The Cogs Are Coming: The Cognitive Augmentation Revolution

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ABSTRACT

We are at the beginning of a new era in human history–the cognitive augmentation era. Until now, humans have had to do all of the thinking. The future will make it possible for humans to partner with cognitive systems doing some of the thinking themselves and in many ways thinking that is superior to humans. Together, humans and "cogs" achieve a higher level of cognition than is possible by either working alone. Current cognitive systems are expensive large-scale pieces of technology affordable only to the biggest companies and government agencies. However, we foresee the evolution of less expensive cognitive systems tailored to individuals and available to the mass market. When these cogs become available, anyone will be able to achieve expert-level competence in any domain–something we call the democratization of expertise. The next few years will see a transformation of how we work, play, and socialize revolving around computer-augmented human cognition. In the coming era, cogs will be everywhere in our lives and become our teachers, co-workers, partners, advisors, counselors, pets, and even our friends. The cogs are coming.

INTRODUCTION

A new era, the cognitive augmentation era, is upon us. For the first time in human history we will soon be using tools capable of performing higher-order cognitive processes (thinking) we do throughout our daily personal and professional lives. A confluence of several technologies is bringing forth this new era including: cognitive systems, deep learning, digital assistants, voice recognition, and big data analytics. We call these thinking tools "cogs." The future will belong to those who can best work in partnership with cogs because their use amplifies the cognitive power of the individual.

Augmenting human activity with computer-like technology has been a goal for a long time although what "augmentation" means has changed. In the 1940s, Vannevar Bush envisioned a system called the Memex and discussed how employing associative linking could enhance a human's ability to store and retrieve information (Bush, 1945). The Memex made the human more efficient but did not actually do any of the thinking.

In the early 1960s, Engelbart and Licklider envisioned human/computer symbiosis. Licklider imagined humans and computers becoming mutually interdependent, each complementing the other (Licklider, 1960). However, Licklider envisioned artificial aids merely assisting with the preparation leading up to the actual thinking which the human would do themselves. Engelbart's H-LAM/T framework described the human as a part in a multicomponent human/computer system allowing human and artificial sys-

tems to work together to perform problem-solving tasks (Engelbart, 1962). Through the work of Engelbart's Augmentation Research Center, and other groups in the 1950s and 1960s, many of the devices we take for granted today were invented as "augmentation" tools including: the mouse, interactive graphical displays, keyboards, trackballs, WYSIWYG software, email, word processing, and the Internet. However, while making it easier for the human to think and perform, none of these actually do any of the thinking themselves.

Envisioned by O.K. Moore in the early 1960s, the talking typewriter sought to create an enjoyable learning environment to teach reading skills to students in K-3 grades (Sanderson & Kratochvil, 1972). This is an early example of human-computer engagement at the personal level but the talking typewriter was just an aid to stimulate thinking and learning by the human. The talking typewriter performed no cognition of its own. Alan Kay's vision of the DynaBook in the early 1970s was influenced by the talking typewriter (Kay, 1972). Kay envisioned the DynaBook as a way to augment human learning and imagined a portable device in use by every human. We recognize the DynaBook today as the tablet computer but in the early 1970s the idea of a handheld computer for personal use was far from mainstream thinking.

Fifteen years later in 1987, well into the personal computer revolution, Apple envisioned a personal digital assistant resembling Kay's DynaBook in a video. This device, called the Knowledge Navigator, was unique in that it interacted with the human user in spoken natural language and seemed able to perform tasks far exceeding the capabilities of software available at the time (Apple, 1987). The idea was so far ahead the video was largely dismissed as science fiction and some experts even joked about the fanciful imaginings. Apple was again ahead of the market in the early 1990s with the release of the Newton, the first handheld digital assistant. The Newton was too far ahead of the market and was not successful (Honan, 2013). It would take another fifteen years for Newton-type functionality to become successful in our cell phones and tablet computers.

Portable digital technology has become ubiquitous and woven into people's daily lives. We now think nothing of the concept of people using connected computers to augment human activity. Today's voice-activated personal assistants like Apple's Siri, Microsoft's Cortana, Google Now, Facebook's M, and Amazon Echo's Alexa accept natural-language requests from users, reply in natural language, and perform services on behalf of the user (Apple, 2015; Microsoft, 2015; Google 2015; Hempel, 2015; Colon & Greenwald, 2015). But these tools simply retrieve information, and perform minor clerical tasks such as creating appointment calendar items. The cog future will see these interfaces being able to think on their own as human experts think. They will become our virtual colleagues rather than mere tools.

If shown today's technology in the early 1960s, many would have claimed the technology as being artificially intelligent. However, today's expectation is different. We recognize the capabilities of today's technology as performing only the lowest form of cognitive processes. True human-cog partnerships of the future will go far beyond today's tools. Instead of just retrieving information, cogs will perform increasing amounts of cognition eventually achieving or exceeding the level of a human expert in a given domain. Recent advances in deep learning such as Google Brain, IBM Watson, and Microsoft's Adam represent early-stage technologies giving us a glimpse into the future (McMillan, 2014; Knight, 2015; Chansanchai, 2014). Cogs will be able to consume vast quantities of unstructured data and information

and deeply reason to arrive at novel conclusions and revelations, as well as, or better than, any human expert.

A sentinel in this revolution came in 2011, when a cognitive computing system built by IBM called Watson defeated two of the most successful human Jeopardy champions of all time. Watson understood clues given in written natural language and gave answers in spoken natural language. Watson's answers were the result of deep search and reasoning about millions of pieces of information and the aggregation of partial results to form a consensus (Jackson, 2011). Watson was not programmed to play Jeopardy. Instead, Watson was programmed to *learn* how to play Jeopardy, which it did in numerous training games with live human players before the match. In doing so, Watson achieved a performance at the level of an expert.

Watson represents a new kind of computer system—a cognitive system (IBM, 2015c). We use computers today as tools to gather and process information, however, humans still perform most of the thinking. Cognitive systems are capable of doing some of the thinking on their own. As such, cognitive systems promise a new kind of human/computer interaction. In the cog era, cognitive systems, *cogs*, as we call them will become our partners collaboratively working with us on a task.

John Kelly, Senior Vice President and Director of Research at IBM describes the initiative as follows (Wladawsky-Berger, 2013; Kelly & Hamm, 2013; Isaacson, 2014):

> *"The goal isn't to… replace human thinking with machine thinking. Rather, in the era of cognitive systems, humans and machines will collaborate to produce better results – each bringing their own superior skills to the partnership. The machines will be more rational and analytic – and, of course, possess encyclopedic memories and tremendous computational abilities. People will provide judgment, intuition, empathy, a moral compass and human creativity."*

IBM is actively commercializing Watson technology to serve (and in many ways create) the emerging multi-billion dollar cognitive computing market. Much of the commercialization effort to date revolves around the identification of a large store of information in a specific domain (such as medical diagnosis) and the customization of Watson technologies to work with employees in that domain (such as nurses and doctors). We call these types of systems *enterprise cogs.* In 2014, IBM announced the creation of two new groups. The Cognitive Business Solutions group acts as consultants helping companies create enterprise cogs. The Watson Health group's focus is to commercialize Watson technology for the health sector (IBM, 2014; 2015a; 2015b; 2015d Sweeney, 2015).

In her January 2016 keynote address at the Consumer Electronics Show, Chairwoman, President, and CEO of IBM Ginni Rometty announced more than 500 partnerships with companies and organizations across 17 industries each building new applications and services utilizing cognitive computing technology based on Watson (Gugliocciello & Doda, 2016; Rometty, 2016). In one of these partnerships, Under Armour is building a personal health consultant and cognitive coaching system based on Watson technology (Haswell & Pelkey, 2016). This cog will serve as a fitness trainer and assistant providing athletes with timely, evidence-based coaching, Based on consuming enormous quantities of unstructured data from the Internet and data from health monitoring appliances on and near the body, the cog

will offer expert-level help with sleep, fitness, activity, and nutrition, by matching your situation and condition with others like you. It will be as if the user has a professional trainer as a constant companion. Importantly, this cog will be available to anyone and everyone. It is not possible for millions of people to have the service of a human expert personal trainer, but this cog will bring that level of service to millions allowing the masses to perform at the level of an expert.

Another success of Watson commercialization is medical treatment suggestion at Memorial Sloan Kettering Cancer Center (Kelly & Hamm, 2013; Sloan Kettering, 2014). Watson was trained with hundreds of thousands of pieces of medical evidence, millions of pages of text, 25,000 training cases, and over 14,000 person-hours of fine-tuning with human experts. Watson's accuracy has reached 90%, vastly exceeding human accuracy of 50%. Watson has achieved expert-level performance in this field. 90% of the nurses and doctors use Watson's treatment suggestions (Upbin, 2013). Together, working in partnership, nurses, doctors, and Watson form a cognitively augmented ensemble that is exhibiting a higher level of performance in speed and accuracy (cognitive power) than either the humans or Watson could achieve on their own.

Over the next few years a cog will be constructed to operate at the level of an expert in any field humans are expert in. Partnering with these cogs will give average humans the ability to perform at the level of an expert in any domain—something we call the *democratization of expertise*. This will finally fulfill the dream of human cognitive augmentation originally envisioned decades ago. The coming era promises to forever change the way humans interact with and use computers. Yet we are at the very beginning of the cog revolution. But be sure, the cogs are coming.

COGNITIVE AUGMENTATION

Cogs represent incursion into a new domain, the cognitive domain. Cogs will perform some of our cognitive work for us and this will change everything. But what does "cognition" mean? When will we know when a cog is performing cognition? How do we measure the increase in cognition facilitated by partnering with a cog? To address these questions we must first identify what a cognitive process is. At the simplest, a *cognitive process* is anything that transforms data, information, or knowledge into a higher-value form. This transformation requires an amount of processing, therefore, we can define a cognitive process by the change in value of data, information, and knowledge. If we refer to data, information, and knowledge generically as *information stock, S*, we can view a cognitive process as the transformation of information stock from an input form to an output form requiring the expenditure of a quantity we call *cognitive work, W*, as given by

$$W = \left| \Psi(S_{out}) - \Psi(S_{\square}) \right| + W_{lost} \quad W = \left| \Psi(S_{out}) - \Psi(S_{\square}) \right| + W_{lost} \,,$$

Eq. 1

where $\Psi(x)$ is a function calculating the value of a piece of information stock. For brevity, we leave the nature of $\Psi(x)$ generic and the subject of future work. How one measures the value of information stock is a complex subject. There may very well be no one single metric to satisfy all contexts and such a discussion is the scope of a subsequent paper. For our discussion here, it is sufficient to simply recog-

nize that information stock has a value and that value can be increased or decreased by the performance of a cognitive process.

We use the absolute value in Eq. 1 because it is possible for $\Psi(S_{out})$ to be smaller than $\Psi(S_{\square})$ seemingly resulting in a nonsensical *negative* amount of cognitive work. Any kind of transformation involves a nonzero and positive amount of effort, so we desire cognitive work to always be a positive quantity. W_{lost} captures cognitive work that goes into producing S_{out} but is not represented in S_{out} directly. For example, a cognitive process may transform S_{in} into a number of intermediate forms before it produces the output. If the intermediate forms of S_{out} are never output to the outside world, they are not accessible to anyone or anything and therefore the cognitive work expended to generate them is not accounted for by simply calculating $S_{out} - S_{in}$. Instead, we account for this cognitive work via the W_{lost} term. W_{lost} here is similar to waste heat in the physics of a heat engine.

Cognitive work is expended over an amount of time. Expenditure of effort over time is generally regarded as *power* in science and engineering. In similar fashion, we define *cognitive power, P*, as the amount of cognitive work over time,

$$P = \frac{W}{T}$$

Eq. 2

where T is an arbitrary period of time, and W is cognitive work given in Eq. 1. P is a measure of *cognitive efficiency* with respect to time. Increasing the value of an amount of information stock over a short period of time (a larger P) can be viewed as more efficient than increasing the value over a longer period of time. Likewise, increasing the value by a greater amount even though it may require more time can also be viewed as more efficient.

Engelbart's H-LAM/T framework models an augmented human as part of a system consisting of: the human, language (concepts, symbols, representations), artifacts (physical objects), methodologies (procedures, know-how), and training (Englebart, 1962). We can now update Engebart's framework to include cogs. In the coming cog future, cogs will be the artifacts in Engelbart's framework. The human and the cog(s) will work together on a cognitive task. To perform the task, the system as a whole executes a series of cognitive processes with the human performing some of the processes, the cog performing some processes, and other processes performed by a combination of human and cog. At one extreme, a human operating in isolation without a cog performs all cognitive processes. At the other extreme, if all cognitive processes are performed by a cog we will have a truly independent artificial intelligence.

Cognitive augmentation lies somewhere between these two extremes. In the cog era, humans will be cognitively augmented by working in partnership with artificial systems capable of higher and higher levels of cognition. Most discussion of augmented cognition boils down to a matter of how the cognitive processes are distributed across the human and cog. Following Eq. 2, the amount of cognitive processing done by the human is P_{Human} and the amount performed by the cog is P_{Cog}. The expectation be-

hind human cognitive augmentation is humans and cogs working together as partners will achieve a cognitive power exceeding that of either the human or cog,

$$P^{\square} \geq \sum_{i} P^{i}_{cog} + \sum_{j} P^{j}_{human} \quad , \qquad \text{Eq. 3}$$

where P^{*} is the cognitive power of the human/cog system as a whole involving the individual contribution of *i* artificial systems, cogs, and *j* humans. The key characteristic of a human/cog partnership is how much cognitive work is done by the human and how much is done by the cog. We call this ratio the *augmentation characteristic* as given by

$$+¿\frac{P_{cog}}{P_{human}} \quad . \qquad \text{Eq. 4}$$
$$A^{\square}$$

A non-augmented human is characterized by $P_{cog} = 0$ meaning $A^{+} = 0$ (no augmentation at all). As long as A^{+} is non-zero but less than 1, the human is contributing the majority of the cognitive power. Indeed, this is the case today. However, when $A^{+} > 1$, we will have entered into a new realm in which an artificial construct will contribute more cognitive power than the human. Once we cross into that realm, there is no limit to A^{+} as it increases to infinity. Interestingly, if the human component falls to zero, A^{+} becomes undefined. This is appropriate because at that point we will have an independent artificial intelligence operating without human assistance—no longer human cognitive augmentation.

THE COG ERA

Democratization and Commoditization of Expertise

We predict the emergence of *specialty cogs* and *personal cogs* intended for the mass-market and anticipate the vertical development of cogs pertaining to a specific domain. We foresee a class of specialty cogs being developed for almost any subject matter for which exists a human expert. Unlike enterprise cogs, specialty cogs will be made available to the mass market. Anyone will be able to access, purchase, and rent specialty cogs from a variety of retail outlets via the Internet and brick-and-mortar stores. We foresee both the creation of new cognitive applications and modern-day apps evolving into ever-smarter versions gradually adding cognitive capability over time. These cogs will be bought and sold by average people through existing sales channels much in the same way apps, music, and books are sold now. These cogs will service us through voice-activated dialog and will be available to us via our handheld, portable devices. This will give every person access to professional-level expertise in any domain. This democratization of expertise will lead to changes similar in scope to the way the democratization of computing and information has changed us over the last few decades.

Because cogs work in partnership with humans, there will arise the need for experts in a field to work with cogs and develop their own unique store of knowledge, something we call a *cogbase*. Entities in industries such as financial services, investment services, legal, medical, news, politics, and technology will compete in offering access to their “superior” store of knowledge created through the interaction of

their experts and their cogs. In the cog era, *knowledge* and *expertise* will become an economic commodity.

Personal Cogs

We also foresee the development of another type of cog we call a *personal cog*. These cogs will certainly possess expert knowledge and ability in a given domain, like specialty cogs, but also will maintain a record of all interaction with the human and use that information to improve its cognitive services over time, even years or decades. Humans will form relationships with personal cogs growing and expanding over time much like with siblings, spouses, co-workers, and friends. Each human/personal cog relationship will evolve to be unique and produce a knowledge store of great value.

Teacher Cogs An interesting example of a personal cog are teacher cogs. A teacher cog will have access to everything that is knowable about a particular subject matter. Through customized and personalized interaction with a person, teacher cogs will impart this knowledge to the student in ways similar to the master/apprentice model of education. The best teacher cogs will be personal cogs able to remember every interaction with a person over an extended period of time, even years or decades. Imagine an algebra cog able to answer a question by a 35-year old user/owner who it has been working with since grade school. We anticipate teacher cogs to evolve for every subject taught in schools and beyond. There may even be *master cogs* developed incorporating the domains of several individual teacher cogs. One can imagine an engineering cog being comprised of an applied calculus cog, an algebra cog, and a differential equations cog. We think students of future generations will start using cogs all throughout their education and then retain the cogs, and years of interaction, through the rest of their lives. Again, we foresee vigorous competition arising from different teacher cog providers attempting to bring to the market the best teacher cog for a particular subject matter.

Advisor, Coach, Self-Help, and Pet Cogs Humans will interact with cogs using natural language and many other mechanisms. People will have conversations with cogs and the cogs will respond in creative, knowledgeable, and personalized ways. It is natural for humans to form emotional relationships with just about anything, biological or artificial, they can interact with. Indeed, people form emotional relationships with animals and technology today. We foresee cog technology giving personalities to artificial systems. Since cogs will be able to give expert-level advice in any domain, we predict the evolution of a host of self-help cogs ranging from relationship advice to life/work balance, to grief counseling, faith-based counseling and beyond. People will confide intimate details to these cogs and receive advice of great personal value and satisfaction. People will spend hours conversing with their personal self-help/companionship cogs. We can easily envision the development of virtual pets with cog-based personalities and communication abilities. In the cog era, we will love our cog pets. In fact, this is already happening. In China, millions of young people are chatting with an artificial intelligence bot, named Xiaoice, programmed to behave like a 17-year-old girl (Larson, 2016). Xiaoice was created by Microsoft's Application and Services Group East Asia and gives relationship advice, is empathetic, humorous, and sometimes divisive. Yet, Xiaoice is far from being a full-fledged cognitive system like IBM Watson. Though primitive still, Xiaoice portends the future. Another example of a primitive, but indicative, artificial entity is Microsoft's Tay (Deveau & Cao, 2016). Tay chats with humans on Twitter and other messaging platforms and learns by parroting comments and then generating its own answers and statements based on all of its interactions. Tay emulates the casual speech of a stereotypical millennial. Tay ran into trouble within a few days of launch when a concerted effort taught Tay to spew

offensive remarks. However, expect artificial entities to get smarter. We predict millions of people will soon be conversing with an artificial entity via social media and other means without even realizing it.

Productivity Cogs We predict every productivity application in use today will become enhanced by cog technology in the future. Indeed, applications like word processors, spreadsheets, presentation editors, Web browsers, entertainment apps, games, graphics editing, etc. may become a primary interface point for humans and cogs. Cog capabilities will both be built into the applications themselves and provide expert-level collaboration to the user and also evolve into stand-alone cogs for a particular task. For example, we can imagine a future version of Microsoft Word coming complete with embedded creative writing cog services. We can also imagine purchasing a creative writing cog from an app store operating independently of a specific word processor.

Personal productivity cogs will understand our recent context in a deep manner and use that to customize their assistance and interaction with us. Imagine, for example, a word processing cog that understands you are writing about the future of cognitive processing but also knows that you have communicated with several others via email on that and related topics and can also take into consideration every article or Web page you have accessed in recent months while researching the paper. Such a cog knows a lot about you personally and can combine that knowledge with its own searching and reasoning about the millions of documents it has searched on the Internet. Personal productivity cogs will become our intelligent virtual colleagues.

Collaborative Cognition In addition to enhancing current productivity applications, we expect an entirely new genre of cog-based productivity app to arise, collaborative cognition. We envision new kinds of problem solving, brainstorming, business/competitive/market analysis, and big data analysis. We foresee multi-cog "collaborative virtual team" applications being created. *Cogteams* will consist of several cogs, each with their own domain of expertise, engaged in discourse with one or more humans and offering advice, answering questions, and performing research and analysis as the meeting dictates. Collaborative cogs will become our artificial intelligent team members. Again, we see a vigorous and dynamic competitive market arising around the idea of collaborative cogs. By partnering with humans, cogs achieve ever-increasing levels of knowledge in a particular area. Therefore, considerable market value will be attached to collaborative cogs that have worked with the best experts in the field. The cog era will bring forth a new kind of virtual consultant.

Research Cogs We foresee future graduate students, entrepreneurs, scientists and any of us creative and inquisitive people conducting research by conversing with their research cog(s) instead of searching and reading scores of journal articles and technical papers. Today, I tell my graduate students the first step in their research is to go out and read as many articles, books, and papers as they can find about their topic and I try to give them guidance. My future research students' first action will be to sit down with his or her research cog and ask "So what is the current state of the art in <insert domain here>."

Cogs will be able to consume billions of articles, papers, books, Web pages, emails, text messages, and videos. This far exceeds the ability of any human. Even a person spending all of their professional life learning and researching a particular subject is not able to read and understand everything available about that subject. Yet, future researchers will be able to *start* their education from that vantage point

by the use of research cogs. In the cog era, the best new insights and discoveries will come from the interaction between researchers and their research cogs.

Here again we see evidence of knowledge becoming a commodity. Today, we may be able to learn a great deal from the notebooks of great inventors like Tesla, Edison, and DaVinci. In fact, notebooks of inventors like these are worth millions of dollars. But image how valuable it would be if we had access to Einstein's personal research cog he used for years while he was synthesizing the theory of relativity. In the cog era, not only will cogs assist us in coming up with great discoveries, they will also record and preserve that interaction for future generations. Such cogs will be enormously valuable economically, socially, and culturally. One can imagine cogs belonging to historically significant figures being accessible in future museums where patrons can have a discussion with a digital likeness of the person.

Discovery Engines Even though cogs are intended to partner with humans and improve their knowledge and ability over time as a result of this interaction with humans, cogs will evolve to be able to perform an enormous amount of cognitive work on their own. We fully expect cogs working semi-autonomously to discover significant new theories, laws, proofs, associations, correlations, etc.

In the cog era, the cumulative knowledge of the human race will increase by the combined effort of millions of cogs all over the world. In fact, we foresee an explosion of knowledge, an exponential growth, when cogs begin working with the knowledge generated by other cogs. This kind of cognitive work can proceed without the intervention of a human and therefore proceed at a dramatically accelerated rate. We can easily foresee the point in time where production of new knowledge by cogs exceeds, forever, the production of new knowledge by humans.

In fact, we anticipate a class of *discovery engine cogs* whose sole purpose is to reason about enormous stores of knowledge and continuously generate new knowledge of ever-increasing value resulting ultimately in new discoveries that would have never been discovered by humans or, at the very least, taken humans hundreds if not thousands of years to discover.

Cognitive Property Rights Today, intellectual property rights represent a significant value, as much as a third of the US gross domestic product (USPTO, 2012). The cog era will bring forth new questions, challenges, and opportunities in intellectual property rights. For example, if a discovery cog makes an important new discovery, who owns the intellectual property rights to that discovery? An easy answer might be "whoever owned the cog." But, as we have described, we anticipate cogs conferring with other cogs and using knowledge generated by other cogs. So a cog's work and results are far from being in isolation. We predict existing patent, copyright, trademark, and service mark laws will have to be extended to accommodate the explosion of knowledge in the cog era.

SUMMARY

Over the last fifty years, we have seen vast cultural, social, legal, and economic changes due to the information age, the computer age, the Internet age, and now the social media age. We are at the boundary of a new era, the cog era, and we will see similar upheavals as a result. For the first time in history, humans will be able to partner with artificial systems able to think as good as or better than they can. This will extend human capability into a new dimension. For millennia, humans have used tools like hammers, saws, and shovels to extend physical performance. In the cog era, cognitive systems, called

cogs, will extend human cognitive performance. Cognitively augmented humans will create a new standard of performance in which the successful ones will be the ones who can best partner with cogs and demonstrate superior mastery of a resource that does some of the thinking for them.

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