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Disruptive Technologies: An Educational Perspective

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Abstract

Preparing graduates for professional career is one of main objectives of high education institutions. In the past few years a growing number of disruptive technologies have emerged including Cyber Physical Systems (CPS), the Internet of Things (IoT), and Machine-to-Machine (M2M) learning. These technologies have the potential to reshuffle the global industry structure, create new markets, improve labor productivity, drive growth in advanced economies, create new lines of products, challenge exiting industries, replace incumbent and older industries, support the analysis of big data that can help in developing new drugs and therapies, and transform how people live, communicate and work. Adoption of many of these technologies can change the competitive advantage of nations. Industry adoption of these technologies may change the competitive advantages of nations. Professional career in many of these new businesses will require different skill sets than those needed in older ones. In this paper, we provide an over view of some of emerging disruptive technologies and discuss curriculum changes needed to prepare our students for careers in the industries of the future.

Keywords

Cloud computing, cyber physical systems (CPS), embedded processing, internet of things (IoT), and machine-to-machine (M2M) learning.

1. Introduction

In the past decade, professional business, entrepreneurial and economics publications [1-11] have provided lists of emerging disruptive and potentially transformative technologies, and their potential applications that will have massive and broad impacts on the quality of life, business and global economy. The list of identified disruptive technologies include cloud computing, mobile internet, cyber physical systems, Internet of things, machine learning, autonomous vehicles, advanced genomics, advanced robotics, energy storage, advanced materials, and automation of knowledge work. These technologies have the potential to reshuffle the global industry structure, create new markets, improve labor productivity, drive growth in advanced economies, create new lines of products, challenge exiting industries, replace incumbent and older industries, support the analysis of big data that can help in developing new drugs and therapies, and transform how people live, communicate and work. Adoption of many of these technologies can change the competitive advantage of nations.

The development of such technologies are the results of the development of innovative business models. Based on their potential to create new key business applications, better products and

sustainable environment, the estimated potential economic impacts of identified disruptive technologies is between \$14 trillion and \$33 trillion a year in 2025 [7].

This paper is organized as follows. Section two of this paper will provide brief descriptions of the differences between sustainable and disruptive technologies. Section three will provide description of key disruptive technologies and brief analysis of their economic and social impacts. Section four will provide a road map for creating courses to provide students with essential skill sets necessary for professional careers in three of these technologies, namely, Cyber-Physical Systems (CPS), Internet of Things (IoT), and Machine Learning. A summary of the contribution of this paper is given in section five.

2. Sustainable and Disruptive Technologies

Sustainable innovations are the results of established businesses efforts to increase their market share by improving the quality of their existing products or introducing new products to satisfy the needs of their customers. Such innovation help maintain the short-term growth of companies. Examples of sustainable technologies include added features to next year's cars or smart phones.

Disruptive technologies aim at creating new business models, products and markets that do not exist at the time of technologies conception.

3. Over View of key Disruptive Technologies

Key disruptive technologies include cloud computing, mobile internet, cyber physical systems, Internet of things, machine learning, autonomous vehicles, advanced robotics and automation of knowledge work. A brief description of each of these technologies and their economic and/or social impacts follows.

a. Cloud computing

Cloud computing is one of the main disruptive technologies that drive innovation and create new customer relationship management (CRM) business models and improve enterprise IT productivity.

The cloud is a massive global network of computer hardware and software to store and manage data remotely over the internet reducing the need of companies to create, maintain, and upgrade private data centers and servers. Currently, the main commercial providers of public cloud providers include Amazon (Amazon Web Services (AWS)), Microsoft Azure, Google Cloud Platform, and IBM Cloud.

Cloud providers allow customers to share computer hardware, high-capacity storage and continually-updated software packages, applications, and pre-built services reducing their needs to buy expensive technologies that may quickly become obsolete. In return, customers pay their cloud providers a subscription fee or pay according to their resource usage. In general, cloud computing services can be divided into the following three categories: a) Service as a Software (SaaS); b) infrastructure as a service (IaaS); and c) platform as a service (PaaS).

Examples of SaaS includes the Microsoft's office 365, Google's G Suite, and Oracle's ERP suite [12]. Customers access these application over the internet through a browser. They can also configure these applications according to their needs. IaaS public clouds provide customers with high-capacity storage, virtual private networks, and computer hardware. Customers of IaaS providers may also get access to a wide-variety of software tools including scalable database development, machine learning, and big data analysis. PaaS cloud usually offer developer with a variety of software resources and services needed for application development, testing, and deployment, thus, reducing time to market. In the US, the potential economic impacts of cloud computing in 2025 is estimated between \$1.7 trillion – \$6.2 trillion. In Europe, it is estimated that cloud computing could add EUR 449 billion to the EU28 GDP in the next five years [13].

Like other types of technologies, cloud computing comes with a wide variety of risks and challenges. Key among those challenges are cyber security threats, information security and privacy risks, and customers losing full control of their IT environments.

b. Information Technology and Automated Everything

Information technology is omnipresent. Most of newly developed disruptive technologies are directly or indirectly enabled or enhanced using information technology. The development of powerful and inexpensive mobile computing devices coupled with more capable internet connectivity made it possible to develop a wide range of disruptive technologies. Continual advances in artificial intelligence, machine learning, and natural user interfaces are making it possible to develop advanced robots, autonomous vehicle, drones and remote aerial vehicles, and advanced knowledge automation tools. These tools also helped making it possible to automate of many knowledge worker tasks such as customer relationship management through the use of intelligent agents and chatbots such as Siri, Alexa, and Cortona. Intelligent agents do not only interact with customers, but they also collect and analyze information that help them personalize their responses to individual customers. Advanced analytical tools that are based on artificial intelligence and machine learning tools can help highly-skilled worker to become more productive. However, these tools can eliminate many menial and manual jobs or make them economically uncompetitive. For example, in the automotive manufacturing industries, advanced robots are replacing human in cars assembly plants.

c. Embedded processing

Embedded processing systems are not considered as disruptive technology; however, they are the foundations of Cyber-Physical Systems, the Internet of Things, which are the two cores of the fourth industrial revolution. Embedded processing systems are utilized in a wide variety of applications including computing systems, consumer electronics, industrial applications, defense systems, automotive systems, avionics equipment, robotics, drones, manufacturing and production systems, process control systems, medical device and systems, power systems management and control systems, communication and information systems, interactive multimedia, and wearable devices. In the 21st century, the list of applications of embedded systems keeps growing due to the creation of new paradigms such the Internet of Things (IoT),

and Cyber Physical Systems (CPS). Such applications arguably dominate most aspects of modern life. According to Zion Market Research 2017 report, the embedded system market is projected to reach USD 225.35 billion by 2021, growing at CAGR of more than 6% between 2016 and 2021 [14].

Embedded computing systems have distinctive characteristics than those of traditional computing systems. These systems are designed for a dedicated functionality using a combination of hardware and software components. The hardware may include sensors and actuators. The common characteristics these systems are dependability and efficiency. Many embedded systems need to operate under stringent real-time constraints. In [19], dependable real-time embedded systems must be easy to maintain and upgrade, reliable, safe to operate, and resilient. They also need to be efficient in terms of computational power and performance, power management, code size, weight and cost.

The ever-shrinking time-to-market, the ever-increasing embedded systems design complexity and the development of powerful, integrated system-level design environment have made heterogeneous FPGA systems equipped with traditional reconfigurable logic, distributed memories, advanced communication protocols, and multi-core microprocessors the platform of choice for developing embedded systems with complex functionality that are dependable, efficient, robust, and resilient. FPGA are becoming the core technology used in the implementation of high performance digital systems.

d. Cyber-Physical Systems

The term CPS was coined at the National Science Foundation (NSF) in the United States around 2006 [15]. The CPS approach has been recognized as a paramount and prospective shift towards future networking and information technology (NIT) by the 2007 report of the President's Council of Advisors on Science and Technology (PCAST). PCAST recommends the reorganization of the national priorities in NIT research and development (R&D) and putting CPS at the top of the research agenda [16].

Cyber-Physical Systems are tight integrations of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa. Spectacular progress in microelectronics and information technology created a big stimulus towards development of advanced embedded processing applications and cyber physical systems that couple the digital (cyber) systems with the physical world leading to the internet of things. Applications of CPS include new generation automotive systems, high confidence medical devices, avionics, smart power infrastructure, process control, distributed robotics, and others. All such systems exhibit stringent real-time and safety requirements: computation must progress in parallel with physical processes in the environment, and system disruption can lead to catastrophic consequences. Compared to traditional embedded systems, the vision for CPS calls for open, interconnected systems rather than closed, "black box" devices. The National Academy of Science has issued a report named, "A 21st Century Cyber-Physical Systems Education." to

promote and guide the creation CPS programs and courses at all levels [17]. The National Science Foundation (NSF) has increasingly provided funding opportunities to the scientific community to promote transformative research on CPS [18].

The economic and societal potential of such systems is vastly greater than what has been realized, and major investments are being made worldwide to develop the technology. Emerging applications of CPS has applicability across almost all industry domains including transportation, healthcare, energy, intelligent manufacturing, entertainment, consumer electronics and appliances, environmental monitoring, etc., all of which will be essential pieces of our social infrastructure.

The European Union's joint technology initiative, called Advanced Research and Technology for Embedded Intelligence Systems (ARTEMIS), has invested in research and development (R&D) efforts on the next generation engineered systems with public-private partnership between European Nations and the industry to fulfill the vision of a world in which all systems, machines, and objects become smart and physically-aware, have a presence in the cyber-physical space, exploit the digital information and services around them, and communicate with each other as well as with the environment [19]. Moreover, the European Commission has launched a new research and innovation program, namely Horizon 2020, at the end of 2013 to develop new strategies for tackling societal challenges. Horizon 2020 is the biggest research and innovative program yet with a budget of nearly EUR 80 billion. Horizon2020 covers CPSs and advanced computing research and innovation [20].

e. Internet of things

The Internet of Things (IoT) refers to the use of interrelated computing devices, electrical, mechanical and digital systems, advanced sensors and actuators, and data communication technology to create physical objects that are connected to the internet. Each object is provided by a unique RFID tag and has the capability to communicate data regarding its location, environment, and performance without human interaction allowing these objects to be tracked, controlled, and reprogrammed across the internet.

The IoT has a wide range of applications in health care, remote monitoring and tracking, public service sector optimization and predication, and control of operation of power and smart grids, navigation systems, unmanned vehicles and drones, home appliances, manufacturing machinery, traffic control, and countless other physical devices. According to [21], it is estimated that as many as 50 Billion objects will be connected through the IoT. According to [22], with enacting polices and regulation that provide incentives for using newer technologies coupled with creative business models allowing the adoption of IoT based-systems could generate between \$3.9 to \$11 trillion per year by 2025.

f. Machine Learning

Machine learning is the science of getting computers to act without being explicitly programmed. In the past decade, machine learning has provided us with self-driving cars, natural speech recognition, natural language processing, robotic process automation, intelligent agents, effective web search, and a vastly improved understanding of the human genome. Advances in artificial intelligence, machine learning, and natural user interfaces (e.g., voice recognition) are making it possible to automate many knowledge worker tasks that have long been regarded as impossible or impractical for machines to perform. This opens up possibilities for sweeping change in how knowledge work is organized and performed. Sophisticated analytics tools can be used to augment the talents of highly skilled employees, and as more knowledge worker tasks can be done by machine, it is also possible that some types of jobs could become fully automated.

Continual improvements in machine learning are having significant impacts areas such as big data analysis, development of new drugs, and speed of driverless cars. The development of a smartphone application that can help in the early detection of skin cancer with 81% accuracy is reported in [23]. Various application of machine learning in pharma and medicine including disease identification and diagnosis, personalized treatment and behavior modification, drug discovery, identifying candidates for clinical trial research and epidemic outbreak predication have been reported in [24]. The use of supervised and unsupervised machine learning algorithms in self-driving cars to provide continuous rendering of neighboring environment and predicting possible changes to driving environment such as the detection and identification of an obstacle, and object localization and prediction of its movement is reported in [25].

4. Recommended Curriculum Changes

The following discussion provides recommendations for course development in cloud computing, embedded processing, cyber physical systems, and machine learning.

a. Cloud Computing Courses

Cloud computing programs, certificates, and courses are being offered at many universities. These courses provide students with essential knowledge about cloud computing basics, concepts, infrastructure, networking, service models (IaaS, PaaS, SaaS), big data management, key characteristics and components of cloud computing service-oriented architectures and its topology, converting logical models into applications operating in the cloud environment, and how to access and manage security and privacy risks and challenges. Major providers of cloud computing services are offering courses leading to professional certificates such as Architecting Microsoft Azure Solutions Certification and Amazon's AWS Certified SysOps Administrator.

b. Embedded processing Courses

Embedded processing systems are utilized in a wide variety of applications including computing systems, consumer electronics, industrial applications, defense systems, automotive systems, avionics equipment, robotics, drones, manufacturing and production systems, process control systems, medical device and systems, power systems management and control systems, communication and information systems, interactive multimedia, and wearable devices. In the

21st century, the list of applications of embedded systems keeps growing due to the creation of new paradigms such the Internet of Things (IoT), and Cyber Physical Systems (CPS). Such applications arguably dominate most aspects of modern life. Embedded processing courses enhance the career opportunities for students by provide them with the technical skills demanded by many industry and academic jobs.

Embedded computing systems have distinctive characteristics than those of traditional computing systems. These systems are designed for a dedicated functionality using a combination of hardware and software components. The hardware may include sensors and actuators. The common characteristics these systems are dependability and efficiency. Many embedded systems need to operate under stringent real-time constrains. In [26], dependable real-time embedded systems must be easy to maintain and upgrade, reliable, safe to operate, and resilient. They also need to be efficient in terms of computational power and performance, power management, code size, weight and cost.

Embedded processing courses should provide students with the solid foundations in the design and analysis of complex embedded systems from inception to the prototyping of a model of the system. These courses should make use of both commercially of the shelf (COTS) microcontroller systems, and heterogeneous FPGA boards coupled with assortment of sensors and actuators. Real-time, dependability, efficiency, hardware/software co-design and partitioning, use and reuse of intellectual product (IP) components, and model-based design should be introduced in these courses. These topics will provide students with practical skills in developing application software and device drivers, interfacing to hardware, processors, and peripheral devices, hardware/software system integration, testing, and the use of development and verification tools.

Lecture courses should be accompanied with a series of laboratory exercises and a semester long project. Theses laboratory exercise will help student learn the basic concepts of designing embedded systems and mastering the lectured materials. Laboratory exercises and projects can utilize popular kits such as the ARM-based Rapid Embedded Systems Design Education Kit or low-cost FPGA embedded systems development boards. Laboratory exercises and projects should leverage proficiency gained from other core engineering courses such as C/C++ programming language, assembly language, and computer organization courses in designing real-world embedded applications.

c. Cyber Physical Systems Design Courses

Cyber-Physical Systems (CPS) are systems featuring a tight integration of computation with physical processes. Applications of CPS include new generation automotive systems, high confidence medical devices, avionics, smart power infrastructure, process control, distributed robotics, and others. All such systems exhibit stringent real-time and safety requirements: computation must progress in parallel with physical processes in the environment, and system disruption can lead to catastrophic consequences. Compared to traditional embedded systems, the vision for CPS calls for open, interconnected systems rather than closed, "black box" devices.

Cyber physical systems design courses should introduce students to key challenges, design methodologies and research directions in the field of cyber-physical systems. These courses should cover topics such as challenges in CPS design, predictable computer architectures, scheduling of hardware resources, operating system abstractions for CPS, timing and performance analysis, modeling and verification, CPS applications. They should also show how CPS requirements of predictability and reliability lead to significant changes in the hardware architecture. Due to the multidisciplinary nature of CPS design, these courses should also touch on related topics such as predictable operating system abstractions, timing analysis, and modeling and verification. Lecture course should be accompanied with a series of laboratory exercises and projects. A larger lists of cyber physical system courses can be found in [17].

d. Machine Learning Courses

Machine learning is the science of getting computers to act without being explicitly programmed. In the past decade, machine learning was a key technology in the development of self-driving cars, practical speech recognition, effective web search, and a vastly improved understanding of the human genome. Many researchers also believe it is the best way to make progress towards human-level artificial intelligence (AI).

Machine learning courses should provide students with a broad introduction to machine learning, data mining, supervised and unsupervised learning, processing of complex data structure, data mining, and data visualization. These courses should expose students to the theory, best practices, and implementation of most effective machine learning techniques and tools and provide them with the practical knowledge on how to apply these techniques to new applications such as harvesting actionable information from “Big Data”. Laboratory exercises should draw from numerous case studies and applications including how to apply learning algorithms to CPPS data analysis, building smart robots (perception, control), text understanding (web search, anti-spam), computer vision, medical informatics, audio, database mining, and other areas. MATLAB modeling and simulation software, data acquisition equipment and software (NI LabVIEW & NeuroSolutions) can be utilized for these courses.

5. Summary

This paper provides description of some key disruptive technologies with significant economic impacts. The paper also provides recommendation for curriculum development in the areas of cloud computing, embedded processing systems, cyber physical systems, and machine learning. These courses will provide students with the technical skills needed for the 21st professional careers.

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