1
The 4th Industrial Revolution Impact

Introduction

Technological advance through history predates the recent *digital era* and *computers* to previous centuries that saw radical change in political and social beliefs, as well as the spread of political power and material wealth through changing technological development in society.

Technology has traditionally been defined as the way in which scientific knowledge evolves in the production of goods and services or in achieving goals using tools and techniques to achieve outcomes. The term "technology" originates from the sixteenth century use of the Greek word tekhnologia "systematic treatment" and tekhnē "art, craft" and logia "-ology" [1]. The late renaissance period in Western Europe saw great progress in the arts and science, as well as social upheaval bridging the middle ages and modern history. Technology changed human skills-sets, we learnt how methods and processes were deployed to wield natural resources and gain advantages in competition and acquisition. The limitations of human mechanical strength and the discoveries of fire, metals, and enlightenment [2] brought the development of tools that assisted or substituted human effort.

Machines were constructed in order to provide a means for humans to operate and achieve certain tasks, or to replace the human effort in its entirety. Machinery consumed and converted energy provide by mechanical, chemical, thermal, electrical, or other means to convert work from one state to another. This evolved from personal and local use into a phenomenon that transformed society and the industrial economy.

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The noun ‘industry’ stands for the production of goods or services through technology and commercial organizational advances, and ‘industrialization’ stands for the development of industries on a wide scale. The development of scientific knowledge and technology were essential for the emergence of industrialization, which in western cultures happened around the 1770s. The change from an agrarian society, based on agriculture and human social organization, to an industrial one based primarily around industry, has since become to be known as *“The Industrial Revolution”* [3].

The period from the late 1770s to the present day would witness a five-fold rise in global population, and a tenfold rise in GDP wealth, rates that were unheard of prior to the 18th century [4].

Most noticeable would be the shift in growth rates between the Western and Eastern economies; however, they are both converging in this information age and thereby helping to ignite the 4th Industrial Revolution, which we explore in the next section.

This chapter we shall discuss the following topics:

- The four Industrial Revolutions
- The transformations of energy and computation
- The foundations of Industrie 4.0 and cyber-physical systems

The Four Industrial Revolutions

The industrialization of the west and east of the global is a story of social and economic development that took divergent paths driven by geography and local regional power that grew with technological. It is generally accepted that the term “Industrial Revolution” refers to the period from the 1770s to the middle of the 1870s, where technological change enabled humanity to harness mechanical and electrical forces for its own endeavors. As a result, there were many changes in manufacturing and production methods, and working practices, which created new modes of transportation and provided a new kind of infrastructure for much of society. While its genesis in the west was in Great Britain, transforming it and its empire into the workshop of the world [5], within a century it had spread to the new world and through Asia and Pacific (see Fig. 1.1).

The term Industrial revolution first came into the lexicon of thought in 1799 [6]. By the end of nineteenth century, human society would witness world population double to 1.6 billion, a rapid rise in global GDP, and new inventions of electricity, mass production and globalization that we recognize today. The first few decades of the twentieth century saw the

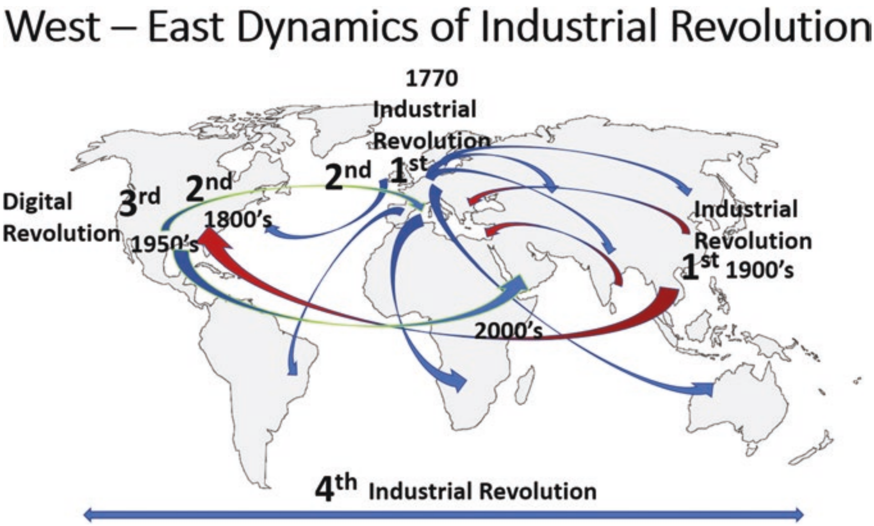

Fig. 1.1 West–East dynamics of Industrial Revolution

conflict of world war, and rapid changes in global power as west met east, the dawn of nuclear power and electronics. These transformations instigated the third revolution of information systems, and the automation of manufacturing and production. The geographical and time zone boundaries shrunk as telecommunications and new enlightenment in biology, miniaturization, transportation, media and engineering spread to consumerization and commercial acceleration through the twentieth century. The drivers for the latency with which the Asian markets, China and India in particular, arrived at industrialization were mainly due to geopolitics, proximity of a labor force and natural resources as well as colonization. In the case of India, it was a massive source of cotton and indigo that became a huge market resource for the products of the industrial revolution. The colonization of India provided huge capital funds to the British Empire, whose corporations and control of the shipping routes at that time prevented inward investment in India for its own industrial development [7]. Both India and China where affected by other factors including domestic political and military upheavals during the 1700s while Europe was going through scientific developments. China had other impacts of a large geographical country with a larger population of manual labor and relative isolation from trading marketing with other parts of the world. As recent as the 1960s, over sixty percent of the Chinese population worked in Agriculture [8]. It was not until the mid-twentieth century that industrialization at scale arrived in China to meet the needs of a rapidly growing domestic population and agricultural famine, driven by the Maoist Great Leap Forward plan in the cultural revolution of the People's Republic of China [9].

In recent times the technologic genius of humans is perhaps most visibility illustrated by the ability to break free of the earthly boundaries as seen in the space race. From the first earth orbiting satellite Sputnik in 1957 [10] during the dawn of the space age to manned mission landing on the moon. Robotic satellites have now visited all planetary bodies in the solar system, and reached out to the outer edges of the solar system in the Oort cloud of interstellar space with the Voyager space craft launched in 1977 [11]. All this achieved in the 3rd Industrial revolution.

This revolution, which started from manufacturing, will create more capital and enable humans to accumulate more wealth to drive economic growth, is perhaps moving from technology to one based on knowledge and accelerated social change [12]. No longer is technical automation a transformation from one energy to another at a faster rate as we saw in the steam and electrical revolutions of the eighteenth and nineteenth centuries. We can look back at the twentieth century as a kind of preparation, a prelude to a new era with the digital revolution laying the ground for electronics and computing that would spread knowledge and ideas built on the earlier industrial revolutions.

The Fig. 1.2 illustrates the major trends of change that are apparent in the transitions from the 1st Industrial revolution to the present day 4th industrial revolution and decades ahead. These can be summarized to include the movement of globalization through mechanical, electrification,

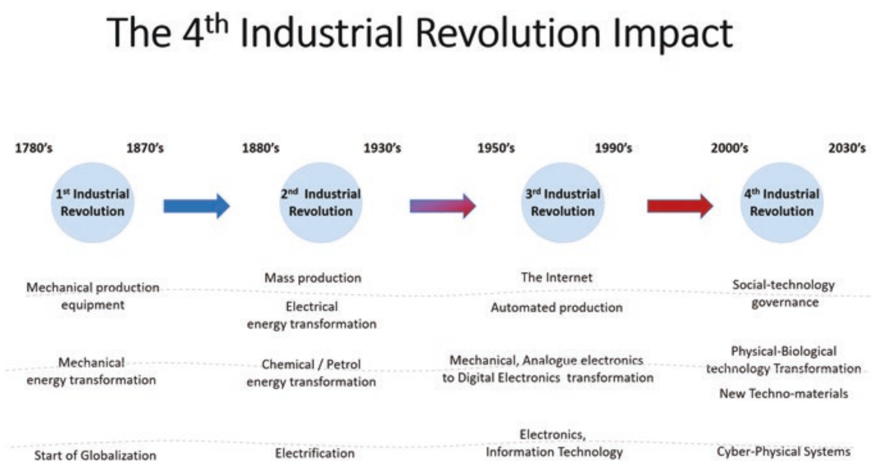

Fig. 1.2 The four Industrial Revolutions

petrochemical combustion and the internet digitization. A second trend is the harnessing of transformation of energy for work; the third, the rise of machinery automation that would enable mass production and the creation of mechanisms that exceed human limitations and the creation of new science and insights. There is a trend here, because the changes that we see through the eras have associated with them consequences for social interaction and societal values, which must evolve with the advent of new technology.

The 1st and 2nd Industrial Revolutions

Prior to mechanization, human endeavor was driven by hand and animal stock to build, work the land and travel. Mechanical action from water, wind and fire had been used for thousands of years, from the sales on a ship to the water wheel.

The first steam engine was built by Thomas Savery in 1698 in England, called the Savery engine, [13] it was used to pump accumulated water up from coal mines but had limited application, because it used atmospheric pressure and worked against the vacuum of condensed steam to draw water. It could not be more than 30 feet above the water level and therefore had to be installed down in the mine shaft itself. It was not until 1712 that Thomas Newcomen developed the first commercial steam engine based on a piston design. It could lift ten gallons of water from a depth of 156 feet that represented 5.5 horse power [14]. The jump from vacuum pressure, to mechanical kinetic energy, to continuous rotary movement did not occur until 1781 with the advent of James Watt's revolutionary design for his steam engine. This ten-horsepower engine enabled a wide range of manufacturing to production and agricultural machinery to be powered. This ushered in what is described as the 1st industrial revolution, because it enabled production of mechanical energy from thermal energy generated from combustion of chemical and oxygen, which could be applied to a range of movement and processing. It's revolution was the ability to harness mechanical energy on-demand without the use of human or livestock intervention. It enabled humans to work more effectively using mechanical energy that ranged from fixed stationary pumps, crane lifts and mills to locomotion in the form of trains and horseless cartridges; moreover, it signaled the beginning of mechanization.

By 1886, steam engines were capable of developing 10,000 horsepower, and were used to large scale ocean steam ships and long range industrial locomotive apparatus [15]. But around that time the 2nd Industrial revolution had already begun to arrive with the advent of industrial scale electrification and electric motors; the advent of petrochemical combustion engine and the early prototype for the modern gasoline engine enabled Gottlieb Daimler to build the first automobile in 1885 [16].

Beyond the Digital Revolution

The 3rd industrial revolution has been defined as the *digital revolution* that began with micro-electronics and semi-conductor developments in the mid 1950s through to the early 1970s, which saw the first very-large-scale integration (VLSI) processes create integrated circuits (IC) by combining thousands of transistors into a single chip [17]. The integrated circuit expedited the move from mechanical and analogue technology to digital electronics, and fundamentally changed (by orders of magnitude) the digitization of information and instigated pervasive computing. This ushered in the age of information technology at an industrial scale with enterprise computing from IBM, Hewlett Packard, Microsoft, Sun Microsystems and a plethora of others driving rapid expansion into automated services and production. Developments in telecommunications led to the inception of the Internet by the 1990s that in the following decade saw the ground work laid for global data centers and the emergence of search engines, online marketplaces, social media and mobile devices by Google, Amazon, Apple, Facebook, Twitter and a legion of others, that spread the digital revolution to all corners of the globe and industries.

The 3rd Industrial revolution connected people and industries on a unprecedented scale. This information technology scope included connected devices and industrial scaling of telecommunications infrastructure, and the phenomenon of massive computing both at the data center scale and micro-miniaturization and commoditization of mobile cell phones. The birth of the World Wide Web brought with it a new syntax and protocol that enable machinery to "talk" to each other and with humans. The rapid advances in spectrum and bandwidth investment provided links to business enterprises and cities, to the transportation, energy, and utility network infrastructures. Digital Marketplaces and digital workforces became possible, "hollowing out the internet", meaning that businesses and people could connect and exchange products and services. Scott McNealy, the chief executive of Sun Microsystems in 1999, famously remarked, "You have zero privacy anyway. Get over it [18]." This was a realization that internet enabled access (and personalization) would also collect your data and activities. The term "hollowing out" is now viewed with concern, the rise of automation and globalization has an impact on lower and middle-class jobs, creating what some observers describe as a “digital divide” in the inequity of internet access and monopolization of the large. These social issues are perhaps the real consequence of the rapid changes brought on by digitalization. Technical advances in materials science, new manufacturing techniques, machine intelligence, biological research, as well as changes in medical and healthcare have enabled developments within the 4th revolution that have the potential to change whole industries and human experience. We will explore some of these changes in the chapters that follow.

The 4th Industrial Revolution

The 4th Industrial Revolution (4IR) is described in the 2016 book by Klaus Schwab, Founder and Executive Chairman of the World Economic Forum [19], as a culmination of emerging technologies fusion into the physical and biological worlds the likes of which has not been seen before (See Table 1.1).

Industrie 4.0

The earlier version of this description with a similar namesake had been the Industrie 4.0 or Industrial 4.0 and the Industrial Internet of things (IIoT) developed four years earlier in 2010 by the German Government [20]. In 2006, Helen Gill at the American National Science Foundation (NSF) [21] coined the term Cyber-Physical Systems (CPS), which was born in the realm of machine-to-machine automation that lead to the Smart Factory. This is now viewed as part of the 4th Industrial Revolution and is part of a wider reshaping of all industries and a new genre of economic, social and societal change.

By 2014 the German federal government supported this idea by announcing that Industrie 4.0 will be an integral part of their “High-Tech Strategy

Table 1.1 Definition of the 4th industrial revolution

Definition: The 4th Industrial Revolution (4IR)
“The fourth industrial revolution, however, is not about smart and connected machines and systems. Its scope is much wider, Occurring simultaneously are waves of further breakthroughs in areas ranging from gene sequencing to nanotechnology, from renewables to quantum computing”
“It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions”

Table 1.2 Definition of Industrie 4.0

Definition: Industry 4.0 (I4.0)
The convergence of industrial production and information and communication technologies. Industrie 4.0 relates to the convergence of Internet of Things (IoT), the Internet of People (IoP), and the Internet of Everything (IoE) (22)

2020 for Germany" initiative, aiming at technological innovation leadership of the German economy. In 2016, research initiatives in this area were funded with 200 million euros from governmental bodies [23] (see Table 1.2).

Internet of Things

During the 1970s factory production systems began to adopt ideas from Computer Integrated Manufacturing (CIM), Just-in-Time (JIT) and Theory of Constraints (ToC). This evolved rapidly with various quality management fads as well as advances in computer processing, storage and Computer Graphics rendering in engineering CAD and CAM systems, together with the desire to connect with various enterprise and SCADA process control systems.

The *concept* of Internet of Things originated with the concept of "Ubiquitous Computing" at Palo Alto Research Center (PARC) by Mark Weiser [24], during the 1990s. Nearly ten years later, Kevin Ashton [25] coined the *term* "Internet of Things" (IoT), during the development of Radio Frequency ID (RFID) tagging and feedback loop optimization, for Proctor & Gamble's supply chain management.

By the early 21st century the fusion of these ideas enabled the customer to manage assets from the factory to their not just the production of goods, but also asset management from design, manufacturing through to delivery.

The term IoT subsequently evolved and by 2014, by which time it included a spectacular variety of sensors and devices, ranging from piezoelectric, solar panels, thermoelectric and a multitude of others, causing much confusion with the use of term "Internet of Things". For example, General Electric (GE) have challenged the current Consumer IoT focus, which is seen as populist notions of consumer home appliances and voice control services, as a limited view of the customer centric experience of connectivity and automation that use sensors and smart products [26]. GE further developed the discussion around the Industrial Internet where the focus is on the Industrial Internet of things (IIoT) that has given rise to a more effective minimum viable product (MVP). Moreover, this approach covers the whole life cycle [27] beginning with design, development, manufacturing through to delivery and services.

Table 1.3 Definitions of Internet of Things

Definitions: Internet of Things (IoT)
Industrial Internet (II), Industrial Internet of Things (IIoT)
The automation and communications network of smart embedded and external sensors and machines representing an intelligent industrial factory and supply chain lifecycle
Internet of People (IoP)
The personal data and human centric network of products and services. The focus is on privacy and personal-centric internet
Internet of Things (IOT)
Sensors and actuators embedded in physical objects, which are connected to the Internet
Critical – Internet of Things (C-IoT)
Sensor networks and systems relating to critical infrastructure at a corporate and national level. It refers to the control, security and robust design features of platforms that support mission-critical systems from on-board controls for automated vehicles; medical automation in surgery and cancer research to national energy and utility infrastructure
Massive-Internet of Things (M-IoT)
The huge growth of usage data and sensors at "the edge" of local, personal and internet network services. It refers to the scale and magnitude of large datasets generated and the unique characteristics of platforms able to handle and operate with hyperscale data generated by massive-IoT such as mobile, social media, wearables to municipal city and transport services

Recent classifications of IoT have been a key enabler in connecting trillions of assets, smart wearables for connected life-styles and health, to the future of smart cities and connected driverless transport. Concerns are growing over issues related to cyber-security and personal data collections. Table 1.3 provides some of the current definitions in use by Industrial, retail and telecommunications organizations in IoT.

The growth of IoT sensors, low power pervasive networks and advanced data collection techniques have accelerated the development of machine learning systems that use neural networks. This is mainly due to the widely available training data, such as text, images and spoken languages that have become available at sufficient volume and reasonable cost.

Cyber-Physical Systems

These concepts developed ideas in connected systems, and the role of organizations as complete system of systems [28, 29]. Within CPS, they evolved into the notion of CPS-VO (Cyber-Physical System Virtual Organization). CPS-VO recognizes the holistic nature of real-world systems and the need for physical and digital integration to work symbiotically with the organization itself, as well

Table 1.4 Definition of Cyber-Physical Systems (CPS)

Definition: Cyber-Physical System (CPS)
Is a system that integrate cyber components (namely, sensing, computation, and human users), connecting them to the Internet and to each other. It is the tight conjoining of and coordination between computational and physical resources called a digital twin (the physical assets, components, energy, materials, interfaces) and the cyber representation of the physical system (the software, digital data, usage, sensors that enables higher capability, adaptability, scalability, resiliency, safety, security, and usability [30]
"Such systems use computations and communication deeply embedded and interacting with physical processes to add new capabilities to the physical system. These CPS range from miniscule (Heart pace makers) to large-scale (the national power-grid)" (CPS-Summit 2008) [31]

as other systems and operations inside and outside the organization, in what could be considered to the connected supply chain networks (Table 1.4).

CPS embodies several key concepts to be found in Industrie 4.0:

Digital Twin Model tight integration: The creation of a digital model with sensor-feedback actions typically in, or near, real-time. The critical concept is that the physical asset, interaction and behavior, are digitally modelled and connected through external or embedded sensors with the physical system.

Outcome driven: Overall system properties that are cross-cutting concerns about the total CPS status within its organization or as a working subsystem (such as an onboard connected car platform for example) that has responsibilities for safety, efficiency, and secure operation of the overall system.

Automated machine to machine: A Level of automation that may include interaction with humans, but more typically involves autonomous operations between machine to machine.

Total Cost and Operational Lifecycle TCO LC: Integration of the life-cycle of the system and its various states of maintenance and connection to other systems and resources. Typically, both the capital expenditure (CAPEX), and operational costs of running and support operational costs (OPEX), which together combine to a complete total cost of operational expenditure (TOTeX) model of operation is considered the scope of the CPS.

CPS systems have grown most rapidly in the Digital Manufacturing and Smart factory concepts within Industry 4.0. It is predominately about connected factory automation and self-management of the subsystems and the overall automation of the factory and its operations. Similar initiatives with the Future of Manufacturing in the European Union and Manufacturing 2.0. [32] (around 2007) had similar initiatives, but originated from Demand-

Table 1.5 Definition of Human Computing Interaction HCI and Machine to Machine M2M

Definition: Human-Computer Interaction (HCI) researches the design and use of computer technology, focused on the interfaces between people (users) and computers. Researchers in the field of HCI both observe the ways in which humans interact with computers and design technologies that let humans interact with computers in novel ways
Definition: Machine to Machine M2M The direct communication between devices using any communications channel, including wired and wireless. This includes machine sensors to collect and provide data on machine performance and software that can use this data to modulate itself and/or other machines automatically to achieve some goal. A key feature of M2 M is automation that excludes human intervention but may be part of a process for HCI

Driven Value Networks (DDVN), concepts that perpetuated as recently as 2014, and were from the Web 2.0 era of web services messaging across a supply chain network [33].

The concept of CPS has grown to include new human-computing Interactions (HCI) and the combination of Internet of Things embedded technologies of sensors and devices, into machine to machine (M2M) automation and embedded systems into product-service systems (see Table 1.5).

The concept of CPS, of tight digital twining of technology and the physical and biological domains, has evolved from its origins in manufacturing into many other industries at the small and large scale.

Micro-and Nano Scale Technology

New technologies have developed at the micro-scale and nano-scale physical materials in nanotechnology and miniaturization. 3D printing, also known as additive manufacturing [34] is a key example of digital control systems that manipulate molecular level composites.

Nanotechnology [35] is a field that is concerned with the manipulation of atomic and molecular levels through the use of advances in electron microscopes (scanning tunneling Microscope) and nanoparticles, such as Buckminsterfullerene's (buckyballs) or Fullerenes carbon molecules [36]. The development of several new fields of science, engineering and medical engineering became possible through direct control of matter at the atomic and molecular level, such new surface materials, nanotubes materials, semiconductor design, microfabrication and molecular engineering.

This field is closely associated with bioengineering [37] and genetic engineering [38] that involves the creation and manipulation of genes to biomedical engineering of organs, prosthetics and many neuro, immune, cellular, pharma and biochemistry manipulation and applications. Developments in gene therapy, genetically modified crops (GMO) using biotechnology to manufacture and control biological processes.

Macro Scale Technology

At the macro scale, new technologies can be found as a development of connected systems across many industries. These include a plethora of growing use cases in embedded sensor controlled components found in mobile cell phone devices, connected home appliances, connected automobiles to human wearables, bioimplants for pacemakers, patient care monitoring to crowd surveillance in cities, airports and sports grounds.

The wider landscape of cooperating Internet of Things, people and places through devices and systems will include next-generation power grids, new retail delivery supply chains, new open banking systems, future defense systems, next generation automobiles and intelligent highways, flexible robotic manufacturing, next-generation air vehicles and airspace management, and other areas, many of which are as yet untapped.

The New Fusion of Physical, Digital and Biological Domains in the 4th Industrial Revolution

These new technologies have generated new kinds of interaction from the macro, the micro and nano levels (see Fig. 1.3).

Fusion is the key, in which the digitization and information coupled to feedback loops have enabled new kinds of IoT machine and Human generated data.

The phenomenon of the 4th Industrial Revolution sees both human and machine intelligence as becoming increasingly intertwined.

In the next chapter, we will explore the types of technologies that are integrating physical materials, locations and machines with biological processes, human physiology and psychology. The fusion of physical, digital and

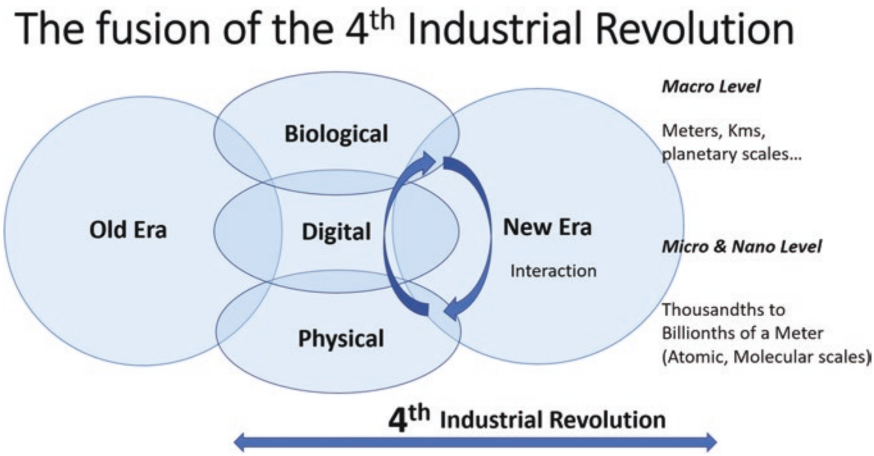

Fig. 1.3 The new fusion of the 4th industrial revolution

biological domains with various new kinds of technologies are now able to interact in an intelligent manner, and thereby generate new forms of intelligence. This is the key concept that makes this an industrial revolution – the 4th Industrial Revolution.

Harnessing the Transformation of Energy

1st Industrial Revolution

The term "horsepower" is defined as a description of energy needed to lift an average body weight of 75 kg by 1 meter in 1 second. The first commercial steam engine, the Newcomen steam engine in 1712 could produce 5.5 mechanical horse power. The James Watts steam engine (around 1765) introduced the first rotary piston that became a key design moment in the industrial revolution and produced 10 horse power [39].

James Watt used the term horsepower to demonstrate the efficiency that resulted from artefacts engineered using steam. The term horsepower and Watts as units of power, illustrate a feature that we see time and again in the translation of one era to another, that have a cultural overhang from the vocabulary and mindset of the early generation, in the first case the horse. Even today the term Watt hearkens back to an earlier progenitor of Steam.

3rd Industrial Revolution

In 1969, the Saturn V Launch Rocket that took NASA astronauts to the Moon had five engines with a combined thrust of 7.5 million pounds, equivalent to 160,000,000 mechanical horsepower, 500,000 sports cars, or 543 jet fighters [40].

The current world's largest Nuclear Power station located in Japan, the Tokyo Electric Power Co.'s (TEPCO) Kashiwazaki-Kariwa, has seven boiling water reactors (BWR) with a gross installed capacity of 8,212MegaWatts equivalent to 11,012,000 mechanical horsepower [41].

The most powerful Nuclear bomb was the U.S.S.R.'s Big Ivan Bomb–a multistage RDS-220 hydrogen. On Oct. 30, 1961, Mityushikha Bay Nuclear Testing Range, Arctic Sea, it generated and average power of 5.4 yottawatts, approximately 1.4% of the power output of the sun. The blast was 10 times greater than all the munitions set off during World War II and destroyed everything within a 40-mile radius of epicenter. This is equivalent to 5.4 x 1024 watts or 39.1 x 1028 xenotta mechanical horsepower [42].

The 4th Industrial revolution will harness a range of energy sources that will become critical for enabling the connected digital society, addressing the massive growth in population and their demand on resources, as well as having to deal with the increases in climate change threats.

In "Part III Cross-cutting Concerns", we shall discuss the paradoxes and challenges that ensue from the 4th industrial revolution.

Harnessing the Transformation of Computation

The game of chess has long been held as an example of intelligence and in the 20th century became the first great public test for artificial intelligence versus the human.

The history of chess can be traced back nearly 1500 years. The earliest origins are believed to have originated in Eastern India, c. 280–550 [43] in the Gupta Empire [44]. By the 6th Century was known as chaturaṅga (Sanskrit: चतुरङ्ग), literally four divisions [of the military]—infantry, cavalry, elephants, and chariotry, represented by the pieces that would evolve into the modern pawn, knight, bishop, and rook, respectively.The game reached Western Europe and Russia by at least three routes, the earliest being in the 9th century. By the year 1000, it had spread throughout Europe [45]. The old form of chess that originated in this period was known by the Arabic work Shatranj, in Middle Persian Sanskrit chaturanga چترنگ) meaning catuḥ: "four"; anga: "arm". Western culture through the Persians, Greeks and India via the Persian Empire. Around 1200, the rules of shatranj started to be modified in southern Europe, and around 1475, several major changes made the game essentially as it is known today [46].

The game indirectly led to the rise of wisdom and the documentation of Knowledge. A famous example of this is the Libro de los Juegos, ("Book of games"), or Libro de axedrez, dados e tablas, ("Book of chess, dice and tables", in Old Spanish) was commissioned by Alfonso X of Castile, Galicia and León and completed in his scriptorium in Toledo in 1283, is an exemplary piece of Alfonso's medieval literary legacy. This was part of the search for wisdom by the Spanish King Alfonso X, also called Alfonso the Wise [47]. Alfonso was instrumental in the formation of an academy where learned Jews, Muslims, and "Christians" could collaborate. To facilitate their work, the king created and financed one of the world's first State libraries.

In 1947, the world's first chess computer programs were developed by the British World War II codebreakers at Bletchley Park. Members of that team, Shaun Wylie along with Donald Michie designed an early form of computer program called "Machiavelli" which competed against a program designed by Alan Turing called "Turbochamp". Both were paper based programs as there was no software or hardware available at that time that could run the programs [48].

In 1996, IBM developed Deep Blue, a super computer of it's time, that became famous for the first computer chess playing system to win both a chess game and a chess match against a reigning world champion, Gary Kasparov, under regular time controls.

After initially defeating Deep Blue in 1996, Kasparov issued a rematch challenge for the following year. To prepare, the team tested the machine against several Grandmasters, and doubled the performance of the hardware.

A six-game rematch took place in New York in May 1997. Kasparov won the first game but missed an opportunity in the second game and lost. Kasparov never recovered his composure and played defensively for the remainder of the match. In the last game, he made a simple mistake and lost, marking May 11, 1997, as the date on which a World Chess Champion lost a match to a computer [49].

Technical specification of Deep Blue at that time in 1996 was an IBM RS/6000 SP parallel supercomputer Thin P2SC-based system with 30 nodes, with each node containing a 120 MHz P2SC microprocessor, enhanced with 480 special purpose VLSI chess chips. Its chess playing program was written in C and ran under the AIX operating system. In June 1997, Deep Blue was the 259th most powerful supercomputer according to the TOP500 list, achieving 11.38 GFLOPS on the High-Performance LINPACK benchmark [50]. By joining special purpose hardware and software with general purpose parallel computing, the team developed a system with a brute force computing speed capable of examining 200 million moves per second – or 50 billion positions – in the three minutes allocated for a single move in a chess game, with a typical search to a depth of between six and eight moves to a maximum of twenty or even more moves in some situations [51].

Deep Blue was the fastest computer that ever faced a world chess champion. Today, in computer chess research and matches of world class players against computers, the focus of play has often shifted to software chess programs, rather than using dedicated chess hardware. Modern chess programs like Houdini, Rybka, Deep Fritz, or Deep Junior are more efficient than the programs during Deep Blue's era. In a November 2006 match between Deep Fritz and world chess champion Vladimir Kramnik, the program ran on a personal computer containing two Intel Core 2 Duo CPUs, capable of evaluating only 8 million positions per second, but searching to an average depth of 17 to 18 plies in the middlegame thanks to heuristics; it won 4-2. [52].

Successors to Deep Blue have added more processors and decreased power requirements. Blue Gene, a more recent product of IBM research improves performance by a factor of 100 over Deep Blue. In March 2005, Blue Gene had reached peak performance of more than 100 teraflops, capable of doing simulations that used to take hours in nanoseconds. But Blue Gene, for all its computational skill, occupied up to 20 refrigerator-sized racks and continued to consume massive amounts of power, although considerably less than Deep Blue.

The fastest Super computer in the world in 2017 is currently the Sunway TaihuLight in the National Supercomputing Center in Wuxi, China. It has 10,649,600 Cores and been measured with a peak processing speed of 125,435.9 TFLOPS and 15,371 KW Power consumption [53].

IBM have recently been reported to be developing the next generation Supercomputer with a peak performance speed of 200 PFLOPS by 2018 [54].

By comparison, an Apple iPhone7 plus with a A10 quad core System on a Chip (SoC) has been reported to rate at between 47GFLOPS and greater than 1 TFLOP performance, or something like having four Deep Blue super computers in your hand depending on how you benchmark it [55].

Our human brain runs on no more than 20 watts of power equal to the refrigerator bulb. The Average Human Adult consumes 100 Watts of energy by the brain only covert 20% of that, 20 Watts [56].

The 4th industrial revolution will be a scale of computational power leading to astonishing possibilities of data and intelligent processing scale. We are as the cusp of what some call the "post Moore's Law" revolution that representing the doubling of processing chips using silicon coming to an end. We explore this phenomena in later chapter as the new technology of the 4th industrial revolution.

After the Apollo Moon Landing Era

In W. David Woods 2011 book, "How Apollo Flew to the Moon" he presents details of NASA's planning and engineering rocket science; eloquently explained the climax of an era that was at the cusp of the 3rd industrial revolution. "The 12-year Apollo lunar exploration program (1961 through 1972) occurred during the second half of a transformational period between the end of W-W-II (1945) and the demise of the Soviet Union in 1991, a period of major technological, political, economic, and cultural dynamics. Technologically, the digital computer was in its infancy, yet automation and robotics were clearly imminent. The Apollo astronauts were required to bridge this gap, as humans capable of using a computer to assist in manually operating the vast array of systems, techniques, and procedures necessary to leave the earth, fly to the Moon and explore the surface of the Moon, and safely return. The crew had to operate the hardware manually because computers did not yet have the reliability or capability necessary to operate autonomously and by the nature of the design strategy, Mission Control Center (MCC) did not really "control" the spacecraft either. At any point in the mission, the crew had to be prepared to operate on their own without any contact from Earth, using only the equipment and computers on board, together with pre-calculated maneuver data" [57].

Achieving such goals was driven by the belief that technology innovation would be able to reach such heights, whereas the ability to solve the real-world challenges of complex problems would require the human as interpreter and go between. The idea of the automatic machines that could perform such tasks was well advanced, yet the reality in practice fell to the ingenuity, bravery and the ability to organize humans and activities effectively [58].

The 3rd Industrial revolution of digital computation and the rise of knowledge in materials, physics and biological processes was racing ahead, opening up new frontiers of possibility but presenting new challenges and skills to learn. Over 400,000 people worked on the Apollo program and ranks as one of the great engineering achievements in human history [59].

The Shuttle, international space station and the grand tour of the planets by robotic satellites demonstrated our ability to orchestrate a multitude of interdependent tasks, involving technology and other resources to achieve such ambiguous goals. However, it was reaching the moon that marks our crowning achievement of what is possible, when we adopt new thinking, ways of working, and the utilization of connected technology to solve problems thought impossible. Moreover, it clearly showed that such skills would be essential in the future to meet other grand challenges and overcome them.

> "Apollo was the combination of technologies, none of which was particularly dramatic. Combining it was the achievement. This was a bunch of people who didn't know how to fail. Apollo was a triumph of management, not engineering" [60].

It is important to remember just little computational power the computers of the "Apollo era" had when compared to today's laptops and mobile computing devices. It has been often cited that the total onboard computing power was less than a washing machine of present day standards [61]. The Saturn V for example, had two Apollo Guidance Computers (AGU), one mounted on the control panel of the Command Module Capsule and another in the Lunar Landing Module (See Fig. 15). The AGC was one of the first integrated circuit-based digital computer designed by the MIT Confidential Instrument Development Laboratory (later named the Charles Stark Draper Laboratory in honor of the American scientist and engineer who pioneered the inertial navigation and the AGC).

The AGC ran programs for guidance, navigation and control of the spacecraft and approximately 64k of memory made up of 16-but word length, 2048 words RAM (magnetic core memory read-write) and 36,864 words ROM made from wires weaved through magnetic iron cores. Astronauts communicated with the AGC using a numerical display and keyboard called the DSKY. Instructions could be entered using verbs and nouns by the astronaut as machine code and the unit ran a program called Luminary, written in a language called Mac (MIT Algebraic Compiler). The AGC is regarded as the world's first embedded computers [62].

In passing from the 3rd industrial era to the 4th industrial era we have encountered many such challenges, although many of the goals were not as lofty as reaching the moon. The "spin-offs" that went into industry and society from the Apollo program included examples such as fuel cells, inertial guidance systems, fire-retardants and cooling garments for firefighters, freeze-dried foods for military and survival use. It was perhaps the microelectronics of electric circuits that was the most significant contributor to many innovations after the Apollo program. These included the video, lasers, the Personal Computer, the Graphical User Interface and mouse controller to the mobile cell phone.

The World in 2050

In a 184-page report by the National Academies of Sciences, Engineering, and Medicine (NASEM) was produced in 2017, which was co-chaired by Professors Erik Brynjolfsson, an economist at the Massachusetts Institute of Technology's Sloan School of Management, and Tom Mitchell, a computer scientist at Carnegie Mellon University. The report described the issues faced by the job market and the impact on employment, as a result of advances made in A.I. during recent years. The key findings of the study concluded that "advances in information technology (IT) are far from over, and some of the biggest improvements in areas like artificial intelligence (AI) are likely still to come. Improvements are expected in some areas and entirely new capabilities may emerge in others." [63] Brynjolfsson and Mitchell discussed the finding of the report that describe new forms of business on-demand models from Uber, Lyft to Etsy, eBay and a myriad of other types of human "contract by internet" services. More notable was the rise of Artificial intelligence as a new force of change in the way jobs and tasks could be automated and transformed in new ways. Machine algorithms and deep neural nets where being used across various industry sectors, from retail recommendations, medical research in image recognition to driverless cars, robotics and many others. Their report concluded a lack of data on the consequences of this new technological revolution meant governments where "flying blind" in being able to assess and plan ahead for the impact of predominately artificial intelligence on the workforce, workplace and wider economy.

The report recommendations included the need for improvements in track how technology is changing work by introducing measuring systems to provide an "index of technology displacement" the impact of technology is and will have on the creation or replacement of jobs [64].

Over the past 30 years information technology has moved from the 3rd Industrial revolution. This digital revolution originally saw huge analogue and digital machinery, specialist computing systems that used to fill large air conditioned rooms that run basic operations, finance, administration and planning tasks. Then the PC together with the Internet broke down various barriers and introduced an extended interconnected world, which in a short space of ten years in the new millennium, underwent a second shift as mobile devices, tablets fuelled by massive social networks and multi-media digital services. This shift exploded the volume of collective information about people, products, places and workspaces on a planetary scale. So entered the scaling of the digital revolution into the physical and social domains of the 4th Industrial Revolution.

New physical and virtual connections have created new kinds of social and machine innovation, and interconnected supply chains that work across many country borders. Together with advances in computing power, speed, storage, and falling costs have given rise to machine learning techniques that have transformed the threshold of computing and changed the job skills arena [65].

The information era created by various information technologies, has brought with it an exponential scale of inter-connections and exabytes of information. Moreover, it has introduced a new level of on-demand computing power that fits within the palm of your hand. This empowers many task that previously required educated learning and skills in order to navigate, interpret and make complex decisions. Tasks, which in 2017 remain difficult, may not be such an obstacle by 2050. (See Table 1.6).

These examples are just the tip of the technological enabled innovation curve that may be possible sooner or later in the oncoming drive for move advanced and effective technology. But what does this also mean for the jobs of brown collar and white collar worker, the middle classes maybe under threat?

Table 1.6 The world 2050

Computing tasks in 2017	Computing tasks in 2050
• Optical face recognition • Voice translation • Location awareness • Transport simulation • Basic robotic movement • Biological wellbeing • 3D Printing (Digital to physical object - basic)	• Emotional interpretation built-in by default • Natural language subject expert advice by default • Location sensing and context advise—protect, promote and coordinate unconnected or connected participants • Real time integrated transport systems • Natural physical movement in situ of other objects and humans • Integrated body implants/augments and health services • 3D assembly and fabrication manipulation of complex objects

In 2013 there was a report on the impact of automation on jobs by the Oxford Martin Institute (OMI) and the Department of Engineering Science, Oxford University by Carl Benedikt Frey, Co-Director Oxford Martin Programme on Technology and Employment Citi Fellow, and Michael A. Osborne, Dyson Associate Professor in Machine Learning Oxford University and Co-Director of the Oxford Martin Programme on Technology and Employment. The Report had conducted an early assessment of 702 occupations from the impact of computerization and famously concluded that up to 47% of U.S. jobs in the next twenty years could be replaced by automation.

Among many recommendations of such reports, include suggestions of new links between data analytics monitoring worker jobs at risk from automation with new online eLearning platforms. These new systems will alert, and enable, the workforce to plan and retrain as existing jobs are automated, and the workers will need to acquire new skills in order to move onto new jobs. Ironically both data analytics and eLearning are new forms of 4th Industrial revolution technologies that blend digital and human needs but seem to be part of the new era that creates new business and social transformation. Many more studies will become necessary for governments and enterprises seeking to understand impacts of the 4th Industrial Revolution.

It is not an exaggeration that these converged physical, digital and biological domains will redefine the living and workspaces by becoming automated with artificial intelligence that the world of 2050 will see changing whole groups of jobs and activities into automated services.

Summary

The definition of technology we started with was the application of scientific knowledge for practical purposes, especially in industry, perhaps does not adequately describe the many boundaries that technology has connected and is changing.

Neither is just technological change the only area of change that is an adequate definition of 4th industrial scale transformation. This is also being driven by increased world populations and migrations, rising climate change, emissions and weather pattern changes; stresses on food supply security as well as energy security to support populations in these changes. These transforming forces are not just in business transformation. The are also in the social and political transformation of society to finite and renewable resources, food and energy. These are pervasive systemic changes brought on through automation, rising consumption affecting the balance of power in demand and supply. They are deep structural changes at the ecosystem transformation at macro and micro technological, economic, biological, social, societal, ethical, legal, political and personal levels.

The twenty first century is the first century that will really feel the impact of these convergences in the lifetime of many of the readers of this book. This new era will require new skills and a new language to describe the impact, to harness the power of these technologies and to understand the consequences.

In the next chapter, we explore the combinations of physical, digital and biological domains, the rise of the intelligent systems and the central role of Artificial Intelligence within the 4th Industrial Revolution.

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