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TECHNOLOGICAL CHANGE PART III

THE TRAJECTORY OF TECHNOLOGICAL DEVICES AND SYSTEMS

"Understanding means knowing generalizations, and real intellectuals look for generalizations in all subjects." (Thomas Hurka)[1]

Trajectory

> "The term 'technological trajectories' expresses in analytical terms the basic cumulative and evolutionary features which mark the developments and changes experienced by technologies as they are diffused and employed in production and services. It also expresses the idea that, following paradigmatic scientific and technological breakthroughs, one will find an initially unmapped technological potential to be exploited and expanded. Experts in the theory and/or history of technological innovation refer to this potential in a variety of different ways: . . .increasingly, today, 'technological paradigms'." (Organization for Economic Cooperation and Development, 1992)[2]

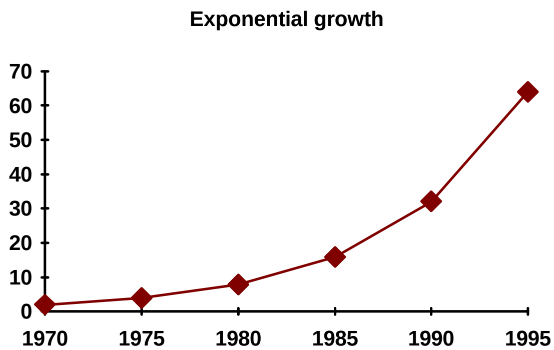
In this chapter I examine the "basic cumulative and evolutionary features which mark the developments and changes experienced by technologies as they are diffused and employed in production and services" and discuss to what extent, if any, this is the result of a selection process akin to "natural selection" in the biosphere. Some books on the history of technology[3] make much of the parallel between the trajectory of devices and the evolution of species[4] and I have explored this idea in an essay "The Darwinian Evolution of Machines." But the following discussion will make it plain that there are many factors, other than technological "fitness", which result in a given device or system conquering the market. A small digression on "fitness landscapes" is included.

The trends observed in technological trajectories are both quantitative and qualitative. Quantitatively, for economic reasons, there is a trend to reduce the input of energy, capital and labour required to produce a given quantity of output. The input of information, on the other hand, tends to increase. Another quantitative trend is toward enhanced performance, measured by various parameters. This is discussed in the following section on "patterns of growth". Most of the lecture is devoted to the more qualitative tendencies that have been observed to occur, or reported in the literature, in a large number of cases. These are "regularities" rather than "laws".

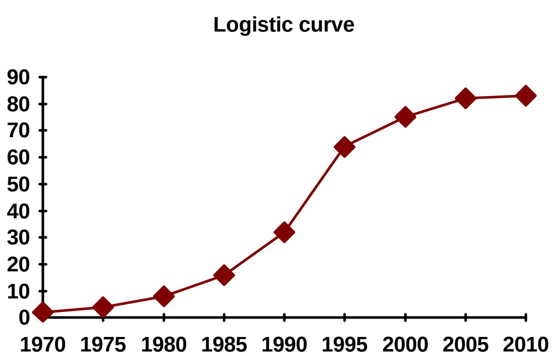
Patterns of growth

All processes and products aim for a certain ideal performance which is measured by suitable parameters (such as speed). In general, things are constantly redesigned in order to go faster, higher, deeper, achieve greater capacity (e.g. memory), etc.. The trajectory of a technology can be mapped by plotting the key parameter against time.

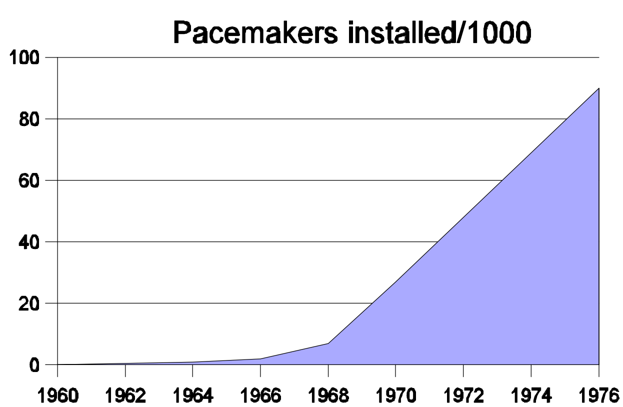
The curves representing these plots fall into three types: linear, exponential and logistic. When plotted graphically with time along one axis (the X axis by convention) and the variable (or quantity being measured) along the Y axis, the graphs have the shape of a straight line, a J and an S respectively. So people speak of J-curves and S-curves or sigmoid curves instead of exponential and logistic growth curves.



Incremental linear growth characterizes a system without feedback, exponential growth a system with positive feedback and logistic growth a system with both positive and negative feedback.[5]



The systems approach is more intuitively grasped than a purely mathematical one and, in the growth of technology or of production it truly represents what is happening.



Very few products have linear growth, but Figure 102 (Sales of Cardiac Pacemakers 1960-1975) shows an exception. The number of pacemakers added in any year was independent of the number of devices already sold. In other words there was no feed-back to the order desk from the people out there with pacemakers. They were not going out and persuading their friends to have them.

In the diffusion of a technology there is generally an initial stage of exponential growth when equal time periods are marked by doubling. A well known example from the computer industry has been called Moore's Law since Gordon Moore predicted in the 70s that the number of bytes of memory placed on a single microchip would double every year. This trend has continued or even accelerated (as of 2000).

Now it is perfectly obvious that this doubling cannot go on for ever. Everyone has heard the famous story of the Sultan who agreed to give a philosopher one grain of wheat on the first square of his chessboard, two grains on the second, four grains on the third and so on... Mathematically he would have to give him 2**64 which is some huge figure with 19 noughts and it would not take too many doublings to equal the weight of the earth. So what happens? Because we live on a finite planet, all phenomena showing exponential growth must, in fact, be in the initial stages of what will eventually become either a logistic pattern, if we get what the economists term a "smooth landing", or a collapse pattern if development follows another mathematical model provided by catastrophe theory. Smooth landing is not the best term because it can be shown mathematically that simple negative feedback with any sort of delay in its effects causes oscillations.

The negative feedback arises from the approach to some sort of limit whose depiction on the graph is known technically as the *asymptote*. The closer the measured quantity comes to the limit, the stronger the negative feedback. Market saturation would be a good example of a limit giving rise to negative feedback. The unit size of a single atom would offer a physical limit to miniaturization. As the asymptote is approached it takes more and more effort to achieve any advance.

Exponential curves have the useful property of plotting as straight lines on semi-logarithmic paper, that is, when a logarithmic scale is used for the variable and an arithmetic scale is used for the horizontal (time) axis. When logistic curves are plotted on semi-log paper they show a straight early portion and then bend to adopt a more or less horizontal late portion.

Figure 17 shows a family of logistic curves representing the growth in speed of various transportation technologies. Characteristically, new technologies do not at first achieve the performance of existing ones, but they are introduced by visionary entrepreneurs who see their potential.

Figure 19 shows the increase in acceleration energy achieved by successive generations of particle accelerator design.

In both cases a line, called the "envelope", has been drawn to embrace the best performance of the set of technologies being plotted. In Figure 17, the envelope has a logistic shape. In Figure 19 it shows "diminishing returns" over the entire period represented, indicating that each incremental step requires successively greater effort than the last.

Determinism

The path of technological advance is by no means determined. It depends on a wide range of economic factors, social values and arbitrations on the part of the main actors. (See Chapter Determinism)

"Increasing returns to adoption" is a technical economic term referring to the effects that follow from the fact that the more of a product is bought, the more people want to buy it and the greater the economies of scale and the resulting profits generated. This is a positive feedback effect. As a result of it, some technologies will not be selected on account of their superior efficiency but, rather, may become efficient because, and after, they have been chosen. Of course, as mentioned in the chapter on determinism, they may be sufficiently "locked in" or "entrenched" that they don't bother to become efficient. The phenomenon of "inertia" is like lock-in; if a certain developmental path has been followed for a time, the technology can be deflected from it only with great difficulty. The expression "resilience of socio-technical systems" has also been used for this phenomenon. The QWERTY keyboard is the best known example. More recent examples of a more subtle type include the replacement of automated voice responses in a telephone system which was changing from a monopoly to a competitive service oriented company. The corporate culture was deeply entrenched. The new CEO of Telus reports that "That school-marm voice was embedded right in the switches. And it was programed to cut you off if you did something wrong. We had to change it so that it wouldn't do that and it was harder than we thought."

Technologies developed without adequate market research, or by government technical laboratories unfamiliar with research in social anthropology, may be so biased that they can only with great difficulty be adapted to the marketplace. Telidon, the Canadian-developed interactive television system, has been cited as an example of such a technology, although in fact it later found application in the United States.[6]

The practice of benchmarking, (See "One Best Way" in chapter on Determinism) in which firms look for the best practices in all phases of their business by comparing their performance with that of their competitors, is a homogenizing force. There is much to be said for it as it prevents firms from scattering their talent too thinly. However it may inhibit the development of novel solutions, since it assumes that, at any given time, there is "one-best-way." It is the approach of the engineer rather than the scientist.

Fitness landscapes

The idea of a fitness landscape has been developed in the course of research into the application of complexity theory to biological evolution. In my opinion, the principles of *natural* selection cannot be applied without modification to the selection process which takes place in the social milieu, of which the marketplace is but one - though perhaps the dominant - element. Nevertheless, the idea of a fitness landscape does seem to be applicable. The following account has been drawn from a biologically oriented text with the wording minimally changed to fit the technological case. The concept of a prototype device has been substituted for the original "individual of a species" and its attributes representing the gene variations in its chromosomes.

You have to think of the "fitness" of a prototype in terms of the different combinations of features, functions and capabilities that it might have. "Now think of a landscape, in which each different point on the landscape represents slightly different packages of these variants. Lastly, if you imagine some of the packages being fitter than others, raise them up as peaks. The fittest of the packages has the highest peak. The landscape overall will be rugged, with peaks of different height separated by valleys. Remember, this landscape represents fitness probabilities, places where..." prototypes might be, depending on the combination of features incorporated in them. If a prototype happens to be in a fitness valley, then research and development "might push it up a local peak, representing a rise in fitness. Once on the local peak, it may, metaphorically, gaze enviously at a nearby peak, but be unable to reach it because that would require crossing a valley of lower fitness." (passages in quotation marks from Lewin, *op. cit*. p.57)

Fitness landscapes explain technological multistability (see "One best way" in Determinism)

Trends in energy supply

Changing fuels led to a trend toward increasing the independence of location from the source of energy supply. Early technology used local sources of energy; the first textile factories were located where swift streams supplied hydraulic power or, later, where coal could be mined. After the invention of the railway, and the construction of a canal system, coal could be brought from farther away. The invention of the electrical grid gave free rein to physical dispersal. The move away from coal to oil and natural gas as the principal contemporary sources of primary energy has made location independent of railways but dependent on pipelines and ocean-going tankers. It has obviously had profound geopolitical effects, of which the Gulf War is but the latest example.

A specifically technological trend has been toward increased mechanical efficiency due to the greater specific energy content of petroleum fuels over coal. This is believed to have had a significant influence on measures of labour productivity in the first half of the 20th Century.

Trends in automation

In the history of technology, [7] we observe four stages

I Tool (energy comes from the subject)
II Machine (energy is objectified)
III Automata (control is objectified)
IV Devolution of control to consumer (Automated Banking Machines)

Marx pointed out that in the early stages of development of mechanization the machinery is designed to copy some human action (anthropomorphic). It is only later that mechanisms peculiarly adapted to machinery, as such, are introduced (mechanomorphic). Contrast early attempts to fly using flapping wings, with later attempts using propellers. Reciprocal motion eventually gives way to rotary motion and one of the breakthroughs in mechanization was the conversion of reciprocal energy to rotary energy as exemplified by the evolution of the reciprocating steam engine into the steam turbine.

The chemical industry evolved from batch processing to continuous flow processing. Biological reactions have proved more stubborn than inorganic reactions to this evolution but eventually they succumb. Commercial bread making and the making of the "standard suds" type of beer have moved from batch to continuous flow while bioreactors, which I used to use as examples of resistance, are in the process of conversion.

A decisive moment in the evolution from tool to machine took place when the slide rest (a tool-holding device) was installed on a lathe. The operator was removed from direct control of the cutting tool and established indirect control by rotating screws. "Distancing" took a quantum leap.

Standardization and replaceable parts

A prior condition of mass production is the standardization of parts. There is a constant struggle between standardization and innovation. If standards are adopted too early they lock-in a favoured manufacturer, possibly at the risk of stultifying further improvements. If they are adopted too late they risk being ignored. Much disregard for standards is due to a combination of ignorance and moral irresponsibility - sometimes combined with hubris. Any one who has tried to assemble a computer from parts made by different manufacturers will have been frustrated by the lack of cabling standards. At a very primitive level of technology, the reuse of glass containers is made extremely difficult by a lack of standards e.g. in beer bottle shape and capacity (of imports). Canada's failure to adopt the International System of Units after spending nearly $100 million in preparing for it has been a costly fiasco.

The introduction of replaceable parts was achieved first in the United States and became known as the American System of manufacture. It was first used in the manufacture of side-arms. Before that time each part had to be fitted by filing. The skilled craftsmen who performed this task were known as "fitters" (a term that persists in artillery regiments and various engineering applications).

Concretization

What Simondon has called a movement from the abstract to the concrete[8] (I do not care for the terms) describes what is at once the formation of functional complexes and the simplification of their expression (increase in compactness) through the reduction of parts[9]. In American literature devoted to the moulding of plastic parts, this has been referred to as "net-shape production" described as "consolidating many small parts, each individually fabricated, into a single large part moulded to net shape."[10] To take an older example, consider the air-cooled engine. In early designs, the heavy cylinder is cooled by vanes that are welded to it. In later designs, the vanes are incorporated into the casting in such a way as to give strength to the cylinder, whose walls can then be made much thinner.

Volume diminishes over time, as do mass, number of parts, time of response and price.[11] All parameters tend toward an asymptote and the trajectory is eventually logistic. Note, however, that some parameters may be incompatible. For example, miniaturization often comes at a cost: compare the price of a desk-top computer with that of a Notebook with equivalent performance.

Notice that the criteria used to improve the design may emphasize manufacturability as much as functionality for the end user[12]. To this we may now add the increasing importance which designers have to give to the ease of disassembly into recyclable or reusable elements. As total-cycle economics is adopted in the future this will play an increasing role.

Multipurpose devices (Polyvalence)

There is an extremely important class of devices which Ellul called "*polyvalentes*" or "multi-purpose" (a multipurpose village hall in France is called "Salle polyvalente"). These devices have a *radiating trajectory*. Their paths branch out in many directions as different fields of application are found for them. e.g. the microchip, the laser, the genetically engineered cell. Historically, the electric motor is the archetypal polyvalent device. "..Edison's exploration of the possibilities of rotating cylinders with patterned surfaces which could be created by and could control the movement of, a sensitive stylus (which might be a beam of light) led to copying machines, to an automatic telegraph repeater, to the phonograph and to the kinetescope, an early motion picture device."[13]

It is of the greatest economic importance to be able to identify, at an early stage of development, the polyvalent potential of a new invention. The microchip is the current polyvalent device, par excellence. The laser is another polyvalent device whose trajectories are still radiating. Fuel cells, primarily developed for automotive propulsion, may find even earlier mass adoption for domestic power systems. Sensors are an increasingly important class of devices whose applications will radiate into almost every conceivable field. An example of a crude sensor is the accelerometer that causes an air bag to expand: a sophisticated sensor would detect the presence and mass of a passenger and adjust the force of inflation accordingly. This will use MEMS technology (MicroElectroMechanicalSystems)[14] which can build an accelerometer on a single chip for a couple of dollars. The impact of sensors does not stop at mere sensing. When eyes, ears and sensory organs are put on devices they will be programmed not only to observe but to manipulate. This will contribute to a great leap forward in hyperautomated manufacturing and thus expand the possibilities of mass customization[15], a trend foreseen by Alvin Toffler who gave it the name "demassification". The trend to Mass customization has been most vigorous in the clothing industry (Levi Strauss & Co.'s "Personal Pair" line; Custom Foot of Westport, Conn.), eyeglasses (LensCrafters), and computers (Dell has more than 14,000 configurations.)[16]

Transfer of techniques (Exaptation)

A special case of polyvalence is provided by technologies that are developed with one aim in mind but then applied to a quite different purpose. In many cases the second application proves to be viable while the first is a fizzle.[17] The term "exaptation" has been applied to cases in biology where an organ adapted to one purpose through natural selection later becomes adapted to another purpose[18], and could usefully be applied to inanimate objects.

Examples of the origin of important technologies by transfer include the classic case of the punched card which had its first manifestation as a means of producing music in automata; the next very important application was in directing the weaving pattern in a Jacquard loom; the best known derivative of this was the Hollerith punch card used to control early computer programs.

The non-stick frying pan was invented by a Frenchman, Marc Gregoire (1916-1996) who developed the process in order to provide a mould for plastic fishing rods.[19]

Scotch tape was first developed as a masking tape for painting two-tone bodies in the automobile industry. The idea was transferred to cellophane by a young lab technician, Richard Drew and used for general purposes. Later the 3M company introduced Scotch Magic Transparent Tape with the advertisement that "It unwinds easily. You can write on it. You can machine copy through it. It's water repellent. And, unlike the earlier tape, it won't yellow or ooze adhesive with age."[20]

At the beginning of the 1990s Philips and Matsushita developed thin-film magnetoresistive heads for their Digital Compact Cassette system. But this system was a commercial flop and in 1996 Matsushita adapted the digital heads for use with analogue tape decks. They will minimize background hiss.[21]

Reverse Salients

The last example above illustrates an important principle of development identified by Henry Petroski: *"Form follows failure"*. Improvements are spurred by failures in the existing product - all of which are clearly set out in the above quoted advertisement for its replacement! It might be better to say "form follows dysfunction" to emphasize the reference to the aphorism "form follows function".

The birth of the piano from the harpsichord is said to have come about through the frustration of Bartolomeo Cristofori (Florence abt. 1698) that no matter how percussively he played, the strings were plucked sweetly. He replaced the picks with hammers and developed a key mechanism to control their volume.

Another way of referring to this trend is to say that inventors tend to attack "reverse salients". A reverse salient is a "pocket of resistance" left behind in the general advance of an army - or, in this case, a technology. As systems grow, the need for organization is often a reverse salient. The invention of the holding company in the 1920s corrected one such reverse salient. Industrial research laboratories were invented to provide conservative inventions at reverse salient sites.[22] They were not expected to provide radical innovations ("Von Gedankenblitz keine Spur!" Carl Duisberg, director of Bayer before W.W.I)

Convergence of modes (complexification)

The mirror image of the divergent trajectories of polyvalent devices is represented by the convergence of modes, particularly in communications devices. This is achieved by the synergistic merging of two or more technical systems into a new complex.[23]. Early examples include the phone and the copying machine merging to form a fax, the phone and the computer merge to form another sort of communication device providing E-mail and access to the Internet. Now we are seeing whole systems of information, entertainment and interactive services such as shopping and banking coming together. Even the information is there for fun - as infotainment.

As a result of all this convergence "There is a blurring between goods and services. In fact most goods are sold as a complex package of goods and services."[24]

The currently envisaged end term of the hardware following this trajectory is the Wallet PC described by William Gates in several public lectures and in his book, The Road Ahead. This will combine a computer, smart card, global positioning device, satellite communication system and personal organizer into a slim pocket-sized device which, amongst other things "... will be able to keep audio, time location and eventually even video records of everything that happens to you. It will be able to record every word you say, every word said to you, body temperature, barometric pressure, blood pressure etc. etc."[25]

The term "convergence" is also being used in a different sense by business writers to describe the convergence of rival systems at a common point in the market place where they may collide. The convergence of telephone companies and cable companies toward rival interactive multimedia systems is a case in point. Both parties have appealed to regulatory authorities for protection from each other.[26]

The biological analogue of convergence is "symbiogenesis"; we could therefore speak about "symtechnogenesis". Lynn Margulis, the biologist, claims that the most useful inherited variation comes from mergers: the incorporation of microbial genetic systems into progenitors of animal or plant cells.[27]

Invisibility

In his figure/ground theory[28] McLuhan made much of a general tendency of technology to become invisible to those who use it.

> McLuhan's point was that most people are trained not to look for the ground in any situation. They focus on one part and ignore the rest. If people consider the motorcar, for example, they focus on the car itself, rarely perceiving the network of gas stations, highways, neon signs, parking lots and all the altered habits and perceptions that arise out of the existence of the car -- the ground, in other words, of the automobile. (Marchand, 1989, p.248)

The thought was by no means original to McLuhan. Lewis Mumford had the insight that this was a psychological necessity as the complexity of the technological environment increased[29].

> "To reduce the constant succession of stimuli, the environment must be made as neutral as possible. ...So that if the canon of economy and respect for function were not rooted in modern technics, it would have to be derived from our psychological reaction to the machine: only by aesthetically observing these principles can the chaos of stimuli be reduced to the point of effective assimilation.".

There are several ways by which this is brought about. One of these is a progressive dematerialisation of technology as the power of mind substitutes for mechanical force and mass. Two other important ways in which technology achieves invisibility are closure and physical concealment.

Dematerialisation

George Gilder has written that "The central event of the twentieth century is the overthrow of matter. In technology, economics, and the politics of nations, wealth in the form of physical resources is steadily declining in value and significance. The powers of mind are everywhere ascendant over the brute force of things[30]."

There is progressive substitution of knowledge for matter and energy in the production process. The process becomes dematerialized. I have in the past used the prior term "etherialized" coined by Arnold Toynbee in his Study of History[31], though I no longer think it exactly fits the bill. Toynbee at first thought that technology had historically followed a path of simplification, because that was the trend observed in linguistics as inflection was replaced by auxiliary words. But then he wrote "...the process liberates forces that have been imprisoned in a more material medium and thereby sets them free to work in a more ethereal medium with a greater potency. It involves not merely a simplification of apparatus but a consequent transfer of energy, or shift of emphasis from some lower sphere of being or of action to a higher. Perhaps we shall be describing the process in a more illuminating way if we call it, not simplification, but etherialization." Buckminster Fuller recognised the process of dematerialisation and termed it "ephemeralizaton"[32]

An example that epitomises the process has been documented by Bruno Latour in his history of the development (and eventual abandonment) of the Personal Rapid Transit device known as Aramis[33]. Aramis was designed to woo Parisians[34] from the private automobile by offering the flexibility of personal destination selection combined with the rapidity of non-stop rail travel. The computer-controlled cars holding small numbers of passengers would branch off to local destinations or join together to form trains. The coupling of the cars was, however, non-material. It was achieved through remote sensing (sonic at a distance and optical within the last metre). M.Parlat, interviewed for the history project by Latour said, "Aramis, the heart of Aramis, is nonmaterial coupling." But at this point exaptation steps in! In 1999 Daimler Chrysler announced a research project[35] to close-couple heavy trucks into convoys for aerodynamic efficiency gains (estimated at 15%). To what extent Aramis technology is being used I do not know; but although the application is different the concept is the same - to effect the coupling without mechanical linkages.

A new $50 million research project announced at MIT in 2000[36] aims to banish computers as we know them "into thin air". The Oxygen Alliance is a five-year project, involving at least 250 researchers,"designed to make computers as prevalent and invisible as oxygen." Desktop computers and keyboards would be replaced by small, hand-held devices and out-of-sight units embedded into walls and ceilings that respond to voices, not the click of a mouse.

Besides the substitution of knowledge for matter and energy, dematerialisation includes the movement from a tangible to an intangible economy as we move from a fascination with things to a fascination with experiences.[37] Ide and Cordell describe this as "the emergence of content as commodity..." Is this the redemption of the message from the medium? This trend was foreseen by John Ruskin over a century ago, in the book[38] that inspired Mahatma Gandhi, where he wrote, "Some day it should turn out that mere thought was in itself a recommendable object of production..."

The dematerialisation described above happens in the dimension of space. Equally important, but often overlooked, is the potential for dematerialisation in the dimension of time. This would take the form of design for durability, ideally as an entity, but at least as recombinable elements so that the material and energy used for a particular function is minimized over time. (See further observations in Resolutique.)

Closure and Ubiquity

A phenomenon observed in the trajectory of many devices is "closure". This is the freezing of a design at a certain state of perfection. It is not to say that absolute perfection has been or even could be attained. But a consensus seems to develop amongst designers that further efforts at improvement would be counterproductive - the public resists change in these naturalized objects. Naturalized objects recede into the background of our awareness. We do not focus on them expecting to see the latest or any improvements. The canoe is such a naturalized form. The automobile seems to be approaching it.[39] For a long time the piano was thought to have achieved closure but this has recently been challenged by computer modellers.[40] The analogous process in the world of biological evolution is known as "stasis".

Often coincident with closure in design is the phenomenon of ubiquity - being present everywhere - and for that very reason unnoticed. The pencil has been so familiar an object for so long that even Thoreau, who came from a family of pencil-makers, forgot to include it on the list of necessities he prepared for his wilderness cabin![41] The personal computer, already in 1997 owned by 4.2 million of the 11.6 households in Canada, is approaching ubiquity, while the smoke detector has already achieved it[42].

As Wiebe E. Bijker has "demonstrated in a close examination of the archives of Bakelite's inventor Baekeland, the participants often collude in re-describing the events that led up to an innovation so that the result appears to be the natural and only possible outcome."[43]

> [Bijker] suggests that the fixing of meaning of a technology constitutes a form of power, the result of negotiations within the social group. The allows a way of understanding the obduracy of technology, the apparently natural character of accepted design solutions in political terms.[44]

Clearly, there is more to the phenomenon of closure than its role in contributing to invisibility.

Physical concealment

Physical concealment of our life support apparatus takes place in ways that include: ascension, submergence, black-boxing,[45] opacity, miniaturization and the aesthetics of inconspicuousness.

Ascension

The metaphor of ascension has been used by Hardison to describe the vanishing of large technological systems, such as banks, as the functions previously performed by humans are taken over by microprocessors. Hardison uses the metaphor of banks vanishing through their own skylights[46]. He adds:

> "More to the point, the computer has already all but disappeared -- it has ceased to communicate in a significant way with its creators. The days when man and the gods walk the earth together in fellowship will evidently be few. They will be followed by an ascension, by which is meant an event that renders the gods invisible."

A speech given in London by Bill Gates expressed exactly this view. The newspaper headline read, "Computers on way to invisibility: Gates"[47]

Submergence

Before the plastic black box was invented, engineers and others were hiding the nuts and bolts behind walls or underground. Since Hardison used the metaphor of ascension, perhaps we can describe this mirror image as submergence. Certain artefacts present themselves to us like the tip of an iceberg, masking the great mass below. The telephone, the electric light switch and the faucet come to mind. How often do we give a thought to the huge network of cables and pipes that lie submerged beneath the soil and our consciousness in order to supply us with a stream of ordered bits, electrons or molecules?

Wolfgang Sachs wrote, in this context:

> "Whoever puts his foot down on the accelerator or pulls a lever also commands a remote, an invisible world in order to precipitate an event in the immediate, visible everyday world. All of a sudden, incredible power or speed becomes available, whose actual causes lie hidden far beyond the horizon of direct experience. The fireworks display happens, so to speak, front stage, whilst the gigantic machinery that makes it all possible ticks away backstage, out of sight. In this separation of effect and cause, in this invisibility of the systems that pervade society and produce technical miracles, lies the reason for the magic of technology, which, especially in the Third World, holds so many people spellbound. The appeal of technical civilization often depends on an optical illusion."[48]

H G Wells, in his classic science-fiction story "The Time Machine" (1895), provided, whether wittingly or not[49], a vivid allegory of the phenomenon of submergence. His time traveller into the future finds that human beings, by a gradual accentuation of the differences between Capital and Labour, have become two distinct species. Above ground, the effete Eloi live indolent lives of undemanding pleasure, while underground, in dark tunnels, all the machinery that provides the necessities of life is tended by the brutish Morlocks.

There is a macabre twist to the tale in which Wells, no doubt drawing on Hegel's reversal of the master-slave relationship, reveals that the Morlocks are now dominant and use the Eloi for meat. Wells makes much of the fact that the Eloi will not face the reality of the underground realm and will not discuss the significance of the wells that rise to the surface from this buried world of machinery.

Black-boxing

Norbert Wiener used the term "black box" to describe a unit designed to perform a function before one knew how it functioned. It therefore had a connotation of mystery as well as of invisibility of its contents, which, for that matter, the white boxes in Wiener's laboratory also shared. The essence of black-boxing is mystery; but, since one cannot know what is going on inside, one ignores the box itself. In Michel Callon's essay "La boîte noire", the baker's shop is the paradigm of nested black boxes. To the customer, all behind the counter is a black box; Madame penetrates through the door into the storeroom but is then confronted with the black box of the workshop; Monsieur operates in the workshop but faces the black box of the oven; only the mechanic penetrates into the works of the oven..

More and more essential components of our every-day devices are being literally sealed inside black plastic boxes marked "No User-Serviceable Parts Inside" which really means "Keep Out -- None of Your Business." Vital parts of your automobile are now a complete mystery to the auto repair man at your local service station. The trend toward placing chip-based devices in protective, user inaccessible, boxes has meant a further withdrawal of technology from our understanding and control.

Mathematics, which educators are inclined to tell us is a necessary skill for survival in "this technological age", has in fact retreated into a black box readily available to us in the form of a miniature scientific calculator. A correspondent in the Globe and Mail business section observed "Almost no one does mathematics on the job any more"[50] That confirms my own business experience. I need hardly say that this does not relieve us of the need for numeracy.

Since we cannot see inside black boxes, we cannot understand, and since we cannot understand, we ignore. The whole function sinks into invisibility.

Opacity

One can also see the process of black boxing metaphorically as technological artefacts become as it were "opaque"[51]. We cannot see through them to determine their true nature and origin. Cool Whip, says Borgman, is an opaque article. "Its origin and substructure are concealed by a vague and implicit understanding of anonymous research and development scientists." I think Coffee Whitener is an even better example since it is both literally and metaphorically a creator of opacity.

Miniaturization

Progressive miniaturization has reinforced the trend to invisibility in its own right as well as facilitating concealment in boxes. There are good technological reasons for much miniaturization, such as reducing the mass of portable devices, economizing on materials and reducing the distances that signals have to travel in order to increase the speed of communication within devices such as microchips. Other devices seem to have been miniaturized just for the sake of it -- wrist calculators, for example. One may refer to this type of scalar extremism as "The Guiness Syndrome".

Potentially, the most important development in miniaturization is the gradual perfection of nanotechnology, the manipulation of individual atoms and bonds under high vacuum so that molecules can be isolated. This is an example of the Engels Effect where a quantitative change in scale results in a qualitative change in the kind of technology being addressed. It is a very active field of research but concrete results have been slow in coming. The interested reader may follow developments at the Foresight Institute http://www.foresight.org.

Aesthetics of Inconspicuousness

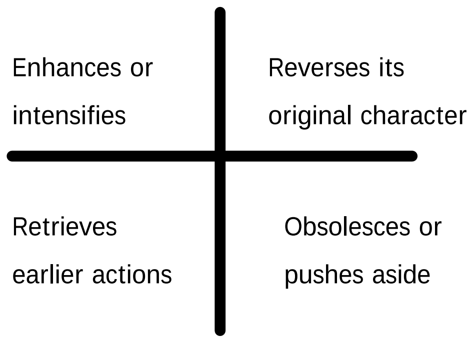
Derrick de Kerkhove[52] has recently pointed to a trend in design toward what he calls inconspicuousness. As he puts it "Things want to hide, to meld into the background. Functions cease to be evident in some quality machines. This discretion is like a new world of 'manners' in design. Although the trend of global economic austerity may account for a recent tendency to avoid external signs of wealth, there may be more to the developing aesthetics of disappearance than an economic base". He observes that the higher the tech the more discrete the medium.

A striking and exceptional countertrend to inconspicuousness is illustrated by the IMAX system of cinematography.[53] In IMAX theatres, the technology is the experience and for most viewers the content is secondary: this is the quintessential medium as message. At some sites the operator is enclosed in a plastic bubble so that the audience may marvel at the equipment. At all sites there is an explanatory technical display in the lobby.

Laws of media[54]

McLuhan's four "Laws of media" are partly self-evident and the claim for their novelty is overblown. They have been assembled into an easily remembered form which the McLuhans (father and son) called "the tetrad" (Fig. 49).

Fig. 49 McLuhan Tetrad



Each of the four parts of the tetrad may be said to constitute a trend.

$ (Enhances) A new technique would hardly be introduced if it were not seen to be an improvement on existing techniques.

$ (Obsolesces) If the function is already being performed by another technology, that technology will become obsolete (or will become an art form, McLuhan suggests).

$ (Retrieves) Dénis Debray implies that the idea of the déjà vu, that a new technology retrieves some function from the past, is a well known phenomenon when he writes, "in conformity with the rule of the spiralling recurrence of the most ancient in the form of the most new."[55] The FAX retrieved the personal touch of handwriting, eliminated by the Teletype that the FAX made obsolete. We may include here the class of now functionless features such as dummy rivets, corrugations, tenons in stone, etc., known as skeuomorphs[56] held over from the past where they were required by the material of construction. "They seem to be very common in motor car design, particularly where changes are made from ferrous metals to non-ferrous metals or plastics." An example that may be familiar to many readers is the "card-index" facility provided in many computer software package; it mimics the old "Rolodex" in its imagery!

$ (Reverses) The idea of reversal is at least as old as Hegel who attributed the fall of civilizations to the intensification of their own first principles. George Soros has recently drawn attention to this phenomenon in his critique of contemporary capitalism.[57]

Robert Wright, the unorthodox economist, in his discussion of the relationship of Man to technology, emphasises *process* over *stocks*, the reverse of orthodox economics. Wright claims that process can involve growth, decay, metamorphosis or inversion - a foursome strongly suggestive of McLuhan's Tetrad. Certainly, Wright's "inversion", of which Hegel's master-slave relationship is cited as the archetype, relates closely to McLuhan's "reversal". Wright applies the idea of inversion to the technology-man relationship, writing, "Humans originally developed technology to serve their own ends, but an inversion has occurred and now, as Emerson observed tersely, 'things are in the saddle and ride mankind.'"

Conclusion

There are no doubt many other trends, shared more or less generally by evolving technologies. By observing these trends we are forced to accept the fact that no simple explanation of technological development is convincing. Market pull is seldom evident although entrepreneurs always have the vision of a market and this is what drives them forward. The market is where the final selection takes place -- but not necessarily on the basis of least cost or superior performance.

Nevertheless, overall, and with many exceptions, the course of technological development seems to be one of increasing economy of means as "more is achieved with less". Here, the world of the artefact stands in sharp opposition to the organic world where, as Lotka found half a century ago, the trend of evolution is towards the maximization of energy throughput.[58] As the concept of sustainability is adopted by more and more people as the guiding ethos of the 21st century, this divergence of technological trends from those of "Nature" should be accelerated **B** a difficult conclusion for those who see salvation in a "back to nature" movement.

1."Why intellectuals care about the Flintstones." In Foundations: Society, Challenge and Change. James V. Rudnick, ed. Toronto: Thompson Educational Publishing Inc., 1995, 24-25.

2.The terms "technological trajectory" and "technological paradigm" appear to have been proposed first by G. Dosi (1982). Research Policy, v.11, 147-62.

3.George Basalla (1988). The evolution of technology. Cambridge University Press. Stuart Kauffmann (1995) At home in the universe: the search for laws of complexity. Viking.

4.Anatol Rapoport (19896) devotes the first part of his essay on "The technological imperative" to a discussion of the analogy between biological and technological selection with the role of "breeder" being played by "inventors, industrial managers, various professionals and investors." (Man-Environment Systems, v.16, p.47-54).

5.This insight was provided by General Systems Theory, (Von Bertalanffy).

6.Jerome Durlak (1995) Perspectives on Convergence: Oral Presentation (reported on WWW by students of Doug Brent, University of Calgary)

7.Arnold Gehlen , (1980 p.19)

8.Gilbert Simondon, Du mode d'existence des objets techniques. Edition augmentée d'une preface de John Hart et d'une postface de Yves Deforge. Aubier, 1989

9.A reference in Petroski, not followed up, is to Adrian Forty's Objects of Desire which identifies the same trend toward complication plus compactness.

10.Hawken, P., Lovins, A and Lovins, H (1999) Natural Capitalism, p.75.

11. Deforge, op.cit

12.Simon Head, The New Ruthless Economy, New York Review, 29 Feb. 1995

13.Hamlin p.529

14.Saffo, Paul (1998) Sensors: The Next Wave of Infotech Innovation. Menlo Park CA: Institute for the Future.

15.Davis, Stan (1996, 1987) Future Perfect. Addison-Wesley.

16.Church, Elizabeth (1997 04 11) “Levi’s sizes up its customers”. Globe and Mail, B9.

17.Don Ihde (Philosophy of Technology, p.116) calls "the designer fallacy" the attempt to interpret a technology in terms of its original intent. The typewriter was invented as a possible way for blind persons to write and the telephone to assist the hearing-impaired.

18.Attributed to Stephen Jay Gould in Brockman, John. The Third Culture: Beyond the Scientific Revolution. NY: Simon and Schuster, 1995.

19.Obituary notice "Non-stick frying pan inventor dies", G&M 12 Jan. 1996.

20.Henry Petroski (1992). The evolution of useful things. Knopf, p.80-83.

21.New Scientist 27 Apr 1996, p.23.

22.The Social Construction of Technological Systems edited by Wiebe E. Bijker, Thomas P. Hughes and Trevor J. Pinch. Cambridge MA: MIT 1987

23. "en conformité avec la loi universelle de centro-complexité" Teilhard, Le phenomène humain p.341.

24.Ide and Cordell (p.29) . Albert Bressard referred to these complexes as "compax" (the term did not catch on).

25.William Gates, 1995, The road ahead, p.247.

26."Bell seeks permission to test potpourri of new services: Cable firms say it's only trying to leap into their business." Globe and Mail 30 Jan. 1996, A1, A2.

27.Brockman, John. The Third Culture: Beyond the Scientific Revolution. NY: Simon and Schuster, 1995. p.130 et seq.

28.Clearly explained by his biographer Philip Marchand (1989, p.240 et seq.)

29.Technics and Civilization p.357

30.George Gilder, 1989 "Microcosm".

31.1933. Abridged version by D.C.Somervell, 1948, 198.

32.A biographer, Hugh Kenner writes "...what Bucky call the prime theme of man's recent evolution: the transition 'from tracked to trackless, from wired to wireless, from visible to invisible.' But no one seems to have intuited a large-scale pattern of that order, and even when it has been clearly stated most people still have trouble remembering it most of the time, though Bucky reduces it to a single word: Ephemeralization." *Bucky: A guided tour of Buckminster Fuller*. New York: William Morrow, 1973, p.56.

33.Bruno Latour (1996). Aramis or the Love of Technology. Translated by Catherine Porter. Cambridge MA: Harvard University Press. [Aramis is an acronym for Agencement en Rames Automatisées de Modules Indépendants dans les Stations.]

34.Paul Viveret, editor of Transversales Science Culture, estimated in 1999 that 90% of the real operations of the French economy had already been “immatérialisés”. (Personal Communication, Marc Luyckx)

35.Daimler-Chrysler Hightech Report ‘99.

36.Emery, Theo (2000 06 21)Associated Press. Project aims to banish computers into thin air. I am indebted to Sean Tubbs for this reference.

37.Ide and Cordell (1992)

38.Ruskin, John (1906) Unto This Last: Four Essays on the First Principles of Political Economy.. London: George Allen.

39.Simondon and Deforge develop this theme.

40.Phil Novak. Taking the pain out of piano. Globe and Mail 6 Apr 1996.

41.This story is told in H.Petroski's The Pencil, according to information in the electronic journal C-Theory v.19, no.3 (Internet 1996 12 05).

42.Alaton, Salem (1999 03 08) “Welcome to the age of qualified ubiquity.” Globe and Mail, A20.

43.Steve Woolgar, New Scientist, 9 Dec. 1995, 49.

44.Woolgar, op.cit.

45.The term black box is used in this paper to designate a concealed piece of equipment, often enclosed in an actual black box. It does not have exactly the same meaning that it did when first introduced. Peter Galison (1994, p.246 and footnote 46, p.247) writes "Black boxes, as [Norbert] Wiener used the term, meant a unit designed to perform a function before one knew how it functioned; *white boxes* designated that one also specified the inner mechanism".... "The term *black box*, commonly used at the MIT Radiation Laboratory during the war, became popular through the use of black-speckled boxes to encase radar electrical equipment such as amplifiers, receivers, filters and so on. [Norbert] Wiener himself referred during the war to "boxes" with unspecified interiors......After the war, Wiener elaborated the notion of a black box, contrasting it with a "white box" in the sense invoked here.

46.Albert Teich, The future of technology, 6th ed. p.24

47.Reuters in Calgary Herald, Dec.4th, 1995.

48.Wolfgang Sachs (Interculture 1990, p.16)

49. Paul Lathrop after reading a draft of this passage observed (personal communication 2000 11 03) “perhaps wittingly” as Wells had remarked that there is a tendency to use the underground space for “the least ornamental purposes of civilizations”.

50.Ian Gatensby in a letter to Report On Business (March 1994).

51.Borgmann (1987) Revue Internationale de Philosophie no.161, Part 2, 239-241.

52.The skin of culture

53.Charles R. Acland, Shadows on the landscape: notes toward an anatomy of IMAX. Point of View, Summer/Fall 1995. No.27, p.8-10, 27-29..

54.McLuhan, M and McLuhan E. Laws of Media: The New Science. Toronto: University of Toronto Press, 1988.

55.In Nunberg, Geoffrey (Ed.) . (1996) .The future of the book. Berkeley CA: University of California Press, p.146.

56.From the Greek skeuos (vessel) and morphe (form). OED "1981 Chartered Mechanical Engineer, Sept20/3. Note also a reference to "vestigial features" in Anatol Rapoport's "The technological imperative", Man-Environment Systems, v.16, nos. 2&3, p.48 (1986).
An alternative spelling and etymology gives skiamorph from the Greek skia (shadow).The term skeuomorph has also been used in biology by Nicholas Humphreys for analogous relics in our sensations (see Brockman, John. The Third Culture: Beyond the Scientific Revolution. NY: Simon and Schuster, 1995, p.205..)

57.Soros, George (1997) Atlantic Monthly. (February) p.45-55, 58.

58.Lotka, A. J. (1945) The law of evolution as a maximal principle. Human Biology, v.17, no.3, 167-194.