# Face the Future

## What disruption and exponential acceleration means for you?

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# INTRODUCTION

**Pay attention! This is important!**

We say this to our children, but it often falls on deaf ears. That's because everything is important! The same thing applies for technological breakthroughs. We're constantly bombarded with news about new technologies that could either give us a bright new future or wipe out the entire human race. We have become desensitized to these proclamations. This notwithstanding, we're going to go out on a limb with this book…because it *is* important! The world as we know it is on a path towards unprecedented acceleration – and it's well worth your while to understand why and how this is.

We have both been fascinated by technology all of our lives, and exploiting technology and technological developments has always been an integral part of our work. We revel in the speed and diversity with which technologies evolve and have not shied away from making bold predictions about the future. However, it was through our encounter with Singularity University that we both discovered the explanatory power of the exponential perspective and how it has spread from computers and networks to a number of other fields. Since then, we have worked to heighten awareness of exponential growth. Exponential technologies represent both an opportunity and a threat for societies and companies, and have given numerous talks on this topic both in Denmark and abroad.

Collectively, we have participated in all the different programs at Singularity University. We consider advances in technology to be a source of wealth and peace and we endorse the University's mission to positively impact 1 billion people within 10 years. On a somewhat smaller scale, Jannick organized a 24-hour, 24-speaker conference for top executives entitled "The Year 2020", and Anders has founded and run an Entrepreneur Challenge – www.DanskeIdeer.nu – in 2014 and 2015. Over 200 young entrepreneurs competed with projects that could positively impact at least one million Danes. The two winners each won a scholarship to Singularity University. *DanskeIdeer.nu* is now a yearly event and has been expanded to incorporate a larger educational component in order to train all participants in exponential thinking for a full week.

As part of our mission to heighten awareness of exponential growth, we have started a consultancy business – DARE DISRUPT (www.daredisrupt.com) – where we monitor technological developments in a wide range of industries, help established companies to interpret their technological reality, and facilitate innovation processes based on disruptive technologies. Our goal is to *empower a million minds*…to create a million new opportunities and millions of new jobs.

Jannick B. Pedersen holds a Master of Science degree in Macro Economics and is Co-Founder and Chairman of the Board at DareDisrupt and FranklinCovey Denmark. He is a serial entrepreneur and an active business angel focusing on impact investing.

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# 1 FACE THE FUTURE

Humanity has continuously evolved: from hunter-gatherers to agrarian societies; from industrialization to today's Information Society. From our earliest beginnings, we have strived to improve our circumstances with the aid of technology, and each transition from one stage to the next has brought with it new narratives, new ways of organizing ourselves, and new political power hierarchies. The most significant difference between then and now is the speed at which things are changing. Homo sapiens spent 200,000 years as a hunter-gatherer. The rate of change during this period was so slow that changes were not noticeable by any single individual. Generation after generation we repeated ourselves, re-created what we had learned from our forefathers.

12,000 years ago, the Agricultural Revolution spread and supplanted hunters and gatherers over a period of a couple of thousand years. However, the Agricultural Revolution had more far-reaching consequences than just a new way of producing food; it brought with it towns, specialization and new technologies. Technological development consequently had a big impact on how we organized ourselves.

A mere 200 years ago, people's lives were transformed yet again by the technologies of industrialization. Industrialization meant using the power of machines instead of manpower, and the introduction of chemical production processes. The Industrial Revolution was a major milestone in our history and changed almost all aspects of people's daily lives. For the first time in history, the population as a whole experienced sustained improvements in its standard of living. Industrialization also meant explosive population growth, the organization of labor, and the establishment of city societies as we know them today.

What we today refer to as the Digital Revolution began sometime between the 1950s and the 1970s. This revolution represented the transition from analogue, mechanical, and electronic technologies to digital technologies. The first digital computer was developed during this period. During the 1990s, things went to the next level when the Internet became ubiquitous. The Digital Revolution, with the computer and the internet, has brought us to what we today call the Information Society. The Information Society has created a knowledge-based society which is important in itself and which has also had a significant impact on both the manufacturing and service sectors by, among other things, enabling the optimization of manufacturing processes and providing a foundation for mass customization.

However, the most interesting aspect of these developments is neither the Information Society nor the Knowledge Society: it's the digitization! Digital products have a number of characteristics that set them apart from the physical products we are familiar with today. A digital product can be replicated *ad infinitum* without any loss of integrity and can be transported to the other side of the world in a matter of seconds. Finally, the relationship between price and performance for digital products can be expressed by an exponential function. We have discovered that the number of calculations that can be performed by a computer (for the same price) doubles every second year. The smartphone in your pocket today is already several thousand times faster and over a million times smaller and cheaper than the world's fastest computer was in 1968. Realizing this is essential to understanding the evolution of digital products today.

A plethora of technologies are beginning to benefit from this development because they, too, have gone digital. This includes robots, artificial intelligence (AI), biotechnology, and 3D printers. By going digital, they can take advantage of the enormous computational power that digitization brings to the table. And when digitization becomes the driving force, things go exponential.

But exponential growth is difficult for people to understand intuitively. We overestimate the rate of change in the short term and underestimate it in the long term. We see possibilities and are thrilled in the short term, but overestimate the consequences. Three years later, we are disillusioned and discard our projections, only to be taken completely by surprise 10 years further down the road when change hits us like a freight train.

Artificial intelligence (AI) is also part of this development. Artificial intelligence is the ability of machines to make decisions based on input from their environments. Our ability to manufacture small, digital, and intelligent entities that can communicate with each other has now reached the stage where we can both embed and activate them in all the physical objects we surround ourselves with. The world we live in is awakening.

In the future, things around us will no longer be dumb and passive. They will begin to do our bidding and may even take the initiative on our behalf. The Digital Revolution in itself encompasses more than just the Information Society. This new era will be intelligent. We call it the Age of Intelligence.

At the first stage, your washing machine will start washing when there is a surplus of energy on the grid and the thermostat will turn on the heating when you approach your home. At the second stage, we will see somewhat more complicated things such as self-driving cars or digital bank clerks. At the third stage, your smartphone will notify you that you are about to become depressed or manic, and may even initiate treatment…

The same thing applies to biology. In the first phase, digitization makes it possible for us to visualize and understand correlations in extremely large datasets. We can "feed" an AI with so much knowledge and so many research results that it will be better than any doctor at making diagnoses and developing therapeutics. In the second phase, we can start to manipulate human DNA, and in the third phase, we can print new organs in a 3D printer and manufacture nanorobots that repair the human body from the inside…

In particular, the ability to manipulate DNA, the building blocks of life, makes for some very interesting perspectives. As a hunter-gatherer, mankind lived off nature. In the agricultural revolution, we learned to tame and control nature's fecundity through cultivation. For industrialization, it was no longer sufficient to control: we started to form nature. Digitization enables us to take the next step: we are now in a position to mold nature.

Change has always met with open resistance because it often eliminates people's livelihoods. Consider how a coachman must have experienced industrialization and a typesetter digitization. But the rest of us, who won't necessarily become redundant to start with, are also hesitant, presumably because the changes encompass more than just the technological advances. Incumbent institutions, such as political and religious hierarchies, cannot cope with the complexity that the new technologies introduce. Because of this, the new technologies can often be considered a threat to the very foundations upon which our society is built.

We hope that this book will provide you with a perspective from which to view technological developments – developments which will have a massive impact on our future. Not just in the guise of cool gadgets, but as fundamental changes to education, the workplace, and healthcare.

In the first part of the book, we explain the switch from linear to exponential growth. An understanding of exponential growth is the key to understanding the digital revolution, and is a central feature of the era we are entering.

In the second part, we describe developments within the fields of information technology, artificial intelligence, biotechnology, and nanotechnology. We will describe current developments in each of these four fields as well as the disruption they will cause.

FACE THE FUTURE

In the third and final part of the book, we will look at the implications of the technological developments for a number of key areas such as education, the workplace, the energy sector, and healthcare. We will also describe how technological developments led to the demise of Kodak and created new markets for companies such as Netflix and Amazon.

The book is primarily concerned with technology and, to a lesser extent, with the people that will use it. Our mission is first and foremost to make exponential growth visible and intuitive for the reader. By so doing, we hope to establish a framework for the subsequent, and very important, discussion of how we should face the changes.

Happy Reading!

# PART 1
# INNOVATION AND THE EXPONENTIAL PARADIGM

# 2 INNOVATION: PAST, PRESENT AND FUTURE

He stood by the large beech tree at the edge of the settlement. Deep in thought. They hadn't had a successful hunt for months and everybody was tired of eating only whatever could be foraged. Maybe the forests to the north held more game, but the journey would take many days, and they couldn't manage it if they didn't have fire with them. That, on the other hand, was a problem he could solve.

He cut a large piece of tinder fungus from the beech tree at the edge of settlement and went back to the cooking fire. Here he removed the outer skin of the tinder fungus and placed the porous pulp in the warm lye. When the pulp had absorbed the fluid, he hammered the pulp flat and laid it out to dry in the sun. By mid-afternoon, it was bone dry. He then cut it into small pieces, set fire to them, and tipped them into the birch bark container.

Now he had portable fire – for the long journey to a better future!

## 2.1 INNOVATION

Mankind didn't invent fire, but we did tame it. Building upon thousands of innovations, our forefathers invented useful things such as the campfire (for light, warmth, and protection), the torch (a portable source of light), the cooking fire (for efficient cooking), the stove (for space heating), and the furnace (for smelting).

Some of these innovations were radical. The torch, for example, enabled us to move about at night. But most innovations were small, continuous improvements – incremental improvements – such as the fastest way to start a campfire, the best way to tend a birch bark container so the embers lasted as long as possible, and the best way to build a chimney to minimize the amount of smoke from the fire.

It can be instructive to consider innovation as either being radical or incremental, although in reality, it's a continuum. A radical innovation positions a company way ahead of its competitors. This advantage makes it possible to earn abnormally large profits, at least in the short term, and this period can be extended by incremental innovation – small, continuous improvements. The honeymoon ends when a competitor is also successful with a radical innovation of its own. Consider, for example, Nokia, Apple, and the evolution of the smartphone.

Necessity is the mother of invention in the same way that innovation is driven by the dream of success – but innovation is also driven by human traits such as curiosity and the creative urge. The economic rewards and defense against the competition are sufficient reasons and incentive enough for companies to invest in innovation. But there are other good reasons to do so. A company that focusses on innovation will attract the most creative employees. The economic rewards that accompany successful innovation will therefore become a badge of success and not a goal in itself.

It is easiest for us to think of innovation in the context of a new or significantly better (physical) product that is manufactured by a company. But innovation is not just restricted to physical products. We can also innovate processes and procedures. The term "social innovation" further broadens the definition to encompass the management and organization of companies as well as the creation of new and more effective organizations within healthcare, education and public administration.

## 2.2 THE THINKERS

We owe much of our current understanding of innovation to three extraordinary individuals.

The Austrian economist Joseph Schumpeter is often credited with having framed the concept of innovation (1934). He insisted that innovation must have economic value if the innovator is to be worthy of the name, but at the same time he called innovation "creative destruction."

Management consultant, educator, and author Peter Drucker identified "the unexpected" as the first of seven sources of innovation (1985). What didn't go according to plan? What opportunities do we now have to do things differently?

Clayton Christensen, a professor at Harvard University, introduced the concept of disruptive innovation (2002). Disruptive innovation does away with the status quo by creating something new and more appealing. One of the more interesting aspects of Christensen's theory is where he describes the danger of a company becoming entangled in the relationships between its customers, employee competencies, and suppliers. New competitors can take over a market by using radical innovations to make products or services available to customers that previously either couldn't afford to buy them or weren't sophisticated enough to use them; in other words, customers that weren't important for the existing players. As the technology gradually matures, however, the old customers will also switch and leave the existing suppliers in a particularly difficult situation.

Christensen uses the development of the market for computer hard disk drives as an example. What's interesting about the case is that the existing players are not being threatened by any kind of technological quantum-leap: it's something as trivial as the reduction in size of the drives. The possibility of manufacturing smaller disk drives was not important for the existing players, which meant that the new competitors could easily establish themselves in this market with completely new customers. The performance of both the new and the older formats improved faster than the customers' needs. Soon the new, small drives met customer expectations and the secondary consideration of size suddenly became the deciding factor in choosing a drive. The new competitors took over the old customers and made the established manufacturers redundant.

And this isn't just a theory. The newspapers are full of stories about disruptive innovation in established markets; new mobile payment solutions, armbands that monitor your health, and so on.

## 2.3 THE PROCESS

Innovation, by its very nature, cannot be reduced to a formula, but we can choose between different approaches. We can do it in isolation (the lone genius), in collaboration with others (open innovation), or even more decentralized (user-driven innovation). One could say that we are shifting from product development to co-creation.

One example of the power of user-driven open innovation is the growth of the internet from when the first website was published (in 1991) to today. In 1991, a British physicist at CERN, Tim Berners-Lee, needed to be able to share documents with others, so he developed the Hypertext Transfer Protocol (HTTP) web technology to solve the problem. Did he make any money out of it? No, but he set in motion a user-driven innovation process that continues to grow explosively to this day today.

User-driven innovation can be extremely powerful and the growth of the internet is probably the best example there is. The internet is, architecturally speaking, a "dumb" network. The intelligent solutions are built at the edge by us, the users. We have experienced a veritable explosion of new concepts, services, and business models, all based on the internet infrastructure. With an expected additional three billion people finding their way to the internet before 2020, the opportunities for exploiting this source of "super-intelligence" will increase.

Author and opinion leader Chris Anderson describes it as an "innovation explosion", driven by the sharing of information through videos uploaded to sites like YouTube, where more and more people share insights and creations and inspire each other.

And we aren't just talking about uploads from self-taught musicians and inventors: even researchers are now breaking out from the traditional but slow and restrictive publication channels. JOVE (Journal of Visualized Experiments) publishes research results in the form of short, instructive videos. JOVE's mission is precisely to increase the productivity of scientific research.

There are countless examples of where engaging the users is an integral part of the business model. One such area is financing ideas for new companies: crowdsourcing. You not only get money to develop your product; you can also validate whether it's relevant for your future customers. Other solutions enable users to share their worldly goods with each other: a spare bed, a lawn mower, or even their car.

## 2.4 TECHNOLOGY-DRIVEN INNOVATION

This book's primary focus is technology-driven innovation; more specifically, technologies that grow exponentially. This does not imply that processes, customer needs, market development, etc. are irrelevant, but we will focus on the ever-growing "space of opportunity" that technology creates.

Innovation is an important part of our lives; we can't help trying to improve one thing or the other during the course of a normal day. But we do so from a predominantly linear perspective, even though we live in an exponential world.

In what way does innovation change in a world that is exponential? Keep that in mind as you read the following chapters. We will present our answer to that question in the last part of the book.

# 3 SWITCHING THE PARADIGM TO EXPONENTIAL GROWTH

Our world is undergoing a transformation. From having been local and linear for thousands of years, it's now both global and exponential. The objective of this chapter is to make you really feel the paradigm shift in going from linear to exponential thinking. And in order to ensure that you literally can feel it, we are going to chain you to a seat in the uppermost tiers of a stadium and try to drown you. But before we do that, a short introduction…

We talk about paradigm shifts when our understanding of something or other changes radically. Some paradigm shifts can be like an epiphany while others can be very painful. A paradigm shift typically results from the realization that a new way of doing things would be more appropriate. These new ways of doing things will lead to new results, and therefore real change. In other words, changes in attitudes lead to changes in the way we do things, which in turn lead to different results. The consequences of a paradigm shift can be quite extreme. In many ways, we can claim that industrialization, when viewed as a paradigm shift, led to urbanization and the educational and democratic institutions that we have today.

If we believe that the earth is flat, then we will have little or no desire to sail too far out towards the edge: the risk of "falling off" will be too great. On a flat earth, nobody would be interested in financing a sea voyage, and any sea captain struck with wanderlust would consequently have difficulty finding backers.

But if our world view changes to that of a round earth, then suddenly a sea voyage doesn't seem so dangerous anymore. We ought to be able to count on coming back home if we just sail far enough, right? The paradigm shift from the flat to the round earth took place over several hundred years, and was one of the reasons why longer sea voyages could be financed. These journeys led to fantastic discoveries and made the involved parties very rich. This in turn led to more trade, economic growth, the rise of limited companies (for shared ownership of ships), the introduction of exchanges (to facilitate the sale of ownership of the ships), and the start of globalization (which is still going strong).

The flat earth is a historical curiosity that we can afford to smile indulgently at today, but major paradigm shifts occur all the time. Take, for example, our brain. Hardly a month passes without some researcher presenting new insights into how the brain functions, and why we do what we do. We're often only paying attention half the time, so perhaps we haven't noticed the following significant paradigm shift.

We have been told – we don't remember exactly by whom – that a fully-grown brain has a finite number of cells and that they slowly die as we grow older. That is, if they don't die faster during a weekend binge! This paradigm may have kept us from drinking too much alcohol during our youth. Maybe. Either way, we felt bad about our brain every time we had a hangover!

New research shows, however, that we generate new brain cells throughout our entire life. And in particular, that we generate new brain cells whenever we exercise. Physical activity causes, quite simply, new brain cells to be produced. How do we view the relevance of exercise within this paradigm? We have long known that we ought to exercise more, but suddenly we have a much clearer picture of the "return on investment". Even more recent research indicates that new brain cells die if we are not engaged in learning. How do we view the relevance of lifelong learning within this paradigm?

William Gibson said in 1993: "The future is already here – it's just not evenly distributed." The same thing applies to paradigm shifts based on new research and insights. When the flat earth paradigm was replaced by the round earth paradigm, people didn't suddenly start sailing around the world or financing sea voyages. New insights diffuse slowly.

Today, because of the internet, ideas spread much faster than before. On the other hand, there is now so much new knowledge that today's world "knowledge map" is essentially one big white spot, just like the map of Africa was in Livingstone's time. Not only is the amount of knowledge growing rapidly, we share this knowledge so much faster as well. Research results from a university in Australia can be made globally available as text and video the same day the project is completed.

We are "African Explorers" again, armed with a map of Africa covered with large blank areas. We explore and are amazed by all the discoveries we make on our way through the internet jungle.

## 3.1 EXPONENTIAL GROWTH AS A PARADIGM SHIFT

One of the most important concepts which, this notwithstanding, is often misunderstood, is the concept of exponential growth. We've probably heard of Moore's law and we may have learnt how to calculate compound interest, but exponential growth is the key to understanding the remainder of this book and, not least, our future.

Both of us have given many talks in recent years about future trends, and we often ask the audience to perform a small task in order to test their understanding of exponential growth. Irrespective of whom the audience is, our experience has been that the vast majority are surprised by the result.

Come with us into Levi's Stadium in Silicon Valley, all the way up to the highest tiers. Here, you are chained to a seat with a good view, but with no means of escaping. Beside you is a water tap.

You are a bit concerned about what's going to happen now because you have just been told that the stadium will be filled with water according to the following formula: one drop of water (1 ml) during the first minute, two drops of water during the second minute, four drops of water during the third minute, etc. By the way, we have wrapped the entire stadium in plastic so no water can leak out…

It takes approximately 7 days to die of thirst and 30 days to die of hunger. You know you won't die of thirst after 7 days because we have placed the dripping tap right beside you.

The question is: will you die of hunger – or will you drown?

You drown, of course! Otherwise we wouldn't have asked you the question. But approximately how many days will it take to fill up the stadium with water?

Two days? More?

The correct answer – accurate to within one or two minutes depending on the exact size of the stadium – can be found at the end of this chapter.

The next, and equally important, question is: when will you realize that you have a serious problem on your hands?

Presumably, only first when the football field is covered with water – and that will only occur after 80% of the time has elapsed! Most of the time you can't even see the water, and even when a puddle does appear, it won't look particularly threatening. When you finally figure out the relationship between the height of the water and time, it'll be too late to do anything about it. This is a thought-provoking and frightening realization.

The moral of the story is that we must all – as individuals, companies, and society as a whole – start being more proactive about the future than we have been. If we wait until we can see that the situation is getting critical, it will often be too late.

Is exponential growth a new concept? No, buwt from being a mathematical curiosity, it has suddenly become essential for most of us to understand these exponential curves. According to investor, entrepreneur, and founder of Singularity University, Ray Kurzweil, exponential growth is "the nature of order" in the context of developments within information technology.

## 3.2 A RULE OF THUMB AND A COUPLE OF EXAMPLES

Exponential growth is used to describe the amount of something that increases by a constant factor over time. If you can get 3.5% in interest from your bank, how long will it take for 100,000 dollars to increase to 200,000 dollars? Unless you have studied statistics, it can be difficult to see beyond the first couple of years. How long will it take before the amount has doubled?

Here's a simple rule of thumb. The doubling time is equal to 70 divided by the rate of growth. In our example, the doubling time is equal to (70/3.5) = 20. In other words, it takes 20 years to double the original amount. 20 years is such a long time that we don't consider the growth to be exponential but linear.

The most well-known example of exponential growth is the legend about the origins of the game of chess. It is told that the king was so delighted with the game that he permitted the inventor to name his price. The inventor, who was quite clever, requested that one grain of wheat be placed on the first square, two grains on the second square, four grains on the third square, and so on. The king, who had no real understanding of the exponential function, almost felt insulted by the investor's humility and ordered that the grains of wheat be counted out right away. The inventor received 1,2,4,8,16,32,64,128,256, and 512 grains for the first 10 squares, respectively. 10 doublings gave a thousand-fold increase of the original amount. After 10 more doublings, they reached one million grains: after 10 more doublings, one billion grains.

If the king were, in theory, to carry out his promise (because it can only be done in theory), then he would have had to hand over 18,446,744,073,709,551,615 grains of wheat. That corresponds to 461,168,602,000 metric tons of wheat or a mountain of wheat bigger than Mount Everest. Or over 1,000 times more than the entire global production of wheat in 2010.

Even though at first glance, it just appears to be an entertaining anecdote, we should keep in mind that this is the way the world about us changes. It is this principle of exponential acceleration upon which any predictions of the future we make should be based. And, just for the record, we are far from being the first to point this out.

Let us present three personages that all have made exponential growth a central theme of their work.

## 3.3 ROBERT MALTHUS

300 years ago, Robert Malthus made a shocking discovery: the human race was going to die of starvation!

This would come about because the population was growing exponentially while food production was only growing linearly. At some point in time, we wouldn't be capable of feeding the growing population and only starvation would keep the population growth in check. Spreading this message was so important for him that he updated his famous "An Essay on the Principles of Population" six times over the course of 30 years. What Malthus didn't foresee was that we would discover ways to increase food production – so it, too, grew exponentially – and that we would also invent ways to limit the number of childbirths.

But the specter of overpopulation has not gone away. Reducing population growth has been a key goal for foreign aid programs. When the number of people on the planet surpassed seven billion in 2011, the media were yet again awash with overpopulation doomsday scenarios.

## 3.4 GORDON MOORE

Probably the best known of the three personages is Intel engineer Gordon Moore and his conjecture about the growth of computing power. In 1965, Gordon Moore, who was one of the foremost integrated circuit designers at the time, and who would later become the chairman of the board at Intel, observed that the number of transistors that could be put on an integrated circuit doubled every two years. This conjecture has been confirmed numerous times since and has subsequently been dubbed "Moore's Law."

It's somewhat amusing to note that Moore himself, back then in 1965, predicted that his "law" would only hold for 10–15 years. Today, almost 50 years later, it still holds, but Gordon Moore is still skeptical. As recently as 2011 he repeated that it won't last forever: "There is a physical limit to how thin the semiconductor layers can be. Today we're fabricating gates that are five atoms thick. But we can't go below an atom in thickness: that's the end of the road," says Gordon Moore.

## 3.5 RAY KURZWEIL

But it won't come to an end, if we are to believe Ray Kurzweil. "We just switch to a new technology paradigm," according to Ray Kurzweil, who has spent many years extrapolating developments in technology and making rather precise predictions about the future.

In his book "The Singularity is Near", he describes how the processing power of computers has grown exponentially during the past 110 years while simultaneously going through five technological paradigms. When a technological paradigm (for example, the integrated circuit) runs out of steam, a new one takes its place. So even though a given technology may follow an S-curve-like trajectory and end up plateauing, the concatenated sequence of S-curves will trace a beautiful exponential curve.

Consequently, Ray Kurzweil predicts that the exponential growth will still hold; that the performance-to-price ratio will double every year. Furthermore, the rate at which these paradigm shifts are occurring is also increasing exponentially, he says. In the first half of the last century, the performance to price ratio doubled every three years; in the second half, it doubled every two years; now it's doubling every year.

But there's more. Ray Kurzweil hammers home the most important conclusion: that increasingly more technologies will "go digital" and thereby grow exponentially. It is all these simultaneous exponential growth trajectories that give rise to completely new perspectives for the future.

But how can it be that the processing power of computers has grown exponentially during the past 110 years, and that the computer itself has gone through a technological evolution consisting of five completely different technology paradigms? If we are to believe that the growth will both continue and spread to other areas of technology, we must try to understand why that is the case.

What if investments in new technologies were primarily driven by what goals one expected to achieve? That we believe that we can double the memory capacity of a hard disk or the number of pixels in a digital camera? Right! Then we'll allocate the necessary resources to achieve it. Moore's law then becomes a self-fulfilling prophecy. If we believe that our competitors are following the curve, then we had better do so too. If we fall behind, we need to shake up our development team. It would also explain why the doubling time for many of the growth parameters we see is typically somewhere between one and two years. It typically takes two years to conceive, design, prototype, test, manufacture, and market a new product, and an increase by a factor of two is a more realistic goal than a factor of five or ten. The rate of growth (the curvature, or the slope of the curve) will in this case reflect the way in which the company is managed, and not something inherent to the technology itself.

But it can't be the entire picture. There are many technologies for which growth does not appear to follow an exponential curve – skyscrapers, batteries, or jet engines – and where the companies involved undoubtedly still have ambitious goals. Then there are other technologies that have followed an exponential trajectory even though it would seem that no one had consciously set that as the goal. This applies for DNA sequencing which has recently been shown to have a price per base pair half-life of 22 months.

In his book "What Technology Wants" from 2010, Kevin Kelly, founding executive editor of Wired magazine, observes that we primarily see exponential growth in those technologies where the improvements derived from scaling things down, making things smaller, packing things closer together etc. In a microcosm where the building blocks are electrons, photons, genes, bits, frequencies or pixels, exponential growth can be sustained. That's the reason why skyscrapers "grow" slowly. It's also why it's proving difficult to make batteries smaller and more efficient: they have to store as much energy as possible.

The conclusion is that in a world that is developing exponentially, we – as individuals, companies, and society – must be more proactive with respect to the future than we have been up until now. As companies, we must be careful not to invest too heavily in current technologies: as individuals, we need to become increasingly better at revising our understanding of what is possible.

*Answer: It'll take 44 minutes to fill up the stadium (8,796,093 $m^3$ of water).*

# PART 2
# FOUR EXPONENTIAL TECHNOLOGIES

# 4 COMPUTING AND COMMUNICATIONS

Before we take a closer look at the technologies themselves, we will introduce three concepts that we will refer to throughout the following chapters: *Exponential Acceleration*, *Creative Crossing,* and *Development Disruption*.

*Exponential Acceleration* is a way to describe the rate of change we are facing. That exponential growth exists is nothing new. An annual population growth of 3% or an interest-bearing bank account with an interest rate of 1%, are both examples of exponential growth. We just don't perceive them as being exponential since the growth rate is so slow – and we have plenty of time to adapt to the changes. However, when the doubling time is just one or two years – as exemplified by Moore's law – we need to be vigilant and agile.

*Creative Crossing* is a way to describe the creation of a new technology, a new product, a new process or a new procedure by crossing two or more existing technologies. This convergence between and intersection of different technology trajectories is an important concept to understand to fully appreciate the implications of the subsequent developments. It is often through interaction with other technologies that new, previously unseen, and surprising possibilities emerge. Smartphones a cross between computers, phones, cameras, soon credit cards, and, let's not forget, wireless and network technologies are a good example. Amazon – born at the intersection of bookstores, websites, and mail order firms is yet another. Fortunes can be made at Creative Crossings.

*Development Disruption* is used to describe those situations where an established trend or development path suddenly comes to an end, and the boundary conditions change drastically. Examples of this include the collapse of planned economies, the fall of the Berlin Wall, and the Arab Spring. These changes can be attributed indirectly to developments in technology. But your Development Disruption is somebody else's Creative Crossing. Examples of this include the printing press, which made the manuscript-copying monks in the monasteries redundant, or the digital camera, which rendered Kodak's film obsolete. A company on the losing side will consequently perceive a competitor's technological breakthrough as a Development Disruption. Despite the fact that a Development Disruption may seem to happen quite abruptly, it is often the culmination of a longer process, exactly the same way the fall of the Berlin Wall was.

We have tried to make our treatment of each field of technology and the associated concepts as accessible as possible while, at the same time, forcing the acceleration. So fasten your seatbelt!

## 4.1 EXPONENTIAL ACCELERATION

These days, most of us are quite familiar with computer technology and networks. After 30 years of increasingly faster and cheaper computers, combined with 15 years of increasingly faster telecommunication technologies, we've become accustomed to the exponential growth that characterizes this space, and take it for granted.

It is precisely the exponential growth in computing power, i.e., our ability to perform an ever-increasing number of calculations, that is crucial here. This is also the basis of the other fields of technology that we will describe later. They've all gone digital and have consequently latched onto an exponential trajectory.

However, the exponential growth within the field of computation is not just restricted to microprocessors or integrated circuits. The amount of data that we can store on a hard disk (in bits per dollar) or the amount of data that we can transmit wirelessly (in bits per second) is also growing exponentially. In reality, computer technology comprises several technologies, each of which is growing exponentially, but with different doubling times! They include microprocessors (price per transistor cycle, MIPS), RAM (bits per dollar), and storage density on hard disks.

If, for example, we plot the number of bits per dollar in RAM as a function of time, the curve goes from one bit per dollar in 1965 to 100 million bits per dollar in 2010: exponential growth with a doubling time of approximately 18 months.

For many years, the exponential growth within the field of networking technologies has been even more dramatic than the corresponding growth in the yield/price ratio for microprocessors or memory chips, and its impact is no less important. This growth includes significant improvements in fiber optics, optical switches, etc. We are moving towards a cable-free world. The curve representing bits per second, per dollar for wireless data transmission as a function of time doubled every 11th month (1990–2004).

The number of computers connected to the internet and the amount of data that is transmitted via these machines is also growing in the same manner: exponentially. These two technologies – computing power and data transmission bit rates – are converging naturally, and therefore mutually enhance each other's impact considerably.

What are the implications of essentially free and unlimited computing power combined with cheap broadband connectivity for products, services, and jobs? What kind of Creative Crossing could it lead us to?

## 4.2 CREATIVE CROSSING

Creative Crossing is a way to describe the creation of a new technology, a new product, a new process or a new procedure, by crossing two or more existing or emerging technologies. Searching for a creative crossing between computing power and data transmission speed doesn't make much sense. It is precisely this convergence that is the wellspring from which the vast majority of technological developments emanate. We have therefore chosen three Information Technology (IT) examples.

### 4.2.1 CLOUD COMPUTING

The first and most obvious result of crossing computers with communications is Cloud Computing, i.e., the ability to run programs or store data on servers with internet access, located remotely from our own computer. The old software development paradigm of developing, releasing, and subsequently patching the software with updates once a year, is history now. Microsoft, in particular, was created within this old paradigm, and this is one of the reasons why they are having difficulty coping today.

Today, quite a considerable number of services are run in browsers and on web servers. Versions are launched in beta before they are completely finished. They are continuously being developed and, as a rule, based on input from users. One of the consequences of this is that software – as a product – has become considerably more fluid. Agile is the new black. There is a razor-sharp focus on customer value; the business model is either a subscription-based model or revenue from secondary revenue streams, and the life expectancy of any given product is often short. Google is the poster child for this paradigm.

### 4.2.2 THE INTERNET OF A 1000 THINGS

Another predictable Creative Crossing which will radically change our world is the interconnection of all the things we surround ourselves with, also known as The Internet of Things. The idea is that when both computers and communication technologies become ubiquitous and cheap, it'll be worth our while to build them into physical objects around us. In this way, all things will be able to perform simple calculations, know where they are, and transmit and receive data. This means that they will be able to perform simple tasks autonomously, collaborate with each other, and know where they are located.

This connection between our things and software will enable new ways of using them, and our smartphone will play a key role in this process. It will function as the user interface to our things. It means that you'll look to your smartphone whenever you want to check your weight, your blood pressure, how much you've exercised, or if you want to turn up or turn down the lights in your living room.

Initially, it makes most sense to connect things that pertain to people (pedometers, weighing scales, light bulbs, etc.) and things that move (such as cars and busses) to The Internet of Things but gradually, as our telecommunications infrastructure become more powerful, it will make sense to collect, collate, and share data between the vast majority of things.

This is already happening, albeit only for the nerds among us. With the aid of so-called "If this, then that" applications on our smartphones, we can switch on the light in our bedroom when the alarm clock rings.

And it's not just about small conveniences such as avoiding having to turn on the light or switch off the wireless network ourselves. The ability to match people's needs plays right into the Sharing Economy. Car sharing, where technology takes care of the complexity, and makes sure that we end up at the right place. Or collaborative consumption and deals, courtesy of your fridge, shopping in concert with your neighbors' fridges.

In this way, our smartphone is a platform that can spawn a fantastic number of new possibilities. A substantial number of us carry a smartphone that not only packs a relatively large amount of computing power and is connected to the internet; it's also full of sensors such as a GPS, motion sensors, a compass, a microphone, etc. It's this platform that's the basis for an awful lot of new services that are unreasonably difficult to compete with.

### 4.2.3 VIRTUAL OR AUGMENTED REALITY

The third Creative Crossing taking shape is the growth of virtual (VR) and augmented (AG) reality. Augmented reality can be described as enhanced reality. The more powerful communication networks and increased computing power make it possible superimpose an information filter on reality. In this way, you can enrich the reality you're looking at with digital information.

You can already try out the first generation of products if you install the LAYAR application on your smartphone, and stroll around your local shopping area with LAYAR running. When you hold up the phone in front of a restaurant or a café, you can see their current food hygiene inspection report (and maybe even the Menu of the Day) superimposed on the phone's camera image. For shops, it would be the latest deals. In London, The Tube has developed an application that shows colored stripes superimposed on the pavement and that you can follow to the nearest tube station.

Facebook and Google have already implemented automatic face recognition for photographs, so it's only a matter of time before they launch an application that will make it possible for you to point your smartphone's camera at someone and view whatever information Google can gather about them– perhaps as text floating above their head, along with their latest Facebook updates?

Augmented reality is itself an offshoot of virtual reality, which was predicted a very rosy future 15 years ago. The vision was that by putting on virtual reality googles, one could experience computer-simulated worlds (such as for training or games) or explore large datasets (such as financial or medical data). The growth of virtual reality has haltered, but now the pace is picking up. In particular, a small company by the name of Oculus VR has attracted a lot of attention on account of its virtual reality goggles, Oculus Rift. (So much so that the company was acquired by Facebook in 2014.) The sensation of entering into the computer's domain is fascinating, and the prospects are staggering.

Try to imagine what will happen when the virtual world becomes just as convincing as the real world. Will you still continue to travel? In virtual reality, you not only can travel quickly, you can also travel through time. What will a workplace look like now? Will we still attend conferences?

## 4.3 DEVELOPMENT DISRUPTION

The exciting and productive Creative Crossin*g* will be viewed as a Development Disruption by the established companies and could force them to innovate or shut down. We have chosen two examples.

### 4.3.1 HERE YOU GO – IT'S FREE

Right now, the business models that currently underpin digital businesses are undergoing a revolution. Most products are free for the average user, and services for companies are sold as subscriptions at very competitive rates. Revenue is generated from supplemental services, advertising, and data mining. At the same time, the rate at which these companies can scale up is incredible. Google is, again, the classic example of free products and extreme scaling. How will your company survive if your competitors give away their products for free?

The rationale behind these developments can be found in the relationship between the digital product itself and the exponential growth of the performance-to-price ratio. In order to manufacture and sell traditional, physical products, one requires resources. Transportation alone restricts how large a share of the global market a single company can capture. More importantly, manpower is required to produce them. The cost of data communication, computing power, and data storage is practically zero. Once the digital product has been developed, it is for all intents and purposes irrelevant whether it is used by one or one billion people. The marginal costs are effectively zero. Perhaps you recall the French mathematician, Joseph Bertrand, and his axiom from 1883: "In a free market, the price will approach the marginal cost."

### 4.3.2 EVERY HOME A HOTEL, EACH CAR A TAXI

This relationship gives companies with digitally-based business models an awful lot of room to scale up their products and generate revenue in a variety of different ways.

AirBnB and Uber are good examples of this. AirBnB is well on its way to becoming the world's largest hotel chain. The only difference is that AirBnB doesn't own a single bed; instead they broker their users' private dwellings. It's the users themselves that post and update their advertisements and interact with the guests. The cost of adding an additional bed to their website is zero for AirBnB. The cost for a traditional hotel is high; they have to build it, furnish it, and hire staff to run it. Who's going to win market share in that competition? Uber does exactly the same thing in the transportation space. And in both cases, it's the users themselves that invest by choosing to live in a slightly larger dwelling with a room with a view, or to buy an extra car, just for Uber.

### 4.3.3 THE SINGULARITY AND LOST ARTS

Ray Kurzweil maintains that the growth of computing power will bring us to a point where machine intelligence will surpass our own, and that we will begin to integrate with the machines before that point. In much the same way that we formerly couldn't manage without books, and then we couldn't manage without TV or radio, today we can't cope without smartphones or the internet. When Jonathon Foer, in his book "Moonwalking with Einstein", talks about why memory techniques (mnemonics) have become a lost art, he rationalizes along the same lines, that unlike Cicero, we no longer *have* to commit speeches to memory. We can, just like Barack Obama, use a teleprompter; we already use to-do lists, calendars, phonebooks, diaries, and the internet!

In the future, will it be possible have a cache surgically implanted? Or wirelessly connect the brain to external memory? Have Wikipedia in the cerebral cortex? We truly believe that the answer is yes. And soon. It may sound crazy, but so far we haven't had any problem integrating with technology: from spectacles and hearing aids to prostheses and pacemakers. The question is: what other faculties of the mind like mnemonics will disappear when we are continuously connected to the "Cloud"?

# 5 ARTIFICIAL INTELLIGENCE

When the American mathematician John McCarthy coined the term Artificial Intelligence (AI) in 1956, he defined it as intelligent machines. Today, we view AI more as software. Even though the code is run on a microprocessor, we don't consider the microprocessor to be a machine, but rather an intermediary between us and the machine.

The criteria we use to determine what Artificial Intelligence is are also in flux. For hundreds of years, the ability to play chess has been universally regarded as a sign of high intelligence. Around the end of the 18th century, a chess-playing automaton under the name of the Mechanical Turk toured Europe. It was a life-sized mannequin torso, decked out in a turban and with a long beard, and was built into a desk with a chessboard. It actually played a pretty good game against its human opponents. However, the Mechanical Turk turned out to be a hoax. A chess-playing human operator was hidden inside the desk: it was he who decided and controlled the automaton's moves. An artificial artificial intelligence, you could say.

Artificial intelligence is also inseparable from robotics. Navigation is a key aspect of artificial intelligence. By that we mean the ability of the robot to move about and perform its tasks. Artificial intelligence can therefore have a physical embodiment in the form of a robot, or be software that runs on a computer.

## 5.1 EXPONENTIAL ACCELERATION

The Mechanical Turk finally became a reality in 1997 when IBM's computer, Deep Blue, beat Gary Kasparov in a chess tournament. Today, however, not many people consider Deep Blue to be truly intelligent. The computer can only calculate a greater number of potential moves on account of its size, just like a crane can lift more than a human can. A remarkable consequence of the hold that computers have on the game of chess is that Grandmasters and international chess tournaments are no longer the focus of worldwide attention they once were. When Boris Spassky and Bobby Fischer vied for the title of World Champion on Iceland in 1972, it was framed as a duel between the ideologies of the Soviet Bloc and the Free World. Technology is always fascinating, and when it surpasses the abilities of humans in a particular field, the performance of humans in this field suddenly becomes boring and uninteresting.

We often distinguish between weak and strong artificial intelligence. The chess computer is an example of weak AI in that it solves simple logical problems by virtue of its computing power alone. A host of solutions within this category are available today. Siri, the occasionally not-so-understanding assistant on your iPhone, is another example. In addition to speech recognition capabilities and access to the functions on your phone, Siri has access to answer engines such as Wolfram Alpha, and can answer simple questions such as how many people live in, for example, the US. Other examples of weak AI include autopilots, warehouse robots, or Wilson, IBM's Jeopardy-playing savant.

It's difficult to delineate between strong and weak AI. The closest we can come in practice to defining strong AI is still the Turing Test, proposed by Alan Turing in 1950. We consider AI to be strong if, after conducting an extended dialogue with an AI via a neutral communications channel (for example, text based communication via the internet), we are convinced that we have been communicating with another person.

However, as early as in 1966, a relatively simple computer program by the name of Eliza was capable of deceiving quite a lot of people. Today, it is not uncommon to come across so-called chatbots on the internet. Google "Eliza" and see for yourself how friendly and reassuring "she" is to talk with or, alternatively, try googling "Jabberwacky", which is wacky enough to make it quite interesting for you to see if you can figure out how it thinks.

Our experience with the Turing Test and chatbots would seem to indicate that what we consider to be intelligent is anything that demonstrates a versatile ability to understand ambiguous communication – and with which we can establish a rapport. What is particularly interesting is that our relationship with IT as a tool will change when we can communicate via a natural language interface with an entity that understands what we say. In this way, AI will make technology a more integral part of our lives.

AI is a multi-facetted field with many interdependent disciplines. At the core, we have the cognitive functions such as problem formulation, analysis, and interpretation. We could also add flexibility and "fuzziness" here (call it creativity and innovation). Then there are the input-output functions such as speech synthesis and speech recognition. And finally, there are robots' physical functions, which can in turn also be split into sub-categories.

Acceleration in this field is influenced by a number of tangible factors, each of which is of an exponential nature. First and foremost is the exponential growth in computing power: this is mandatory. Second is the growth of the amount of knowledge available in an electronic format and that can be tapped into by AIs. Third is the growth of the number of people who have internet access: from 500 million people in 2001 to 2.7 billion people in 2013. The five-fold increase can obviously not be repeated, but ITU (International Telecommunication Union) expects that the number of internet users will increase from three billion to six billion during the course of the next decade.

These three factors alone would seem to indicate that there is a greatly increased probability that AI will grow exponentially – and on a steep trajectory at that.

## 5.2 CREATIVE CROSSING

### 5.2.1 ADVANCED PATTERN RECOGNITION ON THE STOCK MARKET AND IN HEALTHCARE

The human brain is good at pattern recognition, but not, however, when the patterns occur over longer periods of time. In this situation, computers are significantly better. The methodical chess computer has consequently found its niche in a number of areas where there are large amounts of data and where variations over time are crucial.

One of these areas is the stock market, where the returns that can be earned by a successful implementation can obviously be quite considerable. In 2007, Rebellion Research launched the first AI hedge fund. The AI wasn't seeded with any particular strategies or rules, but it has itself analyzed how different factors affect stock prices. All on the basis of 20 years of data from markets from all over the world.

Today, there are considerably more AI funds on the market, just as AI decision support systems for, for example, risk management have also appeared. The amount of data is growing at a fantastic rate, and it's no longer possible for any single individual to keep track of it all. That's not a problem for AI. The more data it processes, the better it gets. In addition to being able to sift through huge amounts of data, AIs have another advantage compared to their human colleagues: they don't have any emotions. Put another way, they don't get "carried away," which can often be a problem for humans and which has a negative impact on returns. Today, the majority of the investment funds managed by humans still perform better than AI funds, but for how long?

Developments within the fields of cognitive functions and speech recognition have also been significant. In January 2011, IBM presented the Watson program, which was capable of very advanced interaction with humans. Watson aced Jeopardy which, in addition to a very broad knowledge base, also requires the ability to comprehend ambiguous questions. IBM's objective was obviously not to make a game-playing computer but to communicate, quite brilliantly, to its broad customer base, that the company has a product that is capable (via a speech recognition interface) of understanding a complex field, searching databases for answers, drawing conclusions and communicating the answer verbally in an easily understood format.

IBM is now launching Watson in a number of exciting areas. One of these is health: in particular cancer diagnosis. The ambition here is to gather together all available medical research, pharmaceutical data, and a relevant group of patients' DNA, and use the Watson technology to discover previously unknown correlations. The hypothesis is that cancer is best characterized by associating it with a specific DNA mutation rather than in which part of the body it manifests itself. By fine-tuning the treatment according to the type of mutation rather than the location, the efficacy of the treatment can be increased. The ability to see correlations in such huge datasets is only possible with AI.

Watson can be used in areas other than cancer within the healthcare sector. Developments within the sector are driving increased specialization, thereby making it more and more difficult for the specialists to maintain a holistic view of the patients when diagnosing. Watson could play a significant role here as the doctor's assistant.

We can envisage many more possibilities such as Watson the board member. In addition to performing regular board duties, Watson would be able to datamine the companies' IT systems and provide the board with much more insight than previously possible. IBM has developed Watson in such a way that it can easily be integrated into one's own IT solutions.

Many help desk and call center functions have been outsourced to the Far East from Europe and the US in recent years because the technical expertise required to provide the service is available there at a much lower cost. But it is not beyond the realms of possibility that the next generation of call centers will just consist of a good speech recognition program, some complicated algorithms, 4–5 Terabytes of specialized knowledge, and internet access.

And call centers are only the first of many service functions than can be "AI-sourced." Throughout the entire 20$^{th}$ century, the Industrial Society's work functions have been increasingly automated, and this trend will accelerate more when computers and robots are intelligent enough to perform the Knowledge Society's core functions. At Oxford University, the *Oxford Martin Programme on the Impacts of Future Technology* found that up to 50% of all current job titles are likely to be automated during the course of the next 20 years. Some of the job titles on the list: drivers, shop assistants, office personnel, machine operators, security guards and accountants.

These perfect workers don't need to sleep and don't go on vacation, and, given the right learning algorithms, they can take of their continuing education themselves.

How long will it be before AI supplants all white-collar workers, either partially or completely? What kind of education would you recommend to your children?

### 5.2.2 AI AND ROBOTS

Robots and AI are joined at the hip: the ability to move about freely requires intelligence. This becomes clear if we look at Nature, where things that are fixed – such as grass, trees, and bushes – don't have a brain, whereas things that can move about – such as mice and birds – do. The brain's original function is best described as a navigation system. We got it so we could move about without hurting ourselves.

That's why robots are also so dependent on AI. The best example of this is the self-driving car. The car itself is just like those we are familiar with today, and the sensor technologies that are used to gather information about what's happening in the vicinity of the car aren't particularly new. What makes the self-driving car possible is the computing power in the computer that processes the input from all the sensors. Google, who are leading the field in this area, expect to have the first self-driving car ready for consumers in 2020. The biggest obstacle to self-driving cars is no longer technology, it's legislation.

Self-driving cars are an interesting development that will have many implications. For example, how will the real estate market react when transport time is now “time for work” or “time to sleep”? What about ownership of cars? When the car can come to me, then it might just as well as be one that matches my current transport needs (long trip, short trip, with or without luggage?). This opens up whole new business opportunities: who will be the Spotify for cars?

Take drones, small unmanned aircraft that could easily be employed for more peaceful purposes than is the case today. Examples include transportation and search and rescue operations in inaccessible regions.

Intelligent robots are also making inroads into healthcare: robots to help the physically handicapped to eat and care-giving robots for dementia patients. Or what about the world-famous physicist Stephen Hawking, who has had developed increasingly sophisticated gadgets which make it possible for him to communicate with people around him despite the fact that he is almost totally paralyzed by Lou Gehrig’s disease.

Robots are beginning to encroach on types of work that we would have insisted – at least several years ago – required a human touch to handle. It’s said that pornography was a major contributing factor to the growth of the VCR (Video Cassette Recorder) and later the internet.

Will sex androids be robotics’ big breakthrough?

## 5.3 DEVELOPMENT DISRUPTION

First of all, we need to do away with the idea that AI and robots are more stupid than humans and can only perform tasks that we don’t want to do ourselves. The objective of AI is not necessarily to create a copy of human intelligence. Today, AI is already far superior to the human brain in a number of areas. And as we look towards the future, the number of areas will increase. In other areas, AI is way behind. They are two different types of intelligence, and it rarely makes sense to compare them with each other. We should use AI where we are weak, and hold our own where we are strong by virtue of our intuition, emotions and creativity.

From Rabbi Loew, who created a living Golem out of clay in the streets of Prague, to Goethe's Faust and Frankenstein's Monster, to HAL in "2001: A Space Odyssey." On the one hand, we dream of a utopia, where intelligent and helpful robots cater to our every whim. On the other hand, we fear that this technology can be abused or, even worse, that the technology itself becomes "self-aware" and decides to control us instead of serving us.

From the fields of robotics and computer animation we have the term "The Uncanny Valley." This refers to the sense of revulsion that people experience when human-like imitations (robots, for example) look and act as if they are human, but aren't.

As robots and computers become more and more life-like, we will slowly but surely begin to regard them as something other than machines or software. When we saw photographs of the Earth from space for the first time in the middle of the 1960s, we saw a bright, isolated and unprotected planet. A lot of people experienced a disconnect then because this was at variance with their established view of Earth as their home and the basis for our existence. Just like the feeling you get when you orbit the Earth in Google Earth.

In the film "Her", Theodore Twombly falls in love with his computer's operating system. What kind of Development Disruption do you think you would experience if, at some point in the future, you look into an android's eyes, listen to its voice, and suddenly feel your heart skip a beat?

# 6 BIOTECHNOLOGY, A NEW HEALTHCARE SYSTEM AND ETERNAL LIFE

Biotechnology is the Next Big Thing being driven by digitization. Developments in this field will change the way we both perceive ourselves and the world around us. Until now, healthcare development and medical research have, in many regards, been relatively haphazard. True, we have managed to discover many new and useful treatments, but they have also had side effects. Now it looks like we can design biology exactly the way we want it.

We have always strived to understand what life is by, among other things, trying to find progressively smaller building blocks. The discovery of DNA by Friedrich Miescher in 1871 and the description of the structure of DNA and its function in cells by James Watson and Francis Crick in 1953 were pivotal. With the advent of bioinformatics, these biological processes have "gone digital." We can now begin to synthesize DNA. The race for the ultimate personalization of everything from food to medicine has begun.

However, something interesting is happening in the sector in parallel with these epic discoveries. Something that is, in many respects, comparable to what we saw happen in the IT sector during 1980s. Many young, creative types are turning their backs on the large corporations in order to start their own companies in their garage, just like Steve Jobs and Bill Gates did. There is a burgeoning "Do It Yourself" (DIY) movement which growing rapidly along with open workspaces such as BioCurious, a hackerspace for biologists.

We can consequently expect to see many exciting applications in the years to come.

## 6.1 EXPONENTIAL ACCELERATION

Biotechnology is a combination of biology and technology. The biological part is that we use living organisms to make products such as yoghurt, cheese, beer, washing powder, and penicillin. The technological part relates to how we optimize the production processes.

A deep understanding of biotechnology requires an understanding of the biology of the smallest of organisms, such as bacteria and viruses (microbiology); an understanding of their chemical processes (biochemistry); and an understanding of the individual components, such as proteins and carbohydrates (molecular biology). But it also requires an understanding of how to fit the processes together, i.e., process technology.

Mankind has made use of biotechnology for many thousands of years – to produce wine and cheese – and has increasingly industrialized production processes in, for example, breweries. The potential for biotechnology is unlimited in areas such as therapeutics, food production, etc. The field is so extensive that it's almost impossible to summarize it; from the production of washing powder to designing humans. Biotechnology is becoming increasingly more digitized; processes that were formerly physical processes are now also going digital.

The exponential curve manifests itself in two ways: bioinformatics and parallel processing.

Because of bioinformatics, we can analyze significantly greater amounts of data: we can see patterns, draw conclusions, and propose designs. And since it's an information science, bioinformatics is, per definition, already on an exponential trajectory, driven forward by Moore's Law.

We realize parallel biological processing by putting a fully-functional laboratory onto a single chip that only measures a couple of square millimeters in area and that requires incredibly small fluid volumes to perform assays. In this way, it's possible to perform huge numbers of laboratory assays in parallel and thereby get our research results that much faster.

Because of this transition from analysis procedures that require physical handling at intermediate steps to chip-based processes, the growth in biotechnology will follow the same type of exponential path as those for computer and data communication network technologies. The time required to complete research projects will fall dramatically and some of the ideas will give birth to new, unexpected products. Try to google "lung on a chip", a three-dimensional chip which is expected to supplant animal testing when testing for allergic reactions, among other things.

Finally, research results and discoveries can be spread more quickly between researchers because of IT and the Internet. The DIY movement in particular is driven by these possibilities. In the following section, we will take a closer look at two areas where this acceleration is particularly visible: genetics and neuroscience.

### 6.1.1 GENETICS

In 1953, when James Watson and Francis Crick first discovered the chemical structure of the DNA molecule, no one could envisage the consequences it would have. 10 years would pass before it finally became clear, that the language of the genes, with very few exceptions, is universal. In other words, all life can be described using the same alphabet. We are neither chemistry nor molecules: we are information.

As if that wasn't enough, in 1973, biologists Stanley Coen, Herbert Boyer, and Paul Berg showed that information can be transferred from one organism to another by using enzymes to cut out and splice in selected sections of DNA. Now it was possible to transfer genes for desirable traits from one organism to another.

Today, we can both describe and compare all kinds of different life forms: viruses, bacteria, fungi, plants, and animals. However, the goal is not just to describe, but also to accelerate our understanding of diseases and disorders. The largest of these projects was The Human Genome Project, which evolutionary biologist and debater Richard Dawkins christened the "Son of Moore's Law" because the exponential growth of DNA sequencing could be attributed directly to Moore's Law for digital media.

When the project was initiated in 1990, many critics were quick to point out that it would take 100 years to map all the genes in the human genome given the speed at which sequencing could be performed at that time. At first glance, it seemed they had a point: after the first six years, less than 1% of the genome had been mapped. Despite this, the (projected) 15 year project was completed two years ahead of schedule for the sole reason that the speed at which the sequencing could be performed grew exponentially. This growth has continued after the completion of the project. The total cost for the Human Genome Project was approximately 2.7 billion dollars: today it is possible to sequence an entire human genome in less than two hours for approximately 1,000 dollars. (Question: did this thought just strike you?…"OK, so that means that in 10 years it will only cost one cent… You know, this means it costs next to nothing to let the toilet test for cancer cells after each visit!" If you answered yes, then you *truly* have understood this book's message: you have taken your first step along the path – the exponential path).

Now that the human genome has been sequenced, research is focusing on understanding the differences between humans in terms of variations in our genomes. The method is quite simple. We investigate the genomes from a group of people who all have the same illness and compare them with the genomes from a healthy control group. We look for the so-called SNPs, which are both large and small mutations in the DNA. Those who have the same mutation as the patient group consequently have an increased probability of developing the illness in question.

We've both had sections of our genome mapped by 23andMe, who now keeps us continually updated on all new discoveries pertaining to the specific variations in our genetic material. Here, we can track the genetically determined probability that we will develop a number of different illnesses, and how our genetic makeup affects how we will respond to different pharmaceuticals. Companies such as StationX have taken it a step further and offer tumor-DNA mapping services to cancer patients, so that the patients can choose the treatment that is optimal for them.

There are two major drivers in biotechnology today. First of all, it has gone digital: collecting the data and testing the pharmaceuticals can all be taken care of by a computer. Secondly, the price of the equipment used is falling dramatically: what was leading-edge science a couple of years ago is already commercially produced and available for purchase today.

There are several examples of this. One example is Modern Meadow from Singularity University who employs techniques from tissue and stem cell engineering to make leather. The ultimate goal is to use the same techniques to produce so-called "slaughter-free" meat. That may sound strange at first, but if potentially nine billion people are to be able to consume as much meat as we currently do in the developed countries, then this will be mandatory.

Another example is Evolutionary Solutions, who uses electromagnetic fields to control the proteins that synthesize DNA. Their technique reduces both errors and production costs substantially. Just design the DNA sequence you want synthesized on your computer, and then have it delivered to your door.

Finally, on a lighter note, the Canadian fruit producer, Okanagan Specialty Fruits, has discovered a way to suppress the gene that causes apples to turn brown when they come into contact with air.

### 6.1.2 NEUROSCIENCE

A completely different area is the study of the human brain. Neuroscience has been around for some time now, but combining biology, measurement techniques, and psychology in an interdisciplinary field has accelerated things.

Increasingly sophisticated scanners make it possible to see how the brain processes sensations, how and where thoughts manifest themselves, and identify behavioral markers with greater precision. It gives real hope that it will be possible to seriously address illnesses such as Alzheimer's disease and Parkinson's disease, as well as obtain a deeper understanding of disorders such autism and schizophrenia. But it also brings us so much closer to a better understanding of ourselves as humans, to why we react the way we do, and how our phenomenal brain does its job. These are insights that feed directly into the next generation of artificial intelligences.

## 6.2 CREATIVE CROSSING

As described in the previous section, biology has gone digital. The laboratory is now a computer. This has resulted in a substantial decrease in development times for new projects. It has long been said of internet companies, that development times for new projects there are measured in months compared to years in other industries. One of the consequences of exponential growth within biotechnology could well be development times measured in weeks or days!

### 6.2.1 CONVERGING INFORMATION AND SENSOR TECHNOLOGIES

The healthcare sector faces a paradigm shift on a number of fronts. When our knowledge of biology, genetics, and healthcare converges with sensor networks, wireless data transmission technologies, and artificial intelligence and its ability to analyze extremely large datasets, completely new and self-initiated ways of monitoring and diagnosing ourselves, as well as sharing our experiences with others, become possible.

We are transitioning from a passive to a proactive understanding of our health and well-being, from treating illnesses first when they occur to preventing illnesses. A number of companies make it possible for us to explore our genetic profile and perform health studies with similarly inclined people. We're talking about Quantified Self and personalized studies. Business opportunities of comparable magnitude as those of Google and Facebook will emerge, because who doesn't want to do something about their health?

## 6.3 DEVELOPMENT DISRUPTION

The accelerating number of opportunities for developing and testing are a growing threat for Big Pharma. What happens when we can test the different treatments for various illnesses ourselves? Many cures consist primarily of changing one's behavior rather than from patented products such as vitamins. How many of the large pharmaceutical companies will survive this Development Disruption?

### 6.3.1 DIY MEDICINE AND DIY TREATMENTS

Social media platforms on the internet have made it easy for us to find others who share the same interests as ourselves. Websites such as "patients like me" make it easy for people with illnesses to meet others in the same situation as themselves, share their experiences, and compare treatments. Now that it's possible to share information about one's genetic material, these sites could well become a serious alternative to the research that is currently performed within the healthcare sector. Perhaps we will see medical doctors and researchers selling their services as project managers for these groups of thousands of people who want to test treatments on themselves *without* waiting for FDA approval!

There are a number of Development Disruptions that are interesting to look at in this field. The entire "Do It Yourself" (DIY) trend is a reaction against the power of experts, institutionalized research, and the time it takes to develop new cures and treatments within the field. The predominant discontinuity, however, is the change in our lifespans.

### 6.3.2 DRAMATICALLY EXTENDED LIFESPANS

There is no objective way to determine a body's age. It would seem that our bodies don't have anything analogous to tree-rings or anything that would facilitate a "Carbon-14 dating" – like measurement of our age. However, some do point to telomere length as an indicator of biological aging. Perhaps a new biomarker will be discovered one day but until then, age is subjective. You're as young as you can make yourself be.

The average life expectancy has increased by three months per year during the past 100 years or so. This can be attributed primarily to significant advances in disease control and the widespread automation of debilitating physical labor. Today, we are at the cusp of simultaneous breakthroughs in a number of areas which, collectively, can extend our lifespans appreciably, not just because we are finding cures for illnesses that are some of the leading causes of death, but also because we can slow down the body's aging process.

One of the most controversial researchers in this field is Aubrey de Grey from the SENS Foundation. He professes, albeit with a twinkle in his eye, that aging is an illness, and accuses it of being the leading cause of death. Through his research, he has identified seven causes of aging and death, and is active in gathering and financing research into these topics.

Aubrey de Grey, Ray Kurzweil, and other life extension researchers talk about a crossover point they call the "Longevity Escape Velocity." This is the point at which the expected life expectancy increases by more than one year per year. At this point, your expected time of death will move further and further into the future! We will return to this topic in the last part of the book.

An accelerating growth could potentially result in lifespans that are 2.5 or 25 times longer than is the case today! "I'm not sure if I want to be that old" is the usual reaction we are met with when we share these thoughts. But the comparison shouldn't be made based on our current conception of an old age, epitomized by weakness and illness. It's the healthy and active life that's extended. Picture your 237$^{th}$ birthday as a party!

The implications of lifespans of this order are difficult to imagine. Even today, we see that many people choose not to retire and continue working right into their '70s and '80s. Given the prospect of a significantly longer life, will we then choose multiple careers, multiple educations, and multiple marriages?

# 7 NANOTECHNOLOGY, THE WORLD'S SMALLEST CONSTRUCTION SITE

Nanotechnology is Lego for adults, except we're playing with the world's smallest Lego bricks: atoms and molecules. One nanometer is equal to one billionth of a meter, yet we can only see objects larger than 20,000 nanometers with the naked eye. Ergo, we're "building blind."

We're also way below the scale of life. The smallest living organism we know of is 200 nanometers long. With nanotechnology, we can make things that vary in size from 0.1 to 100 nanometers. An entire Legoland beyond the range of our senses.

Nanotechnology's possibilities have already enthralled researchers, investors, and customers. However, true nanotech products are still few and far between, and the technology is still best characterized as immature. It is somewhat reminiscent of the internet bubble in 2001. But the technology continues to develop, even if some people lose money along the way. Ultimately, nanotechnology will enable us to design and build our own bodies, brains, and the world we will integrate with, atom by atom. The coming revolution, at least, is clearly discernable.

In 1957, the physicist Richard P. Feynman gave birth to the idea of the world's smallest construction site (in a talk entitled: "There's Plenty of Room at the Bottom") but the word "nano-technology" was first used in 1974, by Japanese scientist Norio Taniguchi. However, K. Eric Drexler, an American molecular engineer, is probably the best-known proponent in this field. In 1986, he published his book "Engines of Creation: The Coming Era of Nanotechnology" in which he describes how one can build molecular machines that can both copy themselves and build other objects.

The invention of the Scanning Tunnel Microscope, which enabled us to "see" nanostructures, was instrumental in accelerating developments in nanotechnology in the 1980s and 1990s. After 2000, the European Union and governments from all over the world started to invest in research programs within the field, and the first commercial applications of nanotechnology started to appear.

## 7.1 EXPONTENTIAL ACCELERATION

Nanotechnology is, nonetheless, still at the start of the exponential curve, and it's not about to accelerate wildly any time soon. However, nanotechnology's possibilities and the projects currently in the lab are nothing short of fantastic. Our ability to produce at smaller and smaller sizes is growing exponentially by a factor of four per decade. If we can maintain this pace, the size of the majority of mechanical and electronic components will become nanoscale (less than 100 nanometers) during the 2020s.

One example of our ability to manufacture at smaller sizes is MEMS. MEMS are Micro-Electronic-Mechanical Systems. The word is used indiscriminately for both the product category and the technology. They contain components that are of the order of 1–100 micrometers in size (one micrometer is equal to one millionth of a meter), i.e., 1,000 times larger than a nanometer. There are two main categories of MEMS: sensors, that measure some parameter in the environment; and actuators, that move in a well-defined manner. A MEMS is produced in a manner similar to that employed for microelectronics, i.e., thin layers of material are deposited on a substrate, which is subsequently etched until one has a three-dimensional structure with mechanical and electrical properties. The electronic parts handle the data and the mechanical parts perform the tasks.

The end result is a complete system on a chip. Integrated circuits supply the "brains" while MEMS take care of measurement and control. MST (Micro System Technology, as it is known as in Europe) is already in widespread use in a variety of products such as airbags (where MEMS are responsible for detecting collisions and deploying the airbags), inkjet printers (where the MEMS chips precisely regulate the nozzles that deliver the ink), and video projectors (where MEMS control the small mirrors that adjust pixel brightness).

### 7.1.1 MASS PRODUCTION

It's one thing to build "top-down," i.e., build at progressively smaller sizes: building "bottom-up" is something else entirely. A good portion of nanotechnology research is focused on building relatively large objects atom-by-atom, molecule-by-molecule. The challenge here is to create a means of production that is big enough to make objects than can be handled by people. In other words, the machine needs to be capable of reproducing itself. However, we don't necessarily need to be capable of building something human-sized before things start getting interesting. Building nanorobots that can perform tasks inside the human body is another exciting area of research.

But there are other perspectives as well. When the scale of the structures that are being built are on the order of a nanometer in size, the structures can directly affect and interact with their surroundings on a molecule-by-molecule basis. This means that it's possible to fine-tune and tailor metal surfaces so that they can catalyze a given chemical reaction as optimally as possible. We can imagine all kinds of applications spanning from fuel cells (for generating electricity from hydrogen and oxygen) to self-cleaning clothing and extremely strong materials constructed with carbon nanotubes.

The next step for nanotechnology is biology. Completely new enzymes (biological catalysts) can now be designed from scratch. In this case, both the sequence of base pairs *and* how the proteins fold about themselves, i.e., the morphology, are important. Small, nanosized air bubbles are already being used, on an experimental basis, to aerate polluted lakes in China.

Nanoscale electronics can exploit electron quantum effects in completely new ways, resulting in semiconductor chips that are faster, cheaper, and with bigger memories. IBM expects to launch a carbon nanotube-based chip for the semiconductor industry's 5 nm "node" in 2019. Nanotechnology is, in many ways, the basis for the continued exponential growth in computer technology.

The wavelength of visible light is also measured in nanometers. This enables us to modify the interaction of light with matter and make, for example, "invisibility cloaks" that deflect light instead of reflecting it (this is already routinely done with microwaves).

## 7.2 CREATIVE CROSSING

It's hard to find an area of technology where improved capabilities to build at smaller sizes doesn't automatically result in new and interesting applications. Initially, it primarily revolves about material properties and sensors, but ultimately, it's all about what uses we can find for machines when they are so small. We have selected a couple of examples where nanotechnology will have a huge impact.

### 7.2.1 MEDICINE, HEALTHCARE AND NANOTECHNOLOGY

Within the field of medicine, our ability to perform precise surgical procedures has long been recognized as the best way to avoid complications and undesirable effects. The less invasive the surgery, the lower the probability of infection, and the faster the patient will recover. This is why doctors use keyhole surgery in many situations today. In these cases, the tools are so small that the operation can be performed via a small tube. Nanotechnology will make it possible to fabricate small robots that will travel throughout the entire body via the cardiovascular and lymphatic systems and attack disease wherever they encounter it.

IBM and Singapore's Institute of Bioengineering and Nanotechnology are already experimenting with this technology today. It transpires that IBM's competencies in developing polymers for ever-faster semiconductor chips can be used to "build" medication to fight antibiotic-resistant bacteria. The polymers are modified so that they attach themselves to the bacteria's membrane, cause the membrane to rupture, and release chemicals that can destroy the bacteria much more effectively. More recently, researchers have attached a protein to the nanocell so it won't be attacked by the body's own immune system.

At a certain point, we will become so proficient at building at ever smaller sizes, that we will be capable of building small robots that can transport themselves around our body and treat illnesses. One of the nanorobots that's on the drawing board is the respirocyte, an artificial red blood cell (a nanoparticle with a store of oxygen) which can be injected into the bloodstream. These particles remain dormant until they're needed. In other words, until your heart fails or you need to exert yourself for a prolonged period of time. In these situations, the respirocytes will release a steady stream of oxygen until you can be brought to a hospital and have you heart repaired (we will meet the respirocyte again later in this book).

This is, of course, taken care of by nanorobots that are injected into the body, make their way to the heart, and carry out the necessary repairs. Unless, of course, you would prefer a brand-new, 3D-printed heart instead?

## 7.3 DEVELOPMENT DISRUPTION

It's difficult to imagine what kind of world we will come to live in when the promises of nanotechnology are fulfilled. One thing is certain: the materials we will use and the surfaces that we will surround ourselves with will be completely different than those we are familiar with today.

One of the biggest disruptions that nanotechnology can precipitate is a radical transformation of our understanding of the biology of humans. Nanotechnology heralds, more than anything else, the transition to transhumanism: the potential to not just make us less susceptible to illness, but also more intelligent and stronger – not to mention faster healing and maybe even with the ability to see in the dark.

A completely different, yet very important, aspect of nanotechnology is the risk. If we are capable of building everything at the scale of the atom and the molecule, it will have major repercussions for a large proportion of the manufacturing industry and the work force. The current equilibrium between the work force and the economy will be displaced. However, the ultimate doomsday scenario is that the Earth ends up being covered with a gray, self-replicating sludge that devours everything. Try looking up "gray goo" on Wikipedia. Nanotechnology is no different from any other technology in this regard: it has the potential to be both a boon and a bane. Consequently, nanotoxicology and related areas should be taken very seriously.

# PART 3
# HOW WILL EXPONENTIAL ACCELERATION IMPACT YOU?

# 8 THE IMPLICATIONS

The accelerating developments in technology will have huge implications for us, not just as individuals but also for some of society's most deep-rooted institutions. In the digital age, the system's complexity is increased, and the current organizational structures are no longer adequate.

## 8.1 EDUCATION

The manner in which education is organized today is essentially the same way it always has been for the past 300 years in Europe. The centralization of schools is based on the premise that both teachers and buildings are scarce commodities and that the educational system is an important element of nation-building. Globalization and the digitization of the dissemination of knowledge have altered this basic assumption. Furthermore, the acceleration of the rate of change means that the current model, whereby we educate ourselves for the first 25 years of our lives in order to work within the same area for the following 40 years, is no longer tenable. We expect huge changes within this field.

At the macroscopic level, the monopoly that the existing educational institutions have had will crumble. Change will come about in three waves. In the first wave – which is already happening – content will be democratized and the learning experience itself will be digitized. In the second phase, artificial intelligence will enable unprecedented customization of the learning experience. In the third wave, we will be able to incorporate machines into our bodies: machines that will supplement our own memory and accelerate our learning processes.

Just like other institutions, education will also gravitate towards a decentralized organizational structure. The outcome of this will be that everyone will have access to high quality material from relevant schools. We are still in the early stages of this transition, but there are already a large number of free courses available to everyone with internet access. Some of them are just video recordings of lectures; others are much more interactive, with pop quizzes and feedback modules. In countries where everyone has access to free, high-quality education, the effect at this point in time is minimal. However, in regions where education is restricted to the "haves", the impact is huge. Now education is no longer hampered by inadequate access to educational resources, but instead by inadequate access to the internet.

The optimal learning process will include elements of face-to-face interaction and digital platforms. But while the virtual, digital universe is growing exponentially, the institutions' bricks and mortar learning environments are on a flat, linear trajectory. Consequently, the digital universe will gradually take over more and more of the learning process.

Artificial intelligence will make digital teaching a unique experience for everybody. Next generation software will be able to ascertain the strengths and weakness of each individual student and, based on this, customize both the material and the exercises. We will distance ourselves from the mindset of the Industrial Revolution, where students are grouped according to their year of birth and all taught in exactly the same way.

As bandwidth grows, the impression of being physically present will be enhanced via virtual immersive environments. According to Ray Kurzweil, by the first half of the 2020s, these virtual environments will be so compelling that people will prefer them to being physically present.

The next big revolution will come when we are able to integrate non-biological memory with our brains. At that point we will be able to download new knowledge the same way we download software today: it'll be like being able to "google" with our thoughts.

### 8.1.1 QUESTIONS TO PONDER

Are you aware that it's possible to further educate yourself through MOOCs (Massive Open Online Courses) such as Coursera and Udacity?

How can you broaden the use of online training in your workplace?

Will it be through the medium of games and gaming that we will work and learn in the future? (Google "gamification.")

Do you want to change the way we learn? The XPRIZE Foundation has launched a competition to develop an app which can teach people who are illiterate to read. (Google "Global Literacy XPRIZE.")

## 8.2 ENERGY

Mankind is in a symbiosis with Nature. When we breathe, we convert oxygen to carbon dioxide. When we plant forests, we convert the carbon dioxide back to oxygen again. The extent and ramifications of our interaction with Nature are incredibly complex. We want to take care of the environment. We want to protect the Earth from ourselves, we say. But we might as well as admit – like the Fisherman's Wife in the tale collected by the Brothers Grimm – that we want to reign over the sun, the moon, and the stars. We would rather decide ourselves and control everything around us. We would rather understand the consequences of our actions, and either change our ways or counteract them with intelligent solutions. We want to be in total control.

Energy is pivotal in the Environmental Ecosystem. Here, at the beginning of the 21st century, it would seem that our energy consumption is one of the biggest causes of harm to the environment. We are trying to compensate by reducing our energy consumption and by switching to $CO_2$-neutral sources of energy, such as wind and solar. However, population growth and increased living standards in many parts of the world make this a losing battle.

Perhaps the solution is not to reduce consumption; perhaps the solution is to leverage technology to find new, sustainable ways of producing energy. Increased computing power means that we can untangle increasingly complex correlations and run more and more realistic climate models to simulate the impact of different factors. In particular, the growth of cheap solar energy will, in the long run, provide us with almost free, $CO_2$-neutral energy.

We have made use of the sun as a source of energy for thousands of years. Wind energy exploits the fact that the sun does not heat the Earth uniformly, and consequently creates areas of high and low pressure. Hydropower plants exploit the fact that the sun melts glaciers and snow up in the mountains. What's new is that we can convert solar energy directly to electricity – and it's getting cheaper and cheaper to do so. We're asymptotically approaching zero cost. The total amount of solar energy that is absorbed by the Earth during the course of a year is approximately 7,000 times greater than our annual energy consumption: 3.8 million EJ compared to a total energy consumption of approximately 500 EJ. Even if our consumption were to increase by 20% per year (as it is does right now), it would take about 49 years to reach this level. In the medium term, solar energy is the obvious choice. In the short term, a combination of many different sources is the obvious choice. In the long term, however, we need to think out of the box.

The growth in the ratio between yield and cost for solar energy has long followed an exponential curve. And if we extrapolate this growth, we will reach a point where the cost of energy will be same as the cost of water – essentially free. The ratio between solar energy and cost is increasing exponentially too. According to Travis Bradford, President of the Prometheus Institute for Sustainable Development, the cost of solar energy has fallen 5–6% each year: this implies that the energy/cost curve has grown, doubling every $15^{th}$ year.

Note that the doubling time in this case is considerably longer than those of microprocessors and DNA sequencing. This is primarily because energy doesn't scale the same way that electrons and bits do. However, it's also because the cost of energy is a complex beast, affected by factors such as demand, distribution, and policy decisions to a much greater extent than the cost of computing power.

Up until now, it has been more expensive to produce electricity from solar energy, but we are approaching parity. Solar energy is competitive, but only with subsidies that cover 10–30% of the costs. Continued innovation means continued cost reductions, so in a few more years, subsidies will no longer be necessary. Things will really take off then.

In his book "Abundance," Diamandis writes: "So when critics point out that solar currently accounts for 1 percent of our energy, that's linear thinking in an exponential world. Expanding today's 1 percent penetration at an annual growth of 30 percent puts us eighteen years away from meeting 100 percent of our energy needs with solar." Given a 5% reduction in unit cost per year, the unit cost in 18 years will be 60% less than it is today.

### 8.2.1 QUESTIONS TO PONDER

A considerable number of products are built upon the premise that energy is a scarce resource. How would essentially free and clean energy impact your workplace and your products?

What impact would it have on water shortages in the world?

What impact would it have on pollution and the environment?

## 8.3 WORK AND MANUFACTURING

Over the course of the next 20 years, all routine manual and mental labor will become automated. Like the transitions from agrarian societies to industrialized societies to the Information Society, it will involve a radical change to the kinds of tasks we humans perform. The challenge this time round is that the transition will take place considerably faster than was the case for industrialization, and will be more comprehensive than the transition to the Information Society.

The tasks that we perform as workers will also change considerably. Robots and artificial intelligence will take over a large proportion of our tasks. Some types of jobs will disappear completely. Taxi drivers and truck drivers that are replaced by self-driving vehicles are the classic example. The same applies to pilots, store assistants, teachers and accountants. A wide range of other types of jobs will be performed considerably more efficiently because of automation, making many of us redundant. Somewhat surprisingly, photo models also risk being more or less completely replaced by "perfect" virtual robots. As discussed earlier, several research institutes have calculated that up to 50% of the work force is at risk of losing their job as a consequence of these developments.

But it's not just what we do: the way we organize ourselves will also change. The dynamics that characterize corporations will also change. Back in 1937, the British economist, Ronald Coase, argued in his Nobel Prize winning article "The Nature of the Firm", that companies arise because their internal organization is more efficient than the market's. Up to a certain point, it's more effective to have employees rather than cope with the complexity involved in entering into contracts for everything in a free market. Search is probably *the* technological parameter that has had the greatest impact on this balance. Over the last 20 years, the internet has brought us much closer to perfect market information transparency and shifted the equilibrium point between the organization and the market more towards the market.

Another significant parameter which upsets this balance is the globalization of markets and the hunt for talent. As Bill Joy, cofounder of Sun Microsystems, has been quoted as saying: “No matter who you are, most of the smartest people work for someone else.” No employee can deliver anything that is better than what the entire amount of talent that can be accessed in a structured manner via the internet can. Your organization’s success hinges upon your ability to access and exploit all the talent available in the global marketplace. The classic narrative is the story about the Goldcorp mining company, a company which, among other things, inspired the development of the Linux operating system. Goldcorp made all its geological data publically available and held a competition to see who could find the most gold. This approach was a huge success for Goldcorp: 110 new sites were identified, of which 80% yielded substantial deposits, and the company’s market capitalization increased from 100 million dollars to nine billion dollars.

These new dynamics are mainstream now. There are companies such as 99designs for design and Kaggle for data analysis who offer to hold competitions for your company. The crucial parameter for success is no longer capital, but talent. The organization of the future will comprise of a small core team and a large group of “workers for hire” or perhaps even a passionate group of volunteers.

### 8.3.1 QUESTIONS TO PONDER

How will your job be affected by automation?

How can your workplace access talent outside of the company?

Perhaps you should make your talents available outside of your company and share your talents among several employers?

## 8.4 DISRUPTIVE COMPANIES

People and companies react differently to change. Some regard it as an opportunity while others consider it to be a threat. Some don’t even see it coming! When we talk about change as a direct consequence of technologies that grow exponentially, the latter is often the case. We see neither the threat nor the opportunity before it’s “game over.”

Important as it is to understand the rate of change, it’s just as important to understand where the competition is coming from. The threat of disruption doesn’t come from the established players that resemble oneself. It comes from the small startups that bring technology into play in unprecedented ways, and who understand how to exploit the exponential growth of their core technologies.

#### 8.4.1 KODAK

The best example of a company that became obsolete is Kodak. There was a time when pretty much everyone in the Western Hemisphere – and elsewhere – bought Kodak film regularly. When Kodak was at its zenith in 1988, it had no fewer than 145,300 employees. Kodak was also extremely profitable, and was traded at 100 dollars per share as recently as 2000. But within the space of a decade, the share price dropped to under 25 cents, and in 2012, the company filed for Chapter 11 bankruptcy protection.

The digital photo represented something completely different to what Kodak stood for. It could in no way match the image quality requirements that Kodak's customers expected, but it could do something else. The digital photo heralded a completely different way of taking pictures. Not only could one take as many as one wanted to, one could also easily share them with friends and family. These secondary features became the decisive ones and ended up making Kodak redundant.

Note that it was not the digital camera itself that was Kodak's downfall. It was the convergence of digital cameras with high-capacity hard disks (how many pictures can you take before you have to offload them?), social media (where sharing photos is what you do), and increased bandwidth (the ability to share photos both quickly and easily).

Why didn't Kodak get with the program? In fact, it was Kodak's engineers who had invented the digital camera in the first place. In 1991, they were good enough to fly with NASA. The R&D people at Kodak knew what was going on: they just underestimated how quickly it happened. Up and until 2000–2003, film sales continued to increase! And the transformation was difficult too. Kodak's core competencies were photography, chemistry, and paper, and the business model was built around this. Digitization made a number of Kodak's competencies redundant and – even more importantly – it kicked the legs out from under the business model. Real change at Kodak would have required new employees and new business models. Kodak lived and died with its technology.

Kodak clearly illustrates that even though one has seen it coming, it can still be impossible to make the necessary changes. Not least of all because the transition is so rapid.

### 8.4.2 NETFLIX

Another good example is Netflix. Netflix was competing with Blockbuster for the DVD rental market. Blockbuster distributed through their stores, Netflix sent the DVDs by mail. In 2007, Netflix began to offer access to movies via the internet. The quality was nowhere near as good as the DVDs, and very few customers could connect their computers to their TVs and see the movies on a big screen. None of Blockbuster's customers expressed an interest in renting movies via the internet, so Blockbuster consequently decided to wait and see.

Bandwidth and the proliferation of smart-TVs, tablet computers, smartphones and other equipment that could be connected to the internet (and could therefore be used to view Netflix) grew exponentially. By April 2011, Netflix had 50 million subscribers. Blockbuster had already gone bankrupt in 2010.

### 8.4.3 AMAZON'S E-BOOK

Amazon's sale of e-books is interesting. The story is similar to that of Kodak and Netflix in that the product, the e-book, did not initially meet the customers' basic needs. The e-book has a number of advantages that a traditional book does not have. In just a matter of minutes, one can access a selection of books that far exceeds that of any bookstore or library. Digital books don't have to be printed or distributed, and are therefore cheaper. While reading, one can look up a word directly from the text, share blocks of text and notes, and see how much longer it will take to finish reading the current chapter. We can also read e-books on a variety of devices (e-book readers, tablets, smartphones, etc.) and they don't take up any space. Despite all these advantages, paper books still outsell e-books.

There's something about paper that's difficult to circumvent. Studies show that we both understand and remember what we read on paper better than what we read on a screen. In other words, there's something about the physical nature of paper and books that e-books can't yet emulate.

If we apply Clayton Christensen's model for disruptive innovation to the book's specific function (to display text), paper books ought to have been retired a long time ago. Yet they haven't been. In the transition from the physical world to the virtual world, there can be linkages to the physical product that alter the picture.

### 8.4.4 WHO'S NEXT?

Exponential growth can be extremely profitable for those who can both recognize and take advantage of the trajectory. But the trajectory destroys those who realize too late where it's heading. Exponential growth can either lead to fortune or to failure.

Disruptive changes will indiscriminately strike both large and small industries. For some industries, change will be obvious; for others, it will come as a surprise and be impossible to predict. Common for both is the need to be acutely aware of the transformational power that technology can wield and stay up-to-date on developments in the sector. "Only the paranoid survive," as former Intel CEO Andrew Steven Grove writes.

It's just as important to experiment by continuously introducing new concepts and products in collaboration with suppliers and customers. The experiments yield priceless insights and, quite often, a valuable network.

In the next chapter, we will present our proposal for a methodology to create innovative ideas by combining exponential technologies.

### 8.4.5 QUESTIONS TO PONDER

Can you detect signs in your own company that you are "trapped in a relationship" with your current customers, suppliers, and the company's current core competencies?

Are small startups among the pool of competitors that you monitor?

Do you keep abreast of new technologies that could potentially create new business opportunities?

## 8.5 HEALTH AND LONGEVITY

One of the more difficult topics to reconcile ourselves with is changes to our biology, i.e., our bodies and our life expectancy. We already use technology today where our own bodies are deficient. We transplant organs, insert pacemakers to monitor our hearts, and replace our hips and knees with artificial ones. This trend will continue as the technology develops, and consequently, the line between man and machine will become blurred in the future.

Quantified Self or "self-tracking" is only the first step in this direction. Our wish to optimize our activities – "to get more out of life" – is a strong motivator. Combining software and simple sensor data has given us unprecedented insights into our movements and our progress. The next generation of sensors will be in contact with our skin, and will not just gather information about our activities, weight, or sleep patterns, but also about our pulse, heart rhythms, perspiration levels, and body temperature. We will also be able to measure less tangible parameters such as what mood we're in, our well-being, and nourishment.

Self-tracking will make us aware of causes and effects in our lives that we simply weren't aware of before. There's no guarantee that our lives will improve because of it, but now we have the option to make the changes and track the consequences.

The next stage will be more invasive: we will insert technology into our bodies. Nanotechnology will reach the stage where it's feasible to introduce so-called nanobots into our body, initially to maintain and strengthen our biological system, but ultimately to replace it in the form of artificial organs, etc.

As we mentioned in a previous chapter, one of the more interesting nanobot ideas is Rob Freitas' red blood cell: the respirocyte. Our biological red blood cells don't perform their task particularly efficiently, so Freitas has redesigned them so that they perform optimally. His calculations indicate that these red blood cells will be 100 times more effective at distributing oxygen throughout the body. In other words, anyone with these red blood cells would be able to survive for hours without breathing. However, don't hold your breath: we're probably going to have a wait a couple of decades for Rob Freitas' red blood cells.

All these technologies will not just improve our lives within the current frame of reference. With the aid of technology, we will be able to extend our current lifespans considerably. As was discussed in a previous chapter, the aging process which takes place in our body over the course of a lifetime is, in many regards, due to the accumulation of damage. During the early years of our lives, the damage is limited, but when we're around 80 years of age, the accumulated damage is so great, that we start developing age-related illnesses such as Alzheimer's. At some point, the accumulated damage will become so great that we die. Life Extension Researcher Aubrey de Grey's goal is to stop the aging process itself. His contention is that if we can stop the aging process, we can also stop age-related illnesses.

This is a very unorthodox perspective in medicine today. What Aubrey de Grey is basically saying is that we should shift our focus from curing illnesses to removing what causes them to occur in the first place. In other words, it's not about extending your life when you grow old, but more about regenerating your body when you are middle-aged. Our lives will be both longer and of better quality. While the total cost of treating illnesses may decrease, the cost of healthiness will increase.

The average life expectancy has increased by three months per year during the past 100 years or so. Both Aubrey de Grey and Ray Kurzweil are convinced that new research will enable us to increase that number to 5, 6, and 13 months per year. This growth trajectory is extremely interesting and has a slew of economic, political, and ethical ramifications.

### 8.5.1 QUESTIONS TO PONDER

Singularity University's Exponential Medicine Program showcases a cavalcade of revolutionary advances in medicine that all point towards dramatically extended lifespans. If you are in good health 30 years from now, it looks like technology might give you an extra 30 years. And after these extra 30 years have passed, how many more years may you expect from exponential growth?

What are you doing today to ensure that you are still healthy 30 years from now?

Have you thought about how you are going to finance a longer life? Jannick is prepared: he has purchased a life annuity contract that first starts paying out when he reaches the age of 90.

When you need medical treatment, do you make sure that you know at least as much about your condition as the person treating you? Would deferring it by, for example, 5 or 10 years give you other treatment options because of new technologies?

# 9 THE EXPONENTIAL CURVE EXPLORER

When the rate of change accelerates as we have just described, it becomes more important than ever to be able to foresee technological developments. If we don't do so, the odds of becoming obsolete are high. In this chapter, we will introduce a methodology which makes it possible to understand, discuss, and work with innovation in an increasingly accelerating technological world.

It's not that it's difficult; it's just that it takes some effort. Technological developments within a number of core technologies can be extrapolated relatively easily. The challenge lies in figuring out how the different technologies will converge, or bring each other into play, so that previously unknown possibilities can emerge. We mentioned the Kodak case earlier where increased bandwidth and social media services such as Facebook made the digital photo much more relevant and superior in its battle with paper prints.

Our methodology is based on technological developments and the disruptive innovation that comes of it. In other words, the products or services, that by their very nature, replace what was there before. They are particularly interesting because, on the one hand, they can completely eradicate a company's livelihood whereas, on the other hand, they also have the potential to conquer new markets and ensure a company's survival in the long term.

A disruptive technology is particularly difficult for a company to face since it challenges the existing relationships with customers, products, suppliers, and prior technology choices. This network of relationships is also reflected in the organizational power structure that the company has built up. While this ensures that the company is competitive in the existing market, it can make it blind to the possibilities of a new, disruptive technology.

Our methodology is not in itself disruptive; neither does it guarantee disruptive products. However, it frames technological developments in such a way that the disruptive potential can be more easily seen. This is achieved primarily by identifying lucrative technology discontinuities.

The methodology is based on the three concepts – Exponential Acceleration, Creative Crossing and Development Disruption – that we employed when we discussed the exponential technologies. We call the model the Exponential Curve Explorer, or ECE (pronounced "easy").

## 9.1 EXPONENTIAL CURVE EXPLORER™ (ECE)

### 9.1.1 STEP 1 – DECONSTRUCT

The first step in the Model is to deconstruct. Deconstruction entails analyzing the existing product (or service) with a view to identifying and listing the most important technologies that it incorporates. Even though the product (or service) itself may not be based on a given technology, the manufacturing, handling, delivery or usage of the product (or service) may be linked to a technology. These aspects should therefore also be taken into consideration.

The list of technologies is then supplemented with other technologies that one expects to be relevant for the product at some point in the future. In other words, technologies that will or could be introduced in and around the next generation of the product. It's important to focus on technologies that are on exponential trajectories: technologies such as AI, robotics, biotech, nanotech, medicine, neuroscience, energy, and IT. The "List of Emerging Technologies" on Wikipedia can also serve as a source of inspiration.

The list will probably be relatively long, so select the 3–4 most important technologies for the next steps.

### 9.1.2 STEP 2 – ACCELERATE

The second step is to accelerate. It is assumed that each technology is on an exponential trajectory, so plot them each in on a 20-year exponential curve and mark off 5, 10, and 20 years. Now try to imagine what impact the technology would have on your product if the performance/price ratio increases by a factor of 30 after 5 years, by a factor of 1,000 after 10 years, and by a factor of 1,000,000 after 20 years.

At this stage, it's vital that you address the acceleration of each technology individually, and don't try to visualize them intersecting with any other technologies. We will address intersections when we reach Step 4.

After you have let your imagination run riot, you now turn to the data. You need to determine how fast each technology's performance/price ratio is *really* growing. We have initially assumed that the exponential rate of growth corresponds to a doubling each year, i.e., 100%. In reality, the growth rate could be either greater or less than this. Start by determining the curve's acceleration (or growth) for the past 10 to 20 years. If the technology has "gone digital" within the past 5 to 10 years, assume that the current growth rate will continue. If the technology has only just recently "gone digital" (or maybe hasn't even been digitized at all), then it is best to assume that the rate of growth will increase dramatically. Redraw the curve with the correct slope and recalculate the realistic performance/price ratio after 5, 10, and 20 years. This calculation will, in all likelihood, deviate from the initial estimate where it was assumed that the growth rate was 100%, i.e., a doubling each year.

When things change as quickly as is the case with these technologies, it's vitally important that the innovations anticipate the changes and thereby follow the exponential curve. Steve Jobs' hockey metaphor captures it very well: "…don't skate to where the puck is, but where it is going to be."

### 9.1.3 STEP 3 – SENSE THE ABYSS

The third step is to sense the abyss. We will now try to identify what kinds of discontinuities and development disruptions we could potentially be subjected to.

We start by reviewing a variety of technologies. Are there any disruptive technologies on the way that could essentially render us obsolete from one moment to the next? A disruptive technology can be characterized by a completely different price, performance, and/or user experience compared to the existing technology.

It's worth pointing out that digital products often follow a completely different logic compared to "traditional" products as far as pricing is concerned. The performance/price ratio for hard disks and data transmission rates are both growing exponentially. This means that the cost of storing and delivering digital products – the marginal cost – is approaching zero. When a digital product is first developed, it costs very little to scale up. This allows novel pricing strategies and even free products.

Following this, we then review trends in the market, demographics, and political factors. When we are done with all this, we ought to have an overview of the critical assumptions that need to be valid for our product to continue to be relevant. The objective being, of course, to develop our products so they are not dependent on these assumptions.

### 9.1.4 STEP 4 – INTERSECT!

The fourth step is to intersect, or "cross creatively." First of all, you try to imagine what would happen if all these technologies were to intersect with each other. What kind of new functionalities, products, processes, and methodologies emerge from these creative crossings? Next, you include additional technologies and repeat. There really is no limit to how many times you can repeat this particular step. On the contrary: inspiration from completely different fields is very important. Science fiction, in particular, can often be a useful device to get our imaginations to roam.

Note that product lifetimes become a lot shorter when the underlying technologies are growing exponentially and converge with other technologies. The products need to be updated continually, and product lifetimes of 3–5 years are not unusual.

Some of these products could very well lie outside our current business areas. A very important part of the process is, therefore, to evaluate the consequences for our current strategy. Would the introduction of these new products necessitate new competencies, a new organization, new partnerships, et cetera?

### 9.1.5 STEP 5 – DREAM

The fifth and final step is to dream. This is where you bring it all together. The previous four steps should have given you a good overview of the technological landscape for your future products. So now you should try to imagine, based on this landscape, dream-like, yet undreamed-of customer needs. You should also avail yourself of megatrends such as Personalization and the Sharing Economy. Try to create a product or a service that meets a broad, generic need – or one that no one realizes that they need – and that makes the world a better place.

And it doesn't have to be nonprofit. As they say at Singularity University: "You want to be a billionaire? Go solve a problem that affects a billion people!"

**HAVE FUN!**