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INFORMATION TECHNOLOGY AND SOCIAL CHANGE

AN EVOLUTIONARY SYSTEMS ANALYSIS

It is known that technology plays a major role in catalysing change in contemporary societies, but current empirical studies do not clearly elucidate the generic role of technology as a social change agent. This study seeks clarification by adopting an evolutionary systems perspective in light of which societies are complex and open dynamical systems in constant interaction with other societies as well as their natural environment. Technology is an indigenous factor shaping this interaction and prompting modification in societal structures. Information technology, in rapid development for the past hundred years and in explosive evolution during the last decade, constitutes a variety of technological innovation that specifies as well as intensifies the historical impact of the operative technologies on the societal structures exposed to them.

Key Words: dynamical system, information, technology, social change.

It is generally recognized that human societies are presently in a period of transition. In the 1970s the transition was said to be from industrial to postindustrial society, while in the 1980s the concept of information society came increasingly to the fore. The driver of the transition was first called the "second industrial revolution," later the "post-industrial revolution," and is currently known as the "information-communication revolution."

The shift in terminology has sound reasons: the effect of the growing flows of information on society is unmistakable. But there is comparatively little clarity concerning the **nature** of the effect. In order to shed light on this question, this paper shall first review the current development of information technologies, and then analyse societies as energy and information-processing systems sensitive to, as well as productive of, changes in their environment.

1. THE CURRENT DEVELOPMENT OF INFORMATION TECHNOLOGIES

The current development of information technologies can be traced to long-term developments that moved to the take-off stage in the span of the last one-hundred years.

Technologies of information processing have been known and in use for thousands of years: the invention of the alphabet and of the number system are among the most profound information-technological breakthroughs of all times. Calculating devices have also been known: the abacus, a simple but powerful instrument still used in many parts of the world, has been around for three millennia. On the other hand machines that would perform computations by executing algorithms with built-in programs appeared only in the 17th century. In 1642 Blaise Pascal invented an adding machine that may have been the first digital calculator, and in 1671 Leibniz created an instrument that multiplied by repeatedly adding. In 1833, Babbage produced the Analytical Engine and created a logistical basis for building genuine computing machines.

About one hundred years ago artificial information-processing technologies reached the take-off stage. Hollerith automated the US census at the end of the 19th century; Bell invented the telephone; Hertz developed the principle of wireless communication and pioneered the development of radio. Computing systems came into their own a few decades later: Konrad Zuse built his Z1, Z2 and Z3 computers in the 1930s, and Eckert, Mauchly and Goldstein created the cumbersome but accomplished ENIAC computer in 1946. UNIVAC I, a vast machine with 5,000 heat-generating vacuum tubes taking up an area of 220 square feet and weighing five tons, emerged into prominence when it predicted the landslide victory of Dwight Eisenhower in 1952.

The mid-century invention of the computational architecture of digital data-processing by mathematician John von Neumann permitted a quantum leap in electronic information processing. Through digitalization, numbers, letters, words, sounds, images, and the measurement of mechanical and electrical instruments could be rapidly and accurately transformed into strings of electronic pulses. Digital signal-processing computers benefited from the concurrent mass production of transistors for hearing aids and radios and became commercially available in the early 1950s. In the 1960s computers entered the field of production. CAM harnessed the new-found powers of the digital computer, and CIM integrated the different elements of manufacturing, enabling enterprises to operate the whole process as a single system.

During the past decade information technologies have been in explosive development. Qualitative development concerned miniaturization and power multiplication. In the 1980s the computing power of the already powerful mainframe systems of the 1970s was compressed into tabletop workstations and personal computers. Similar capabilities were further compressed in the early 1990s into laptop computers of notebook size. The systems coming on line have been progressively more powerful, with the 386 and 486 processors of today's laptops outdistancing the most sophisticated PCs of the late '80s. Hardware is still in rapid development. In 1985 about one million components could be integrated on a chip, and by 1990 the number has grown to five billion. Some experts predict chips with one thousand billion components by the year 2000.

Also software is developing explosively, with computers rapidly climbing the ladder of human skills. Earlier systems replaced mainly lower-level skills, such as addition and subtraction, and the simpler forms of man-machine communication. With the advent of CIM, CAM and CAD, computers moved into slots that were previously the preserve of human technicians. And sophisticated programs, such as Automatic Theorem Proving (ATP) in mathematics and the automatic sequencers used in the Human Genome Project encroach even on the skills of scientific specialists.

Quantitative development is noteworthy as well. In 1985 there were roughly 400 million microprocessors in use worldwide, incorporated in some 4 million computers and in various control and command systems, household appliances and electronically steered devices. By 1991 the number of microprocessors in worldwide use had grown to three billion, and according to current forecasts by the year 2000 there may be 10 billion microprocessors in use. At that time the number of artificial computing devices will exceed the number of natural computers, that is, human brains (ten billion humans are expected on this planet around the year 2010).

The rapid growth of information technologies is creating a kind of nervous system in society. This system is exosomatic: it operates outside human bodies and is not limited by a finite cranium. Artificial information processing systems have almost infinite growth potentials, with bounds given only by the minimum size beyond which there is noise or cross-talk among electrons and the maximum quantity of data held by a chip. And even these limits are expandable through optical processors and holographic data storage. It is calculated that a one-inch square hologram has nearly 100 million resolvable spots available for recording. This allows some 10,000 light sources to be linked up with 10,000 light sensors, a recording magnitude well beyond the absolute physical capacity of chips. Moreover holograms, the same as chips, can be superposed and act as three-dimensional storage-media rather than as two-dimensional surfaces. In principle a hologram the size of a cube of sugar, being capable of handling all the possible interconnections of one million optical elements, could store the entire contents of the US Library of Congress.

Because microprocessors can be interconnected in networks of quasi-unlimited extension and density, also the outside dimensions of information processing systems are practically unbounded. The three billion microprocessors and 500 million telephones in service today are only the advance guard of an integrated globe-girdling system such as the Integrated Services Digital Network (ISDN). Such a system can be connected with networks of automated data processing and can transmit data as well as voice quasi-instantaneously the world over. The technical potentials of the system exceeds the requirements of purely human communication: it is estimated that a global telecom system operating at 100 gigabits per second and using six satellites could transmit in just eight months all the verbal and written messages produced by five-and-a-half billion people in ten years. (Pelton, 1982) The excess capacity of the system could then be taken up with the transmission of machine-generated data flow. The latter is expanding exponentially, at a rate far higher than human-to-human (written or voice) communication. (Goonatilake, 1991)

Information cannot circulate among human beings without having some effect on them. When Adam and Eve ate of the tree of knowledge they obtained fresh information, and the effect was both immediate and drastic. Likewise when in today's world a growing flood of information is circling the globe and filling the electromagnetic spectrum, the "revolution" it implies is not likely to be merely technological: it is bound to affect both individuals and societies. But just how do the new information technologies impact on society? This question merits asking, for the answer to it is by no means clear. While the effect of information technologies on societal processes has been analysed in various sectors and fields, primarily in the sphere of the economy - for example, in regard to employment, the balance of trade, patterns of communication, and so on - the interaction between information and society is likely to be complex, and hence the nature of the impact is unlikely to be properly elucidated by comparing and averaging the results of specialized case studies.

A more fruitful approach would be to attempt analysis on the full system level. We shall do so by taking societies as energy-and information-processing systems in interaction with their natural and societal environment. In our analysis technology will function an indigenous factor, and changes in technology that is, technological innovations - will become logical agents of social change. We can then view the development of information technology as a form of technological innovation and can relate its societal impact to the general process by which societies maintain themselves in interaction with their milieu.

We propose, then, a review of the relevant characteristics of dynamical open systems; systems that are exemplified not only by human individuals, but also by the societies jointly formed by them. (Laszlo, 1987)

2. SOCIETY IN THE SYSTEMS PERSPECTIVE

The dynamical in state of complex systems

According to Ilya Prigogine, systems in the real world can exist in one of three kinds of states: **in** thermodynamical equilibrium; **near** thermodynamical equilibrium; or **far from** thermodynamical equilibrium. (Prigogine, 1977, 1984)

In a state **in** thermodynamical equilibrium, energy and matter flows in the system cancel differences in temperature and concentration; the elements of the system are unordered in a random mix and the system is homogeneous and dynamically inert. The elimination of differences between concentrations corresponds to chemical equilibrium, just as uniformity of temperature corresponds to thermal equilibrium.

In a state **near** thermodynamical equilibrium there are minor differences in temperature and concentration in the system; the structure is not random and the system is not inert. Such systems will tend to move toward equilibrium as soon as the constraints that keep them in nonequilibrium are removed. For systems of this kind equilibrium remains the "attractor" which it reaches when the forward and reverse reactions compensate one another statistically, so that there is no longer any overall variation in the concentrations (a result known as the law of mass action, or Guldberg and Waage's law). In a nonequilibrium state systems perform work and therefore produce entropy, while at equilibrium no further work is performed and entropy production ceases.

Systems that exist **far from** thermodynamical equilibrium do not tend toward minimum free energy states and maximum entropy production but behave in a relatively indeterminate fashion. They pass through chaotic phases in the course of which they may amplify certain fluctuations and evolve toward new and more complex and dynamic energy regimes that are radically different from states at or near equilibrium.

The behaviour of systems in the third state does not contradict the Second Law of thermodynamics, although it is not explained by it. According to the well-known Second Law, in any isolated system organization and structure tend to disappear, to be replaced by uniformity and randomness. Any system that performs work dissipates free energy so that, unless it replenishes its energy stores, it will run down. This is true also of machines that need to be re-fuelled to keep running, and may be true of the universe as a whole, in the event that it is heading toward an ultimate state of "heat death." But it is **not** true of a variety of complex systems in nature. These systems are neither isolated nor closed: they are open to inflows and outflows of energy, and often also to flows of matter and information. Consequently the Second Law does not adequately describe what takes place in complex natural systems, more precisely, between the systems and their environment. Although internal processes within the systems obey the Second Law (free energy, once expended, is unavailable to perform further work), energy available to perform further work is transported across the systems' boundaries from their environment. This creates a flow of negative entropy into the systems, and maintains them in the third state, far from thermodynamical equilibrium.

Free energy in a system is inversely related to entropy, as given by the equation

$$F = E - TS \qquad (1)$$

(where F is free energy, E is total energy, T is absolute temperature and S is entropy). At any given temperature, the smaller the system's entropy the greater its free energy, and vice versa. In the case of open (as opposed to closed) systems, change in entropy is defined by the so-called Prigogine equation

$$dS = diS + deS \qquad (2)$$

(where dS is the total change of entropy in the system, diS is the entropy change produced by irreversible processes within it, and deS is the entropy transported across the system's boundaries.) In an isolated system dS is always positive, for it is uniquely determined by diS, which necessarily grows as the system performs work. However, in an open system deS can offset the entropy produced within the system and may even exceed it. Thus dS in an open system need not be positive: it can be zero or negative. The open system can be in a stationary state ($dS = 0$), or it can grow and complexify ($dS < 0$). Entropy change in such a system is given by the equation

$$deS = (diS \leq 0) \qquad (3)$$

that is, the entropy produced by irreversible processes within the third-state system is shifted into its environment.

When the free energy within the system and the free energy transported across the system boundaries from the environment balance and offset each other, the system is in a steady-state. Since in a dynamic environment the two terms seldom precisely balance over any extended period of time, realworld systems tend to fluctuate around their steady-states rather than settle into them without variation.

Complex open systems in the third state evolve in all domains of the natural world, in the physical universe as well as in the biological realm. The systems emerge and subsist in constant and rich energy-flows. Laboratory experiment testify that such a flow passing through complex systems drives them toward states characterized by increasing levels of free energy and decreasing levels of specific entropy. The explanation of this phenomenon in thermodynamic terms was given by Aharon Katchalsky in the 1970s: constant energy penetration drives systems consisting of a large number of diffusely coupled nonlinear elements into states of increasing nonequilibrium. (Katchalsky, 1971) Processes that exemplify this principle range from the creation of Bénard cells in a liquid, to the emergence of life in the biosphere.

Chemistry describes how systems of interacting elements move from states at or near equilibrium to the domains of nonequilibrium characteristic of systems in the third state. In experiments pioneered in the 1960s by Harold Morowitz, sets of chemical reactions are irradiated and forced to move progressively further from chemical equilibrium. Relatively near chemical equilibrium the reaction system is still successfully described by solving the chemical kinetic equations that apply at equilibrium as well as those that correspond to the Brownian motion of the molecules and the random mixing of the components. But, as reaction rates are increased at some point the system becomes unstable and new solutions are required to explain its state, branching off from those that apply near equilibrium. The modified solutions signify new states of organization in the system of reactants: stationary or dynamic patterns of structure, or chemical clocks of various frequency. Where the equilibrium branch of the solution becomes unstable the reaction system acquires characteristics typical of complex open systems in general: coherent behaviour appears, bringing about a higher level of autonomy vis-à-vis the environment. The elements cohere into an identifiable unity with a characteristic spatial and temporal order; there is now an integrated dynamical system, whereas near equilibrium there were but sets of reactants.

Systems with ordered structure and behaviour emerge when sets of reactants are exposed to a rich and enduring energy flow. If the flow endures, the systems exposed to it tend to become more structured and complex. Because the systems move ever further from equilibrium, they also become more unstable. Their persistence is then due to the catalytic cycles that evolve among their principal components and subsystems.

Third-state systems in nature almost always exhibit some variety of catalytic cycles. There are two varieties of catalytic cycles: cycles of autocatalysis, where a product of a reaction catalyses its own synthesis, and cycles of cross-catalysis, where two different products (or groups of products) catalyse each other's synthesis. An example of auto-catalysis is the reaction scheme

$$X + Y \longrightarrow 2X \qquad (5)$$

(starting from one molecule of X and one of Y, two molecules of X are catalysed). The chemical rate equation for this reaction is

$$dX/dt = k\,X\,Y \qquad (6)$$

(when Y is held at a constant concentration there is an exponential growth in X.)

Cross-catalytic reaction cycles have been studied in detail by the Brussels school. A model of such reactions, known as the Brusselator, consists of the following four steps:

$$\begin{array}{lll} (1) & A & \longrightarrow X \\ (2) & B + X & \longrightarrow Y + D \\ (3) & 2X + Y & \longrightarrow 3X \\ (4) & X & \longrightarrow E \qquad (7) \end{array}$$

In this reaction model X and Y are intermediate molecules within an overall sequence through which A and B become D and E. In step (2) Y is synthesized from X and B, while in step (3) an additional X is produced through collisions of 2X and Y. Thus while (3) in itself constitutes autocatalysis, (2) and (3) in combination make for cross-catalysis.

The discovery of catalytic cycles has an impressive history. As early as 1931, Lars Onsager could demonstrate that in a steady state system cyclic matter-energy flows are likely to arise. For example, in a simple chemical system composed of three types of molecules, A, B, and C, in which both forward and reverse reactions are possible

$$A \Longleftrightarrow B,\ B \Longleftrightarrow C,\ C \Longleftrightarrow A \qquad (8)$$

the introduction of continuous energy irradiation into one of the cycles

$$A + h\nu \longrightarrow B \qquad (9)$$

tends to move the system into a cyclic pattern

$$A \longrightarrow B \longrightarrow C \longrightarrow A. \qquad (10)$$

In relatively simple chemical systems autocatalytic reaction cycles tend to dominate, while in more complex systems entire chains of cross-catalytic cycles appear. The fact is that cross-catalytic cycles tend to be naturally selected in the course of time in virtue of their remarkable stability under a wide range of conditions. These cycles turn out to have great resilience and fast reaction rates. Manfred Eigen and Peter Schuster have shown that such cycles underlie the stability of the sequence of nucleic acids that code the structure of living organisms. (Eigen and Schuster, 1979)

Given sufficient time, and an enduring energy flow acting on organized systems within permissible parameters of intensity, temperature and concentration, the basic catalytic cycles in the systems tend to interlock in higher-level hypercycles. Hypercycles maintain two or more dynamic systems in a shared environment by coordinating their functions. For example, nucleic acid molecules carry the information needed to reproduce themselves as well as an enzyme. The enzyme catalyses the production of another nucleic acid molecule, which in turn reproduces itself plus another enzyme. The loop may involve a large number of elements but it ultimately closes in on itself, forming a remarkably fast and stable reaction cycle.

THE EVOLUTION OF DYNAMICAL SYSTEMS: THE CASE OF HISTORICAL DEVELOPMENT

In light of the sciences of thermodynamics and dynamical systems, developmental processes in diverse spheres of observation and experience exemplify the evolution of complex systems in the third state. The development of life on Earth in its more than four-billion year time-span during which it emerged from the protocell illustrates evolutionary laws, the same as the evolution of human societies in the 20-30,000 year history of development from kinship based nomadic tribes into modern techno-industrial systems.

Human societies can be viewed as coherent inter-personal structures formed by human beings as they associate in groups. When so viewed, the development of human societies in history can be analysed as a special case of the evolution of third-state systems in nature.

In order to highlight the role of technology in the historical development process, the description of societal evolution can be segmented in regard to three operative factors: (A) the dynamics, (B) the products, and (C) the drivers of the historical process.

A. The dynamics of historical development

Historical development, like evolution in nature, appears to have a strongly nonlinear character. The concepts that best describe this process are bifurcation, and order (vs. chaos).

Bifurcations (from the Latin **bi**, meaning two, and **furca**, fork) describe major phase-changes in the evolutionary trajectory of complex systems, regardless of whether the systems are natural or societal. Order is a factor of stability as well as a precondition of intelligibility; it is the invariant pattern in space and time through which a process of change is stabilized and by which it can be described. Chaos, however, is not the opposite of order but its refinement: it is a subtle, complex, and ultrasensitive form of order. The world's weather, for example, constitutes a chaotic system, with myriad subtle inputs nucleating and creating bifurcations. Also the dynamics of turbulence, known in fluid dynamics to be a form of chaos, now turn out to exhibit complex varieties of order.

In its mathematical models dynamical systems theory identifies diverse scenarios leading from order to chaos. Depending on whether the phase-change is smooth and continuous, sudden, or entirely abrupt, the bifurcation it illustrates is "subtle", "catastrophic" or "explosive." (Abraham and Shaw, 1984-1988) Subtle bifurcations indicate increasing instability in complex dynamical systems. A stable system, such as a series of chemical reactions, begins to oscillate; or an oscillating system, such as a "chemical clock," becomes turbulent. Catastrophic bifurcations model how systems move from turbulent to freshly ordered states through the reconfiguration of their attractors. These are of particular relevance to developmental processes in history: they simulate revolutionary transformations in human societies.

Bifurcations involving the alternation of chaotic and ordered phases underlie the evolution of all varieties of human societies, from comparatively simple and small (but by no means "primitive") traditional tribes to large and complex contemporary techno-industrial states. Consequently patterns of system development in which complex systems pass through a chaotic phase as part of the trajectory that leads them to new ordered states simulate a basic dynamic of the development of societies.

B. The products of historical development

The formation of cross-catalytic hypercycles allows dynamical systems to emerge on successively higher levels of organization. The shift from level to level of organization through hypercycles is a result of the evolutionary dynamic: in the sphere of history it produces the convergent aspect of the societal development process.

Convergent systems on successively higher levels of organization set forth the process by which systems in the third state access, use and retain increasing amounts of free energy in increasingly complex structures. On higher levels the amount of complexity that can be developed in a system is greater than on lower ones due to the greater diversity and richness of the components and subsystems: the wider range of structural possibilities offers fresh opportunities of evolution. Molecules built of diverse atoms and cells, themselves built of various molecules, evolve toward the complex polymers that are the basis of life; living organisms composed of a single cell or a relatively small number of cells evolve toward the higher, multicellular forms of life, and local ecologies based on a few variety of species and populations build toward highly complex and diversified regional and continental ecosystems.

In the sphere of history, human societies, built of diverse populations and levels of organization, evolve toward progressively more embracing units: nations and regional communities of nations, and ultimately a global system of a variety of nations and multinational communities. Indeed, history is the record of a progressive if intermittent shift from smaller and relatively simple to larger and more complex societal structures. The progression began in the Stone Age when nomadic kinship-based tribes functioned by a comparatively simple division of labor based on age and sex; it includes the classical era when settled villages and extensive empires had relatively complex and specialized role-structures made up of farmers, warriors, scribes, priests, and governors, and it extends to the intricate socioeconomic and political structures of modern industrial societies. Higher-level structures of control and coordination are periodically added to already existing structures, impelling interacting societies to converge within progressively more embracing (regional, continental, and global) communities.

When earlier in this century European states relinquished their overseas colonies, the process of convergence was temporarily reversed. Notwithstanding the recent dissolution of such arbitrarily unified nation-states as the Soviet Union and Yugoslavia, the process of inter-national convergence has been resumed. Pressures are building for the integration of the almost 180 nation-states of the world within broader regional structures, and for the integration of national markets and economies within global-level economic and financial structures. The enlarged European Community itself is an instance of the evolutionary process of socioeconomic convergence in the contemporary world.

C. The drivers of the historical process

As noted above, a rich and enduring flow of energy drives systems in the third state toward increasingly structured dynamical states. Energy "structures" open systems, doing so proportionately to the extent that the systems access and absorb the free energies that exist in their milieu. In the case of human societies, the free energy entering the systems from their environment has increased progressively, though non-linearly, throughout history. In prehistoric tribes, the free energy that entered the systems was largely restricted to the caloric energy of food. Ever since the Lower Paleolithic, however, human groups increased their access to, and use of, the environment's free energies. First they learned to use and control fire; then they invented the wheel and domesticated draft animals. At the same time they slowly but irreversibly developed a series of hand tools such as levers and axes, and then invented mechanical contraptions such as watermills and windmills.

The factor that enabled societies to access and consume ever more free energy can be identified as "technology." In this generic sense technology is the instrumentality for accessing and using free energies in human societies for human and social purposes.

By injecting growing quantities of free energy into the groups of people that make use of them, technological innovations structure and complexify the user societies. On the one hand new technologies require more efficient organizational structures for their effective use, and on the other they permit people to liberate themselves from subsistence chores and to engage in a wider range of activities and occupations.

The prehistoric technologies of the lower Paleolithic were limited to kindling and to some extent controlling fire, and to making and using hand tools such as the axe, the dagger, and various cutting and scraping implements. During the Neolithic tools such as hammers, saws, daggers, knives, and sickles came into use. When agriculture became the principal mode of food production, tools made of metals - first copper, then bronze, and later iron - appeared on the scene.

The rhythm of technological innovation accelerated at an exponential rate. It took tens of thousands of years to evolve an axe with a whole into which a handle can be fitted, and once it was evolved it remained relatively unchanged even to the Modern Age. Indeed, except for relying on steel rather than on iron, during the 8,000 years that separated the Neolithic Revolution from the Industrial Revolution relatively few innovations occurred in basic agricultural tools: the sickle, the hoe, the chisel, the saw, as well as the hammer and the knife continued almost unchanged in general use. But then the Industrial Revolution of the 18th century brought an entire battery of new technologies on the scene, led by the newly discovered power of steam. In Europe and North America the Revolution had radical societal consequences: it shifted the focus of development from agriculture to industry, and from the countryside to the cities.

The first of a rapidly accelerating series of technological breakthroughs occurred in England in the textile industry: innovations in spinning cotton stimulated a chain of related inventions which led to the emergence of machines capable of factory-based mass production. Industrial development spread from textiles to iron, as cheaper cast iron replaced the more expensive wrought iron. Closely on the heel of innovations in the machine-tool industry were developments in the chemical sector. By the middle of the 19th century Britain was a major manufacturing power, followed closely by Germany, France, and the United States.

In the course of the 20th century a new type of technological innovation came about, one that replaced reliance on massive energy inputs - first steam and then oil - with a more intangible factor: information. In itself, this was not an unprecedented development: the progressive rise of information technologies can be traced throughout history. But, while traditional societies were shaped mainly by the information processed in human brains, in the course of the Modern Age human brain-processed information has been supplemented by information processed in technical systems. In the last century the rate of this substitution accelerated fast enough to make for a veritable explosion.

The growing "informatisation" of modern societies not only shifted the focus of development from the countryside to the cities, it also created new patterns of employment. The workforce shifted from agriculture to industry, and within industry from raw-material and energy-intensive branches to the information-intensive sectors. While in 1860 the largest workforce in the United States was the agricultural, between 1906 and 1960 the industrial labor became predominant, peaking with 40 percent of the total in 1946. Then, as new information-based technologies made their appearance, the proportion of the industrial workforce began to decline, falling by the 1970s to 25 percent, to be replaced by labor in the primary and secondary information sector. Indeed, the proportion of the workforce employed in information-intensive industry branches rose from a modest 5 percent of the total in 1860 to over 50 percent by 1990. Today, the primary and the secondary information sectors in the US account for over 50 percent of the country's GNP as well. (Porat, 1977)

With the progressive transfer of cognitive processes to computers also control is increasingly transferred, with the result that information processing systems acquire considerable autonomy in society. International banks and financial institutions, among others, have almost completely delegated their financial routines to computers tied into worldwide telecommunication networks. Information processing systems are used in manufacturing (CAM and CIM), in design (CAD), and in inventory control (Just-in-Time systems). They perform essential functions for the military (Early Warning systems), in telecommunications (communication satellites), in ground and air transportation (automatic rail switching systems, autopilots and instrument landing systems), and in such complex operations as balancing the atomic chain reactions of nuclear power stations. The systems have become well-nigh indispensable. They can neither be substituted by human brains (it is estimated that, in Germany alone, it would take seven million persons to carry out the computational workload of the automated banking system), nor can they be "switched off" without inducing dramatic consequences that range from stock market chaos to nuclear melt-down.

Information has also become the crucial factor in channelling flows of capital. The information standard has replaced the gold standard as the basis for international finance. Worldwide communications enable money to move anywhere around the globe in response to information - or misinformation.

Technological advance is an irreversible process. Whatever its nature, innovation has always been from the hoe to the plough, and not the other way around. Even if many technological procedures have been invented, only those have been adopted and handed down that produced an improvement in the effectiveness or efficiency of some element of human performance. Because in the final analysis technological innovation always has one or more of three functions: it extends the power of human muscles; and/or it enhances the power of human sense organs; and/or it multiplies the computing and communicating power of the human brain. Muscle power has been extended by the lever and the wheel, arch-technologies in use for thousands of years. Their modern counterparts are the many varieties of mechanical systems, from motorcycles to jet engines and launch-rockets. The technological enhancement of human sense organs began with such early devices as sound-signal transmitting tubes and light-signal transmitting torches, bonfires and smoke. Their more recent counterparts are the magnifying glass, the microscope, the telescope, and such scientific instruments as electron-microscopes, radiotelescopes, x-ray devices, and various medical probes. The multiplication of the computing powers of the brain began with classical devices such as the abacus but took off in the span of the last onehundred years with the invention of the above-reviewed series of information-technological inventions.

Although the technological multiplication of the computing powers of the brain came last in history, during the 20th century this branch of technological advance caught up with, and then overcame, advances in all other spheres. Technological innovations that until the last two hundred years were predominantly in the nature of improved tools for the production of food, moved into the area of energy and raw-materials intensive mass production in the span of the past two centuries, and shifted toward information-intensive applications in the past 50 years. Since that time the information accessed, stored, elaborated, and transmitted in man-machine systems has been the decisive factor structuring the institutions and living patterns of society.

3. THE GENERIC IMPACT OF INFORMATION TECHNOLOGY ON SOCIETY

We are now in possession of the conceptual tools for elucidating the main topic of this paper: the basic generic impact of the new information technologies on society - in other words, the role of information technologies as agents of social change.

We began by noting that the human-performance ameliorating functions of technology are on the whole irreversible. They have infused the history of humanity from the control of fire and the invention of the wheel to development of the solar cell and the microprocessor. The macro-scale irreversibility of technological innovation has been moving society into progressively higher regimes of free energy use, on progressively more complex levels of structure and organization. As social scientists noted, a society based solely on the mastery of fire, the use of draft animals and of the wheel could make do with a two or three-tier social structure consisting of hunters or farmers, warriors, and elders, but a society using the technologies of the industrial and the post-industrial revolution requires sophisticated administrative, executive and control structures. Consequently as new technologies bring improvements in the efficiency of accessing, storing, processing, and making use of free energies and information, human communities grow from the low-energy and structurally comparatively simple tribal groups of the Paleolithic to the highly structured and complex socio-technological systems of our day.

Today, the rapidly evolving information technologies are the principal engines of social change. Their impact can be viewed in light of the impact of earlier technological innovations in history. Much as muscle-power and sense-organ capacity enhancing innovations did in the past, the brain-power multiplying innovations of the new information technologies can be seen to drive societies toward more and more dynamic high-energy regions further and further from thermodynamical equilibrium, characterized by decreasing specific entropy and increasingly dense free-energy flows, accessed and processed by more and more complex social, economic, and political structures.

The complexification of society's structures can be analysed in terms of two processes that take place simultaneously. In the sociopolitical sphere, one process is the **diversification of societal subsystems** (social and ethnic groups, residential and sociopolitical communities, cultural and interest groups, etc.), and the other the **convergent integration of the existing systems on successively higher levels of organization** (e.g., the creation of multicultural communities, multi-ethnic societies, diversified or federated nation-states, regional economic, monetary and defence communities, multinational federations, commonwealth systems, and the like). In the economic sphere the parallel processes are the diversification of the operative structures of enterprises in regard to their subsystems (corporate divisions and subdivisions, subsidiaries and work-teams) and the integration of individual companies within strongly interacting industry clusters (flexible manufacturing networks, upstream and downstream marketing-production associations, and so on).

It appears that the societal impact of information technologies manifests itself as a two-pronged development which is contradictory at first sight but is profoundly consistent on a deeper analysis. It consists of the simultaneous "upward integration" and "downward diversification" of operative structures in contemporary societies. States, republics, provinces, regions, as well as ethnic groups and other subcultures clamor for independence and attempt to secede from, or to win greater autonomy within, the encompassing sociopolitical structures of monolithic nation-states. At the same time the nation-states themselves seek closer ties with each other within transnational economic, political and sociocultural communities, federations, or associations. In the sphere of the economy the corresponding two-pronged development is the diversification of locally constituted and oriented firms or subdivisions providing personalized services and custom-tailored products, simultaneously with the agglomeration of the parent companies or networks within transnational corporations, industry clusters, and a variety of production and marketing associations. It appears that the intensifying flows of technological, organizational and marketing information drive enterprises toward more differentiated organizational and product modalities, while the new technologies of information transmission enable them to relate to one another more intensely and effectively.

Empirical evidence confirms that upward integration joined with downward differentiation are hallmarks of social change in the 1990s. There is the integration of European states and the disaggregation of the Soviet Union; the creation of economic communities and common markets in East Asia and Latin America; and the rise of regionalism and ethnic consciousness in the US and of secession movements in Canada. In the business world there is the emergence of global enterprises, such as ABB and McDonald, that operate as vast networks of local suppliers, manufacturers, and services.

The contemporary world is becoming more diversified at the same time as it is becoming more integrated. As this paper attempted to show, these effects can be traced to the structuring impact of explosively evolving technologies that access, process, store, and transmit information within contemporary social, political, and economic systems.

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