Industry 4.0 and Cyber-Physical Systems: A Primer

Preface

One of my friends asked me to write a brief note explaining Industry 4.0 and Cyber-Physical Systems with reference to an article from the World Economic Forum in Davos, Switzerland [1]. As a research scientist in this domain, here are my thoughts written with a layperson or a technical non-expert reader in mind.

What is Industry 4.0?

The term Industry 4.0 was coined in Germany, stylized *Industrie 4.0* in German, and is intended to suggest a ***fourth industrial revolution*** that the latest technological advances[1] will bring about in the manufacturing sector. Before we dive deeper into what it is, let's start with why you should care, and for that, let's look at the history.

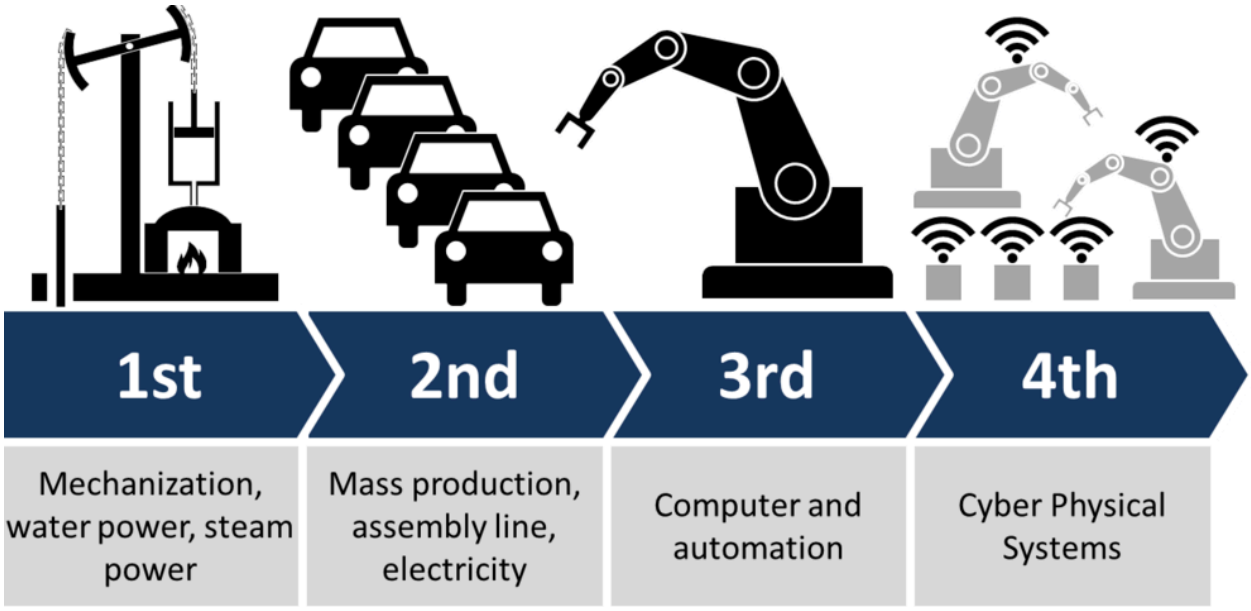

Figure 1: Industry 4.0: A schematic from Wikipedia.

The ***first industrial revolution*** triggered by James Watt's discovery of steam power led to mechanization of production. The ***second industrial revolution*** was brought about by mass production, fueled by mass production of steel, widespread electrification, railroads network, and the use of petroleum brought about the Gilded Age in the US, and made US the global superpower. The ***third industrial revolution*** brought about by automation (think CNC

[1] Particularly in the domain of Cyber-Physical Systems (CPS)

machines and robot arms on the factory floor) put Japan and S. Korea on the world map as the global centers of automobiles and consumer electronics.

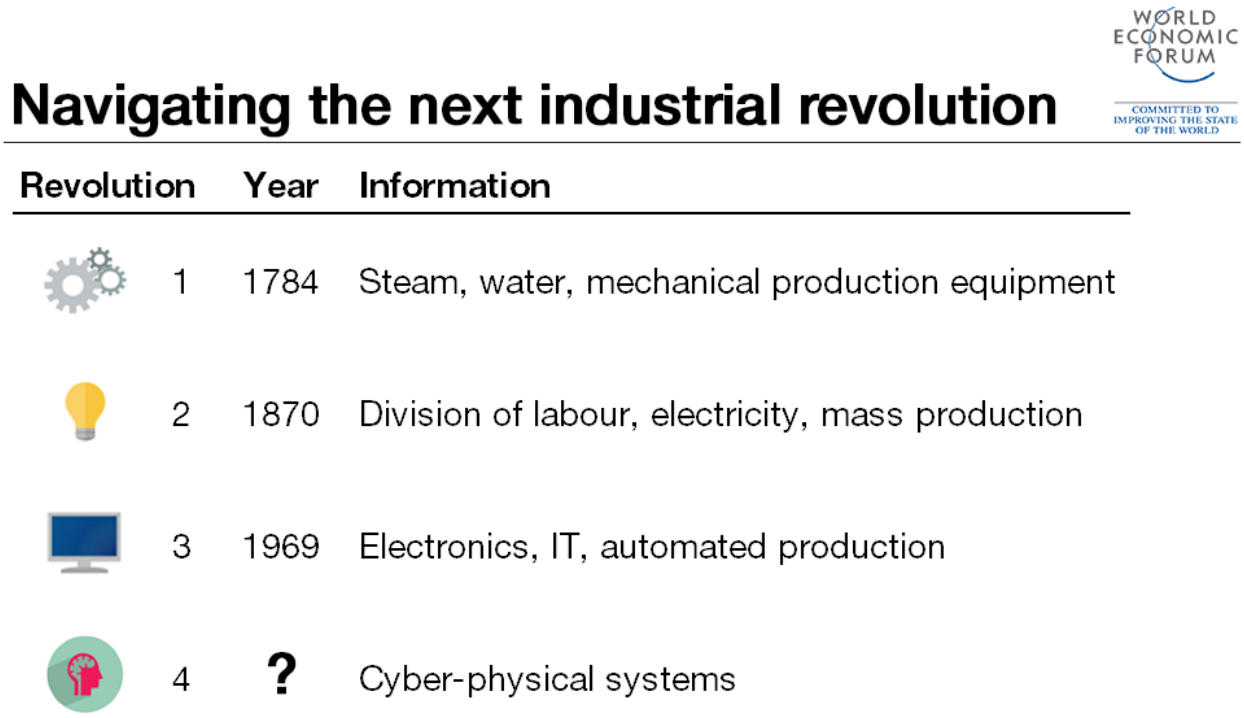

Figure 2: Fourth Industrial Revolution: A graphic from [1].

Why should I care?

You see, all of the previous three revolutions have led to major shifts in geopolitical balance of power, and more importantly, left the 'old' ways of earning a livelihood obsolete. The first industrial revolution led to skilled labor and workforce in Asia and Africa going out of business unable to compete with the cheap goods produced on factory floors in Western Europe, ultimately leading to colonization of the two continents. The labor exploitation and upheaval during the second industrial revolution ultimately led to labor unions and labor laws, and five-day 40-hr workweek. In the third industrial revolution, repetitive tasks were automated by machines, and people who used to do those tasks lost their jobs. In short, if there is another revolution that leaves any of today's jobs or job titles obsolete, you should care!

What are Cyber-Physical Systems (CPS)?

'Cyber-Physical Systems' is an umbrella term more than a precise definition. Broadly speaking, these are ***computer-controlled physical systems*** *that use* ***interconnected computational elements*** *to* ***sense and control the physical environment***. Let's elaborate on these two distinguishing features a little bit.

Two Key Distinguishing Features of CPS

Tight Coupling between Computation and Physics

When I was an undergraduate student, and even when working at my first job out of college, the term for *computer-controlled physical systems* was ***Embedded Systems.*** An example of embedded system would be a washing machine, where a microprocessor controls the physics, i.e., the spinning motion of the drum, based on some logic.

So what has changed in the past decade to necessitate a new term? Well, with the continuation of ***Moore's Law***, electronics is continuing to get *smaller*, *faster*, and *cheaper*. Some staggering statistics from the past decade are that it is cheaper to produce a transistor than it is to print a single character in a newspaper, and we produce more transistors than grains of rice produced in the entire world! It is no surprise, then, that we see more and more compute power embedded in our physical environment, in our pockets, on our wrists, and even inside our bodies [2]. It's getting to a point where the computational elements are so deeply-embedded and tightly-coupled with the physical environment that it isn't possible to design or analyze them independently anymore. This is the distinguishing feature #1 of CPS.

As a result of this abundance of low-cost hardware, we have more and more computational elements deployed in novel ways.

Interconnectivity between Computational Elements

At the same time, ***improvements in communications technology*** (e.g., 5G) have enabled fast and reliable communication between the computational entities. This has enabled distinguishing feature #2 of CPS, which is the interconnectedness of the computational elements. This interconnectivity has allowed the computation to be *distributed* among several interconnected components.

Impact

The cost of computing is rapidly approaching zero! You can buy a fully-functioning computer for as little as $5 [3]. The impact of abundantly-available cheap compute power in addition to the networked connectivity has opened up a new way of solve problems, and doing business: the *Internet-of-Things* (IoT) way [4]. Here, lots of low-cost hardware ('things') collect lots of data that they send to some central server to make sense of it all.

Industry 4.0 as an application of CPS

Because CPS have so much revolutionary power, it's even been in the vocabulary of politicians [5]. But how exactly will CPS bring about the fourth revolution? Well, as a direct consequence of the two distinguishing features we just saw. Cheap network (and internet) connected compute power means that we are able to collect tons of data. Some even say data is the new oil [6, 7], but even reusable, and not finite [8].

Abundance of data has enabled new advances in, so-called, "artificial intelligence[2]" (AI), and this is where the crux of the issue is. Many of today's jobs, particularly those that involve matching patterns and looking up information, can and will eventually be replaced by AI. Examples are doctors that make a diagnosis [9], lawyers [10], financial advisors [11], insurance agents [12], etc. And these are just the advances in the 'cognition', or the 'decision-making' aspect. When coupled with control systems, AI and software is able to tackle remarkably amazing problems, such as driving a truck down a highway [13], vacuuming houses [14], moving objects in warehouses [15], and even making food for us [16].

Not all tasks can be automated, and indeed there are several professions that cannot be easily automated. Achieving a 'common sense' in AI is still far out, for example. And, of course, while some jobs will be eliminated by the advances of technology, there will be new kinds of jobs created to work with the AI/robots of tomorrow. In the meantime though, as a society, a key question we need to address is how to cope with large sections of society about to be displaced by technology, and retrain them to these new kinds of jobs.

References

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[2] although terms like "machine learning" and "deep learning" are more accurate. We are still far away from achieving artificial "intelligence."