2
The Technology of the 4th Industrial Revolution

Introduction

This observation of a shift to pervasive machine automation has been made by many observers, driven by artificial intelligence into products and services; in living experiences; in design and manufacturing capabilities; to utilities and transport infrastructure and changing social and work boundaries. This topic was raised in the recent Davos 2017 Summit in a public discussion lead by Klaus Schwab, Founder and Chairman of the World Economic Forum, with Sergey Brin, Co-Founder of Google, Alphabet [1]. During the conversation, Klaus Schwab reflected that since the publication of his original book on the 4th Industrial Revolution just 12 months prior (in 2016), that much had changed. New technologies had appeared, including commercial drone deliveries, 1 Terabyte SD memory cards, carbon nanotube transistors, dust-sized sensors that can be implanted within the human body, SpaceX and Blue Origin reusable rocket landings, while Google's Artificial Intelligence beat the world-class Go player, Lee Se-dol, 4-1 [2]. But the most notable change they both agreed had been in artificial intelligence. Sergey Brin pointed out that "When I was heading up GoogleX a few years back we had one project which is now called "Google brain" (a deep learning research project at Google). I did not pay attention to it at all. Myself had been trained as a Computer Scientist in the 90s and everybody knew AI didn't work. People had tried neural nets but none of them had worked out. But Jeff Dean, one of our top computer scientists, (Google Senior Fellow in the Systems and Infrastructure Group) would periodically show examples (of machine

M. Skilton and F. Hovsepian, *The 4th Industrial Revolution*,
https://doi.org/10.1007/978-3-319-62479-2_2

learning) in development but that was a few years ago. Now Google Brain touches every single one of our main projects, ranging from search, photos, adverts, to everything we do at Google. There is a revolution in deep neural nets has been very profound and surprised me, even though I was sitting right there and could throw paper clips at it! This is an incredible time and very hard to forecast what these things do, we don't really know the limits" [3].

Driven by such rapid change is polarizing opinions across the spectrum of legal, technical, academic and government practitioners. This includes the dangers of social order from changes in jobs automation to new ways of doing things with technologies, which challenge the traditional economics view that new technology will replace the old and create new jobs from new technology. The 4th Industrial Revolution has this time raised the question whether this technological revolution might result in an overall reduction in human jobs, in the near term and decades ahead. But it also has the potential to revolutionize knowledge, science, and human potential, via robotics and augmented intelligence. This is set against the larger global issues of population growth and wellbeing, greenhouse gases, resource scarcity and sociopolitical change.

Sergey Brin and Klaus Schwab elaborated that the consequences of these technological changes deserve a lot of thought and that you cannot stop it, but you can try to channel it. There is a combination of the biological and digital revolution seen in examples such as CRISPR-Cas9 gene-editing [4] to genomics. On the other hand, machine learning has enabled advances in many fields impacting the economy, electronics to astronomy. Investing in these new kinds of intelligence creates a multiplier effect in many industries. We now have the ability to change our genes, to embed sensors into our body to connect and integrate into the social fabric of society. It seems to challenge what it means to be human in the future, what is individuality, and what kind of society do we want.

Technology is moving beyond the analytical to predictive and prescriptive powers with the rise of artificial intelligence. These technologies change how humans need to look at the values and norms of society. The agrarian revolution mechanized farming in the 1st industrial revolution, changing the availability of food and working practices, leading to cities and the infrastructure to industry and urbanization. Nevertheless, with the advent of 4th Industrial revolution we are beginning to see different concerns, which may have both good and bad consequences.

Klaus Schwab postulated that "we are looking at technology as threatening our present thinking and interpretation of how the world evolves, we need new thinking to define meaning, new concepts to define what humanity is, and what is the purpose of our lives?" [3].

This chapter provides a brief primer of the emerging technologies that are part of the 4th Industrial revolution, and considers how they are combining physical, digital and biological contexts that are radically altered by automation. In addition, we look at the rise of intelligent systems via advances made in artificial intelligence.

- The new technologies of the 4th Industrial Revolution
- The impact of physical, digital and biological systems
- The rise of Intelligent Systems

The New Technologies of the 4th Industrial Revolution

The digital revolution developed from the 1960s to the 1990s, during which time we saw the rise of digital electronics and its miniaturization, video, lasers to the personal computer and the mobile cell phone. The birth of the internet, together with advances in material and biological sciences instigated a fusion of these technologies, moving them into industries underpinned by telecommunications and computing. The 4th industrial revolution brought forward new breakthroughs in science, commerce, engineering but also and most significantly, cross-cutting issues in governance of society and social impact from these pervasive technologies.

It is perhaps surprising that historically many of these breakthrough technologies have origins well before the present decades and began in the middle to early part of the last century.

Technologies including digitization advances in Internet of Things (IoT), Virtual Reality (VR), Augmented Reality (AR), quantum computing and artificial intelligence (AI); to new physical manipulation in materials science in nanotechnology and 3D printing; to biological manipulation in bioengineering of genes, robotic surgery, prosthetics and wearables all have origins that can be traced back through several evolutionary steps (see Fig. 2.1). It is only when certain materials, physics, computational and commercial cost considerations are available, and properly aligned that ideas become a reality and move into the mainstream of use.

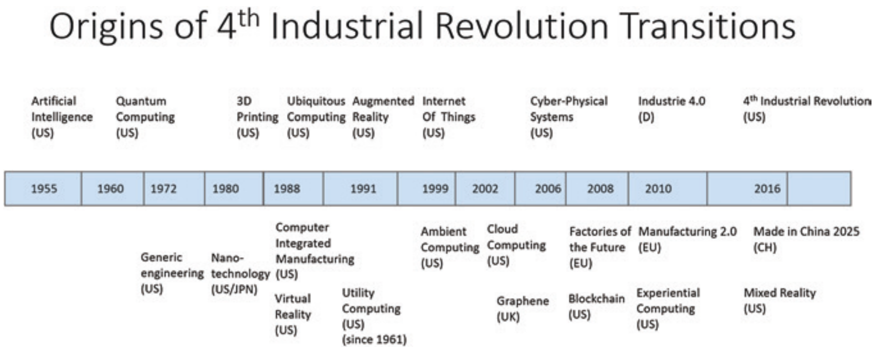

Fig. 2.1 Origins of the 4th industrial revolution transitions

Cloud Computing Multisided Platforms

Before we examine these technologies, it is important to remember that the genesis of on-demand computing happened during the digital revolution when the Internet was created. The protocols and networks established during that period saw the rapid rise of utility computing and functional architectures, which enabled the on-demand computing that we see today. Utility computing originated around 1991 but can be traced back to the early 1960s. John McCarthy, American Computer Scientist pioneer, speaking at the MIT Centennial as far back as 1961 said “Each subscriber needs to pay only for the capacity he actually uses, but he has access to all programming languages characteristic of a very large system. Certain subscribers might offer service to other subscribers. The computer utility could become the basis of a new and important industry. If computers of the kind I have advocated become the computers of the future, then computing may someday be organized as a public utility just as the telephone system is a public utility” [5].

While this story is now decades old it is also an important aspect of enterprise computing that enabled provisioning of computational resources, accelerating digitization across all industries and company sizes. Current debate and academic research, places great emphasis on digital platforming strategies, such as the multi-sided platforms (MSP) that can service multiple markets and customer sizes, as well as facility sharing and co-selling of the platform as-a-service [6]. We are surrounded by a multitude of examples from etsy and eBay, uber and Lyft, PayPal and Stripe, to amazon and Alibaba, google, Facebook and twitter. This is the shift to the “gig economy”, “uberization” and massive networked marketplace infrastructures for exchange, collaboration and trading. MSPs and other forms of digital platforms are significant in the 4th industrial revolution, because they establish the utility infrastructure on top of the internet that enables, at scale, various kinds of enterprise and social computing architectures and solutions. Just looking at the current Amazon Web services platform, demonstrates a huge variety of computing resources that include, processing, storage, databases, network and content delivery, analytics, artificial intelligence, security, identity and compliance, mobile, Internet of Things and messaging. Together with a polymorphic range of development tools and software, and access to a skills marketplace, make this a readily available platform for on-demand with pay-as-you-go services. This transition has catapulted utility computing into a global market size for cloud computing in 2017, estimated by Gartner at $246.8 billion with the fastest growth in cloud infrastructure services (IaaS) at 36.8% [7], from a total global Software and IT services spending in the IT industry of $3.5 Trillion for 2017 [8]. All this in a mere ten years that saw the first Amazon EC2 Elastic Compute Cloud service launched (2006) and the first Apple iPhone in 2007, quite astonishing.

Machine Learning and Artificial Intelligence

The first use of artificial intelligence in mainstream research was in 1956, at the Dartmouth conference organized by John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon, and is commonly cited as the birth of AI as a professional field of study [9]. The concepts of Artificial intelligence developed with other computational fields in database and programming languages, hardware developments and Graphical Unser interfaces and the invention of Very Large Scale Integration micro-electronics and semi-conductors in the 1970s. The 1980s saw new foundations laid in neural networks theories as well as the introduction of intelligent agents. The emergence of powerful computing resources, and the availability of vast amounts of information during the 1990s, enabled researches to develop more powerful models of computer learning, such as "deep neural networks", that we see today.

The concepts of the thinking machine, brain theories and neural nets and the first programmable Digital Computer were ideas that had been born in and not long after the WWII years by Alan Turing [10] and many others together with parallel processing theory by Richard Feynman the connection machine [11] in the 1950s. Foundations of Computational algebra originated form the work of John Von Neumann self-self-reproducing automata [12], Kurt Gödel incompleteness theorems [13] and Solomon Lefschetz work on algebraic topology [14] in the 1920s and 1930s. The concepts of cybernetic and formalization of the notion of feedback was instigated from the work of Norbert Weiner, Professor of mathematics at MIT [15] in the same period.

One approach to estimating the size of today's machine learning and artificial intelligence global market is to consider the chipset computing markets that specialize in machine automation, as well as the more general range of specialist machine learning functionality; termed machine learning as a service (MLaaS), which is emerging in a many specific industry sectors. Machine learning chipsets by Technology are predicted by marketsandmarkets.com to be a market worth $16.06 Billion and a CAGR of 62.9% from 2016 to 2022 [16]. These include deep learning chips set such as Graphical Processing units GPU, Google's Tensor Processing Units (TPU), for example, which are specialized for neural network computation acceleration. Software personal assistants that are algorithms for querying methods to Natural Language Processing (NLP) are other examples of a huge number of applications of AI. The fields of robotics and context aware processing, such as image recognition and sensor-actuator automation, are also increasing the range and scope of the AI market. The Machine learning as a service (MLaaS) is a rapidly growing new market with examples from Amazon Artificial Intelligence, Google AI and IBM Watson. Market size forecast by marketsandmarkets.com is a nacient $613.4 million expected to grow to 3.75 Billion at CAGR of 43.7% from 2016 to 2021 [17]. Featured services of MLaaS include software tools and environments for enterprise to build machine learning algorithms and neural networks, and an increasing library of commercially available algorithms covering examples such as marketing, risk analytics & fraud detection, predictive maintenance, to network Analytics.

The surveys report wide range of industry adoption of AI technologies in several industries such as manufacturing, media and advertising, healthcare, BFSI, and transportation and automotive as the key factor supporting the growth of the AI market in the North American region.

For the remainder of this chapter, as well as subsequent chapters, we will explore how Artificial Intelligence has become a critical technological change for the 4th Industrial Revolution.

Internet of Things, Micro-Electro-Mechanics and Bio Sensor Tech

The Internet of things (IoT) as described in the previous chapter originated as a term during the late 1990s with advent (and industrial usage) of Radio Frequency ID (RFID) tagging technology. This was the outcome of research and development efforts by organizations such as Proctor & Gamble [18].

IoT has long ago moved past RFID technology to embrace many types of sensors and telemetry to become a cornerstone of integrated and embedded systems feedback and control.

IoT in physical fusion is now common place in advanced engineering assets from jet engine turbines to automobile condition monitoring systems and nuclear power plants. Instrumentation connected to programmable controllers that integrate with supervisory control systems are found in supply chains automation and robotics, to metrology devices for measurement and calibration. Drones, be they manned or unmanned, semi or fully autonomous vehicles, work through sensor technologies to provide accurate and timely information on contextual situations; this information is used by the on-board computer and for the remote control of the vehicle. Drones are commonly used for location and remote operation of assets.

In Biological fusion, miniaturized IoT sensors may be attached to the human body (epidermis), ingested or integrated with organs, thereby enabling biological monitoring and augmentation of the host organism. These kinds of devices perform a vital role in mHealth and eHealth, such as mobile monitoring and measurement of medical and well-being status, as well as remote diagnostics and response. Wearable technologies use a variety of sensors that measure psychological and physiological states through sensory data collection, aggregation and analytics. Biological fusion also includes plant, animal and biosphere monitoring and integration as seen in automated agriculture and hydroponics.

Estimating the market size of IoT has proven difficult due to its many sub-segments with a wide range of variance in estimate from many analysts, consultancies and vendors. Examples include Gartner estimating 8.4 Billion connected things by 2017 [19] growing to 50 billion objects by 2020 in earlier forecast by Cisco and others [20]. Current estimated market valuation vary from examples of $8.6 trillion and 212 billion connected things by 2020 forecast by IDC in 2012 [21] revised in 2015 to $1.7 trillion [22] to BCG predicting the market will reach $276 Billion by 2020 [23]. Gartner forecast by 2020, more than half of major new business processes and systems will incorporate some element of the internet of things and a rise in IoT Security will become a key sub-segment of the market [24].

IoT and concerns centered around cyber security have become a major cross-cutting feature of the 4th Industrial era technology that we discuss in detail in a later chapter of Part III. This topic was again in a recent lecture at the November 2016 ReWork NewScientist Reinventing Energy Summit in London. Mustafa Suleyman, co-founder of Google DeepMind, reminded the audience that with recent IoT attacks publicized in the media, such as remote hacking into cars and changing traffic lights remotely, highlight the fact that connected systems are particularly vulnerable to such security breaches. Hooking up everything to machine intelligence so that it can regulate and solve problems for us such as saving energy, reducing greenhouse emissions, enabling home appliances and the interconnected city infrastructure is very attractive because it's convenient. Optimizing these may require controlling people's habits and behavior when they don't really want to be told what to do, so working in background may be more practical. But at the same time, it makes us a bit more vulnerable because if you connect everything IoT, it will increase the surface of attack. While we have many conventional methods to harden and take action to secure those systems, it is one of those trade-offs we need to make, in order to benefit from these new automated intelligence enabled systems. We need to pursue the utility and powerful agency these systems can deliver, but only to the extent to which we can do that safely and with all of the guarantees of security that we would like [25].

Robotics

While artificial intelligence in the form of software algorithms could be described as the "soft" side of machine intelligence, it is the physical manifestation of machinery acting on the physical world, using sensors from IoT integrated into robotics that present a new form of automation. This field is a great example of the 4th industrial revolution fusion of potentially all digital and biological concepts in automata related to remote and unmanned activity, as well as human augmentation and human mimicry.

This can be seen on the wide range of robotics systems born from the earlier era of cybernetics that involved the study of complex control systems pioneered by Norbert Wiener in the 1930s. In recent years the classifications made, for example, by the International Society of Intelligent Unmanned Systems (ISIUS) of the robotics field for unmanned and automated systems [26] include:

- Unmanned systems
  - Unmanned aerial vehicle controlled remotely or by onboard computers (UAV)s, Micro aerial vehicles (MAVs) that are a miniaturized class of UAVs and can be 15 centimeters or less to insect size. Unmanned marine vehicles (UMVs), under water vehicles (UVs).
  - Multi-agent systems used in network load balancing, traffic management to perimeter security defense systems (MAS). Unmanned guided Vehicles (UGVs), blimps, swarm intelligence, autonomous flying robots (AFRs), and flapping robots (FRs).

- Robotics and biometrics
  - Smart sensors, design and application of Micro-Electro-Mechanical systems (MEMs) and Nano-Elecro-Mechanical (NEMs) that use. These fields develop micro and nanosystems technology and micro and nanomachine technologies and nano materials science such as nanowires that are nanostructures of $10-^{9}$ meters.
  - Intelligent robotic systems, evolutionary algorithms, control of biological systems, biological learning control systems, neural networks, and bioinformatics.
- Context Aware Computing
  - Software computing also referred to as computational intelligence (CI) that focus on use of inexact solutions to computationally hard tasks, ubiquitous computing, distributed intelligence, distributed/ decentralized intelligent control.
- Control and computation
  - Distributed and embedded systems, embedded intelligent control, complex systems, pervasive computing, discrete event systems, hybrid systems, network control systems, delay systems, identification and estimation, nonlinear systems, precision monitoring control, control applications, computer architecture and very-large-scale integration (chip design) VSLI, signal/ image and multimedia processing. Software-enabled control, real-time operating systems, architecture for autonomous systems, software engineering for real-time systems and real-time data communications.

Todays forecast for the market for unmanned and remote controlled Drones (UAVs) ranges from a predicted $21.23 Billion by 2022 by marketsandmarkets.com [27] to $127 Billion by 2020 forecast by PwC [28].

The growth area of Industrial Robotics in manufacturing and assembly processes has seen more mainstream development with Asian markets, China being the biggest robot market since 2013. This is followed by Europe leading the development and implementation of robotic automation in electronics, metals, chemical, plastics and rubber and automotive sectors. The current market size is forecast to grow to $79.58 Billion by 2022 [29] with 160,600 units sold in Asian markets a rise of 19% followed by Europe at 10% growth to 50,100 units and 38,100 industrial robots shipped to Americas, 17% more than 2014 [30].

Virtual Reality, Augmented Reality and Mixed Reality

Creating a virtual model of the real world from data from the physical and biological inputs and events have been around since the early Victorian days when the magic lantern image projector was introduced. The earliest known sound recording device, the Phonautograph by French inventor Édouard-Léon Scott de Martinville was developed between 1853 and 1861. The world's first digital camera was created by Steve Sasson an Engineer at Eastman Kodak in 1975. The 8 pound camera recorded 0.01 megapixel black and white photos to a cassette tape. The first photograph took 23 seconds to create [31]. Seeking ways to blend real world and imaginary images was seen in examples such as stop-motion capture of Ray Harryhausen in the Science Fiction movies of the 1950s, including the Oscar winning special effects in the 7th Voyage of Sinbad in 1958, and the famous skeleton sword fight in the 1963 film, Jason and the Argonauts [32]. This form of 3D motion capture was seen as recent as Clash of the Titans movie of 1981 but has since been superseded by full digital motion capture of objects and human body and complete digital image design and digital motion animation by the 1990s.

In 1968, Ivan Sutherland with the help of his student, Bob Sproull, created the world's first virtual reality and augmented reality head-mounted display system (HMD), which he affectionately named the "Sword of Damocles" after an ode to the threat of power everywhere [33].

The notion of virtual worlds modelled by software as three dimensional representations can be seen within the ideas of virtual reality (VR) that aim to immerse the human user in images, sounds and other data that represents the real physical environment or an imaginary setting. By the 1980s the ideas of VR were becoming mainstream by pioneers such as the company VPL Research in 1984 by Jaron Lanier, a futurist who popularized Virtual Reality impact on Society and introduce early VR technology concepts [34]. The 1990s saw the first commercial VR headsets including Sega-VR [35], and Nintendo stereoscope 3D projection game "virtual boy" in the video gaming market [36]. Full PC powered VR gaming and industrial usages followed in the 2000s and 2010s from medical imaging, advanced engineering design and simulation; digital building architecture and geospatial mapping systems (GIS). Today, VR technology provides complete immersive headsets, or stereoscopic glasses, for use in systems that can include fully render wall, floor, ceiling to complete 360-degree room with 4K photorealistic environments. Compare this to the visual resolution of a human eye is about 1 arc minute, which a viewing distance of 20″ that is about 170 dots per inch or pixels per inch PPI. A 30″ monitor to achieve 170 dpi would need 4400 × 2600 pixels. An Apple MacBook Retina display is 2880 × 1880, a 5K screen is 5120 × 2880 and 8K is 7680 × 4320 pixels but varies with distance, the human eye's own visual acuity quality based on the Snellen chart (20/20) [37]. VR is now combined with motion sensors, wearable feedback groves and sensors offering six of more degrees of freedom movement capture, it is possible to interact with the VR objects in real-time.

Consumer products in VR, such as Google's glass entered the market in 2012 providing flat screen projection in line of eyesight, but was later discontinued in January 2015 [38]. Other developments include, Microsoft HoloLens that focused on augmented and mixed reality started in March 2016 [39] and included computer vision and object-recognition to enable the spatial positioning of real objects.

Real world spatial contextual awareness is where overlaid virtual objects and physical objects can be seen together in the same physical location. This requires physical positional data from GPS/GLONASS geolocation that is accurate to a few meters, or from physical symbols such as QR code (or other propriety barcode), which is able to link the physical location of specific digital data relative to a physical location. Techniques such as 360 degree photography, laser light detection and range scanning called LiDAR 3D scanner, are able to generate and collect a geographic "point cloud" of x, y and z coordinates of objects and their positions. These are commonly used in LiDAR Aerial Surveying (LAS) and in 3D modelling of buildings and objects such as AutoCAD Map 3D [40].

Mixed reality (MR) has now become the latest mainstream idea of blending physical and digital objects co-existing and interacting in real-time. This requires "digital twining" as a concept from Cyber-Physical Systems (CPS) that was first defined as a term by Paul Milgram, Haruo Takemura, Akira Utsumi and Fumio Kishino from ATR Communications Systems Research Laboratories, Japan in 1994 as "Virtuality continuum" of combined physical and virtual reality [41].

The current market size of Virtual Reality is positioned as a niche market from $3.7 Billion in 2016 to $40.4 Billion by 2020 by Statista.com [42]. The Augmented reality market is estimated to be $162 Billion market disrupting mobile by 2020 forecast by IDC [43].

3D Printing, Additive Manufacturing and Near Net Shape Manufacturing

The development of digital information for physical design and materials manufacturing in computer-aided design (CAD) originated in 1961 with Ivan Sutherland who, then at MIT, described a computerized sketchpad, while under the supervision of his PhD by Claude Shannon [44]. This representation of digital information has become common place with integration into Computer aided Manufacturing (CAM and CADCAM) creating a flow of digital design, testing into manufacturing and production. This led to the rise of new forms of integrated design, manufacturing, assembly and production including Discrete manufacturing systems (DMS), adjustable manufacturing systems (AMS), and the rise of flexible manufacturing systems (FMS) and reconfigurable manufacturing systems (RMS). These paradigms have been enabled by the use of machine learning, robotics and advanced materials manipulation that have changed design, fabrication, assembly machines and configurations into more configurable and responsive systems for higher efficiencies through modularity and adaptability [45].

3D printing, also sometimes termed "Additive Manufacturing" represents a new digital to physical fusion of technology, printing and materials design and fabrication that originated from stereolithography back in 1986 by Charles Hull [46]. The speed and choice of materials are today rapidly increasing to a stage where additive manufacturing is seeing 3D printing machinery embedded into mainstream flexible and reconfigurable manufacturing in examples of printing jet engine parts by GE [47] to and in medical breakthroughs for human tissues [48]. "Near net shape" manufacturing is another related technique within additive manufacturing that aims for the initial production to be physically made near the completed final product as possible, to reduce additional completion stages. This technique has advanced due to recent developments in ceramics, plastics, metals and composition molding and forming technologies.

The 3D printing market is forecast by marketsandmarkets.com to be $30.19 Billion by 2022 [49] with expectations to become further integrated inline into smart flexible manufacturing process and customer centric systems as seen in the Adidas 3D printed soles of sports shoe wear [50].

Quantum Computing, Nanotechnology and Biochips

High performance computing (HPC) and more generally described by the term "supercommmputing", were developed in the early 1960s by Tom Kilburn at University of Manchester, UK [51], and Seymour Cray at Control Data Corporate who went on to found Cray computers [52]. The technology was built using germanium and silicon based semiconductors or what is often classified as complementary metal-oxide-semiconductor (CMOS) technologies, and its design features in metal oxide semiconductor field effect transistors (MOSFETs) for logic functions. Supercomputing is the specialist field of computation tasks widely used in complex modelling from weather forecasting, advanced physics research to biomolecular simulation. Supercomputers of this type use the method of "parallelism" involving multiple computation at bit, instruction, data and task levels simultaneously, using techniques of multi-threading and hardware configurations, including multi-core, multi-processor, clustering and other methods to accelerate specific computational tasks.

The speedup of the overall task by splitting it into sub-tasks increases latency with more sub tasks [53], and is known as Amdahl's law, which was introduced in 1967 to describe the upper limits for these kinds of parallelism techniques. While this law only fits and restricts certain types of tasks, there are other considerations on the limits of current computing architecture models that include limits of Moore's Law and number of transistors in a dense integrated circuit doubles approximately every two years [54].

Present chip technology transistor component density is 22 nanometers (nm) in 2012, 14 nm in 2016 and 10 nm is predicted by late 2017 with a revised deceleration of Moore's law scaling to two and a half years [55]. While 7 and 5 nm (sub 30 atoms scale) technologies are envisaged by Brian Krzanich, Intel CEO [56], the costs and time scales to innovate this level of design is increasing each year, driving exploration for alternative methods and new technologies beyond silicon.

Apart from atomic scale limits, increasing energy consumption is the main issue for high-performance computing physical limits as well as increasing effects of quantum physics at this nano scale with atoms used in silicon chip fabrication around 0.2 nm.

Other current research fields are looking into alternative computing architectures [57]. The IEEE international Roadmap for devices and systems in 2016 looked beyond CMOS to emerging ideas, highlighted conventional and novel new approaches to computing architectures [58]. These included moving towards non-Von Neumann non-procedural, less-than-reliable computing models and data centric approaches that use machine learning techniques including neural network as new computing architectures that we discuss in more detail in later chapters of this book. The field of nanotechnology development for these reasons discussed here are reaching a critical point in the next decades when we are moving from evolutionary CMOS to revolutionary CMOS in the 22 nm to beyond sub 10 nm that is the level of molecular and atom manipulation manufacturing that has been aptly described in the IEEE roadmaps as "exotic science" and "really different" [58].

Quantum Computing

Quantum computing represents an alternative computing model that was founded on principles developed by Richard Feynman in the 1960s and in the 1980s [59]. David Deutsch demonstrated in 1985 the ability to use quantum properties that interfere constructively and destructively to perform complex calculations, infeasible by classical computing. Quantum computing techniques were shown to enable processing such as factoring very large prime numbers [60]. The key principles of quantum computing based on "superposition" and "entanglement" to perform calculations.

A "qubit" is a term used to define a quantum computing (QC) unit of information. There are several techniques to manufacture a qubit at atomic scale that seeks to hold the qubit in a stable state called "coherence time" that has been shown to last from seconds to hours, or minutes at cryogenic and room temperatures respectively [61].

Superposition is a quantum mechanical property that exists in subatomic scales enabling the use of a quantum bit to hold both 0 and 1 state simultaneously. While a quantum computer is running, the qubit can also be in any one of an infinite number of superposition between 0 and 1, so the qubit has a probability that it is in state 0 and a probability that it is in state 1. Nevertheless, superpositions are very fragile, and if we attempt to measure the value of a qubit the wave collapses into one of the basic states, 0 or 1.

Technically speaking, 2 qubits can be in any one of four basic states, |00>, |01>, |10> and |11>, which are the states that 2 classical bits can assume, however, there are infinitely many states formed by superposition (or linear combinations) of these basic states.

In order to understand this a little better, let us return to the case where we have just one qubit, that has two states, |0> and |1>. Let us consider a superposition, which might look something like

$$\sqrt{2/3} \cdot |0\rangle + \sqrt{1/3} \cdot |1\rangle$$

What does this mean? It means the following: if you attempt to observe, or measure, this qubit, 66% of the time you will find it in state |0> and 33% of the time you will find it in state |1> (Fig. 2.2).

One can represent the qubits as points on the unit circle, and in such a case the horizontal distance from the origin represents the probability of the qubit being observed in state |0> and the vertical distance from the origin represents the probability of the qubit being observed in state |1>. Note, that in this representation a classical bit would appear as two distinct points on the unit circle, one at (0, 1) and one at (1, 0).

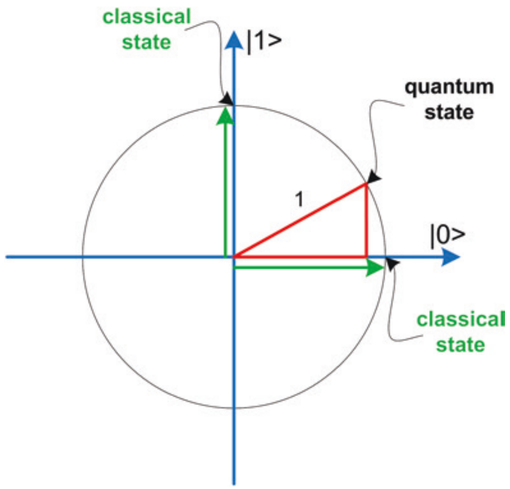

Fig. 2.2 Quantum and classical states

Quantum calculations involve the movement of this coherent transfer of a superposition spin state. The nuclear spin and electron split for "processing and "memory". An electron spin is suitable for a qubit in quantum processor, because an electron spin can be manipulated and can be coupled to other electron spins with a much shorter time scale than a nuclear spin. A nuclear spin is suitable for a qubit in quantum memory, because a nuclear spin has a much longer coherence time than an electron spin [62, 63].

Qubits can be currently manufactured using a range of evolving techniques. These include silicon QC to lithographically place atoms, nuclear magnetic resonance (NMR) QC, Superconducting QC, Ion Trap QC, Linear Optical QC (LOQC), Nitrogen-vacancy (N-V) center in diamond, electrostatically defined quantum dot, and several other competing technologies, many of which are still in the research stage [64].

Entanglement is a second physical property when pairs, or groups of particles, are generated in ways such that the quantum state cannot be described independently of the others, even when separated by large physical distance they remain the same and the quantum state. In quantum computing, calculations are made in quantum circuits using quantum gates and a n-qubit register performing several types of quantum algorithms. When processing the entangled states use quantum mathematics that can be manipulated and on termination of the algorithm the states fall out of quantum entanglement become decoherent and the result can be read off as a classical probability. Developing protocols to detect and quantify the entanglement of many-particle quantum states is a key challenge for present day quantum computing but has been successfully commercialized recently.

The most famous enterprise example has been the D-Wave corporation that demonstrated a prototype 16-qubit quantum annealing processor in 2007. The D-Wave one was launched commercially in 2011 and described by D-Wave as "the world's first commercially available quantum computer", operating on a 128-qubit chipset [65]. quantum computer model D-Wave 2000Q shipping in January 2017 [66] and IBM launching a new quantum computing division "IBM Q" in March 2017 using IBM's publicly available quantum processor. IBM aim to build IBM Q systems with approximately 50 qubits in the next few years to demonstrate capabilities beyond today's classical computers [67]. Googles quantum computing partnership with NASA in 2015 used D-Wave 2X quantum computing machine [68].

Quantum computers can solve specific types of problems that classical computing cannot do because of limitations in digital computing speed previous discussed. The term qubit was in fact indirectly defined by Stephen Wiesner in 1983 from seeking to develop "quantum banking" that aimed to prevent bank notes from being forged using a technique called conjugate coding [69]. Quantum computers are described as quantum Turing machine (QTM) also known as a universal quantum computer that is a model of the concepts of the quantum computer that Alan Turning described between 1936 and 1937 and seen as the foundations of modern procedural computers [70].

Quantum computing processing power by comparison has been described, for example, as 10^8 more powerful than a classical digital computer but this is for specific tasks that benefit from quantum parallelism typically in applications include complex mathematical calculations in fundamental research, machine learning with the potential to undermine cyber security through integer factorization, which underpins the security of public key cryptographic systems. Quantum computing can factor two 300 digital primes quickly that would be infeasible computationally for digital computers. Quantum cryptography is where quantum speedup properties have been successfully used in security systems using quantum entangled keys to prevent correction of the security keys. Recent examples of quantum encryption has been achieved by Chinese researchers in June 2017 sending quantum encryption between earth and orbiting satellites as "spooky action" at a record distance of entanglement of 1200 km.

Today's market size for quantum computing is still nascent with marketsandmarkets.com forecasting the High-performance computing and supercomputing market to grow from $28.08 billion in 2015 to $36.62 Billion by 2020 [71]. The Quantum computing market forecast by marketsandmarkets.com to reach $5 Billion by 2022 [72].

Neuromorphic Computing

Carver Mead along with Nobel laureate Richard Feynman, the distinguish professor John Hopfield established three new fields of study, namely: Neural Networks, Neuromorphic Systems and Physics of Computation. The trio attempted to understand the morphology of individual neurons, the circuits they form, and the behavior that results as a consequence of these particular kinds of biological elements. Moreover, they attempt to understand the computational aspects of such systems, namely its ability to store (or represent) information and how to process this information in a manner that is robust to damage, yet able to learn and adapt to various environmental influences. Neuromorphic Engineering focuses on producing devices specifically aimed at modelling and implementing devices within the realm of human perception, such as vision, touch, auditory and olfactory systems.

In a very interesting interview, Carver Mead [73] has this to say about computing hardware suitable for processing biological perception type problems:

> … it's also true that [digital] isn't the only paradigm for doing that kind of computation, and that the digital machines that do discrete symbol manipulation are not exactly matched to this very soft kind of fuzzy computation, that goes on in perception systems. The neural technology that's coming along on silicon also, it's piggybacking on the same base technology that the digital stuff is driving, are evolving to where we're starting to be able to do really very competent things for ten thousand times less energy than you can do them with the same [digital] technology

The current trend is to utilize what are called mixed-signal techniques to design these artificial neural systems, which function in a manner analogous to the spiking of the natural biological neurons, but constructed out of a different material (silicon rather than a carbon-based material that is commonly found in mammals). Carver Mead was initially inspired by Max Delbruck, and the observations of synaptic transmissions in the retina, which motivated Mead to consider the transistor as an analog device rather than a digital one.

Not only did Carver Mead instigate this entire field of research, but also collaborated with others (including some former students) in order to establish start-up companies that developed and sold some of these inventions, which are in everyday use today. Some of these inventions include cochlea implants, the touchpad found on most modern computers and silicon retina, not to mention some of the first noise cancelling microphonic chips that were used in early smart phones.

Nevertheless, given the significant results shown by these mixed-signal chips, especially their ability to operate at very low power, has attracted the attention of giants within the world of microelectronics, such as IBM who have a massive effort in place to create neuromorphic computing devices of their own [74, 75], as well as efforts by Qualcomm [76], which are in the form of a software SDK for their popular Snapdragon platform. In addition, one should mention the effort underway by the group of ten organizations that make up the European Human Brain Project, including the effort by Manchester University's Prof. Steve Furber who is building a vast neural device called SpiNNaker [77] using chips from ARM.

According to Karlheinz Meier, a physicist who is a computing pioneer working within the realm of neuromorphic computing and currently the leader of the European Brain Project [78]:

> Moving to neuromorphic computing architectures, he believes, will make emulating the brain function not only more effective and efficient, but also eventually accelerate computational learning and processing significantly beyond the speed of biological systems.

Technically, traditional kinds of processors (CPUs) operate using a global clock, a kind of metronome that dictates when instructions are to be moved and when they are processed. However, by distributing the neuromorphic equivalent of cores in a manner that allows them to operate in parallel—using an event-driven model, means these kinds of distributed processors operate without the need of a global clock, using a spiking behavior. This architecture not only reduces the huge power overhead, but also operates thousands of time faster than conventional systems.

Why is this a big deal? First reason relates to the long-awaited end of Moore's Law, which now seems ever more imminent, therefore researchers around the world are evaluating different models of large-scale computing that is often inspired by nature. Second, AI systems typically require lots of processing power, processing power in the past meant computers needed huge power sources, making them impractical where mobility was concerned. The typical power consumption of a neuromorphic chip made by IBM, which contains five times as many transistors as a standard Intel processor, yet consumes only 70 milliwatts of power, whereas the comparable Intel processor would use approximately 70 watts of power, almost a thousand times more.

So where are the challenges? Modern neuromorphic chips act like a general processor, similar to the way that our own cortex does. While this may sound like the kind of thing we all would like to have, we have to remember that such processors are only useful if they have some kind of algorithm, or program, specifically designed for them—hence the challenge for these kinds of chips.

There are some groups working on solutions that will aid the development of such algorithms and simulations. One such group is lead by Chris Eliasmith at University of Waterloo, who together with his team have created Nengo: a python tool for building large-scale functional brain models [79]. The point about Nengo is that not only is it able to run on conventional hardware, but also more specialized neuromorphic hardware such as SpinNaker.

Nengo is built on the Neural Engineering Framework (NEF) [80], which is a framework for constructing neural simulations.

Market segment for neuromorphic processors is looking very bright, according to recent reports

> Future Market Insights' report, titled "Neuromorphic Chips Market: Global Industry Analysis & Opportunity Assessment, 2016-2026," projects that the global neuromorphic chips market, which is currently valued at an estimated US$ 1.6 billion, will rake in revenues worth US$ 10,814.9 million by 2026 end. According to the report, the size of global neuromorphic chips market will expand exponentially – at 20.7% CAGR. [81]

The global neuromorphic computing market size was valued at USD 1490.8 million in 2016, and expected to reach USD 6480.1 million by 2024 according to a new study by Grand View Research, Inc. [82]

Biochips

Other research outside of CMOS and quantum computing has been in the fields of biological computing and examples including Nanomorphic cells and the use of DNA as a storage medium that seek to learn approaches from biology and nature. This field combines both nano-engineering and biotechnology, and is another great example of the 4th industrial revolution's fusion of physical, digital and biological, as the limits of the digital revolution are reached in the micro and nano scales. Research into bacteria cells as computers describe single-cell living organisms as having Turing Machine [70] features they exhibit behavior following Von Neumann concepts of information processing [83] as building blocks of the cell itself. In addition, the cell also exhibit the ability to learn, communicate with each other and to self-repair and reproduce. Research has shown that human designed and developed, nano scale semiconductors could not match biological living cell processing capabilities that include: 1000 times more memory capacity, Logic greater than 10 times, 1 million times more power efficient and algorithmic efficiently 1000 times greater [84]. A research collaboration between Harvard Medical University, Wyss Institute and John Hopkins University in 2012 saw researchers demonstrate storing an entire genetics textbook in less than a picogram of DNA—one trillionth of a gram—an advance that could our ability to save data. 5.27×10^6 bits [85].

These ideas of fusing biological and technologies systems have ramifications for the future of energy management and new biotechnological systems based on natural systems.

The need for increasingly faster computing have been grounded on the wider planetary scale problems of increasing population, global warming, water and other resource scarcity. These complex, often seemingly intractable factors, require more complex models of processing to resolve these impacts. There is a race between the latency of time to research in order to bring these technologies to mainstream use and the costs of getting this wrong, and the potential existential risks to humanity is a core feature of the 4th industrial revolution [86].

The basic equation of computing efficiency as a function of algorithmic logic speed, memory storage capacity and inputs and outputs interaction within a given volume of space, heat dissipation and energy consumption requirement is challenging the ideas of silicon. Research measurements made comparing the human brain computational power has established this as 10^{19} bits per second binary information throughput [87] and 10^8 MIPS instructions per second [88]. And the human brain does all this computation consuming less than 30 Watts of power. Biological cell processes work at extraordinary scales at exa (10^{18}) speeds and memory speeds that far exceed todays silicon based computing technology. We experience this every moment with an almost instant response of brain-eye object recognition, hand-eye-movement coordination, language, deliberate movements, controlling body organs and hormones and many others. This all happens continuously and real-time in fractions of a second. This suggests basic algorithms need to work in very few steps and on tiny energy consumption, heat generation and spatial resources at the molecular and nano scale [89].

An argument for the importance in pursuing alternative technologies was put forward by John Schmitz in 2009 IEEE International Integrated Reliability Workshop suggested the need for new chip design that went beyond "Moore's law" that combined measuring logic processing speed and memory capacity to what he called "intelligent systems". These would include power management, communications and sensor-actuator functionality. These would be the hybrid devices that are already emerging today and include MEMS devices, Biosensors, magnetoresistive (MR) sensors, RFID sensors, e-Pill, security and Secure Sockets Layer encryption SSL, Hybrid car power and battery management and in vehicle networked devices that represent the fusion of next technologies of the 4th industrial revolution [90].

Blockchain

Satoshi Nakamoto, is a name reference to an unknown person or group of people, who in 2008 created the first reference implementation specification that theorized the design of a distributed database made of records called "blocks" or "blockchains", each block of which contains a timestamp and is linked to previous block. A key feature is that data is distributed across the whole network of blocks making its almost impossible to attack, as a there is no central point that hackers might exploit, therefore the data stored in the blockchain is regarded to be incorruptible. Blockchain security includes the use of a public key cryptography that is an address held on that blockchain. It can be generally summarized that every node or miner in the decentralized distributed ledger owns a copy of the blockchain that is propagated by massive data replication and computational trust. No centralized copy exists and all users are equally trusted.

When a blockchain technology is used to execute a transaction, the digitally signed transaction is sent to the node miner to verify the transaction, which is then broadcast to all connected nodes as a block. The network validates the data using a consensus algorithm of a certain time duration and o successful validation, a time stamp as proof of the transaction by all the blocks is made and the receiver receives the transaction [91].

Blockchain was originally created as a form of cryptofinance payments that are made directly between payer and payee (P2P), which removes the need for a central authority but can be used for many other transactions requiring transaction exchange and verification.

Blockchain technology is generally ran and developed as public open source protocols and algorithms to create transparency and network effects. There are several types of blockchain that have evolving including permissionless that uses blockchain as a transport layer to private and permissioned blockchains that can restrict to some degree participants but can lack transparency. Groups of users can do what is termed software forks, or hard forks, which create different descendant blockchains with separate histories from that point forward. Soft forks are backward compatible with older blocks while hard fork are not. Types of blockchains include transactional blockchains and logic optimized blockchains, which can embed additional code and state information which can be used to create online markets and programmable transactions known as "smart contracts" [92]. Smart contracts have additional properties that can facilitate the execution of contracts with complicated outcomes. They can also be used to create auctions. A smart contract, for example, can be coded to sell an item at a predefined price. Buyers will bid and transfer their payments, yet the smart contract will only pick up the maximum offer and transfer back the remaining amount of money to the bidders [93].

Blockchain has also been described as a threat to national government currencies as it creates an unregulated currency denomination that is not overseen by any central bank. The nature of the blockchain does away with intermediaries, in the case of financial services industry Iris Grewe, a Partner at the UBS Innovation Forum in December 2016, described the blockchain innovation as having the "internet of information" today as one's and zero's transporting content, but not the ownership level or the payment level. With blockchain you separate this so you essentially create an "internet of value" in one step, which has the potential to be very disruptive to many kinds of business models. Before blockchain technologies, companies have information flows on one level, and then payments and ownership levels being organized and involving several parties at another level. We also currently have mediators and brokers that organize all this such as the financial stock exchange, banks and clearing houses. With blockchain technology we do not necessarily need these anymore. But there are areas that have not yet been addressed by the blockchain communities that include examples such as credit finance, large infrastructure finance and investment management syndication. This is still areas where the existing banking organizations could setup their own blockchain environment for these services [94].

There are today many examples of open-source, public, blockchain-based distributed computing platform including public chains where anyone can access, read and transact. For example consortium blockchains that use consensus processes controlled by a pre-selected set of nodes such as a group of financial institutes. Another example is private blockchains were permissions are kept centralized to one organization and may allow public or restricted read access [95].

The early rate of adoption of blockchain had reported problems but is now following the technology adoption path that some observers describe as similar to TCP/IP as a foundational technology with great potential [96]. Today's cryptocurrency market capitalizations value bitcoin BTC at $19,361,633,948, followed by ethereum ETH $4405,266,360, Ripple XRP $1255,129,952, Litecoin LTC $559,794,449 and Dash DASH, Monero XMR and others [97]. Cryptocurrency usage is in alternatives to credit card and PayPal transactions and in software based purchases in online retailer and selected business starting to adopt it as an alternative currency with minimal transaction overhead.

Blockchain is not just a system for financial transactions but as a system for assurance of potentially any transactions that require 'smart contracts" of exchange. Examples include

- Utilities
  - Blockchain technology is used to develop smart digital grids that include consumers being able to buy and sell solar energy peer-to-peer P2P trading. Trials are already underway in business-to-business B2B energy trading using blockchain technology between Utility conglomerates and other utilities. Blockchain can also be used to authenticate and manage utility billing processes for Electric Vehicle charging stations. This together with smart contracts to manage cost savings across the utility industry [98].
- Healthcare
  - Blockchain could transform electronic patient records enabling interoperability between different providers and the patient and carer parties more efficiently. It could also drive personal data management to enable personal records to be accessed and managed securely by the public [99].
- Land Registry
  - Land registry control could be automated through blockchain technology simplifying the processes of registration and governance.
- Taxation
  - Blockchain technology could be used to create new taxation mechanisms that are built into the blockchain itself such as small transaction tax enabling the potential for real-time taxation.
- Real estate
  - Properties and exchange of sale could be managed through blockchain technology.

- Legal
  - Law firms that utilize the blockchain technology and deal with law suits related to cryptocurrencies, which are also known as crypto-law enterprises, can convert content of various documents into hashes to deposit onto a blockchain. Given the fact that hashes stored on the blockchain can never be altered, the documents' validity can be universally confirmed in front of any court of law. Storing legal documents on the blockchain promotes the credibility and integrity of court data and legal evidence and renders tampering with such sensitive data an impossible task to achieve.
- IoT Security
  - Blockchain could support remote device and edge sensor security. Blockchain technology can be utilized to investigate the history of various devices connected to the IoT. Furthermore, it can be utilized to execute and confirm transactions taking place between various devices connected across the IoT. This can help in taking IoT to a whole new level of maturing independence via using the public ledger technology to record all data exchange operations among devices, human users and services connected via the IoT [100].
- Pharmaceutical Supply chain security
  - Block chain can be used to manage subscriptions for drugs, drug product serialization of drug categories that could help stem the flow of counterfeit drugs. Blockchain could enable blockchain registered supply chain pharmaceutical packaging. One such branded solution Cryptoseals uses provides tamper-evident seals with a Near Field Communication (NFC) chip embedded with unique identity information which is immutably registered and verified on a blockchain. In addition to an object's identity, the seal also records the identity of its registrant and packaging or asset metadata to the blockchain [101].

An interesting aspect of Blockchain is that it is based on distributed consistency protocol. This concept in general uses nodes (also sometimes call "miners") to validate and authorize transactions collectively to a consensus written into the "blocks". While digital currencies are typically held by individual's digital wallet that is updated with the blockchain "virtual ledger". Several examples of problems have been highlighted and hackers have exploited these and other weaknesses. Overall the benefits of the distribute ledger and that these types of attack are very rare, and difficult to achieve, which makes blockchain a reliable and significant technology, though technically no system is ever totally secure in reality but work within limits of trust and validation. Some of the famous examples of blockchain problems are listed here.

- Double spending problem
  - Occurs if an individual can spend the digital currency balance more than once. Protection against this can be through a confirmation process verifying each transaction has not been previously spent. While extremely difficult with the nature of the distributed consistency of blockchain, it is possible to double spend leaving a node miner not receiving digital currency payment, this is regarded as accounting fraud [102].
- Two Generals problem
  - Related to getting consensus between two nodes where either node may be at error due to incorrect information sent or received, or deliberately fraudulent. It is so known as the coordinated attack problem and illustrates communications between two or more nodes over an unreliable communications link that may arbitrarily fail [103]. Each tries to confirm a message to the other over a constantly unreliable link and this can perpetuate indefinitely. Mathematically this has been proven to be unsolvable because it is impossible to get consensus when its uncertain either party may be erroneous [104].
- Byzantine Generals problem
  - Is a generalized case of the unsolvable two generals problem that applied to the problem of coordinating common consensus across multiple distributed nodes, is sometimes also called the byzantine failure or the byzantine fault tolerance (BFT) [105, 106].

The Fusion Impact of Physical, Digital and Biological Domains

We can see that the 4th Industrial revolution described by Klaus Schwab as a fusion of physical, digital and biological domains is really a recognition of new technological structures that are radically transformational. This is the "post Moore's law" world that in a sense looks beyond what defined the silicon semi-conductor and digital era, while by no means over, has reached the

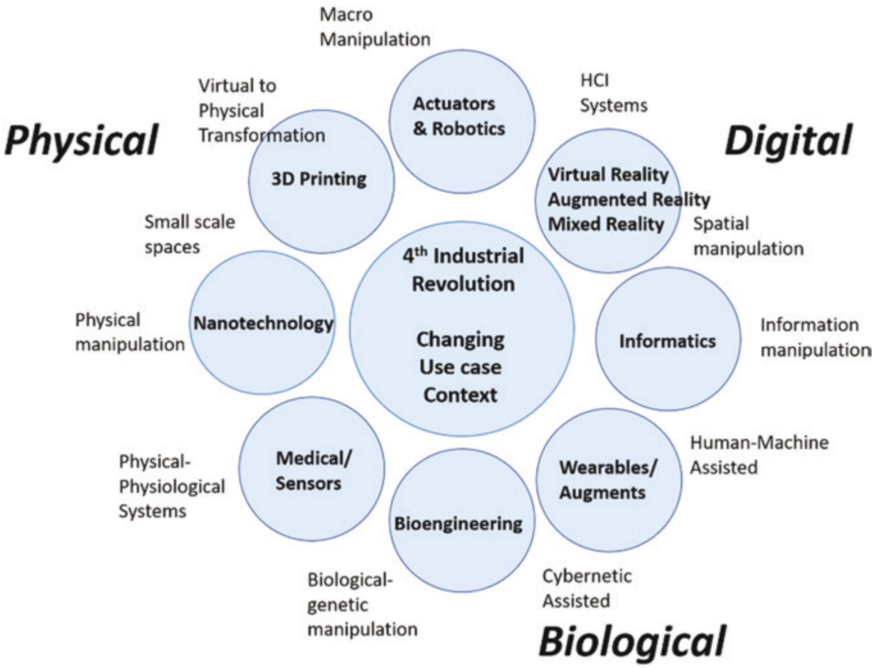

Fig. 2.3 The fusion into changing context of experience

exotic limit stage of sub 10 nano meters. This is a world of atoms and molecular engineering, evident in the silicon world but in the 4th era is also seeing this spread to bioengineering and physical materials manipulation. This is what the underlying themes of the 4th Industrial revolution meant by the *fusion* of these technology across boundaries, as well as moving into advanced new ways to build, and change, the context in which they are used.

This is the fusion of new technologies that are becoming increasingly interconnected with each other. The rank and scale is enormous, just consider medical sensors in wearables can take continuous body temperatures readiness, many other parameters that are transmitted through an Internet of Things IoT network to a range of services we have only just begun to explore (Fig. 2.3).

New kinds of interactive experience will be possible as the immersive world of social media and new forms of virtual media and augmented devices increasingly blend the physical world and the overlay of virtual and augmented experiences as seen in emerging VR and AR technologies.

But these will not only change how physical, biological and enabling digital information processing can be connected, it will change the nature of living in those domains as well as forms of non-human agents, such as robots that can move and manipulated manufacturing, services and transportation processes. The development of connected homes and work environments are just one of the things that will radically evolve as they become augmented with data and intelligence about activities, work and collaborative activities.

The Rise of Intelligent Systems

The physical state of materials, objects and information on their energy, rate of use and performance are becoming integrated back into themselves. Social and societal interactions have equally become integrated into social media and telecommunications connected domains that can reach, and at times divide the social and economic communities that have access (or lack access) to these modern physical and virtual architectures and infrastructure edifices the 4th industrial era.

Massive data and informatics generation from digital, physical and biological domains are giving rise to new forms of information and *intelligence* about those macro and micro environments at unprecedented rates.

This is a key difference that the 4th industrial era has from the previous eras of energy and material transformations, which saw material wealth and geographical globalization. This time it involves changes to the nature of control and feedback that we are now able to exert on our planet, down to the local effects of crowd and material manipulation right down to the micro and nano scales.

Therefore our human relationship to these changes of context of social, material and digital manipulation are transformational in the level of insight and automation, which is now possible and what may come in the near future.

The fusion of physical and digital control is creating intelligence about those materials and energy requirements. Consumption of power, commodities to advanced engineering and transactional capabilities from machine integration into these processes and physical artifacts.

Complex systems relationships are forming when these physical, biological and digital domains entangle and converge. Information is now shared and disseminated through the internet and collective awareness of groups. What kind of planned directed and emergent behavior can result creating new experience and social interaction?

In what the World Economic Forum described as the technological tipping points and societal impact [96], are changes that will matter to individuals, enterprises governments and society as a whole.

The impact of the 4th industrial revolution as we saw in the industrie 4.0 of cyber-physical systems CPS, have the capacity to transform interaction

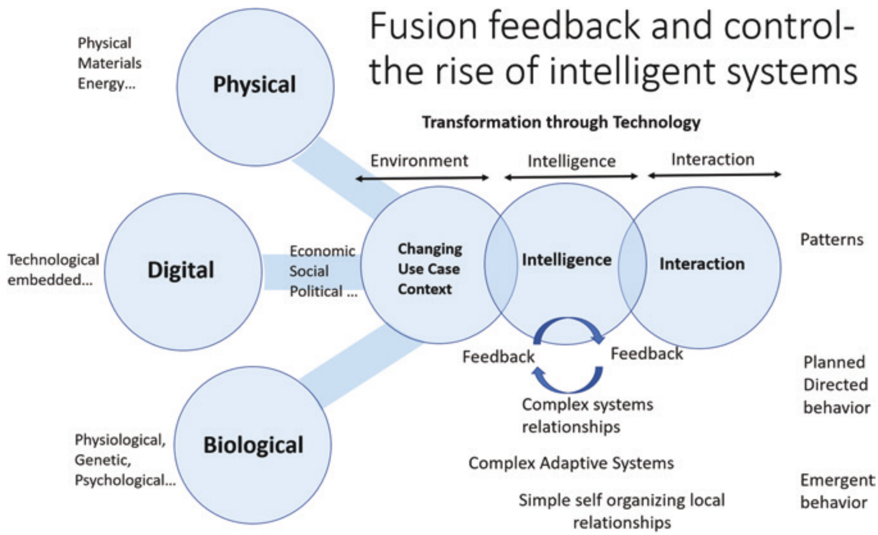

Fig. 2.4 Fusion feedback and control—the rise of intelligent systems

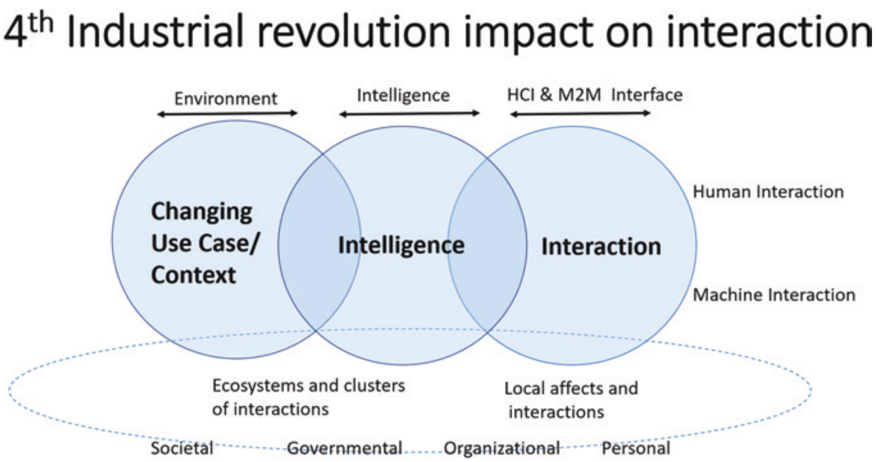

Fig. 2.5 4th industrial revolution interaction impact

between humans and machines, and in machine to machine automation (see Figs. 2.4 and 2.5).

This experience augmented by such technologies is crossing the boundaries of personal data liberties, biological insights and new forms of responsive care and lifestyles. This can transform practitioners, consumers, partnerships and collaboration crowd sourcing information sharing and insights. But on the other hand requiring new governance over personal data privacy, ethics and cyber security controls and broader governmental regulation and policy making for this future.

We see this everywhere we look with these technologies becoming increasing embedded into contextual experience across all industries.

It is this transformative impact on the spatial, temporal experience in these contexts, the rise of machine intelligence and new immersive and embedded technology which will shape the next era.

How will ecosystems, clusters of organizations and supply chain networks, work in this ever expanding and connected world? What will be the affects and interactions in the way services and products are created, manufactured, delivered and consumed?

These and many others changes as described by Klaus Schwab as a fusion of physical, digital and biological domains is really a recognition of new technological structures that are radically transformational [96].

Paradoxes of the 4th Industrial Revolution

In this book we seek to explore several interconnected consequences of this transformation as we begin to see the effects to the fusion of new technologies (see Fig. 2.6).

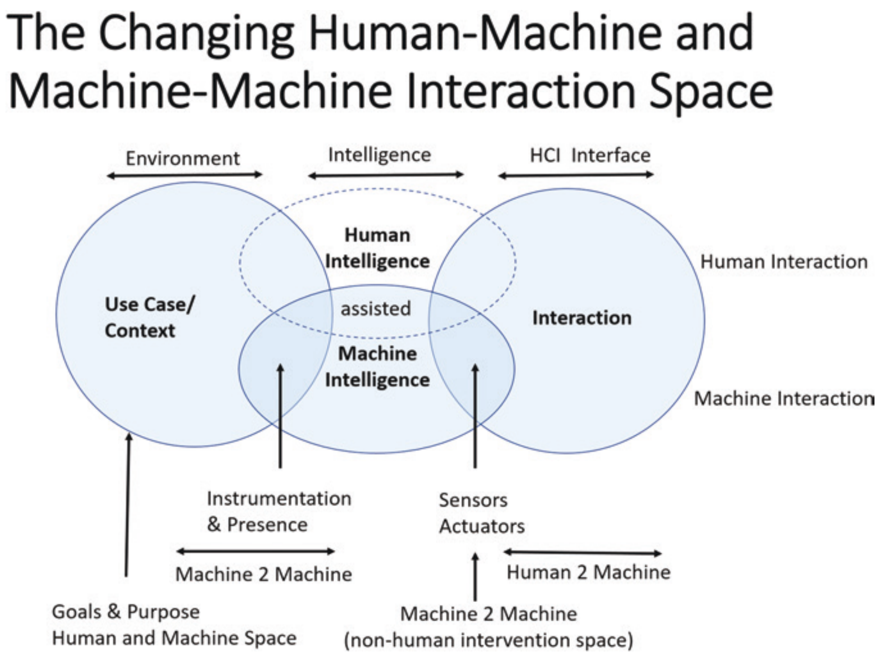

Fig. 2.6 The changing human-machine and machine-machine interaction space

4th Industrial Revolution Technologies

4th industrial revolution Technologies represent ways to develop new industries and to disrupt and change existing industries. Examples of these include driverless cars, smart factories, smart utility grids, digital banking and many others.

4th Era Transformation of Skills, Jobs, Work and Things

This leads to the consequences of planned change or the result leading to unintended disruption to skills, employment and everyday objects and items that may become connected or as-a-service.

Degree of Automated Interconnected Industries

These transitions of machines, work and objects will have transformational impact on interconnected industries. Examples of these include integrated connected transport, automated supply chains, digital finance and banking mediation, connected health, digital government and many others.

Cross-Cutting Concerns

The paradoxes of change are seen as new technologies change patterns of jobs and employment, and the resulting changes impacting industry, mar-

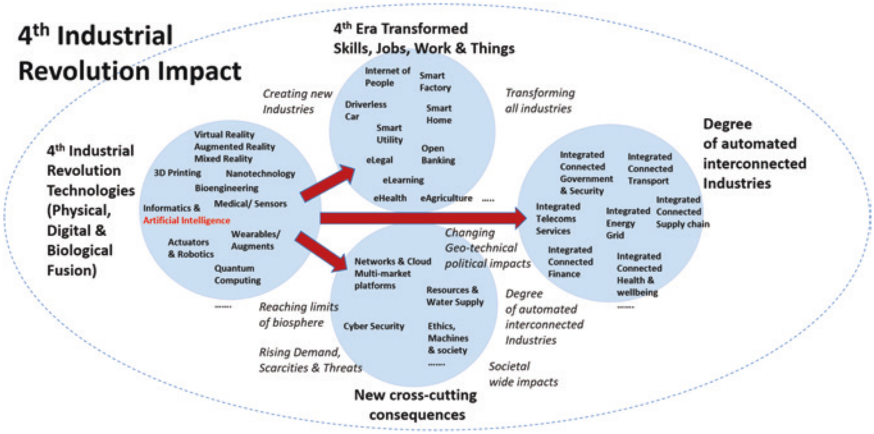

Fig. 2.7 Paradoxes of the 4th industrial revolution impacts

kets and enterprise level organizations. The 4th industrial revolution will drive cross-cutting concerns that will have an impact on the nature of work, security, transparency, trust and privacy for human kind [96]. It will also change economic activity, ways for government to protect its citizens, and the concept of national identity that must bridge between physical and connected worlds. The definition of what is an organization or a community and the very essence of what it is to be an individual, will also change as information and shifting ownership of assets occur, wealth and society values will be challenged by these intelligence systems (see Fig. 2.7).

Summary

We have examined the technological impacts on the larger scale of society and industry, however, at the human level there is the expectation that these changes will go beyond disruptive digital transformation of work and industrial operations. What is clearly different is the rise of automation and machine intelligence or Artificial Intelligence (see Fig. 2.8).

The ramifications are only just becoming apparent and is a key issue for governments and enterprise, as the speed and changes brought on by the 4th Industrial revolution technologies starts to impact. How will economic

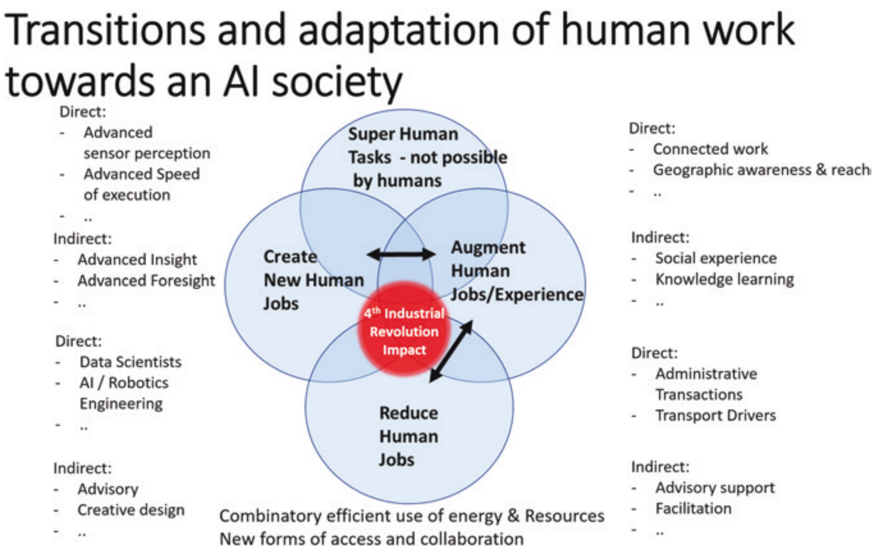

Fig. 2.8 Towards an AI society

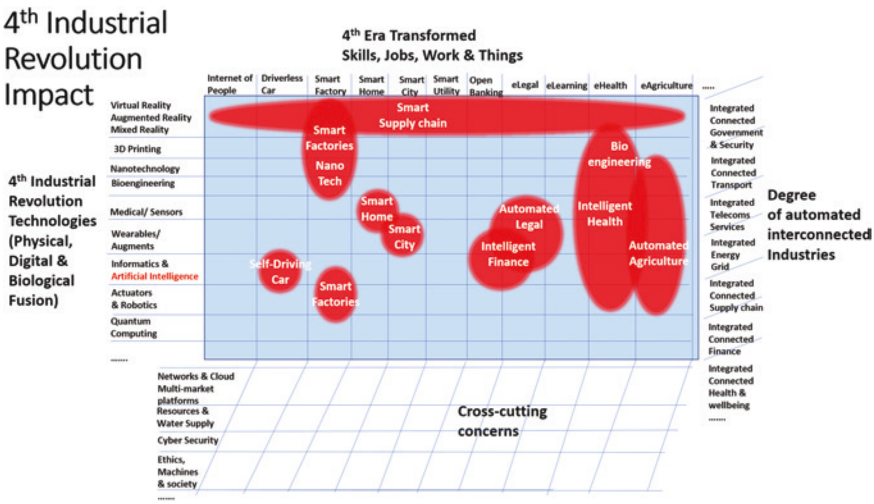

Fig. 2.9 The 4th industrial revolution impact

growth be generated and competitive industry function with these changes in light of recent developments in intelligent systems?

The near to longer term impact of Artificial Intelligence and the fusion of intelligent systems into industries, individuals and societies will have profound impact on the role of the human at work and human experience [107, 108].

A central theme of this book is to explore these impacts for the practitioner who is faced with the challenges of learning what these technologies are, and what they are capable of, so they may prepare for the impact of these changes on their organization.

How will these technologies create new forms of skills and employment, or will it reduce and remove tasks from humans through automation? Will there be a augmentation of these technologies to support and enhance human experience and work? Where will the impact of intelligent systems be? and what concerns will there be in navigating and responding to the rise of this AI society? (Fig. 2.9).

Notes and References

1. Klaus Schwab and Sergey Brin in conversation, Davos 2017, World Economic Forum. https://www.youtube.com/watch?v=30rx3dBPbIs.
2. The 10 Best Technology Advances of 2016, Luke Larsen, Paste magazine, December 23, 2016, https://www.pastemagazine.com/articles/2016/12/the-10-best-technology-advances-of-2016.html.

3. Davos 2017—An Insight, An Idea with Klaus Schwab and Sergey Brin in conversation, World Economic Forum. https://www.youtube.com/watch?v=ffvu6Mr1SVc&t=732s.
4. CRISPR/Cas9 and Targeted Genome Editing: A New Era in Molecular Biology, https://www.neb.com/tools-and-resources/feature-articles/crispr-cas9-and-targeted-genome-editing-a-new-era-in-molecular-biology.
5. The Cloud Imperative, Business Report, MIT Technology Review. Simson Garfinkel, October 3, 2011, https://www.technologyreview.com/s/425623/the-cloud-imperative/.
6. Platform Revolution: How networked markets are transforming the economy and how to make them work for you. Geoffrey G. Parker, Marshall W.Van Alstyne, Sangeet Paul Choudary, W.W. Norton & Company. 2016.
7. Gartner Says Worldwide Public Cloud Services Market to Grow 18 Percent in 2017, February 22, 2017, http://www.gartner.com/newsroom/id/3616417.
8. Gartner Says Global IT Spending to Reach $3.5 Trillion in 2017, October 19, 2016 http://www.gartner.com/newsroom/id/3482917.
9. A proposal for the Dartmouth Summer Research Project on Artificial Intelligence, August 31, 1955, Hannover, New Hampshire, http://www-formal.stanford.edu/jmc/history/dartmouth/dartmouth.html.
10. Computing machinery and Intelligence, Alan Turing, MIND, A quarterly Review, October 1950.
11. Richard Feynman and The Connection Machine, W. Daniel Hillis for Physics Today, http://longnow.org/essays/richard-feynman-connection-machine/.
12. Theory of Self-Reproducing Automata, John Von Neuman, edited and completed by Arthur W. Burks, University of Illinois Press, Urbana and London 1966. http://cba.mit.edu/events/03.11.ASE/docs/VonNeumann.pdf.
13. Gödel's Incompleteness Theorems Jan 20, 2015, https://plato.stanford.edu/entries/goedel-incompleteness/.
14. Algebraic Topology, Solomon Lefschetz, American Mathematical Soc., 31 Dec 1942—Mathematics—389 pages.
15. Norbert Wiener Invents Cybernetics, livinginternet.com http://www.livinginternet.com/i/ii_wiener.htm.
16. Artificial Intelligence (Chipsets) Market worth 16.06 Billion USD by 2022, maeketsandmarkets.com, http://www.marketsandmarkets.com/PressReleases/artificial-intelligence.asp%20.asp.
17. Machine Learning as a Service (MLaaS) Market by Component (Software Tools, Services), Organization Size, Application (Marketing, Risk Analytics & Fraud Detection, Predictive Maintenance, Network Analytics), Service and Region—Global Forecast to 2021, http://www.marketsandmarkets.com/Market-Reports/machine-learning-as-a-service-market-183667795.html.
18. Harnessing the power of feedback loops, Wired, June 2011, https://www.wired.com/2011/06/ff_feedbackloop/all/1.

19. Gartner Says 8.4 Billion Connected "Things" Will Be in Use in 2017, Up 31 Percent From 2016, Gartner, February 7, 2017, http://www.gartner.com/newsroom/id/3598917.
20. The Internet of Things: How the Next Evolution of the Internet is changing Everythings, Dave Evans April 2011, Cisco Internet Busness Solutions Group (IBSG), www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf.
21. The Internet of Things Is Poised to Change Everything, Says IDC, Business Wire, October 3, 2013 http://www.businesswire.com/news/home/20131003005687/en/Internet-Poised-Change-IDC.
22. Internet of Things Market to Reach $1.7 Trillion by 2020: IDC, June 2, 2015 https://blogs.wsj.com/cio/2015/06/02/internet-of-things-market-to-reach-1-7-trillion-by-2020-idc/.
23. Winning in IoT: It's All About the Business ProcessesJANUARY 05, 2017 by Nicolas Hunke, Zia Yusuf, Michael Rüßmann, Florian Schmieg, Akash Bhatia, and Nipun Kalra, https://www.bcgperspectives.com/content/articles/hardware-software-energy-environment-winning-in-iot-all-about-winning-processes/.
24. Gartner Says By 2020, More Than Half of Major New Business Processes and Systems Will Incorporate Some Element of the Internet of Things, Gartner Newsroom, Jan 14, 2016. http://www.gartner.com/newsroom/id/3185623.
25. Reinventing Energy Summit, Nov 25, 2016, London 2016 https://www.re-work.co/events/reinventing-energy-summit-london-2016.
26. International Society of Intelligent Unmanned Systems ISIUS http://www.isi-usys.org/.
27. Drones Market worth 21.23 Billion USD by 2022, marketsandmarkets.com http://www.marketsandmarkets.com/PressReleases/commercial-drones.asp.
28. World Drone Market Seen Nearing $127 Billion in 2020, PwC Says, Bloomberg.com Wojciech Moskwa, May 9, 2016, https://www.bloomberg.com/news/articles/2016-05-09/world-drone-market-seen-nearing-127-billion-in-2020-pwc-says.
29. Industrial Robotics Market by Type (Articulated, Cartesian, SCARA, Cylindrical, Parallel, Collaborative Robots), Component (Controller, Robotic Arm, End Effector, Sensors, Drive), Vertical and Geography—Analysis & Forecast to 2022, marketsandmarkets.com http://www.marketsandmarkets.com/Market-Reports/Industrial-Robotics-Market-643.html?gclid=CjwKEAjwrMzHBRDW3saA88aT80MSJACbvo1TvbSlz-JI8wGWSES9_W37E2EAIcgMzI3f4vnUq41kYRoCYIrw_wcB.
30. Executive summary World Robotics 2016 Industry Robots, https://ifr.org/img/uploads/Executive_Summary_WR_Industrial_Robots_20161.pdf.
31. The World's First Digital Camera by Kodak and Steve Sasson, Michael Zhang, Aug 05, 2010, PetaPixel. https://petapixel.com/2010/08/05/the-worlds-first-digital-camera-by-kodak-and-steve-sasson/.

32. The Ray & Diana Harryhausen Foundation, http://www.rayharryhausen.com/.
33. Ivan Sutherland A.M.Turing Award 1988, http://amturing.acm.org/award_winners/sutherland_3467412.cfm.
34. Virtual Reality Society VPL Research Jaron Lanier, https://www.vrs.org.uk/virtual-reality-profiles/vpl-research.html.
35. Sega-VR headset 1991, http://segaretro.org/Sega_VR.
36. Virtual Boy Nintendo 1995, http://nintendo.wikia.com/wiki/Virtual_Boy.
37. What is the highest resolution humans can distinguish? Eyewear April 21 2013, http://blog.eyewire.org/what-is-the-highest-resolution-humans-can-distinguish/.
38. The history of Google Glass, http://glassalmanac.com/history-google-glass/.
39. "With HoloLens, Microsoft aims to avoid Google's mistakes". Reuters. May 2016, Sarah McBride, San Francisco, http://www.reuters.com/article/us-microsoft-hololens-idUSKCN0YE1LZ.
40. About Point Clouds and LiDAR Data, Feb 8, 2016, Autodesk, AutoCAD Map 3D, https://knowledge.autodesk.com/support/autocad-map-3d/learn-explore/caas/CloudHelp/cloudhelp/2016/ENU/MAP3D-Use/files/GUID-7C7DD8A7-B561-45B0-A803-852E0A667F3C-htm.html.
41. Augmented Reality: A class of displays on the reality-virtuality continuum: Paul Milgram, Haruo Takemura, Akira Utsumi and Fumio Kishino from ATR Communications Systems research Laboratories, Japan SPIE Vol. 2351, Telemanipulator and Telepresence Technologies (1994), http://etclab.mie.utoronto.ca/publication/1994/Milgram_Takemura_SPIE1994.pdf.
42. Virtual reality software and hardware market size worldwide from 2016 to 2020 (in billion U.S. dollars), https://www.statista.com/statistics/528779/virtual-reality-market-size-worldwide/.
43. The virtual and augmented reality market will reach $162 billion by 2020, BI Intelligence IDC, August 2016, http://uk.businessinsider.com/virtual-and-augmented-reality-markets-will-reach-162-billion-by-2020-2016-8.
44. Sketchpad: A man-machine graphical communcations systems, Ivan Edward Sutherland, Technical Report, Number 574, University of Cambridge, computer Laboratory, UK, UCAM-CL-TR-574, ISSN 1476-2986, Sept 2003, https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-574.pdf.
45. Assessment of reconfiguration schemes for Reconfigurable Manufacturing Systems based on resources and lead time, Erik Puik, Daniel Telgen Leo van Moergestel, Darek Ceglarek, Robotics and Computer-Integrated Manufacturing 43 (2017) 30–38.
46. History of 3D printing, https://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/history/.
47. Additive Manufacturing, GE, the world's largest manufacturer, is on the verge of using 3-D printing to make jet parts. MIT Technology Review Martin LaMonica, https://www.technologyreview.com/s/513716/additive-manufacturing/.

48. A 3D bioprinting system to produce human-scale tissue constructs with structural integrity, Hyun-Wook Kang, Sang Jin Lee, In Kap Ko, Carlos Kengla, James J Yoo,& Anthony Atala, Nature, Biotechnology, 34, 312–319 (2016) http://www.nature.com/nbt/journal/v34/n3/full/nbt.3413.html.
49. D Printing Market worth 30.19 Billion USD by 2022, http://www.marketsandmarkets.com/PressReleases/3d-printing.asp.
50. Adidas is going to sell 100,000 sneakers with 3-D printed soles, cnbc, April 7, 2017, http://www.cnbc.com/2017/04/07/adidas-3d-printed-trainers-futurecraft-4d.html.
51. Memories of the Ferranti Atlas computer, http://curation.cs.manchester.ac.uk/atlas/elearn.cs.man.ac.uk/_atlas/.
52. Seymore Cray, Cray.com, http://www.cray.com/company/history/seymour-cray.
53. "Validity of the Single Processor Approach to Achieving Large-Scale Computing Capabilities" Amdahl, Gene M. (1967). AFIPS computer conference. http://dl.acm.org/citation.cfm?id=327215.
54. Cramming more components onto integrated circuits. Gordon Moore, Electronics, Volume 38, Number 8, April 19, 1965, http://www.monolithic3d.com/uploads/6/0/5/5/6055488/gordon_moore_1965_article.pdf.
55. Intel pushes 10 nm chip-making process to 2017, slowing Moore's Law, Infowrold, James Niccolai, Jul 16, 2015, http://www.infoworld.com/article/2949153/hardware/intel-pushes-10nm-chipmaking-process-to-2017-slowing-moores-law.html.
56. Intel CEO Says Reports of the Death of Moore's Law Have Been Greatly Exaggerated abc news, Alyssa Newcomb, April 27, 2016, http://abcnews.go.com/Technology/intel-ceo-reports-death-moores-law-greatly-exaggerated/story?id=38703042.
57. Beyond Moor's Law: SRC Views on Nanoelectronics, Victor V. Zhinov, Ralph K. Cavin,, Nano-tec Workshop, Barcelona, Spain, Nov 6–7, 2012, SRC Semiconductor Research Corporation is a consortium of companies including IBM, AMD, Intel, and others.
58. Roadmap for devices and systems, 2016 that looks beyond CMOS to emerging devices. IEEE 2016, http://irds.ieee.org/images/files/pdf/2016_BC.pdf.
59. Simulating Physics with Computers, Richard P. Feynman, International Journal of Theoretical Physics, Vol 21, Nos. 6/7, 1982, https://people.eecs.berkeley.edu/~christos/classics/Feynman.pdf.
60. Deutsch, David (1985). "Quantum Theory, the Church-Turing Principle and the Universal Quantum Computer". Proceedings of the Royal Society of London A. 400 (1818): 97–117. http://rspa.royalsocietypublishing.org/content/400/1818/97.
61. Kamyar Saeedi et al. (2013). "Room-Temperature Quantum Bit Storage Exceeding 39 Minutes Using Ionized Donors in Silicon-28". Science.

342 (6160): 830–833. Bibcode:2013Sci…342..830S. doi: 10.1126/science.1239584. PMID 24233718.
62. Chapter 14, Spin Qubits for Quantum information Processing, http://www.nii.ac.jp/qis/first-quantum/forStudents/lecture/pdf/noise/chapter14.pdf.
63. Vladimir Privman, Dima Mozyrsky, Israel D. Vagner, Quantum computing with spin qubits in semiconductor structures. Computer Physics Communications 146 (2002) 331–338, https://arxiv.org/abs/cond-mat/0102308.
64. T. D. Ladd, F. Jelezko, R. Laflamme, Y. Nakamura, C. Monroe, & J. L. O'Brien, Quantum Computers, Nature Vol 464 / 4 March 2010 / doi: 10.1038/nature08812 http://qeg.mit.edu/images/QuantumComputing.pdf.
65. D-Wave Announces Commercially Available Quantum Computer, Forbes Alex Knapp, May 17, 2011, https://www.forbes.com/sites/alexknapp/2011/05/17/d-wave-announces-commerically-available-quantum-computer/#20bd6e1b3707.
66. D-Wave Announces D-Wave 2000Q Quantum Computer and First System Order, Jan 24, 2017, https://www.dwavesys.com/press-releases/d-wave%C2%A0announces%C2%A0d-wave-2000q-quantum-computer-and-first-system-order.
67. IBM Q, Building the first universal quantum computers for business and science, http://research.ibm.com/ibm-q/.
68. Google's Quantum Computer Is 100 Million Times Faster Than Your Laptop David Nield Dec 10 2015 Science Alert. http://www.sciencealert.com/google-s-quantum-computer-is-100-million-times-faster-than-your-laptop.
69. S. Wiesner, "Conjugate Coding," SIGACT News, Vol. 15, No. 1, 1983, pp. 78–88. doi: 10.1145/1008908.1008920, http://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=629285.
70. Turing, A.M. (1938), "On Computable Numbers, with an Application to the Entscheidungsproblem: A correction", Proceedings of the London Mathematical Society, 2 (published 1937), 43 (6), pp. 544–6, http://onlinelibrary.wiley.com/doi/10.1112/plms/s2-43.6.544/abstract.
71. High Performance Computing (HPC) Market worth 36.62 Billion USD by 2020, 2015, marketsandmarkets.com, http://www.marketsandmarkets.com/PressReleases/Quantum-High-Performance-Computing.asp.
72. Quantum Computing Market Forecast 2017–2022, marketreserearchmedia.com March 2017, https://www.marketresearchmedia.com/?p=850.
73. Deep shift—Technology tipping points and societal impact: Survey Report, September 2015, World Economic Forum. http://www3.weforum.org/docs/WEF_GAC15_Technological_Tipping_Points_report_2015.pdf.
74. "How Things Really Work, a lecture by Gordon Bell and Carver Mead", https://youtu.be/zBpWkTETwD8?t=9m16s.

75. "Introducing a Brain-inspired Computer TrueNorth's neurons to revolutionize system architecture", http://www.research.ibm.com/articles/brain-chip.shtml.
76. "How neuromorphic 'brain chips' will begin the next era in computing" (2016), https://www.extremetech.com/extreme/236362-how-ibms-neuromorphic-brain-chips-will-begin-the-next-era-in-computing.
77. "Chip giants pelt embedded AI platforms with wads of cash" (2016), https://www.theregister.co.uk/2016/08/17/chip_giants_invest_heavily_to_boost_changes_in_embedded_ai_platforms/.
78. Furber, S. and Temple, S. "Neural Systems Engineering" J. R. Soc. Interface (2007) 4, pp. 193–206.
79. Think Fast – Is Neuromorphic Computing Set to Leap Forward? https://www.hpcwire.com/2016/08/15/think-fast-neuromorphic-computing-racing-ahead/.
80. Bekolay, Trevor et al. "Nengo: A Python Tool for Building Large-Scale Functional Brain Models." Frontiers in Neuroinformatics 7 (2013): 48. PMC. Web. 13 Apr. 2017.
81. Global Neuromorphic Chip Market to Surpass US$ 10 Billion in Revenues by 2026; Smart Machine Integration & AI Systems Driving Market Growth, http://www.futuremarketinsights.com/press-release/neuromorphic-chip-market.
82. Neuromorphic Computing Market Analysis By Application (Signal Processing, Image Processing, Data Processing, Object Detection, and Others) By End-use (Consumer Electronics, Automotive, Healthcare, Military & Defense, and Others), Expected To Reach USD 6,480.1 Million By 2024, http://www.grandviewresearch.com/industry-analysis/neuromorphic-computing-market.
83. von Neumann, John (1945), First Draft of a Report on the EDVAC, https://web.archive.org/web/20130314123032/, http://qss.stanford.edu/~godfrey/vonNeumann/vnedvac.pdf.
84. Danchin A. Bacteria as computers making computers. FEMS Microbiol Rev. 2009 Jan; 33(1):3–26. doi: 10.1111/j.1574-6976.2008.00137.x. http://onlinelibrary.wiley.com/doi/10.1111/j.1574-6976.2008.00137.x/full.
85. Next-generation digital information storage in DNA. George M. Church, Yuan Gao, Sriram Kosuri, Science Express, 16 August 2012 / Page 1/ 10.1126/science.1226355, http://arep.med.harvard.edu/pdf/Church_Science_12.pdf.
86. Igor L. Markov Limits on fundamental limits to computation, Nature 512, 147–154 (14 August 2014) doi: 10.1038/nature13570, http://www.nature.com/nature/journal/v512/n7513/full/nature13570.html.
87. H. Moravec, When will computer hardware match the human brain?, Journal of Evolution and Technology. 1998. Vol. 1, http://www.jetpress.org/volume1/moravec.htm.
88. Gitt W, Information—the 3rd fundamental quantity, Siemens Review 56 (6): 36–41 1989.
89. L.G. Valiant, A quantitative theory of neural computation, Biol, Cybern. 2006 95, http://amygdala.psychdept.arizona.edu/Jclub/Valiant_2006.pdf.

90. Reliability in the more than moor Landscape, Keynote, John Schmitz, IEEE International Integrated Reliability Workshop, October 18, 2009, http://www.iirw.org/past_workshops/09/IIRW_keynote_final_posting.pdf.
91. Nakamoto, Satoshi "Bitcoin: A Peer-to-Peer Electronic Cash System" October 31, 2008, http://nakamotoinstitute.org/bitcoin/.
92. Bitcoin Developer Guide, https://bitcoin.org/en/developer-guide#block-chain.
93. The blockchain technology, smart contracts and legal procedures. Tamer Sameeh, deep.dot.web. March 2017, https://www.deepdotweb.com/2017/03/14/blockchain-technology-smart-contracts-legal-procedures/.
94. Blockchain and bitcoin - Interview Iris Grewe, Partner Financial Services, BearingPoint, UBS Innovation Forum, December 2016 BearingPoint channel YouTube. https://www.youtube.com/watch?v=8OkDDb5igxc&t=77s.
95. Types of Blockchains, https://blockchainhub.net/blockchains-in-general/.
96. Marco Iansiti, Karim R. Lakhani, The Truth About Blockchain, Jan–Feb 2017 HBR, https://hbr.org/2017/01/the-truth-about-blockchain.
97. CryptoCurrency Market Capitalizations, http://coinmarketcap.com/.
98. James Basden, Michael Cottrell, How Utilities Are Using Blockchain to Modernize the Grid, March 2017 HBR, https://hbr.org/2017/03/how-utilities-are-using-blockchain-to-modernize-the-grid.
99. John D. Halamka, MD, Andrew Lippman, Ariel Ekblaw, The Potential for Blockchain to Transform Electronic Health Records, March 2017, HBR, https://hbr.org/2017/03/the-potential-for-blockchain-to-transform-electronic-health-records.
100. How can the blockchain technology take the security of IoT to a whole new level?, Deep.Dot.Web Tamer Sameeh, Dec 27, 2016, https://www.deepdotweb.com/2016/12/27/can-blockchain-technology-take-security-iot-internet-things-whole-new-level/.
101. Chronicled launches blockchain-registered supply chain and pharmaceutical packaging, Ian Allison, Dec 7, 2016, http://www.ibtimes.co.uk/chronicled-launches-blockchain-registered-supply-chain-pharmaceutical-packaging-1592220.
102. How does a block chain prevent double-spending of Bitcoins? Sean Ross, Investopedia June 19, 2015, http://www.investopedia.com/ask/answers/061915/how-does-block-chain-prevent-doublespending-bitcoins.asp.
103. Leslie Lamport, Robert Shostak, and Marshall Pease, The Byzantine Generals Problem, ACM Transactions on Programming Languages and Systems, Vol. 4, No. 3, July 1982, Pages 382–401. http://www-inst.eecs.berkeley.edu/~cs162/fa12/hand-outs/Original_Byzantine.pdf.
104. Minimum Viable Block Chain, Iiya Grigorik May 5, 2014, https://www.igvita.com/2014/05/05/minimum-viable-block-chain/.
105. Transaction processing for distributed systems, Jan 20, 2014, Chen Hao. Coolshell. http://coolshell.cn/articles/10910.html.

106. Contemporary Approaches to Fault Tolerance, Alex Wright Communications of the ACM, Vol. 52 No. 7, Pages 13–15 2009. doi: 10.1145/1538788.1538794, https://cacm.acm.org/magazines/2009/7/32080-contemporary-approaches-to-fault-tolerance/fulltext.
107. Deep Shift: Technology Tipping Points and Societal Impact, Survey Report, September 2015, Global Agenda Council on the Future of Software & Society World Economic Forum, http://www3.weforum.org/docs/WEF_GAC15_Technological_Tipping_Points_report_2015.pdf.
108. Eliasmith, C. Anderson, C.H. (2003). Neural Engineering: Computation, representation, and dynamics in neurobiological systems. Cambridge, MA: MIT Press.

http://www.springer.com/978-3-319-62478-5

The 4th Industrial Revolution
Responding to the Impact of Artificial Intelligence on Business
Skilton, M.; Hovsepian, F.
2018, XXXV, 322 p. 35 illus., Hardcover
ISBN: 978-3-319-62478-5