Guest Editorial
A Remarkable Resurgence of Artificial Intelligence and its Impact on Automation and Autonomy

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"After many false starts," declared the Economist magazine in a June 2016 Special Report[1], "artificial intelligence has taken off." This special report examined "how artificial intelligence, associated with hubris and disappointment since its earliest days, has suddenly become the hottest field in technology." The report also heralded the return of the *machinery question,* first posed nearly 200 years ago in the context of industrial revolution, on the impact of such disruptive technologies on different classes of society.

Other popular publications have been covering similar stories about the rise of artificial intelligence (AI). In June 2016, the Wall Street Journal[2] asked several business leaders about the future of AI. These leaders offered an upbeat technological assessment of AI, while expressing concern about the societal changes AI will certainly bring.

The rise of AI has also caught the attention of policy makers at the highest levels of governments. In the U.S.A. the federal government released a report[3] on future directions and considerations for AI. A companion report[4] laid out a strategic plan for funding research and development in AI. The U.K. government recently issued a report[5] announcing that "artificial intelligence has arrived," and touting that AI "offers huge potential to enable more efficient and

[1] The Economist, Special Report, Artificial Intelligence, The return of the machinery question, June 25, 2016.

[2] The Wall Street Journal, The Future of Everything, What's next for artificial intelligence, June 14, 2016

[3]https://www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/preparing_for_the_future_of_ai.pdf

[4]https://www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/national_ai_rd_strategic_plan.pdf

[5]https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/566075/gs-16-19-artificial-intelligence-ai-report.pdf

effective business and government, but the use of AI brings with it important questions about governance, accountability, and ethics."

Leading economists view AI as a potential enabler to increase national productivity growth that has been sluggish over the past decade[6]. These economists are concerned that national productivity growth has slowed in 30 of the 31 advanced economies – slowing from a 2 percent average annual growth rate from 1994 to 2004 to a 1 percent average annual growth rate from 2004 to 2014. In fact, these economists worry that we don't have enough of AI to grow our productivity.

What triggered this remarkable resurgence of AI? All evidence points to an interesting convergence of recent advances in machine learning (ML), big data, and graphics processing units (GPUs). A particular aspect of ML – called deep learning using artificial neural networks – received a hardware boost a few years ago from GPUs, which made the supervised learning from large amounts of visual data practical. This breakthrough surprised even experts in the field of image recognition using ML, which was until then confined largely to academic research. Since then, interest in ML has exploded due to industrial and commercial success with autonomous navigation and mining of big data, and ML has moved beyond image recognition.

The recent success and the resulting popularity of ML have been assimilated into a growing body of successful and popular AI technologies. There have been several popular episodes in the last two decades of machines outperforming humans in tasks that have long been considered to belong to the exclusive domain of human intelligence. In 1997 IBM's Deep Blue beat Garry Kasparov in chess, and in 2011 IBM's Watson won against two of Jeopardy's greatest champions. More recently, in March 2016, Google's AlphaGo defeated Lee Sedol, one of the best players in the game of Go. Each of these victories was based on different aspects of information technology – ranging from a special purpose chess-playing computer to general purpose statistical learning software – but they all left a singular indelible impression of the success of AI in the public imagination.

The private sector has been quick to exploit the success and advances in AI and ML. Building on its success with Jeopardy-winning Watson, IBM is anticipating what it calls cognitive computing – which can be viewed as AI by another name – will be a major foundation for its business growth. Google and Baidu routinely use ML to improve their products and services. Product recommendations from services such as Netflix and Amazon that evolve through users' own experiences are powered by ML. Start-up companies around the world are pushing the application frontiers of ML and AI with noticeable success – as evidenced by the fact that these companies are prime targets for acquisition.

How is the academic community reacting to these developments? Anecdotal evidence suggests that interest in ML and AI has reached far beyond computer science departments in universities. Many engineering students and faculty members are now learning the techniques and tools of ML, and are looking for important applications in their fields. For example, during the IEEE International Conference on Automation Science and Engineering held in Fort Worth, Texas in August of 2016, the main topic of discussion among the attendees following a plenary

[6]https://www.whitehouse.gov/sites/default/files/page/files/20160707_cea_ai_furman.pdf

talk[7] was on the application of ML to modern manufacturing. From such observations, it is clear that the academic community is well versed in the emerging techniques and tools of ML, but is starving for the large amount of open, curated, and labeled data needed to train and test their software on important problems.

Part of the current appetite for ML in the engineering and manufacturing communities can be traced to their eagerness to build empirical models from experimental data and use these models to make predictions. This is the goal of predictive analytics using big data. When reliable mathematical models based on fundamental physical and chemical laws are either unavailable or result in equations that are too difficult to solve, empirical modeling using experimental data is the only available course for engineers. In fact, there is a long and successful history of applying statistical techniques such as design of experiments and response surface methodology to build and use empirical models in industry. One may view the current advances in ML as yet another important milestone in the march towards more general and automated empirical model building. Better empirical models and improved ability to recognize patterns may even serve to improve our theoretical understanding and modeling of the underlying physical phenomena.

Such observations have led to the conclusion that we are making inroads only in the field of Narrow AI, as opposed to general AI (also known as Artificial General Intelligence, or AGI). The current applications of ML are confined to building specific empirical models in particular domains. AGI has a much greater ambition of acquiring and exhibiting general intelligence that spans a full range of cognitive tasks. The considered opinion of many experts is that we are several decades away from realizing even a rudimentary level of AGI.

Even with the restrictive scope of Narrow AI and ML, what we have been able to achieve so far shows a promising trend. For the first time, researchers have been able to reach beyond *automation* and explore the terrain of *autonomy*. As various ML schemes – such as supervised learning, reinforcement learning, and unsupervised learning – mature, systems will be designed and built with increasing levels of autonomy. The transition from automation to autonomy is one of the striking features of the rise of AI and ML. Autonomous vehicles on land, air, and water will form the prime platform for advancing the engineering of autonomous systems. These will inform NASA's efforts to develop and deploy autonomous systems on Mars, where these systems will learn to adapt to new and unforeseen circumstances. In fact, some subsystems that perform a limited number of autonomous tasks have already been deployed.

In manufacturing, autonomy will be realized as machines become more capable of detecting and responding to changes in their own performance; they may become capable of eventually predicting the need to adjust their performance based on system inputs or changing priorities. Robots, which are now typically restricted by safety zones, will become more capable of close interaction with their human operators as sensing and response capabilities improve. Beyond subsystem autonomy, we may begin to see symbiotic systems with new assistive technologies that enhance the capabilities of human operators, such as immersive environments that allow a person to remotely control higher-level operations and predictive retrieval which anticipates what a person will need.

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[7] K. C. Morris and Vijay Srinivasan, Models and Modularity – A modern manufacturing perspective, Plenary talk, IEEE CASE, August 20-24, 2016, Fort Worth, Texas, U.S.A.

This brings us to an important question: What is the role of humans in such autonomous systems? Apart from creating these systems, we can expect that humans will play both collaborative and supervisory roles. For a start, AI shows promise in educational systems, where the material presented to a learner is tailored to that learner's abilities[8]. AI will guide a person's learning until ultimately the person makes decisions that are beyond the capabilities of the AI system. A recent study of AI systems and pathologists in image interpretation for cancer showed that a collaborative team of an AI system and a pathologist performed better than either of them working alone. There are both technical and ethical concerns that dictate that humans should play an active supervisory role in the deployment and operation of AI systems.

But concerns remain about the impact of AI on the labor market. According to a Pew Research Center survey[9], experts in the U.S.A. are divided about the net impact of robotics and AI: 48% of experts think that AI will displace more jobs than it creates leading to a decline in employment, and 52% believe that it will create more jobs and lead to an increase in employment. However, evidence suggests that the types of jobs that are created will be very different from those being replaced. There will be a greater need for expertise that complements AI, especially in the areas of STEM (Science, Technology, Engineering, and Mathematics). In addition, tasks difficult to automate and autonomize – such as those requiring complex perception and manipulation operations – will continue to require human intervention.

There is also the possibility of AI creating new jobs due to increased productivity. A recent visit to an industrial factory showed an increased need for artists and designers due to increased production capability obtained by incorporating robotics and AI in the factory's production process; additional programmers and 3D modelers were also needed. Combined with other information and communication technologies, AI can lead to more efficient, on-demand manufacturing capabilities through more effective scheduling, better supply chain management, and better customer awareness. In the design space AI can contribute to more elegant and efficient solutions using AI capabilities for design generation.

In the context of manufacturing, performance of these new AI systems will need to be measured in new and different ways. We need to factor in not only resource efficiency, productivity, quality, and sustainability but also balance these with human factors. As AI eases the burden of mundane tasks, we may want to include such factors as worker engagement and job satisfaction.

AI is here, and organizations that are resistant to adopt it will face increasing pressure from companies both within the country and overseas that learn how to make the most effective use of AI to increase productivity and reduce cost. As with any technological revolution, the structure and capabilities of the workforce will have to evolve to best accommodate the new technology. As the IEEE Robotics and Automation Society organizes future conference sessions and special publications on the science and engineering of AI, the return of the machinery question will ensure that societal concerns will dominate the public debate on the future of AI.

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[8]http://www.forbes.com/sites/barbarakurshan/2016/03/10/the-future-of-artificial-intelligence-in-education/#3aa3104e1e64

[9] http://www.pewinternet.org/2014/08/06/future-of-jobs/

We should be prepared to offer science-based perspectives on the value of AI to national as well as individual prosperity.

K. C. Morris
Craig Schlenoff
Vijay Srinivasan

Engineering Laboratory
National Institute of Standards and Technology[10]
Gaithersburg, MD 20899
U.S.A.

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