Multiplicity:
How AI and Robots Can Diversify, Rather than Replace, Human Thinking

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Intellectual, economic, social, and political polarization has become a major issue of our time. The concept of an AI-based "Singularity" is a symptom of this trend: it hypothesizes that a new form of intelligence will be separate and superior to that of humans. In contrast, this essay proposes "Multiplicity," which emphasizes constructive collaboration between groups of people and machines. Multiplicity emphasizes diverse ways of experiencing and interpreting where artificial intelligence is just one of many dimensions of intelligence. Multiplicity counters polarization by recognizing the value of collaboration and cognitive diversity for learning, problem-solving, and innovation.

Artificial Intelligence (AI) has surpassed humans at Jeopardy and Go, and driverless cars are widely believed to be around the corner. News articles claim we're on the brink of a "Singularity" a hypothetical point in time where AI and robots surpass humans and steal our jobs. Are AI and robots an existential threat to humans, as Elon Musk warns? Or is Mark Zuckerberg right in stating that humans still have many good years ahead? "Automation Anxiety" has a long history, from Prometheus to the Terminator, but almost all computer scientists agree that predictions about AI and robots surpassing general intelligence and stealing a majority of jobs are greatly exaggerated.

Multiplicity: a Realistic, Inclusive Alternative to "Singularity"

Rather than worrying about an impending Singularity, consider instead the concept of *Multiplicity*: where diverse combinations of people and machines work together to solve problems and innovate. Multiplicity is not science fiction. A combination of machine learning, the wisdom of crowds, and cloud computing already underlies tasks that Americans do every day: searching for documents, filtering spam emails, translating between languages, finding news and movies, navigating maps, and organizing photos and videos.

Multiplicity allows Amazon to recommend books, Netflix to suggest movies, and Facebook to organize news feed posts. As people click on links, that data is used to build and maintain statistical models that predict what users will want. The key is clustering people and items, which allows the algorithm to make recommendations under the assumption that similar people have similar tastes. A continuing stream of human interaction ensures that the system evolves as new items are introduced and as tastes change.

Consider Google's search engine. It runs on a set of algorithms with ongoing input from a large number of human users who share valuable feedback every time they click on or skip over a link. The same is true for spam filters. Every time someone marks an email as spam or overrides a filter, it helps fine-tune the system for determining what is relevant.

While scientists still don't understand Multiplicity very well, the many benefits of machine diversity are well known. Researchers study *ensemble methods*, in which a set of specialized algorithms work together to produce a single result. One variant, known as *random forests*, was developed by Leo Breiman and Adele Cutler at the University of California, Berkeley, who proved that in complex problems with noisy data, a group of decision trees will always outperform a single tree—as long as the trees themselves are sufficiently diverse.

Similarly, the benefits and challenges of *human* diversity have been recognized for centuries in political science, economics, and sociology. Experiments with group problem solving show that the diversity of the people involved is more important than their total IQ. An exciting area of machine learning is deep learning, where millions of parameters are tuned and re-tuned based on diverse training examples of speech or images that have been labeled by people.

Multiplicity + Robotics: Ensembles of Atoms, Bits, and People

Similarly, in the field of robotics, much of the exciting progress can be characterized in terms of Multiplicity. For example, Tesla uses data from tens of thousands of human drivers to learn appropriate responses to varying driving conditions. These data train multiple statistical machine-learning algorithms, which run on distributed hardware. The system must be continuously fine-tuned based on changes in weather and traffic conditions, and as human expectations evolve.

A related new development is "Cloud Robotics and Automation," a new paradigm where robots and automation systems share data and code, and perform computation via networks that are constantly building on emerging research in cloud computing, Deep Learning, Big Data, open-source software, and government/industry initiatives such as the *Internet of Things, Smarter Planet, Industrial Internet, Industry 4.0,* and *Made in China 2025.*

The Cloud has potential to enhance robots and automation in four ways: 1) Big Data: access to vast libraries of images, maps, object data, and code on demand; 2) Cloud Computing: access to parallel grid computing for statistical analysis, learning, and motion planning; 3) Collective Learning: robots and systems sharing trajectories, control policies, and outcomes, and 4) Crowdsourcing: enlisting human skills for labeling images and video, classification, learning, and error recovery. It's also important to recognize that Cloud robotics and automation raises critical new questions related to network latency, quality of service, security, and privacy.

A combination of collective intelligence with AI enables many of the most sophisticated and effective systems in use today; and if people stopped providing input, these systems would

quickly become outdated and deteriorate. Despite years of experience in human factors and human-machine interfaces, more research is needed on the best ways to combine diverse groups of people with diverse groups of machines. The most important question we're facing is not, "When will machines surpass human intelligence?" but instead "How can humans work together with machines in new ways?"

Automation Has Potential to Change the Way We Learn

In 1910, only 10% of American students attended high school; and in that year, emerging advances in farm automation gave rise to what was called the *High School Movement,* which focused on the goal of transforming education to prepare students for jobs other than farming. In a relatively short span of time, thousands of high schools were built and new curricula developed. The result? By 1950 80% of Americans attended high school.

Consider a new version we might call the "*Multiplicity Movement*"[1]. This time the goal is to evolve the way we learn to emphasize the uniquely human skills that AI and robots cannot replicate: creativity, curiosity, imagination, empathy, human communication, diversity, and innovation. AI systems can provide universal access to sophisticated adaptive testing and exercises to discover the unique strengths of each student and to help each student amplify his or her strengths. AI systems could support continuous learning for students of all ages and abilities.

Much of education today still emphasizes conformity, obedience, and uniformity. The important question is not when machines will surpass human intelligence, but how humans can work and learn with computers in new ways. This requires that we combine AI with IA: Intelligence Amplification where computers help humans learn and work.

Rather than discouraging the human workers of the world with threats of an impending Singularity, let's focus on Multiplicity where advances in AI and robots can inspire us to think deeply about the kind of work we really want to do, how we can change the way we learn, and how we might embrace diversity to create a myriad of new partnerships.

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