Experience Teaching Emerging Information Technologies

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Abstract

This paper discusses our experiences teaching a doctoral-level course in emerging information technologies. The concept of emerging technologies is put into context by describing the technology life cycle. The emerging information technologies of current interest – Artificial Intelligence and related areas, Collective Human-Computer Intelligence, Blockchain, Quantum Computing, Cybersecurity, Biometrics, and Internet Platform Businesses – are described and the distinctions among them explained. We conclude that teaching emerging information technologies is an area rich with opportunity for growth.

Introduction

The rapid digitization of our world, with the subsequent blurring of the boundary between the physical, digital, and biological, together with continual improvements in the cost/performance of computing, storage, and networking, are driving the emergence of novel, rapidly evolving technologies that have a strong potential for impact in the future. These technologies are often disruptive; they can change the way businesses and whole industries operate, have socio-economic impacts (e.g., eliminate jobs and create new ones), and raise new ethical, legal, policy, and regulation challenges. For all these reasons, it is important for students to have a basic understanding of current emerging technologies and the impact they can have (and are having) on government and citizens, industry and employees, and academia -- including students, faculty and staff.

Our focus is on emerging and disruptive information technologies (not, for example, genetic engineering or additive manufacturing). We cover selected technologies based on faculty background and interests and potential industry collaboration. Currently, these include (1) Artificial Intelligence, Machine Learning, Deep Learning, and Neural Networks and their application, (2) Collective Human-Computer Intelligence (Malone 2018), (3) Quantum Computing (for exponential scaling in performance on important applications), (4) Cybersecurity and Biometrics, (5) Internet platform businesses, and (6) Blockchain (a distributed ledger) and its application.

Pace University has individual graduate courses in many of these areas. The course under discussion here introduces the technologies, identifies open research problems, discusses potential long-term impact and current applications, raises awareness of ethical issues raised, and addresses new business models, e.g.,

"Internet Platforms" (McAfee & Brynjolfsson, 2017). Students graduating from the course have a strong understanding of emerging technologies and their application, understand the potential for applying them in their own work (business or research), and may get ideas for their doctoral dissertations. In the future, we hope to include topics in imbedded intelligence (e.g. robotics, autonomous vehicles) and cyber-physical security.

Given the pervasiveness of many of these technologies and the rapid rate of change, a course on Emerging Technologies would serve the needs of students enrolled in undergraduate and graduate degree programs in Computer Sciences and Information Systems. We believe the Emerging Information Technologies course (in Pace University's Doctor of Professional Studies (DPS) in computing) can be effectively re-structured to serve this need.

The following sections describe the technology life cycle, the doctoral course we are currently teaching, the various emerging information technologies of current interest, and some conclusions.

The Technology Life Cycle

To put the concept of an emerging technology into context, it is important to describe the "S" shaped curve representation of the technology life cycle (Fig. 1). This curve shows the four main phases of the technology life cycle: the invention of the technology, the emergence as the technology is being developed, the maturity when the technology becomes established and accepted, and finally saturation when the technology becomes wide-spread and fully appreciated, as shown by the flattening of the growth curve.

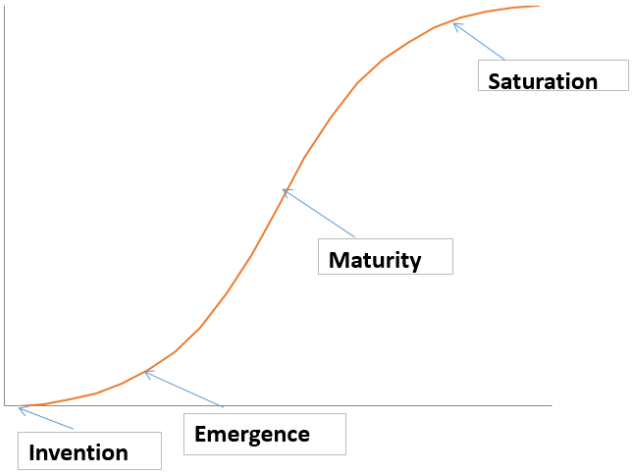

Fig. 1. The "S" shaped curve of the technology life cycle (drawn by authors).

These phases of the technology life cycle, together with some additional phases, have been described by several authors, including Kendall (1999) and Kurzweil (1999) whose life cycle phases are shown in Fig. 2. Let's follow some technologies through the life cycle. The airplane was invented in 1903 by the Wright brothers when they achieved the first powered and controlled machine flight. Shortly after the invention, longer powered flights were performed by planes with improved designs as the technology emerged and developed. Airplanes were further developed and used during WWI and WWII, and with the wide-spread availability of air travel today the technology is currently fully matured and established, but may not have reached saturation because there remain many regions of the world having little access to airplanes. Another phase of Kurzweil's life cycle is the dream or contemplation and, in this case, long

before the invention, Leonardo da Vinci in the 15th century contemplated flying machines through his sketches and designs.

Turning to the technology of writing instruments, not too long ago we used pen and ink, first using pens that were dipped into ink and then using fountainpens that allowed the user to write for some time before having to refill the ink bladder of the pen. These technologies are now obsolete and relegated to antiquity, except perhaps for their use by calligraphers, because they have essentially been replaced by the ballpoint pen.

Kendall	Kurzweil
	0. Precursor (dream/contemplation)
1. Invention	1. Invention
2. **Emergence**	2. **Development (emergence)**
3. Acceptance (established)	3. Maturity (established)
4. Sublime (fully appreciated)	4. Pretenders (threat by upstart)
	5. Obsolescence (by new tech)
5. Surplus	6. Antiquity

Fig. 2. The Kendall and Kurzweil phases of the technology life cycle (drawn by authors).

Although the exponential growth curve of a technology flattens out, new technologies invariable emerge to keep growth exponential. An example of this is the growth of computer technology – from mechanical switches in the 1890s to relay-based switches in the 1940s to vacuum tubes in the 1950s to transistors in the 1960s and to integrated circuits in the 1970s. Just-in-time arrival of new technologies pick up from the flattening technology curve to maintain exponential growth (linear growth on a log scale). Each technology has an S-shaped growth curve and the concatenation of these S-shaped curves produces an exponential curve Fig. 3 (left). Furthermore, when the arrival of new technologies is accelerated through synergies, the result is accelerated returns (change) faster than exponential growth, curving toward double exponential growth (Kurzweil, 1999), shown as an exponential on a log scale in Fig. 3 (right). An example of the accelerated growth of a technology through the synergistic effects of enabling technologies is the human genome project (1990-2003) that was estimated to take 1000 years of research but was completed in 13 years (Human Genome Project, 2019). Perhaps it should not surprise us that a 1000 year project took only 13 years at a double exponential rate since $2^{10} \sim 1000$.

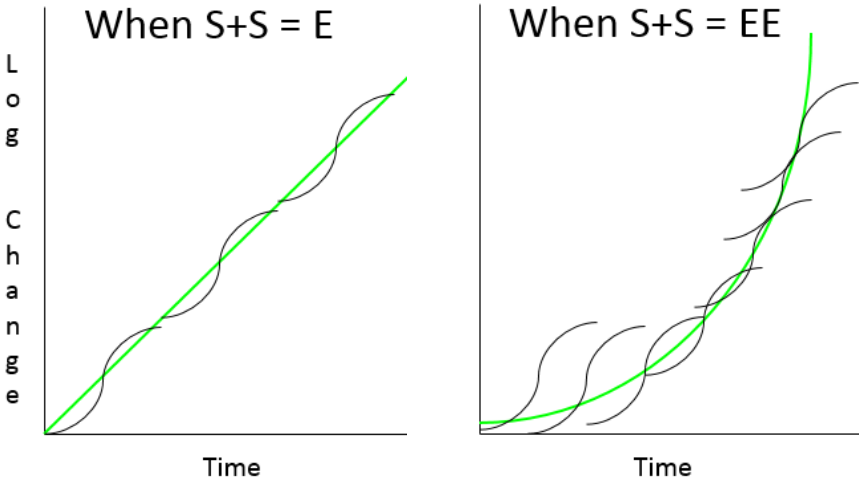

Fig. 3. Log scale just-in-time new technology arrival yields exponential growth (left), while synergy-accelerated arrival yields double exponential growth (right) (drawn by authors).

More recently, the maturity phase of the life cycle S-shaped curve has become steeper (Fig. 4). People are adopting technologies at an unprecedented pace, and good examples are social media and smart phones. It is difficult to predict the impact of technologies like computer vision and speech recognition that are at the cusp of a steep maturity curve. In business, predicting the adoption rate accurately can be the difference between success and failure. In an emerging technologies course, instructors should be careful about claims and students made aware of this unpredictability through examples.

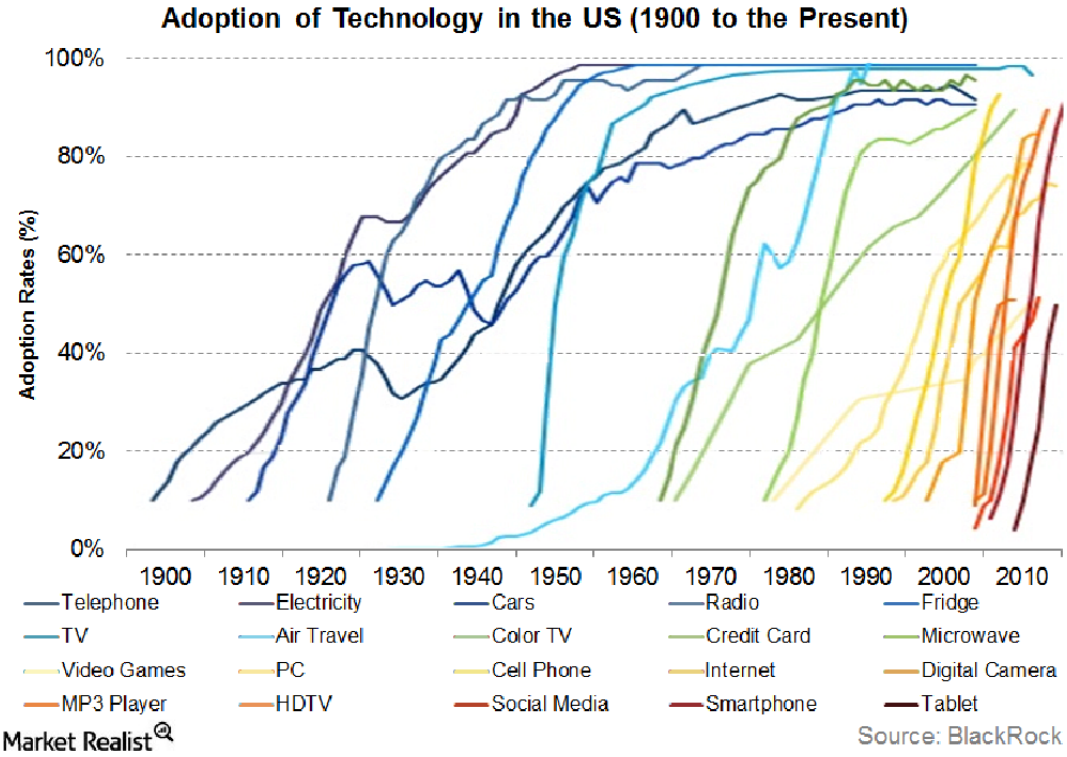

Fig. 4. Recent technologies have shown increasingly steep curves (Rieder, 2015).

Teaching a Doctoral Course in Emerging Information Technologies

A two-semester course on emerging information technologies has been taught in Pace University's Doctor of Professional Studies (DPS) in computing program for the last 20 years. The DPS program "provides IT professionals with a unique opportunity to pursue a doctoral degree while continuing to work full time. It supports interdisciplinary study among the computing disciplines and applied research in one or more areas of the field, providing a background highly valued by both academia and industry. It is an innovative, post-master's, research doctoral program structured to meet the needs of the practicing computing professional" (DPS, 2019). The students come to the university five weekends a semester, roughly once a month, to attend courses and they do additional work between meetings – readings, assignments, teamwork.

The emerging information technologies course sequence is taught in the second-year of the program. Fifteen to twenty students take the course sequence each year and the students are divided into 4-5 person teams. Assessment varies depending on the material covered but usually each team investigates and makes a presentation on an emerging IT topic of current interest, and writes a technical paper to be submitted to our internal computing conference (Research Day Conference, 2019). Because this is an executive program for working professionals, the underlying technical details of the emerging information technologies are not covered in class but teams covering topics in these areas will explore the topics in greater detail. As these areas are explored, the focus is on potential dissertation and discussion material.

The learning objectives of the course are:

1. Learn about important emerging and disruptive technologies and their application.
2. Understand the potential impact on science, engineering, business, and national security.
3. Learn to apply these technologies to their research and engineering projects.
4. Gain an awareness of the ethical issues that decision makers at all levels will face.

Emerging Information Technologies of Current Interest

This section briefly describes many of the emerging information technologies of current interest and explains the distinctions among them. Note that many of these areas of technology overlap.

Artificial Intelligence (AI), Machine Learning (ML), Deep Learning, Data Mining, Data Science, and Big Data Analytics: These technologies are highly overlapping, see Fig. 5. Artificial Intelligence (AI) refers to an artificial creation of human-like intelligence. So far AIs have been in specific narrow areas:

- In 1997 IBM's Deep Blue beat the world's best human chess player
- In 2011 IBM's Watson beat the world's best human jeopardy players
- In 2017 Google's AlphaGo beat the world's best human Go player
- The Google search engine quickly finds information
- Apple's Siri and Amazon's Alexa voice services answer questions

AI has been around for many years and there is currently a renewed focus on Artificial General Intelligence (AGI), AIs that can perform any intellectual task that a human can. Machine learning is a sub-area under AI and deep learning is a sub-area under machine learning. With advances in computing power, applications in these areas can now effectively utilize large quantities of data, thus enhancing the capabilities of data mining and data science that use machine learning algorithms.

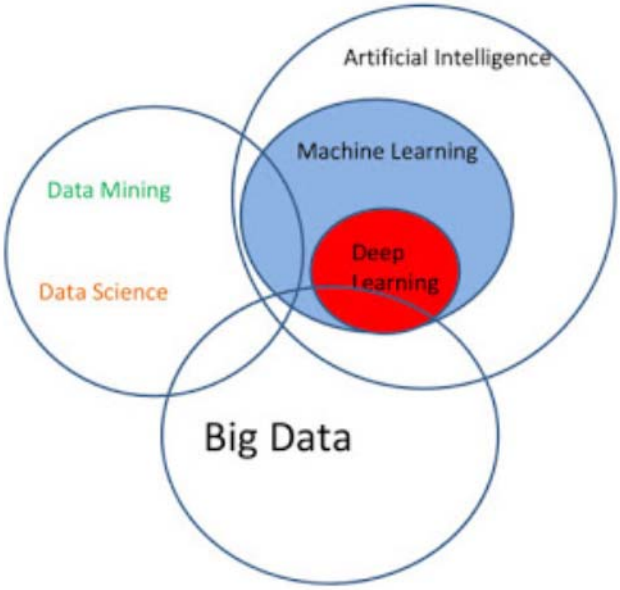

Fig. 5. AI, ML, Deep Learning, Data Mining, Data Science, and Big Data (AI Venn Diagram, 2016).

Deep Neural Networks (DNN), neural networks having multiple layers between the input and output layers (Fig 6), is the newly developed technology of deep learning that is winning most of the contests and outperforming other machine learning technology in most applications, such as in the areas of machine vision and speech recognition (Siri and Alexa), and playing the game of Go (Fig. 7).

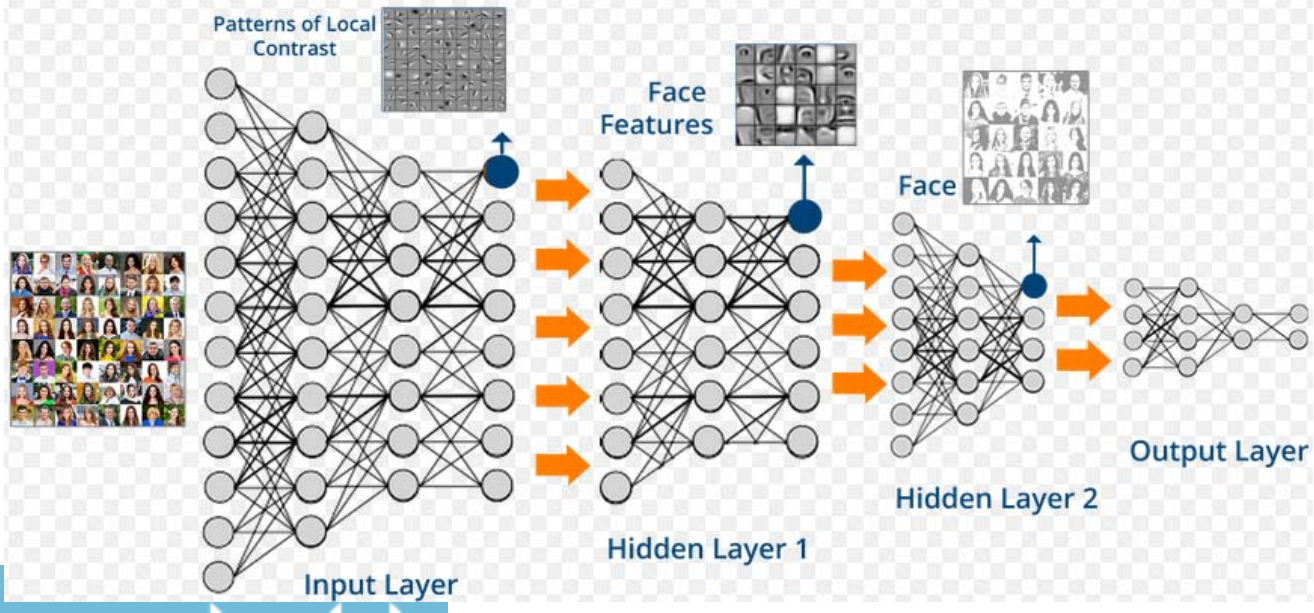

Fig. 6. A Deep Neural Network (DNN) for face recognition (Grigsby, 2018).

Fig. 7. Google's AlphaGo AI wins three-match series against world's best Go player (Phys.Org, 2016).

Other areas of AI are more directly infiltrating our daily lives. Social media has a powerful influence on our lives and increasingly with unintended consequences. McNamee (2019) contends Facebook is creating a political and cultural crisis with a serious danger to democracy, and to support his contention he discusses events like the following:

- 2016 US presidential election and Brexit campaign
    - Cambridge Analytica accessed Facebook user profiles to send targeted ads to influence the election and Brexit
- 2018 MIT study – Twitter fake news is shared 70% more often than factual information
- 2018 United Nations report accused Facebook of enabling religious persecution in Myanmar and Sri Lanka, many were killed

With the soon-to-come driverless cars and humanoid robots we may be on the threshold of an AI-dominated reality. As with many new technologies, there are potential dangers. For example, the predicted "singularity" is said to occur when machines become as intelligent as humans because once that happens they will quickly become far more intelligent than humans causing an unfathomable rupture (singularity) in human experience and could be the end of humanity as we know it today. The Singularity, if it occurs, will be a milestone in AI, not a technology. As to when the singularity might occur, in recent surveys AI experts estimates it could occur with 10% chance by 2022, 50% chance by 2040, and 90% by 2075, and some say it will never occur (Fan, 2019).

Another interesting Venn diagram focusing on the data scientist is shown in Fig. 8. At the center is the perfect data scientist with capabilities in the four areas of communication, statistics, programming, and business. Those with capability in only one of the four areas are the accountant in business, the hacker in programming, the data nerd in statistics, and hot air in communication. An interesting two-area person is the sales person, perhaps the used-car salesman, with capability only in communication and business.

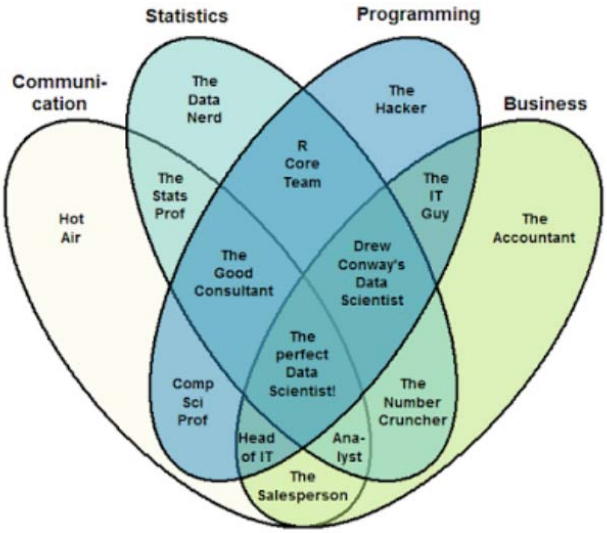

Fig. 8. The data scientist Venn diagram (Big Data, 2016).

Collective Human-Computer Intelligence (Superminds): A supermind is a group of individuals acting together in ways that seem intelligent. Collective intelligence, a property of a "supermind", is the result of groups of individuals acting together in ways that seem intelligent. There are two types of intelligence: specialized intelligence, the ability to achieve specific goals effectively in a given environment, and general intelligence, the ability to achieve a wide range of different goals effectively in different environments. The definition of general intelligence is similar to that used by psychologists and what is measured by intelligence tests (Malone, 2018). A similar breakdown into specialized and general intelligence is also used between artificial intelligence (AI), which today is specialized to a specific task, artificial general intelligence (AGI). The technologies here are core to building "smart spaces" where computers and people interact to solve problems in a variety of environments. A core question is "Can people and computers be connected so that – they act more intelligently than any person group, or computer ever has before" (Malone 2018).

Blockchain: Blockchain is a system that maintains a record of transactions across several computers that are linked in a peer-to-peer network. Blockchain technology has been known as the original digital currency platform since the development of Bitcoin, the first and the largest of the cryptocurrencies. Some companies develop blockchain solutions for other companies. For example, to explore the blockchain area IBM first developed a blockchain solution to transfer money from one IBM facility to another, realizing substantial savings due to the increased speed of transactions. Currently, IBM develops blockchain solutions for banks and other industries – for example, IBM has developed a blockchain shipping solution with Maersk (Fig. 9).

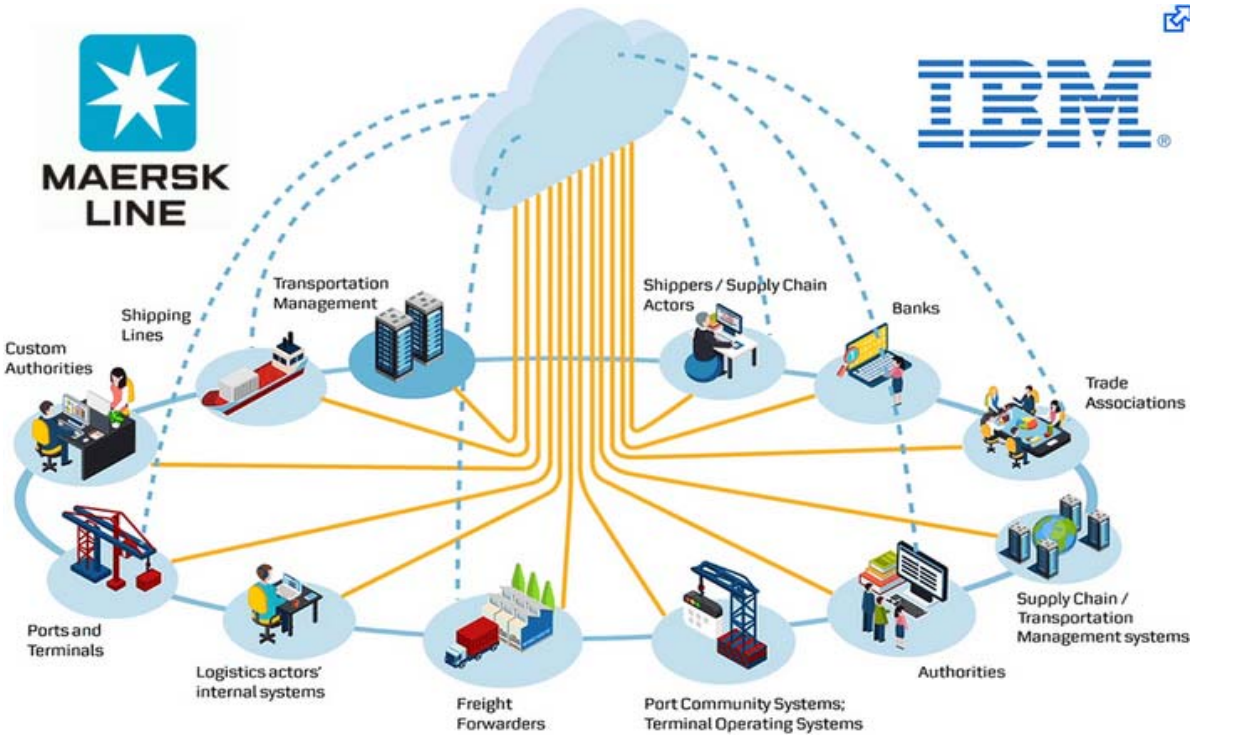

Fig. 9. The 2018 Maersk and IBM Blockchain Shipping Solution (Hannover Messe, 2018).

Quantum Computing: Quantum computing is the use of quantum-mechanical phenomena such as superposition and entanglement to perform computation. There is a quantum computing race among the tech giants Google, IBM, and Microsoft, including to a lesser extent Amazon and China's Alibaba. Governments, particularly America and China, are funding work in the area with the concern that quantum computers may soon crack current encryption methods, giving the country that gets there first a major advantage (The Economist, 2018). Teaching quantum computing at Pace University is described in a companion paper (Tappert, et al., 2019).

Public key cryptography is an asymmetric system using two keys, a public key and a private (secret) key. RSA (Rivest-Shamir-Adleman) is the most commonly used public cryptosystem (Whitman & Mattord, 2003). The keys are related mathematically but the security of the private key depends on the difficulty of computing the private key from the public key. However, Shor's quantum computing algorithm greatly reduces the estimated time to crack the standard RSA encryption method, Fig. 10, essentially by factoring the product of two large prime numbers into their factors. RSA encryption will be cracked once we have reasonably robust quantum computers, currently estimated at 200+ qubit machines with reasonable coherence.

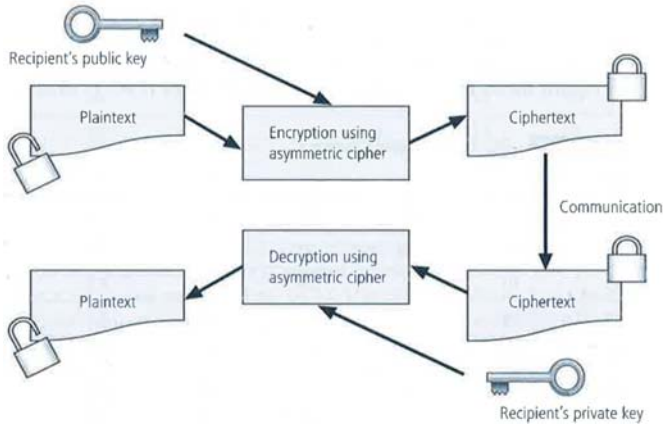

Fig. 10. RSA asymmetric encryption method (Whitman & Mattord, 2003).

Cybersecurity: Cyber security, also called information technology security, concerns the technologies, processes, and practices designed to protect networks, devices, programs, and data from attack, damage, or unauthorized access (Cybersecurity, 2019).

Pace University is a NSA and DHS designated National Center of Academic Excellence in Cyber Defense Education. Funded by NSA and NSF we conduct summer cybersecurity workshops for high school teachers and for high school students. Working with the Department of Defense we offer Information Assurance Scholarships. Working with the National Crime Agency, we conduct mobile application research. We also run a Computer Forensics Laboratory in NYC.

Biometrics: Biometrics refers to the measurement of human characteristics. Biometrics is a common area of research for our doctoral students and our masters-level capstone projects course has had many projects over recent years. We focus on the not-well-studied biometrics because it is easier to do original research and publish results. Understandably, it is hard to compete with companies specializing in the established biometrics, such as fingerprint, face, iris, and voice.

The keystroke biometric involves the authentication or recognition of a typist and Pace University currently has the world's best keystroke biometric system. In the 2016 major biometrics conference, Dr. John V. Monaco, a Pace PhD graduate working for Army Research Labs, overwhelmingly won the Keystroke Biometrics Ongoing Competition, his 15 entries outperformed all the entries from the three other competitors (KBOC, 2016).

Internet Platform Businesses: A new development in the business world is companies based on internet platforms. A platform is a digital environment characterized by near-zero marginal cost of access, reproduction, and distribution. Platform economics, together with Moore's law, and combinatorial innovation continue to reshape industries as dissimilar as computer hardware and recorded music. Major platform companies include: Uber which owns no vehicles, Facebook which creates no content, and Airbnb which owns no real estate (McAfee & Brynjolfsson, 2017).

Conclusions

Teaching emerging information technologies is an area rich with opportunity for growth. Our current course is taught at a high level in our doctoral program for working professionals. Pace University has a business school and in their undergraduate Bachelor in Social Marketing program they just had a new course approved, entitled Emerging Technologies for Business, that our computing school will teach starting in 2020. In addition, we are currently proposing to the computing curriculum committee in our school two new courses in this area. The first course for PhD and advanced masters students is a rigorous computer science course that will cover the underlying theory of these technologies in detail and will have midterm and final exams. The second course at the computer science undergraduate level will cover the highlights of the technologies without going into rigorous detail and is designed to attract and retain undergraduates. This course may be combined with the business school course where project teams would combine computer science and business students with the computer science students performing the technical aspects of the project work (programming, etc.) and the business students focusing on the business aspects of the project work. Teaching emerging technologies is relatively new and our university is creating new courses in this area.

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