THE TECHNOLOGY OF FREEDOM

By George Gilder

Every era achieves a cultural pinnacle. In the Middle Ages it was probably the giant cathedral, whether Gothic or Baroque. Wrought of rock and sand and glass, these cathedrals stand today as a cultural and religious epitome, a beacon of faith and aspiration reaching forth over the centuries — issuing a reproach to most of the architecture and art of the current epoch.

Nonetheless, our own age, I believe, has summoned a monument of aspiration and faith, devotion, diligence, and art as formidable as the great cathedrals of the past.

The cathedral of the twentieth century is the microchip, a tiny computer inscribed on a small piece of semiconductor material. Like the medieval cathedrals, the microchip is wrought of the commonest elements in the earth, being earth itself. But seen through a microscope, that semiconductor shape emerges with the opalescent symmetry of a cathedral window.

I would sum it up in a vision of sand and glass. The sand is the substance of microelectronics. It comes in the form of a silicon sliver the size of a thumbnail that bears a pattern of wires and logic as complex as a street map of America, switching traffic in trillionths of seconds. At the heart of a microchip is the microswitch: the transistor. Twenty years ago transistors cost $7 apiece and were plugged into circuit boards one at a time by hand. Today far better, faster and more useful transistors cost a few ten thousandths of a cent.

Current chips contain as many as 20 million transistors. Scores can be placed not on the head of a pin but on the point of a pin. Switched in trillionths of seconds, these devices transcend all the normal constraints of time and space. Their development is by far the most important event of the current era.

The microchip of sand, however, joins with another amazing technology made of glass.

The glass in the vision is so pure that if it were a window you could see through miles. But it comes in fiber optic threads the width of a human hair and as long as Czechoslovakia. It is fed by laser diodes the size of a grain of salt and as bright as the sun. Today these threads flash information between the East Coast of America and Chicago in the Midwest at a pace of 8.6 gigabits a second. A thousand bibles a second.

This technology represents a vast leap ahead of the copper wires that transmit most phone calls around the globe. For example, the U.S. Con-

gress maintains a library holding all the publications of the Nation over the last 100 years. Using copper wires and 9600 baud modems, it would take 500 years to transmit the contents of the Library of Congress. Using fiber optic threads it would take just 8 hours. That's a 547-thousandfold advance.

As this technology moves into homes and offices over the next decade, it will hugely enhance the powers of individuals to send and receive communications of all kinds, from movies and other digital video products to whole libraries of data and text. In the process it will replace the dumb television terminal with a telecomputer that can not only receive but also shape and send digital data and images. It will endow what is currently called a TV receiver with powers exceeding TV stations today.

As fast as fiber optic technology is advancing, however, chip technology is improving still faster. Within the next 10 years, it will be possible to put as many as one billion transistors on a single sliver of silicon. One billion transistors is equivalent to the computing resources of 16 of the world's most powerful supercomputers, Cray YMP machines that cost some $20 million apiece. Within the next 10 years or so, this computer power will be inscribed on a single chip that will cost less than $100 to manufacture. Such an advance will mean approximately a millionfold rise in the cost effectiveness of supercomputing hardware in 10 years.

Together these two technologies will create a global ganglion of computers and cables, a worldwide web of glass and light and sand that leaves all history in its wake. For good or ill, this technology will shape the future of all nations through the twenty-first century.

The rise of these miraculous tools, I believe, both necessitates and enables a radical change in the economic structure of the formerly Communist states. These microelectronic tools will allow Czechoslovakia to move toward capitalism without suffering the pains and setbacks that economists often prescribe for you. You will not fall into Europe with the gravitational force of heavy industry; you can leap into Europe by providing homes for the most powerful computer and telecommunications technology in the world. However, the use of these new tools utterly requires the abandonment of all dreams of a centralized or protected economy. You can lead the world only by being open to it.

Last year even Mikhail Gorbachev showed a recognition of this imperative. He pointed to the most valuable resource of the age. He did not mention oil or gas or gold, missiles or nuclear power. Instead he decalred: "In the age of information sciences, the most valuable asset is knowledge, which is a creation of human imagination and creativity. We were among the last to comprehend this truth and we will be paying for this oversight for many years to come."

Gorbachev may be too pessimistic. Czechoslovakia in particular is full of the most valuable asset of the information age, full of well-trained and resourceful men and women. Czechoslovakia faces no inherently difficult problem of transition. You merely face the challenge of liberating your crucial resources of knowledge, now incarcerated in a million mazes of bureaucracy and still largely cloistered from the rest of the world.

T.J. Rodgers of Cypress Semiconductor, one of the leading American microchip entrepreneurs, recently discovered how rich is Russia in the crucial resources of this new age. He visited the USSR this summer intent to license a graphics chip design. He expected to find the Soviet Union far behind the U.S. in semiconductors. In many ways he was right. In manufacturing and selling chips, the Soviet Union is indeed in the Dark Ages. Compared to state of the art American chips, Soviet devices are big and slow. But in a crucial way, T.J. discovered that he had greatly underestimated the Soviets.

Rodgers found that adversity breeds creativity. The Soviet failure to develop advanced hardware had induced great ingenuity in computer architecture and software. The absence of leading edge computer technology impelled Soviet engineers to an early mastery of the algorithms of parallel processing: using many low performance microprocessors in parallel to emulate the most advanced single processors. Soviet computer architects and chip designers, Rodgers discovered, emerged from their crucible of privation as some of the best in the world.

Some Americans making such a discovery would have hastened back to the Pentagon to report the terrible news of a new Soviet threat in microelectronics. Some American businessmen might have petitioned the government for new subsidies and supports to help keep pace with the Soviet designs. Even in America, many people see the world as a zero sum game, with every gain for one country — or company — a loss for someone else. Prevailing through the centuries, this attitude — the view that the success of others is a threat rather than an opportunity — has blighted most of human history. The view that creators of wealth somehow oppress the poor is the most crippling prejudice of Marxism. T.J. Rodgers, however, is imbued with a different spirit: the spirit of enterprise.

Being an entrepreneur, T.J. on the spot decided to buy licenses to all the salable technologies he found. He bought licenses for nine chip designs. He launched a major computer project with a Soviet team. Entitled "Mir," it will be executed by a 50 man team in the USSR. Today some 15 leading Soviet engineers are working at Cypress in the U.S.

T.J. was thrilled with the computer people he met. As an entrepreneur he could launch mutual projects with them almost immediately. Did he

exploit the Russian designers he dealt with? No. They all will gain hard currency royalties from any chips sold in the U.S. Most of their designs were too complex even to be manufactured in the Soviet Union. They will have their chips produced on the best semiconductor production lines in the world. They gain financially and they gain from the experience of having their ideas realized in hardware and sold widely to customers.

In such deals, former communist states gain technologies that were previously unavailable to them and markets that were previously beyond their reach. Thus they will gain guidance about where to focus future efforts. The Soviet computer men who dealt with T.J. Rodgers came away as big winners.

How about T.J.? He gained access to the most valuable resource of the information age: human creativity and imagination. He gained entrance to what will be a tremendous new market for high technology devices. He too was a big winner.

That is the key secret of capitalism: win-win rivalry. Everybody wins; no one is exploited. Because every deal is voluntary, both sides gain; every transaction is a positive sum. If anyone feels unsatisfied with the terms, the deal cannot go through. Since each side improves its position through the transaction, the very process of free capitalist trading assures that national wealth increases with every exchange.

Gross domestic product (GDP) rises even without the creation of any new product. The free market enhances the value of all the production of the nation by assuring that it will go to the people who want it most and can use it best.

Until T.J. showed up in Zelenograd, most of the chip designs and computer architectures of the USSR were valueless because they could not find customers or manufacturers. His entrepreneurial vision lent value to intellectual properties that were valueless in a communist economy.

In contrast to chip designs deemed worthless in the USSR, T.J. also visited a great center of wealth and power as judged by Soviet authorities. He visited the office of the man he said "has the worst job in Moscow." That is saying a lot. That man is the noted physicist name Yurij Pavlov. He does not sweep the streets or clean the public toilets. His job is "General Director of Moscow City Council Scientific Development Conglomerate for Automated Control Systems." He runs Moscow's governmental computer center.

The wonders of central planning mean Yurij has to plan the movement of bread and milk. He tries to make the line shorter. He also keeps track of health care, drug prescriptions, retirement payments, water bills, apartment rents and allocations and a long list of other services for nine million people of the city.

Under communism, Yurij Pavlov was a man of great relative wealth and power. He commanded arrays of seemingly valuable computers. He helped rule the lives of millions. Unlike the chip designs deemed worthless in the USSR, Pavlov's establishment was supremely valuable in the planned economy.

In a market system, however, all Pavlov's panoply of powers and machines is less than worthless. The old IBM compatible computers he used could hardly be sold as scrap in the U.S. The work he does is irrelevant in an economy where economic planning is performed voluntarily by millions of individuals.

It is often said that Eastern Europe cannot prosper without huge inflows of capital from the outside world. That is an absurd assumption. Eastern Europe is already glutted with capital: roads, factories, weapons, mines, tractors, schools. For decades, the communist world invested a hugely greater proportion of its wealth than the U.S. Communist systems are nearly always awash with useless capital. But without freedom, capital is blind and sterile.

In a capitalist system, you do not need new capital to create wealth. Freedom in itself creates wealth just as T.J. created new wealth in Russia. By allowing the perpetuation of economic planning, outside capital may even reduce the real wealth of Eastern Europe. It may plunge the real capital of these nations — their creative citizens — into the darkness of production without free customers.

Freedom means the right to fail. The key reason the U.S. economy is more successful than communist economies is that the U.S. allows more failure. U.S. scientists and engineers outproduce Soviet scientists and engineers not because they are more numerous or better trained or more talented. In fact, there are many times more highly trained scientists and engineers in Eastern Europe than in the U.S. and your students outperform American students on international tests.

American students go to some of the worst socialist schools in the world, completely run by huge educational bureaucracies. Socialist bureaucracies in the U.S. may even be worse than socialist bureaucracies in Europe because U.S. bureaucrats can feed their mistakes from the prosperity around them. Subsidized socialism is less productive even than penurious socialism.

U.S. scientists and engineers create more value because they collaborate with millions in the marketplace around the world. Socialist scientists

and engineers collaborate only with each other and their political bosses. U.S. scientists and entrepreneurs can prevail because they can fail.

Bankruptcies play the same role in economic progress that falsification plays in the progress of ideas. The eminent philosopher of science Karl Popper identifies a valid scientific proposition chiefly by whether it is stated in a form in which it could possibly be disproved or rejected. If a theory — such as that people born in August under the sign of Leo tend to be temperamental — is too general or flexible to be proven wrong, it is incapable of generating new knowledge. Similarly, if an economic plan cannot be rejected by the marketplace, it cannot generate new value.

Every new business, however, provides an entrepreneurial test of a new idea. Unlike a national plan, a business plan is falsifiable. Because it can fail, it can also generate new knowledge. In fact, entrepreneurs often learn more from their failures than from their successes.

By the very process of acquiring profits, they learn how to use them. By the very process of building businesses, they gain the discipline to avoid waste and the knowledge to see value. By the process of creating and responding to markets, they orient their lives toward the service of others. Entrepreneurs who hoard their wealth or seek governmental protection from rivals or revel in vain consumption or retreat to selfish isolation betray the very essence of their role and responsibility in the world. To that degree, they are no longer entrepreneurs or capitalists but relics of the feudal and static societies of the precapitalist era.

Every capitalist investment has a dual yield: a financial profit and an epistemological profit. One without the other is barren. Economies progress when the process of investment is informed by the results of previous investment. Entrepreneurs like T.J. Rodgers spread wealth because they constantly accumulate new knowledge by risking failure. This new knowledge is the most crucial capital they wield.

For many years, Marxists have believed that they could solve the knowledge problem of socialism through the creation of ever larger knowledge machines: computers. Giant computers could simulate markets and thus render freedom unnecessary and obsolete.

I believe, however, that it is the computer that makes communism obsolete. The microchip may indeed offer the solution to the problem of socialist bureaucracy. But it is also the dissolution of socialism and all other centralized systems.

The key problem of the planned economy is the explosion of complexity. In the planned economy only the bureaucrats can plan. But their plans inevitably break down in the nearly infinite complexities of a large economy.

In a free economy, all citizens and businesses can make plans. Because individual businesses face manageable complexities, they can actually carry out their plans. The paradox of the planned economy is that it prohibits all practical planning.

This problem can be summed up as the law of complexity. It shows that complexity arises by the square of the number of entities to be organized — whether phones in a network, chips on printed circuit boards, or prices and quantities in an urban economy. This law of complexity even confounds computations in physics, where the so-called many-body-problem afflicts all analysis of relations between large numbers of entities.

Arno Penzias, the Nobel laureate physicist, explains the problem in terms of the impact of an additional child arriving at a party. The noise level does not rise by the increment of one more child; it rises exponentially in proportion to the additional child and all the other children he may shout at and interact with. Another form of the many body — and vocal chord — problem.

That's the law of the macrocosm — complexity arising by the square of the number of entities to be organized.

The microcosm of silicon chips, however, a completely different law applies: the law of the microcosm. On silicon, not complexity, but efficiency rises by the square of the number of entities to be organized. The more transistors crammed on each microchip the cheaper, faster, cooler, more powerful and more valuable they are. This relationship is measured in the industry as the power-delay product, relating the power consumption (and heat) to the speed of operation of a microelectronic device.

On individual microchips the power-delay product improves exponentially with the increase in the number of transistors and thus the closeness they are packed together. As electrons moving in a transistor approach their mean free path — the distance they can travel without colliding with the structure of the silicon crystal — they move faster and more efficiently. It is as if a million more children arrived at the party and the noise level went down.

These gains in efficiency, however, apply only on individual chips. You begin combining lots of chips together and the law of complexity takes hold again. The is why the Elbus strategy for saving socialism — the big computer dream — will inevitably fail. All computers will eventually become single chip systems, basically equal in power and cheap enough for anyone to buy. Any top down structure of organization — any hierarchy — will eventually collapse into a heterarchy, where equal processors, or individuals, communicate with one another on an essentially equal basis.

Once again, this is not an optional outcome; it is inherent in the very physics of computation. What is happening is the overthrow of the previous relationship between the cost of wires and the cost of switches. Wires are the communications medium between chips and switches are the transistors that give the computer logical powers.

When wires are cheap and switches expensive, it makes sense to centralize. It pays to run a few more wires to an expensive central processing unit dominated by switches. This was the case at the beginning of the computer era when switches were fragile and expensive vacuum tubes.

Today, however, switches are virtually free — infinitesimal transistors on a chip — while wires are relatively expensive. Under these conditions, it pays to distribute intelligence on single chips.

The obsolescence of the big computer is already evident. For example, in 1977 nearly 100 percent of all the computer power in the world was commanded by large machines with dumb terminals attached. Just 13 years later, that figure had dropped to well under 1 percent. There are now over 100 million personal computers in the world and they command virtually all the globe's computer power.

It is this change that dooms socialism. It is this change that permanently overthrows Marxism. Although Marx was wrong about many things, he did sense a crucial fact about the past industrial order. In the past, machines were hostile to human values. Factories worked best when individual workers adapted themselves to the machine. Industrial analysts would actually measure the movements of workers and attempt to adjust them to the requirements of the equipment they used. Even in free market economies, the factory or assembly line tended to be a top down hierarchy, a master slave system.

This system resulted in huge gains of human productivity. But whether in the East or West, it was deeply inimical to the nature of human beings. Human beings are far more like chips than like assembly lines. We have the most powerful processors in the world between our ears. Two human eyes, for example, can do more image processing than all the supercomputers in the world put together. But as in the case of chips, our communications power is strictly limited. About 50 bits per second is the estimate of the experts.

The chemist, Michael Polanyi, has explained the effects of this relationship. It means that the bulk of human learning is tacit knowledge: it is literally incommunicable. For example, there is no way to explain how an individual reaches out and picks up a glass of water and brings it to his lips. Most of what we know about our jobs is this kind of tacit knowledge.

Although the industrial era hugely enhanced the productive power of human beings by raising their physical strength, this gain came at the cost of a holocaust of tacit knowledge.

The nature of human beings means that an organization functions best when individuals can be coupled as closely as possible to specific problems. Leaders can offer general goals and directions. But specific guidance and controls will cost far more in tacit learning than they will gain in efficiency. Workers must have common visions but not detailed supervision. Top down bureaucracy, private or public, obliterates the crucial mental powers of human beings that elevate us above the apes and give us mastery of the world.

The microchip is the first technology that accords fully with the nature of human beings as thinking creatures. Favoring heterarchy over hierarchy, it overthrows all top down systems.

As the chip reorganizes industry and commerce so also will it reorganize the powers of states and nations. The laws of the microcosm subvert any attempt to capture, intimidate, confine, or overwhelm the exertions of mind by the tyranny of matter.

The mobility and ascendancy of mind among all the forms of capital deeply undermine the power of the state.

Quantum technology devalues what the state is good at controlling — material resources, geographic ties, physical wealth. Quantum technology exalts the one domain the state can never finally reach or even read: mind. Thus the move from the industrial era to the quantum era takes the world from a technology of control to a technology of freedom.

The most evident effect of the change is a sharp decline in the value of natural resources. The first industrial revolution vastly increased the value of materials. All the dirt, rock, and gunk that had been ignored for the centuries suddenly acquired worth in the age of mass manufacturing. The new industrial revolution is a revolution of mind over matter and it is rapidly returning what used to be called "precious natural resources" to their previous natural value as dirt, rocks, and gunk.

The use of steel, coal, oil, and other materials is plummeting as a share of value added in the economy. As a symbol of the shift, consider two smelting processes. Smelting iron, you banish silicon in the slag as dirt; "smelting" silicon, you get rid of the iron as conductive waste. A silicon chip is less than 1 percent raw materials. A few pounds of fiber optic cable, also made essentially of sand, will soon carry as much information as a ton of copper. A single satellite now displaces many tons of copper wire.

This change has transformed the very foundations of geopolitics. Raw materials have long constituted a leading reason and reward for military aggression. In the past, ownership of particular regions imparted great political and economic power. The balance of power in Europe depended in part upon who controlled the coal and steel in the Ruhr Basin. The Ruhr Basin is now a European sink of government subsidies.

We live in an epoch when desert bound Israel can use computerized farming to supply 80 percent of the cut flowers in some European markets and compete in selling avocados in Florida; when barren Japan can claim to be number one; and when tiny islands like Singapore and Hong Kong can far outproduce Argentina or Indonesia.

To comprehend the change, consider a steel mill, the exemplary industry of the previous epoch: A huge manufacturing plant entrenched near iron and coal mines, anchored by a grid of railways and canals, served by an army of regimented workers, all attended by an urban infrastructure of physical systems and services. At every step the steel mill can be regulated, taxed, and controlled by government.

Compare this massive array of measurable inputs and outputs to a man at a computer workstation, with access to databases around the world, designing microchips of a complexity exceeding the entire steel facility, to be manufactured from pattern generation tapes. Even the tape, the one physical manifestation of his product, has become optional. Without any fixed physical manifestation at all, the computer design can flow through the global ganglion of telecommunications into another computer attached to a production line anywhere in the world.

The decline in the value of raw materials entails an equal decline in the value of geography. In an age when men can inscribe new worlds on grains of sand, particular territories are fast losing economic significance.

Not only are the natural resources under the ground rapidly declining in value, but the companies and capital above the ground can rapidly leave. Commanding a worldwide network of transport and communications, the businessman sends wealth flashing down fiber optic cables and caroming off satellites at the speed of thought rather than of things.

Capital is no longer manacled to machines and places, nations and jurisdictions. Capital markets are now global and on line 24 hours a day. People — scientists, workers, and entrepreneurs — can leave at the speed of a 747, or even a Concorde. Companies can move in weeks. Ambitious men need no longer stand still to be fleeced or exploited by bureaucrats. Geography has become economically trivial.

The global microcosm has permanently shifted the world balance of power in favor of the entrepreneurs. Using the planetary utility, they can avoid most of the exactions of the state. Without their fully voluntary cooperation a government cannot increase revenues, enhance military strength, provide for the public welfare, or gain economic clout.

This good news for individuals and entrepreneurs, however, is bad news for socialism. The state can dig iron or pump oil, mobilize manpower and manipulate currencies, tax and spend. The state can expropriate the means of production. But the so-called means of production as defined by Marxists and even by many capitalists, are actually meaningless for real production. Geography hardly matters at all.

For example, where is Cuba? Most people in America would answer that it is an island in the Caribbean 90 miles off the coast of Florida. But that is no longer true.

Following good Marxist precepts still popular in American universities, Fidel Castro expropriated the means of production in Cuba. The result was that most of the men of production — the entrepreneurs — fled to America. As a result, in every meaningful sense, Cuba is no longer an island in the Caribbean. Cuban culture, Cuban enterprise, even Cuban cuisine have all moved to Florida and other parts of the U.S. The Cuban means of production are now in America. Indeed, the total gross national product of Cubans in the U.S. is at least six times the subsidized product of the Caribbean island.

If communist expropriators took over the means of production in Silicon Valley, the seat of the U.S. computer industry, they would find mostly sand. For the men of production, the entrepreneurs, run for the daylight of liberty. One way or another, most of the time, the entrepreneurs take their money with them or send it on ahead. But always they take their minds, and knowledge is their crucial power.

Ideas are subjective events and always arise in individual minds and ultimately repose in them. The movement toward a quantum economy necessarily means a movement toward an economy of mind. Collective institutions will survive only to the extent that they can serve the individuals and families who comprise them.

This is the age of the individual and family. Governments cannot take power by taking control or raising taxes, by mobilizing men or heaping up trade surpluses, by seizing territory or stealing technology. By imperialism, protectionism, and mercantilism, nations eventually wither and weaken into third worldly stagnation.

In the modern world, slaves are useless; they enslave their owners to systems of poverty and decline. The chief source of the new wealth of

nations is free immigrants; the nations of the baby dearth will compete for them to pay the pensions of their aging societies. Today nations have to earn power by attracting immigrants and by liberating their people, their workers and their entrepreneurs.

The gains of the quantum era could yet be destroyed by some thug offering a final horrible holocaust to the Moloch of matter. But the logic of the technology, the logic of the microcosm, which is becoming the logic of history, runs the other way. History has capsized every prophecy of triumphant bureaucracy.

Rather then a New Industrial State, this era will disclose the new impotence of the state. Rather than the Revolt of the Masses under the leadership of demagogues, this era will see the revolt of the venturers against all forms of tyranny. Systems of national command and control will wither away. Systems of global emancipation will carry the day. The dismal science of the economics of aggregates — capital, labor, and land — will give way to a microeconomics of liberty. The beggar thy neighbor strategies of mercantilism — of trade as weapon of state — will collapse before the strategies of global wealth creation under the leadership of entrepreneurs. The economics of scarcity and fear will surrender to the economics of hope and faith.

The new technologies — themselves largely the creation of Promethean individuals — completely transform the balance of power between the entrepreneur and the state. Inventive individuals have burst every link in the chain of constraints that once bound the entrepreneur and made him a servant of parliaments and kings. He is no longer entangled in territory, no longer manacled to land, capital, or nationality.

These developments are no special American monopoly. Indeed, much of the benefit will be lost if only the United States and a few Asian capitalist countries follow the crucial lessons of the new technology. For the central lesson is that information technology is not a zero sum game to be won by some governmentally supported monopolist. Information technology constantly redistributes its own powers as it is used. The final and most flexible source and vessel of these powers is the individual human mind. The power of information always ultimately gravitates to individuals.

This is not a world in which the gain of one nation can only come at the expense of another. All the world will benefit from the increasing impotence of imperialism, mercantilism, and statism. In this new economy of freedom, Americans must hope for the prosperity and freedom of Russians and Chinese. We must celebrate the successes of Koreans and Japanese. We must relish the increasing wealth and power of the Third World.

Most of all, we must hail the liberation of Eastern Europe — the inspiring new leadership in Prague.

Depending on an altruistic spirit, the microcosm requires not only a technological renaissance but also a moral renewal. All Americans will cheer the success of Eastern Europe in its great adventure of reform. Within the spiraling gains of capitalism, impelled by the spread of information technology subverting all tyrannies, there is room at the top for all.