Without doubt, at a time further into the future than we are here looking, digital technology will, for better or worse, come deeply to grips with the biology and chemistry of the world around us. The engineers, scientists, medical researchers and other professionals working on the chemistry of industrial processes, manipulating atoms using nanotechnology or mapping out the sequence of the three billion-long code in the human DNA molecule are taking the first steps towards a technological revolution which is likely to be wholly more transformative than any which will be brought about by the current generation of information products.

9

Who Are We in the Digital Age?

In the last months of the year 1899 the world's newspapers made predictions about the forthcoming century. The prevailing view, as typified by this commentary in Paris *Figaro*, was that the world was finally entering a period of scientific rationalism:

> It will be a majestic spectacle, the onset of which I should like to see myself. We shall begin to hope that the nineteenth century which nurtured us will sink into centennial oblivion together with the stupid hatred and all those idiotic mutual recriminations and cretinous calumnies which have darkened its last days and are unworthy of reasonable people.

The guiding force for this optimism was scientific progress. The explosion of technological knowhow at the turn of the last century, dramatic even by today's standards, seemed destined to end so many of the problems which had bedevilled mankind in the past. For this commentator – requoted recently in *History Today* in an article aptly named 'How the Future Didn't Happen' – and his contemporaries, there seemed not the tiniest sign that the advanced nations of Europe, of which they were the proud citizens, were about to embark on a half-century of strife awful beyond their imagination. The rate of technological progress would not disappoint – but it would be accompanied by appalling suffering in trench warfare, holocausts, gulags and killing fields as nations and ideologies entered into 'mutual recriminations and cretinous calumnies' as never before. It was not enough for there to be a rational new technology-led route forward. Much stronger forces – human greed, nationalistic, ideological and religious fervour, lust for power – were to play themselves out on the world's stage.

Maybe it is because another century is beginning; more likely it is because for the second time we are going through a period of exceptional technical progress – for whatever reason, the business of futurology is experiencing another bout of technological determinism. This time round it is the computer which is seen as driving us towards a more rational future, with processing power rising and costs falling as the chip motors along the learning curve. In 1998 Michio Kaku of the City University of New York, in his book *Visions* (reflecting his interviews with over 150 scientists, many of them Nobel Laureates) echoed the words of *Figaro* in 1899 when he concluded that

> the information revolution is creating global links on a scale unparalleled in human history, tearing down petty, parochial interests, building and forging a common planetary culture.

Wired magazine devoted a cover to 'The Long Boom', announcing:

> We're facing 25 years of prosperity, freedom and a better environment for the whole world. You got a problem with that?

The detail was contained in a chart entitled 'The Future History of the World' that described how technology would affect economics, politics and society, finally bringing about, some fifteen years from now, 'the beginnings of a global civilization of civilizations'.

In the 1930s the French scientist, sociologist and theologian Pierre Teilhard de Chardin predicted the emergence of a noosphere, a network linking mankind at the mental rather than the physical level. Teilhard described this noosphere partly in physical terms, as an information network, and partly in spiritual and philosophical language, as a force which would act to unify society. One of the many metaphors which he used to put the concept across was that of a 'halo of thinking energy' encircling the planet. Today the same combination of technical, sociological and philosophical terminology is used to describe the Internet.

Arguably, the technology – that is, the hardware – for Teilhard's vision is about to be with us. But when he spoke of a future noosphere he did not mean only, or even mainly, the means of physically reaching across the globe. He referred to a further development in the process of human evolution which would lead eventually to the attainment by mankind of a greater unity of mind, body and spirit; there would be a sharing of purposes and ideas and values across societies. When speaking of a future networked society, a global culture or a new phase of civilization based on the interchange of ideas, we must take care to distinguish between a network in the technical sense and a network in the human one. Technically, we have wired the planet. Yet at another level, that of our complex interaction in social and economic settings, much less is changing.

I have gleaned two lessons from the history, short as it has been, of electronic technology; they are, inevitably, oversimplifications, but they have been my guide. The first is to regard almost any prediction of the future power of the technology itself as understated. The second is to regard almost any prediction of what it will do to our everyday lives as overstated. We must keep in mind, as so often when analysing the impact of information technology, that this is a technology of machines which transmit and process data, and that the basic dynamic within and between organizations is that which takes place among people who originate and consume knowledge. If the analysis set out in this book is correct, computing machines will transform the channels but not the content – the form but not the substance – of our interaction with one another.

The new technology can be thought of as a digitally formatted stage on which individuals who work with knowledge will continue to play the parts which they, variously, already play. The engineers will engineer, the marketing executives will market, the bankers will bank, the teachers will teach, and so on. For the technology industry, the task is to continue to improve this stage, this infrastructure of machines and networks, in such a way that anyone of reasonable ability can act on it. For individuals and organizations in any field of endeavour, the challenge ahead is to continue, through investment in human capital, to develop the ability to play out those roles – roles in a drama which will be acted out between people, not between machines.

Lurking behind predictive scenarios of a computer-driven society is an emaciated view of what it is to be human: a model of the person as an entity whose objectives we have

understood and can deliver by programming machines – who is satisfied with the simulation as much as with the reality, who is responding to images and sounds and not to the hearts and minds of those behind the images. In fact, we are exceedingly complex organisms, pursuing goals we don't understand, in ways which we cannot grasp, for reasons which we certainly have no ability properly to fathom. It is precisely these qualities of unfathomability and unpredictability – free will – rather than our powers of logic that make us still unique in the age of digital machines. There is no scientific evidence or philosophical argument that technology is developing in a direction to emulate those qualities.

The first round of the computer revolution was the introduction of mainframe computers to replace the armies of clerical workers undertaking routine data-processing tasks. Today a $1,000 notebook with a Pentium chip running Office 97 can look after an executive's data needs more effectively than a $2 million IBM 360 with its software-support team, and there is as little nostalgia for those big old machines as for the factory-like offices they replaced.

But in one respect at least the earlier era could be said to have been a golden age of computers. Precisely because they were so expensive and difficult to program, they were used for what they were suited to best and people suited to least: calculating, sifting and storing in a context, like bank-account reconciliation, where there is not the slightest advantage to be gained from the human/analog touch. They were used, in short, for computing.

Thirty years later, by contrast, digital machines could replace receptionists and answer the telephone – inspiring the Dilbert cartoon of a machine-generated voice saying to customers: 'Your call is important to us. Please hold the line while we ignore it.' Technology by this time was clearly beginning to enter into roles in which a human rather than a computational touch did indeed have value. Whether the bank would give you an overdraft became no longer a decision that would be handled by a bank officer but instead would be handed over to an expert-system program which would weigh up your creditworthiness by algorithm. The computer was surreptitiously crossing the barrier from what it was ideal for – keeping track of your bank balance and calculating the interest – to what it was not, because it was being asked to deal with problems which it could encode only by narrowing the problem to fit its own constraints.

Our societies are now embarking on the long task of integrating computing machines into daily lives. There will be many opportunities to substitute the quick decision of a machine for the more cumbersome human-generated thought process which preceded it. Each time there will be a small gain, direct and easily measured. But there are also costs being incurred – maybe small ones that are greatly outweighed by the benefit, but costs nevertheless. The person who is being replaced is not just a data-manipulating device, a preprogrammed Turing machine. It is well to remember that the substitution cannot be complete – to remember, in short, the role of people in the digital era.

The computer may have cracked the technical problem of encoding information digitally, but it cannot yet deal with us on a level to which we relate. In January 1998 Douglas Rushkoff wrote in the *International Herald Tribune*:

> We've bought the notion that our computers have brought us into the Information Age and that we are now in the realm of bits. It's not bits we're exchanging, but our very essence in the form of ideas, e-mail, graphics and chat. When I go online to engage in human interaction, I log off energized. When I search databases or shop in online malls, I leave the experience feeling drained and alone. This is because the former involves communicating with other living beings while the latter concerns only machines and their information.

To even the most avid fan of the Internet, the machines in the Net do not understand the terms and requests keyed in. The network's search engines will do their best and give you many leads to sites relevant to your quest, but still won't capture what you are *really* after. You are left with the deeply felt sense that the software is not communicating with you on your terms.

Virtual-reality pioneer Jaron Lanier is well placed to understand the power of the new machines. He puts it this way:

> Trying to understand how communication can be possible in the first place gets us into very mysterious territory. You can believe that a conversation between two people consists of objectifiable pieces of information that are transmitted from one to the other and decoded by algorithms, or that meaning is something more mysterious than that, something that no one has yet been able to find a method of reducing. I am in the latter category. I think that the fundamental process of conversation is one of the great miracles of Nature, that two people communicating with each other is an extraordinary phenomenon that has so far defied all attempts to capture it. There have been attempts made in many different disciplines – in cognitive science, in linguistics, in social theory – and no one has really made much progress. Communicating with another person remains an essentially mystical act.

The text of a poem or business memorandum is easily digitized. However, that does not make the poem or memorandum the product of a digital machine. It is the product of a human being; it is very humanly crafted and it requires a human mind to understand what it is communicating. There is a yawning gap between data shuffling, on the one hand, and thinking, on the other. We are certainly digitizing practically all forms of recorded information, and then processing them using digital techniques. But that does not mean that the information itself is intrinsically digital or, more importantly, that the operations which we as human beings wish to have performed on it are amenable to digital logic.

As the world becomes comprehensively wired we will need more than ever to understand the difference between data, information and knowledge – that raw data is a mass of symbols, that information is something more useful distilled from the data, and that knowledge is a still higher level of meaning, as information enters the human creative process.

The difference between data and knowledge is like the difference between raw food and the nourishment we obtain by eating it. An intermediate step, like information, is the meal we prepare from the raw ingredients and serve on the plate. Data's role in the quest for knowledge, like raw food's role in the quest for nourishment, is the starting point: the vegetables, the grains and the livestock in the fields. We then make it into a meal, selecting the raw foodstuffs according to our needs and processing them for taste and digestibility. The processing may be light, as in cleaning a salad or squeezing a fruit juice, or heavy, as in making milk into butter or meat into stew. Then we eat the prepared food to obtain nourishment: energy to live and chemicals to renew and grow our bodily cells. Knowledge is like the nourishment we receive after taking in and digesting the meal.

As modern farm machinery helps us grow the food we need for nourishment, so networks now bring us the data

we use to build up knowledge. Modern technology has brought to every locality almost limitless access to up-to-the-minute data, just as we now find fresh food from every corner of the world in our local supermarket. And the comparison extends also to processing. The computer in the living room can scan, select and process the data into carefully tailored information nuggets of our choosing, just as the appliances in the kitchen convert the supermarket food into meals ready to eat. But to convert that information into the electrical and chemical changes inside our heads which store knowledge? That, like the conversion of meals into nourishment, is beyond the reach of technology.

Nobody has yet replicated what happens to food when it gets inside the body. We are extremely complicated chemical factories which Nature has evolved over billions of years to convert the food we ingest into carbohydrates, sugars, fats and proteins which are needed in various parts of the organism. Wouldn't it be like a dream, for some at least, if technology could give us the nourishment directly, under our instruction? We could, for example, make the spare fat store itself where we wanted, not where the metabolism puts it. Our muscles would be re-energized the moment we desired them to be – no more tired feeling at work in midafternoon.

But it's not like that – we can't penetrate the metabolic process and take it over. And the brain is an even more complicated knowledge factory than the lower body is a metabolic factory. Nobody has been able to replicate what happens to information when it gets inside our brain. As to how the thinking process works, science is as stymied today as philosophy was 2,000 years ago.

The new technology has done to data processing what the old technology did to fabrication. It has introduced – at the levels of data and information, not of knowledge – mass production. Electronics has brought the cost of digitally processed data down to the cost of the software doing the processing – at the margin, practically zero. Operations which can be done by a computer, be they the solving of a tax computation or the creation of a digital movie character, become replicable and marketable. Processed information has become a commodity. The same programs available to us are available also to friends, neighbours, colleagues and competitors. And, like plastic ballpoint pens and other mass-produced gadgets of the industrial age, they lose value as they become available to all. Floppy disks and CD-ROMs collect dust on our desks and in the kids' playrooms. Each of them contains millions of bytes of so-carefully crafted software – piled up high through the economics of duplication.

We have spent centuries wanting more information, so it's astonishing that it has become so cheap. But then who could ever have imagined in the eighteenth century, when a simple manufactured article like a knife could cost a month's income, that machinery of the complexity of thousands of knives would be left to rust in back yards – dishwashers discarded because a new model had come along or even just because the old one did not fit in with the colour-scheme of the new kitchen?

What will retain value, both personally and professionally, in this age of machines that can conjure up and process information in limitless quantities is that which computers cannot produce – just as what had value during much of the twentieth century was what could not come off a mass-production line. The source of unique advantage, of value, lies elsewhere. It lies in the minds of the millions who are the ideas-creators of the post-industrial age.

It has to be accepted that the ideas we create may want for quality. Thomas Aquinas's *Summa Theologica* is, by common consent, the greatest intellectual achievement of medieval Europe. A comprehensive restatement of Christian values and mores based on the philosophy of Aristotle, it runs in at least one current edition to thirty-three volumes – some 8,000 sides of text. And it was written in a thirteenth-century monastery equipped with a library and quill pens. We should not expect anyone to produce a finer work tomorrow just because information technology has advanced so very considerably since the thirteenth century. But the ideas will certainly be there in greater *quantity* than in previous centuries. More people have time, intellectual preparation and now – thanks to the Net, computer and CD encyclopedias – unprecedented amounts of information to work on. Mass-produced digital devices will give us every technical assistance.

James Bailey, author of *After Thought: The Computer Challenge to Human Intelligence* (1996), points out that we have been taught since the time of the ancient Greeks that rational thought is the pinnacle of human mental achievement: 'We as a species made a decision at some point to define human uniqueness around our intelligence.' If by 'rational thought' is meant logical processing, it is a bad place to plant our flagpole. Human intelligence is much broader. Schopenhauer emphasized almost everything else in our mental armoury: the power of will, drive, emotion. These are deeper planes of human interaction, and much more uniquely ours than data sorting. If computers have devalued one particular aspect of our intellectual powers – pure computation – by cheapening it, as industrial machinery devalued the ability to pull a heavy load, so be it. There are plenty of human qualities left untouched, and they will become the more valued. Bailey points out that, if the emergence of powerful computers like Deep Blue forces us to realize that logical processing is not a unique quality of humanity, then this is for the better:

> It's going to be a painful process, but if in that process we come to understand that we are not essentially analytical beings, that our essence is something higher, then that's a positive development.

What the future will bring by way of new combinations of human and machine information processing we cannot know. But so far the front-running hypothesis is that the creative engine remains the human, with the machine as its servant at a fairly low level of processing – excellent communications, good housekeeping of data, very hygienic in presentation. This hypothesis is also the one that gives us the most respect as people, and the one for which we should prepare.

It is not being Luddite or otherwise unenthusiastic about the possibilities of digital technology as a tool to refute the new value systems and philosophies surrounding it, or the notion that the technology will bring about a new phase of human civilization. There is a middle ground, one which recognizes the power of the tool while studiously avoiding the pitfall of assuming that the rationality of the new machines will be matched – whether for good or evil – by a rational approach to their use. The eminent Spanish–US philosopher Manuel Castells writes in the third and final volume of his *The Information Age*:

> The twenty-first century will not be a dark age. Neither will it deliver to most people the bounties promised by the most extraordinary technological revolution in history. Rather, it may well be characterized by informed bewilderment.

We do not yet live in the world depicted in Andrew Niccol's film *Gattaca* (1998), Hollywood's first full-scale exploration of a world in which genetic engineering is

routine and babies' genes are tested and 'improved' within days of conception. But, as knowledge accumulates exponentially, new classes of issues will arise which have never faced humanity before. Biotechnology, especially genetic engineering, could change our species; the Institute for the Future has held a meeting, rather chillingly, on the coming of the 'post-human' society. In the next half-century there will be shifts in economic and social structures and in individual values which we cannot predict but which will be as transformative as any we have so far experienced – tinkering with human DNA might make this an understatement. The coming decades will bring surprises to leave us gasping – developments which will make the electronic revolution taking place in our offices and homes seem minor by comparison.

The strategic and military consequences of the path this technology is taking are not, in the main, weighing on the minds of its developers.

Columnist Thomas L. Friedman, writing in the *New York Times*, said of the present culture in the industry:

> There is no geography in Silicon Valley, or geopolitics, only stock options and electrons. Unless you look at both geotechnology and geopolitics, you cannot explain (or sustain) this relatively stable moment in world history.

Robert Kagan of the Carnegie Endowment has made the same point in different words:

> The people in Silicon Valley think it's a virtue not to think about history because everything for them is about the future. But their ignorance of history leads them to ignore that this explosion of commerce and trade rests on a secure international system, which rests on those who

have the power and the desire to see that system preserved.

The intense but somewhat single-minded culture born in computer laboratories in the 1970s – a drive for peer respect, more recently spiked by the taste of wealth – is still prevalent in the hotbed of creativity which is the high-technology industry. The checks and balances that will be needed to prevent chaos – a fanatical Third World group declaring war on the Information Superhighways of the West, perhaps – would come more suitably from outside that particular culture; but how many outside the culture really feel for the problem?

A press release issued by IBM in January 1998 describes a software package which allows the three-dimensional visualization of objects on a screen. It is being used to help reconstruct Dresden's Frauenkirche, one of the numerous buildings destroyed by the firebombing of the city in February 1944. Most of the historic edifice was reduced to a pile of sandstone rubble which has remained on the site ever since; to quote the computer firm – may the elders of Dresden forgive the ludicrous euphemism – 'Allied bombing changed the church's architectural make-up for ever'. Now the new software is being used to enable as much as possible of the original sandstone – some 30 per cent – to be put back in its rightful place during the reconstruction.

At basically optimistic times – times of economic boom, like ours, when people are looking to the future with more enthusiasm than foreboding – the presumption is that technology will drive change for the better. But for a brutal (and ironic) reminder of the strict neutrality of technical progress in the human drama, one need look no further than IBM's next press release on the same visualization software. It describes a different application, in a factory in Munich, where the package is 'trimming production costs, shortening throughput times and optimizing the process chain'. The products being manufactured? Guided missiles, tomorrow's bombs.

As the millennium approached, a much sterner lesson was being learned by society as it adopted the new technology, a reminder that information machines can impose on society large-scale economic as well as security risks when an error occurs.

Worries about the millennium bug have been circulating among computer experts since the early 1990s; by 1997 they were being analysed with concern in the information-technology departments of banks, utilities, processing plants and distribution companies. In early 1998 the sounds of panic began to reverberate around the boardrooms of the world. Estimates of the cost this tiny programming quirk might inflict reached many billions of dollars, then began to top a trillion. The hurried patter of feet abandoning a sinking ship could be heard; headhunters reported droves of IT executives leaving the jobs where the systems they had installed might be infected – to take up jobs running systems equally tainted, but where they could be part of the solution rather than the problem. Insurers wrote liability for millennium-bug losses out of their policies. Auditors demanded directors' declarations as to the adequacy of steps being taken to combat the ailment. Government authorities in the United States, Europe and the rest of the developed world set up task forces and allocated budgets to publicize, cajole and threaten business leaders to face the problem.

The millennium bug brought home the uncomfortable truth that the leaders of commerce and industry, so much in control of the other technology and practices within their organizations, had not been in control of their information technology. Not only did they not know whether the computers were adding to profits, they did not really know what the computers did; they certainly didn't know what would happen if the computers stopped doing whatever it was that they did.

This new technology, in the literal sense closer than any other to company management because it was a technology of the office, was, in the sense that actually mattered, more remote. The way in which the computers went about the silent task of processing the data which flooded into and out of them was in reality a mystery to the people in charge. They did not know what standards were being employed to check data, to document programs, or to decide when code should and should not be used. Corporations, therefore, had little idea what to do in response to this predictable yet unexpected threat, or indeed how serious it might be.

The various other technologies deployed in modern economies have been subject to checks and balances that have been finely honed over many generations. Factory and construction equipment is designed and installed by engineers who acquire their qualifications after five or even seven years of education and traineeship. The same is true of administrative practices: the financial operation of any firm is under the control of senior accountancy personnel who have graduated typically twenty years earlier and, as they made their way up through the profession, gathered experience relevant to the ways in which financial controls can work or fail.

Software writing, however, is a profession that lacks such checks and balances. The fact that, in this new technology, the professional path is not one of apprenticeship and careful graduation from less to more important tasks as individuals broaden their experience of life is both a source of dynamism and a potential danger. At 18 you can be a professional programmer; at 20 you can be an old hand; and at 22 you can be at the top of your profession. Nothing wrong with that if the deployment of the programs is governed by

procedures and professional practices which have been geared to deal with the unexpected, when there is supervision by people who have seen what happens when machinery fails or humans err. But, as the affair of the millennium bug has shown most vividly, software deployment is not under any such control. Among IT professionals there are many eminently responsible people, but the culture is still very much one of the loner, the creative genius, rather than the safety-conscious bridge designer or the cautious and sceptical financial auditor.

The millennium bug has, then, sounded a warning bell, and not just to firms but to society at large. It offers a graphic example of the information-technology project getting slightly ahead of itself. Not to the point of disaster – the billions or even trillions of dollars spent to correct it is a cost which the global economy can, if somewhat unhappily, take in its stride – but enough to make it worth asking whether the information-technology mores should be tweaked to give more weight to reliability, care and checking and less to immediate performance.

In fact, the bell was sounded at a good time, because the problem hit the world while digital technology was still largely a white-collar affair, limiting the chaos to the administrative and financial side of commerce and industry. The consequences of, say, a supermarket chain's automated stock management system deciding on 1 January 2000 that it is 100 years behind in fruit stocks, is not that its stores will actually find 100 years' worth of fruit being delivered through their doors. Such systems are currently automated only to the point that computer-generated *instructions* are given – to drivers, warehouse managers and other human operatives, people who would not be so stupid as to implement the absurdity. Consider, by contrast, how much greater the alarm would have been if the trillions of dollars' worth of computers in the world had been embedded in the 'real' economy rather than the 'information' one, so that trucks and other industrial plant started blindly implementing 100 years of activity in a single day. Truly awful chaos could have ensued, the stuff of a Hollywood horror movie.

The phase of the digital revolution which the bug affected was the first phase: the widespread adoption of computers by businesses. There are at least two more phases to go, each rendering us vulnerable to damage much more costly than that wrought by the bug.

The second phase is networking, which began to be adopted extensively in the 1990s, in the form of the Internet, but which will clearly have its major impact in the coming decade and beyond. Linking the world's information sources by so powerful a communications system provides enormous opportunities for economic efficiency and social connectivity – but brings a completely new level of danger from abuse or failure. At least the millennium-bug problem can be addressed by each major computer installation or group of installations independently: the computer systems of companies and other organizations are still primarily self-standing. The linkages between them are a secondary feature, a later add-on.

With the arrival of the networked world this is changing. Networks are what computing is to be about; it is precisely through the comprehensive interconnection of computer systems – of companies with customers, of governments with diplomats and the military, of families in one country with relations across the globe – that we will arrive at the next plateau on the continuing path towards an information society.

Along with the benefits will come unprecedented opportunities for damage through error and ill will. Tasters of what awaits us have included the success a 13-year-old in a small town in England had in penetrating the deepest secrets of the Pentagon in Washington. Congress has responded to this

episode with a penetrating investigation, but will be powerless to avoid a more dangerous repetition as networks continue to integrate. The standardization offered by Internet protocols is a boost to hackers, spies and terrorists, making easier the task of roaming the world's wires in search of the computer installations that enemies need to access to wreak their havoc.

And what of the third phase, the transition of computers out of the information environments of offices and living rooms and into the 'real world' of genes and atoms? The imagination can hardly begin to grasp what the consequences of error or fanaticism could be. By the time computers are mastering matter at this *real* level, rather than an administrative one, it would be well for us to have improved our mastery over them.

We must make a choice as to how we are to prepare the next generation for this changing and no doubt bewildering world. A widely held view is that the most important new factor in education must be the new technology. In a 1996 poll US teachers ranked computer skills and media technology as 'more essential' than biology, chemistry and physics; than European history; than reading modern US writers like Steinbeck and Hemingway, or classic ones like Plato and Shakespeare; or than dealing with social problems such as drugs and family breakdown. Reporting these results in *Atlantic Monthly* Todd Oppenheimer described actions being taken by schools across the USA in response to such views. In Mansfield, Massachusetts, administrators dropped proposed teaching positions in art, music and physical education and spent a third of a million dollars on computers. The President's National Information Infrastructure Advisory Council, a group of thirty-six leaders from industry, education and other fields, provided endorsement for this approach at federal level. The council has suggested reducing various activities in order to make way for computers, among them field trips – direct experience takes second place to the screen.

In 1974 an infant Italian boy, only days old, suffered an injury to one of his eyes. As a routine part of the treatment, a patch was put over it for the duration of the two-week healing period. When the patch was removed he was blind in that eye and, sadly, he will stay that way for the rest of his life. Because of the patch his brain detected no light signals coming from the optic nerve, decided the eye was dysfunctional, and so failed to grow the necessary connections into the visual cortex. That mistake will not be made again. With each new such case medical scientists learn more about the remarkable malleability of the young brain. The way it wires itself up is enormously dependent on the early stimuli it receives.

By the time children are of school age they do not risk blindness in the eye being caused by lack of optical stimuli. But they do risk blindness to ideas and to ways of thinking, analytical skills and creativity. If we try hard enough we may indeed produce a generation which is more at home with data than with knowledge, with numbers than with cultures, with computers than with people. We can aim education so that the new generation will feel more comfortable with the analytical thinking in which computers can assist us than with the softer modes of thinking which until now have been afforded their due place in education.

But would that not be the worst possible outcome? Computer specialists speak as if their non-technical counterparts underestimate the significance of the information revolution. My concern is the contrary – that it is these experts who may underestimate it, by focusing on the digital bits in machines. What is happening is much broader, a technology-assisted speeding up of the surge of ideas which began with the Enlightenment and is taking us to . . . we

don't know where. To cope with it we will need all the mental flexibility we can build. That non-digital quality of wisdom, and the creativity of which we seem to be capable – those are the assets which will help us tackle the problems of the twenty-first century. As information technology becomes more pervasive in our lives, it is easy to overlook how important the softer side of human reasoning was – and still is.

During the last technological transformation of comparable scale and speed – the one which between 1875 and 1950, the span of a single lifetime, moved us from an essentially pre-industrial life to electricity, cars, jet travel, domestic appliances, steel, plastics, modern medicine and the nuclear bomb – education retained its emphasis on fundamentals, not practical training. The world was awash with new techniques and products, but schools did not put these on the syllabus. Although industrialization was proceeding at enormous speed, the educationalists did not drop algebra or literature to teach car mechanics or domestic wiring. The stress remained on mental training through mathematics and sciences, and on understanding the totality of the human experience through the humanities. Able people became industrial and commercial leaders without learning at school the specifics of the technology their industry or commerce employed. They achieved their successes because their minds were acute, creative, sensitive and suited to solving problems in changing circumstances.

Historically, civilizations have maintained a balance between the emphasis given to the logical and precise modes of digital reasoning and the softer and more humanist – analog – view of the world. University students majored, in more or less equal numbers, in the humanities and the sciences. It should not be assumed that technology has overturned the age-old balance between the two modes of thinking: the vigour of mathematical studies and the less easily definable understanding of human nature learned through history and literature. The penetration of computer technology does not imply that more of the prizes of life will be handed to those who have mastered the logic of digital machines.

With human knowledge accumulating at such a pace, the prudent are limiting themselves to one forecast only: change. In the next half-century there may be shifts in economic and social structures enabled by this technology, or by a different one, or just through the thrust of societal forces, as transformative as any we have experienced. If this brief history of the cyber age is correct – if information technology is playing only a part, as follower more than leader, in a much more comprehensive knowledge revolution – the last thing the next generation needs is to swap its education in the lasting richness and complexity of the human spirit for expertise in today's computer technology. The future will belong to those who participate in the new information age in its broadest sense, not in a narrow one.

It would be too simplistic to dismiss the current vogue for seeing the future of human affairs as dominated by the computer as a repeat of earlier periods of technological determinism. The technological elite is, at its best, keenly aware of past mistakes in this regard. That elite is, nevertheless, convinced that this time around things are different. Computers really get to us in a deeper way: the idea has gained ground that there is something of us about them.

Bill Gates put these ideas across to an interviewer from *Time* in January 1997:

> I don't think there is anything unique about human intelligence. All the neurons in the brain that make up perceptions and emotions operate in a binary fashion. We can someday replicate that on a machine. Eventually we'll be able to sequence the human genome and replicate how Nature did intelligence in a carbon-based system.

His interviewer pressed him: wasn't there something special, perhaps even divine, about the human soul? 'I don't have any evidence on that,' Gates replied.

Such comments on human and machine intelligence reveal a thoroughly computer-like view of what constitutes human biological life and consciousness. The human genome, the three billion-long combination of atoms inside each of our cells which allows us to replicate ourselves so accurately, is tantalizingly digital in its precision. The exact sequence in which this DNA molecular sequence is arranged has led to excitement in the computer community that there is something deeply digital – and hence computer-like – about human life. The notion that the interchangeability of people and computers is deeply grounded *philosophically* would tie in nicely with the prognostications of the digital age. Its most energetic protagonist, Richard Dawkins, wrote in *River Out of Eden* (1995):

> Francis Crick and James Watson should, I believe, be honoured for as many centuries as Plato and Aristotle. What is truly revolutionary about molecular biology in the post-Watson–Crick era is that it has become digital. This digital revolution at the very core of life has dealt the final, killing blow to the belief that living material is deeply distinct from nonliving material. There is no spirit-driven life force, no throbbing, heaving, pullulating, protoplasmic, mystic jelly. Life is just bytes and bytes and bytes of digital information.

But it's not that easy. There is no denying the importance of the DNA discovery; it is clearly the defining discovery of the twentieth century in biology, which looks set to become the defining science of the twenty-first. It is true that DNA molecules, being made up of precisely arranged sequences of the four atomic combinations, lend themselves especially well to digital techniques of analysis. However, to read off the digital sequence of the DNA molecule is a far cry from understanding how this sequence translates into the remarkable phenomenon of life.

The way digital genetic code maps itself into actual biological shapes, structures and operations is still one of science's mysteries, and will remain so long after the sequence itself has been fully read off. The mystery arises because of the great intricacy of the inside of a cell. Although your body consists of a trillion of them, each of the cells is itself a finely balanced chemical-engineering factory containing thousands of different types of molecules, all interacting among themselves. Even individual cells are, after all, complex enough to be capable of separate life and reproduction. The widely studied *E. coli* bacterium uses a genetic code of 50,000 digits to reproduce just itself – a single cell.

The folding of a protein inside this living chemical factory is not only guided by the DNA molecules; it is subject to numerous environmental factors. The consistency of shape produced by the digital code is impressive. Identical twins come from the same fertilized egg, and hence the placement of every atom in their three billion-long DNA sequence is the same; the visual similarity at birth can be remarkable. But, deep down, as in the way the brain formed, the differences produced by the folding process are there: studies show that there is as much variation in intelligence between pairs of genetically identical twins as in the population as a whole.

Each new life starts out with a digital code for reproduction but also develops very much within the analog fabric of the material world.

To say that human life is, in essence, digital code because our cells reproduce with the help of numerically precise arrangements of atoms in our genes is not a scientific statement but wordplay masquerading as philosophy. The inference that the body's functioning is computer-like (digital) because its molecules are made up of exact numbers of atoms is like concluding that ballroom dancing is digital because dancers have exactly two feet. What defines a dance is how the dancers move around the floor. And the dance of the molecules as a cell evolves under the guidance of its genes – the protein-folding process – is, as biologists know well, of quite awesome intricacy. It operates under a combination of chemical and other influences which are very much analog, and not remotely understood.

The very idea that we are completely described as six billion digits is nonsensical: that which is analog is by definition of infinite variability. Insofar as we wish to call the sequence of atoms in DNA *information*, this information can be used only within a context, a physical environment. And this context is the hugely complicated chemical factory that is the human cell. The information can be read off only within that 'throbbing, heaving, pullulating, protoplasmic, mystic jelly' which is a living cell. The genetic material is not in itself a living cell; it is part of the mechanism by which a *new* living cell is copied out of a *pre-existing* one. The information required to produce each newborn creature is much more than its DNA. Insofar as our bodies are constructed in accordance with an instruction set, it is not just the one in our genes but also the one that has been produced as a result of the cumulative effect of four billion years of protein development.

Think through a scenario. An exchange of neutron bombs is about to obliterate all life from the face of the earth – every microbe, every insect and, of course, every human being. A group of technicians makes a last gambit to give the human species another chance. They put together a nanotechnology robot which can assemble molecules of DNA, atom by atom, and leave it a CD containing the complete human genetic code. When the neutron radiation ebbs, the robot picks up the CD, reads off the sequences and reconstructs the spirals of genetic matter, exactly according to the coded specification. It winds them alongside each other in pairs, just as they are wound together in a human embryo cell which is about to reproduce, and waits for life to spring forth again from this precisely configured data-set.

And spring forth it will not.

Whatever it was that caused life to begin, back in prehistory, it will have to cause it again if plants and animals are ever to return. The agonizingly slow evolutionary process will have to begin all over once more – billions of years of thrashing around of increasingly complex proteins until, *maybe*, a living being emerges.

To reiterate, the fact that the atoms in protein molecules (such as DNA) are digitally precise does not mean that the molecules *are* just information, equivalent to bits in a computer program. Molecules make up the *real* world, not the virtual world. Information is a quality we as humans can interpret from things, but it is not the things themselves. I emphasize this distinction because the term 'digital' is, understandably, so widely associated with the term 'information' that the two can sometimes seem synonymous. In fact information has both analog and digital character – as in a vinyl record or a computer program – and so, with digital atoms in analog space and time, does matter. We do not need to descend to the atomic level to appreciate these distinctions, for they occur in everyday life. The number of chairs around a dining table is digital – you can place seven or eight, but not seven and a half. The placing may convey information – if there are seven chairs and eight people arrive for dinner, the implication is that someone arrived

uninvited! – but nevertheless each chair is a chair, not an item of data.

In the year 2005, if the fifteen-year international project to achieve this goal runs to schedule, biologists will have sequenced the human genome; we will know in what sequence the three billion A, T, G and C molecular structures appear in human chromosomes. A few scientists (and more than a few journalists) will then announce that we have decoded our DNA. But what we will have done, in fact, is merely to list the order of the atoms on it. We will 'understand' our genetic code in the way that a child 'understands' a scientific article if he or she can identify the sequence of alphabetic letters in it. Bill Gates spoke of 'sequencing the human genome and replicating how Nature did intelligence'. The step from 'sequencing the genome' (making a digitized listing of atoms and transferring it to a CD) to understanding 'how Nature did intelligence' is akin to the step between listing the letters in an encyclopedia and understanding the wisdom contained within it: we're talking about two quite different things. Understanding 'how Nature did intelligence' is not a fifteen-year project: whether it will take 150 years or 1,500, or whether it will just never happen, is anybody's guess.

The digital revolution has certainly provided an intriguing new toolkit for thinking through questions at any level, even the philosophical. What can't be allowed to go by is the claim that, by deciding we're computers, we've cracked the mystery of human life. Through the ages people have spent their lives grappling with this deepest of puzzles, deploying in their quest philosophy and science and theology and history and literature and art, and they have cumulatively built up not any kind of answer but only a glimpse of the vastness of the question.

★

The afterlife will be like the Internet, said a priest in a recent broadcast on BBC Radio. We will interact, have experiences, gain knowledge – but we will not be there physically, because it is not a physical place. He was telling his audience that we can now comprehend how a soul can live on for ever, unconstrained by space or time. A soul, in his depiction, is noncorporeal and immortal, pure form without matter, like the code in a computer program. Deep down, we are pure knowledge without a place in time or space; the flesh is just its temporary incarnation. A nice analogy – the afterlife as cyberspace: disembodied intelligence, dematerialized existence. Arch-Darwinist Richard Dawkins, of course, has no time for clerics, nor for what he calls their 'mystical and obscurantist views of life'; it is the selfish gene, pure genetic data, which is the key to our existence. Like the priest, though, he uses digital data as the basis for his parable.

History has its grandest sweep as the history of ideas: the foundations of philosophy laid in ancient Greece, the mysticism of the Middle Ages, the scientific revolutions of Newton and Einstein. A new chapter in this history of ideas is being written, timed to perfection (even if by coincidence) for the new millennium: the existence of a digital world to rank alongside the natural one – bits in silicon to compete with life in carbon.

Plato thought the world was virtual, consisting of idealized Forms; his student Aristotle saw it as real, tangible Nature around us. Thinkers have been arguing ever since. Western philosophy, in the memorable summary by A.N. Whitehead, is a series of footnotes to Plato. By showing how intricate and rich can be the realm of pure Forms, digital processing has given the Platonic model an encouraging nudge forward.

In philosophy as in the business office, computing provides a new toolkit for working through old questions. But it does not take sides. The biggest questions still remain

unanswered, and each of us we will have to continue to look for the answers, if we wish to, using whatever combination of reasoning and beliefs we find convince us.

The journalist interviewing Bill Gates for *Time* did not let up on his questioning after the interview ended. He e-mailed Gates on several technical issues but also on the big ones: Can intelligence somehow be replicated in binary code? Has watching a two-year-old daughter learn to smile at her father's face changed his view at all? Answers to the technical questions came back promptly, but on the deeper ones there was silence. Finally, weeks later, a message from Gates arrived in the e-mail system:

> Analytically, I would say Nature has done a good job making child-raising more pleasure than pain. But the experience goes beyond analytic description. Evolution is many orders of magnitude ahead of mankind today in creating a complex system. I don't think it's irreconcilable to say we will understand the human mind someday and explain it in software-like terms, and also say it is a creation that shouldn't be compared to software. Religion has come around to the view that even things that can be explained scientifically can have an underlying purpose that goes beyond the science. Even though I am not religious, the amazement and wonder that I have about the human mind is closer to religious awe than dispassionate analysis.

Could it be that even the standardbearer of the new technology hesitates to embrace the new idea that a human being is a digital machine when confronted with the living evidence of his own growing child? While the new computing machines are spectacular in their digital precision, there is a more mysterious information-processing device which resides in each of our heads. Any forecast of the future path of the information age must acknowledge the human brain's abundant patterns of thinking and feeling, the richness of this natural ability of ours, and the complexity of the social fabric which human minds have built up over the course of the millennia. Fifty years of computer technology will not substitute as easily as technology enthusiasts would have us think for the natural processes of interaction between people and other people, and between people and their surroundings.

Epilogue

Emma (her real name) is 11 years old. She lives during the week in Boston, Massachusetts, and spends the weekends in a farmstead at the base of Mount Washington, near the small town of Jefferson, New Hampshire. She likes drawing and writing poetry, the subject matter being invariably Nature; depictions of butterflies, trees and hills, accompanied by whimsical lines in a child's hand, are framed on the farmhouse staircase. She attends ballet classes, which she enjoys, but her biggest passion is for horses. Riding and grooming are the chief lure of the weekend home, to which she is driven in a black BMW M3 of which she disapproves – 'It's a drug-dealer's car, Dad.'

Actually, what her father deals in is specialized business software, which accounts for the liberal sprinkling of computers on desks in both houses. On these computers Emma does her homework, plays games, surfs the Net and writes to friends and family.

One often hears it said that it is only today's children who will be truly adapted to the computer – who will have grown up completely at home with the new technology. Emma is certainly at home with it. This term her school is doing a special project on Africa, and her responsibility is Ghana. She is collecting materials on that nation's geography, its peoples, its economy and its political systems, from which she will put together a paper to present to the class. The computer is her research tool for preparing the project; it is also her typewriter for producing it and her postal system for delivering it – not to mention, of course, her game machine for diversion when she is fed up working on it.

The world has embarked on the long process of taking advantage of the tools which have been created by the new revolution in technology. The tools will be used to create many things that we do not want but, on balance, many more things that we do. In that regard this revolution is not different from the previous one, which transformed daily life in the late nineteenth and early twentieth centuries; indeed, it is an extension of it.

In many respects the new technology is more benign than the old. Its products are tiny and consume minimal resources; their production does not kill, pollute or cause cancer. In one respect, though, we must be more on our guard, not less. These new tools are *mental* tools, not physical ones, and, just as the previous technology had the power to change our physical world, this one has the potential to change our value system. This technology is better at processing data than knowledge, information than wisdom, facts than ideas. If we decide that we should adjust our sense of what is important to reflect what the technology can do, perhaps for convenience or in pursuit of efficiency, we will change our value system. By moving away from what is

human to what is mechanical, we will take a step backwards.

At some level, any object can be described in numbers, in bits and bytes. Guides showing school parties around the great medieval churches of Europe reel off data like baseball commentators. Notre-Dame de Paris is 130 metres long and 48 metres wide. Its roof is 35 metres high, and its two massive early Gothic towers rise 68 metres above the square on which the church was built. Construction of the building lasted from 1163 to 1250 AD; further embellishments took another hundred years. The colossal statue of St Christopher stands 8.5 metres tall, and the slender spire, or *flèche*, on the roof is 30 metres high. And so it goes on . . .

But the numbers do not convey the spirit of the cathedral, the beliefs which launched its construction and the determination which brought it to completion. These qualities the visitors will have to comprehend for themselves, and if anything helps them do that it will be not the statistics but the artistry and the majesty of it all.

We are only one generation into the digital revolution, and a fascination with the new scale of availability of information is understandable. But we must not mistake gigabytes for wisdom, or megahertz of clock speed for intelligence.

There is a danger that the computer will be allowed to impoverish the human experience. Some overreaction to the potential of this new offering is inevitable, as it was to the offerings of the industrial age. In Emma's home town of Boston, a $15 billion federally subsidized project is now under way to put underground the unsightly elevated highways which had been allowed to blight the city centre in the heyday of the automobile; the reclaimed land will be restored to greenery. There will be some blighting of our mental landscape by the new technology, just as there was of our physical landscape by the old.

*

But, from the evidence of Emma and her classmates, the computer will be kept well in check. To her generation it is very much: a tool to get things done, not something bigger than themselves and their friends. Emma would be surprised to hear that learned men and women are debating the equivalence of humans and software programs, or that educators are saying that computer skills should displace history and geography in her school. The difference between these machines and people is more obvious to her and her contemporaries than to those who were already adult when the computer age burst upon them. Because the young have played with computers since the age of three, they see right through them. They see the graphic spectacles appearing on screens for what they are: artifices of a machine which may be impressive and fun to play with, but not like the real human life going on around them.

Emma is not especially interested in computers. She is getting to the age when she wants to know more about people, cultures and societies. The boys in her class dream of football stardom and cars, but not, in the main, of computers. Those who spend their free time by the screen rather than outdoors are seen as inadequate rather than impressive, escaping from the rough and tumble of life rather than getting to grips with it.

To a child brought up with computers it is obvious that, no matter how good the simulation you see of your friend's face on the monitor, it is not actually your friend. It is clear that a movie starring a computer-generated character does not have the emotional impact of a film in which the star is a living person, someone to like or dislike in real life as much as on the screen. It will be manifestly clear to the generation of tomorrow that, however much data and information you amass, you do not necessarily acquire knowledge and wisdom, just as we know that, however many plastic beads a factory churns out, it is not making

pearls. The difference between the ability of a machine to process data and a human to create ideas will be instinctively obvious to the younger generation.

Since her childhood in pre-industrial Krakow, Janina Suchorzewska, the protagonist of our Prologue, had moved with the times, as mankind harnessed electric power, made the car and the plane, split the atom, created radio and television, discovered DNA, developed antibiotics and heart surgery, took to space, and learned how it could blast itself out of existence. Yet the memory I have of her is of a woman in her nineties, decades into retirement, sitting at her piano and surrounded by her paintings, the fervour still there but now expressed through the keys. Her life had returned full circle, slowed again to the pace of the nineteenth century, to the music and art and ideas of her youth.

If living through ninety years of the most tumultuous technological and societal changes the world has known left her and her contemporaries with their values and ideals undiminished, we can have every hope that today's technical revolution will likewise leave our human qualities intact. Technology is changing the stage on which we are acting out the drama of human life, but it is not replacing the actors, who are still people – biologically, intellectually and emotionally the same people as those of ancient Greece, the European Renaissance or the American Revolution.

We have every hope that in the twenty-first century Emma will not have to face conflicts as appalling as those experienced by Janina in the twentieth. But in other respects we can expect that her life will be every bit as full of human drama, the logic of computers not subtracting a jot from the range of emotions and drives which will shape the behaviour of the people around her.