Between wisdom and medicine there is no gulf fixed.
—Hippocrates, *The Decorum*

**THE ACCELERATING PACE OF LIFE**

No one interested in the life sciences can fail to notice how the pace of life always quickens. This seems so whether we look back a few years of our own lives, or millions of years of the evolution of life. The story starts slowly. But whatever evolutionary phase of pre-human life or human lifestyle that we look back on, the last small fraction always represents a new explosion to a previously unparalleled sophistication. Some 3 billion years ago, there were the first complex cells, some 550 million years ago, the first complex multicellular life, some five million years ago, the hominids (the Homo species). A million years ago, the early protohumans, *Homo erectus*, were chipping away at stone to make their first crude devices, developing the technology of fire. Just short of 200,000 years ago, anatomically modern humans were living, dying, and leaving their bones in Ethiopia, the earliest known *Homo sapiens* bones at the time of writing. There were accelerating waves of migrations out of Africa to colonize the world about 50,000 to 80,000 years ago, a new, literally “cutting edge,” technology arises: humans begin to develop new blade tools, fashioned from bone and antlers as well as stone. Armed with their New Stone Age blade...
technology, a few thousands of humans began a new diaspora out of Africa, their descendants displacing the Neanderthals and all previous modern ex-African humans, to the extent of wiping all modern traces of their genetic heritage and leaving only their own. Over the past 8,000 to 20,000 years the fixed-locale, agricultural lifestyle began the city era, the formation of the first towns, and cities, including such sites as those at Jericho and Catal Huyuk. In this progression from tribes to villages, and villages to cities, tribes-folk became citizens, and began to specialize into sophisticated craftsmen, warriors, administrators, thinkers, spiritual leaders, ... and physicians.

This quickening pace continues into the historical period (which can also be considered as due to biological and evolutionary forces). In the past 3,000 years, we have seen the rise of logical thought processes, including some 2,400 years ago the birth of modern public and private medicine and healthcare due to the philosophy of Hippocrates. Some 700 years ago, there was the European Renaissance, and the beginning of the spread of European civilization across the world. Then some 300 years ago, there was the Age of Enlightenment, leading rapidly to the Industrial Revolution 200 years ago, with its flux of populations into the great cities. There were the much less enlightened slave trades, representing the last great diaspora out of Africa, except that this time millions of Africans spread their genes across the world. Some 150 to 100 years ago, there was the consolidation of modern science in the form of most disciplines now established in academe, and of engineering using electricity. In the past 80 years came electronics, and 50 years ago, computers, software, increasingly pervasive smart devices, and then the Internet developed, all of which we call IT or information technology. This technology and not least the democratic structure of the Internet was crucial to support the international genome projects, the sequencing, or “readout” of the DNA in the genome of living organisms.

The Internet is a global network connecting millions of computers in more than 100 countries, and exchanging data, news, and opinions originally among scientists, and later the public. It is worth reminding, however, that unlike centrally controlled online services, each participating computer, sometimes called a host, is independent and of equal rank. It is amazing, and perhaps to many unexpected, that out of that democratic chaos has emerged order and vast utility.

“Future shock” arose as an issue in the twentieth century when the accelerating pace of the transitions described became very significantly shorter than the period of a typical human life. Indeed, at the start of the current millennium, new discoveries capable of transforming healthcare were emerging on an almost daily basis. A particularly watershed day was June 26, 2000. The world formally completed its first draft of the human genome, and life on Earth
began to look back and within, understand its origins and nature, and to contemplate itself in detail.

Of course, when progressing at an ever-quickenning pace and looking backward contemplatively, it is all too easy to trip over one’s own feet! Most of the themes in this book relate to the dizzying pace of progress, especially in information technology, and how we should watch out for its consequences for healthcare. For the most part we believe that progress is good, even great, news. However, the pace has caused some problems in recent history. These problems need to be put right, and there is some justice in the fact that accelerating developments in other areas, especially IT (again, information technology), can help us do just that. For example, the major theme for this book is that in the industrialized Western world, at least, many of us transiently lost something of importance in the twentieth century. The accelerating pace of medical technologies yet poor communications between those technologies, increasing dominance of economic considerations, and a much higher ratio of patients to physicians than in early village culture, lost the ancient personalized, holistic (i.e., whole-life-embracing) touch of medicine. US doctors, in particular, often lost their bedside manner, and patients began to be processed as if on a conveyor belt that passed through a physician’s office. Yet this has been a production line whose high-throughput aspirations have been in marked contrast to the miserable inefficiency with which data are passed back and forth almost every time the patient is the primary source of all data about past medical history. But the big message here is that information technology has precisely the ability to restore the dissemination of useful information from few physicians to many and back again, to help us all spare more time for each other. It can help us restore these proven ancient personal and holistic approaches, and spread them, laced with new science, to the whole, still largely underprivileged, world.

To consider how to approach this ideal, we must address in this book six main issues that set the stage. None of these issues can be considered in any meaningful sense as positive or negative. That is, with the exception of number 5, whose gloomy situation yet represents a glowing opportunity for the IT industry, they represent things just as we find them at this moment in the human story. But that should detract nothing from the excitement of the challenges.

1. **Genetic diversity.** The recent awareness of the extent of human individuality is seen in the diversity of the genomics of the human race that has evolved over many thousands of years, and that is responsible for the uniqueness of all of us through our differing risks of developing diseases and differing responses to pharmaceutical drugs.

2. **Cultural and intellectual diversity.** Our no less diverse cultural heritages, belief systems, concerns, and prejudices epitomized by the still significant split between Western medicine rooted in Hippocrates and Galen, and the endurably popular systems of alternative and Eastern medicine.
3. **Patient rights.** The delicate balance between privacy and autonomy, or self-interest and solidarity, and sharing medical data and participating in studies for the common good.

4. **The economy.** The issue of timeliness of waves of new industry and economy that may now be working in healthcare’s favor, thanks largely to the rise of the Internet.

5. **Legacy healthcare systems.** The healthcare and health insurance systems of today, which are often entrenched and bureaucratic Towers of Babel and yet typically beset by mountains of paper, high rate of medical error, and the challenge of the aging baby boomer population, and internationally polarized between managed healthcare and socialistic philosophy.

6. **Pharmaceutical industry transition.** The genetic diversity and the role and mode of practice that are currently caught in the transition between the revenue model of one blockbuster drug for everyone and the multiple personalized approaches that our differential genomics demands.

Despite the huge global economic downturn of 2008, the president-elect of the United States, at time of writing, is giving high priority to modernizing the healthcare system with leverage of the 21st-century technology. Building the new healthcare system is not a one-off computer deal but a basis for an information technology that will continue to become more and more part of our lives.

Prehistory and history, ancient and modern, is important for the provenance or historical origin and justification of the moral issues to be addressed. If we are not to trip up, and to avoid wrong turns and rough ground, we must often look forward, and practice some futurology. So another theme of this book relates to the fact that life on Earth has not only begun to look back and within and contemplate its nature in detail but has begun to look forward into the distant future to see no visible limits to the growth of technology. As pointed out by science fiction writer and visionary Arthur C. Clark, any sufficiently advanced civilization is indistinguishable from magic. If we do not consider our scientific potential and the kind of scenarios it can ultimately create, we may find ourselves in a dark future, with a very alien definition of well-being. To build well at the boundary of tension between the past and the future and try and understand what human society most generally considers right and wrong, it helps to draw insight both from mythology and ancient teachings and from science fiction, as we will do from time to time.

Recent revelations have been the incredible vision of what technology can do for progress of medicine. But both in our current and in our projected modes of thinking, ethical considerations are vital to guide us. The nature of medicine, after all, is that it can potentially change what we are, hopefully for the better, and our ethics may, and perhaps must, similarly evolve. In the future of health care, we are our own moving target.

Vision is not the sole prerogative of the modern world. This is manifestly obvious in regard to great engineering feats. Stonehenge had to be planned. Yet the cautionary biblical story of the ill-fated Tower of Babel reminds us
that grandiose engineering aspirations were seen occasionally even in very ancient times, while also cautioning us that if we are to look forward, we should try to do so with the best possible clarity and avoid miscommunication. Indeed the ancient Greeks were no slouch in architecture and engineering: if communication had been better and they had got their act together between the human-powered chariot and the spinning steam-powered sphere, they would have had steam engines. Such is the importance of translational research, namely mobilization of latest research and discovery, and for the purpose of healthcare benefit, this represents concept that will be discussed in some detail from the IT perspective.

**SCIENTIFIC ADVANCEMENT ACCELERATES MEDICINE**

Modern IT depends critically on mathematics and physics. The calculations in support of healthcare and pharmaceutical research involve mathematics, physics, chemistry, biology, epidemiology, sociology, and even, by helping in compliance, ethics. Computers are becoming more quantum mechanical and biological: prototypes of quantum mechanical computing and DNA computing already exist. Controversially, humans could progressively become more hardware than machine: right now implanted computer chips could aid in treating epilepsy and Parkinson’s disease, and have already helped correct hearing loss. The barriers between the sciences are breaking down, and in a few hundred years divisions between the sciences will be meaningless. In the far future perhaps, as discussed in the last chapter, the distinction between humans and computers may have less meaning than it has today.

Not surprisingly, almost all great contributors to science have left a legacy that is having or will have an impact on future health care. If we are to name the greatest scientists in the human history, we need to start with the Greek philosopher Aristotle or Aristoteles (384–322 BC) whose works are the foundation of Western physics, poetry, botany, zoology, physics, astronomy, chemistry, and meteorology, geometry, zoology, logic, rhetoric, politics, government, ethics, and biology. We need to include as well Johannes Kepler (AD 1571–1630) who discovered (in 1609) that the planets revolve around the Sun in elliptical orbits. Galileo Galilei (1564–1642), a physicist, astronomer, and philosopher, developed the first two laws of motion and also in astronomy, the telescope, and he is considered the father of astronomy. Next is the physicist, mathematician, astronomer, alchemist, and natural philosopher Isaac Newton (1643–1727) who is best known for his explanation of universal gravitation and three laws of motion that he used to prove that both the motion of objects on Earth and of celestial bodies are controlled by the same natural laws. Our understanding of laws of motion, governing bodies from atoms to planets and stars, are essential today for the computer simulation and design of drugs acting at their targets in the body. Charles Robert Darwin (1809–1882) is best known for the *Origin of Species by Means of Natural Selection* (1859). His thinking is
the cornerstone of modern biology—without it, the new sciences lack assessment based on genetics—and of pharmacogenomics. Without Darwin’s theory, our understanding of human differences that underpin personalized medicine and are rooted in recent human evolution would have no sensible foundation. But not all matters of health are inherited: Louis Pasteur’s introduction of germ theory has become the base of today’s microbiology, and his invention of the process called “pasteurization” has helped destroy harmful microbes while preserving taste and nutritional value.

Albert Einstein (1879–1955) is considered as the great scientist of the twentieth century. He is most notable for his theory of relativity, and he received the Noble Prize in Physics in 1921 for his explanation of the photoelectric effect and for his research in theoretical physics. He was followed closely by Paul A. M. Dirac (1902–1984), who perfected quantum mechanics, a new way of perceiving the world in terms of fundamental uncertainty that Einstein helped create but finally could not accept. Yet quantum mechanics fundamentally underlies electricity, electronics and IT. Neither can we omit the founders of electrical engineering. Thomas Edison (1847–1931) is the great inventor whose over 1,000 patents and inventions include the phonograph, the electric bulb, the telegraph system, the carbon telephone transmitter, and the carbon microphone that was used in telephones until 1980. Nor can we forget Alessandro Giuseppe Antonio Anastasio Volta (1745–1827) an Italian physicist who had much earlier developed the electric battery. He is regarded as the founder of the electric age and consequently the electric unit Volt is named after him. Today the British physicist Stephen Hawking is considered by most as the greatest scientist since Dirac for his big bang and black hole theories; he is famous for his book *A Brief History of Time* in which he sets out a truly cosmological vision in quantum mechanical terms.

With accelerating speed toward the midtwentieth century, there were among the band of actual and mental engineers. Imhotep (c. 2600 BC), Leonardo da Vinci (1452–1519), Jules Verne (1828–1905), H. G. Wells (1866–1996), Isambard Kingdom Brunel (1806–1859), Isaac Asimov (1920–1992), Arther C. Clark (1917–2008), Alan Turing (1912–1954), and Marvin Minsky (b. 1927) who envisioned progressively more incredible devices that could shift great rocks, move unaided, fly and drill, think for us, conquer space, and even time.

Naturally the same dizzying pace in engineering applies to the repair and engineering of human life, and hence to health care. Medicine has been practiced, based on long-standing opinion, as an art; medicine, however, is a science and effectively an engineering science! Physicians are, in a sense, bioengineers; it is just that the state of knowledge until recently has been limiting their activities to maintenance and repair. It is only recently that it has become possible to think of medicine as a kind of engineering because it is only recently that we have been able to “see” the molecular cogs and wheels. New technology allows us images at the molecular level, so we can think of ourselves as repairable and improvable machines, which is to think in an engineering sort of way. Our cogs and wheels are, of course, very small. Access to our
molecular scale selves provides us with matter that we cannot see and manipulate directly, and vast amounts of information too complex for traditional methods to handle. Knowledge of, and influence over, the molecular world is indirect, and IT is required to mediate. Many other engineering disciplines have come to benefit from IT, but they also managed without it. As medicine becomes increasingly molecular, IT is becoming indispensable.

WHAT ROLE IS IT STARTING TO PLAY IN MEDICINE?

For centuries we have been using observation and theory for medical research as these were the two pillars on which science was built. The third pillar of science, “computation,” and hence “simulation,” was adopted a few decades ago for science and engineering disciplines. The HIV protease inhibitors, the AIDS drugs, have been among the first important pharmaceutical molecules to be based partly on rational molecular design on computers, and work continues using the same laws of motion of Newton, often refined by quantum mechanical calculation.

The healthcare industry is lagging behind other industries such as the financial industry in terms of leveraging IT. Computers used by medical staff are largely confined to recording appointments and basic local patient information, word processing, and email. Most patient records are still in paper form. It seems to be the norm for the patient to fill out a form with personal details and medical history every time he or she visits a new physician or a medical center, even if it belongs to the same medical organization as does the primary physician. We are in a time of transition where the digital patient record and vigilance of patient health still has a long way to go, but things are accelerating rapidly. The overall goal set forth in Section 905 of the US 2007 Food and Drug Administration Amendment Act is to create a current and available active surveillance system on the health and response to drugs of a hundred million people by the year 2012 (25 million patients by 2010). It was motivated by apparent under-reporting of adverse reactions to drugs. Such adverse reactions, or sometimes simply lack of beneficial effect, are probably due in large part to the genetic differences between us that demand a more personalized medicine: clinical trials required for approval of new drugs represent, after all, a small and hence unrepresentative sample of the diverse population for which the drugs will ultimately be prescribed. The FDA must submit a report to Congress by 2011, on how it is using this vigilance system.

Today, IT is mostly used in the local management of patient records and medical images. IT has brought massive amounts of geographically dispersed medical information together for the common good, from patient records, medical images, and basic research. Systems are being requested to integrate feedback from physicians and patients, the US Food and Drug Administration, and the pharmaceutical industry. The importance of this accelerating acceptance of IT is its ultimate smooth integration with the simulation,
prediction, and design of molecules. Indeed as was noted by Tony Hey, former director of the UK national e-science program, a new (fourth) pillar of science may be emerging—data-centric science—to enable research that is data intensive, computer-intensive collaborative and multidisciplinary. One of the authors made an assertion that advancement in medical science calls for leverage of the fourth pillar and has filed ten patent applications related to the new pillar of science.

MEDICAL FUTURE SHOCK

Healthcare administration has often been viewed as one of the most conservative of institutions. This is not simply a matter of the inertia of any complex bureaucratic system. A serious body with an impressive history and profound responsibilities cannot risk unexpected disruptions to public service by changing with every fashionable new convenience, just for the sake of modernity. A strong motivation is needed to change a system on which lives depend and which, for all its faults, is still for the most part an improvement on anything that went before. However, this is also to be balanced against the obligation of healthcare, as an application of science and evolving human wisdom, to make appropriate use of the new findings and technologies available. This is doubly indicated when significant inefficiencies and accidents look as if they can be greatly relieved by upgrading the system. Sooner or later something has to give, and the pressure of many such accumulating factors can sometimes force a relatively entrenched system to change in a sudden way, just as geological pressures can precipitate an earthquake. An Executive Forum on Personalized Medicine organized by the American College of Surgeons in New York City in October 2002, similarly warned of the increasingly overwhelming accumulation of arguments demanding reform of the current healthcare system. Later in 2008, healthcare administrators and IT providers listened, with baited breath, to news about the “healthcare impact of the Obama presidency” with expectations of imminent great revisions. In a sense, the large magnitude of the changes, now beginning, needed to be voluntary; if there is to be pain in making changes to an established system, then it makes sense to operate quickly, to incorporate all that needs to be incorporated and not spin out too much the phases of the transitions, and lay a basis for ultimately assimilating less painfully all that scientific vision can now foresee. But scientific vision is of course not known for its lack of imagination and courage, and is typically very far from conservative, still making an element of future shock inevitable in the healthcare industry.

As the accelerating pace in medicine continues into the future, what precisely do we expect to see? As argued in this book, there is reason to believe that the union of IT, telecommunication, genomic and postgenomic sciences within the past half-decade will have profound life science and healthcare applications. Wonderful machines, submicroscopic processors and devices,
robot guardian angels, and complex IT infrastructures will be dedicated to our care, down to the very molecular level. It may be that Earth will run hot again in a new accelerating cycle of evolution, as life turns back not only to contemplate itself but also to repair, improve, and evolve itself, at dizzying speed.

Stop the clock! This is future shock indeed. This expectation of things to come begs some introductory explanation because in a sense many things never change, except in form and sophistication.

ON PLANTS AND STONES: THE EVOLVING MARRIAGE OF TECHNOLOGY AND MEDICINE

Modern medicine consists of plants and stones. The utility of molecules and tools (including computers) is a basic underlying concept that has gone unchanged since ancient humans chewed on their first herbs and appreciated the beneficial result, and chipped their first rocks into axes. What leads to discovery is science that is, rooted in empirical observation, but what transforms it into a social force is innovation.

While it is one thing to speak of discovery and invention as the scientific roots of modern medicine, actual adoption requires innovation and acceptance on a large scale, via marketing and sales. The impact of medicine on society transcends the spark of scientific insight, which many times in history has failed to fuel the fire (where we lack evidence of this, it is probably because it is lost to history!). Innovation does not have to be a radically different scientific world view or even sophisticated high tech, and for most of prehistory it was not: a stone or plant used a new way, or with the birth of ceramics a pot used the first time as a chimney pot, is innovation. Even today, in terms the process of innovation and impact, our technological marvels amount to the same impact as stones and plants. The point is that innovation has to spread and be broadly utilized. Even today there are many things that are done in the mind or laboratory but not on an industrial scale because communicative, distributive, cultural, ethical, and often legal processes are required.

The life sciences and emerging technologies have always had an intimate relationship. New tools enabled agriculture and hence the motivation to master biology, as well as astronomy and meteorology, and predict the course of agriculture. Obsidian blades facilitated ancient surgery, and over the next 3,000 years new technology enabling more sedentary lifestyle turned human thoughts from by the minute survival to more scholarly contemplations of mortality and conquest of disease.

Necessity, it is said, is the mother of invention, and environmental pressures shape cultural views and acceptance of, or desire for, the good life. Herb science is a kind of technology of huge prehistorical, historical, and continuing importance to medicine. The technology of proactively learning to recognize, collect, and cultivate plants with beneficial effects, rather than simply gather or grow extensive fields of plants as sources of metabolic energy, came as a
result of a more settled agricultural life. Less varied food groups caused nutritional problems, largely through crops rich in starch but poor in protein, mineral, and vitamin, compared with the earlier hunter-gatherer period, and the distinction between beneficial effects of animal and plant material for nutrition could not have been well distinguishable from other pharmacological effects. From the Chinese whose food-based medicine can be equated to the emerging science of “nutrigenomics,” we learn that for as long as history an entanglement of herbs in some pharmaceutical awareness dominated medicine for millennia. Monastic gardens kept the science alive through the European Dark Ages. Shakespeare’s plays give several now-obscure references to herbs that indicate medieval and Elizabethan medicinal practices. We now know that certain medicinal plants were efficacious because of the molecules they contain. In that sense through the ages people were practicing a crude technology of active ingredients, essences or “principles” that would await Thomas Sydenham (1624–1689) to clarify in words, early organic chemists to purify and put into bottles, and the pharmaceutical industry of today to redesign, synthesize, and put into pills.

Today, molecular and computer technology are two convergent technologies for medicine. Computers are a kind of sharper stone tool, and the drugs they help design are a modern purified and refined form of the herb. Today, as in the evolution from stone blade to electronics, few of the latest tools have failed to be pressed somehow into the service of agriculture and medicine. In the recent past we have seen new tools necessitate other tools. X-ray machines, magnetic resonance imaging (MRI) machines, positron emission tomography (PET), and other electronic medical devices of twentieth-century medicine are all partly computer operated. Computers additionally process the complex data, help diagnose the medical problem, and even recommend treatment.

As IT has increasingly transcended its purely supportive role, IT’s trans-technological role has put technology as we understand it to human power less as “slave devices” and more as peers of humankind. Devices become smarter, and if we are careful, kindlier. Caring and kindliness required for medicine demands a degree of human-equivalent stature and independence. Who would want a dumb or slavishly obedient physician or nurse? Already in the field of artificial intelligence, mainly due to Marvin Minsky’s initiative at MIT, robots and IT systems, computers and their software, sensors, and so forth, are being designed to be “caring agents” who understand the principle of how to look after us. An important influence in this regard was science fiction writer Isaac Asimov who coined “robotics” in his book I, Robot and defined three laws of robotics that give human-care an ultimate priority over all other responses to instructions. Actually robots do not always walk or look like a human, and they may not walk at all. From present-day trends, we can expect computer processors to become smaller and smaller, down to the molecular scale, but this will be more than compensated by
their insidious incorporation into all things in our environment. Effectively the net mass of computational power working to protect us will increase dramatically.

THE SHARPNESS OF STONES: THE STATE OF ART OF COMPUTERS

A mere 50 years ago computers were cumbersome. By the 1990s, they were powerful enough to be used in routine medical image analysis, and by 2000, IBM was announcing the construction of a powerful new class of supercomputer, Blue Gene, intended to overcome key problems in molecular medicine by running at petaflop speed of 1,000,000,000,000,000 or $10^{15}$ mathematical calculations per second. Another IBM machine, also with molecular and medical applications, recently broke that barrier first (see Chapter 10).

Petaflop speed amounts to $10^{15}$ complex mathematical (floating point) operations per second. For readers not of a numerical or engineering disposition, $10^{15}$ is 1,000,000,000,000,000; that is, the number one followed by 15 zeros. Most often here we will say things like “$1000 \ldots 000$, where there are 15 zeros.” Scientists think that too unwieldy and choose, $10^{15}$ instead. The engineer’s briefer style of writing is to put it all on one line as $10E15$, where “E” means “exponent” or “power,” here just the exponent of 10 (writing 11015 on one line where E is replaced by 10 would have obvious problems). There is about $3 \times 10^7$ or 3E7 seconds in a year, actually 31,536,000 (allowing for leap year seconds, which must be accounted in “time-stamped” medical events on the digital record). Expressions like $3 \times 10^7$ or 3E7 inevitably imply a degree of approximation, that it is closer to $3 \times 10^6$ than $3 \times 10^8$. Typically numbers with exponents are even rougher than that: an exponent like 7 means the number is more like somewhere between 6 and 8. To express the number of seconds to a higher level of precision, scientists write $3.6552 \times 10^{17}$ and engineers write $3.6552E17$. Both are $36552000 \ldots 000$, where there are 13 zeros, as four of the 17 were used up with the “.6552”.

By 2010, computer-based medical and health-care information management may well rise to 60%. In late 2003 we estimated that the Earth will have some 30 to 800 petabytes (1 petabyte is $10^{15}$, i.e., 1,000,000,000,000,000 bytes) of medical information on computers. Today, this may be an underestimate as more than 400 petabytes of medical images (X rays, magnetic resonance images, etc.) could be generated annually (see chapter notes and bibliography at the end of this book).
A “byte” is a package of bits, usually eight of them. Each “bit” (short for “binary unit”) is coded by an on/off state of some electrical switch or up/down of some magnetic element, and is usually represented by 1/0. Bytes can mean one of a lot more things than can a bit, which means just one of just two things. A byte of eight bits can stand for 256 different things, in fact allowing one to code the whole alphabet in lower case a, b, c, …, z and upper case A, B, C, …, Z, numeric digits like 0,1,2, …, symbols like “+” and “@”, and various control characters for computer equipment. “00100001” is a byte that represents an exclamation mark “!” in ASCII code, the American Standard Code for Information Exchange. In most computer languages (the programming language Perl is an exception) numbers like 6.4 intended for rapid calculation are represented differently than by the byte for 6 followed by the byte for “.” followed by the byte for 4. A byte can instead be a binary number 00100001 that stands for its decimal equivalent, 32. Several bytes can stand for very big or very small decimal numbers to a specified level of precision.

For comparison and to get a reference point, let’s take a pause to review the situation right now, at the time of writing. It’s actually quite a bit more advanced than when we first thought of writing this book, and will be more advanced again by the time you read this book. Things are accelerating incredibly rapidly. IT is being used right now for medical imaging, intensive care, and less invasive surgery (e.g., robotic surgery, laparoscopy). One might argue that these are still the only aspects of medical practice that are making really sophisticated use of IT. Even in the relatively industrialized and high-tech US and circa 2005, only 31% hospital emergency departments made extensive use of computers other than, for example, intensive care equipment, and only 27% outpatient departments and 17% physicians made use of computers (the source for most data in this paragraph is David Laskey of the New York-based Markle Foundation, which has a special interest in “digitalizing the US health system”). The situation is only improving in other sectors and EU countries with more social medicine, where there are no fees for service, and in veteran hospitals, departments of defense, small medical groups that interact vigorously internally, and high prices of liability for harming patients.

NOW IS THE CRITICAL TIME FOR IT-BASED HEALTHCARE

The truth is medicine and healthcare and their IT are in a time of transition, and so too is the pharmaceutical industry undergoing transformation, with an increasing eye on using IT to help develop drugs for personalized medicine, that is, for each major different genomic group or “strata” of the patient population. Why do we assume that things are “improving” with more widespread use of computers? Putting aside the thorny issue that some recent systems
NOW IS THE CRITICAL TIME FOR IT-BASED HEALTHCARE

could have been improperly designed or improperly used, and thus making things worse, computers even in the least sophisticated applications help greatly in holding or recovering information rapidly, and communicating among many centers. To see the scale of the problem, let us take the example of the United States. It is not a typical example, but it is nonetheless the big spender. The annual healthcare spending in the United States exceeded $2 trillion and is expected to grow to $4 trillion or 20% of GDP in 2015 according to the nonprofit organization for National Coalition on Healthcare (www.nchc.org). Right now the US scenario, which computers must address, is that medically important paperwork is escalating, in other words, getting hard to locate when you need it, and rarely locatable in time in a medical emergency. For example, five days in intensive care produces a 100-page document, not to mention the medical images like X rays and magnetic resonance imaging (MRI). In the United States there are 300 million people, and each person could have at least such a record over several years. There are about 5,500 hospitals with 2 million nurses, and about 700,000 physicians, 70% of who are in small groups of 3 to 4 physicians at a time. There are about 1,800 health insurance organizations to which 6 million employers make contributions, and 50 different state medical aid programs (every one is different). There are 43 million uninsured people, 24% of who are under 65 years of age. Despite this massive number of players, all who ideally want the perfect healthcare system, most are drowning in paper, hard copy medical images, and telephone calls, causing confusion and mistakes. There are approximately 100,000 preventable deaths in US hospitals, and optimal care is delivered only 55% of time. Overall, the present medical system represents an archaic and inefficient service model. As some counterbalance for this bad news, one might point out that the United States does compensate because of the money invested in research to provide patients, at a price, with the cutting edge technology. US residents have a better chance of having good treatment than most if they can afford it. But “translational research,” meaning the basic scientific research that moves out of the research laboratories to ultimately benefit the patient, takes 15 years to do so. Soon, unless something is done, the curves will cross, and the US citizen will be back in the dark ages as far as his or her healthcare is concerned.

Of course, one hopes that this will not be allowed to happen. We can look at the distant future and compare the present status, and we can hope that positive progress will be made in the imminent future to prevent deterioration of the health system. What will be the key technical issues in the imminent future? Certainly as introduced above, medical images will be important. There will in general be a need for storing, recovering, moving, and displaying large amounts of data in regard to medical history (“digital patient record”), lab results, diagnoses, prognoses, prescriptions, and procedures. An additional important concept, however, is that right now we are said to be in the “post-genomic era,” as we are just at the period when, after the completion of the first draft DNA readout of the human genome, information about patient genes and proteins (proteomics, expression arrays, etc.—to be discussed below)
is coming in. The illustrative fact that there are some 32,000 human genes, which are translated into many more kinds of proteins, makes the ability to handle enormous amounts of data a clear priority. The data that the health informatics or life sciences informatics solutions have to deal with on a daily basis are mind-boggling in terms of the volume in addition to the heterogeneity and multidimensionality. The human genome of about 50 terabytes grows somewhat in information as it is represented in fragments, annotated, and variants are included. One single genome can generate 300 terabytes (i.e., 300 trillion bytes) of trace files. Today a typical pharmaceutical company already generates over 20 terabytes a day of new data. Yet even these numbers pale before the amount of storage, transmission, management, and analysis required for medical and research images. Institutions now consider a cluster of virtual servers and storage systems to manage petabytes of data and beyond.

HEALTH CARE DEMANDS AN EVER SHARPER STONE

So medical data is accumulating in massive amounts, not only in terms of sheer bulk but also in terms of the numbers of parameters and descriptors of things and how they relate. Computers may be millions of times faster than humans at processing medical data, but they cannot always process things on demand and in real time, for example, as in the case of medical emergency. So an issue is computer power, which for the most part means the number of processors or chips running at particular speeds. If you have more chips of greater speed, you have more computer power. But different problems, namely different types of study, analysis, or processing, need different power even when the same data are used as input. So one important aspect of the difficulty of computation is the order of any computational problem, and roughly speaking, this is how rapidly computation gets harder as the data increases. The order of computation determines effectively “the sharpness of the stone” that is needed. In many of the common operations involving medical images and DNA, the bytes of information do not interact much. They involve one-to-one copying: they are said to be “processes of order 1.” The degree of difficulty will merely double if you double the amount of data. The expected “3D and 4D” analyses by sophisticated new medical imaging machines may account for much of the predicted activity, certainly more than a half. These “D” terms, by the way, have nothing directly to do with the order, just the nature of what the data represents. Here 3D means three-dimensional; 4D means three-dimensional motions of the body and its organs, plus motions in time. It does have an effect, but image analysis tends to be of a nature that this is not so much. The computer programmers know how to keep the problem under control. However, operations on the raw data will include not only basic image analysis, but soon also the simulation of body motions including the elasticity, plasticity, and coefficients of friction of nerves, vessels, muscles, and organs to help interpret
HEALTH CARE DEMANDS AN EVER SHARPER STONE

images. These dimensional components of the data will bring us up to computer calculations approximately of order 2. Today, new waves of stand-up imaging machine are arriving somewhat ahead of schedule, and at the time of writing, the managed healthcare in the United States appears to be having trouble keeping up. While the problem of the time scale of the relaxation of nuclear spin used in magnetic resonance imaging has to be overcome to get “movies” in real time, sonograms, which might be combined, are already there. Other kinds of computation may, however, be of still higher order, as discussed below.

The very large amounts of medical data generated by the variety of technologies, advanced medical imaging, DNA and protein analyses, and so on, have to be stored for long periods. At any point in time a large amount will be constantly moving around the Internet or other wide-area network. Figure 1.1 on page 17 shows an estimate of the data volumes devoted to medicine and related matters up to 2010. The lower curve is a base estimate. It assumes clinical and biomedical use will be at least 30% of total world storage in 2010, conservatively set at several hundreds of petabytes. It downplays advanced imaging capabilities. The upper curve, in contrast, represents the case where advanced medical imaging takes off. This is an optimistic projection with an assumption that 50 million \((5 \times 10^7)\) adult population require \(82 \times 10^9\) bytes of medical image data for each adult by 2010. It is primarily based on an assumption of advanced 3D (three-dimensional images) and 4D (plus the dimension of time, as in the movies). Such imaging capabilities could hold approximately 80% of all medical storage and a sizable fraction, maybe 40% to 60%, of all storage. But this may be an underestimate. At the time of writing over 400 petabytes of new medical images are created each year these are currently held locally and not all accessible to all concerned via the Internet; overall, there are believed to be over 150 petabytes \((1.5 \times 10^{17})\) of medical data and laboratory animal data that researches are interested in accessing, especially if combined with other data such as genomic data (see the chapter notes and bibliography for this chapter at the end of the book).

Orders of computation of about 2 may seem moderate compared with other types of calculation considered below, but the real difficulty of a calculation requires how long the calculation takes for a fixed amount of input data, not just how rapidly things get harder as the data increase. Medical imaging is crucial to healthcare and may dominate it in 2010. But as a scientific challenge today’s computation doesn’t even scratch the biological and medical molecule problems that IBM’s Blue Gene supercomputer is supposed to tackle. Blue Gene is intended (but has found many other applications) to help delve into another much deeper and more fine-grained world. It was conceived to simulate the motion of individual atoms in the proteins of our bodies, and ultimately the interactions of those proteins with drugs. Add to the figures above the fact that it takes more than \(10^{21}\) (i.e., 1000 … 000 where there are 21 zeros) of complex mathematical calculations in a second to fold a single protein \textit{ab initio}, as is calculated by the basic principles of physics, and we have on our
hands a further massive amount of data being generated continuously that
didn’t even go into the calculation in the first place. *Ab initio* means that it
simply got deduced from a small number of basic laws. Computers can them-
selves create a lot of data for computers to analyze. That data is important to
the pharmaceutical drug industry. Pharmaceutical drugs must have their ulti-
mate efficacy or otherwise because the protein molecules that they target
typically interact with other protein molecules, and these in turn pass on the
information about the interaction to other proteins, and other molecules, of
the body. How would we therefore simulate the whole body at the level of
every atom? The good news is that, forgetting quantum mechanics for the
moment and remembering the mathematical physics due to Sir Isaac Newton,
these kinds of calculations may take nothing more, or less, than analysis of the
forces within each and every *pair* of atoms, atom with atom, in a system of one
or more molecules at a time. That is, we recall, a calculation of order 2. This
may sound like a lot of computation, and it is. It takes a long time to simulate
in a computer what can take a fraction of a second in the real world. For
example, one of the early reasons for IBM’s petaflop computer project was
that there was some reasonable chance of achieving in a year the development
of a computer capable of processing the complex mathematical calculations
required to simulate the folding up of a protein molecule to achieve its biologi-
cally stable functional structure, a process often taking a second or less in the
real (biological) world.

Yet such medical computations may not be the only demanding computa-
tions. A real challenge to computer power comes from using the vast archives
of patient medical records to discover new associations between laboratory
results on disease and the most effective therapies. This looks much less like
science fiction, and at least to some tastes to represent digital-clerical boredom
of the worst kind. Yet the counter to this boredom is that lives are saved
by aiding diagnosis, prognosis, physician decisions, epidemiology, biothreat
defense, and medical research.

Mathematicians are appreciating that computational needs can dwarf
current protein and drug interaction modeling into insignificance. Unlike the
calculated rules about the energy and behavior of molecules, rules on medical
relationships cannot be always be deduced from pairwise interactions or
repeated multiple bivariate analyses alone. The computer can look at far more
than pairs of things at a time. For example, early programs deem to inform us
that anemic males are not uncommon, and anemic pregnant patients are very
common, and these are pairwise, “order 2,” relationships. But unless it has the
benefit of a full artificial intelligence (AI), and it specifically looks and counts,
a computer cannot deduce from such pairwise things that three-way things
such as anemic pregnant males are a different story. It has to look at these
“order 3” things specifically. And it isn’t the case that the most complex rules
need be just of order 3. In fact complex diseases, like cardiovascular disease
or cancer, may involve analysis problems that require the complex rules in the
order of 100 or more. Let’s imagine that we put each patient record on a
spreadsheet, one patient per row, with $N = 100$ columns to hold all the interesting data to analyze. This kind of data structure is among the least troublesome to analyze. Generally the number of possible rules to consider is about $x^N$ (i.e., $x$ times $x$ times $x$ times $x \ldots$ done $N$ times), where $x$ is often a lot bigger than 2. But for a spreadsheet $x$ equals only 2, and that is bad enough. Let’s say $N$ equals just a 100 (i.e., $2^{100}$). That means that there are potentially $10^{30}$, or 1000 … 000 with 30 zeros, potential rules to consider. On a medical record 2,000 basic features may be more common, and may even be a lot less than many would like.

How can we estimate the computer power needed for the vast data of future? See Figure 1.1. It is believed that each and every petabyte will require roughly a day’s work by a machine, with the kind of processing speed available to Blue Gene to process it. This implies thousands of computers, even hundreds of thousands and maybe more in the years 2010 to 2020, and the heat generated by those massive numbers of computers will require huge amounts of energy for cooling. Certainly, in building this new era, we are acutely aware of the natural tendency of work to degrade to heat, as were the engineers of the first Industrial Revolution. Yet we have only very recently solved the problems of heat production and dissipation for petaflop machines, and certainly not beyond (e.g., exaflop machines, which will be a thousand times faster
than the petaflop machines). “Hot” is, however, rather overstated. The human race will certainly not allow itself to be baked on a world resembling the hot rock that it was before the evolution of life. At least, it will not do so as a consequence of computing! Still we can reasonably expect hundreds of thousands of such superprocessors of some kind to be needed for medicine and healthcare in 2010 to 2020.

Beyond 2020, unless there are profound changes in computing based on subtle analysis of the thermodynamic principles deduced in the industrial revolutions, heat will become an even bigger challenge as in the distant future the mass of the world becomes converted more and more to computer processors. In addition to the heat, we also need to deal with the electric power required by the massive number of processors. A supercomputer of million processors will require 100 megawatts of electricity as an Intel Pentium processor takes 100 watts at the time of writing this book. Also we need to be concerned about the size and space required by those systems as a system with such large number of processors for massively parallel processing (MPP). To minimize the potential leaks of electrical currents out of the connectors and the electrical cross-talk on the adjacent connectors between the transistor gates within the integrated circuits of a silicon chip, the connecting wires must be kept within a certain distance and therefore miniaturization of silicon chips has a limit. However, there is a slight hope that the embryonic concept of photonic computing, using movement of photons instead of electrons, or molecular computing, often referred to as DNA computing may help with those problems.

Quantum technology may provide the ultimate and “sharpest possible stones” of the medical toolkit. Quantum computing holds great promise, not least in the ability to do many calculations at the same time. And quantum technology in general may be so important for medicine that medical physicists at research hospitals are contributing to it. Marke Brezenski and Bin Liu of the Center for Optical Coherence Tomography and Optical Physics, Department of Orthopedic Surgery, Brigham and Women’s Hospital, recently published the paper “Non-local quantum macroscopic superposition in a high-thermal low-purity state” (Phys. Rev. A 78 (2008): 063824). There are many potential medical applications of the curious fact of the quantum world that many things can go on, and exist at multiple places, at the same time, if only the quantum mechanical phenomena, well known in the tiny worlds of both particle physics and molecules, can be stabilized and tamed in the large-scale world of everyday human experience. The medical Internet news service Healthorbit (http://healthorbit.ca/, December 2008) was excited by the possibilities: “Imagine a computer chip so fast, it is capable of doing calculations it would take current computers a billion years to replicate. Imagine the ability to kill a cancer tumor by taking some of its cells and destroying them outside the body and, in turn, cells from that tumor still inside the body would die. Is either example possible? In the case of the computer chip, researchers suggest that by 2025, the chip’s ability to perform more functions at a faster rate will
come to an end. … [The above workers] … using principles related to quantum teleportation, have made an important step which not only opens the way for computer chips to increase the processing rate indefinitely, but information processing and telecommunication in general.” We shall see. While quantum computing is widely accepted as theoretically possible, the idea for selectively killing cancer cells seems most unlikely for several reasons. They include the relatively large scale and complexity of the cancer system, its interaction with the environment, and the very different way that cells have entangled histories compared with much simpler and tinier particles that could show comparable possibilities. But at least now we have an authoritative good guess at a date: 2025. It is not so far off in “healthcare time” even for such Star Trek–style possibilities: if the healthcare continues to modernize, the majority of the older people among us of the “Baby Boomer” generation will live to see if these predictions come true.

**KEEPING OUR HUMANITY**

All this new medical technology, advanced biology practiced by advanced IT, has the potential to profoundly alter the way we live, the very nature of what we are, and how healthy we are. It gives us myriad ways to improve the way we live in our relationship with the world. The very boundaries of life can become blurred, and so in consequence may the nature of what we mean by “health.” Until recently we have been able to work with the ancient dialectic of *secundum naturam* (natural, normal) and *praeter naturam* (unnatural, abnormal). But what will “normal” be? Until recently health could not be associated with the unnatural, the different, and the artificial, except in rather limited ways. This all will change as concepts of genetic engineering, gene therapy, prosthetics, robotics, bionics, and bio-nanotechnology begin to arise, when it is at least glimpsed how one could modify life and extend life capabilities. New classes of life might even need to be created that challenge the very definition of life. In the last chapter we will take this vision into the distant future to imagine minute devices within us, monitoring and even modifying the functions of the organs inside our body, and ultimately vast swarms of minute nanoscale robots, or nanobots. In short, our every need will be nurtured at the molecular level, as powerful, incredibly smart, internal (i.e., implanted) and external computing devices all communicate and direct the show.

Is this blazing technology really what the human race needs? Each of us must assess that for ourselves. But since it seems that wealthy nations will almost certainly take us in the direction of ever-improving medicine, we must be prepared as to how we are going to face it.

If this seems at all a disconnect from our inherent sense of our humanity, the reader may be pleased to learn that we are also going to explore a little the role of *alternative medicine*, that is, alternatives to current mainstream medicine that are often considered more caring and respectful of the patient,
and focusing on wellness and disease prevention rather than reacting upon a
clinical event, that is, when a symptom of disease presents. In particular, we
will touch on two further fundamentally interrelated humanistic approaches
in this book, the whole life approach called holistic medicine and the more
personal touch of personalized medicine. There is absolutely nothing
wrong with these intertwined principles of great antiquity and in very recent
time they have become accepted terms of mainstream healthcare. It is the
twentieth-century medicine that got it wrong by trying to tackle healthcare
based on fragmented (i.e., nonholistic), episodic (i.e., lack of continuum of
services), and external symptom-based (as opposed to dealing with the root
cause of illness) diagnostics and treatments, mostly depending on the one-fits-
all approach and yet on the trial-and-error method for treatments. Alternative
medicine was adopted as a complementary measure, but in the twentieth
century it was not adequately armed with science and technology. But that was
no great loss, since the science and technology were not yet up to the standard
to be fundamentally personal and fundamentally holistic. Today, with deepen-
ing molecular insights and advanced IT, medical treatment can become more
personalized. We will show that IT can be respectful of these alternative dis-
ciplines and even enhance their capabilities.

Some issues discussed above (and others below) relate to medical ethics.
The most routine use of that term in the twentieth century was in developing
the first steps of a strong regulated concept of good and bad medical practice,
to be discussed in regard to the ethical issues and IT in a later chapter. After
the Nazi experiments during the Second World War there were strong move-
ments in regard to patient’s rights, medical research, privacy, and so forth.
Public reaction to subsequent and persistent moral failures concerning human
experimentation in the United States (discussed later) spurred even stronger
legislation. Examples of common ethical topics today include how to respect
an individual’s wishes in medicine and range from what kind of lifestyle an
individual wants to have through to matters of a living will and consent for
use of medical data for research.

Advances in biological technology, of course, raise new issues. Matters of
ethics relate to the sanctity of life and issues on when life begins in regard to
stem cell research. With scientific progress the boundaries of life that seemed
so crisp when viewed on the macro scale can become blurred under the sci-
entific microscope. So does individuality when it comes to cloning. Just how
far can we or we should go with engineering of life? We mentioned above how
we have until recently been able to work fairly well with the ancient ideas of
secundum naturam (natural, normal) and praeter naturam (unnatural, abnor-
mal). The new medical technologies and the new power of biology are begin-
ning to strip away these arbitrary divides. It has become clearer why it never
was easy to define health objectively without getting trapped in a cyclic argu-
ment. The science of medicine, as we understand it, has its province of the
treatment of disease or pathologies. The word medicine is from the Latin
medicina, that is, ars, art of healing, and mederi, to heal. Disease and pathology
are states of being on which medicine acts. A current and growing goal of medicine is the issue of *health*, to prevent disease before it strikes and to build well-being and fitness. Health appears to be a “correct state,” “sound state,” or “vigor state” of life. These terms invoke an impression relative to the counterpart of health, a state that is unsound and nonvigorous. Pathology and disease have no deeper penetrable meaning.

It seems enough of a paradox that medicine will progressively disappear from dominance in healthcare, which will be about, literally, care of health, and prevention of disease, not management of it. But it also opens the new question of what health is, in the current world, when no one is perfect and almost all of us believe we are capable of improvement. There is a market for it. Witness the advertisements and amount of email spam about improving body build, losing fat, enhancing sexual performance, sharpening memory, and improving interpersonal skills. The economics of medicine is in many ways fundamentally different from the economics of other industries. Few people would put limits on the resource that is needed to achieve the goals of medicine, health, happiness, and longevity. In 1968 British Minister of Health Enoch Powell stated in a speech “there is virtually no limit to the amount of health care an individual is capable of absorbing.” If asked, most of us who would choose ambitious goals would primarily go as far as possible on the continuum of a potential that leads from (1) relief from pain, despair, hopelessness, and cure from disease and insufficiency, at one end, through to (2) eternal health, well-being, excellence, and bliss at the other. Why stop arbitrarily at a present point of time when moving on to the future would make today look like a relatively cruel and inhumane Dark Age? We may not all like the world as it is right now, but it is an odd individual who does not want to be happy and productive for as long as he or she can.

Indeed, what do we have as the definition of health by the World Health Organization? Is it that the level of pathogens below a certain load? Is it that laboratory blood and biochemical results are in normal ranges? Is it that your weight and heart behave themselves? Unfortunately, nothing so clinical! The World Health Organization defines health as a *state of complete physical, mental, and social well-being*. Health does not consist only of the absence of disease or infirmity. Good health is in fact an ambitious goal that most of the world, even the industrial world, does not meet. We will constantly touch on this WHO vision.

Ethical issues in social and political science effectively relate to the potential for society to mess things up. How might our goals get messed up? For keeping our humanity, recent debates over matters such as stem cell research and human cloning are barely a glimpse of the controversies to come. That society is at least excited by the challenges is proven because the possible impact of biomedical knowledge has been a mainstay of fiction and speculative essays since the nineteenth century. It has created a market that competes vigorously with the enduring human interests in love and family relationships. It is hardly surprising, bearing in mind that many or all of these fundamental
literary themes can be wrapped into a good biomedical thriller. As the essential point of the story, many books and films describe how new biological and medical technology might go wrong, or lead to questionable accomplishments for humankind. They are basically healthcare-philosophy in biomedical futurology, in fictional form. Glitches of biomedical technology are a constant theme in the works of Michael Crichton: *The Terminal Man, The Androemda Strain, Jurassic Park, Prey*, and so on. *The Terminal Man*, for example, was written in response to real experiments in electrical stimulation of the brain such as those of Jose Delagado. One showpiece was described in the New York Times of 17 May 1965: “‘Matador’ with a Radio Stops Wired Bull. Modified Behavior in Animals the Subject of Brain Study.” Crichton’s stories typically describe one-off events that even within the stories told give the human race time to speculate and prevent problems arising again. Some people write about how civilization could soon be transformed, for better or worse, by biomedical progress: *GATTACA* is a movie about a genetically engineered elite, and Bernard Wolfe’s *Limbo* is a long-standing classic about prosthetic replacement by superior robotic limbs as a preferred practice for almost all.

And what is the perfect life and well-being anyway, if the nature of reality itself is in question? Others address the possibility that well-being can be engineered on demand, and in some cases well-being could mean discarding reality for an *illusion* of a whole world of peace or bliss, chemically, neurologically, or computationally. The drug *soma* of Huxley’s classic *Brave New World*, the humorous science fiction stories of Lanislov Lem, the movies *The Matrix* and *Vanilla Sky*, pithy passages from the works of Robin Cook and Larry Niven address such issues. Related issues even arise for the pharmaceutical industry today, say as to whether a drug which improves the sense of well-being and management of an Alzheimer’s patient is as important as a drug which might restore the patient to a less euphoric normality. But apart from the voices of those who advise strict adherence to the guidance in ancient authoritative works, there is no single popular and certainly no agreed ethical system about those things that will increasingly affect the lives of our children.

The authors do not think that the answer to perfect human existence necessarily lies in a future idyllic village or garden life like that portrayed for the (ill-fated) Eloi in H. G Wells’ *The Time Machine*. Phases of biological and social evolution already passed are not necessarily the best models for biological and social evolution to come, even if we could have total control of the process. But we do think that that the ancient principles of village life, when personal differences and all aspects of life were under the watchful eye of the shaman, do provide some principles for the future of medicine. As we will see, it is in the hands of some great thinkers such as the ancient Greek Hippocrates that the road of medicine split into two paths, at least in the Western world. Still, it could be argued that these two paths, though distinguishable, have been intertwined up to the nineteenth and twentieth centuries, when mainstream
medicine became more organized, but relied on a few highly trained individuals to administer to growing populations. The first doctrines, ideas, and approaches of medicine arose in ancient times when Shamans, folk physicians, and other medical wise men had a lot more time to spend on individuals in their small populations. The ancient wise men, in misty prehistory were born with brains essentially the same as ours. They were probably as smart as physicians today; there was just less data of the kind that we have today on atoms, molecules, and cells. With fewer details like that to think about, they applied (at least in many cases) a lot more effort to considering the whole life, diet, and sense of well-being, including spiritual life. So the ancients derived much wisdom for us by having their minds focused on the personal and holistic view, developing proven approaches for which the analytical science and overburdened and thinly spread health-care system of the twentieth century had little time. It can help with that logistic problem.

Today, a re-emergence of ancient holistic and personalized approaches to medicine is raising their own challenge about how information should be shared between the patients and the providers of patient care. For example, a tension is developing between autonomy—the concern of the patient for maintaining privacy—and solidarity or cooperation—what the patient is willing to share to be pooled for the common good. Personalized medicine, with its focus on the individual, emphasizes autonomy, but it critically depends on solidarity too, as we will see later.

As we move toward the kind of future envisaged here, being ultra-healthy does not mean languishing in some kind of perpetual vacation or even perpetual orgasm. We humans are a restless species. We are always looking to improve our lot in the world. The ability to change is freedom, and that sense of freedom is part of what is needed for contentment. We may feel cramped by the present, but we humankind always want to move on, to migrate, and to improve technologies, and not least the care of our health.

OUR ETHICALLY THERMODYNAMIC FUTURE

So we believe that consideration of the long term is important in formulating the ethics of more imminent future medicine. There are challenging ethical issues in what we mean by life and well-being. However, these ethical and philosophic matters seem to lie far outside the realm of anything that information science and technology can contribute other than, it seems, creating in the first place the opportunities and risks that need to be addressed. But this is not entirely true. There are insights from information science and related disciplines of mathematics physics which give us a rock of cool logic on which we stand and examine the liquid larva that is streaming past us and that will solidify into the future. This is important when the future being considered is still too controversially alien for our current “gut feelings” and everyday frames of reference to apply. The wisdom of the ancients also cannot help us,
unless part of that wisdom can be re-expressed in modern mathematical terms. Strictly speaking, the following is not formally required to appreciate the benefit of information science, but it somehow really seems to help: many modern physicists and mathematicians, such as Gregory Chaitin and Charles Seife, would even hold that everything is information, an intellectual and no less quantifiable extension of Einstein’s proof that all matter is energy ($E = mc^2$). That includes life, as illustrated by the following, but which, it must be confessed, raises its own new ethical issues. Our great grandchildren may decide to opt out in hope of rebirth for a better era and leave all relevant details for their reconstitution, such as their DNA sequences and brain pattern connections, in digital form. A person who might delete such a record could be tried for murder, or another could steal it and copy or modify the information to some dark, or even intended good, purpose, such as removing the genetic defects and enhancing others’ performance. These are complex ethical issues outside our present frame of ethics.

Our answers may come from our consideration of the sibling sciences of thermodynamics and information technology, and include even cosmology. Our medical future may be on a grand cosmic scale. Earth alone, or any future new Earth, will not last forever. As we move forward and evolve, or sicken and die, we all play that life-and-death game within the current laws of what we currently call physics. Entropy and disease are intuitively intertwined. A prominent nineteenth century scientific-philosophical theme since the industrial revolution has been the inevitable increase of entropy, or disorder and decay, in the universe. It is, at least statistically and overall, a force so fundamental that it is believed by many physicists to define the direction of time. Entropy may seem like a wooly concept when described as disorder and decay, but it can be measured by the methods of thermodynamics (the principles of heat engines, and indeed any system) just as much as quantities like energy, pressure, and temperature. Moreover we now know that an increase in entropy corresponds to a loss of information, so entropy is a kind of negative information. If dropping your computer somehow lost you one gigabyte of memory chip, its entropy went up by one gigabyte from that perspective. While that isn’t the unit that the steam engineers used, we could use it equivalently, with a single conversion factor. It also is why running massive computers to keep us alive and well, and away from disorder and decay, necessarily involves a compensating price in terms of heat production. The damaged computer got slightly hotter because the motion of the parts of the memory chip suddenly stopped accelerating smoothly together in a concerted way to the floor, and on hitting the floor, the memory chip started going off somewhat randomly in a less concerted way. Such a disorganized form of energy (motion) appears to us as what we call heat. In addition it seems impossible, at least in practice, to do computations without converting at least some organized energy to heat.

In fact doing anything is difficult without degrading something to heat, with the exception of certain idealized processes (including in computing) that are said to be fully reversible.
From such quantitative considerations we learn that life seems to reverse that process of disorder, at least a bit and at least locally. This is an important concept because it reveals an essence of health and healthcare, since without that constant reversal, we have disruption, disease, and ultimately death. We do know from modern thermodynamics that entropy is negative information, meaning that if the information in a system—such as us—goes up, the entropy goes down.

Yet animate things can look pretty messy and complicated. We need to distinguish the simple everyday dialectic of order and disorder from what is meant here. If information is associated with order, how can it be that the digital pulses encoded on a CD (compact disk) or DVD (digital video disk) can look pretty random. Crystals, on the other hand, have high order and low entropy. Who, however, would want to be something like a crystal of table salt (sodium chloride)? Such crystals are too regular and too frozen in space and time to contain any further information than that the crystal is sitting there with that regular structure! Such regimented lack of disorder seems closer to death than life. The great theoretical physicist Erwin Schrödinger put the relevance of crystals very well. He said that the basis of life and heredity had to be some kind of aperiodic crystal, that is, without a repeating pattern. By this he predicted what we now call DNA. The trick is to understand that the kind of order that interests us is paradoxically and typically a disordered looking mess, but it is one particular disordered looking mess that serves a particular reference point, goal, or purpose, in regard to which we say it has meaning.

The astute reader will note that mathematically and philosophically some fundamental questions remain as to what really is information, what is randomness, what is knowledge, what is consciousness, what purpose means for any string of binary digits, what is a computer program, can it be conscious, what are data, and what is output. These and other relevant questions still defy the best brains, and are far-reaching, intertwining with issues of the apparent direction of time and the nature of space. Ultimately they may turn out to be unanswerable or to have incomprehensible answers, because we are asking the wrong question.

In promoting and maintaining this reversal with health and well-being, what forces will fight that battle for us? Since entropy is negative information by the physicist’s own definition, and if information is something to do with good and entropy something to do with bad, a reasonable answer is that IT will fight that battle for us. IT versus the forces of darkness, the great game of the universe, with human healthcare at stake, is not a bad background story against which to touch on the sometimes seemingly drier issues such as of health insurance and billing systems, federated data bases, data analytics, and computer-aided compliance. They are all essential challenges or tools on the road to a grander vision.

Thus big picture puts the sanctity of life in perspective. While our views on entropy have stayed solid since the nineteenth century, our other views of
cosmology have changed throughout the ages. These days, and since the mid to late-twentieth century, cosmologists believe that the universe began with the Big Bang roughly 12 to 15 billion years ago. Then, some five billion (i.e., a five thousand million) years ago, the hot Earth cooled and life began. That is a reasonably measured pace of interesting events: it seems sobering to many to think that terrestrial life is something between as much as a quarter to a half of the age of the entire universe. Those of us who subscribe to a literal interpretation of the Old Testament Bible like to think that humans are about as old as the universe, and of central importance in it, and so find the new view disturbing. Others may take comfort in believing that the universe is vastly older, perhaps eternal, and life started only in the last tiny fraction, which the latest evidence shows not to be so. But this view also means that if intelligent life took so long to appear, it may be rare. In that view we may be unique, as life is precious. It behooves us to live on, and ultimately that may be among the stars.

**STEPS TOWARD A GOOD END?**

In the late twentieth century such thoughts about computers ensuring our survival were incorporated by some scientific philosophers into visions of the very distant future. This idea of healthcare ultimately placed in the context of computers that will sequester the universe and ourselves with it, will be resurrected in Chapter 10, along with mention of such thinkers as the Jesuit teacher Paul Teilhard de Chardin’s thesis on the “Omega Point,” and other thinkers specializing in eschatology, the destiny of the universe, and see a role for humankind in that.

Probably one of the best known contemporary works by a physicist addressing these issues is that of Frank J. Tipler, with the remarkable title of *The Physics of Immortality: Modern Cosmology, God, and the Resurrection of the Dead* (Doubleday, 2007). Tipler feels that cosmology and what is effectively transforming the universe by, and to, computers, will give us, and all the dead who ever lived, a second chance. It is, in effect, a rather extreme Christian physicist’s view of healthcare IT on the cosmological scale. But suppose he is wrong; how much time do we, or rather our descendants, have before death holds dominion over everything? And if he is even half right, how much time do we have to secure our immortality? We opened this chapter with consideration of how the pace of life, in every interpretation of that word, quickens. But this is not so of the cosmological stage on which the game of life is acted: here the reverse is true. In the first $10^{-43}$ seconds, an atom-size entity explodes and space is created. In the first $10^{-32}$ seconds, which is incredibly slower than the above step, quarks, electrons, and fundamental particles are formed. Atoms form in 300,000 years, and in a billion years the stars form, and ten billion years later life appears. The stage on which we are players now changes the scenes ponderously slowly, and increasingly slowly, compared with the speed at which
the actors change and the plot develops, and the speed of that change increases. It is as if life feeds on the pace of the universe, diminishing it to its own ends. But ultimately if Tipler and others are right, living entities will control everything, and not only move the scenery but redesign the scenery. As an evolving complex system, we are moving faster and faster than the universe of which we are made. Looking even a million years in the future the work ahead seems too huge and incomprehensible a task, but we still have billions of years to get it right. That is, as we used to say during the Cold War, assuming that we do not “blow ourselves up first” or, in contemporary terms, destroy our ecosystem.

Now to start our journey in this book, we have to go back and retrace our steps. We need to discuss in more detail what makes us the humans, and the patients, that we are, with our different tendencies to various diseases, and our different responses to herbs and drugs. We need to consider where common infectious diseases really came from. This story goes back only on a few tens of thousands of years, to the single human beings who left descendants today. Based on analysis of mitochondrial DNA (mitochondria are cellular organelles passed down through the female line), Eve is the name given to the woman who is defined as the most recent common ancestral mother for all currently living humans. She is believed to have lived about 140,000 years ago in an area that is now Ethiopia in Africa. The time she lived is calculated based on understanding of the rate of changes of her descendant’s DNA, as perceived by genetic differences in the current living branches of her family tree of descendants. Her “significant other” was not the genetic Adam of us all. By analyzing Y-chromosomal DNA from people in all regions of the world, geneticist and anthropologist Spencer Wells, who is leading the Genographic Project, has concluded (not uncontroversially) that all humans alive today are descended from just one male who lived in Africa around 60,000 years ago (see the bibliography at the end of the book.). And just about that long ago, a mere blink in evolutionary time, most of us came from just a tribe or two.