THE NEXT BIG THING

From 3D Printing to Mining the Moon

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With Best Wishes,

Christopher Barnatt.

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PROLOGUE

BEYOND THE INTERNET

In 1995 I published a book called *Cyber Business* that predicted the birth of e-commerce and social media. Since that time I have frequently been quizzed about future online trends, and have introduced many individuals and organizations to key developments like cloud computing. Even so, when people now ask me about the world of tomorrow, I often begin by stating that the Internet Revolution has come to an end.

The mainstreaming of the Internet in the closing years of the 20th century was undoubtedly a seminal moment in human history. Nevertheless, no period of revolution can go on indefinitely. Look back 375 million years, and our ancestors were dragging themselves out of the oceans and developing a technology called 'lungs' in what we could term the 'Breathing Air Revolution'. To this day, lungs remain critical to the survival of all mammals. And yet the Breathing Air Revolution has clearly long since ended.

In a similar fashion, now that the Internet has become established as our collective, planetary nervous system, so the idea of the 'Internet Revolution' ought rapidly to be consigned to history. Granted, the online world will continue to incrementally evolve. But those seeking radical, future shaping innovation really need to divert their attention away from the cyber world to which we increasingly retreat.

While our civilization is now reliant on the Internet, we are even more dependent on the sustainable production of physical things. We therefore need to shift our collective focus away from the digital world, and toward the innovation of radical new manufacturing methods and the attainment of fresh resource supplies. If only to ensure our civilization's long-term survival, it is now time for the human race – and the world's stock markets – to recover from Internet fever in preparation for the Next Big Thing.

The following chapters extrapolate from bleeding-edge science and engineering to predict ten dominant technologies and related undertakings of the 2020s, 2030s, 2040s and beyond. In doing so, the four parts of this book additionally highlight four fundamental future transitions. These will take us on a journey from the reign of the microprocessor to that of the microfabricator; from a use of dumb computing devices to a cohabitation with smart synthetic citizens; from consuming less here on the Earth to finding more resources out in space; and from healthcare systems focused on medical maintenance to those which champion generational upgrades of the human form.

While each of the ten Next Big Things that will underpin the above transitions could develop and be studied in isolation, it is my contention that they are all highly interrelated. Understanding these interrelations is also quite important. So, before we get to chapter 1 – and to provide some explanation of the last paragraph! – here is a brief overview of things to come.

LOCAL DIGITAL MANUFACTURING

The current model of industrial production works roughly like this. Somebody dreams up a new product, a factory thousands of miles from most potential customers is tooled up to produce it, and a large number of identical products are manufactured in the hope that somebody, someday will want to buy them. The products are then transported to a ware-

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house, from where they are gradually shipped to wholesalers and retailers for potential sale.

In time, many products are sold, although about one-seventh of the resultant revenues are spent on transportation, warehousing and related logistics services. Unfortunately, some of the products that are manufactured are never actually bought by anybody, and need to be discarded. This highly wasteful, globalized, mass production arrangement works because there are enough relatively cheap natural resources still available for companies to be able to squander a great deal and still make a profit. But as resources become less plentiful and energy prices rise, so how most things are made will have to change. And this is when we will transition to local digital manufacturing.

As detailed across Part I of this book, local digital manufacturing (LDM) uses digital technologies to make products on demand very close to where final consumers actually live. Using future LDM hardware, designs for both inorganic and organic products will be able to be stored and transported digitally, before being locally 'materialized' into a physical format one layer, cell or molecule at a time.

Right now, as we shall explore in chapter 1, the most developed LDM technology is 3D printing. This builds objects in layers, and even today can fabricate items in plastics, metals, ceramics, foodstuffs and living cells. Already jewelry, car bodies, toys, aerospace components, medical devices, works of art and buildings have been 3D printed. Using an organic 3D printing variant called 'bioprinting', living human tissue has also already been manufactured one layer at a time. Of all the Next Big Things detailed in this book, 3D printing may well be the first to enter the mainstream. Though when it comes to local digital manufacturing, 3D printing will be just the tip of the iceberg.

In addition to 3D printing, there is already another highly versatile technology that can turn digital designs into complex physical things in pretty much any location. This amazing technology is life itself, with the DNA of all plants and animals containing a robust digital code that can tell cells how to reproduce, rearrange and subsequently function. So what if we could turn living biology into a construction kit that could be digitally programmed as a production technology? Well, we have already started to do this with the creation of a new science called synthetic biology.

As we shall see in chapter 2, synthetic biology allows living things to be created that have never existed in nature. Already synthetic biology is being applied to develop microorganisms that can ferment organic feedstocks into biofuels, bioplastics, bioacrylics and pharmaceuticals. In time, synthetic biology even has the potential to create new plants and novel animals for specific manufacturing purposes. Consumables for 3D printers, for example, may one day be grown locally in desktop hydroponic devices or urban vertical farms.

As well as relying on 3D printing and synthetic biology, LDM will be facilitated by next generation nanotechnologies. As we will investigate in chapter 4, so-termed 'atomically precise manufacturing' (APM) will permit objects to be fabricated on a molecular scale using a process called 'self-assembly'. Over the next two decades, we are also likely to witness the convergence of nanotechnology with 3D printing and synthetic biology. In turn, this will facilitate the construction of 'microfabricators' that will be able to fashion a very wide range of highly sophisticated products directly from digital designs.

Even today there is an overlap between 3D printing, synthetic biology and nanotechnology, with scientists and engineers in each discipline increasingly sharing knowledge and techniques as they learn to digitally manipulate matter on a very small scale. For example, nanoscale 3D printing processes are starting to be developed that can allow material

composition as well as material placement to be digitally controlled. Add in synthetic biology, and future microfabricators should be able to control the composition, placement and living behaviour of digitally manufactured things. As I said a few paragraphs back, 3D printing will be just the start of the local digital manufacturing revolution.

SYNTHETIC CITIZENS

A score or less years hence, we are very likely to be sharing our first planet with artificial entities more intelligent than ourselves. As we will discover in chapter 4, some of these will be disembodied artificial intelligences (AIs) that will help human beings with specific tasks at which machines tend to excel. Already so-termed 'narrow' forms of AI are able to pilot aeroplanes, drive automobiles, diagnose disease, manage power grids, track vehicle license plates, translate languages, and perform stock market trades. Many people are also starting to use 'virtual assistants' (VAs) like Microsoft's Cortana or Apple's Siri, with the trend to develop AI as a next-generation computing interface set to continue.

Today, Cortana or Siri are novel add-ons bundled with an operating system. Yet in less than 10 years, Microsoft or Apple's primary product may well be a virtual assistant with an operating system and supportive hardware bundled on top. This means that, sometime in the 2020s, we may talk far more about VAs and far less about PCs. Indeed, if you are wondering why there is not a section of this book devoted to future computing, it is because I suspect that we will soon look back on the use of dumb computing devices as a rather quaint late-20th and early-21st century phenomenon.

Exactly when and how 'artificial general intelligences' (AGIs) will be created is a point of significant contention. There are also many who believe that creating highly sophisticated AGIs is a dangerous undertaking that ought to be prevented, or at least very tightly controlled. Personally, I think that the development of AGIs is not just inevitable, but essential if we are to rollout widespread local digital manufacturing and in the process to deal with looming resource scarcity. Granted, current legal frameworks will need to be adapted to deal with very smart technology that can act autonomously and potentially do both very good and very bad things. We may even choose to give future AGIs some legal rights. Nevertheless, the real debate ahead will, I think, be far more about the role to be played in our society by non-human forms of intelligence, rather than whether or not they should be created.

In practical terms, it is likely to be the mainstream rollout of autonomous vehicles in the 2020s, and humanoid robots in the 2030s and 2040s, that will bring the critical debates surrounding AI to the fore. Within 15 years, most people will either be travelling in driverless vehicles, or will be relying on the autonomous carriages occupied by others not to crash into their car or to run them over on the sidewalk. As we shall explore in chapter 5, in a few decades time it is also very likely that humanoid robots will be delivering healthcare, looking after the elderly, and transforming at least some traditional production methods. Our artificial world has been crafted for occupation and manipulation by the human form. It will therefore make sense to build mechanical beings in our own image, even if doing so may not be to everybody's taste.

Robot ascendance is likely to be symbiotically associated with the rise of local digital manufacturing. On the one hand, robots will become a complimentary technology to 3D printing and synthetic biology, as they will be able to locally prepare and assemble product parts and raw materials that are fabricated on demand. The other way around, local digital manufacturing technologies will be critical in robot evolution, as they will become the dominant means of robot procreation. Even today, robot development is being driven forward not

just by the availability of cheap computing power, but due to the existence of low-cost 3D printers that can rapidly and cost-effectively produce custom mechanical components.

As synthetic biology and organic computing develop, it is also quite likely that parts for future robots will be able to be grown. Today, the popular vision of a humanoid robot is of a metal or plastic machine. But in three decades time, our mechanical servants and companions are just as likely to be constructed from living tissue, or else from materials produced via a synthetic organic process. Who knows, 20 or 30 years from now, you may have a warm bucket in a kitchen cupboard in which you are growing a new arm for your favourite android companion.

RESOURCES FROM SPACE

Today, a great deal of attention is starting to be focused on conducting our lives and operating our businesses in a 'sustainable' fashion. Usually this involves attempts to use fewer resources and to reduce our carbon footprint. Most of the time, such initiatives are a great idea. They will also be boosted by innovations in local digital manufacturing that will enable people to produce things using less energy and fewer raw materials.

The above points noted, all current and future attempts to become 'sustainable' can at best constitute a short-term solution to the resource requirements of future generations. Like it or not, it is a physical certainty that the raw materials and energy sources available on the Earth are finite. This means that, in the long-term, the survival of our civilization has to depend on obtaining fresh energy and raw material supplies from beyond our first planet. At least some of the AIs and robots referred to in the previous section will therefore spend their lives obtaining resources from space.

Across Part III of this book we will investigate a wide range of possibilities for extraterrestrial power generation and off-world mining. Staying closest to the Earth, chapter 6 will first detail how 'space-based solar power' (SBSP) could be developed. Future SBSP systems would place solar power satellites in geosynchronous orbit. These would then beam energy to 'rectennas' on the Earth using microwaves or lasers.

NASA began feasibility studies into SBSP in the 1970s. More recently, in April 2014 the Japan Aerospace Exploration Agency (JAXA) revealed a roadmap for a SBSP system to provide energy to Tokyo in the 2030s. The creation of such a system will require significant improvements in all aspects of space technology, as well as the potential development of entirely new means for getting into orbit. In addition to providing an overview of SBSP possibilities, chapter 6 will therefore examine the feasibility of future 'space elevators' that may help off-world energy production to become a reality.

While building solar power satellites may help to meet some of our future energy needs, it will not assist with the supply of physical resources. In chapter 7, we will therefore consider the possibility of mining the asteroids – a proposition already being taken very seriously by two foresighted companies called Planetary Resources and Deep Space Industries. I would already place a fairly safe bet that many of today's young people will one day own a consumer product manufactured at least in part from asteroid deposits.

In addition to SBSP and asteroid mining, we are at some point also likely to return to the Moon in search of new energy and raw material supplies. A potentially very valuable future nuclear fuel called helium-3 is relatively abundant in the lunar regolith, while our lonely satellite is also thought to harbour substantial deposits of cobalt, iron, gold, palladium, platinum, titanium, tungsten and uranium.

Since 2009, NASA experiments have also confirmed the presence of water on the Moon. This could prove critical in

supporting long-term human occupation, as well as providing a source of oxygen and hydrogen for rocket fuel. Chapter 8 will examine a range of options for lunar resource utilization, including the potential development of lunar space elevators and large-scale, Moon-based 3D printers.

TRANSHUMAN EVOLUTION

By the second half of this century, a growing proportion of the world's population will be a mashup of legacy biology and artificial digital technologies. Such 'transhumans' will have had their bodies or brains augmented using technologies including bioprinting, synthetic biology, nanotechnology, cybernetics and genetic medicine. The latter is the subject of chapter 9, where we will examine how – in a new age of post-genomic healthcare – doctors and AI systems are set to become programmers of human DNA. The 21st century is likely to be remembered as the historical period in which humanity took conscious control of its own evolution, and when the line between 'natural' creation and 'artificial' technology became irrevocably blurred.

As we shall explore in chapter 10, a cybernetic synthesis of human beings and machines is an almost inevitable consequence of the development of local digital manufacturing, the creation of robots and AI, and the pursuit of resources from space. Why? Well, for a start, as we learn to digitally manufacture products one layer, cell or molecule at a time, so we will also hone the skills necessary to take digital control of human biology. Since November 2014, bioprinting pioneer Organovo has been 3D printing human liver tissue as a commercial product (if currently for drug testing purposes), while the line between synthetic biology and genetic medicine is already tantalizingly thin.

In the short-term, legal and ethical constraints on the manipulation and adaptation of the human body may limit the extent to which future scientists and engineers will be able to 'play god'. But given that local digital manufacturing will empower individuals as well as corporations to inorganically and organically fabricate anytime, anyplace and anywhere, it seems inconceivable that its technologies will not be widely applied both in healthcare and to facilitate future human augmentation.

Some people may question why, later this century, anybody would want to merge with artificial technology. In part the answer is simply that the pursuit of excellence remains a common individual goal and the driving force of our evolution. More pragmatically, as AIs and humanoid robots become both more intelligent and more physically dexterous than human beings, so it is very probable that at least some people will want to 'keep up with the machines'.

Bioprinted or synthetically grown components for future humanoid robots may well be biocompatible with a genetically re-engineered human anatomy. So when somebody sees a robot strolling down the road with a cool pair of legs, they could favourite the design and have it downloaded and replicated for themselves. Some people in the future may even swap body parts as regularly as we currently change hairstyles or clothes. It may even become common to exchange limbs, eyes, memory circuits and information processing hardware with robotic co-workers or friends.

The above factors noted, the biggest driver of the most extreme form of cyborg synthesis is going to be our requirement to obtain resources from space. To achieve this goal, our civilization will need to send highly adaptable and intelligent beings far from the Earth, and not all of these will be able to be entirely robotic.

Unfortunately, the current human form is about as well equipped to live in space as a fish is suited to reside on dry land. Yes, humans can protect themselves in space suits and pressurized capsules, and can shelter behind radiation shielding when required. We can also take food, water and oxygen

with us from the Earth – or learn to obtain such critical life support supplies off-world. Although, when it comes to large-scale space endeavours, it is going to prove far safer and far more cost effective for future space pioneers to be transhumans with bodies designed for long-term deep-space survival. By the end of this century, we are therefore likely to witness the emergence of a new cybernetic superspecies who will not be reliant on oxygen, water and food, and who will be far less easily damaged by extraterrestrial radiation than their traditional human forebears.

TOWARD THE SINGULARITY

In 1961, science fiction author and futurist Arthur C. Clarke wrote that 'any sufficiently advanced technology is indistinguishable from magic'. Certainly, a great many of the technologies that we currently take for granted would have seemed magical only a century ago. Yet many of the innovations on the medium- and long-term horizon are destined to be even more astonishing. Microfabricators, synthetic citizens, resources from space, and our transhuman evolution, may therefore be perceived as impossible fantasies by the majority of the world's population.

Hopefully, as a reader of this book, you are distinct from the majority and more open than most people to accept the incredible developments and opportunities that lie ahead. As I have detailed in this *Prologue*, four fundamental transitions now loom on the horizon, and will soon drive radical changes in how things are made, who we share the planet with, where resources come from, and the evolution of the human race. Each of these transitions is going to be an extraordinary adventure. I am therefore pleased that, by choosing to read *The Next Big Thing*, you have decided to proactively step on board to anticipate the ride.

In aggregate, all of the technologies and undertakings explored in this book will lead us toward a moment in history called the 'Singularity'. This is a technological event horizon beyond which we cannot see, and that we will reach when exponential progress makes possible anything we can imagine.

Looked at from one perspective, we will arrive at the Singularity when the divide between 'technology' and 'magic' blurs. Or to reduce things to a more practical level, the Singularity will be upon us when we are able to digitally program, replicate, repair and otherwise control all forms of living or inorganic matter. At the Singularity and beyond, we will also no longer face any resource constraints, as we will have learned how to turn waste products into fresh raw materials, or to access the very broad range of resources waiting for us beyond Planet Earth.

Journeying toward the Singularity is likely to require the application of mental and physical capabilities far beyond those of the current human form. The creation of artificial intelligences and very sophisticated robots will therefore be essential if we are to arrive in a new age of enlightenment and plenty. Also very likely to be required will be some transhuman upgrading of *Homo sapiens*.

However magical it may sound, the Singularity is a point in future history that many of today's young people will one day experience, and which could turn out to be the greatest ever Next Big Thing. We live in extraordinary times that are going to get increasingly unbelievable. So, without further introduction, it is now time for us to explore the incredible possibilities that lie ahead . . .

CONTENTS