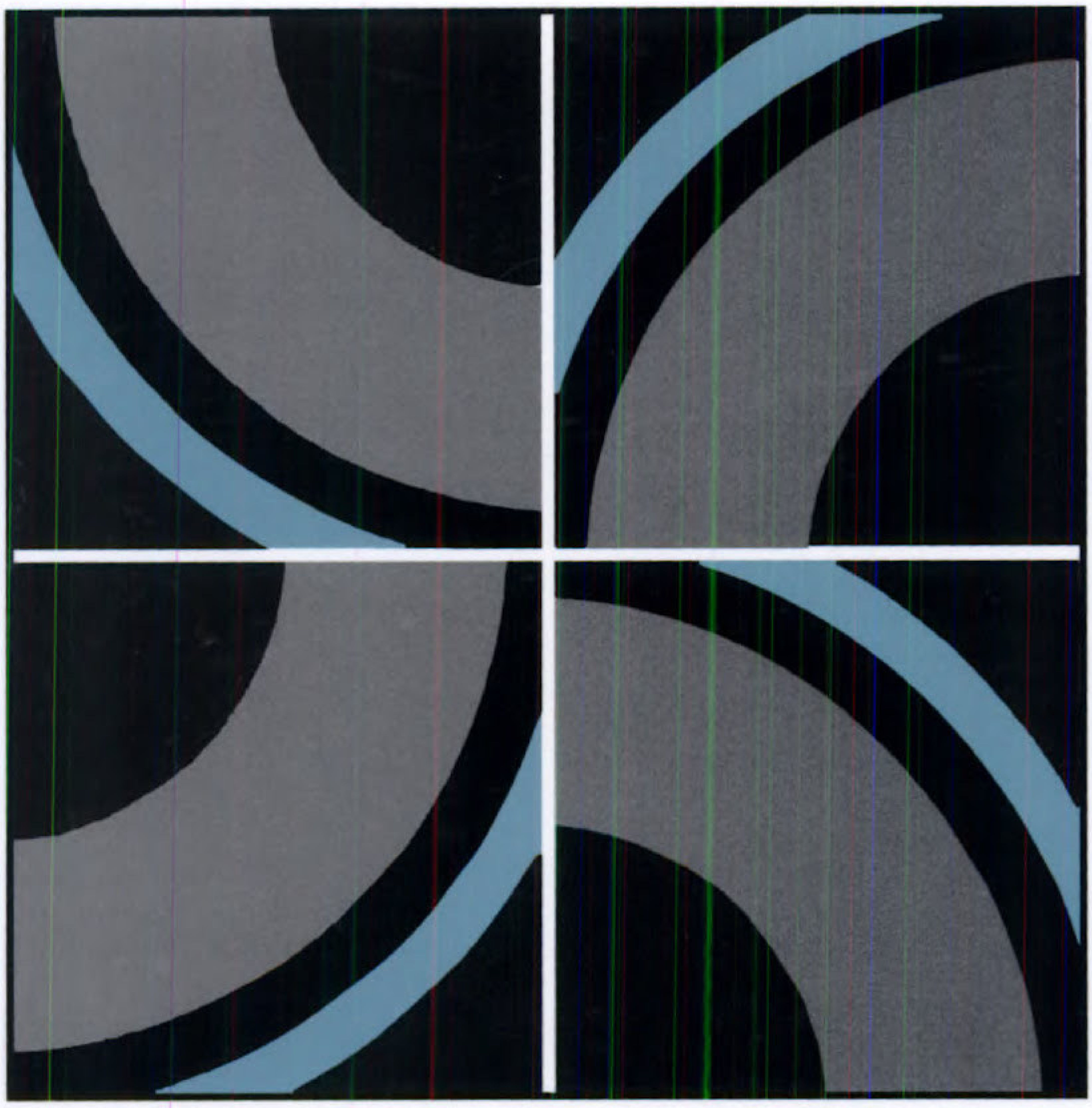
THE CONTROL REVOLUTION

Technological and Economic Origins of the Information Society



JAMES R. BENIGER

"A masterly treatment of some of the most important developments in the making of modern society."
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Technological and Economic Origins of the Information Society

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Introduction

Here have we war for war and blood for blood,
controlment for controlment.

—King of England to the French
ambassador (Shakespeare, *King John*)

ONE TRAGEDY of the human condition is that each of us lives and dies with little hint of even the most profound transformations of our society and our species that play themselves out in some small part through our own existence. When the earliest *Homo sapiens* encountered *Homo erectus*, or whatever species was our immediate forebear, it is unlikely that the two saw in their differences a major turning point in the development of our race. If they did, this knowledge did not survive to be recorded, at least not in the ancient writings now extant. Indeed, some fifty thousand years passed before Darwin and Wallace rediscovered the secret—proof of the difficulty of grasping even the most essential dynamics of our lives and our society.

Much the same conclusion could be drawn from any of a succession of revolutionary societal transformations: the cultivation of plants and the domestication of animals, the growth of permanent settlements, the development of metal tools and writing, urbanization, the invention of wheeled vehicles and the plow, the rise of market economies, social classes, a world commerce. The origins and early histories of these and many other developments of comparable significance went unnoticed or at least unrecorded by contemporary observers. Today we are hard pressed to associate specific dates, places, or names with many major societal transformations, even though similar details abound for much lesser events and trends that occurred at the same times.

This condition holds for even that most significant of modern societal transformations, the so-called Industrial Revolution. Although it is generally conceded to have begun by mid-eighteenth century, at least in England, the idea of its revolutionary impact does not appear until

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the 1830s in pioneering histories like those of Wade (1833) and Blanqui (1837). Widespread acceptance by historians that the Industrial Revolution constituted a major transformation of society did not come until Arnold Toynbee, Sr., popularized the term in a series of public lectures in 1881 (Toynbee 1884). This was well over a century after the changes he described had first begun to gain momentum in his native England and at least a generation after the more important ones are now generally considered to have run their course. Although several earlier observers had described one or another of the same changes, few before Toynbee had begun to reflect upon the more profound transformation that signaled the end—after some ten thousand years—of predominantly agricultural society.

Two explanations of this chronic inability to grasp even the most essential dynamics of an age come readily to mind. First, important transformations of society rarely result from single discrete events, despite the best efforts of later historians to associate the changes with such events. Human society seems rather to evolve largely through changes so gradual as to be all but imperceptible, at least compared to the generational cycles of the individuals through whose lives they unfold. Second, contemporaries of major societal transformations are frequently distracted by events and trends more dramatic in immediate impact but less lasting in significance. Few who lived through the early 1940s were unaware that the world was at war, for example, but the much less noticed scientific and technological by-products of the conflict are more likely to lend their names to the era, whether it comes to be remembered as the Nuclear Age, the Computer Age, or the Space Age.

Regardless of how we explain the recurrent failure of past generations to appreciate the major societal transformations of their own eras, we might expect that their record would at least chasten students of contemporary social change. In fact, just the opposite appears to be the case. Much as if historical myopia could somehow be overcome by confronting the problem head-on, a steadily mounting number of social scientists, popular writers, and critics have discovered that one or another revolutionary societal transformation is now in progress. The succession of such transformations identified since the late 1950s includes the rise of a new social class (Djilas 1957; Gouldner 1979), a meritocracy (Young 1958), postcapitalist society (Dahrendorf 1959), a global village (McLuhan 1964), the new industrial state (Galbraith 1967), a scientific-technological revolution (Richta 1967; Daglish 1972; Prague Academy 1973), a technetronic era (Brzezinski 1970), postindustrial

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society (Touraine 1971; Bell 1973), an information economy (Porat 1977), and the micro millennium (Evans 1979), to name only a few. A more complete catalog of these and similar transformations, listed by year of first exposition in a major work, is given in Table 1.1.

The writer who first identified each of the transformations listed in Table 1.1 usually found the brunt of the change to be—coincidentally enough—either in progress or imminent. A recent best-seller, for example, surveys the sweep of human history, notes the central importance of the agricultural and industrial revolutions, and then finds in contemporary society the seeds of a third revolution—the impending "Third Wave":

> Humanity faces a quantum leap forward. It faces the deepest social upheaval and creative restructuring of all time. Without clearly recognizing it, we are engaged in building a remarkable new civilization from the ground up. This is the meaning of the Third Wave . . . It is likely that the Third Wave will sweep across history and complete itself in a few decades. We, who happen to share the planet at this explosive moment, will therefore feel the full impact of the Third Wave in our own lifetimes. Tearing our families apart, rocking our economy, paralyzing our political systems, shattering our values, the Third Wave affects everyone. (Toffler 1980, p. 26)

Even less breathless assessments of contemporary change have been no less optimistic about the prospect of placing developing events and trends in the broadest historical context. Daniel Bell, for example, after acknowledging the counterevidence of Toynbee and the Industrial Revolution, nevertheless concludes, "Today, with our greater sensitivity to social consequences and to the future . . . we are more alert to the possible imports of technological and organizational change, and this is all to the good" (1980, pp. x–xi).

The number of major societal transformations listed in Table 1.1 indicates that Bell appears to be correct; we do seem more alert than previous generations to the possible importance of change. The wide variety of transformations identified, however, suggests that, like the generations before us, we may be preoccupied with specific and possibly ephemeral events and trends, at the risk of overlooking what only many years from now will be seen as the fundamental dynamic of our age.

Because the failures of past generations bespeak the difficulties of overcoming this problem, the temptation is great not to try. This reluctance might be overcome if we recognize that understanding our-

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Table 1.1. Modern societal transformations identified since 1950

Year	Transformation	Sources
1950	Lonely crowd	Riesman 1950
	Posthistoric man	Seidenberg 1950
1953	Organizational revolution	Boulding 1953
1956	Organization man	Whyte 1956
1957	New social class	Djilas 1957; Gouldner 1979
1958	Meritocracy	Young 1958
1959	Educational revolution	Drucker 1959
	Postcapitalist society	Dahrendorf 1959
1960	End of ideology	Bell 1960
	Postmaturity economy	Rostow 1960
1961	Industrial society	Aron 1961; 1966
1962	Computer revolution	Berkeley 1962; Tomeski 1970; Hawkes 1971
	Knowledge economy	Machlup 1962; 1980; Drucker 1969
1963	New working class	Mallet 1963; Gintis 1970; Gallie 1978
	Postbourgeois society	Lichtheim 1963
1964	Global village	McLuhan 1964
	Managerial capitalism	Marris 1964
	One-dimensional man	Marcuse 1964
	Postcivilized era	Boulding 1964
	Service class society	Dahrendorf 1964
	Technological society	Ellul 1964
1967	New industrial state	Galbraith 1967
	Scientific-technological revolution	Richta 1967; Daglish 1972; Prague Academy 1973
1968	Dual economy	Averitt 1968
	Neocapitalism	Gorz 1968
	Postmodern society	Etzioni 1968; Breed 1971
	Technocracy	Meynaud 1968
	Unprepared society	Michael 1968
1969	Age of discontinuity	Drucker 1969
	Postcollectivist society	Beer 1969
	Postideological society	Feuer 1969
1970	Computerized society	Martin and Norman 1970
	Personal society	Halmos 1970
	Posteconomic society	Kahn 1970
	Postliberal age	Vickers 1970
	Prefigurative culture	Mead 1970
	Technetronic era	Brzezinski 1970
1971	Age of information	Helvey 1971
	Compunications	Oettinger 1971

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Year	Transformation	Sources
1971	Postindustrial society	Touraine 1971; Bell 1973
	Self-guiding society	Breed 1971
	Superindustrial society	Toffler 1971
1972	Limits to growth	Meadows 1972; Cole 1973
	Posttraditional society	Eisenstadt 1972
	World without borders	Brown 1972
1973	New service society	Lewis 1973
	Stalled society	Crozier 1973
1974	Consumer vanguard	Gartner and Riessman 1974
	Information revolution	Lamberton 1974
1975	Communications age	Phillips 1975
	Mediacracy	Phillips 1975
	Third industrial revolution	Stine 1975; Stonier 1979
1976	Industrial-technological society	Ionescu 1976
	Megacorp	Eichner 1976
1977	Electronics revolution	Evans 1977
	Information economy	Porat 1977
1978	Anticipatory democracy	Bezold 1978
	Network nation	Hiltz and Turoff 1978
	Republic of technology	Boorstin 1978
	Telematic society	Nora and Minc 1978; Martin 1981
	Wired society	Martin 1978
1979	Collapse of work	Jenkins and Sherman 1979
	Computer age	Dertouzos and Moses 1979
	Credential society	Collins 1979
	Micro millennium	Evans 1979
1980	Micro revolution	Large 1980, 1984; Laurie 1981
	Microelectronics revolution	Forester 1980
	Third wave	Toffler 1980
1981	Information society	Martin and Butler 1981
	Network marketplace	Dordick 1981
1982	Communications revolution	Williams 1982
	Information age	Dizard 1982
1983	Computer state	Burnham 1983
	Gene age	Sylvester and Klotz 1983
1984	Second industrial divide	Piore and Sabel 1984

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the word *control* for its more determinate manifestations, what I shall call "strong control." Dictionaries, for example, often include in their definitions of control concepts like direction, guidance, regulation, command, and domination, approximate synonyms of *influence* that vary mainly in increasing determination. As a more general concept, however, *control* encompasses the entire range from absolute control to the weakest and most probabilistic form, that is, any purposive influence on behavior, *however slight*. Economists say that television advertising serves to control specific demand, for example, and political scientists say that direct mail campaigns can help to control issue-voting, even though only a small fraction of the intended audience may be influenced in either case.

Inseparable from the concept of control are the twin activities of information processing and reciprocal communication, complementary factors in any form of control. Information processing is essential to all purposive activity, which is by definition goal directed and must therefore involve the continual comparison of current states to future goals, a basic problem of information processing. So integral to control is this comparison of inputs to stored programs that the word *control* itself derives from the medieval Latin verb *contrarotulare*, to compare something "against the rolls," the cylinders of paper that served as official records in ancient times.

Simultaneously with the comparison of inputs to goals, two-way interaction between controller and controlled must also occur, not only to communicate influence from the former to the latter, but also to communicate back the results of this action (hence the term *feedback* for this reciprocal flow of information back to a controller). So central is communication to the process of control that the two have become the joint subject of the modern science of cybernetics, defined by one of its founders as "the entire field of control and communication theory, whether in the machine or in the animal" (Wiener 1948, p. 11). Similarly, the pioneers of mathematical communication theory have defined the object of their study as purposive control in the broadest sense: communication, according to Shannon and Weaver (1949, pp. 3–5), includes "all of the procedures by which one mind may affect another"; they note that "communication either affects conduct or is without any discernible and probable effect at all."

Because both the activities of information processing and communication are inseparable components of the control function, a society's ability to maintain control—at all levels from interpersonal to inter-

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national relations—will be directly proportional to the development of its information technologies. Here the term *technology* is intended not in the narrow sense of practical or applied science but in the more general sense of any intentional extension of a natural process, that is, of the processing of matter, energy, and information that characterizes all living systems. Respiration is a wholly natural life function, for example, and is therefore not a technology; the human ability to breathe under water, by contrast, implies some technological extension. Similarly, voting is one general technology for achieving collective decisions in the control of social aggregates; the Australian ballot is a particular innovation in this technology.

Technology may therefore be considered as roughly equivalent to that which can be done, excluding only those capabilities that occur naturally in living systems. This distinction is usually although not always clear. One ambiguous case is language, which may have developed at least in part through purposive innovation but which now appears to be a mostly innate capability of the human brain. The brain itself represents another ambiguous case: it probably developed in interaction with purposive tool use and may therefore be included among human technologies.

Because technology defines the limits on what a society *can* do, technological innovation might be expected to be a major impetus to social change in the Control Revolution no less than in the earlier societal transformations accorded the status of revolutions. The Neolithic Revolution, for example, which brought the first permanent settlements, owed its origin to the refinement of stone tools and the domestication of plants and animals. The Commercial Revolution, following exploration of Africa, Asia, and the New World, resulted directly from technical improvements in seafaring and navigational equipment. The Industrial Revolution, which eventually brought the nineteenth-century crisis of control, began a century earlier with greatly increased use of coal and steam power and a spate of new machinery for the manufacture of cotton textiles. Like these earlier revolutions in matter and energy processing, the Control Revolution resulted from innovation at a most fundamental level of technology—that of information processing.

Information processing may be more difficult to appreciate than matter or energy processing because information is epiphenomenal: it derives from the *organization* of the material world on which it is wholly dependent for its existence. Despite being in this way higher

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order or derivative of matter and energy, information is no less critical to society. All living systems must process matter and energy to maintain themselves counter to entropy, the universal tendency of organization toward breakdown and randomization. Because control is necessary for such processing, and information, as we have seen, is essential to control, both information processing and communication, insofar as they distinguish living systems from the inorganic universe, might be said to define life itself—except for a few recent artifacts of our own species.

Each new technological innovation extends the processes that sustain life, thereby increasing the need for control and hence for improved control technology. This explains why technology appears autonomously to beget technology in general (Winner 1977), and why, as argued here, innovations in matter and energy processing create the need for further innovation in information-processing and communication technologies. Because technological innovation is increasingly a collective, cumulative effort, one whose results must be taught and diffused, it also generates an increased need for technologies of information storage and retrieval—as well as for their elaboration in systems of technical education and communication—quite independently of the particular need for control.

As in the earlier revolutions in matter and energy technologies, the nineteenth-century revolution in information technology was predicated on, if not directly caused by, social changes associated with earlier innovations. Just as the Commercial Revolution depended on capital and labor freed by advanced agriculture, for example, and the Industrial Revolution presupposed a commercial system for capital allocations and the distribution of goods, the most recent technological revolution developed in response to problems arising out of advanced industrialization—an ever-mounting crisis of control.

Crisis of Control

The later Industrial Revolution constituted, in effect, a consolidation of earlier technological revolutions and the resulting transformations of society. Especially during the late nineteenth and early twentieth centuries industrialization extended to progressively earlier technological revolutions: manufacturing, energy production, transportation, agriculture—the last a transformation of what had once been seen as the extreme opposite of industrial production. In each area industrial-

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ization meant heavy infusions of capital for the exploitation of fossil fuels, wage labor, and machine technology and resulted in larger and more complex systems—systems characterized by increasing differentiation and interdependence at all levels.

One of the earliest and most astute observers of this phenomenon was Emile Durkheim (1858–1917), the great French sociologist who examined many of its social ramifications in his *Division of Labor in Society* (1893). As Durkheim noted, industrialization tends to break down the barriers to transportation and communication that isolate local markets (what he called the "segmental" type), thereby extending distribution of goods and services to national and even global markets (the "organized" type). This, in turn, disrupts the market equilibrium under which production is regulated by means of direct communication between producer and consumer:

> Insofar as the segmental type is strongly marked, there are nearly as many economic markets as there are different segments. Consequently, each of them is very limited. Producers, being near consumers, can easily reckon the extent of the needs to be satisfied. Equilibrium is established without any trouble and production regulates itself. On the contrary, as the organized type develops, the fusion of different segments draws the markets together into one which embraces almost all society . . . The result is that each industry produces for consumers spread over the whole surface of the country or even of the entire world. Contact is then no longer sufficient. The producer can no longer embrace the market in a glance, nor even in thought. He can no longer see limits, since it is, so to speak, limitless. Accordingly, production becomes unbridled and unregulated. It can only trust to chance . . . From this come the crises which periodically disturb economic functions. (1893, pp. 369–370)

What Durkheim describes here is nothing less than a crisis of control at the most aggregate level of a national system—a level that had had little practical relevance before the mass production and distribution of factory goods. Resolution of the crisis demanded new means of communication, as Durkheim perceived, to control an economy shifting from local segmented markets to higher levels of organization—what might be seen as the growing "systemness" of society. This capacity to communicate and process information is one component of what structural-functionalists following Durkheim have called the problem of *integration,* the growing need for coordination of functions that accompanies differentiation and specialization in any system.

Increasingly confounding the need for integration of the structural

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division of labor were corresponding increases in commodity flows through the system—flows driven by steam-powered factory production and mass distribution via national rail networks. Never before had the processing of material flows threatened to exceed, in both volume and speed, the capacity of technology to contain them. For centuries most goods had moved with the speed of draft animals down roadway and canal, weather permitting. This infrastructure, controlled by small organizations of only a few hierarchial levels, supported even national economies. Suddenly—owing to the harnessing of steam power—goods could be moved at the full speed of industrial production, night and day and under virtually any conditions, not only from town to town but across entire continents and around the world.

To do this, however, required an increasingly complex system of manufacturers and distributers, central and branch offices, transportation lines and terminals, containers and cars. Even the logistics of nineteenth-century armies, then the most difficult problem in processing and control, came to be dwarfed in complexity by the material economy just emerging as Durkheim worked on his famous study.

What Durkheim described as a crisis of control on the societal level he also managed to relate to the level of individual psychology. Here he found a more personal but directly related problem, what he called *anomie*, the breakdown of norms governing individual and group behavior. Anomie is an "abnormal" and even "pathological" result, according to Durkheim (1893, p. 353), an exception to his more general finding that increasing division of labor directly increases normative integration and, with it, social solidarity. As Durkheim argued, anomie results not from the structural division of labor into what he called distinct societal "organs" but rather from the breakdown in communication among these increasingly isolated sectors, so that individuals employed in them lose sight of the larger purpose of their separate efforts:

> The state of anomie is impossible wherever solidary organs are sufficiently in contact or sufficiently prolonged. In effect, being continguous, they are quickly warned, in each circumstance, of the need which they have of one another, and, consequently, they have a lively and continuous sentiment of their mutual dependence . . . But, on the contrary, if some opaque environment is interposed, then only stimuli of a certain intensity can be communicated from one organ to another. Relations, being rare, are not repeated enough to be determined; each time there ensues new groping. The lines of passage taken by the streams of movement cannot deepen

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sions and responses. Any tendency to humanize this bureaucratic machinery, Weber argued, would be minimized through clear-cut division of labor and definition of responsibilities, hierarchical authority, and specialized decision and communication functions. The stability and permanence of bureaucracy, he noted, are assured through regular promotion of career employees based on objective criteria like seniority.

Weber identified another related control technology, what he called *rationalization*. Although the term has a variety of meanings, both in Weber's writings and in the elaborations of his work by others, most definitions are subsumed by one essential idea: control can be increased not only by increasing the capability to process information but also by decreasing the amount of information to be processed. The former approach to control was realized in Weber's day through bureaucratization and today increasingly through computerization; the latter approach was then realized through rationalization, what computer scientists now call *preprocessing*. Rationalization must therefore be seen, following Weber, as a complement to bureaucratization, one that served control in his day much as the preprocessing of information prior to its processing by computer serves control today.

Perhaps most pervasive of all rationalization is the increasing tendency of modern society to regulate interpersonal relationships in terms of a formal set of impersonal and objective criteria. The early technocrat Claude Henri Comte de Saint-Simon (1760–1825), who lived through only the first stages of industrialization, saw such rationalization as a move "from the government of men to the administration of things" (Taylor 1975, pt. 3). The reason why people can be governed more readily *qua* things is that the amount of information about them that needs to be processed is thereby greatly reduced and hence the degree of control—for any constant capacity to process information—is greatly enhanced. By means of rationalization, therefore, it is possible to maintain large-scale, complex social systems that would be overwhelmed by a rising tide of information they could not process were it necessary to govern by the particularistic considerations of family and kin that characterize preindustrial societies.

In short, rationalization might be defined as the destruction or ignoring of information in order to facilitate its processing. This, too, has a direct analog in living systems, as we shall see in the next chapter. One example from within bureaucracy is the development of standardized paper forms. This might at first seem a contradiction, in that

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the proliferation of paperwork is usually associated with a growth in information to be processed, not with its reduction. Imagine how much more processing would be required, however, if each new case were recorded in an unstructured way, including every nuance and in full detail, rather than by checking boxes, filling blanks, or in some other way reducing the burdens of the bureaucratic system to only the limited range of formal, objective, and impersonal information required by standardized forms.

Equally important to the rationalization of industrial society, at the most macro level, were the division of North America into five standardized time zones in 1883 and the establishment the following year of the Greenwich meridian and International Date Line, which organized world time into twenty-four zones. What was formerly a problem of information overload and hence control for railroads and other organizations that sustained the social system at its most macro level was solved by simply ignoring much of the information, namely that solar time is different at each node of a transportation or communication system. A more convincing demonstration of the power of rationalization or preprocessing as a control technology would be difficult to imagine.

So commonplace has such preprocessing become that today we dismiss the alternative—that each node in a system might keep a slightly different time—as hopelessly cumbersome and primitive. With the continued proliferation of distributed computing, ironically enough, it might soon become feasible to return to a system based on local solar time, thereby shifting control from preprocessing back to processing—where it resided for centuries of human history until steam power pushed transportation beyond the pace of the sun across the sky.

New Control Technology

The rapid development of rationalization and bureaucracy in the middle and late nineteenth century led to a succession of dramatic new information-processing and communication technologies. These innovations served to contain the control crisis of industrial society in what can be treated as three distinct areas of economic activity: production, distribution, and consumption of goods and services.

Control of production was facilitated by the continuing organization and preprocessing of industrial operations. Machinery itself came increasingly to be controlled by two new information-processing tech-

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nologies: closed-loop feedback devices like James Watt's steam governor (1788) and preprogrammed open-loop controllers like those of the Jacquard loom (1801). By 1890 Herman Hollerith had extended Jacquard's punch cards to tabulation of U.S. census data. This information-processing technology survives to this day—if just barely—owing largely to the corporation to which Hollerith's innovation gave life, International Business Machines (IBM). Further rationalization and control of production advanced through an accumulation of other industrial innovations: interchangeable parts (after 1800), integration of production within factories (1820s and 1830s), the development of modern accounting techniques (1850s and 1860s), professional managers (1860s and 1870s), continuous-process production (late 1870s and early 1880s), the "scientific management" of Frederick Winslow Taylor (1911), Henry Ford's modern assembly line (after 1913), and statistical quality control (1920s), among many others.

The resulting flood of mass-produced goods demanded comparable innovation in control of a second area of the economy: distribution. Growing infrastructures of transportation, including rail networks, steamship lines, and urban traction systems, depended for control on a corresponding infrastructure of information processing and telecommunications. Within fifteen years after the opening of the pioneering Baltimore and Ohio Railroad in 1830, for example, Samuel F. B. Morse—with a congressional appropriation of $30,000—had linked Baltimore to Washington, D.C., by means of a telegraph. Eight years later, in 1852, thirteen thousand miles of railroad and twenty-three thousand miles of telegraph line were in operation (Thompson 1947; U.S. Bureau of the Census 1975, p. 731), and the two infrastructures continued to coevolve in a web of distribution and control that progressively bound the entire continent. In the words of business historian Alfred Chandler, "the railroad permitted a rapid increase in the speed and decrease in the cost of long-distance, written communication, while the invention of the telegraph created an even greater transformation by making possible almost instantaneous communication at great distances. The railroad and the telegraph marched across the continent in unison . . . The telegraph companies used the railroad for their rights-of-way, and the railroad used the services of the telegraph to coordinate the flow of trains and traffic" (1977, p. 195).

This coevolution of the railroad and telegraph systems fostered the development of another communication infrastructure for control of mass distribution and consumption: the postal system. Aided by the introduction in 1847 of the first federal postage stamp, itself an important innovation in control of the national system of distribution, the total distance mail moved more than doubled in the dozen years between Morse's first telegraph and 1857, when it reached 75 million miles—almost a third covered by rail (Chandler 1977, p. 195). Commercialization of the telephone in the 1880s, and especially the development of long-distance lines in the 1890s, added a third component to the national infrastructure of telecommunications.

Controlled by means of this infrastructure, an organizational system rapidly emerged for the distribution of mass production to national and world markets. Important innovations in the rationalization and control of this system included the commodity dealer and standardized grading of commodities (1850s), the department store, chain store, and wholesale jobber (1860s), monitoring of movements of inventory or "stock turn" (by 1870), the mail-order house (1870s), machine packaging (1890s), franchising (by 1911 the standard means of distributing automobiles), and the supermarket and mail-order chain (1920s). After World War I the instability in national and world markets that Durkheim had noted a quarter-century earlier came to be gradually controlled, largely because of the new telecommunications infrastructure and the reorganization of distribution on a societal scale.

Mass production and distribution cannot be completely controlled, however, without control of a third area of the economy: demand and consumption. Such control requires a means to communicate information about goods and services to national audiences in order to stimulate or reinforce demand for these products; at the same time, it requires a means to gather information on the preferences and behavior of this audience—reciprocal feedback to the controller from the controlled (although the consumer might justifiably see these relationships as reversed).

The mechanism for communicating information to a national audience of consumers developed with the first truly mass medium: power-driven, multiple-rotary printing and mass mailing by rail. At the outset of the Industrial Revolution, most printing was still done on wooden handpresses—using flat plates tightened by means of screws—that differed little from the one Gutenberg had used three centuries earlier. Steam power was first successfully applied to printing in Germany in 1810; by 1827 it was possible to print up to 2,500 pages in an hour. In 1893 the New York *World* printed 96,000 eight-page copies every hour—a 300-fold increase in speed in just seventy years.

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The postal system, in addition to effecting and controlling distribution, also served, through bulk mailings of mass-produced publications, as a new medium of mass communication. By 1887 Montgomery Ward mailed throughout the continent a 540-page catalog listing more than 24,000 items. Circulation of the Sears and Roebuck catalog increased from 318,000 in 1897 (the first year for which figures are available) to more than 1 million in 1904, 2 million in 1905, 3 million in 1907, and 7 million by the late 1920s. In 1927 alone, Sears mailed 10 million circular letters, 15 million general catalogs (spring and fall editions), 23 million sales catalogs, plus other special catalogs—a total mailing of 75 million (Boorstin 1973, p. 128) or approximately one piece for every adult in the United States.

Throughout the late nineteenth and early twentieth centuries uncounted entrepreneurs and inventors struggled to extend the technologies of communication to mass audiences. Alexander Graham Bell, who patented the telephone in 1876, originally thought that his invention might be used as a broadcast medium to pipe public speeches, music, and news into private homes. Such systems were indeed begun in several countries—the one in Budapest had six thousand subscribers by the turn of the century and continued to operate through World War I (Briggs 1977). More extensive application of telephony to mass communication was undoubtedly stifled by the rapid development of broadcast media beginning with Guglielmo Marconi's demonstration of long-wave telegraphy in 1895. Transatlantic wireless communication followed in 1901, public radio broadcasting in 1906, and commercial radio by 1920; even television broadcasting, a medium not popular until after World War II, had begun by 1923.

Many other communication technologies that we do not today associate with advertising were tried out early in the Control Revolution as means to influence the consumption of mass audiences. Popular books like the novels of Charles Dickens contained special advertising sections. Mass telephone systems in Britain and Hungary carried advertisements interspersed among music and news. The phonograph, patented by Thomas Edison in 1877 and greatly improved by the 1890s in Hans Berliner's "gramophone," became another means by which a sponsor's message could be distributed to households: "Nobody would refuse," the United States Gramaphone Company claimed, "to listen to a fine song or concert piece or an oration—even if it is interrupted by a modest remark, 'Tartar's Baking Powder is Best' " (Abbot and Rider 1957, p. 387). With the development by Edison of the "motion

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five major categories: education, research and development, communications media, information machines (like computers), and information services (finance, insurance, real estate). He then estimated from national accounts data for 1958 (the most recent year available) that the information sector accounted for 29 percent of gross national product (GNP) and 31 percent of the labor force. He also estimated that between 1947 and 1958 the information sector had expanded at a compound growth rate double that of GNP. In sum, it appeared that the United States was rapidly becoming an Information Society.

Over the intervening twenty years several other analyses have substantiated and updated the original estimates of Machlup (1980, pp. xxvi–xxviii): Burck (1964) calculated that the information sector had reached 33 percent of GNP by 1963; Marschak (1968) predicted that the sector would approach 40 percent of GNP in the 1970s. By far the most ambitious effort to date has been the innovative work of Marc Uri Porat for the Office of Telecommunications in the U.S. Department of Commerce (1977). In 1967, according to Porat, information activities (defined differently from those of Machlup) accounted for 46.2 percent of GNP—25.1 percent in a "primary information" sector (which produces information goods and services as final output) and 21.1 percent in a "secondary information" sector (the bureaucracies of noninformation enterprises).

The impact of the Information Society is perhaps best captured by trends in labor force composition. As can be seen in Figure 1.1 and the corresponding data in Table 1.2, at the end of the eighteenth century the U.S. labor force was concentrated overwhelmingly in agriculture, the location of nearly 90 percent of its workers. The majority of U.S. labor continued to work in this sector until about 1850, and agriculture remained the largest single sector until the first decade of the twentieth century. Rapidly emerging, meanwhile, was a new industrial sector, one that continuously employed at least a quarter of U.S. workers between the 1840s and 1970s, reaching a peak of about 40 percent during World War II. Today, just forty years later, the industrial sector is close to half that percentage and declining steadily; it might well fall below 15 percent in the next decade. Meanwhile, the information sector, by 1960 already larger (at more than 40 percent) than industry had ever been, today approaches half of the U.S. labor force.

At least in the timing of this new sector's rise and development, the data in Figure 1.1 and Table 1.2 are compatible with the hypothesis

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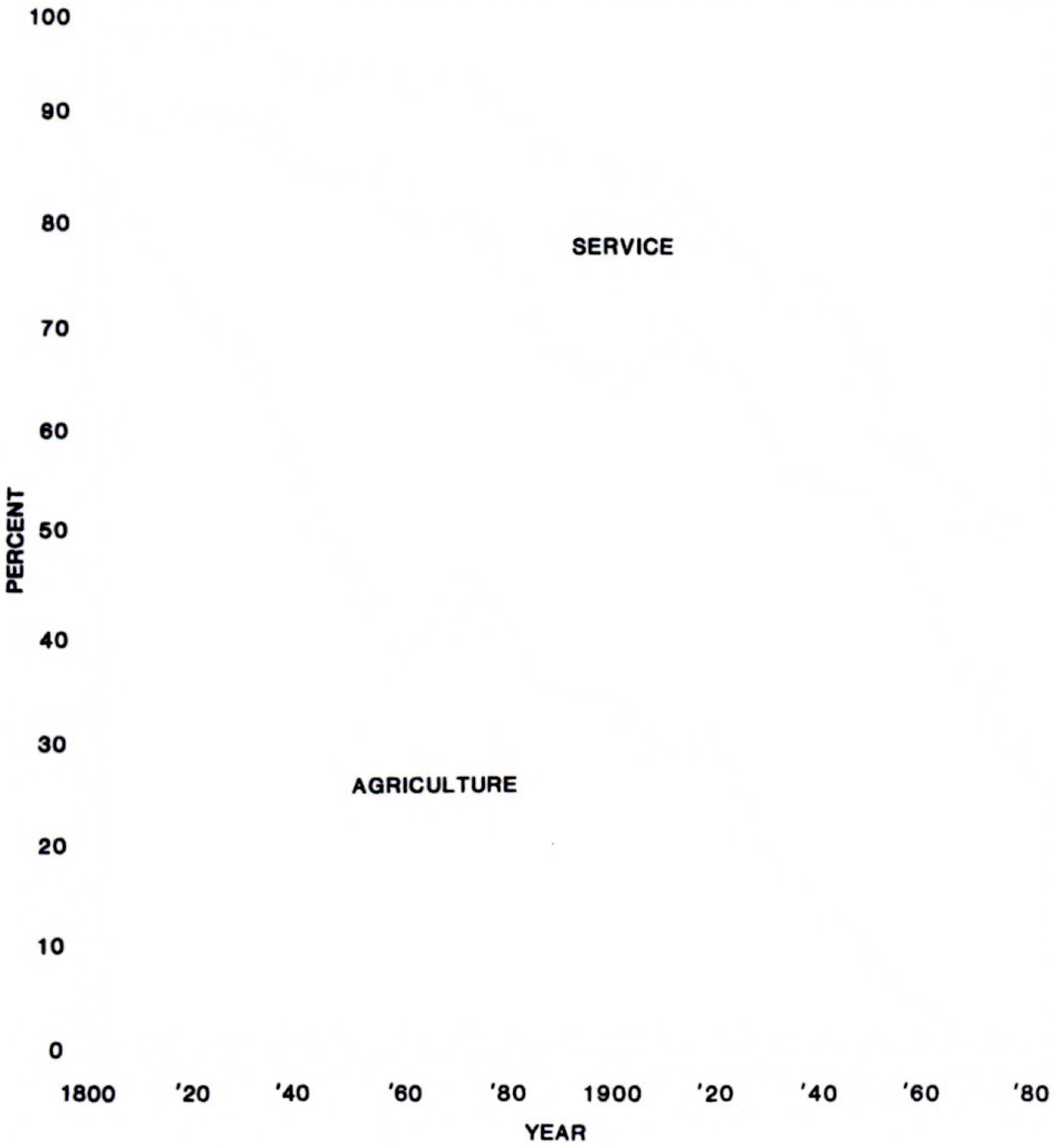

Figure 1.1. U.S. civilian labor force by four sectors, 1800–1980.

that the Information Society emerged in response to the nineteenth-century crisis of control. When the first railroads were built in the early 1830s, the information sector employed considerably less than 1 percent of the U.S. labor force; by the end of the decade it employed more than 4 percent. Not until the rapid bureaucratization of the 1870s and 1880s, the period that—as I argue on independent grounds in Chapter 6—marked the consolidation of control, did the percentage employed in the information sector more than double to about one-eighth of the civilian work force. With the exception of these two great discontinuities, one occurring with the advent of railroads and the crisis of control in the 1830s, the other accompanying the consolidation of

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Table 1.2. U.S. experienced civilian labor force by four sectors, 1800–1980

	Sector's percent of total				
Year	Agricultural	Industrial	Service	Information	Total labor force (in millions)
1800	87.2	1.4	11.3	0.2	1.5
1810	81.0	6.5	12.2	0.3	2.2
1820	73.0	16.0	10.7	0.4	3.0
1830	69.7	17.6	12.2	0.4	3.7
1840	58.8	24.4	12.7	4.1	5.2
1850	49.5	33.8	12.5	4.2	7.4
1860	40.6	37.0	16.6	5.8	8.3
1870	47.0	32.0	16.2	4.8	12.5
1880	43.7	25.2	24.6	6.5	17.4
1890	37.2	28.1	22.3	12.4	22.8
1900	35.3	26.8	25.1	12.8	29.2
1910	31.1	36.3	17.7	14.9	39.8
1920	32.5	32.0	17.8	17.7	45.3
1930	20.4	35.3	19.8	24.5	51.1
1940	15.4	37.2	22.5	24.9	53.6
1950	11.9	38.3	19.0	30.8	57.8
1960	6.0	34.8	17.2	42.0	67.8
1970	3.1	28.6	21.9	46.4	80.1
1980	2.1	22.5	28.8	46.6	95.8

Sources: Data for 1800–1850 are estimated from Lebergott (1964) with missing data interpolated from Fabricant (1949); data for 1860–1970 are taken directly from Porat (1977); data for 1980 are based on U.S. Bureau of Labor Statistics projections (Bell 1979, p. 185).

control in the 1870s and especially the 1880s, the information sector has grown steadily but only modestly over the past two centuries.

Temporal correlation alone, of course, does not prove causation. With the exception of the two discontinuities, however, growth in the information sector has tended to be most rapid in periods of economic upturn, most notably in the postwar booms of the 1920s and 1950s, as can be seen in Table 1.2. Significantly, the two periods of discontinuity were punctuated by economic depressions, the first by the Panic of 1837, the second by financial crisis in Europe and the Panic of 1873. In other words, the technological origins of both the control crisis and the consolidation of control occurred in periods when the information sector would not have been expected on other economic grounds to have expanded rapidly if at all. There is therefore no reason to reject

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the hypothesis that the Information Society developed as a result of the crisis of control created by railroads and other steam-powered transportation in the 1840s.

A wholly new stage in the development of the Information Society has arisen, since the early 1970s, from the continuing proliferation of microprocessing technology. Most important in social implications has been the progressive convergence of all information technologies—mass media, telecommunications, and computing—in a single infrastructure of control at the most macro level. A 1978 report commissioned by the President of France—an instant best-seller in that country and abroad—likened the growing interconnection of information-processing, communication, and control technologies throughout the world to an alteration in "the entire nervous system of social organization" (Nora and Minc 1978, p. 3). The same report introduced the neologism *telematics* for this most recent stage of the Information Society, although similar words had been suggested earlier—for example, *compunications* (for "computing + communications") by Anthony Oettinger and his colleagues at Harvard's Program on Information Resources Policy (Oettinger 1971; Berman and Oettinger 1975; Oettinger, Berman, and Read 1977).

Crucial to telematics, compunications, or whatever word comes to be used for this convergence of information-processing and communications technologies is increasing digitalization: coding into discontinuous values—usually two-valued or binary—of what even a few years ago would have been an analog signal varying continuously in time, whether a telephone conversation, a radio broadcast, or a television picture. Because most modern computers process digital information, the progressive digitalization of mass media and telecommunications content begins to blur earlier distinctions between the communication of information and its processing (as implied by the term *compunications*), as well as between people and machines. Digitalization makes communication from persons to machines, between machines, and even from machines to persons as easy as it is between persons. Also blurred are the distinctions among information types: numbers, words, pictures, and sounds, and eventually tastes, odors, and possibly even sensations, all might one day be stored, processed, and communicated in the same digital form.

In this way digitalization promises to transform currently diverse forms of information into a generalized medium for processing and exchange by the social system, much as, centuries ago, the institution

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of common currencies and exchange rates began to transform local markets into a single world economy. We might therefore expect the implications of digitalization to be as profound for macrosociology as the institution of money was for macroeconomics. Indeed, digitalized electronic systems have already begun to replace money itself in many informational functions, only the most recent stage in a growing systemness of world society dating back at least to the Commercial Revolution of the fifteenth century.

Societal Dynamics Reconsidered

Despite the chronic historical myopia that characterizes the human condition as documented in the opening pages of this chapter, it is unlikely that the more astute observers of our era would fail to glimpse—however dimly—even a single aspect of its essential social dynamic. For this reason the ability of a conceptual framework to subsume social changes noted by previous observers might be taken as one criterion for judging its claim to portray a more fundamental societal transformation. We shall see that the various transformations identified by contemporary observers as listed in Table 1.1 can be readily subsumed by the major implications of the Control Revolution: the growing importance of information technology, as in Richta's scientific-technological revolution (1967) or Brzezinski's technetronic era (1970); the parallel growth of an information economy (Machlup 1962, 1980; Porat 1977) and its growing control by business and the state (Galbraith 1967); the organizational basis of this control (Boulding 1953; Whyte 1956) and its implications for social structure, whether a meritocracy (Young 1958) or a new social class (Djilas 1957; Gouldner 1979); the centrality of information processing and communication, as in McLuhan's global village (1964), Phillips's communications age (1975), or Evans's micro millennium (1979); the information basis of postindustrial society (Touraine 1971; Bell 1973); and the growing importance of information and knowledge in modern culture (Mead 1970).

In short, the argument that motivates our investigation of the nineteenth-century crisis of control and the resulting Control Revolution is that particular attention to the material aspects of information processing, communication, and control makes possible the synthesis of a large proportion of the literature on contemporary social change. It will be useful, however, to consider first the broader theoretical and historical context of industrialization and technological change. A more

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I

Living Systems, Technology, and the Evolution of Control

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2

Programming and Control: The Essential Life Process

The most humble organism is something much higher than the inorganic dust under our feet, and no one with an unbiased mind can study any living creature, however humble, without being struck with enthusiasm at its marvellous structure and properties.

—Darwin, *Descent of Man*

THE CONTROL REVOLUTION and the resulting Information Society now emerging in the United States, Canada, Western Europe, and Japan leave us with certain nagging questions. Why has information, among the multitude of commodities, come to dominate economic statistics—come indeed to replace industry as the sector best reflecting the extent of a nation's development? Among the diversity of technologies, why the growing importance of microprocessors and computers, devices that can do nothing more than convert information from one form to another?

No study of technological innovation or economic history can possibly answer such questions—no more than, say,the history of organic evolution could explain the importance of information to all living things. In both cases explanation lies not in the particulars of evolutionary or human history but in the nature of the physical universe. Historical detail can only obscure the more fundamental laws that govern energy conversion and material processing, for example, in human societies no less than in other living systems. To ignore these laws in attempting to account for the history of the past century would be to forgo answers to the more pressing questions of our current age: Why *information*, and Why *now?*

This is not to imply that the Control Revolution can be explained as the inevitable result of some autonomous dynamic of the material universe. Social change results from the purposive behavior of people acting from individual and often idiosyncratic motives in pursuit of real

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goals, justification enough to study the political and economic history of technological innovation. No amount of innovation can ever free us from the physical laws that constrain all technological development, however, which explains why we will also find meaning in questions posed at the suprahistorical level. For example, could a control revolution have come *before* an industrial one? (The answer, as we shall see, is clearly *no.*)

An earlier materialist historian, Karl Marx, made the same point: "Men make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under circumstances directly encountered, given, and transmitted from the past" (1852, p. 15). That these circumstances have shifted from land and capital to information—that information has emerged as the material base of modern economies—challenges the social theory we have inherited from the nineteenth century, much as the Industrial Revolution challenged Marx and other thinkers of that era to reconsider preindustrial theories. Then rapid industrialization forced theoretical reconstructions in terms of capital, energy, and material processing; today the Information Society demands similar reanalysis according to the physical relationships governing information storage, processing, communication, and control.

Prerequisite for any such reanalysis is a more general understanding of information's role in the production, distribution, and consumption of material goods, processes whose increasing volume and speed brought the nineteenth-century control crisis and resulting revolution in information technology. Such understanding may not require anything grandiose enough to be called a new theory, perhaps, but it would be advanced by a model of society more general than the changes we intend to explain.

Society as Processor

One such model, suggested in the previous chapter, is that of society as a *processing system,* one that sustains itself by extracting matter and energy from the environment and distributing them among its members. The science of economics has for centuries been grounded in the study of such material flows (Quesnay 1758; Walras 1874; Leontief 1941), while energy flows have provided the foundation for ecology since the late 1920s (Transeau 1926; Elton 1927; Tansley 1935). One behavioral scientist describes the processing role of living systems

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more generally: "They are open systems with significant inputs, throughputs, and outputs of various sorts of matter-energy and information. Processing these is all they do—a deceptively simple fact not widely recognized by the scientists who study them" (Miller 1978, p. 1027).

One of the first social scientists to elaborate this view of human society—with far-reaching implications—was the Australian economist Colin Clark in his path-breaking *Conditions of Economic Progress* (1940). Clark divided economic activity into what he called the *primary* (extractive), *secondary* (manufacturing), and *tertiary* (service) sectors of the economy. The relative importance of each sector, Clark argued, is determined by its relative productivity. With increasing industrialization, labor shifts from the primary to the secondary sector and then, with the resulting increase in demand for services, to the tertiary sector. The rate of transfer between sectors is a function of the differential value of their outputs per worker.

Using this conceptual apparatus, Clark measured economic progress as the rate of labor transfer to higher sectors and predicted transitional stages in the development of national economies. Following his lead, Hatt and Foote (1953) split out from the tertiary sector two new ones: a white-collar or *quaternary* sector including services like banking, insurance, and real estate, and an intellectual knowledge or *quinary* sector involving medicine, education, and research. According to their analysis, social mobility, including the increasing professionalization of work, is another major cause of labor shifts among sectors.

Despite the simplicity of these analytic frameworks, they have enabled economists to transcend the detail of a particular economy or historical period. In answer to our question about the timing of industrial and control revolutions, for example, Clark's work and its elaboration by Hatt and Foote suggest that information processing develops subsequent to the extraction and processing of matter and energy, with industrialization of the latter sectors a necessary precondition for the sustained growth of the former. Processing and distribution require control, under this model, and control depends in turn on information services. This would explain why, as we saw in Chapter 1, rapid increases in the volume and speed of throughput processing were accompanied by a spate of innovations in information technology during the late nineteenth century.

Such explanations, derived from the gross properties and physical exigencies shared by all concrete open systems, constitute an impor-

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tant step toward understanding the Control Revolution and resulting Information Society. For a social or behavioral scientist, however, the explanations raise as many questions as they answer. What precisely are the relationships among information, processing, and control and how are these concepts related to other aspects of human society and culture?

Organization for Control

Because the Control Revolution and its aftermath have so forcefully impressed on us the importance of information, we might be tempted to embrace that concept alone as the ultimate means to understand technological development and societal change. As we have seen, however, information is an epiphenomenon of the physical world, one that appears in even inanimate matter and energy when they are ordered, for example, into comets and crystals. To reduce a living system to the level of information, therefore, would be to study the ordering of its matter and energy, that is, to analyze it in terms of chemistry and physics—hardly a new or inspiring idea. If we wish to exploit the higher-order or derivative aspects of living systems, we must instead determine how they differ from the inanimate matter studied by physical scientists; in this sense only will we eschew reductionism.

When we compare even the simplest living systems to the most complex inorganic materials, one difference stands out: the much greater *organization* found in things organic. Living things require many pages to describe the organization of their physical structures, while the structure of an inorganic compound can always be captured in a relatively short string of symbols. Quartz, for example, which accounts for much of the earth's crust, is well described (well enough to replicate most experiments using it, for example) by the chemical symbols SiO_2 or the words *silicon dioxide.* Crystals can be uniquely described by the combination of their chemistry and atomic arrangement: only thirty-two different types of symmetry and seven systems of relationships among axes are possible; angles between corresponding faces must be constant. In other words, the complexity of crystals derives not from organization but from regularity and repetition, that is, from *order.*

Compared to organization, order contains relatively little information. A simple organism like the amoeba, for example, is not at all well ordered; it is a formless bag full of sticky fluid in which irregularly shaped molecules float haphazardly. In stark contrast to even the most

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about molecules in collections of inanimate matter is irrelevant and meaningless" (1975, p. 3). This same distinction, between "the most humble organism" and "the inorganic dust under our feet," is what Darwin (1871, p. 169) celebrated—without benefit of information theory or modern genetics—in the passage that opens this chapter.

Here, then, is the most fundamental reason why the Control Revolution has been so profound in its impact on human society: it transformed no less than the essential life function itself. Rapid technological expansion of what Darwin called life's "marvellous structure and properties" and what we now see to include organization, information processing, and communication to effect control constitute a change unprecedented in recorded history. We would have to go back at least to the emergence of the vertebrate brain if not to the first replicating molecule—marking the origin of life on earth—to find a leap in the capability to process information comparable to that of the Control Revolution. But what precisely is it that living systems are organized to control, and why is this particular function so important to life?

Control and Energy

Similar questions raised about the organization of nonliving matter early in the nineteenth century culminated in *thermodynamics*, the science of heat and its relationship to other energy forms. Although thermodynamics developed out of steam power engineering following the Industrial Revolution, many scientists still consider its laws—whose progressive elaboration spanned the Control Revolution—to rank among the greatest achievements of Western thought.

According to the second law of thermodynamics, the so-called principle of the degradation of energy, a system's energy cannot be converted from one form to another—including work—without decreasing its organization and hence ability to do further work. A steam engine, for example, can work only so long as it is organized into relatively more and less heated parts, the organization known as a *heat gradient*. Because degradation of organization can only increase, according to the second law, the energy available to do work can only decrease.

In closed systems defined by impermeable boundaries, energy must remain constant in keeping with the first law of thermodynamics, the so-called principle of the conservation of energy, that matter and energy can neither be created nor destroyed. Because this total energy must remain constant, a closed system can only *lose* its ability to do

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omy as first delineated by Colin Clark reflect the same essential life process: agriculture and mining, the extraction and breakdown of matter to produce energy; manufacturing, the synthesis of matter and energy into more organized forms; and services, the organization and support of these processes in well-integrated systems.

Unlike living organisms, however, *social* systems are made up of relatively autonomous components—individuals, families, groups, organizations—that can act for different and even cross-purposes. Because system processing must depend on exchanges among these individual components, the need for their coordination and control means that information processing and communication will account for a relatively greater proportion of matter and energy flows than they do in single organisms. The actual proportion will depend on several factors, including size of the population and its spatial dispersion, complexity of organization, and volume and speed of processing, among others.

This conclusion suggests that the proper subject matter of the social and behavioral sciences, if they are to complement studies of the flows of matter (input-output economics) and energy (ecology), ought to be information: its generation, storage, processing, and communication to effect control. Much the same vision of social science has already been expressed in a variety of disciplines. As early as 1950, for example, Norbert Wiener, a pioneer of cybernetic theory, argued that "society can only be understood through a study of the messages and the communication facilities which belong to it" (1950, p. 9). Zoologist E. O. Wilson, after surveying the thousands of social species from colonial jellyfish and corals to the primates, including *Homo sapiens*, declared "reciprocal communication of a cooperative nature" to be what he called the "diagnostic criterion" of society as most generally defined (1975, p. 595). Niklas Luhmann, a German sociologist, proclaims: "The system of society consists of communications. There are no other elements, no further substance but communications" (1984, pp. 1–2).

Living as we do in the Information Society, surrounded by microprocessing and telecommunications technologies, we might suppose that social theorists have always appreciated the importance of information and communication to social organization in general and to human society in particular. What could be more obvious than that, as Wiener put it in his first book on cybernetics, "the social system is an organization, like the individual, that is bound together by a system of communication" (1948, p. 24). With the continuing development of

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global computer networks, telecommunications, and mass media, it grows increasingly difficult to appreciate how relatively recent and different is the information-processing view of human organization and society.

One indication is provided by the Encyclopedia Britannica's fifty-four-volume set, *Great Books of the Western World,* published in 1952. Not one of three key concepts—information, communication, and control—made the list of 102 "great ideas" used to organize 520 classic works from Homer to Freud, a list that did include *form, matter, mechanics,* and *physics*. The three informational concepts did not make Britannica's penultimate list of 115 ideas, nor even the 88 additional ones ranked "among the most likely candidates for inclusion" (Adler 1952, pp. 1223–1224). Even the publication's 1,798-item "inventory of terms" included only *communication,* which turned up twenty-four times among 163,000 citations. Not until the rise of the Information Society, it appears, did concepts like information processing, communication, and control first surface in social theoretical discourse.

Most of the conceptual apparatus we need to understand the Control Revolution, it turns out, was directly inspired by the Control Revolution itself. The new ideas followed major technological advances, with some lag, during especially the period from the 1870s through the 1930s. This means that, although our interest here lies primarily in understanding the Control Revolution, we can also chronicle its impact on the history of ideas even as we develop the same ideas to help account for the larger societal change. For those who consider intellectual history to have a material basis, we could hardly do otherwise.

Control through Programming

One idea directly inspired by the Control Revolution in technology is the concept of a *program,* a word that first appeared in the seventeenth century for public notices but which in the past 150 years has spread through other organizational and informational technologies: plans for formal proceedings (1837), political platforms (1895), broadcast presentations (1923), electronic signals (1935), computer instructions (1945), educational procedures (1950), and training (1963). In general, *program* has come to mean any prearranged information that guides subsequent behavior.

We have already defined *control* as purposive influence toward a predetermined goal. If purpose is to be explained in other than me-

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taphysical terms, however, its goal must exist prior to the behavior that it influences in some material form, on the government rolls, for example, that motivated the original Latin *contrarotulare*. All control is thus *programmed:* it depends on physically encoded information, which must include both the goals toward which a process is to be influenced and the procedures for processing additional information toward that end.

Often such programming is built directly into the physical structure of a purposive mechanism as, for example, information about the length of a minute and the number of minutes in an hour is built directly into the parts of a clock. Genetic programming is of this nature, built into our material essence at the moment of conception. Other programming, like that of an alarm clock, can be modified by the environment. All living systems can be reprogrammed in at least this way—Pavlov's dogs were just one example of the universal rule. Still other information-processing systems, because of their highly generalized capability for purposive action, might be controlled by a wide variety of programming: microprocessors and computers, for example, or bureaucracy, a controlling structure that routinely serves even a radically different government after a revolution or coup. By far the most generally programmable structures to be found in any living system are the brains evolved by the vertebrates, especially the human brain.

To account for purposive processes and behavior in terms of programming might seem merely to shift the problem of explanation from one set of concepts to another—from material action to information—with no real gain in understanding. This characterizes causal explanations in general, however, not just those based on the concept of programming. Without attempting to review the many controversies surrounding scientific explanation, we might simply note that, in seeking to account for purpose in terms of programming, we at least avoid two major conceptual problems, those of *vitalism* and *teleology*.

Unlike other attempts to account for the goal-directed behavior of living organisms, including postulated forces like *animus* (Aristotle 1931), *élan vital* (Bergson 1907), and *Entelechie* (Driesch 1908), programming must at least exist in a *physical* form, thereby eliminating vitalist and other metaphysical baggage. Because programs must exist prior to the phenomena they explain, moreover, they circumvent a major objection to teleological, functional, or "in order to" explanations—that their effects precede rather than follow their causes (Nagel 1961, chap. 12; Wright 1976).

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Programmed behavior is not teleological but *teleonomic*, a term introduced by the biologists Colin Pittendrigh (1958), Julian Huxley (1960), and Ernst Mayr (1961, 1974b), among others, in an effort to rid their discipline of both teleological explanation and a longstanding contradiction: insistence that all natural processes have mechanistic interpretations, on the one hand, in the face of seemingly purposive sequences like organic growth, reproduction, and animal behavior on the other. In Mayr's words, "a teleonomic process or behavior is one that owes its goal directedness to the operation of a program" (1976, p. 389); a program is "coded or prearranged information that controls a process (or behavior) leading it toward a given end" (pp. 393–394).

Teleonomy, in other words, is equivalent to explanation in terms of programming and control. Although grounded in these concepts of modern information theory, teleonomic explanations are compatible with theories arising as early as the secularization of social thought in the seventeenth century. The view that society emerges from the interaction of goal-directed behavior controlled at various levels of aggregation, for example, dates back to the seventeenth-century political philosophers and eighteenth-century economists. The positivist version, stressing that individual goals are conditioned on objective facts like the behavior of other actors, first developed in the writing of Hobbes (1651), Locke (1690), and the classical economists (Smith 1776; Ricardo 1817). The idealist version, emphasizing the normative and subjective programming of behavior, can be traced back to the later writings of Kant, especially to the *Critiques* of what he called *Praktischen Vernunft* or "practical reason" (1788) and *Urtheilskraft* or "judgment" (1790, pt. 2).

In contrast to these classical approaches, however, teleonomic explanations obviate the need to attribute consciousness, planning, purpose, or any other anthropomorphic qualities to aggregate levels, the special problem of *reification*. Adam Smith's "invisible hand" of market forces (1776, p. 423), for example, can be seen to result from the interconnected programming of individuals and their organizations, including individual tactics, strategies, and utilities, on the one hand, and organizational procedures, written law, and cultural norms on the other. This list of programming is more than an analogy. Each item describes a programmable form of control—including both goals and procedures—that might be encoded in some physical form, whether electrochemically in the human brain, in inked patterns on paper, or in charged particles in computer memory. Each program might there-

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to the laws of natural selection and evolution, in favor of social analysis grounded in the voluntaristic action of individuals.

The difference reflects the progress of the Control Revolution which, as already noted, resulted in a fundamental change in human thought between the 1870s and 1930s. At the turn of the century most intellectuals still accepted the view expressed in Spencer's *Principles of Biology* (1864–1867) and *Principles of Sociology* (1876–1896) that social organization and control might be treated as autonomous processes like those studied by physical scientists. By the 1930s, however, social theorists like Brinton and Parsons were beginning to see organization as purposively constructed and effecting control through goal-directed behavior. This new world view, compatible with concepts like information processing, programming, and decision, was at the same time gaining adherents in a wide variety of other disciplines, from mathematical logic, philosophy, and psychology to the founding work in computer theory.

Despite Parsons's early involvement in the change, however, and the great success of his work on action theory, he drifted back to the study of autonomous social systems (1951, 1960, 1971) and even to evolution (1966), eventually becoming what one sociologist ironically called "a Spencerian of sorts" (Bierstedt 1975, p. 155). Meanwhile, according to the same source, Spencer's work has enjoyed "a remarkable resurrection, one that may require the restoration of his statue in the pantheon of sociological heroes" (p. 154). Obviously the distinction that Parsons insisted separated his work from Spencer's was in fact overdrawn. The two theorists merely pitched their analyses at different levels of control: Spencer closer to organization and its processes, Parsons closer to individual programs, their goals, and resultant behavior.

Had Parsons managed to develop the concept of programming, just emerging as he wrote his first book, he would have had the perfect means to reconcile his action theory with the theories of Spencer. Because programming must exist in some material form, it is tractable by positivist-utilitarian methods like those championed by Spencer. Because both genetic and cultural programming can be communicated to new individuals, whether through biological reproduction or through socialization and cultural diffusion, both do indeed evolve much as Spencer argued, whether through so-called natural (nonpurposive) or purposive selection. Parsons's emphasis on normative programming

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1977). Three years later, in *The Theory of Heat*, Maxwell introduced a demon

> whose faculties are so sharpened that he can follow every molecule in its course. Such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform . . . Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics. (1871, pp. 308–309)

According to the second law of thermodynamics, as we have seen, the organization of a closed system like the vessel can only decrease and the process is irreversible, Maxwell's demon notwithstanding. Relative disorganization or randomness of a system is important enough to have been given the special name *entropy*, a term coined by the German physicist Rudolf Clausius in 1865. So basic and pervasive is the tendency toward increased entropy in both nonliving and living systems that the British astronomer and physicist Sir Arthur Eddington declared, "The law that entropy always increases—the second law of thermodynamics—holds, I think, the supreme position among the laws of Nature" (1928, p. 74).

Here, then, was the challenge of Maxwell's demon, which seemed to overturn—by merely opening and closing a small hole—no less than the supreme law of nature. The fact that even the great Maxwell failed to resolve the paradox, not to mention similar failures by three generations of scientists, illustrates how recent and nonobvious are concepts like information, programming, decision, and control—precisely the concepts that Maxwell unwittingly ascribed to his hypothetical demon.

That Maxwell's demon is in fact a program is demonstrated by Figure 2.1, which gives the flow chart of an algorithm that perfectly duplicates the demon's behavior. For each molecule in the vessel, the demon must continually determine two pieces of information—velocity and trajectory—for the program's essential inputs (represented by the parallelogram near the top of Figure 2.1). Based on only these two

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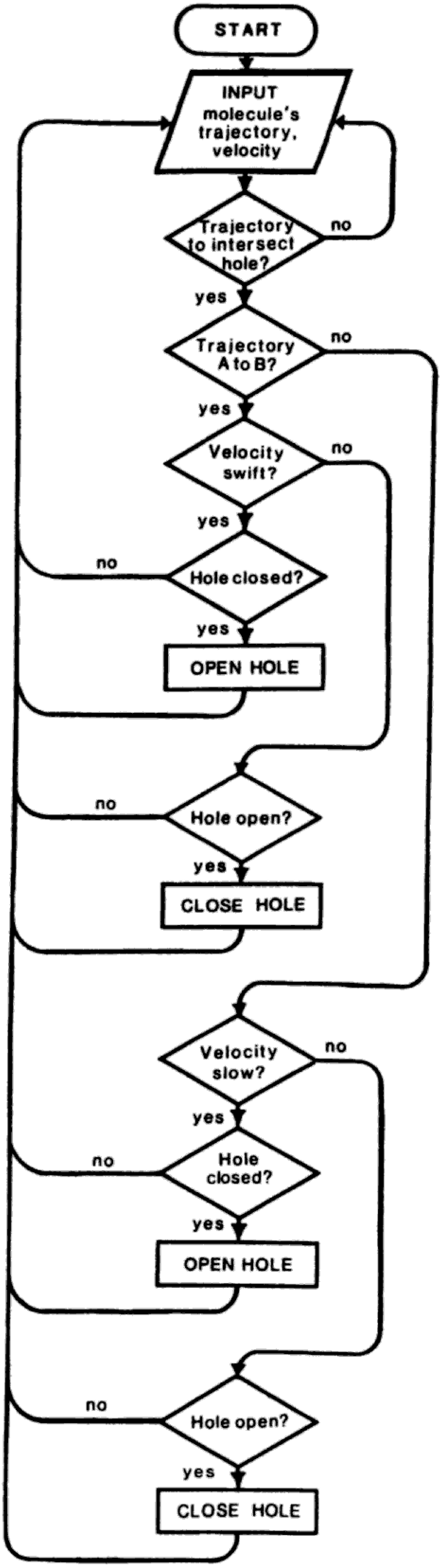

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inputs, the algorithm determines whether or not the demon ought to behave in the only two ways it can: by opening or closing the small hole in the partition separating portions A and B of the vessel (outputs are represented in the flow chart as rectangles).

With the same simple sequence of decisions, some mechanism might in fact be programmed to act in the way described by Maxwell, namely, "to allow only the swifter molecules to pass from A to B, and only the slower ones to pass from B to A." Would such a mechanism overturn the second law of thermodynamics—the supreme law of nature—by reversing the progressive degradation of energy in the vessel and thereby decreasing its entropy?

Because Maxwell took information for granted, he did not consider the costs of providing his demon with a continual flow of inputs to its program. Information always requires at least an expenditure of energy sufficient to transmit it—with a resulting increase in entropy. Unless there is light, for example, Maxwell's demon cannot "see" the molecules in the vessel. Once light is introduced, however, the entropy of the vessel can only increase—despite the demon's best efforts—because the free energy lost in transmitting information exceeds the energy gained by his purposive sorting. Even if the demon does not "see" the molecules, that is, follow them by means of reflected light, he will need some alternative means of acquiring information. Because information can only be communicated in some form of matter or energy, the results are always the same: the demon's energy needs will exceed the energy freed by his sorting and his operation must inevitably succumb to heat death.

This argument was foreshadowed in work on statistical physics that the Austrian Ludwig Boltzmann published in 1894. Boltzmann observed that entropy is related to "missing information," that is, to the number of alternatives that remain to a physical system after all the macroscopically observable information about it has been recorded (Shannon and Weaver 1949, p. 3). Extending this insight, Leo Szilard, the Hungarian physicist who would later be instrumental in building the first atomic bomb, used the statistics of quantum mechanics to calculate the minimum amount of energy required to transmit *any* information. Whatever means of information processing Maxwell's demon might employ, according to Szilard's calculations, the heat gradient would be exceeded by the energy costs of information necessary to sustain it

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Figure 2.1. Flow chart of an algorithm for Maxwell's demon.

(Szilard 1929). In other words, the demon is no threat to nature's supreme law—Maxwell's paradox is resolved.

His demon continues to interest us, however, because its sixty-year career so precisely mirrors the intellectual development of the Control Revolution. Born just three years after Maxwell's seminal paper on control theory, in the same decade that brought technological innovations like the telephone, phonograph, and microphone, the demon was not retired until the understanding of information had reached a high level of quantitative sophistication—owing largely to the work of new communications engineers like Nyquist (1924, 1928) and Hartley (1928) and culminating in Shannon's mathematical theory after World War II.

The basic lessons of Maxwell's demon—that control involves programming, that programs require inputs of information, that information does not exist independent of matter and energy and therefore must incur costs in terms of increased entropy—all seem commonplace today. One evidence is that grade-school children around the world can now program simple algorithms like that used by Maxwell's demon.

Programming and Decision

A second basic concept that, like the idea of a program, was profoundly changed by the Control Revolution in technology is that of *decision*. Although programs are responsible for all control and hence all purposive action, this alone does not explain how such control is possible. How do inert progams manage to influence concrete technologies, not to mention living organisms, guiding both toward predetermined goals? Work in a wide range of disciplines converged by the 1930s on a single answer: programs control by determining decisions.

As we saw in the algorithm for Maxwell's demon, the process of control involves comparison of new information (inputs) to stored patterns and instructions (programming) to decide among a predetermined set of contingent behaviors (possible outputs). As we have seen, this describes the use of official government rolls as commemorated by the medieval Latin verb *contrarotulare*. Contingent decision: If a man's property is listed on the rolls, tax accordingly; if not, assess his property and fine or imprison him. To decide is to control, in short, and to control is to decide; information processing and programming make both possible.

Once again the crucial aspect of a definition is exposed by etymology,

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attempted to formalize various parts of mathematics (van Heijenoort 1967, p. vi). In contrast to axiomization, which uses ordinary language and logic, Frege introduced a formal system based on abstract signs, formulas, and explicit rules for their manipulation. The monumental *Principia Mathematica* of A. N. Whitehead and Bertrand Russell, published in three volumes between 1910 and 1913, helped to popularize Frege's notion of a formal system.

Hilbert, in particular, insisted that all mathematics could be reduced to an inventory of formulas, rules, and proofs, the subject matter of a new science of proof theory or metamathematics. When the International Congress of Mathematicians met in Paris in 1900, Hilbert presented twenty-three of what he considered the most important problems—including several involving questions of decidability—to occupy mathematicians during the coming century. Hilbert himself had already set out to find an algorithm to decide the truth or falsity of *any* mathematical proposition, what came to be known as the *Entscheidungsproblem*. This program occupied many of the world's leading mathematicians, including Wilhelm Ackermann (1924), John von Neumann (1927), and Jacques Herbrand (1930, 1931).

Hopes for the program were dashed in 1931, however, when Kurt Gödel published his famous incompleteness theorem, one of the great intellectual achievements of the century. The theorem proved, in effect, that the procedure sought by Hilbert, including the one suggested by Whitehead and Russell in the *Principia,* could not exist. In any formal system adequate for number theory, Gödel showed, there exists an *undecidable* formula for which neither itself nor its negation can be proved; a major corollary establishes that the consistency of any such system is also undecidable. The revolution in logic begun by Frege a half-century earlier had at last found its dialectical resolution: intuitionism remained dead, on the one hand, but mathematicians were now forced to couch their new formalisms in semiformal language.

Of the many effects of Gödel's theorem, none was more important to the intellectual development of the Control Revolution than the resulting clarification of *decision procedures,* the mechanical rules that determine, in finitely many steps, whether a combination of symbols is decidable. Today the accepted formalization of such procedures is the *Turing machine,* a simple mathematical model of a general-purpose computer introduced in 1936 by the British logician Alan Turing, who evidently took the idea of a "mechanical" rule quite literally.

On the basis of Turing's work and several alternative formulations

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late 1950s applied to popular games in the semipopular press; according to the July 1957 *Technology* magazine, "any game of a finite kind which can be completed in a finite number of moves . . . must have a decision procedure, even though we may not know for any particular game what this procedure is" (p. 182). Three years later the London *Times* discussed "decision-making machines" (March 24, 1960, p. 2); the image of the "decision-taking mechanism of the human brain" dates from 1964 (Young 1964, p. 28).

Games also provided the inspiration for a separate application of decision to control theory, namely statistical decision theory, a formalization of rational choice among alternatives with different probabilities and utilities. Drawing on von Neumann's 1928 paper establishing what has come to be known as *game theory*, the mathematical statistician Abraham Wald in 1939 introduced a more general *decision theory* incorporating classic statistical work on hypothesis testing and estimation. Wald's generalization and synthesis of statistics, including his application of multiple decision spaces, weight and risk functions, and minimization of maximum risks (so-called minimax solutions), provided the basis for much of the intellectual technology of control that would emerge during and after World War II: quality control, linear programming, operations research, systems analysis, and even game theory, which found wide practical application after von Neumann's text with the economist Oskar Morgenstern appeared in 1944. Sociologist Daniel Bell assesses the role of decision theory as follows:

> Any single choice may be as unpredictable as the quantum atom responding erratically to the measuring instrument, yet the aggregate patterns can be charted as neatly as the geometer triangulates the height and the horizon. If the computer is the tool, then decision theory is its master. Just as Pascal sought to play dice with God, and the physiocrats attempted to draw an economic grid that would array all exhanges among men, so the decision theorists seek their own *tableau entier*—the compass of rationality, the "best" solution to the choices perplexing men. (1973, p. 33)

Logical and statistical theories of decision were not the only ones to emerge in the 1920s and 1930s, a period that saw development of the concept in two other areas: normative decision theory and deontic logic. Both were influenced by the work of Frank P. Ramsey, a mathematician who in 1926 stated simple consistency postulates implying the existence of both personal probabilities and utilities.

Psychologist Kurt Lewin, influenced by lectures on decision theory

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that von Neumann gave in Berlin in 1928, formulated the first treatment of utility (what he called *Aufforderungscharakter* or "valence") and related concepts of subjective probability in the early 1930s (1931a,b,c). These and similar formulations gained mathematical rigor in work by Bruno de Finetti published in 1937. Two years later, using Milton's "Reason is also choice" as a motivation, John Hicks applied the developing ideas to economic decision under uncertainty, work for which he received the Nobel Prize in 1972. Following World War II, the ideas of Ramsey, von Neumann, de Finetti, and Hicks found synthesis in work by Kenneth Arrow (1951a,b), corecipient of the 1972 Nobel Prize in economics, and statistician Leonard Savage (1951, 1954); both treatments converged with statistical decision theory. A few years later, Patrick Suppes (1956, 1957) and R. Duncan Luce (1959) began to incorporate many of the same normative decision concepts into psychology (Luce and Suppes 1965).

Ramsey had initially called his theory "a branch of logic" (1926, p. 157), and indeed that idea developed into a fourth distinct approach to decision. Until the late 1920s principles of *deontic* logic, the logic of obligation, tended to be stated as footnotes to work on moral philosophy or *modal* logic, the logic of the possible and necessary. Even modal logic, extensively developed since its origins in ancient Greece, had fallen into neglect during the Renaissance and found little place in modern mathematical logic following Frege. Revival of interest in especially the systematic treatment of modal logic in the 1920s, however, led to attempts to treat deontic logic in a similar fashion.

The first such attempt was that of Ernst Mally (1926), who introduced the modern usage of "Deontik" by adding a modal operator denoting *ought* to the formal language of propositional logic. Despite continuations of Mally's effort by Karl Menger (1934, 1939), Kurt Grelling (1939), and Karl Reach (1939), widespread interest did not come until the end of World War II and publication of the classic paper by Georg Henrik von Wright (1951). Von Wright's essential insight, that there exists a significant analogy between the deontic *obligation* (ought) and *permission* and the modal *necessity* and *possibility*, has influenced most subsequent work in the field.

Thus it was that the simple idea of decision, combined with the concepts of information processing and programming, stimulated considerable intellectual activity during the 1920s and 1930s in four interrelated yet distinct areas: recursive function theory or the theory of algorithms, statistical and normative decision theory, and deontic

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logic. Practical applications of this work in computer control technologies as well as in a wide range of academic disciplines have continued to multiply. Like programming, the concept of decision holds considerable promise for social and behavioral science, especially one grounded in principles of information processing and communication.

As we have already seen, for example, Talcott Parsons might have benefited from explicit use of the concept of programming in his early action theory, a formal model that did include a half-dozen other logical components: an actor, a situation involving both conditions and means, a normative orientation, and an end (Parsons 1937, p. 44). When we compare this schema with the postcomputer interest of philosophers in normative action theory as derived from deontic logic (for example, Rescher 1966), one major addition stands out: explicit attention to decision. Similar integration of deontic logic and other abstract formalizations of decision making has already developed in organizational studies, computer science, psychology, and social theory in general, most notably in work by Herbert Simon (1965, 1966).

With the growing understanding of programming and decision, the intellectual development of the Control Revolution may at last have come full circle from the 1870s and the work of Maxwell and Frege. Consider, for example, the discussion by cognitive psychologists of a "decision demon" (Selfridge 1959), including a lengthy treatment in a textbook (Lindsay and Norman 1977, chap. 7) suggestively titled *Human Information Processing: An Introduction to Psychology*. Could Maxwell have possibly guessed that, in the instant he conceived his own mythical demon, he glimpsed a complex tangle of ideas that would remain at the center of intellectual discourse, technological development, and social change for more than a century?

Life's Decision Demon: DNA

What Maxwell could not have suspected when he introduced his demon, thirty years before Mendel's work on heredity became known and seventy years before the first published hint of a genetic code, is that the heart of his hypothetical creature—that of programming, decision, and control—does in fact beat in every cell of every living thing on earth. This programmable control structure, which first appeared in simple form at the origin of life perhaps four billion years ago, is the complex macromolecule of deoxyribonucleic acid or *DNA*. DNA does not sort molecules by opening and closing a small hole, of course, but

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it does achieve the same result, that of maintaining and even increasing the organization of living materials counter to entropy, in apparent violation of thermodynamics' second law.

This fact is commemorated by the common origin of *organization* and *organism* in the Indo-European *worg*, meaning *work*. A system can sustain work, we have seen, only if its internal energy is purposively organized in a heat gradient, as, for example, in the steam engine, which inspired early work on thermodynamics. Only living systems can maintain and even increase such organization—to work as if guided by some vitalist equivalent of Maxwell's demon. This does not mean that life decreases entropy in the universe, however, but only within its own systems and only by increasing entropy in the matter it consumes. Hence all living systems, including human societies, must be seen as eddies in the entropic stream—as countercurrents resisting for a time the rush of the universe toward final heat death before they too are caught up in the flow.

The continuous processing of matter and energy that makes possible this miracle, apparently unique in at least our own solar system and essential to societies no less than to individual cells, resides ultimately in DNA, the decision demon that organizes matter and energy at the most fundamental level of control. DNA is thus not only the most basic of all control technologies, in the figurative sense, but also one whose capabilities are unlikely to be rivaled by technologies of our own making for many generations to come.

Consider that a one-inch strand of genetic particles can store the amount of information contained in up to twelve thousand typed manuscript pages, the equivalent of about twenty books as long as the one you are reading now. Because the nucleus of a single human cell contains roughly five feet of genetic material, it might store the equivalent of nearly two thousand such books. The same amount of information would fill three to eight thousand floppy disks, depending on the type, or nearly sixty 24-thousand-foot reels of computer tape packed as densely as possible. Some eleven hours would be needed to play as much information on a high-fidelity system or over FM radio, more than forty-six hours to send it via telephone. The programming contained in a single one of our cells, in other words, might easily exceed in information our personal libraries, record or tape collections, and video game cartridges combined.

Even more impressive by engineering standards, all of the cell's information is stored in a structure just barely visible with the most

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As happened so often since the advent of the Control Revolution, concepts from information and communication technology—here Morse's binary telegraph code—helped scientists to reconceptualize traditional subjects like cellular biology. Because information and control are so basic to living systems in general, nonspecialists who understood these concepts have managed to contribute to a wide range of fields. Modern biology, for example, developed through important work by a large number of theoretical physicists and physical chemists: Max Delbruck, Leo Szilard, Francis Crick, Maurice Wilkins, George Gamow, and Linus Pauling, among others (Judson 1979, p. 605).

With the first postulation of DNA structure by Watson and Crick in 1953, literally hundreds of theorists—working more as cryptographers than as biochemists—set out to crack the code by which the four different genetic particles (called *nucleotides)* represent the various amino acids used in protein synthesis. As if to establish the role that informational concepts were to play in modern biology, the first suggestion for a code came not from a biologist but from George Gamow, a theoretical physicist. The importance of this contribution (Gamow 1954), Crick later recalled, "was that it was really an abstract theory of coding and was not cluttered up with a lot of unnecessary chemical details" (1966, p. 4).

Nor could it have been, since Gamow had only sparse knowledge of the relevant biochemistry. He did get the number of basic amino acids correct at twenty, however, which prompted Crick and Watson—immediately on receipt of Gamow's code—to list the correct acids, even though the assumption that so few compounds could be the basis of so many others was, according to one biochemist, "for its time, quite audacious and wholly unsupported" (Stent 1971, p. 35). As one history of modern biology concludes, "Gamow disentangled the problem, stating it for the first time in its modern form" (Judson 1979, p. 250).

Technologies of Genetic Programming

Since perfection of the recombinant DNA process in 1973, modern biology has rapidly spawned *biotechnology*, an application of several academic disciplines—including microbiology, genetics, molecular biology, biochemistry, and chemical engineering—which is already a multibillion-dollar-a-year industry with some one hundred fifty firms (Abelson 1983b). By 1982 the United States was issuing more than

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the inevitable heat death, every living system must maintain its organization by processing matter and energy. Information processing and programmed decision are the means by which such material processing is controlled in living systems, from macromolecules of DNA to the global economy. The Industrial Revolution sharply increased the volume and speed of energy conversion and material processing and thereby precipitated the various technological responses we call the Control Revolution. Even if industrialization had been more gradual, however, the ultimate result would have been much the same.

To understand the basis of human society in information processing, communication, and control, moreover, is to appreciate the profound irony in popular sentiment against technology that has persisted over the past century. Of all the revolutionary innovations in technology since the Industrial Revolution, few have aroused more widespread suspicion, resentment, and even open hostility than have the various capabilities for information processing. Since the mid-nineteenth century, as we saw in the first chapter, increasing bureaucratization has been opposed as somehow dehumanizing, a sentiment that persisted into the 1950s in popular works like William H. Whyte's *Organization Man* (1956). Since then, many of the same feelings have begun to shift to newer information-processing technologies: to the computer in the 1960s and 1970s and more recently to microprocessors, especially as manifest in devices like industrial robots, word processors, and video games, all of which were routinely accused in the early 1980s of dehumanizing influences. Just as the terms *bureaucracy* and *bureaucrat* long ago came to suggest narrow outlook, lack of humanity, and otherwise vague reprobation, similar connotations have been attached to computer technology and personnel, although less frequently as a laity begins to take responsibilities from the priesthood.

The irony, of course, is that information processing might be more properly seen as the most natural of functions performed by human technologies, at least in that it is shared by every cell of every living thing on earth. In view of the fact that information processing distinguishes all living things and a few of their artifacts from the rest of the universe, moreover, the ability must by definition be as old as life itself—on this planet or any other. Information processing is also arguably the most human of life functions in that particular capabilities of our brains to process information best distinguish us from all other species.

No human technology has more in common with all living things

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than do our various capabilities to process information, whether they be institutionalized in the formal structures and procedures of bureaucracy, input electronically to computer memory, or photolithographed into the silicon wafers of microprocessors. It is through the understanding of these capabilities, the essential life processes of organization, programming, and decision to effect control, that we can best hope to answer the many challenging questions raised by the Control Revolution.

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3

Evolution of Control: Culture and Society

Social existence is controlled existence . . . Without some constraint of individual leanings the coordination of action and regularity of conduct which turn a human aggregation into a society could not materialize . . . The concept of social control brings us to the focus of sociology and its perpetual problem—the relation of the social order and the individual being, the relation of the unit and the whole . . . Control is simply coterminous with society, and in examining the former we simply describe the latter.

—S. F. Nadel, "Social Control and Self-Regulation"

TO APPLY the model of the previous chapter to the Control Revolution directly without first considering the earlier evolution of culture and society would be to risk underestimating the importance of control to *all* social structures, those of other species no less than those of our own. It would also be to risk failure in grasping the full impact of the Control Revolution itself. Only through appreciation of even the simplest animal societies as complex systems of information processing and communication—systems that maintain an often fragile balance of control, both internal and external—can we begin to understand the particular way in which industrialization disrupted the material economy of the nineteenth century and why the modern information society emerged as a direct result.

The Industrial Revolution was not the first time that external pressures on processing systems produced a sharp increase in their capability to control throughputs, a change abrupt enough to merit classification as a revolution in control. As we saw in Chapter 2, in the example of rush-hour traffic, living systems have thus far evolved four levels of programmable structures and programs: DNA molecules encoded with genetic programming, the brain with cultural programming, organizations with formal processing and decision rules, and mechanical and electronic processors with algorithms. This succession

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of four levels of programming, each one of which appears to have complemented and extended more than superseded already existing levels, constitutes the total history of control as we know it—a relatively smooth development punctuated by only these four major revolutions in control.

Table 3.1 places each of the four control revolutions in historical perspective. The first, an all but imperceptible molecular change that we revere as the origin of life, occurred approximately four billion years ago, surprisingly soon after the formation of the earth itself. As can be seen in Table 3.1, it took another 3.9 billion years for information processing to transcend the genetic level; this second control revolution occurred about 100 million years ago as certain vertebrates first began to learn through imitation, the earliest and most primitive form of cultural programming. The third control revolution, one that expanded information processing from neural to social structures, came almost one hundred million years later—about 3000 B.C.—in the bureaucratic organizations of Mesopotamia and ancient Egypt. As we saw in Chapter 1, bureaucracy did not become pervasive until the nineteenth-century control crisis and the appearance of a complementary fourth level of control: mechanical, electric, and electronic technologies for information storage, processing, and communication.

Because the first level of control characterizes all living things, the second level the higher vertebrates (birds and mammals), the third and fourth levels only *Homo sapiens*, it might be tempting to stake claim to the superiority of our own species based on this progression. All such claims have been rejected, however—Aristotle's eleven-point *scala naturae* (1912, pp. 732a–733b), his hierarchy of "psychic powers" (1931, pp. 414a–415b), and all forms of the "Great Chain of Being" that dominated science and philosophy until the late eighteenth century (Lovejoy 1936). Even with no knowledge of genetics, Darwin could appreciate the "marvellous structures and properties"—which we now know derive from purposive information processing and control—that characterize "the most humble organism."

Indeed, equally plausible arguments can be made for the superiority of even the simple prokaryotes, which include the single-celled bacteria and blue-green algae. Consider their case: Prokaryotes ruled earth for some three billion years, fully three-fourths of the total tenure of life on the planet. They still rule in that they are found inside all more complex organisms and virtually everywhere else: in the depths of oceans, in arctic glaciers, in hot springs—even at the top of the strat-

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osphere. There are more bacteria, as separate individuals, than any other type of organism—as many as one hundred million in a single gram of fertile soil. Earth's entire ecosystem depends on the algae, primary producers, through photosynthesis, of the energy that powers all forms of life.

It can even be argued that the prokaryotes, as the earliest of life forms still existing on earth, grabbed up all the planet's choicest ecological niches and thereby forced subsequent species to evolve at greater and more inferior levels of size and complexity. By virtue of having only a single cell, after all, the prokaryotes live free of the nagging burden of gravity, one of the so-called weak forces of nature that affect only objects above a certain ratio of surface area to volume. This argument is facetious, of course, but not in its moral: success in control cannot be judged by the nature of its programming or the complexity of the results, only by the persistence of its organization counter to entropy—the one true test of all living systems. By this standard the prokaryotes—with neither brain nor technology—are at least holding their own.

That the prokaryotes have survived virtually unchanged over several billions of years ought to be evidence enough that material processing systems do not necessarily respond to external changes by evolving greater capacities to control their environments—let alone wholly new levels of programmable structures. If we hope to understand the emergence of the most recent control level, that of programmable technology, we might consider this as another instance of the dynamic at work at earlier levels. If the revolution in control technology did indeed come in response to a crisis in the economy's capability to process throughputs, as suggested in the first chapter, then we must seek to understand this in terms of the more general conditions that have constituted the causes of such change. That the change obviously came not through natural but purposive selection by governments and markets, a direct legacy of the third (bureaucratic) control revolution five millennia earlier, ought not to obscure what might be learned from more general features of control common to all living systems.

Three Problems for Control

Undoubtedly the most difficult aspect of control to appreciate, especially in technologies of our own making, is its evolution across gen-

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furnace on and off and thereby control temperature by means of feedback from the environment heated. The major shortcoming of such examples is that they draw attention to the control behavior itself—especially to feedback—and therefore away from the more fundamental aspect of control, namely programming. As Ernst Mayr put it:

> It is not the thermostat that determines the temperature of a house, but the person who sets the thermostat . . . Negative feedbacks improve the precision of goal seeking, but they do not determine it. Feedback devices are only executive mechanisms that operate during the translation of a program. Therefore, it places the emphasis on the wrong point to define teleonomic processes in terms of the presence of feedback devices. They are mediators of the program, but as far as the basic principle of goal achievement is concerned, they are of minor consequence. (1976, p. 391)

Overemphasis on control behavior and feedback may be even more misleading than Mayr suggests. By concentrating on behavior per se, cyberneticists tend to overlook two other aspects of control perhaps most obvious in genetic programming but which must prevail in any control system. At a more fundamental level than behavior itself is maintenance of the *mechanism* on which control depends; at a higher level is the programming process on which depends the continuing *evolution* of control. In a thermostatic system, for example, thermostats must be distributed, positioned, and maintained according to some program; only a still higher-level program can decide that such control is desirable and, if so, whether some other technology might not better fulfill the same function.

We encounter these three levels of control involving mechanism, behavior, and the process of programming in all control systems, from DNA to human organization and technology. The levels might be seen to involve three different temporal dimensions or to address three distinct problems for control:

Existence or being, the problem of maintaining organization—even in the absence of external change—counter to entropy

Experience or behaving, the problem of adapting goal-directed processes to variation and change in external conditions

Evolution or becoming, the problem of reprogramming less successful goals and procedures while at the same time preserving more successful ones

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To have some mechanism that might be programmed and the matter and energy in which to store its programming is the problem of existence or being. Experience or behaving involves the problem of maintaining control regardless of the inputs to an existing program. To be able to reprogram and thereby adapt to new contingencies is the problem of evolution or becoming. Taken together, the three problems subsume all those of programmed control because they exhaust the three different temporal dimensions of one universal problem: how to maintain organization counter to entropy. Existence solves the problem at any one instant in the sense of differential calculus, that is, as time goes to zero as a limit; behavior solves the problem over the lifetime of programs in a single system; and evolution becomes the essential solution across generations of both programs and systems.

With computers, for example, we recognize the fragility of existence in system crashes, power failures, and accidental erasures of memory, the problems of behavior in exceeding parameters or in infinite looping, and the failure of evolution in the impossibilty of reprogramming read-only memory (ROM) to new specifications. Reprogramming is the general solution to problems of both behavior and evolution in all living systems. At the organic level reprogramming comes in response to changes in selection pressure on the replicating programs (genes) *qua* species that both exist and behave, that is, on the class of all entities that might be controlled by the program (Hamilton 1964; Williams 1966; Dawkins 1976, 1982).

Similar categories have already been applied to human societies, for example, to distinguish structure, process, and history in modern structural-functionalist social theory (Merton 1968). According to the venerable campus cliché, a university has precisely the same three functions: to create knowledge (its evolution or becoming in research), to preserve knowledge (the archival function of existence or being), and to disseminate knowledge (the experience or behavior we know as teaching and learning).

A neurophysiologist (Gerard 1960, p. 255) has suggested the terms *being*, *behaving*, and *becoming* for virtually the same three aspects of material systems, an application similar although not identical to the one here. We emphasize not the temporal aspects of the three problems but rather their functional implications as essential elements of control, the solution to any one of which can have unanticipated consequences for the other two. Proliferation of a new control technology, for example, can have major effects on the evolution of programming. As

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we shall see in Chapter 6, the development of mass media and national advertising had precisely such implications for cultural programming by the turn of the century.

An appendix to this chapter, "What Is Life? An Information Perspective," presents my argument that the properties most basic to life itself, in an abstract sense, are subsumed by static and dynamic aspects of the three control functions presented here. Evidence comes from properties of living systems cited by biologists in a half-dozen recent textbooks. The same three functions are shown to correspond to the three fundamental genetic processes of replication, regulation, and reproduction, thereby establishing the control model on the level of programming itself.

In adapting this model to an analysis of the Control Revolution and resulting Information Society, I want to be clear that I do not consider society actually to be an organism, "alive" in some sense apart from the life of its individual members. Considering the misleading inferences that have plagued organismic models since Aristotle's *Politica*, from the pre-Darwinian treatments by Hegel and Comte through those of Herbert Spencer, Oswald Spengler, and the twentieth-century functional theorists, we would do well to avoid such models entirely.

My own analysis of the Control Revolution will be motivated not by any organismic model but by the more modest conviction that all concrete control systems—both individual and collective—must overcome the same fundamental problems if they are to maintain themselves counter to entropy. Living organisms can provide an independent test of our three-dimensional model, by this reasoning, and at the same time afford new insights into the manifest properties of concrete control. This will be indirectly tested in a rapid journey through the first three control revolutions, those that breathed life into an inorganic universe, brought cultural programming to specialized nervous systems, and built formal organizational control in culture-based social structures.

The Origin of Life

We may never know the precise details of what at least for us must be the most sublime of all control revolutions: the origin of life—and of control—on the third planet from the sun, a relatively solitary star on the outskirts of a typical spiral cluster of perhaps a half-trillion stars that we happen to know as the Milky Way, which is itself one of a

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hundred billion such galaxies. Despite the lack of details, however, we can infer what must have happened, albeit at a level of abstraction above that of particular forms of matter and energy, namely at the level of their organization as *information.*

Because even the simplest organic compounds contain much greater energy than the most complex inorganic ones, one obvious place to seek life's origin is in some naturally occurring energy source. Lightning, volcanoes, and of course the sun's ultraviolet rays have all been cited in various speculations. Whatever the source, little energy would have been needed to knock apart particles in the hydrogen-rich atmosphere that must have formed as the earth condensed out of interstellar gas and dust some 4.6 billion years ago. Laboratory tests using electric sparks discharged in containers of methane, ammonia, and other simple gases have produced several amino acids, basic constituents of the proteins found in all living things. Sometimes the amino acids have actually come chained together like simple proteins and even nucleotides, the ringed molecules that constitute the coded instructions of DNA.

Regardless of how it might have happened, more complex molecules must have arisen from the infusion of energy into the early atmosphere. These molecules would have inevitably mixed and combined with other molecules and atoms, the products dissolving in the oceans to form a kind of organic soup of increasing complexity. No teleonomic entity, not life nor any other, could arise from the haphazard combination, breakdown, and recombination of simple compounds, of course; happenstance alone does not yield purpose. Given sufficient time, however, at least a simple molecule would certainly have appeared whose various parts had the particular property of affinity for elements of the same kind (as in crystals) or for their chemical "negatives" (the case, as we have seen, with the DNA molecule). In either event the new molecule—call it *Replicator A*—would have immediately begun to populate the primordial soup with exact replicas of itself, directly in the case of a crystal, alternately with its negative for a molecule like DNA.

Though not itself alive, Replicator A was nevertheless the earliest ancestor of all life on earth, unless, of course, it has had multiple origins. Replicator A was also the first concrete processing system, one capable of taking simple chemical particles and combining them into exact copies of itself. As for the information processing necessary to *control* such a system, Replicator A had the unprecedented ability to copy the instructions for its own composition, what might be called

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Although no trumpets could have sounded when Replicator B first started to compete successfully with Replicator A, life must be said to have begun at precisely this instant. This was the moment when the total programming for constructing molecules on earth was upgraded the first notch *in the direction of functional advantage*. The teleonomy of evolution was born and with it the final step in the goal-directed programming process we know as *life*.

Several points are instructive here. First, Replicators A and B must be said to be alive not because they manifest all of the properties that biologists usually attribute to life (certainly not metabolism or responsiveness) but rather because they achieved all three levels of control: existence, experience, and evolution. Second, life is not a property of individual molecules, which are themselves unchanged from their preliving condition, but rather of the *population* of all replicating molecules. This is contrary to Helena Curtis's conclusion, as noted in the appendix, that "life" itself does not exist, only individual living organisms. Third, and perhaps most important for our investigation here, life would have begun as the response of concrete open systems to external pressures on their capabilities to process throughputs, in this case the manufacture of replica molecules using free-floating chemical constituents.

It may seem that this explanation is too simple to account for the origin of a process that has culminated four billion years later in the wide diversity of complex organisms that we know today. The argument does gain support from the survival of *viruses*, organisms that are nothing more than replicator molecules encased in protein. Fossil evidence suggests that the appearance of such simple life forms may be relatively straightforward, at least compared to that of more complex forms. Although life itself arose only 200 to 600 million years after the origin of the earth, about as soon as the new planet had cooled sufficiently for life as we know it to survive, another three *billion* years passed before the appearance of even rudimentary specialized organs. This suggests that the origin of life may be less difficult to explain than the second control revolution, one that produced the most generalized living organ of all: the vertebrate brain.

Origin of the Brain

The brain is, like the genome, a generalized information processor, controlled by programming and capable of all of the functions that characterize concrete open systems: input, storage, comparison, deci-

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