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INFORMATION TECHNOLOGY: A CONTINUING REVOLUTION

IAN MILES, June 2000

Over twenty years have passed since the first flurries of excitement about new Information Technology (IT) were catching headlines.[1] Public and political interest in automation and computers has indeed a longer history still – even in the 1960s studies were being undertaken of the implications of automation for skills, jobs and working conditions. But it was in the late 1970s and early 1980s that people began talking about the "microelectronics revolution" and the "IT revolution".

The new technology was now something that might be encountered on your desktop or in your home – personal computers and home computers, and the early efforts to introduce online services through videotex. Looking back, we can see a huge surge of interest in IT in the early 1980s, and another surge from the mid-1990s. Now people are talking of the "information society", the "knowledge economy", and the "new economy". And the technologies are even more intimate: laptop and pocket computers, mobile phones and personal organisers, and the homepages of all sorts of individuals and organisations on the World Wide Web.

These waves of interest are not a matter of mere fashion, though there is much of fashion and hyperbole in popular writings about IT. They reflect the emergence, diffusion, and elaboration of uses for IT, and they reflect changes in the underlying technologies as well as in their applications. IT remains a profoundly important technology, with wide-reaching social and economic implications. It is also a remarkably fluid technology, displaying a rapid pace of change. This not only affects the possible application and diffusion of IT: it also means that great caution is required in generalising from past experiences with the technology to those that may be experienced in the future.

This essay will outline the background to the assertions made above, and put the implications into a broader framework. To begin with, we will address the questions: what is new IT? How is it different from the technologies that we have traditionally used for processing information? Why does IT matter?

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[1] Since the term "information technology" necessarily includes "communication technology", we use IT rather than ICT (Information and Communication Technology). The main value of differentiating the two components of the term is in order to reflect the historic and to some extent continuing distinctions between computer and telecommunications industries.

Information Technologies old and new

Information is one of the central features of human life. It is inherent to our interpersonal relationships, our economic production, our culture and society. Information technologies allow human beings to do more things with information than they could otherwise – to store it, transmit it, reproduce it, and transform it. But what are information technologies?

An archaeologist who has dug up a flint axe can deduce a great deal from this artefact about the nature of its production and use. He or she can relate this not only to historical and anthropological knowledge, but also to an understanding of geology (how flints are produced, where they are found), physics (how axes are able to change things in ways which unaided human hands cannot, how flints can be sharpened in particular ways), and so on. It is almost as if the artefact has come with a museum label attached to it, telling us what it was.

In one way then, all technologies can be said to present information to the knowledgeable observer. But we would not normally consider them to be "information technologies". That term is usually reserved for artefacts that are explicitly designed to allow information of one sort or another to be operated on in one way or another.

We could think of human languages as very fundamental technologies – along with mathematics, languages are like the "software" to the "hardware" of technological artefacts. Early artefacts had a limited range of ways in which they operated on information. Information technologies of very ancient origin typically stored information (e.g. rock carvings, written records), displayed it (e.g. symbols scratched onto urns to indicate their contents), or transmitted it over distances (smoke signals, talking drums, etc.) These ancient information technologies required languages of their own – drumbeats, smoke signals, writing (whether pictograph, hieroglyph, or alphabet. Data are being stored and/or transmitted in the form of specialised signs embodied in materials. (The exceptions may be certain auditory and visual signalling devices: drum beats, smoke, heliograph flashes, etc.) The artefact is a tool for people to produce the sign and to make it useful. These people "translate" their speech or thoughts into the new forms in which they are embodied. Sometimes extensive and specialised skills are required for this purpose: as is well known, mass literacy is a fairly recent phenomenon, even in the industrial world.

One other class of information technology was specifically oriented to mathematics, and its applications in navigation and astronomy.[2] (Incidentally, the original meaning of "computer" was a person dedicated to performing tasks of arithmetic.) Various tools to aid arithmetic have their own ancient history, with the abacus probably being the most widely

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[2] The development of methods of mathematical calculation and reasoning was itself highly contingent upon the application of writing, without which feats of mental arithmetic would not merely have been challenging – they would have been extremely hard to verify and to diffuse the relevant skills. The development of arithmetic and more general writing is in any case a closely intertwined phenomenon.

used.[3] Again human skills effect the transformation of information from one form to another, with manual operations substituting for and enhancing mental calculations.

The boundary between information technologies and other artefacts is not always easy to draw, and this is true for "old" information technologies as well as for new IT. Even the flint axe may have been intended to convey information about the social affinities or prestige of its user – for instance in the decoration of its handle. Clothes and jewellery frequently tell the informed onlooker about the state or status of the wearer – this is a bride, this is a chief, and so on. Urns carried information about what sort of grain was contained, and in what quantity (like modern cans), and craft workers have long put their own identifying signs on their products (like modern brand names and designer labels). And so on. While some artefacts have the storage or transmission of information as their main function. For others, this is a secondary function (in most circumstances),[4] and in such cases the purpose of the signs is usually to present some information about the artefact itself, or about its user.[5]

The elaboration of writing proceeded over a long period, and various methods of storing it were established. The inventions of the book and the printing press were vital. Printing in particular allowing for the large-scale reproduction of texts. While printing was a skilled craft, the actual deposition of signs on the paper material was accomplished mechanically, which is how it could be carried out at speeds impossible for unaided scribes. This made possible the mass distribution of books, with vast implications for the ability of state and religious leaders to control information, and for the diffusion of information about science and technology as well as politics and philosophy. Mechanical calculating machines of various sorts were developed over a long period too, with innovations such as the representation of numerals and the "automatic" calculation of a result as a result of rotation of a wheel (by hand or clockwork).

In the nineteenth century, the industrial revolution was accompanied by the emergence of a new wave of information technologies. These featured methods for the mass production of information artefacts, for the long-range rapid transmission of data, and for automatic "capture" of data without human translation into signs. A large number of new branches of knowledge were brought into play, as in the industrial revolution more generally. New energy and motor technologies were applied to the mass production of written texts – the nineteenth century saw a huge boom in books and newsletters. Physics and chemistry were applied in pioneering developments in photography and phonography, for example. In the former case, the application of physics (lenses in particular) and chemistry (light-sensitive substances) allowed for an "analogue" capture of images; in the latter case physics (acoustics, mechanical engineering) allowed for analogue sound recordings to be made and played back on mechanical devices.

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[3] The slide rule, though invaluable for a period, was of much more recent origin and was of more specialised applicability. It has been almost completely displaced by electronic calculators.

[4] Anything can be used as a sign, if the code is shared with the intended recipient. "If the sail is white, the mission has been successful, if black the hero is dead" being an archetypal instance from folklore.

[5] There is likely to have been some technology or technique employed to add specialised signs to enhance the information associated with other artefacts.

An important feature of these technologies for "capturing" and reproducing data was that they typically operated in what we now call an analogue fashion. The data were automatically "translated" from one form into another - from light waves to chemical structures which could reproduce key elements of the visual patterns; from sound waves to variations in the height or depth of grooves from which a similar auditory pattern could be reproduced. When electricity and electronics began to be applied to similar functions, they too involved analogue forms of capture and reproduction. Thus telephones, TV transmissions, and audio tapes all involve data represented via electrical or magnetic charges. The structure of the data followed the structure of the original phenomenon, with the auditory signals converted into electrical pulses, with the visual image converted into a matrix of dots following the spatial structure of the image.

Increasingly, the key science behind information technologies in the first half of the twentieth century became electrophysics (though photography remained a matter of optics and photochemistry). A critical technology here was the thermionic valve, which allowed the control of electric currents – for example amplifying them, turning switches on and off, changing the patterns of electric currents - giving rise to electronics and electronic engineering. The first electronic computers were built using valve technology, but valves were difficult components to deal with. The valve is a device in which an anode is heated in a vacuum or inert gas. Valves thus tend to be bulky and fragile, to require high levels of electrical current, and to create excessive heat.[6]

Computers are an Information Technology that actively processes information: there is a central information processing unit, rather than just methods of storing or transmitting symbols (i.e. moving data though time or space),. The history of calculating machines shows that people have long sought methods to manipulate data, sometimes with considerable effect (as in the case of the abacus in the hands of a skilled user). Computer technology allows for far more versatile manipulation of information, however. Especially important is the introduction of stored "programs", which effectively controls information with information. The program determines **how** the data is to be processed. The first programmable computers were produced just before the turn of the twentieth century, using valves for their information processing functions.

It was a few years later that the transistor was introduced. Compared to the valve, the transistor was small, robust, and safe. It operated not by heating an anode so that it would release electrons, but by using the "solid state" properties of a class of materials known as semiconductors (e.g. silicon, one of the more common elements in the Earth's crust).[7] These allowed transistors to be applied to the tasks previously carried out by valves, and they appeared in an increasing variety of product over the following decades. But further advances in semiconductor technology enabled even more progress to be

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[6] It has now proved possible to manufacture extremely small and robust valves, but this became technologically possible only after transistor systems had effectively displaced valves. It is interesting to speculate that, had transistors not developed, we would have witnessed an information technology revolution occurring at a far slower pace, based on microvalve technology.

[7] Slight variations in the different materials employed allow for specific types of effect to be achieved.

made, and it is these developments that laid the foundation for what would become the IT revolution.

Core Technologies: From Transistors to Microelectronics

Just over a decade from the development of the transistor, the Integrated Circuit (IC) was introduced. Transistors, alongside their other advantages as compared to valve technologies, enabled considerable *miniaturisation* of electronic components. (An early consequence of this was small and lightweight portable radios and similar consumer products.) Individual transistors were connected physically by wires in the early devices, just as valves had been. These systems of connected components were “circuits”. In an effort to achieve yet more miniaturisation, and to reduce the laborious and error-prone business of wiring transistors up, ICs were developed. In an IC, a single “chip” of semiconductor is used as the basis for assembling a large number of individual electronic components (such as transistors).[8] Effectively, whole circuits that had previously involved physically separated components were now put on a "chip" of silicon. This made even smaller, lighter, more robust, and faster circuits possible; they could use less power, and became cheaper to manufacture than the costs of producing and assembling earlier circuits.

The IC became the focus of rapid technological development. Small Scale Integration achieved.the equivalent of 10 transistors per chip; Medium Scale Integration involved around 100 transistors/chip; with Large Scale Integration there were thousands, and with Very Large Scale Integration (VLSI) tens of thousands of transistors per chip; current technologies place hundreds of thousands or millions of transistors on each chip. People began talking of **microelectronic** "chips" in the context of VLSI; microelectronics is the branch of electronics and electronic engineering that deals with these microcircuits. An indication of the scale of change is that the number of transistors on a chip rapidly outstripped the number of stand-alone transistors (let alone valves!) that would have been in place in a complex electronic device of the previous era.

Transistors and then ICs had been incorporated into computers, from about 1960 on. The **microprocessor** was developed at the beginning of the 1970s, initially in the context of efforts to make more effective electronic calculators.[9] Effectively, a microprocessor is a VLSI chip which contains the key components of a computer, forming a central processing unit – thus it was initially often described as a “computer on a chip”. (The circuits have to be able to handle instructions according to logic, and memory capacity has to be built in; and input and output systems, and usually further memory and other capabilities, have to be attached to it.) The first “microcomputers” – small desktop machines – were introduced in the 1970s, and the IT revolution was in its early phases.

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[8] Variations in the materials employed on the silicon chip are the result of “doping” the chip with impurities that give that area of the chip the specific role of, say, a transistor or a diode.

[9] The first microprocessor replaced an 11-chip design, itself the equivalent of 2250 transistors

Microprocessors rapidly became applied in industrial control systems (from systems regulating large-scale process operations to devices such as programmable machine tools and a huge range of sensors, portable computers, etc.). New types of computer application developed as microcomputers became known as “personal computers” (PCs), home computers, laptops, palmtops, portable digital assistants, and so on. Microprocessors were built into communication systems, helping to create more powerful telephone and data communication networks, mobile telephony, digital recording and broadcasting, etc. They have been applied often as “embedded computers”) in the control and information-processing functions of a great many intermediate and final goods. Contemporary toys may pack more processing power than did mainframe computers a few decades ago.

The development of microelectronics (and semiconductor technology more broadly) has been central to new IT.[10] It can be seen as a “heartland technology”, underpinning a new technological revolution. Because of its cheapness, its dramatic reduction in the costs of information processing, its effectively unlimited supply (the abundance of silicon), and the ubiquity of information processing requirements, new IT is providing its unprecedented capabilities to a wide range of activities. However, we need to bear also in mind that:

- Microelectronics is not the only technology involved in the IT revolution,
- Digitalisation is a central feature of new IT, and
- There is continuing rapid development both of the core technologies themselves, and of their applications.

Functions of Information Technology

In the discussion above, we have already made mention of various functions performed by older information technologies and new IT. These reflect the different things that may be done with information (or with data, since information is essentially organised data). Technologies represent the application of physical, chemical and symbolic (software) processes to these functions. Table 1 outlines a set of broad functions where technologies may be applied to enhance human use of information.

However the functions are performed there will need to be some energy inputs to fuel the transformations of information. In the past this energy might have been provided by human beings, but in the twentieth and twenty first centuries electrical power sources have become central. As people in areas remote from electricity grids, and owners of laptop computers, are well aware, the availability of convenient, low-cost, reliable energy sources can be a real constraint to the use of new IT. So, in addition to the technologies performing the informational functions discussed above, we also need to bear in mind the evolution of the supporting energy technologies.

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[10] Just as valve technology might have been developed (albeit much more slowly) to perform the functions that semiconductors have been applied to, so in the future new processing technologies – for example optical chips, involving optronic rather than electronic technology – may displace semiconductor microprocessors.

Table 1 Using Data and Information

In brief, data and information may be:

- "**Captured**" – extracted from the environment (e.g. by sensors), or
- **Input** – deliberately introduced into the system by human agents (e.g. through keyboards or microphones);
- **Stored** – held in some recording medium from which it may be retrieved;
- **Transmitted** – communicated over a distance to a point where it can be received by other users or devices – which requires communications **media** (such as cables or the radio spectrum) and **peripheral devices** (such as radio receivers and modems);
- **Processed** - transformed (especially by means of mathematical or logical operations performed on data represented in digital form, and in the case of contemporary computing devices, performed by means of instructions encoded in software);
- **Output** – in the form of informational outputs as in the case of printed paper, audio output, or more particularly
- **Visual displays** – where the symbolic output is presented as a variable image on a screen or projection of some sort;
- Used for **actuation** – where the output controls some device in order to effect physical or chemical operations (e.g. a robot arm, an automated power generation system).

We can use this list of functions as a loose framework to think about the evolution of IT in the past, and into the future. In addition to consideration these elementary functions, we will need to think about the systems which are created to accomplish them in various combinations. Table 2 sets out a broad overview of the long-term evolution to modern IT. As it makes apparent, one important feature of new IT is the digitalisation of data and of information processing. Data are represented in terms of binary digits – whether we are dealing with a fragment of sound, a portion of a picture, a segment of text, the structure of a human heartbeat, or the X-ray output of a remote supernova, the data will be encoded as a string of ones and zeroes. These can be transformed by various operations to produce the effects desired by the user, by application of an appropriate program.

One result of this is that computer systems are effectively able to process information of any sort. The limitations lie in the ability of human beings to be able to apply their own knowledge to organise the raw data into information, and thus to be able to develop and apply appropriate software. The desktop PC can process written texts, music or video clips, pictures from electronic cameras or scanners, evidence captured by physical, chemical or biological sensors, and so on. All sorts of information that previously could only be captured and displayed, let alone processed, by specialised devices, can now be handled by microprcessors and their associated systems. This makes it easier to transport information from one device and/or process to another.

Digitalisation is at the heart of the so-called **convergence** of computers and communications, and indeed of computers and media of many kinds. Telecommunications networks have themselves been digitalised, and their switching systems controlled by microprocessors instead of the old mechanical and electromechanical switches – people talk of the "intelligent network" (with smart routing, error-trapping and other data-processing features). Computers themselves increasingly communicate, so that perhaps the key development of the 1990s was the massive upsurge in computer networking via the Internet. At the beginning of the twenty first century we see mobile telephones and digital televisions also providing access to the Internet, and both personal and embedded computers allowing many devices to communicate with each other. Two features of this "convergence" are often misunderstood:

- First, it does not mean that we should expect a single all-purpose device to take over – some super personal portable communicator/computer/TV system. What is more likely is a proliferation of different devices optimised for certain functionalities, but with many overlapping features and capabilities.
- Second, traditional industry structures have been very different – telecommunications was for a long time a national monopoly in most countries, as was the broadcasting sector in some, while the film and publishing industries were highly concentrated; the computer and software industries (and now many Internet companies) , while featuring some giant firms, have grown at an extraordinary pace with a very different culture. While alliances across these sectors are common, they have often proved extremely difficult to manage, and few firms can be said to have effectively mastered convergence. Some commentators prefer the term "collision"!

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Table 2 From Ancient to Modern Information Technologies

(a) Preindustrial Era

Traditional "Information Technologies" **(up to early Industrial Revolution)**	
Processors	While the notion of a programme was elaborated in the early C19th in the context of Babbage and Lovelace's work on mechanical computers, in practice all operations were carried out by human beings following specific routines (e.g. with early calculating machines)
Storage	Data stored in the form of signs crafted into materials by human expertise – even when this is aided by machinery such as printing presses allowing for large scale reproduction (i.e. multiple retrievals) of stored material.
Transmission	Stored signs (e.g. written texts) transported by physical means, or else signals conveyed over distances through auditory or visual signals by human skills.
Visual Displays	Nothing equivalent to modern displays; physical media may be used as temporary repositories for impermanent signals crafted by humans (e.g. blackboards).
Inputs	Input devices are determined by the specific technology; range from pens to drumsticks.
Output devices	Output devices are also determined by the specific technology, representing the original information in analogue form as encoded by the human operator, and ranging from parchments to rows of abacus beads.
Actuators	Nothing equivalent to modern actuators, though mechanical valves and switches to regulate, e.g. the flow of water, have a long history.
Software	Nothing equivalent to modern software, though detailed lists of instructions for human craft workers again have a long history.
Systems	A wide variety of systems accomplishing specific purposes with specific underpinning technologies developed more out of practical experience than from codified scientific knowledge. Use often restricted to those with skills that were highly specialised in their era (e.g. reading and writing).
Supplementary Technology (e.g. energy sources)	Clockwork used in some early automata and calculating machines, but in general power sources are human effort.

Source for Table 2(a), (b) (c): Miles (2000)

Table 2(b) Early Industrial Eras

Information Technologies in the Electrophysical Era **(mainly first half of twentieth century, but developments in later nineteenth century involved such advances on earlier systems that they must be mentioned, and there is similarly some blurring of the end date.)**	
Processors	Programmable mechanical computers envisaged by Babbage but not created (Analytical Engine); valve-based computers of huge size and low power (by present standards) created toward the end of this era.
Storage	Analogue storage of data, by physical and chemical means, and then increasingly by electrical and electronic means (e.g. the shift from vinyl recordings to magnetic ones on audiotapes).
Transmission	Development of telecommunications and broadcasting technologies, involving metal cables and radio spectrum, with rapid increases in geographical reach of systems.
Visual Displays	Motion pictures utilising projectors used mainly for entertainment purposes; cathode ray tubes developed for display of television signals and for specialised industrial and military applications (e.g. radar) – but early computer output in form of printed paper (teletype).
Inputs	Wide range of specialised analogue data capture devices introduced – microphones, cameras, temperature and pressure sensors, etc. Complex data captured in highly device-specific form, and limited scope to apply more generally; some very simple on-off signals in the form of electric currents could be produced by sensors.
Output devices	Much use of paper media for photographs, texts, etc; other specialised outputs such as loudspeakers for radio and recording systems, TV and cinema screens, etc.
Actuators	Electronic technology, coupled with more sophisticated mechanical engineering, allows for more complex control of devices, but this is not governed by substantial information processing.
Software	Some industrial era "software" developed to control specialised equipment such as knitting machines; first practical computer software developed at end of this period, and initially required manual setting of switches.
Systems	Many specialised systems, but active information processing systems only emerge at the end of the period, remain extremely rare, large, and cumbersome, and are applied to highly specialised purposes (e.g. military cryptography).
Supplementary Technology (e.g. energy sources)	Electricity grids established and provide the relatively large amounts of power required by most of the electrical and electronic devices described here (though some battery-operated valve-based electronic devices like radios).

Table 2(c) Late Industrial Era

Information Technologies in the Microelectronic Era

(second half of twentieth century, especially last quarter of century, and beyond.)

Processors	Semiconductor technology in Integrated Circuits allows for rapid progress in microprocessor systems, allowing for large-scale manipulation of data in digital form.
Storage	Storage media of numerous forms developed for digital data: semiconductor memory devices, magnetic media (digital tapes, floppy and hard discs), optical media (CDs, DVDs, etc), and many others.
Transmission	Optical fibres allow for transmission of larger volumes of data; cellular systems allow for more efficient use of radio spectrum, as does the broadcasting of material in digital form; satellite communications allow for increased global reach and access to remote areas. Data communications grows more rapidly than conventional voice communications, and with the development of the Internet a worldwide computer system is effectively established.
Visual Displays	Cathode ray tubes remained dominant in twentieth century, but were increasingly complemented by a variety of flat screen technologies for lightweight portable devices (and specialised products like watches, calculators, etc.). Some development of projector systems for large-scale presentation of digital material.
Inputs	Keyboards used for a vast range of devices (though specialised devices still sometimes require specialised input systems – e.g. flight simulators, video games consoles); “mouse” and other pointing devices also popular in personal computers and some remote control devices; growing use of voice input. Many sensors used in specialised industrial, medical, environmental and other applications.
Output devices	Wide range of printers introduced, though little challenge to paper as the recipient medium; audio output used as signalling system in computers.
Actuators	Many specialised actuators in industrial and medical applications, with some consumer appliances (e.g. automobiles) being host to numerous actuators (e.g. for motor and braking control).
Software	Programming languages developed rapidly – e.g. operating systems software, languages for writing applications, generic and industry-specific applications software, etc. Much development of “dataware”, i.e. informational content presented in interactive digital formats (e.g. CD-ROM encyclopaedia). As with other digital information products, costs of reproduction are very low, though costs of production may be extensive. Software engineering becomes an established discipline, with libraries of software components and elaborate systems and tools for software development - but much software production remains craft-like in practice.
Systems	Successively mainframe, minicomputers, desktop and laptop (and other portable) computers develop and gain increasingly huge markets. Embedded computers (and associated inputs and displays) incorporated into a wide range of devices. “Convergence” of devices like computers and telephones, computers and televisions.
Supplementary Technology (e.g. energy sources)	Semiconductor devices have relatively low electricity requirements, and battery technology for portable devices is improved, but with more powerful devices there remain problems with power availability. Electricitry grid still a major source of power.

Continual Technological Change

Practically all of the technologies that underpin new IT are themselves subject to rapid improvements in their power and speed. The descriptions in Table 2[c] reflect this fact. It is possible to transmit, store, and process data in greater volumes, at faster speeds, and at lower costs, year on year. This set of trends is the product of intensive Research and Development (R&D) on the part of the various supplier industries, as firms seek to gain and maintain competitive advantage by achieving superior products.

Though the result of commercial choices, the trends are so striking and persistent that many commentators have regarded them as being self-propelled. The best-known of the trends has even been dubbed a “law” - "Moore's Law", coined in 1964 by Gordon Moore, who deduced from trends then apparent that the number of IC elements that could be placed on a chip would double just about every year. (see Figure 1.) The forecast has been remarkably accurate to date, despite various alarms suggesting that we are close to the physical limits of integration (which presumably must be confronted sooner or later).[11] The increased number of components means an increase in the computing power that a chip can carry, a decrease in the size of system required to carry out tasks. But alongside this are also marked cost reductions in ICs. One reputable estimate is that there has been a reduction of over one-third, each year, in the cost of processing each bit of information. The costs of acquiring information-processing capabilities thus decrease. However, we should note (a) that the supply of new ICs requires increasingly costly capital equipment (thus “Rock's Law”: the capital equipment costs to build semiconductors will double every four years); (b) the cost of some devices, like PCs, has actually remained fairly stable over long periods, because it is expected that the power of the equipment will increase (and indeed, successive generations of software depend on this).

Similar trends can be pointed to in just about every other element of new IT. For example, Figure 2 illustrates the improvements in capacity of hard disc drives over the years – improvements that have taken many commentators by surprise, since they were forecasting the wholesale replacement of hard discs by optical or other media. In fact, many PC systems now use a combination of different memory devices – hard and floppy discs, CD-ROM or DVD, semiconductor memory (Flash cards, memory sticks, etc.) Small hard drives now have the capacity that large drives had only ten years ago, while hard drives’ storage capabilities continue to be amplified.

As for telecommunications, a “Photonics Law” has been proposed by AT&T Laboratories Vice President Larry Rabiner[12] in which he suggests that for the next decade or more, the optical capacity on a single mode fibre will double every 10 months – even faster progress than Moore’s Law. Telecommunications infrastructure takes time to replace, but even so there has been a steady increase in the capacity of national and international telecommunciations systems.

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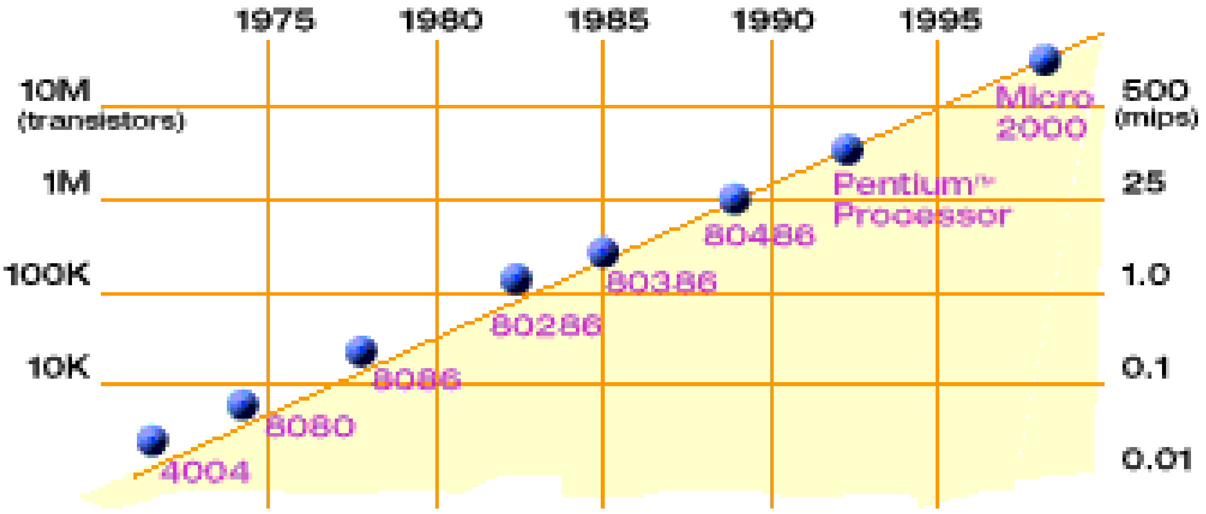
[11] Moore himself is on record in the late 1990s as suggesting that this limit will be reached before 2020.

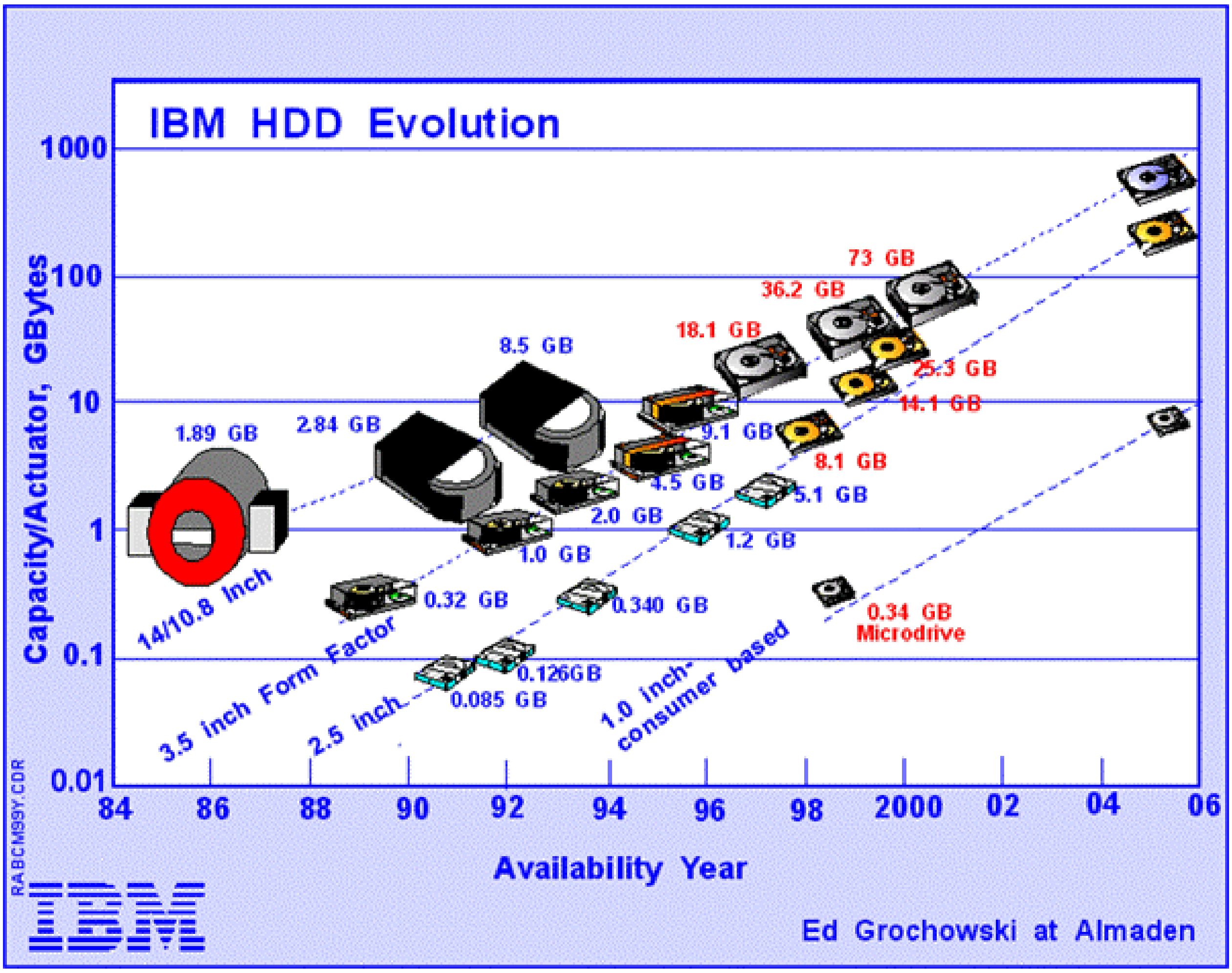
[12] A wide-ranging presentation from January 2000, made available at http://www.research.att.com/forum/

Figure 1 Moore's Law



Source: Intel Museum Home Page http://www.intel.com/intel/museum/25anniv/hof/moore.htm

Figure 2 Hard Disk Performance



Source: PC Guide at http://www.pcguide.com/ref/hdd/hist.htm

The continual rapid change in IT heartland technologies, in computing and communications systems, and in various supporting technologies and infrastructures – and their applications - has meant more than quantitative change. There is qualitative change, too, in the nature of computer systems and other IT applications. This has led various commentators to describe the evolution of new IT in terms of successive "generations".

In the 1980s there was considerable excitement generated by the announcement from Japan of their fifth generation computer project, with ambitious aims in terms of achieving advanced artificial intelligence and high-speed processing using radical new chip technologies. This project is now widely regarded as having been a failure, which should caution us against taking predictions from the industry too much on faith! Most often,, we find proponents of specific technological options identifying their products with the next generation, so while general forecasts about technical potential are often more or less accurate, the specific ways in which these will be achieved, and the applications to which they are put, are more debatable.

Table 3, derived from a variety of sources, seeks to set out one account of the evolution of various components of new IT. Though necessarily very approximate,[13] it shows how far and fast we have come, and provides one strong message. New IT is itself dynamically changing. The apparently smooth trends of increasing IT power are associated with discontinuities in underlying components and IT use. We should not, then, expect the uses and implications of current and future generations of IT to be identical to those which have been identified in the context of past generations of IT. The increasing power, portability, functionality, and availability of newer generations of technology suggest that they will be taken up by new economic sectors and social actors, with far-reaching and unpredictable consequences. It is salutary to recall that early computer pioneers believed that the world as a whole was likely to require only a handful of computers, and that they had what we would now consider the most ridiculously constricted view of the functions to which their inventions (or the inventions that built on these) would be applied to. We can expect new uses and modes of use of IT to continue to evolve.

A more immediate problem for efforts to assess the pace of development of the information economy is also associated with the successive generations of new IT. Efforts to assess statistically what the levels of computerisation are in different economies and sectors, for example, need to take account of the probability that computers acquired only five years apart are likely to be extremely different beasts. Measures of expenditure on IT hide the fact that a given amount of money may be use to buy very different capabilities, so estimates of IT investment may turn out to be highly skewed. Recently, economists have concluded that failure to take improvements in IT – "more bits per buck" – into

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[13] Many details have to be suppressed in such an overview. Component technologies develop at different paces, and have taken off at different speeds one from another and in different countries and economic sectors. Some types of technology have had an extremely long gestation time (e.g. fax), while others have become economically significant almost as soon as they have been invented (e.g. microprocessors). The aim is to illustrate the broad patterns and rhythms of development, not to precisely tie down specific configurations of technologies to specific dates.

account has actually meant substantial underestimation of growth rates and overestimation of inflation in the advanced industrial countries.

The discussion so far has explained that new IT is not just a new product, like television or the whole body scanner. It represents a vast range of products, which encompasses products that can themselves be built into or joined on to many other sorts of product – thus the TV and body scanner themselves are increasingly liable to incorporate microprocessors. New IT also represents more than a radical transformation of a particular economic sector, like to computer and computer services industries. As a revolutionary heartland technology, it is applicable across effectively all sectors – in many cases in new products, sometimes in new production processes, and almost universally in back-office and management. Furthermore, with the continuing increases in the power of new IT, as highlighted in the discussion of different generations of IT, this applicability continues to grow, and planners have become accustomed to taking this into account. This evolution poses substantial challenges to economic analysis and organisational decision-making.

Table 3 Generations in new IT

Successive Information Technologies in the Microelectronic Era **- precise chronology will vary from element to element, and according to how far a technology's development and diffusionn needs to proceed before inclusion.** **But a rough dating would be: 1st Generation: c1950; 2nd Generation c1960;** **3rd generation: c1970; 4th generation: c1985; 5th generation: c1995**	
Processors	• First Generation: vacuum tube valves • 2nd Generation: stand-alone transistors: 32k memory; 200 thousand instructions per second • 3rd generation: Integrated Circuits • 4th generation: VLSI • 5th generation: ultra- large-scale integration, RISC (reduced instruction set) systems • and beyond…: new chip architectures e.g. parallel processing, eventually perhaps biochips, optical chips. 3-D chips.
Storage	• First Generation: Magnetic drums • 2nd Generation: magnetic core memories • 3rd generation: semiconductor RAM, magnetic disks • 4th generation: bubble memories • 5th generation: optical discs (CDROM, DVD) • and beyond…: vastly powerful memory systems of all sizes.
Transmission and Telecommun-ications	• First Generation: traditional telephone • 2nd Generation: digital transmission; pulse code modulation • 3rd generation: introduction of satellite communications; microwave systems; networking; optical fibres; packet switching; telex • 4th generation: ISDN (Integrated Services Digital network); packet switching data communications; some development of videotex and similar telematics systems, take-off of fax (business use) • 5th generation: ATM, Intelligent Networks; take-off of Internet e-mail and World Wide Web; cellular mobile voice and data communications • and beyond…: Internet telephony, take-off of video communcations
Visual Displays	• First Generation: basic cathode ray tube (CRT) displays • 2nd Generation: colour TV • 3rd generation: flat screens for small devices, enhanced Visual Display Units • 4th generation: flat screens for portable devices, large CRT displays • 5th generation: large flat screens, video projectors, widescreen and enhanced TV • and beyond…: virtual reality displays, both portable and large-scale
Inputs	• First Generation: manual setting, punch cards • 2nd Generation: punch cards • 3rd generation: keyboard entry, command line prompting, scanners and plotters • 4th generation: mouse and other pointing devices, "windows"-type interfaces, digital cameras and microphones • 5th generation: some natural language input • and beyond…: more sophisticated visual and speech inputs
Output devices	• First Generation: teletype • 2nd Generation: large typewriter-like and matrix printers, plotters

	• 3rd generation: small dot matrix printers • 4th generation: laser printers, inkjet printers, speakers • 5th generation: colour laser printers, hi-fidelity loudspeakers • and beyond…
Actuators	• First Generation: simple physical and electromechanical switches and valves • 2nd Generation: electronic switches, power chips • 3rd generation: basic computer controlled machine tools, robotics • 4th generation: advanced manufacturing technology, machine tools, robotics • 5th generation: chematronics, mechatronics • and beyond…: nanotechnology devices of many sorts and at various size levels
Software	• First Generation: machine code, autocode. • 2nd Generation: high level languages • 3rd generation: very high level languages; structured programming methods • 4th generation: fourth generation languages (4GLs); widespread use of packaged programs for huge range of applications; object-oriented languages • 5th generation: visual programming, Internet delivery of programs • and beyond: widespread use of expert systems, neural net systems, and other sorts of "intelligence" within programs and to produce new software.
Systems	• First Generation: computers large beast with perhaps with 2kilobyte memory, and very low processing speeds. • 2nd Generation: mainframes still dominant • 3rd generation: timesharing systems widely used by large organisations; minicomputers; memories of 2 megabytes, processing speeds of 5 mips (million instructions per second) • 4th generation: microcomputers, Personal Computers; distributed systems with Local Area Networks (LANs); 8 meg memory, 30 mips processing speed • 5th generation processing speeds of giga and tera instructions per second; increasing • and beyond: High levels of systems integration, access to information networks by numerous devices in practically any location. Vastly powerful chips embedded in numerous communicating devices.
Supplementary Technology (e.g. energy sources)	• First Generation: mains electricity • 2nd Generation: materials science applied to semiconductors • 3rd generation: space technology important for communications satellite launch • 4th generation: small rechargeable batteries for portable devices, optical fibres for telecommunication infrastructures • 5th generation: lightweight, long life rechargeable batteries, low-energy chips and energy conserving software • and beyond: application of biosciences and nanotechnology?

Source for Table 3: Miles (2000)

New Information Technology and the Information Society

There are numerous accounts of, and attempts to define, the “information society”.[14] Some authors stress the long term growth in the significance of information processing activities and occupations of all (or at least many) kinds. While most are simply content to chart (or just to assume) such a trend, a few authors are prepared to articulate the view that there have been qualitative changes in the role of information in society and economy, in the way in which large organisations in particular require information for coordination and control.[15] And have made use of transport and communications technologies to this end. An alternative approach is actually quite complementary to this one, but does suggest that the contemporary era is marked by qualitative changes worthy of terms such as “information society”. This perspective puts more emphasis on new IT, and suggests that we see information society as the latest in a series of transformations of industrial society, in which capitalist economies have promoted and exploited radical technological advances. Earlier advances include such energy technologies as steam and electric power, and the current wave of change is based on the application and ongoing development of new IT.[16] Information society is thus not the break from industrial society claimed by some (who see the information revolution as taking us out of industrial society, much as the agricultural revolution took us out of agrarian societies). Instead, it represents an extensification and intensification of industrial society.

Many human activities can be seen to have become more “information-intensive” (or “knowledge-intensive” in some analyses). A major dimension of this, of course, is the application of science and technology to social and economic affairs, and the associated growth in importance of codified knowledge and training in associated fields. Another important feature has been the separation of mental and manual labour, which has also fed the growth of white-collar occupations and of specialised services activities and firms. These are long-term trends, though they have apparently accelerated lately. The growth of specialised human information-processing activities represents an evident opportunity for the application of new IT, and the most IT-intensive parts of the economy are those with high levels of such information processing – areas like financial services, knowledge-intensive business services, and the like. But it is not only specialised information work that is a focus for IT applications. All work, and all human activities, necessarily involves information processing, and especially where this is a highly standardised or highly

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[14] See for an overview of the various approaches, Alistair Duff, 2000, Information Society Studies London, Routledge.

[15] Especially well-argued is Beinger, ***

[16] There is good reason to think that a biotechnology revolution is now taking off, perhaps standing in the year 2000 much as new IT did c1975. Perhaps in a few years we will talk of the bioinformation society, or simply the biosociety. A few commentators –e.g. castells **** - actually view the new biotechnology as a form of IT in its own right, since genes can be seen as carriers of information. However, the core knowledge bases of the new biotechnology are extremely different from those of semiconductors and software engineering, even if biotechnology does depend upon new IT for many of its basic tools. Rather similar points could also be made about the rapidly emerging field of nanotechnology. However, despite these distinctions, we can expect to see convergence between all three technologies, with biochips, nanorobots, and the like lying in our future.

valuable activity, it has become a candidate for technological intervention. IT is applied to the assembly line and the piloting of ships and aircraft, as well as in office work and the creation of information products. Sometimes this involves substituting for the human element – this is what the term “automation” also refers to – and sometimes it involves augmenting human operators with “computer-aided” or “computer-assisted” support.

Many sectors beyond the "core" IT sectors are acquiring microelectronics and IT systems to build into their products as well as to control their processes. IT-related jobs and skills are thus required widely. These involve "core" IT jobs such as electronics and software engineering, and database, network and website management; but many other occupations have also acquired an IT component, so that many office and craft jobs now require some IT skills (whether these be acquired through formal training or by more informal on the job means).

What is the information society, then? The perspective set out here suggests that the information society is that society which has undergone, or is evidently undergoing, thorough transformation as the result of the widespread application of new IT. This is not to say simplistically that the new technology is *causing* social and economic change. Rather, it is the application of this technology on the part of some (and increasing numbers of) actors, and the responses of others to these applications and their consequences, that constitutes this change.

These applications of new IT are visible in the form of IT-based and IT-incorporating goods and services, production processes and consumption activities, and linkages between people and organisations. Changes in skills requirement, work organisation and management practices; in patterns of demand and ways of life; and in relationships within and between organisation are made possible. As these possibilities become evident, are experimented with and demonstrated by some pioneers, so more actors for whom they appear desirable will seek to adopt them, and build upon them to achieve their own objectives.

The process is not a mechanical one, and the information society may be a misnomer – there may be many different sorts of information society (just as industrial societies in, say 1960, diverge dramatically. The economic power and technical of different actors varies considerably, and all societies and social groups carry their own histories with them. One result of this is that there is considerable variation in the extent to which different styles of application of new IT are explored. Applications depend upon capable human agents perceiving or actively creating opportunities to realise specific objectives by means of the new technological capabilities. Technical skills, economic resources, cognitive structures, and social, economic and cultural interests will interact to facilitate or inhibit the development and diffusion of particular applications.

The patterns of development that emerge involve *bounded* social choice, explicated in terms of the following points:

> “ • IT makes many new options available. But it is a material technology, not a magical apparatus capable of fulfilling every wish (or nightmare) on demand.
>
> “ • IT is an extremely malleable technology, which handles a very pervasive factor of production and consumption - information - it can be applied to many purposes and embodied in many artefacts.
>
> “ • IT is associated with a greater internationalisation of economic activities, which may erode national economies and cultures.
>
> “ • The choice of any one actor or set of actors is strongly conditioned by the choices of others, as are the results of these choices.
>
> “ • All actors are making decisions under conditions of considerable uncertainty - even those with the best understanding of the technical aspects may be ignorant of associated technological developments. They are more likely to be unaware of the social and organisational innovations, but these are nonetheless a standard feature of the learning processes around the introduction of new technologies, particularly those of a large-scale nature.”
>
> Source: Miles (199*, p**)

The choices that are confronted are generally only partially understood, and their consequences are highly uncertain (not least because other actors’ decisions are liable to influence the social contexts into which one’s own choices are worked out). The precise path of social and economic development will result from the interaction of many choices and learning processes. This helps to account for the upsurge of interest in the 1990s and 2000s in Foresight programmes, in which an effort is made to bring together major actors in various areas of social and technological change, and to encourage them to exchange and elaborate their expectations of future developments, and the strategies that will be required to deal with these. And just as the IT industry itself suggests that technical prototyping is an important feature of the construction of large and complex IT-based systems, so social experiments – or at least the systematic evaluation of the consequences of IT-related policies and programmes – should help inform decision-making and public debate.

New Information Technology: Key Features and Trajectories

Given the emphasis on social choice in the preceding section, it may seem to be a reversion to technological determinism to return to a discussion of technological trends. This is not so: the point is that technological trends are the result of social choices, and where clear trajectories can be identified this is the result of powerful social actors consistently making choices that promote the evolution of these trajectories.

It is easy enough, for example, to understand why it is in the interests of major manufacturers to continue to press for evermore miniaturised and powerful microelectronics components, telecommunications systems, and the like. The firms that first produce and constructively apply such technologies will almost inevitably have competitive advantages. Only a little more analysis is required to understand why the *networking* of IT systems is such an important contemporary development. The underlying driver here is the advantages that can be gained from rapid access to information. Microelectronics systems means that information can be processed at remarkable speeds, but where does this information come from? Much of it is not generated at the point of use, by a local sensor or an operator inputting material from a keyboard: and if information does have to be re-entered by the latter route, this involves considerable waste of time and risk of introducing errors. The advantages of rapid and accurate data transmission are evident, and the convergence of computing and telecommunications makes these a reality – with associated challenges in terms of establishing common standards and protocols for data organisation, so that devices can actually "talk to each other" rather than simply having physical connectivity.

This makes possible much greater integration of production and market systems that are spread out across the world, and the new information systems are a vital facilitator of globalisation. (Their use by governmental and voluntary organisations, too, represents part of the social and political response to globalisation that is purely commercially driven.) The development of such interfaces as Web pages and Internet addresses, by making it much easier for users to contact each other and locate relevant information, and the development of virtual trading communities and electronic markets, by making it possible for firms to move from automating their production and design processes to applying new IT to their supply chains, customer relations, and transactions, mark significant steps in this process. Indeed, it could be argues that these have been necessary steps towards the development of information society as outlines above. These are the steps that move us from isolated "islands of automation" to networked economies. There is thus reason to believe that the major transformations associated with the application of new IT are only now emerging, some twenty five years on from the introduction of the microprocessor. Thus, for example, it is argued that we are just beginning to witness the long-expected consequences of years of IT investment in terms of such measures as labour productivity and economic growth rates. [17]

This essay will conclude with an attempt to sketch in some of the key features and emerging trajectories associated with new IT, organised in terms of the categories introduced earlier.

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[17] See the studies on these themes by the OECD, for example ***