Chapter*One*

Transformational Technologies

Futurists and Scientists Look into the Future

Futurists tend to be rather unusual folk whose chosen career, to study trends and factors they believe will influence and shape our future, must leave them with a sense of anticipation and, possibly, frustration. From their perch above time, futurists make deductive predictions on what lies ahead for humankind – sometimes right, most often wrong.

We do confess to have studied the work of some of these futurists, particularly those who write about the *convergence of technology and biology* and how it will dramatically enhance and transform our lives. This is largely because we have been seeking validation for our own strong opinion that this convergence is real and that its impact is under-appreciated. The disruptive effects of the fusion of raw computing power and biology are going to be considerable, and are a key feature of this book.

We have also, perhaps less exotically, studied the works of leading scientists in various fields of technology, physics and bioscience to develop a deeper understanding of what is really going on in science generally, and what lies in store for us humans in the next 10 to 30 years.

Some truly breath-taking innovations are just about to be commercialized, and the effect of these will allow us to live longer, healthier and happier lives. Although we will begin to see some of these new technologies within five years, we will have to wait up to 20 years for others, but of course we are all going to live longer, so that's not such a stretch.

As we share our findings, we hope that the technologies we highlight will blow you away, as they have us, and convince you

COPYRIGHTED MATERIAL
http://www.pbookshop.com

that "the future is already here, it's just not very evenly distributed".[1]

We cannot state often enough how fortunate and privileged we are to be living in the most incredible period of humankind's existence on earth. Already, many things once confined to the realms of science fiction have become fact. Things that did not exist at all not long ago, such as mobile phones and the Internet, are now indispensable (sometimes addictively so) to our way of life.

You might reasonably ask why the biological revolution we are forecasting did not take place earlier, say 5, 10 or 20 years ago. The short answer is that it has taken this long for computer processors to be able to handle the complex work required to study molecular biology and nanotechnology in a productive way.

Allow us to elaborate: one of the futurists whose work we studied is Ray Kurzweil. Mr Kurzweil published a book entitled *The Singularity is Near* (2006). In this book he uses historical data to build a solid case that technological development is growing at an exponential rate. Many people are familiar with "Moore's Law", a trend first proposed by Gordon Moore, the co-founder of chip maker *Intel*, which states that computer processing power doubles every 2 years, and the price halves.

http://www.pbookshop.com

MATHEMATICS FOR BEGINNERS

If you are not too big on mathematics, the vertical scale in Figure 1 is a logarithmic scale, that is, the values are increasing by an order of magnitude, from 100 to 1,000 to 10,000, rather than linearly, such as 100, 200, 300. That is why the line on the graph appears straight. If we were to plot the same points on a linear scale (100, 200, 300 and so on) the line would be exponential and virtually vertical within a few years and we would not be able to fit the plot on a page.

[1] A quote by William Ford Gibson, an American-Canadian speculative fiction novelist.

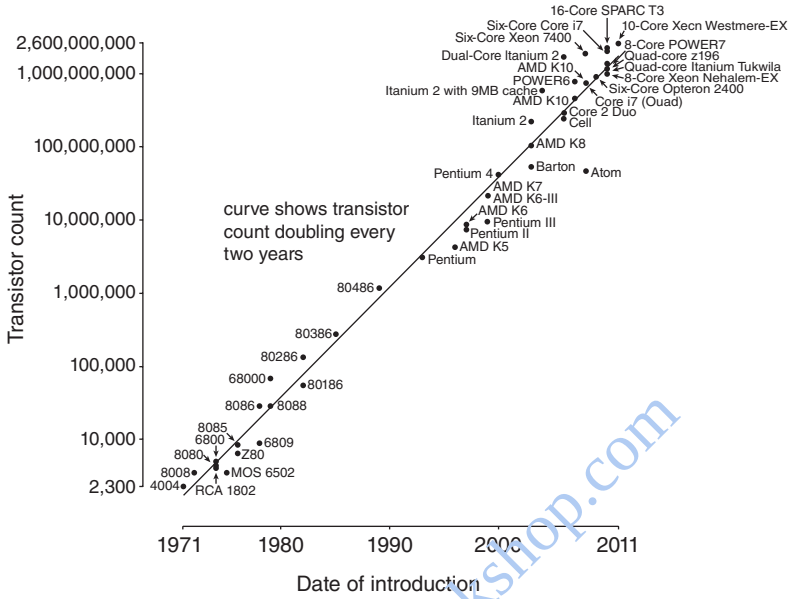

Figure 1: Microprocessor transistor counts 1971–2011 and Moore's Law. Source: Wgsimon *for Wikipedia* (http://en.wikipedia.org/wiki/File:Transistor_Count_and_Moore%27s_Law_-_2008.svg)

http://www.pbookshop.com

Moore first came up with his statement in a paper he wrote some 40 years ago, and it still holds true today. The logarithmic chart in Figure 1 displays the number of transistors in a chip since the early 1970s. This has been remarkably consistent with Moore's Law and there is no reason why it will not continue for the foreseeable future, especially as quantum physics and other technologies work their way into computing.

Sceptics argue that we are within a decade of hitting the physical limitations of Moore's Law – that is, it will be impossible to etch transistors smaller than about 30 atoms across and so at that point Moore's Law will cease to hold true. Forecasters estimate that we will reach this limitation by 2020. Technically, they are correct; there will probably be a wall by around 2020 in terms of flat wafer silicon transistors. But Moore's Law is not limited to the current technology of manufacturing silicon chips; it is about the doubling of processing power every 2 years and in that respect we will see

new innovations that will allow us to sustain the advances posited under Moore's Law well beyond 2020.

In fact, this is already happening today: in May 2011, Intel announced that it will start mass producing its *Tri-Gate* transistor chips in early 2012. These chips will contain the world's first three-dimensional transistors, which allow them to be packed closer together and Intel claims that they will run 37 per cent faster and use up to 50 per cent less power. These new chips alone will allow Moore's Law to be sustained for at least another couple of years.

In addition, in March 2010 *IBM* embarked on a four-year project with two Swiss universities to develop three-dimensional microprocessors (different to Intel's three-dimensional transistors). By stacking the processors on top of each other, the distances that information needs to travel fall to 1/1000th of the existing two-dimensional chips, while allowing up to 100 times more pathways for information to flow. The biggest challenge has been developing an effective way to cool the stack of red-hot chips, which they have successfully done using a complex water-cooled system. In the same way that big cities tend to start building upwards when they run out of space, chips will also be layered in a multi-storey fashion.

In 2008 Professor Eby Friedman led a team at the University of Rochester that successfully created the world's first three-dimensional chip. When asked if we will get to a point where we can no longer make integrated circuits any smaller, Professor Friedman's response was: "Horizontally, yes. But we're going to start scaling vertically, and that will never end. At least not in my lifetime. Talk to my grandchildren about that." [2]

Then there are other developments underway outside the silicon world: an entirely new generation of computers applying an altogether new technology. These are called *quantum computers* and they potentially have orders of magnitude more processing power than the very best of their silicon versions. Although quantum computers are still in their infancy, a significant milestone took place in May 2011 when it was announced that *Lockheed Martin Corporation* was purchasing the world's first *commercial quantum computing* system to be installed at the University of Southern California. The computer

http://www.pbookshop.com

[2] Casey Research: http://www.caseyresearch.com/cdd/3d-computing-way

maker is *D-Wave Systems*, a privately held firm based in British Columbia, Canada. In November, the company's co-founder and Chief Technology Officer, Dr Geordie Rose, was named Innovator of the Year by the Canadian Innovation Exchange. This research is worth keeping an eye on because it may just leapfrog the remaining years of the silicon era and jump-start the quantum one.

By 2020, computer processing power is expected to reach that of the human brain, according to Kurzweil (2006). This is not to be confused with equal intelligence – he predicts this to happen by 2045, an event often referred to as the *singularity*. Futurists define this as being the point in time when *Artificial Intelligence (AI)* surpasses that of human intelligence, making AI computers/machines the smartest and most capable "life forms" on earth.

The term *singularity* is borrowed from physics and means a point of infinite gravity where nothing can escape, not even light. Black holes are singularities. The concept of a technological singularity dates back to 1958 during a conversation between two renowned mathematicians, Stanislaw Ulam and John von Neumann (both worked on the Manhattan Project to develop the atomic bomb).

The thought of a singularity hypothesis coming true is overwhelming on many levels, especially as it is likely to happen within some of our younger readers' lifetimes. The most significant inference of this event is that it marks the point in human existence beyond which we no longer need to invent or make anything else ever again. Think about that: if AI is smarter than the smartest human on the planet, why would we need to use traditional brain power to do "work" anymore?

Another futurist, Dave Evans, is employed by *Cisco Systems*, the American giant technology firm, to gaze into the future and advise the firm on the threats and opportunities ahead. Mr Evans has had this job of Chief Futurist since 1990 – certainly forward-thinking and unusual on Cisco's part!

One of the oft-cited salutary lessons in the tech sector of what happens if you do not anticipate the future correctly is the case of *Microsoft*; it dropped the proverbial ball by underestimating the rapid adoption and impact of the Internet. This opened the door for *Google* to step in and take centre stage. Microsoft remains on the back foot and has yet to re-establish the dominant market position it once had. Its share price has not changed much in 10 years,

http://www.pbookshop.com

having increased over 100-fold over the 10 years preceding the dot-com bubble crash in 2000.

In 2010 Cisco's Evans published a list of his top 25 technology predictions. Here are the four that we believe to be the most significant:

- In the next 10 years, we will see a 20-fold increase in home networking speeds.
- By 2050 (assuming a global population of 9 billion), US$1,000 worth of computing power will equal the processing power of all human brains on earth.
- Within two years, information on the Internet will double every 11 hours.
- By 2030, artificial implants for the brain will be possible.

There's no doubt that humankind has achieved some incredible things even in the last 50 years, but to put into perspective the era of rapid change that we have entered, we paraphrase Mr Evans who said in an interview about the future that "In the next 50 years, 95 per cent of everything we know as a species will be discovered".[3]

So the exciting stuff is only just beginning. . . .

In a *post-singularity* world, we would be able to utilize AI to make further technological advancements at a far greater pace than humans would ever be capable of. After all, machines can work non-stop, needing no lunch breaks, coffee breaks or sleep and so on, they can communicate far more efficiently than us and they can build smarter, purpose-built machines to tackle each new challenge they are tasked with.

Most importantly, AI machines would work for free, apart from their energy consumption. Their prevalence would usher in a new post-capitalist era; a golden time in which our standard of living will be dramatically improved and one in which money would slowly cease to have the same meaning or value as we put on it today.

But all that is many years beyond the singularity, and too far into the future to try and understand the consequences of just yet. In fact, as we have said earlier, we think Kurzweil (2006) and his ilk

http://www.pbookshop.com

[3] http://blogs.cisco.com/news/cisco_futurist_discusses_internet_of_things_tech_predictions_more_on_talk2c/

are somewhat too optimistic – and that's coming from us, who are bursting with excitement!

Sure, there are those who call the singularity the beginning of the end of humankind (giving rise to apocalyptic scenarios as portrayed in films such as *The Terminator* and *The Matrix*), but we and others hold a more optimistic view.

Most likely, by the time the singularity occurs, humans will already be heavily imbedded with bioscience enhancements, and so we will not be "pure" humans anyway. These enhancements could be in the form of *brain boosting implants* (for instance, for augmenting language or mathematical capabilities), or they could be injections of *nanobots* into the bloodstream to repair damaged tissue, or they could even be biomechanical enhancements and prosthetics to replace damaged or amputated limbs.

So humans are probably going to be *cyborg hybrids* by some distant date in the future, and there will be no clear divide between "them" and "us", that is, pure organic humans versus AI computers.

The previous paragraph may generate scary images of robots patrolling the streets and intimidating "basic" humans, but we need not picture these bionic enhancements to humans as clunky, robot-like limbs; think more of Steve Austin[4] rather than *Robocop*. In all probability, we will still look and feel human, just enhanced versions of ourselves – smarter, healthier, stronger and self-repairing. Who can object to that?

We have already started our journey along this hybrid path, albeit in an experimental capacity – humans have begun to incorporate bionic features and computers have begun to incorporate some human features.

Kevin Warwick is a pioneer in the field of *cybernetics* and a professor at the University of Reading in England. In 1998, Professor Warwick had a small chip transponder implanted in his forearm that allowed his movements to be tracked within his department at the university. Various devices were programmed to detect and react to his presence as he moved around. For example, lights and

http://www.pbookshop.com

[4] Steve Austin was a fictional character in the 1970's TV series "The Six Million Dollar Man", played by Lee Majors.

heaters would automatically turn on when he entered a room, and his computer booted-up when he walked into his office. Today, this may seem basic and unimpressive, but in 1998 it was groundbreaking stuff.

Squeamishness aside, a tiny (rice grain size) device implanted just under our skin could come with a multitude of convenient applications. For example, it could serve as our passport/identification, a secure e-wallet that is networked to our bank accounts, and it could contain all our medical records and perhaps be programmed to call for medical assistance if it senses any anomalies in heart rate or blood pressure, giving our exact location at the same time.

Take it one step further and we could have all the current features of a smart phone, including broadband Internet, embedded within us, allowing us to search and retrieve information at will. Fingers are a slow and awkward interface with computer devices and limit the rate at which we can communicate. Keyboards are a legacy from the days of the typewriter; it would be far more efficient to interface with a device through voice or even thought, and we'd still have our hands free to do other things.

But really to have thought-controlled devices, we would need somehow to connect our brain with a computer. Experiments to do just that have already taken place. Following the simple implant procedure in 1998, Professor Warwick underwent another procedure in 2002, as a result of which he technically became the world's first *cyborg*. This time the surgery involved implanting a device into the nerves of his left arm that connected his nervous system to a computer. One of the truly amazing experiments he carried out while wearing the implant involved a robotic hand located some 5,500 kilometres (3,500 miles) away. Professor Warwick went to Columbia University in New York and "connected" his bionic hand to the Internet. Across the Atlantic at the University of Reading, he had a robotic hand also connected to the Internet. Connected to each other in this way, Professor Warwick succeeded in getting the robotic hand to mimic his own hand's movements in real time.

These and other such experiments serve as examples of the inevitable converging paths of biology and technology. Although it is fascinating to learn about what awaits humans in the long-term future, we are more interested in the 5 to 15 year time horizon.

http://www.pbookshop.com

Where are we with AI today?

Based on the current logarithmic path of development (shown in Figure 1), we are within 20 years of being able to get a computer to pass the *Turing test*, which is an assessment of AI that renders it indistinguishable from communication with a human, in a verbal not visual manner. In other words, if a human were speaking to another voice over the phone, that human would not be able to determine whether she is speaking to another human or an AI machine.

AI was once a distant concept portrayed only in Hollywood blockbuster films, but tangible new breakthroughs are arriving with increasing frequency, and as we have mentioned previously, progress is exponential due to Moore's Law. One of the early AI milestones took place in 1997. It involved a custom-built computer by *IBM* called *Deep Blue* that succeeded in winning a chess match against the then world chess champion, Garry Kasparov.

The thinking required for chess, be it human or artificial, is mathematical, logical and empirical. Players need to run through multiple scenarios and sequences of moves before selecting the most favourable one. This does not require any non-chess knowledge or the capability to understand speech and respond appropriately in natural language. So Deep Blue, although impressive at the time, had a very limited sort of intelligence.

It took almost another 15 years before the next major breakthrough in AI was made. Again it was by IBM, but this time it was a computer called *Watson* that in February 2011 successfully won on the popular American TV quiz show *Jeopardy*. Not only did it win, but it beat the show's two most successful and celebrated contestants. For Watson to win, it had to "hear" and understand the voice of the show's host, decide on an answer, buzz before the other contestants and "say" the answer. This was the first time a computer has been able to understand natural language and respond in the same. Furthermore, in Jeopardy the host does not ask a question but rather reads a statement. The contestant's response has to be in the form of a question. This may sound confusing if you have never watched Jeopardy before so here is a simple example:

The host would ask: "He's worth every penny as Alfred Pennyworth in *The Dark Knight*".

The correct answer would be: "Who is Michael Caine?"

http://www.pbookshop.com

The answer is not that straightforward, especially for a computer. First, it has to look up Alfred Pennyworth (that's the easy part as it had many terabytes of information stored on its servers); the search may return that he was the butler in the Batman comic books and subsequent films. Second, Watson has to "deduce" that the "Dark Knight" is the name of a Batman film and this nuance is a potential stumbling block because the host did not say ". . . in the film called *The Dark Knight*". This is reasonably obvious to us humans and extremely obvious to Batman fans, but not so simple for AI.

Watson is by no means flawless – for example, one of the gaffes it made, which would never happen with a human contestant (even an unintelligent one), was to give a response that another contestant had just given for that question and was told it was incorrect. Watson cannot "hear" the other contestants, a feature that its developers will no doubt incorporate into any future upgrades.

Watson is clearly many years from being a household item. For instance, its internal memory is 16 terabytes (that's 16,000 gigabytes) – a reasonably fast home/office computer in 2011 has around 8 gigabytes of memory – so Watson has 2,000 times more internal memory capacity. With today's technology, Watson is still an extremely bulky machine; its servers occupy 10 racks, which is virtually an entire room (see Figure 2). But the main reason why we are unlikely to see Watson in people's homes any time soon is its price tag – the estimated cost of developing Watson is rumoured to be US$1–2 billion.

Nevertheless, it's a wonderful demonstration of what is possible with today's technology, and with Moore's Law at work, today's processing power will increase fourfold in just three years, and so faster, cheaper, smaller is the unrelenting mantra that is driving us towards the singularity.

Even Watson's "brain" power today has incredible capacity to serve society, given the right application, which is what IBM is currently busy trying to figure out.

One such application for Watson could be in the field of medicine; Watson's virtually limitless data storage capability combined with its incredible recall ability makes it a natural diagnostician. Imagine if Watson's memory contained the medical history of every patient, as well as all medical knowledge known to humans

http://www.pbookshop.com

Figure 2: IBM's *Watson* supercomputer.
Source: Clockready for Wikimedia Commons

http://www.pbookshop.com

so far, including experimental treatments. If provided with all the symptoms of a patient with a disease that doctors have been unable to diagnose correctly, Watson could come up with a few likely diagnoses as well as suggest the best course of action given the results from thousands of previous cases.

Better still, if Watson had an additional module installed that allowed it to extract all the information it needs from a patient's blood or tissue sample, it could be an all-in-one medical provider. Taking it one step further, Watson could also be programmed to find certain patterns in disease and treatment. Its vast database would be able to pick up trends and patterns that may be too subtle for humans to detect.

In fact, IBM has already entered into a research agreement with a company called *Nuance Communications*, to explore, develop and commercialize Watson's advanced analytical capabilities in the healthcare industry. Nuance Communications (NASDAQ: NUAN) has a market capitalization of over US$7 billion at the time of writing and is trading at almost 50 times its trailing earnings, so clearly the market strongly believes in the huge commercial opportunity that lies ahead in this sector.

The law would be another wonderfully powerful application for Watson. Totally impartial, Watson the lawyer, or perhaps more controversially, the judge would have access to every case in history as well as all the world's laws and legal systems. Think of how quickly and efficiently cases could be heard and resolved. Most of all, think about the potential billions of dollars saved in legal fees that would otherwise be racked up by using human lawyers!

Incidentally, the fastest computer in the world at the time of writing this book in 2011 is in Kobe, Japan. It is called the K computer and it was developed by Fujitsu. It guzzles almost 13 megawatts of power to run, which is roughly the power used to run 125 car engines.

http://www.pbookshop.com

Consciousness

As the processing power of computers continues to increase and AI slowly progresses from being narrow (i.e., very good at a specific task) to strong (i.e., very good at many things), there will come a time in the next few decades when a computer or machine will experience consciousness. It will then become a *sentient* being – a *synthetic* life form derived from technology. Later in this chapter we discuss *organic synthetic* life forms, so there will be two types of synthetic life forms, and humans will likely be sitting cosily in the middle.

But is consciousness an easy thing to measure? After all, how do we know we are conscious or how do we measure consciousness in others? Through our senses, we acquire and store memories, facts, experiences, knowledge, skills and apply our powers of deductive reasoning and learning. If an artificial life form were to acquire these qualities, would that constitute a form of machine consciousness? It seems somewhat conceptual given that this scenario is still some 30 plus years out, but we believe the answer would be yes.

Once these *synthetic life forms* develop a consciousness, they will eventually need recognition in our society and they will probably expect rights and fair treatment. We will need to find a way to accommodate these new species peacefully and we will have to implement new laws for them. Fortunately that is too far into the future for any of us to have to try and figure out just yet.

The Convergence of Technology and Biology

Author and former *Bell Labs* engineer Andy Kessler published a book with the rather amusing title of *The End of Medicine: How Silicon Valley (and Naked Mice) Will Reboot Your Doctor* (2007). This book was inspired by the rather antiquated medical examination he had when he went for a full body check-up shortly after a close relative suddenly died of a heart attack, and a close business associate was diagnosed with cancer.

In most diseases, especially cancer, the earlier it is diagnosed the higher the chances of survival, which is what prompted Mr Kessler to go for a full medical exam. But he quickly realized that diagnostic medicine was still in its infancy and lagging behind technology. The anecdote he uses to illustrate this point is when his doctor took out a rubber hammer and tapped it on his knee. He could not believe that this practice still went on in the 21st century. As a former microchip designer, he felt that technology was just a few years away from transforming the field of medicine (Kessler, 2007).

Every year microchips become smaller, faster and cheaper and we are at a point now where the chips are small enough (less than 20 nanometres) to be attached to antibodies and injected into the body to detect various diseases at an early stage. At Stanford University, experiments have been successful in detecting ***breast cancer*** in mice by injecting nano-probes into their bloodstream. The exact location of the cancer cells (in three dimensions) can be found, so that these cells can be irradiated, excised or frozen off when they still number just a few hundred thousand and have not begun to spread elsewhere in the body.

In the next 5 to 10 years, this procedure will be part of a routine check-up and that is where Mr Kessler sees the transformation in medicine – a shift away from treating a disease to one of detecting it early enough before it spreads to other organs and becomes life-threatening (Kessler, 2007). Such a shift in how medicine is practised will save billions of dollars in the long run and free up valuable medical resources. This will mean that our quality of life will improve dramatically and we will have very few medical "surprises" as we get older because all diseases will be picked up in their very early stages and treated effectively.

http://www.pbookshop.com

What is DNA?

DNA is the commonly used abbreviation for deoxyribonucleic acid, which is a polymer or long chain molecule found inside each living cell. DNA contains all the genetic instructions, or blueprints, for the development and functioning of all living organisms.

Did you know that if you were able to lay out a human's DNA flat on the ground, it would measure over 183 centimetres (6 feet long), yet it is coiled so tightly that it fits inside the nucleus of a single cell.

Within just a few years, humans can expect to live dramatically longer lives because we will be able to grow new organs from our own DNA, so there will no longer be the risk of the body's immune system rejecting a donor organ. Also, there will not be a long waiting list for a donor. Within 15 years, we can also expect to have nanobots permanently in our bloodstream working with our own immune system on the lookout for threatening germs, cancers and viruses, while at the same time restoring our living tissue to its optimal state.

Just about all published works that make some sort of prediction about humans' future discuss a convergence of the sciences. *Nanotechnology*, *biotechnology* and *information technology* will become virtually one field. This convergence will provide humankind with unprecedented benefits in terms of healthcare, convenience and quality of life.

http://www.pbookshop.com

The advent of synthetic biology

As a consequence of the human pursuit to decipher DNA, a relatively new scientific field has emerged: *synthetic biology*. The best way to describe synthetic biology is to first consider all living cells as information processors, with DNA as the programming language for those cells.

For several decades now, scientists have been able to engineer genetically or modify the *genome*[5] of organisms such as crops to, for

[5] An organism's entire hereditary information.

example, create a strain of wheat that grows faster and is resistant to diseases. Synthetic biology goes one step further than simply altering existing genomes – it creates them from scratch. In other words, synthetic biology is the science of creating entirely new life forms . . . and it is no longer a theoretical science.

After more than 10 years of work and a cost of US$40 million, scientists announced in May 2010 that the world's first synthetic life form had been "born". Heading up the team of scientists was Dr Craig Venter (the man behind the first private company to sequence the human genome) who announced that he and his team of some 20 scientists created a bacterial cell controlled by a chemically synthesized genome; that is, its DNA was made from scratch.

This truly incredible milestone occurred almost 60 years after the discovery of the double-helix molecular structure of DNA by James Watson and Francis Crick. But it happened only four years after the completion of the sequencing of the first *human genome* (the last *chromosome* sequence was published in the scientific journal *Nature* in May 2006). This is yet another illustration of the rate of accelerating returns and how we can continue to see progress push forward at an exponential pace. The sequencing of the first human genome in the early 2000s was just the beginning of the race; the use of the technology is in its infancy and will evolve extremely rapidly from here.

Synthetic biology will eventually end up being one of the world's biggest industries and we do not think that we are exaggerating when we say this. Think about the limitless applications – life forms could be customized to serve a specific purpose, such as creating organisms that feed on radioactive or toxic waste and render it harmless. It will be possible to synthesize organisms that feed off certain unwanted pollutants in our atmosphere, perhaps carbon dioxide, methane or sulphur dioxide. The possibilities are endless as we refine our DNA "programming" skills.

Scientists around the world are busy sequencing the *base pairs* of organisms. The human genome comprises some 3 billion *DNA base pairs*. For the past 20 years, *GenBank*, an open access sequence database has been accumulating sequencing information for all types of organisms. Thanks to the efforts of laboratories from all over the world, GenBank's database is doubling in size every 18 months (Moore's Law at work again). Additionally, there is the

http://www.pbookshop.com

European *Molecular Biology Laboratory (EMBL)* and the *DNA Bank of Japan*.

As of February 2012, there were over 137 billion bases in 149.8 million sequence records in the database from over 100,000 distinct organisms. Of course there is still a massive amount of work to do to uncover all the secrets of the genome; only when that happens will it become easier to move from knowledge about what a specific gene does to creating viable therapies for all diseases. This is particularly the case where multiple genes are implicated in a disease, such as in cancer and ***heart disease***. The "book of life" is open but still hard to read.

Personalized, or precision, medicine

Another new field of medicine that is developing is *personalized medicine*. Our deeper understanding of our genetic and molecular make-up means that the treatment we receive can be tailored to us specifically. This would result in the treatments prescribed being more targeted and more effective than the existing traditional "one-size-fits-all" approach to medicine.

Personalized medicine is already being used to treat certain types of diseases. A simple example is in the treatment of patients who suffer from blood clots. An effective treatment of this disease is to administer a blood thinner called **warfarin**. Historically, doctors and their patients go through a process of trial and error to determine the correct dose to administer, because each person metabolizes the drug differently. A dose too high or too low can be equally dangerous, and so patients can now undergo a genetic test that determines the rate at which the drug would be metabolized, resulting in the patient receiving the correct dose the first time.

http://www.pbookshop.com

Getting to know yourself . . . genetically

Mass customization is the way medicine is heading. No longer will one drug be used for one disease for all sufferers of that disease; there will be a limitless combination of medicine available to treat each person's unique disease to account for the fact that we all respond differently to various drugs. All we need is our *genetic code* – our blueprint – and getting our hands on this is getting cheaper by the day.

Each human has between 20,000 and 25,000 sets of *genes*, the exact number is not known. The things that make us different from one another are the result of the very small variations in these genes. When we say small, we mean tiny – all humans share 99.5 per cent of their DNA, so just that half a per cent accounts for all the variations in us as a species. Incidentally, we are not that different to chimpanzees, genetically speaking of course; we share 98.5 per cent of our DNA with them.

As recently as 2008, the cost of sequencing a human genome was over US$1,000,000. By 2011, that number had plummeted to a little over US$4,000 – that's even faster than Moore's Law. By the end of 2012, that cost will likely fall to below US$1,000, at which point it will almost certainly start to become a standard part of a full medical exam or check-up.

There is an alternative to sequencing an entire human genome called *genotyping*. Genotyping is an efficient and affordable alternative to *genome sequencing* because the process only involves looking for variations in individual base pairs. These variations are commonly referred to as *SNPs* (pronounced "snips", which stands for *Single Nucleotide Polymorphisms*). There are about 10 million SNPs in the human genome. These SNPs are linked to specific diseases and commercial services attempt to use them to predict the chances of contracting specific diseases.

There are several companies offering human genotype services, one of which is called *23andMe* (www.23andme.com). The 23 obviously refers to the 23 pairs of chromosomes that we each have. It is still privately held and was founded in 2006 by two women, Linda Avey and Anne Wojcicki, the latter being married to Google co-founder Sergey Brin.

At the last visit to the 23andMe website, they were offering a US$99 deal to genotype your DNA. All you have to do is post them a sample of your saliva. After six to eight weeks, they will email you to let you know that your results are ready on the website. You then simply login and view your report.

The report summary is presented in a neat four-quadrant format (you can visit the website to see a sample):

- The first quadrant is your predisposition to certain diseases – a percentage indicating the average risk and one for your risk of, say, ***colorectal cancer***, Alzheimer's, ***asthma*** and so on.

http://www.pbookshop.com

- The second quadrant is your carrier status, that is, whether your genes carry diseases such ***cystic fibrosis*** (caused by a mutation of the CFTR gene) or ***sickle cell anaemia***.
- The third quadrant is a list of your traits, such as hair and eye colour or whether you are lactose intolerant.
- The fourth quadrant is a list of pharmaceutical drugs and your responses to them if you were to take them.

23andMe also have an ancestral lineage offer so you can find your global heritage, distant relatives and so on. It might not offer any health benefits but it is fascinating to learn about nevertheless.

As the technology improves, these reports will become more comprehensive and more accurate. Chances are, by the time you read this book, this will already have happened. And the cost will no doubt have gone down too. This marvellous technology will save millions of lives in the future and billions of dollars in healthcare costs as preventative medicine or early treatment of a disease is both more effective and much cheaper than treating a disease that already presents symptoms.

http://www.pbookshop.com

Tailor-made body parts

There have been a number of films and books released on the subject of cloning including *The Island* (2005), *Never Let Me Go* (book 2005, film 2010) and *The Sixth Day* (2000). All these works share the premise that at some point in the future, humans will resort to cloning themselves so that if accidents or diseases were to injure or damage part(s), they would be able to harvest their clone's organs or even "transplant" their mind to their clone's body.

These would be the ultimate life insurance policies but given how the biotechnology industry is progressing, we think it an unlikely scenario for the future. That is because by the time we will have developed the technology to clone humans, we will certainly possess the technology to clone or grow individual body parts and organs independently. With the availability of this technology, why would we choose to replicate an entire sentient being for harvesting specific body parts if we can grow these body parts in isolation outside a human body on demand? Additionally, cloning an entire human being unnecessarily raises all sorts of ethical and moral dilemmas.

Already there has been serious resistance and objections to using human embryos and *stem cells* in research; can you imagine the public outcry to human cloning? Biologically, cloning is the same as having two identical twins born who possess the same DNA; there would just be an age gap between the clones, whereas identical twins are born within a few minutes of each other. The clone would not be the same person in the same way that two identical twins are different people. But creating a clone purposefully and exclusively to sacrifice his or her life and body parts in the future for the "master" would raise ethical issues concerning human rights and equality among human beings. For all these reasons, we do not believe that it is realistic to expect to see *donor humans* anytime in the future.

Scientists, however, have been working on some ground-breaking technology for creating new organs with the patient's own cells. Doing so overcomes one of the major risks of organ transplants, which is rejection. This is common following transplant surgery where the immune system of the patient starts to attack the new organ and does not recognize it as being one of its own. Rejection is usually addressed by having patients take immunosuppressant medication for the rest of their lives. The side effect of taking such medication is a weakened immune system, which makes a person more susceptible to disease and infection. In some cases, the body rejects the new organ anyway despite the medication.

So would it not be great if we could be certain that the patient's body will not reject the new organ after transplant surgery?

To build a new organ without the risk of rejection, the patient's own cells are used. But these cells have no structure and are unable to develop into new organs, and so scientists have found a way to use a framework or "scaffold" from an existing organ to build a new one.

Dr Harald Ott from *Massachusetts General Hospital* discovered and perfected a method for stripping an organ of its own cells and then infusing the remaining scaffold with new cells from the recipient of the new organ. He does this by taking an existing organ from an animal, such as a pig (a pig has very similar organs to humans, both in size and complexity), or a cadaver and then soaks it in a chemical that strips out all the cells and leaves the proteins that comprise the scaffold.

http://www.pbookshop.com

At the end of this process, the organ looks like a colourless version of its former self. This *cell-less scaffold* is then seeded with cells from another body, such as that of the recipient of the new organ, and placed in an incubator for a few weeks to allow the cells to multiply and to populate the scaffold.

When we started writing this book, the most advanced procedure on a human using this technology was on a patient in Spain who had a severely damaged *trachea* (windpipe), due to ***tuberculosis***, making it very difficult for her to breathe. The Italian surgeon, Paolo Macchiarini, performed the procedure by harvesting a trachea from a cadaver and then stripping it of all its cells. He then seeded the *trachea scaffold* with the patient's own cells and incubated it for a few weeks to allow the cells to reproduce.

Once ready, he performed the procedure, which involved first removing the segment of the patient's trachea that was damaged and replacing it with the new part that had been grown in an incubator. The procedure was performed in 2008, making it the world's first such procedure. The patient recovered quickly and today leads a healthy, normal life.

Dr Paolo Macchiarini has since performed over 10 similar procedures, but always until recently with a cadaver trachea that has been seeded with the patient's own cells.

Then in July 2011, a new milestone was reached when Dr Macchiarini and his surgical team replaced a cancer patient's trachea with an entirely synthetic one. Scientists at *University College London* created a perfect copy of the patient's trachea and two main branches (bronchi) from a spongy polymer, providing the scaffold for the patient's own cells to grow. This is further evidence that demonstrates the pace and sophistication of *regenerative* and personalized medicine. No doubt additional breakthroughs will have been made by the time this book reaches your hands.

Performing these kinds of procedures using major organs, such as a heart, is still under development although Dr Ott's progress to date has been truly remarkable, having succeeded in bringing the heart of a rat back to life.

Dr Ott started with the scaffold heart from one rat (stripped of its cells); this was then seeded and incubated with the cells of another rat. The heart was then given an electrical signal, blood pressure and oxygen, that is, all the various things it would have in

http://www.pbookshop.com

its normal working environment, and after a week or so, the heart started to beat again. It is probably the closest thing to Frankenstein's monster humankind has achieved to date.

At the *Massachusetts Institute of Technology (MIT)* a synthetic alternative to using actual organs is being tested. *Bio-rubber* as they call it, can act as the scaffold material on which cells are able to grow. For example, bio rubber can be moulded in the shape of a human ear and then seeded with cells from the recipient of the ear. Once incubated, it can be transplanted with no risk of rejection from the patient.

Along these lines, scientists are also working on developing a *three-dimensional bio-printer* that can build the organic scaffold in the shape and size of the organ or body part required. The printer resembles a modern day inkjet plotter, the key differences being that the "ink" is a liquid made from a bio-rubber type material, and the printing needs to be done in three dimensions.

The printer would therefore build the structure from the bottom-up as the liquid solidifies. Once the scaffold structure is completed, it can then be seeded with living cells from the future recipient and incubated until ready for transplantation. Again, there would be no risk of rejection by the patient and no long waits for a donor organ/part.

http://www.pbookshop.com

http://www.pbookshop.com