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INTERNET OF THINGS AND DATA ANALYTICS IN THE CLOUD WITH INNOVATION AND SUSTAINABILITY

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1.1 INTRODUCTION

In January 2016, the US NASA's Global Climate Change reported [1]: "Earth's 2015 surface temperatures were the warmest since modern record keeping began in 1880, according to independent analyses by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA)."

> The planet's average surface temperature has risen about 1.8°F (1.0°C) since the late 19th century, a change largely driven by increased carbon dioxide and other human-made emissions into the atmosphere (Figure 1.1).

The World Bank issued a report in 2012 [2] describing what the world would be like if it warmed by 4°C (7.2°F): "The 4°C world scenarios are devastation: the inundation of coastal cities, increasing risks of food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter, unprecedented heat waves in many regions, especially in the tropical substantially exacerbated water scarcity in many region, increase frequency of high-intensity tropical cyclones and irreversible loss of biodiversity, including coral reef system."

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

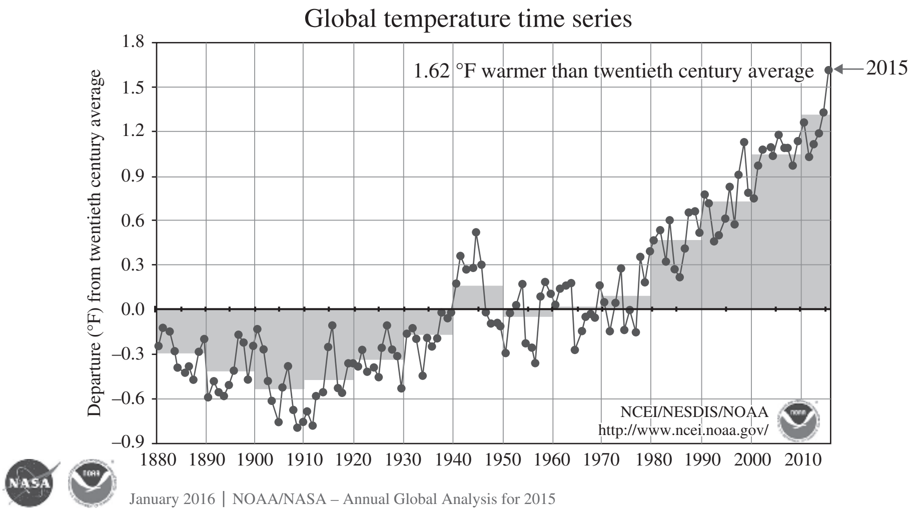


FIGURE 1.1 2015 was planet Earth's warmest year since modern record keeping began in 1880, according to a new analysis by NASA's Goddard Institute for Space Studies. Source: NASA and NOAA.
Note: NASA's data showed that each month in first half of 2016 was the warmest respective month globally in the modern temperature record.

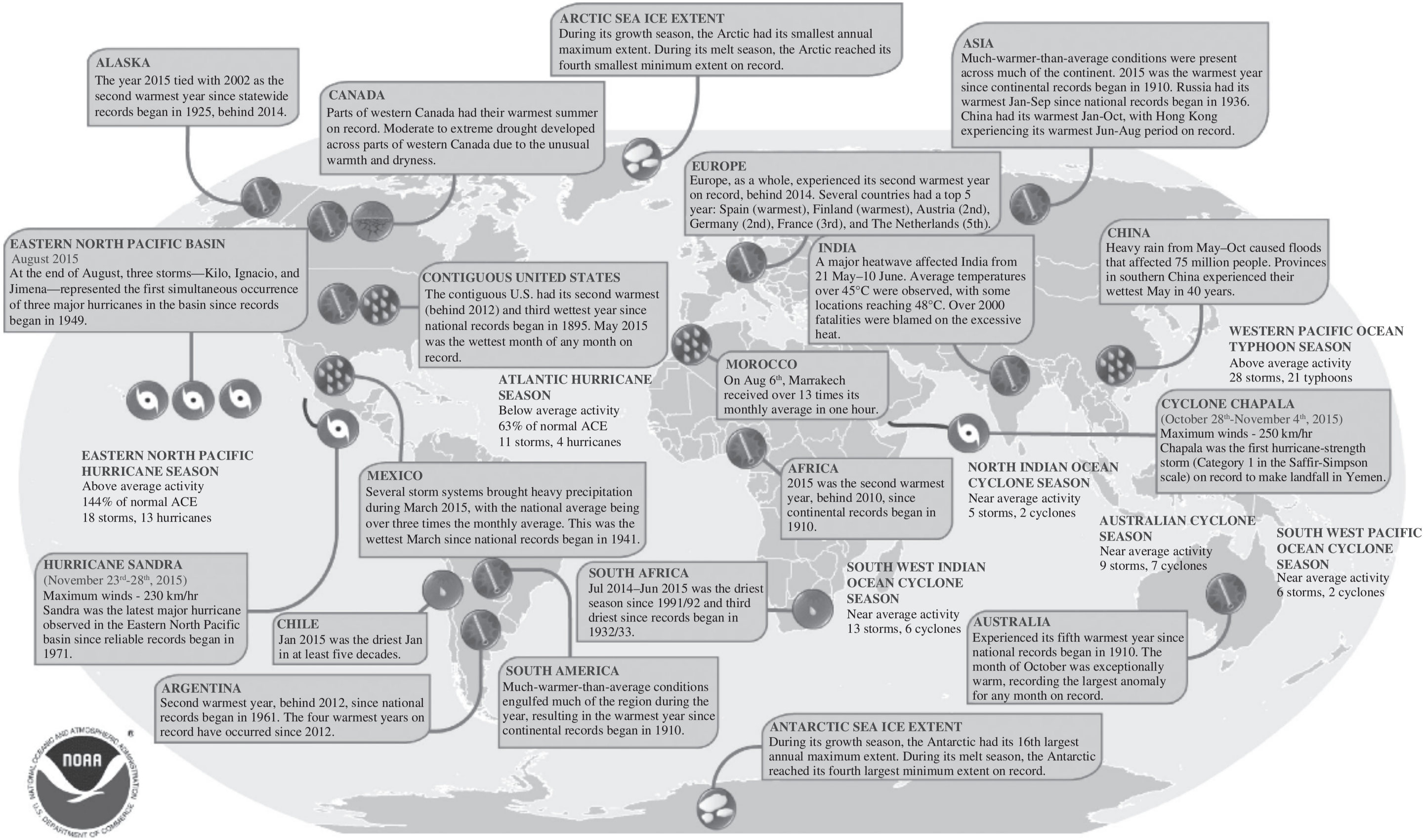
Figure 1.2 shows significant climate anomalies and events in 2015 by major regions or countries. Significant temperature increases and global warming are caused by CO_2 greenhouse effect [3].

Researchers have proven that increasing greenhouse gases (GHGs) and global warming are due to human activities. Human beings generate all kinds of heat from homes, transportations, manufacturing, and data centers that host daunting Internet-related activities [4].

1.2 THE IoT AND THE FOURTH INDUSTRIAL REVOLUTION

The first Industrial Revolution (IR) started in Britain around late eighteenth century when steam power and water power transferred manual labor from homes to powered textile machines in factories. The second IR came in the early twentieth century when internal combustion engines and electrical power generation were invented that led to mass production of T-Model cars by Ford Motor Company. The first two IRs contributed to the higher living standards for mankind. The third IR took place in 1990s when electronics, personal computers, and information technology were used in the automated production systems. Along with technological advancements, the IRs introduced air and water pollution as well as global warming.

The Internet of Things (IoTs) and data analytics are the most significant emerging technologies in recent years that have a disruptive and transformational effect to every industry around the world. The IoT is a technology digitizing the physical world [5].



Please Note: Material provided in this map was compiled from NOAA's NCEI State of the Climate Reports and the WMO Provisional Status of the Climate in 2015.
For more information please visit: http://www.ncdc.noaa.gov/sotc

FIGURE 1.2 Selected significant climate anomalies and events in 2015. Source: NOAA.

The IoT is a prominent driver to the fourth IR that will have impacts across the business and industry continuum around the world. Business executives and informed citizens are positively anticipating of the fourth IR and digital revolution with low impacts on employment [6].

Applying it into the realm of our lives opens up a host of new opportunities and challenges for consumers, enterprises, and governments. IoT products and digital services enable improvements in productivity and time to market and create thousands of businesses and millions of jobs. Our living standard is improved but at a cost of higher energy consumption that directly impacts our environment. The IoT technology will revolutionize our life and must be implemented with considerations of our quality of life and sustainability.

1.3 INTERNET OF THINGS TECHNOLOGY

The IoT has been successfully adopted in many commercial applications. Wearables and cell phones offer tracking on personalized data such as daily steps, heart rate, calorie burned that result in improving one's health and fitness. Nest, best known as a smart thermostat with machine learning algorithm, centers on the IoT by controlling home temperature through a smartphone from afar [7]. Nest's security system allows you to monitor your home 24/7 through handheld devices. The US Intelligent Transportation Systems (ITS) [8] and connected vehicles improve transportation safety and traffic control. Long-Term Evolution (LTE), or 4G LTE, advises drivers on traffic patterns to avoid jams and reduce fuel consumption that also reduces GHGs.

"The emergence of the Nexus of Forces (mobile, social, cloud, and information) and digital business" are driving forces of "Megatrends" according to Gartner's researches. The megatrends include IoT, smart machines and mobility, digital business, digital workplace and digital marketing, cloud, and big data and analytics [9].

There are hype and reality (Figure 1.3) with many unexplored opportunities that could apply the IoT technology and reduce GHGs. Examples include: (1) using 3D printing to build needed products just-in-time without inventory and with minimal transportation [10]; (2) connected homes that apply the IoT to monitor and control heating and cooling of a house, lighting, entertainment, security, and turn-on appliances when electricity rate is low. Amazon is anticipated to use drones to deliver packages that operate with clean battery power that will reduce CO_2 emission. In data centers, hundreds of temperature sensors are deployed and connected wirelessly to monitor and improve cooling efficiency, thus reducing energy consumption [4]. Wireless sensor networks are installed for structural health monitoring (SHM) that consumes minimal energy during data collection [11].

In 2015 United Nations Climate Change Conference held in Paris, there is one word you won't find in the negotiating documents: military. Although there are no official figures on the amount of GHGs generated from wars, the temperature curve in Figure 1.1 reflects a spike in 1940s when the World War II and explosion of atomic bombs took place. It is needless to say operating armored vehicles, bombers, battleships, and bombings in military actions generate enormous heat and emission that are

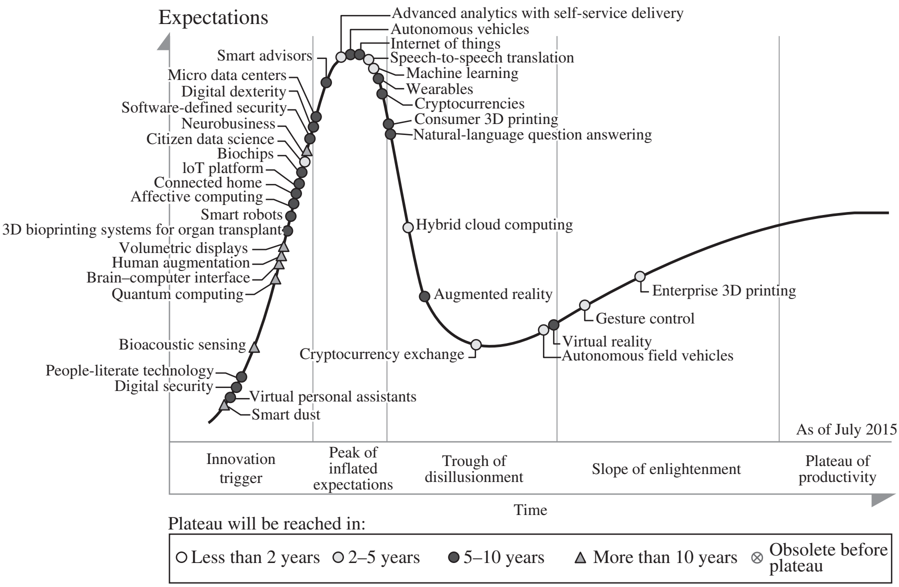


FIGURE 1.3 Hype cycle for emerging technologies, 2015. Source: Gartner (August 2015).

unwarrantedly creating heat to our environment. We have long been taught to help each other, share, keep our hands to ourselves, and work things out. War is an unacceptable behavior that is contradictory to what we have been teaching to our future generations. It creates GHGs that are harmful to our environment.

1.3.1 Definition of IoT/CPS

The term "Internet of Things," also known as "cyber–physical systems (CPS)," at macro level, was first coined by Kevin Ashton in his presentation made to Procter & Gamble (P&G) in 1999. Kevin was working at MIT's AutoID Lab to improved P&G business by linking its supply chain with Radio-Frequency Identification (RFID) information to the Internet.

IEEE has defined it as follows [12]: "Broadly speaking, the Internet of Things is a system consisting of networks of sensors, actuators, and smart objects whose purpose is to interconnect 'all' things, including everyday and industrial objects, in such a way as to make them intelligent, programmable, and more capable of interacting with humans and each other."

1.3.2 Internet of Things Process and Value Chain

A generic way of describing the IoT process was implied in Mark Weiser's ubiquitous computing (ubicomp), and it is well illustrated in the National Institute of Standards and Technology's (NIST) big data reference architecture (Figure 1.4) [13]. The architecture is organized around two axes representing the two Big Data value chains:

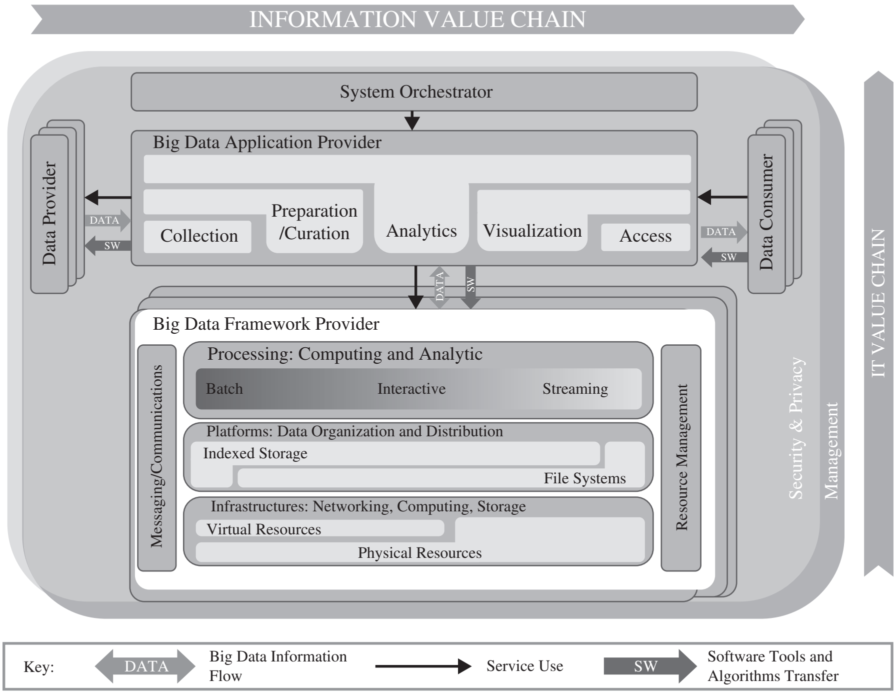


FIGURE 1.4 Big data reference architecture. Source: NIST.

(1) the information (horizontal axis) and (2) the Information Technology (IT) (vertical axis). Along the information axis, the value is created by data collection, preparation/curation, analytics, visualization, and access. Along the IT axis, the value is created by providing infrastructures, platforms, computing, and analytic processing. At the intersection of two axes is the Big Data Application Provider component, indicating that data analytics and its implementation provide the value to Big Data stakeholders in both value chains within "Security and Privacy" and "Management." The names of the Big Data Application Provider and Big Data Framework Provider contain "providers" to indicate that these components provide or implement a specific technical function within the system.

1.3.3 IoT, Pervasive Computing, and Ubiquitous Computing

The IoT, pervasive computing, and ubicomp all share an important trait: computing any time and at any place.

Mark Weiser defined ubicomp as: "enhances computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user."

Both the IoT and pervasive computing use smartphones or handheld devices in the information value loop. "Things" become smarter after being tagged, but ubicomp has horsepower to conduct advanced computing [14] in an environment that is invisible to human beings. Technology advancements over time will narrow the boundaries among IoT, pervasive computing, and ubicomp.

1.3.4 IoT by the Numbers

Gartner research (Table 1.1) shows 4.9 billion connected things worldwide in 2015. A total of 6.4 billion things connected in 2016 (0.9 things per person in the earth), and it will reach to 20.8 billion things (2.7 things per person) in 2020.

In terms of IoT spending, it was $1.2 billion in 2015 and will reach $3.0 billion in 2020 (Table 1.2).

GE estimated that Industrial Internet has the potential to add $15 trillion to global GDP over the next 20 years. IDC's 2015 IoT Global Survey reflects that companies are shifting from planning to execution on IoT plans. The IoT future is here, and we will continue to witness the IoT market in transformation.

1.3.5 Anatomy of the IoT Technology

The concept of IoT is not new. Programmable Logic Controller (PLC) in 1970s is a micro-model of the IoT system that was widely used to control machines and processes within a factory. A PLC consists of inputs (sensors, actuator, and on/off switches), output (digital or analog data), CPU, and communication between components. PLC systems were within a factory, not connected in the Internet and cloud.

Many technologies enable the IoT in connecting products, or things, and services (Table 1.3). The new version of the Internet Protocol (IPv6), supporting 128-bit or 3.4×10^{38} addresses that can connect most atoms in the world (1.33×10^{50} atoms) [15], enables almost unlimited number of devices connected to networks. Sensor prices have declined over the past decades [16]. The size and price of integrated circuit

TABLE 1.1 Internet of Things Units Installed Base by Category (Millions of Units)

Category	2014	2015	2016	2020
Consumer	2,277	3,023	4,024	13,509
Business: cross-industry	632	815	1,092	4,408
Business: vertical specific	898	1,065	1,276	2,880
Grand total	**3,807**	**4,902**	**6,392**	**20,797**

Source: Gartner (November 2015).

TABLE 1.2 Internet of Things End Point Spending by Category (Billions of Dollars)

Category	2014	2015	2016	2020
Consumer	257	416	546	1,534
Business: cross-industry	115	155	201	566
Business: vertical specific	567	612	667	911
Grand total	**939**	**1,183**	**1,414**	**3,010**

Source: Gartner (November 2015).

TABLE 1.3 The Technologies Enabling the Internet of Things

Technology	Definition	Examples
Sensors	A device that generates an electronic signal from a physical condition or event	The cost of an accelerometer has fallen to 40 cents from $2 in 2006. Similar trends have made other types of sensors small, inexpensive, and robust enough to create information from everything from fetal heartbeats via conductive fabric in the mother's clothing to jet engines roaring at 35,000 ft.
Networks	A mechanism for communicating an electronic signal	Wireless networking technologies can deliver bandwidths of 300 megabits per second (Mbps) to 1 gigabit per second (Gbps) with near-ubiquitous coverage.
Standards	Commonly accepted prohibitions or prescriptions for action	Technical standards enable processing of data and allow for interoperability of aggregated data sets. In the near future, we could see mandates from industry consortia and/or standards bodies related to technical and regulatory IoT standards.
Augmented intelligence	Analytical tools that improve the ability to describe, predict, and exploit relationships among phenomena	Petabyte-sized (1015 bytes, or 1,000 terabytes) databases can now be searched and analyzed, even when populated with unstructured (e.g., text or video) data sets. Software that learns might substitute for human analysis and judgment in a few situations.
Augmented behavior	Technologies and techniques that improve compliance with prescribed action	Machine-to-machine interfaces are removing reliably fallible human intervention into otherwise optimized processes. Insights into human cognitive biases are making prescriptions for action based on augmented intelligence more effective and reliable.

processors have dropped with increasing capabilities thanks to Moore's Law. Internet IC chip prices have been declining exponentially. High-bandwidth network technologies such as LTE and LTE-A have arrived. Smartphones become a standard consumer's device that serves as a hub or remote control to IoT. Examples include a personal connected fitness center, connected home, connected car, or connected workplace. Advancements in wireless networking technology and the greater standardization of communications protocols make it possible to collect data ubiquitously from these sensors [17] at very low cost. The IoT technology, in conjunction with big data, has fundamentally transformed how organizations create value to make our lives better.

1.4 STANDARDS AND PROTOCOLS

The Open Systems Interconnection (OSI) model, developed by ISO, is a framework for network communication. The OSI contains seven layers: application, presentation, session, transport, network, data link, and physical. Each layer uses services provided from the layer below it and offers services to the layer above it. The IoT technology concentrates on two broad types of standards, namely, (1) technology standards (network protocols, communication protocols, and data aggregation standards) and (2) regulatory standards related to security and privacy of data [18].

The information collected by sensors must be communicated or transferred over a network, wired or wireless-connected, to other locations for storage and analysis. The process of transferring data from one machine to another needs a unique address for each machine. Internet Protocol (IP) is an open protocol that provides unique addresses to an Internet-connected device such as mobile phones or laptops. For IPv6, there are 128-bit or 3.4×10^{38} (340 undecillion or 340 trillion trillion trillion) Internet addresses.

The Data link layer handles error-free transfer of data frame from one node to another. The data link layer contains two layers: Logical Link Control (LLC) and Media Access Control (MAC). The LLC upper layer controls the multiplexes protocols that provide flow control, acknowledgment, and error notification. The MAC sublayer determines who and when to access media. Some of MAC include IEEE 802.15.4, Wi-Fi, Bluetooth, LTE, ZigBee, NFC, Dash7.

The session layer manages connections, message passing, and termination of a connection between different operating systems. There are many standards and protocols in session layer that include MQTT, XMPP, DDS, SMQTT, OPC UA, CoRE, AMQP, CoAP.

1.5 IoT ECOSYSTEM

We live in a world of cyber and physical things that are fast connecting to each other. They are also ubiquitously connected to our ecological environment that has profound impacts on global warming.

In the IoT ecosystem, all physical things are digitized with digital services and cyber connected, interacted, and functioned to one another and to their physical surroundings. Applying IoT technology will make tremendous economic and environmental impacts that affect global citizens. The following subsections list what potential IoT applications in different sectors that including consumer, government, and enterprise (Figure 1.5) fit together in the IoT ecosystem. Each subsection provide some examples that could be used to facilitate your thoughts to inspire and accelerate the pace of creativity, invention, and innovation.

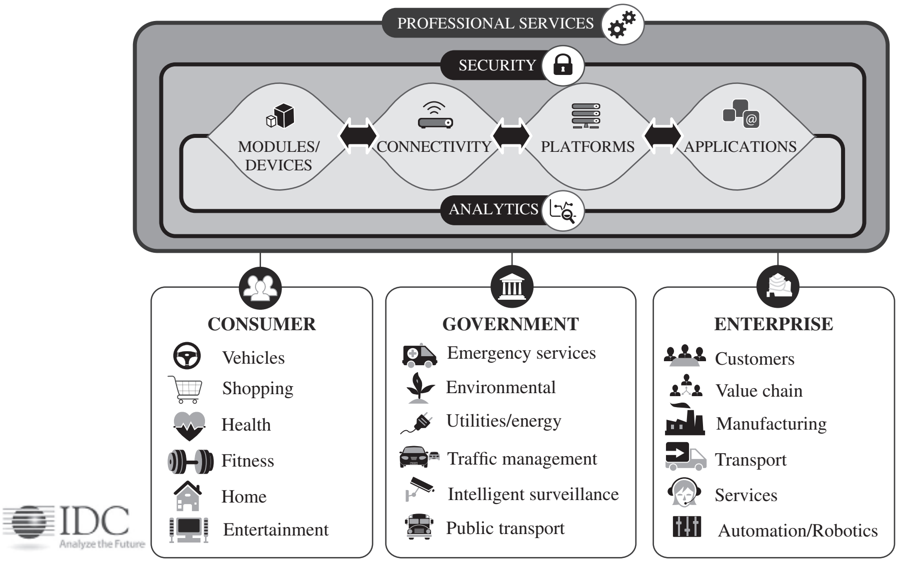


FIGURE 1.5 Internet of Things ecosystem. © International Data Corporation. Use with permission.

1.5.1 Consumer-Facing IoT Applications

Smart home: energy management, water management, home and chore automation, home robots, safety and security, air quality

Connected vehicles: autonomous vehicle, navigation, logistics routing, operations management, condition-based maintenance

Healthcare: illness monitoring and management, personal fitness and wellness

Life and entertainment: hobby, gardening and water, music, smart pet

1.5.2 Government-Facing IoT Applications

Smart city: power and lighting, adaptive traffic management, parking meter, surveillance, events control, natural or human-made disaster management, emergency response system, resource management

Smart transportation: fleet management, connected car, roadway, rail, aviation, port

Smart grid: demand response, power line efficiency

Smart water: domestic waterworks and waste water management

Smart infrastructure: SHM

Environment: environmental monitoring, air quality, landfill and waste management

1.5.3 Enterprise-Facing IoT and Industrial IoT Applications

Energy (Oil/gas, solar, wind, etc.): rigs and wells predictive maintenance, operating management, spill accident management

Smart healthcare: hospital, emergency ambulance service, emergency room, clinic, lab diagnosis, surgery, research, home care, elder care, billing, industrial IoT (IIoT) equipment efficiency, asset management

Smart retails: digital signage, self-checkout, in-store offers, loss prevention, layout optimization, beacon routing, inventory control, customer relationship management

Smart agriculture: wireless sensor on water, tracking cattle, organic food certification

Smart banking: ATM machine, e-statement, online car, or home mortgage

Smart building (office, hotel, airport, education campus, stadium, amusement park, fab and cleanroom, industrial building, data center): energy and water conservation, environment health and safety, security, operating efficiency, equipment maintenance

Smart construction: health, safety, security, inventory control

Smart education: distributed online learning, deep learning

Smart insurance: accident claims, natural disaster claims

Smart logistics: real-time routing, connected navigation, shipment tracking, flight navigation

Smart manufacturing: IIoTs, smart factory, robotics, industrial automation, asset management, energy management, operations management, predictive maintenance, and equipment optimization

1.6 DEFINITION OF BIG DATA

The term "Big data" was first dubbed by Michael Cox and David Ellsworth in 1997 [19]. Big data collects from social networking, video sharing, Internet communication, mobile devices, healthcare (medical records, MRI, CT scan, etc.), science research (astronomy, aerospace, environmental, weather), transportation (land, air, marine traffics), finance and stock market transactions, and sensors and smart devices from IIoTs.

NIST has defined big data as follows: "Big Data consists of extensive data sets—primarily in the characteristics of volume, variety, velocity, and/or variability—that require a scalable architecture for efficient storage, manipulation, and analysis" [20].

1.6.1 Characteristics of Four Vs and the Numbers

Douglas Laney, an analyst at Gartner Research in 2001, introduced the 3 Vs data management concept. Volume, velocity, and variety are known colloquially as 3 Vs. IBM added one more V, veracity, to the 3 Vs. Other Vs that business decision makers, data scientists, and computer scientists have concerns with include value, visualization, validity, volatility. Essential characteristics of 4 Vs (volume, velocity, variety, and veracity) are described in the following sections.

1.6.1.1 Volume Big data implies enormous amount of data at different process that encompass to collect, store, retrieve, process, or update the data. Large data set generated by social media or collected by sensors are large and analyses are massive.

1.6.1.2 Velocity Big data is often collected in real time at high speed from sources such as businesses, machines, social media, or human interactions via things such as mobile devices. Once received, how fast data could be stored, accessed, processed, analyzed, visualized, and acted becomes crucial.

1.6.1.3 Variety Big data comes from many sources and can be in homogeneous (structured) or heterogeneous (unstructured) forms. Big data may not be big in number, but may be big in dissimilarity and complexity. For structured data, they could be temperature information from machine tools, mileage information for car maintenance, or turbine blades running hours. For unstructured data, they could be car crash and airbag deployment information, social media with text and video streams, emails with PowerPoint file that contains images, audios, videos, and so on, that are difficult to be sorted. Presenting and rectifying variety of data elements accurately will result in machine learning, quality analytics, precise assessments, and adding value in making informative and accurate business decision.

1.6.1.4 Veracity The quality of collected data may vary that affects accuracy of analysis. Veracity denotes the completeness and accuracy of the data. There are many uncertainties in the data. The data collected may have "irregularity," "noise," or "dirty" data. It is often said that "garbage in, garbage out."

Big data and the numbers are best illustrated by Figure 1.6 that is presented in the "IBM Big Data and Analytics Hub" [21].

1.6.2 Data Analytics Value Chain

Dan Wagner was the "targeting director" in 2012 President Barack Obama's campaign. He was responsible for collecting voter information, feeding them into his statistical models, and analyzing it. This helped the Democratic National Committee (DNC) to rally individual voters by direct mail and phone. DNC used data analytics technology and successfully aimed and rallied voters, resulting in the return of Obama to office for a second term [22].

NIST describes data life cycle in the Big Data Interoperability Framework [23] having the following components:

- Collection: This stage collects raw data, gathers, and stores data.
- Preparation: This stage screens raw data and cleanses data into cleaned and organized information.
- Analysis: This stage produces knowledge based on cleaned and organized information.
- Action: This stage produces knowledge to generate value for the enterprise.

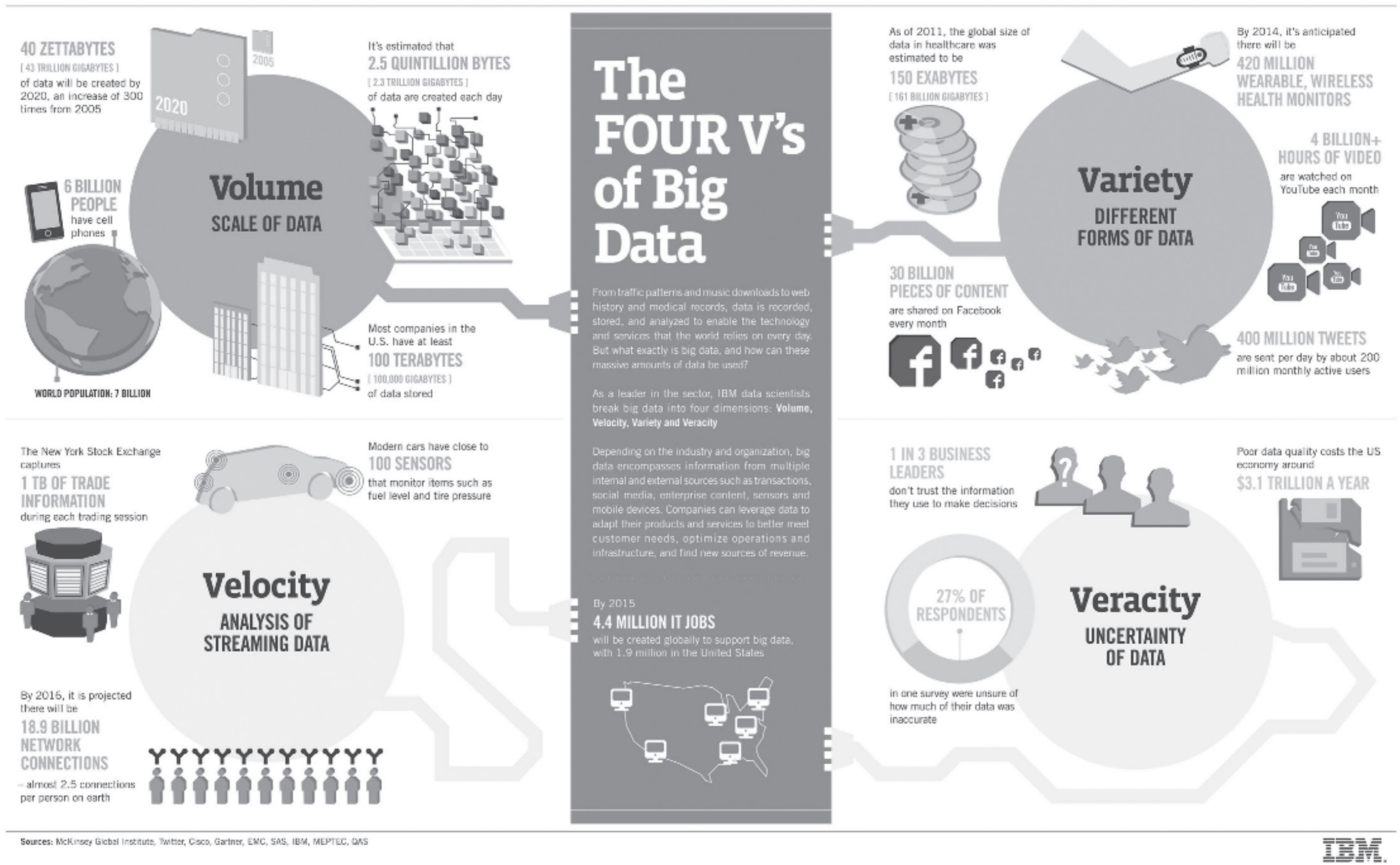


FIGURE 1.6 Big data by the numbers from IBM big data and analytics hub (http://ibmbigdatahub.com). © IBM Analytics. Use with permission.

The analyses encompass Descriptive Analytics, Diagnostic Analytics, Predictive Analytics, and Prescriptive Analytics that lead to desired actions. The analytics in statistics and data mining focus on causation—"being able to describe why something is happening. Discovering the cause aids actors in changing a trend or outcome" [23]. Causation (smoking causes lung cancer) is not correlation (smoking is correlated with high alcohol consumption). It is important for management to embrace data-driven decision process and decision making.

1.6.3 Extraction, Transformation, and Loading

An Extraction, Transformation, and Loading (ETL) tool contains three separate functions that are combined into one tool. The Extraction function reads homogeneous (structured) or heterogeneous (unstructured) data from multiple sources and validates to ensure that only the data meeting established criteria are included. During the initial data collection stage, traditional statistical techniques could be used to downsize the data before analysis so that the size of data set is reasonable on hardware that otherwise could not accommodate the size of data set.

Next, the Transformation function splits, merges, sorts, and transforms the data into a proper format for query and analysis. Finally, the Loading function integrates, arranges, and consolidates data and stores it in a data warehouse ready for analytics applications (Figure 1.7).

ETL tools organize and store the data in relational databases that are easier to query using Structured Query Language (SQL). SQL provides users to modify or retrieve data in centralized or distributed databases. ETL tools can handle data in terabytes (10^{12} bytes) to petabytes (10^{15} bytes).

1.6.4 Data Analytic Process

NIST characterizes three essential analytic processes [23]: "Discovery for the initial hypothesis formulation, establishing the analytics process for a specific hypothesis, and the encapsulation of the analysis into an operational system."

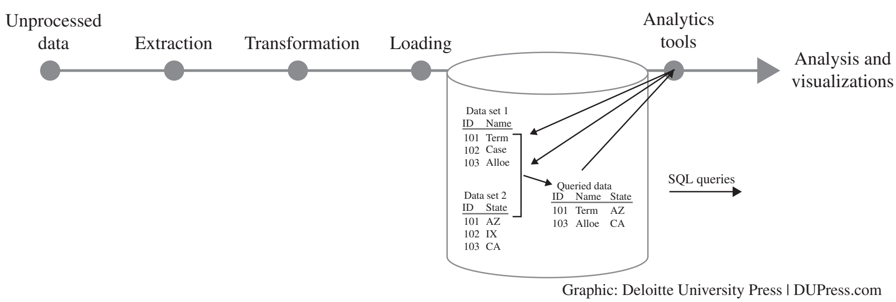


FIGURE 1.7 Typical data aggregation process. © Deloitte. Use with permission. Source: Deloitte analysis. http://dupress.com/collection/internet-of-things/.

Data analytics process can be further detailed in the following value chains:

- Identify problems and determine your business goals.
- Collect, screen, condition, and secure data.
- Explore data and plot the data to see anomalies or patterns.
- Hypothesize and build models.
- Test, validate, and, refine models.
- Deploy model.
- Monitor results and refine model.
- Present for business decision.

"Today, most analytics in statistics and data mining focus on causation" [23]. It is important to emphasize that correlation doesn't imply causation [24].

1.6.5 Data Analytics Tool

There are many data analytics tools available for businesses. The tools cover data cleaning, library, machine learning, statistical analysis, visualization, and Geographic Information System (GIS) mapping. Those data analytics tools enable users to analyze a wide variety of structured and nonstructured information.

Some tools offer free of charge for personal use, such as IBM's Watson Analytics, that get access to cognitive, predictive, and visual analytics. They are "ease of use (no coding and intuitively designed), powerful capabilities (beyond basic excel), and well-documented resources" [25].

A tool interface that supports handling of generic command-line options. Apache Hadoop®, a tool interface that supports handling of generic command-line options, is an open-source framework developed by Apache Software Foundation using Java-based programming framework. The following are some of the tools used in data analytics: Hadoop Distributed File System (HDFS), YARN, MapReduce, Spark.

There is another critical feature of analysis tool: "communicates insight through data visualization." Data visualization and presentation are useful in capturing huge inflow of data and explaining complex results to nontechnical audiences.

1.6.6 Security and Privacy

With the arrival of big data with volume, velocity, variety, and veracity, data security and privacy must be addressed. Security must be given to the retention and use of the data and its metadata (the data describing other data) [18] beyond accessibility. To support big data, the IoT platform must be equipped with protection that has understanding and enforcement of security and privacy requirements (Figure 1.5). The security of the platform must consider distributed computing systems and nonrelational data storage as well as various data sets that are increasingly containing with personal identifiable information. Preventing privacy risks on unauthorized access must be considered and designed into IoT applications.

1.7 IoT, DATA ANALYTICS, AND CLOUD COMPUTING

The IoT and big data store and access data and programs over the Internet, or cloud computing, instead of your computer's hard drive or a dedicated Network-Attached Storage (NAS). NIST defines Cloud computing as "A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

A cloud model consists of five essential characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. Cloud computing applies similar business model as utility companies (electricity, natural gas, and water) that is charged as you use.

Mega data centers must have scales in provisioning for peak usage. There is risk of over provisioning due to underutilization.

Cloud computing provides service-oriented architecture, utility computing, virtualization, infrastructure-as-a-service, platform-as-a-service, software-as-a-service [4], and other Web services in cloud. Cloud computing services need no up-front capital investments, pay-as-you-go, no overhead to manage data center, and has speed to deployment. Cloud computing is reliable, scalable, and sustainable.

Cloud computing services are often offered by high-tech companies such as Amazon, Google, Microsoft, and Oracle in the United States. IDC estimates 90% of data for the IoT and Data Analytics will be hosted in cloud in not far future.

Most cloud computing providers experienced crashes and service outages with various recover time. One of the concerns is who own the data that is created in the cloud.

1.8 CREATIVITY, INVENTION, INNOVATION, AND DISRUPTIVE INNOVATION

The IoT is no longer a buzzword; it is a fact of life. The cycle starting from creativity to invention to innovation is a compulsory backbone to flourish products applying IoT technology. A clear understanding will facilitate the discussion of creativity, invention, and innovation.

1.8.1 Creativity, Invention, and Innovation

Creativity is an ability to perceive something unusual and novel as a result of curiosity, inspiration, and imagination (Figure 1.8). Great examples include Sir Isaac Newton and his theory of gravity inspired by a falling apple and Archimedes' Eureka on the volume of water displaced as relating to the volume of his body submerged in a bathtub. Creativity is the capability of conceiving something original. Albert Einstein once said: "Creativity is seeing what everyone else has seen and thinking what no one else has thought."

FIGURE 1.8 Foster creativity. © Amica Research. Use with permission.

Invention is developing something new, satisfying a specific need, and having potential utility value. Bell's telephone and Edison's phonograph and telegraph are well-known examples of invention. Augusta Ada Byron (1815–1852) conceptualized how to instruct a computing machine in binary notation to perform an operation before the first computer was introduced in the 1940. In this way, she was the world's first computer programmer.

"Innovation is making changes to something that already exists by introducing new ideas, new processes, new products, or new business models" [4]. Some good examples include:

1. Flying objects evolved from gliders, propeller airplanes to jet engine airplanes.
2. Light bulbs evolved from incandescent, fluorescent lamps, CFL energy-efficient bulbs to LED lights.

In the article titled "Innovation is not creativity" published in the *Harvard Business Review*, Professor Vijay Govindarajan stated: "Creativity is about coming up with the big idea. Innovation is about executing the idea—converting the idea into a successful business."

1.8.2 Disruptive Innovation

The end of creative, inventive, and innovative cycle is where disruptive (DI) innovation starts.

Professor Clayton Christensen at Harvard Business School coined the term disruptive innovation. "It is a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market, eventually displacing established competitors" [26]. DI is "often centered on customer problems. It is simple yet convincing, accessible, and often cheaper than its competitor."

Classic examples of DI are many: Steve Job's iPod replaced Sony's Walkman; Digital cameras replaced film cameras; LCD terminals replaced CRT terminals; hospitals evolved to clinics in office settings.

There are vast opportunities to applying DI with novel IoT technology in conjunction with drone technology, Uber business model, and many other technologies and business models. "Disruptive" does not have to be novel.

1.9 POLYA'S "HOW TO SOLVE IT"

To brainstorm IoT projects and prepare data analytics model, or business model, the processes explained in the "How to Solve It" by Professor George Polya (1887–1985)—one of the most influential mathematicians of the twentieth century—are extremely helpful. The "How to Solve It" described a heuristic technique in problem solving. The process and steps are excerpted as follows:

- Understanding the problem
- Devising a plan
- Carrying out the plan
- Looking back on your work

1.10 BUSINESS PLAN AND BUSINESS MODEL

What business models are available for your IoT project to be successful? A business model is a simple version and the core concept of a detailed business plan. Peter F. Drucker's theory of business poses a series of assumptions: "assumptions about what a company gets paid for…these assumptions are about markets. They are about identifying customers and competitors, their values and behavior. They are about technology and its dynamics, about a company's strengths and weaknesses…What is the purpose of your business? Who is the customer? What does the customer value? How do you deliver value at an appropriate cost?"

In Professor Michael Porter's "Competitive Strategy," he describes three generic strategies: differentiation, cost leadership, and focus. Those basic strategies still hold true with adding connectivity from the IoT technology.

Clay Christensen suggests a business model should consist of the following elements: a customer value proposition, a profit formula, key resources, and key processes.

Oliver Gassmann's "archetypal business model" illustrates the relationship among key components of a business model (Figure 1.9).

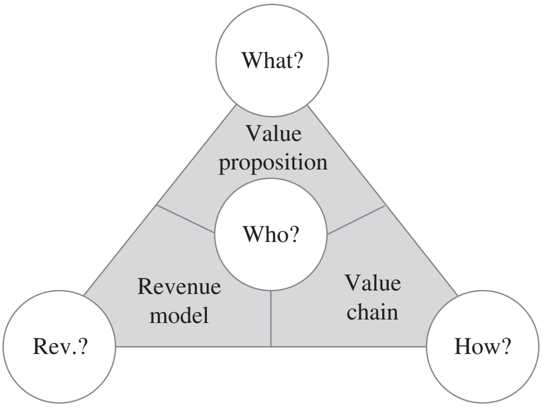


FIGURE 1.9 The archetypal business model. Gassmann O, Frankenberger K, & Csik M, 2014 © Gassmann, Frankenberger, Csik. Use with permission.

1.10.1 Business Model

A business model typically describes a plan on how you transform your creativity, invention, or innovation into a practical product, how you produce, how you market your products, and how you sell them to customers at a profit. The concept of a business model has existed for thousands of years and continues to evolve today. Business models have now propagated with connectivity and sustainability. In Internet age, a product or service can be in the cyber or physical world. By applying the IoT and data analytics technologies along with a "mindset shift" (Table 1.4), many new products with new business models could be created.

1.10.2 Business Model Examples

Exhaustive lists of potential business models with regard to IoT may be found on various websites. One such comprehensive list, "Business Models and the Internet of Things," was prepared by Fleisch, Weinberger, and Wortmann at Bosch IoT Lab, University of St. Gallen, Zurich (www.iot-lab.ch). The following list gives some examples of successful business models for IoT products:

- Add-on model: core is competitive with numerous extras for additional charge such as SAP.
- Affiliation model: someone who helps sell a product in return for commission such as Amazon.
- Digitization: "digitizing physical products" such as Facebook, Dropbox, Netflix.
- Leverage customer data: "making use of what you know" by evaluating customer behavior such as by Amazon, Facebook, Google, Twitter.
- Open source: setting standards by working together and share resources to a community of users, such as the Open Compute Project by Facebook.

TABLE 1.4 The Internet of Things Requires a Mindset Shift

THE INTERNET OF THINGS REQUIRES A MINDSET SHIFT Because you'll create and capture value differently.			
		Traditional Product Mindset	Internet of Things Mindset
Value creation	Customer needs	Solve for existing needs and lifestyle in a reactive manner.	Address real-time and emergent needs in a predictive manner.
	Offering	Stand-alone product that becomes obsolete over time.	Product refreshes through over-the-air updates and has synergy value.
	Role of data	Single-point data is used for future product requirements.	Information convergence creates the experience for current products and enables services.
Value capture	Path to profit	Sell the next product or device.	Enable recurring revenue.
	Control points	Potentially include commodity advantages, Internet Protocol Ownership, and brand.	Add personalization and context; network effects between products.
	Capability development	Leverage core competencies and existing resources and processes.	Understand how other ecosystem partners make money.
SOURCE SMART DESIGN			HBR.org

Source: Hui [27]. © Gordon Hui. Use with permission.

- Pay per use: applying IoT and cloud and pay as you go such as Software as a Service.
- Performance-based contracting: monetizing specialty services based on fee and results by HP, IBM, Oracle.
- Razor and blade (Bait and Hook model): selling razor at low cost with high price on blades for a lifetime of patronage by Gillette razor, Hewlett-Packard's printer and cartridge.
- Servitization: making a product part of a larger service and complete solutions by GE aircraft engine, MRI scanner, Whirlpool washer.

1.10.3 Servitization and Sustainability

Manufacturing companies, for example GE and Whirlpool offer a business model called "servitization." This business model extends product warranty and aftersales service all the way through the end of the product life cycle. By applying cloud computing, this business model can collect big data through embedded sensors, communicate to cloud, analyze the data with machine learning to predict and optimize performance, and even provide prompts for when a component needs maintenance or replacement. Applying IoT with servitization eliminates downtime, extends product life, minimizes overall cost of ownership, saves energy, and maximizes the product performance. The data collected may also be used to improve product design, thus ultimately improving the performance of future products [10]. This business model warrants cradle-to-cradle sustainability.

1.11 CONCLUSION AND FUTURE PERSPECTIVES

IoT technology is here to stay. Big data analytics and machine learning provide intelligence and play a pivotal role in driving IoT devices. These technologies have the potential to improve our economy, productivity, quality of life, and environment if the IoT devices are designed and implemented correctly. But there are many challenges in implementing these technologies as they are new and evolving. Users are inexperienced in selecting IoT platforms, Data Base Management System (DBMS) for multi-Vs data, and IoT services and using complex data analytics tools in modeling with unclear goals. Building a consumer's IoT infrastructure is a complex challenge, and understanding IoT is even a more daunting task. We as a society have an unprecedented opportunity to harness IoT for public good.

To be better prepared and to set the course, it is essential to understand what IoT is, what machine learning and data analytics is, and how to design devices with low power consumption, power harvesting, and sustainability. This chapter introduced the fundamentals and anatomy of IoT and data analytics technologies. The IoT and data analytics technologies interconnect with breadth, depth, and ubiquity. The IoT ecosystem is organized in consumer-facing, government-facing, and enterprise-facing applications. Within each group, different sectors and potential applications are suggested. To fuel new products and new processes in the IoT ecosystem, this chapter also discusses creativity, invention, and innovation as well as DI and "How to Solve It!"

Setting IoT's vision, goals, strategy, and implementation roadmap is challenging due to the nascent nature of technologies, business models, standards, security, and privacy [28]. Huge amounts of heterogeneous data require practitioners from science, mathematics, and statistics to work together with data scientists. This need for cooperation should start with creating interdisciplinary teams from the bottom to the top. Combining big data with machine learning and artificial intelligence for prediction and optimization will provide the greatest value. Pareto's principle, or the 80/20 rule, can be applied as a strategy in selecting IoT projects and prescreening data used in data analytics. Advanced manufacturing with cradle-to-cradle sustainability must be incorporated into IoT products.

To embrace some current conditions and future predictions, the NIST has been actively promoting Global city projects. Many smart city projects have been done in Europe, China, Japan, Korea, Singapore, and other countries [29].

IDC's 2015 IoT Global Survey indicates that "home automation and control represents 35% of consumer IoT installed base by 2020." Connected cars can affect megasized impacts to consumers and society in terms of pollution reduction, improving living standards, increasing social life, and ensuring safety, among many potential benefits. Retail section has the lowest IoT opportunity but is the fastest-growing sector among other sectors that include manufacturing, consumer, and transportation. Standardization will occur in the IoT technology. Security attacks will be handled by automation.

Many topics discussed in this chapter are addressed more fully in other chapters by experts from nine countries around the world. With collective effort, we can apply best practices to accelerate the pace of invention and innovation in IoT products that will improve our life and sustainability.

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