based information systems such as WAIS, Hytelnet, Gopher, and UseNet.

The number of web sites grew from basically zero in 1993 to 100,000 in December of 1995, and to over 1,000,000 by December 1998. Web revolution has already proven itself to be bigger than the PC revolution. Java, Netscape did not exist before 1994. Now dot-com guys are all over the place.

6. ECONOMICAL IMPACT

Alan Greenspan is notoriously cagey when he speaks in public, especially he speaks on the future of US economy. He would normally envelopes himself in sentences so long and intricate that even the Wall Street Journal cannot quote them in their entirety. However, when it comes to information technology, he is very explicit, "The rapid acceleration of computer and telecommunication technologies can reasonably be expected to appreciably raise our productivity and standards of living in the twenty-first century".[13]

There is no doubt that the US is experiencing the longest economic boom since the 1850s, when the federal government first began collecting economic statistics systematically. The current blend of steady growth and low inflation is so unusually favorable that many economists believe the country is experiencing fundamental changes.

The US monetary policy is guided by a simple and longstanding bit of economic logic: Over the long run, the economy can sustain a growth as fast as the growth of the labor force, plus the rate of productivity improvement. The labor force has been increasing at a rate of 1% per annum, and productivity, as officially measured, has been increasing by a similar amount. However, in the current economic boom, the economy grew by 4.3%, with barely a hint of inflation! Have computers and telecommunications raised our productivity level more than we had anticipated?

Some economists, including Robert Gordon of Northwestern University, believe that "the recent acceleration in productivity is at least half due to the improvements in computer productivity". In other words, the Clintonomic boom is a reflection of Moore's Law. If Gordon is right, it is rather ironical that just as economists are beginning to grasp the significance of Moore's Law, engineers are beginning to worry Moore's Law petering out.

6.1. IN RETROSPECTIVE

After World War II, US experienced decades with productivity growing at an average of about 3% per annum. This is tantamount to saying the standard of living doubled every generation. In early 1970s, productivity suddenly stunted to 1.1%. The result was stagnation. The

[13] Alan Greenspan, "Remarks before the National Governors Association", Feb. 5, 1996, pp. 1.

unproductive 1970s and 1980s were years of inflation, recession, unemployment, social conflict and economic budget deficits.

When Moore's Law started to become a market dictate of the microchip industry, the US, drawn by rapidly improving products and rapidly falling prices, started to invest heavily on computers. Spending on computers has risen in the past twenty years at an average annual increase of 24%. For instance, in 1999 US companies spent $220 billion on computer hardware and peripherals, more than any other durable equipment. Computers became so ubiquitous that the nation was in a "digital revolution". Throughout the 1980s and the first part of the 1990s the huge national investments in digital technology seemed to have no payoff. Moore's Law seemed to have boosted profits for chipmakers but everyone else. Robert Solow, the MIT Economics Nobel Prize Laureate, is known to have remarked in 1987, "We see computer age everywhere except in the productivity statistics." This puzzle, huge expenditures with little payoff became known as the productivity paradox.

The pendulum swung in 1995. Without any fanfare, it abruptly began rising at an annual average of 2.2%. According to Alan Blinder, a Princeton University economist, "In the mid-90s, the rate of computer deflation moved from minus 10% per annum to minus 25%. And although computer industry is a small fraction of GNP - less than 2% - the drop in costs has been so severe that as a matter of arithmetic it knocks a noticeable piece of the overall price index." According to economist Paul David, electricity took more than two decades to exert an impact on productivity. Computers simply encountered the same lag. But by now, computers are the most important single technology for improving living standards.

7. FUTURE OUTLOOK

Pre-1895, flying was thought impossible until the airplane came into being in 1895. In 1920, the television was invented. In 1940, space travel was proven possible and culminated in the 1969-moon landing. In mid 1970s, home computers were born. In the late 1980s, through miniaturization, hand-held computers were introduced. In the 1990s, after further miniaturization, increased storage capacity and accompanying rapidly falling prices, many smart gizmos and gadgets were introduced. So what is in store in the future?

We have discussed how we use computer to extend our computing and reasoning faculties. We compared computer speeds in terms of brains, the CPUs of an organism. We have also discussed how one computer interacts with another through networking. We shall now turn our attention to the most important aspect of all, the users.

Our human body will not change as fast as we can advance technologies. Our human body is the product of millions of years of evolution, and it is best suited for the natural environment we now have. It might seem that our technologies are advancing along a path independent of our human body. This may very well be a fallacy. Though not usually emphasized, implicit in the technological advances are human-machine interfaces. Products of technological advances that are not easily adapted to our bodily functions will quickly die out for there will be a lack of market for such items.

7.1. IT MAKES SENSE TO GO BACK TO HUMAN BIOLOGY 101

In short, we interact with our environment (and technological devices) through the five basic biological senses:

1. Vision: We watch for thrills (sports), and for admiration (beauty).
2. Auditory: We listen for potential danger and for pleasure (bird calls).
3. Touch: We feel things, and we grope in the dark.
4. Olfactory: We smell pheromones (animal attractions) or perfumes.
5. Taste: We eat to live (for the slim) and we live to eat (for the obese).

Looking back from the future, we can extend the form-function matrix of Table 1 to include three additional forms: touch, smell and taste.

Table 6. Form and function are the essentials of architecture[14].

FUNCTIONS FORMS	Generation (G)	Processing (P)	Storage (S)	Transmission (T)
Data (D)	(D,G)	(D,P) Computers started here	(D,S)	(D,T)
Text (T)	(T,G)	(T,P)	(T,S)	(T,T)
Sound (S)	(S,G)	(S,P)	(S,S)	(S,T) Telephones started here
Image (I)	(I,G)	(I,P)	(I,S)	(I,T)
……….	**……….**	**……….**	**……….**	**……….**
Touch (T')	(T',G)	(T',P)	(T',S)	(T',T)
Smell (S')	(S',G)	(S',P)	(S',S)	(S',T)
Taste (T")	(T",G)	(T",P)	(T",S)	(T",T)
……….	**……….**	**……….**	**……….**	**……….**

Virtual reality has already been exploiting haptic touch and visuals. These leave us with two sensory organs still not quite exploited: olfactory (smell) and taste (oral). Smell had been attempted in the 1950s.[15] Smell-O-Vision tried to integrate smell with movies but flopped miserably because they could not get rid of the scent fast enough. Today, in movie theatres of Disney World, besides rocking seats to give the audience a sensation of what they see on the screen, scents are also sprayed to give them the odor of what is shown on the screen. Ambryx (San Diego) and DigiScents (Oakland) are two examples of R&D companies working on digitizing scents.

Note that we allow room for more forms. For example, there are people who are studying perception, intuition, and brain wave, and these may be added to the form-column. In principle, the list can go on.

[14] Stan Davis, and Bill Davidson, "2020 Vision", Simon & Schuster, New York, 1991.
[15] Carolyn Said, "Digitized odors don't appeal to this nose", San Francisco Chronicle, March 27, 2000, pp. C3.

7.2. DIGITIZATION INTO SENSE PORTALS

The dictionary defines a portal as a door or entrance, especially a grand or imposing one. It also lists portal the communicating part or area of an organism. On the Internet, a portal is both an entrance and a communication point. When a portal caters to a single need, it is a vertical portal or vortal. In extrapolating the concept of portals, we will have haptals (touch), snortals (for smell), tastals (for taste) in the future. And further into the future, extal (extra-perception), intuital (intuition), noodal (noodle for brains). The only thing that is standing in the way is digitization of these forms. If all forms can be digitized, the form-function matrix will collapse to a one-dimensional row, with different functions operating on only data ("0" and "1"). The verticals will collapse into a horizontal, i.e., the form-function matrix will be a verizontal.

8. DISCUSSION AND CONCLUSION

It is undeniable that our life has been made more comfortable and convenient as a whole by the advances in technologies, and of late, the rapid advances in computer and telecommunications technologies. The way we interact with our environment and surroundings has changed drastically. To fend ourselves, we create tools and weapons. To guard against natural elements, we build shelters and clothe ourselves. To make life more comfortable, we invent many of today's conveniences: automobiles, telephone, cellular phone, computer, and others. To entertain ourselves, we invent TV, make movies, and other amenities.

In experiencing the technological advances, we also witness heightened productivity when more systematic methods were introduced. Automation brought in an increase in productivity. With the recent information technology breakthroughs, we are experiencing yet another increase in productivity. Many gizmos come on the market. Many of these gizmos are wants, but because of the self-feeding good economy as a result of the information technology boom, wants become needs. Notebook computers, cellular phones, palm organizers are the *vade mecums* of today's urban trendsetters. And the need for more smart gizmos is not ebbing.

Returning back to the bipartisan pro, Alan Greenspan, when he was explicit about the future of information technology, he knew that the investment the US has been putting into info-infrastructure has finally matured and the time has come to reap the yield. This explains the current economic boom of the nation. The recent waves of demise.com, and layoffs.com from dot-com guys are, in our opinion, just a minor correction. Streamlined layoffs.com companies include ExciteAtHome, Amazon.com. This correction is just a form of dot-com Darwinism of the survival of the fittest. Having said this, we do want to emphasize there are rising stars on the Internet horizon, for example, Alibaba.com.

So what will we see if we peep through the telescope into the future of high tech:[16]

1. Fiber optics will double or triple performance annually - Industry leaders like Lucent Technologies and Cisco Systems will continue to develop better high performance circuits.
2. Bandwidth demand is insatiable - Telecommunication lines gush data at terabits per second link most American cities, but few homes have access to even a megabit of that torrent. The

[16] John Doerr, a partner with Kleiner Perkins Caufield & Byers, Menlo Park, California.

last-mile bottleneck continues to pinch the promise of the Internet. Fiber optics or coaxial cable (CATV, >50 times faster than 28K modem) of AT&T, DSL (digital subscriber line, between 14 and 50 times faster than 28K modem) of SBC, wireless of MCI WorldCom and satellite are a few potential technologies that may lead the way.

3. New wireless technology - For example, software-defined radio hold the promise to let mobile phones and radios of the future adapt more easily to new, cutting-edge services as they become available. A cellular phone can download services over the airwave like a desktop. The services can be upgraded without requiring new hardware.[17]
4. Java boasts ever more applications - Currently, Java developers are increasing at a rate of 1,000 per day. By the end of 2000, there will be 300 million Java platforms in place.

These first four items will form the infostrature on which further advances in information technology will reside.

5. The web changes everything - In 1994, Bill Gates said "The web revolution would be larger than the PC revolution, and the most successful companies in it wouldn't even have been heard of".
6. Increased best net service companies will arise - Survivors of the fittest on the Internet will begin to show. These companies will be the best of the net, and cannot be undertaken in any better way. This is simple cyber-Darwinism.
7. $300 set-top computer is ubiquitous - Set-top computers will be as common as PC by 2001/2002.
8. The Internet will become the common platform for global healthcare - Healthcare providers will connect payers, providers, employers, and suppliers via the Internet to allow them to share information and synchronize delivery systems.
9. The education between homes and schools will become commonplace - This is self-explanatory because the Internet will be very common. What has not been working in the K-12 has to be fixed. Digital divide may be bridged as computers become more affordable and the Internet is easily accessible.
10. Data, voice, and video communication will converge - As Moore's Law is defied, more complex and smaller chips will be produced. Convergence of data, voice and video will become a reality.
11. Genomics and bioinformatics will have great impact on drug discovery - As the first working draft of the human genome was completed in May 2000, we are in the golden age of bioinformation.

In fact, the active and fast growing business entity in Science Applications International Corporation (SAIC) called “Next Generation Information Network” is a case in point in addressing item 10. HUBS (Hospitals, Universities, Businesses and Schools) Project, inspired by the political leadership of the Four States (Delaware, New Jersey, Maryland and Pennsylvania) is designed to be the catalyst and the integration of information systems in the Four-State region and is now managed by a Fortune–500 information technology corporation: SAIC, for which one of us (DHF) has been appointed as the Vice President and General Manager of HUBS. The project has received over $25 million of federal funding between FY98 to FY00. Among its many goals, HUBS is working toward the goal of item 9 above. D'Trends, Inc.

[17] Kalpana Srinivasan, "Next for wireless - adapting cell phones and radios on the go", San Francisco Chronicle, Tuesday, March 28, 2000, pp. C3.

(Silicon Valley, California), a software and database emerging company serving the biotech, pharmaceutical and healthcare sectors, is working toward items 8 and 11.

9. DISCLAIMER

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10. About the Author

Professor Da Hsuan Feng is currently Vice President of Science Applications International Corporation, a Fortune 500 high technology company and is on-leave-of-absence from his position as M. Russell Wehr Professor of Physics of Drexel University. He received his doctorate in Theoretical Nuclear Physics from the University of Minnesota. Prior to joining the Physics Department of Drexel University in 1976, he was a United Kingdom Science Research Council fellow and a Senior Scientist at the Center for Nuclear Studies of the University of Texas at Austin. In 1983-85, he served as Program Director of Theoretical Physics at the National Science Foundation and visiting Professor of the Niels Bohr Institute of the University of Copenhagen. Currently he holds the Honorary Professor/Senior Research Fellow of six universities/academy of sciences in China.

Feng is an expert in mathematical physics, nuclear physics, nuclear astrophysics, fundamental issues of quantum mechanics, network architecture and computational physics. He was also a consultant to the theoretical physics groups of Los Alamos National Laboratory, Oak Ridge National Laboratory, Brookhaven National Laboratory and United Kingdom’s Daresbury Laboratory.

Feng has served as technical advisor to Congressman Curt Weldon, Chairman of the House Armed Services Committee Subcommittee on Military Research and Development and senior member of the House Science Committee, regarding South Africa, Central Europe, especially Hungary, issues and China. He was a member of the Congressional Delegation to both East Asia and Central Europe in 1997 and 1999 respectively.

In the past three years, he has worked on the HUBS (Hospitals, Universities, Businesses and Schools) project. The HUBS project, inspired by the political leadership of the Four States (Delaware, New Jersey, Maryland and Pennsylvania) is designed to be the catalyst and the integration of information systems in the Four State region and is now managed by Science Applications International Corporations (SAIC). The project has received over $25 million of federal funding between FY98 to FY00.

Feng is currently the President of Monte Jade Science and Technology Association of Mid-Atlantic States, a chapter of a national organization of Chinese Americans entrepreneurs, with over 300 multinational corporation as members, a Business Board Chairman of D’Trends Inc, a leading Bioinformatics company in San Ramon, California, a special advisor to the Editor-in-chief of Korean American Science and Technology Network (which is read by 15,000 Koreans globally), a member of the Industrial Advisory Board of the Interactive Multimedia Intelligent Tutoring Center of Temple University and a member of the Computer Science/Engineering Technical Evaluation Advisory Committee of the Provost and President of the University of South Carolina and a past Vice Chairman of the Board of CyberFone Inc.

Feng has published over 180 scientific papers, wrote and/or edited over 20 books, and has served as editor of 4 scientific journals. In recognition to his contribution to the field of nuclear physics, Feng received the accolade Fellow of the American Physical Society, an honor bestowed to only 0.4 percent of the physicists in the United States. He is also the recipient of the 1999 Millennium Award for Vision and Leadership in Technology, TechFEST '99 in Allentown and the 1999 Delaware Valley Technical Recruiting Network 1999 TECHIE Award.

Dr. Hwa A. Lim was born in Malaysia and is a naturalized US citizen. He has a Ph.D. and an M.A in Science, and an MBA (Masters in Business Administration, with emphasis on strategy, market research and business laws) from the United States, a B.Sc. (Hons.) and ARCS from the United Kingdom.

In 1997, he founded D'Trends, Inc. (headquartered in the Silicon Valley, California, USA), a software and database emerging company serving the biotech, pharmaceutical and healthcare sectors. Prior to this new venture, he was Vice President of Science & Technology, Pangea Systems (now DoubleTwist, going public, 1996-1997), Director of Bioinformatics, Hyseq, Inc. (now a public company with ticker symbol HYSQ, 1995-1996). Dr. Lim was a tenured faculty member at Florida State University (1989-1995), and Program Director, Supercomputer Computations Research Institute, Florida State University (1987-1995). He has participated in two different projects that went on to win Nobel prizes, authored/edited nine books.

Dr. Lim is a well-sought after keynote speaker at international meetings. He is credited with coining the word "bioinformatics" and for initiating the first bioinformatics conference series (Bioinformatics & Genome Research), which is still ongoing. In addition to his scientific background, he has strong experience in market research and developing strategic alliances internationally.

In 1995, he decided to vacate his tenured position in the academia and join the private sector in the Silicon Valley, California, USA. Since he has been a very successful academia-turned-entrepreneur in the US and other parts of the world.

Currently he also serves as a bioinformatics expert for the United Nations, a review panelist for the United States National Science Foundation and the United States National Cancer Institute.

11. About VERIZONTAL Publications

VERIZONTAL is a mosaic of four words: verify, vertical, horizontal and portal. The dictionary defines a portal as a door or entrance, especially a grand or imposing one. It also lists portal the communicating part or area of an organism. On the Internet, a portal is both an entrance and a communication point. When a portal caters to a single need or concentrates on a single subject in deep, it is a vertical portal or vortal. Similarly, when a portal caters across disciplines, it is a horizontal portal or hortal.

VERIZONTAL is not meant to be a regular publication like daily, weekly or monthly publications.

Goals:

1. Its primary goal is to educate and inform the public. Instead of reports based on interviews, it fills a niche by reporting based on solid research work written by individuals with expertise in the field.
2. Its secondary goal is to help propagate an important issue, which the news media are very good at, but cannot afford the luxury of more detailed explanation. Thus VERIZONTAL shall bridge between technical articles and popular media.

Distinctions:

1. It is published whenever there is an important issue, a topic for discussion, or a trend on the horizon that will interest the general public.
2. Each publication contains only one article. The article can focus on a topic in detail (vertical), or can be trans-disciplinary (horizontal).
3. Unlike newspapers or newsletters, it has full citations so that interested readers can pursue the subject further if so desired. Thus all facts are verified by referring to their sources.
4. Unlike books, it is much shorter in length, but is self-contained. Because of the quick turn-around, it is also more current than books.
5. It is written at a level that is understandable to laypersons and newcomers. Experts will also find enlightening fresh perspectives.