
How Personal Cognitive Augmentation Will Lead To The Democratization of Expertise

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Abstract

In the coming era of personal cognitive augmentation, humans and artificially intelligent entities, we call cogs, will work together in a natural and collegial partnership where the total amount of cognition is a combination of human and artificial thinking. Advances in cognitive computing, deep learning, and several other fields make possible cost-effective development of personal cogs possessing expert-level performance in a defined field. If a human can be an expert at something a cog will be developed with that expertise in the near future. When such cogs are available to everyone via Cloud, Internet, and our everyday devices, they 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 lead to dramatic social, cultural, and economic changes as all revolutions do.

1. Introduction

When something becomes available to the average person, we say it has become *democratized* (Friedman, 1999). The printing press democratized knowledge and freed knowledge from being the sole property of the elite by enabling books and other publications to be distributed to the masses for the first time. Societal, cultural, political, and religious revolutions followed. A few hundred years later, microelectronics and software democratized computers and information processing. In the early days of computing, computers were owned and operated by only the largest companies and government agencies. Computers were accessible only to those with special knowledge and training. Desktop and personal computers running easy-to-use software brought the computer to the masses and we have all become *information workers* and *knowledge workers* as a result. World Wide Web technologies similarly democratized the Internet and now billions of people access the Internet. Electronic devices, computers, and the Internet have transformed how we live, work, and play.

In 2011, a cognitive computing system built by IBM, called Watson, defeated two of the most successful human Jeopardy champions of all time (Jackson, 2011). Watson received clues in natural language and gave answers in natural spoken language. Watson's answers were the result of searching and deeply reasoning about millions of pieces of information and aggregation of partial results with confidence ratios. Watson was not programmed to play Jeopardy. Instead, Watson was programmed to *learn* how to play Jeopardy, which it did in many training games with live human players before the match (Ferrucci, 2012; Ferrucci et. al., 2010). Watson

practiced and achieved expert-level performance within the narrow domain of playing Jeopardy. With an architecture featuring an advanced natural language interface, distributed information retrieval, knowledge representation, automated reasoning, and deep learning, Watson represents a new kind of computer system (Wladawsky-Berger, 2013; Isaacson, 2014).

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; Sweeney, 2015). In January 2016 in her 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).

An early success of Watson commercialization is medical treatment suggestion at Memorial Sloan Kettering Cancer Center (Kelly & Hamm, 2013). 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.

In another example, 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, a good example of the democratization of expertise.

We think IBM's commercialization activities and stated vision for its cognitive computing technology signals that something new is about to become democratized. We are entering the era of personal cognitive augmentation in which humans will routinely engage with cognitive systems performing at the level of a human expert and beyond in a number of domains. Currently, cognitive augmentation systems are available only to large companies, governments, and the "elite" with special knowledge and training. But, we predict cogs will soon come down to the personal level and be available to the masses. We call this class of cognitive systems *personal cogs* and they will change everything.

2. Motivation

Why should we think a new era is upon us? Humans routinely “partner” with technology now so what is different about the personal cog era? Systems with human-like intelligence have been the goal of artificial intelligence, expert systems, and cognitive systems research for decades and people have been promising “new eras” all along. So what is different about personal cogs? First, the personal cog era is the confluence of a number of factors:

- **Deep Learning:** Recent advances in efficient algorithms capable of multi-level unsupervised and semi-supervised feature learning and complex concept abstraction significantly reduce the time and effort required to develop systems with human expert-like performance.
- **Big Data:** The availability of a virtually unlimited training set make it possible and affordable to develop systems in almost any domain of discourse with a minimum of knowledge engineering and preparation.
- **Internet of Things:** The availability of ambient data makes it possible for systems to acquire data and information from all aspects of our lives without having to be explicitly input by the human.
- **Open Source AI:** The free and open availability of powerful resources historically available to only large corporations and research institutions enable millions of developers to develop systems and applications leading to a boom market similar to the “dot com” boom of the late 1990s and the social media boom of the 2000s.
- **NLI:** Natural language interfaces with our devices are rapidly becoming ubiquitous greatly reducing the complexity of the user interface meaning anyone can interact with personal cogs without special knowledge or training.
- **Connected Age:** The enormous number of people already connected by, and comfortable using, high-bandwidth handheld electronic devices enables a low cost of delivery of personal cog technology via the Internet, Cloud services, and on-demand streaming to a mass market ready to accept it.

Even though these are the culmination of decades of development across many fields, they are only just now coming together in a way suited for mass-market products. In short, it’s the right time for something revolutionary. We think the revolutionary type of application/system will be in the *cognitive augmentation* arena, the enhancement of human cognitive ability. Recent successes have demonstrated systems utilizing one or more of the above factors capable of performing at the level of a human expert. Major companies such as IBM, Microsoft, Google, and

Amazon are investing billions of dollars into developing “AIs.” While these AIs are not personal cogs, we foresee the personalization of these kinds of systems as being the next step. When that happens, expert-level performance in a variety of domains will be in the hands of the ordinary individual.

But haven’t we heard this kind of hype before? The idea of an artificial system performing like a human expert describes a branch of research in artificial intelligence called *expert systems*. In 1980s, research and development of expert systems was a thriving endeavor. However, by the last half of the 1990s, interest in expert systems had largely vanished (Haskin, 2003). Expert systems never reached into the personal mass-market. One reason was the cost and effort of developing an expert system. Being based on a set of if...then rules captured by interacting with one or more subject matter experts, development required extensive and time-consuming engineering of the knowledgebase. Another reason was the lack of a mass market ready to accept the technology. The peak of the expert system era was before mass-adoption of the Internet, the World Wide Web, on-demand, streaming, and handheld, connected electronics and natural language interfaces were still in the research phase. The ecosystem is now favorable for development of mass-market expert systems for reasons given above and we think personal cogs will be the incarnation.

We think personal cogs will redefine the relationship between people, their environment and their technology. Personal cogs will be available to us at any time of the day through a variety of interface methods, including natural language. We will come to view personal cogs as helpful entities always available in our environment whether at work, play, or leisure. Cogs will play the role of assistant or coach, will act autonomously and semi-autonomously, be prescriptive, suggestive, instructive, or simply entertaining.

3. Cognitive Augmentation

The idea of enhancing human cognitive ability with artificial systems is not new. In the 1640s, mathematician Blaise Pascal created a mechanical calculator (Chapman, 1942). Yet, the Pascaline, and the abacus thousands of years before that, are just mechanical aids executing basic arithmetic operations. The human does all the real thinking. In the 1840s, Ada Lovelace envisioned artificial systems based on Babbage’s machines performing musical composition (Hooper, 2012; Isaacson, 2014). But Ada imagined the machine composing the music, not a machine enhancing a human’s ability to compose music. 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 on its own. In the 1950s, Ross Ashby coined the term *intelligence amplification* maintaining human intelligence could be synthetically enhanced by increasing the human’s ability to make appropriate selections on a persistent basis (Ashby, 1956). But again, the human does all of the thinking. The synthetic aids just make the human more efficient. 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 the artificial aids merely assisting with the preparation work leading up to the actual thinking which the human would do. Engelbart’s H-LAM/T framework described the human as a part in a multicomponent human/computer system allowing human and artificial systems 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 actually do any of the thinking themselves. The idea of human and machine working together is a powerful one though and one cogs are bringing into reality.

Since coining the phrase *artificial intelligence* (AI) in 1955, at least three generations of researchers have sought to create an artificial system capable of human-like intelligence (McCarthy et. al., 1955). Expert systems using if-then production rules have captured experts’ knowledge and simulated the logical inference of experts in a field of discipline (Hayes-Roth, Waterman, Lenat, 1983). But these systems are laboriously programmed and brittle in the face of uncertain or conflicting information. Artificial neural networks have demonstrated a human brain-like response to multiple, partial, and uncertain stimuli including adaptability and learning. But these systems lack general strategic and tactical reasoning ability such as goal-based search, planning, and synthesis.

The concept of machine learning has long been a staple of artificial intelligence research. However, most of the early machine learning required careful and precise engineering and preparation of the information prior to the introduction to the machine doing the learning. We desire systems that can learn in the real world and with unstructured data and information. We are beginning to see this come true with *deep learning* (Deng & Yu, 2014; Itamar, Rose & Karnowski, 2013). Recent advances in deep learning have resulted in systems learning multiple levels of representations corresponding to different levels of abstraction. The levels form a hierarchy of concepts and result in deep understanding. Furthermore, deep learning algorithms learn from unstructured, voluminous, and disparate forms of information such as by watching videos, consuming millions of documents, mining social media, and observing human behavior.

It seems the primary goal of AI has been to replicate human intelligence with the idea to ultimately compete with or replace humans. Indeed, much has been written recently about the fear that AI will take over and make us obsolete. Cognitive augmentation is different. Cognitive systems seek to act as partners with and alongside humans. John Kelly, Senior Vice President and Director of Research at IBM describes the coming revolution in cognitive augmentation as follows (Kelly & Hamm, 2013):

The goal isn’t to... replace human thinking with machine thinking. Rather...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.”

Thirty years ago, Apple, Inc. envisioned an intelligent assistant called the *Knowledge Navigator* (Apple, 1987). The Knowledge Navigator was an artificial executive assistant capable of natural language understanding, independent knowledge gathering and processing, and high-level reasoning and task execution. The Knowledge Navigator concept was well ahead of its time, however, some of its features are seen in current voice-controlled “digital assistants” such as Siri,

Cortana, Amazon Echo. The Knowledge Navigator was envisioned as a collaborator much like IBM's vision of Watson-derived technology.

More recently, (Forbus & Hinrichs, 2006) described *companion cognitive systems* as software collaborators helping their users work through complex arguments, automatically retrieving relevant precedents, providing cautions and counter-indications as well as supporting evidence. Companions assimilate new information, generate and maintain scenarios and predictions, and continually adapt and learn, about the domains they are working in, their users, and themselves. Like companions, the personal cogs we envision will operate in a limited domain, however, will achieve expert-level performance in that domain, often exceeding that of a human expert. Like truly human companions, personal cogs will be able to interact through spoken natural language, although not be limited to this form of communication.

(Langley, 2013) challenges the cognitive systems research community to develop a synthetic entertainer, a synthetic attorney, and a synthetic politician as a way to drive future research on integrated cognitive systems. The vision here is to develop a virtual human. We maintain the goal should be not to create a virtual human capable of being an entertainer, an attorney, or a politician, but rather create a cognitive system capable of expert-level performance in entertainment, a different cognitive system capable of exhibiting expert performance in a subfield of law, and a cognitive system capable of expert politicking. This is indeed the vision of IBM as it commercializes its Watson technology. We feel the natural extension of this technology will result in personal cogs being virtual entities capable of expert-level collaboration in a relatively narrow domain of discourse. Collaboration with the personal cog will enhance the human user's cognitive ability.

This begs a few questions. With the human doing some of the thinking and the personal cog doing some of the thinking, how do we characterize and measure cognitive augmentation? How can we tell when the human is being cognitively augmented? We can begin by defining a cognitive system as any entity performing one or more cognitive processes resulting in the transformation of data, information, or knowledge to a higher value form. In performing the transformation, cognitive systems expend a quantity of *cognitive work*. When acting as partners with humans on a task, the human performs an amount of cognitive work, W_{human} , and the cog performs an amount of cognitive work, W_{cog} . Together, human and cog perform an aggregate amount of cognitive work, W^*

$$W^* = W_{human} + W_{cog}. \quad \text{Eq. 1}$$

With *cognitive power*, P , being the execution of cognitive work over a period of time,

$$P = \frac{W}{t}, \quad \text{Eq. 2}$$

the cognitive power achieved by a human/cog partnership is greater than that either the human or cog could achieve on their own. The aggregate cognitive power of a cognitively augmented ensemble is

$$P^* = P_{human} + P_{cog}. \quad \text{Eq. 3}$$

Current cognitive systems perform cognitive processes at only a rudimentary level, so P_{cog} is relatively small. However, as cogs evolve, they will execute high-order cognitive processes, thereby performing even more cognitive work. Over time, the balance between how much of the thinking is done by the human and how much is done by the cog will change. This ratio is called the *augmentation characteristic* and is given by

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

In most cases, humans still perform more cognitive work than cognitive systems, so $A^+ < 1$. In the future, cogs will perform more cognitive work than the humans with $A^+ > 1$ and increasing to infinity as cogs get more capable.

4. The Democratization of Expertise

Consider the world in which we have been living in so far, one without cogs at all. A person seeking advice, assistance, and service from a human expert in a certain domain must engage with that expert (usually at a cost of a certain amount of money). If the cognitive power of the human expert is expressed as P_{expert} then a person engaging with the expert results in a total cognitive power of $P_{person} + P_{expert}$. The cog era promises to replace the human expert with a cognitive system resulting in $P_{person} + P_{cog}$. This effectively gives the person the ability to perform at the level of an expert in that domain. We foresee cogs being developed for any enterprise a human can be an expert at. When such cogs are available to everyone, 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*. We view the democratization of expertise as the natural evolution in the democratization of technology (Friedman, 1999). In addition to the democratization of knowledge, information, technology, and finances we will soon be able to add the democratization of expertise.

We view enterprise cogs described earlier as intended for corporate use however we foresee the evolution of personal cognitive systems along at least two lines of development: *specialty cogs* and *personal cogs* both of which will be intended for the mass market and available to anyone. We predict these will take the form of cog apps, cog-based Cloud services, and even cog-based devices. These cogs will become pervasive throughout our lives in many ways similar to how computer and digital technology pervades our lives today. We also foresee the evolution of an entire industry (the “cog boom” if you will) rivaling the personal computer, the dot com, and the social media booms.

Cogs will personally interact with us naturally throughout the day, through a variety of interactivity mechanisms, helping us in every aspect of our lives. Personal cogs will build a history with us over time. We can see the beginning of this style of interface technology in today’s voice-activated personal assistants like Apple’s Siri, Microsoft’s Cortana, Google Now, Facebook’s M, and Amazon Echo’s Alexa (Apple, 2015; Microsoft, 2015; Google, 2015; Hempel, 2015; Colon & Greenwald, 2015). Each accept natural-language requests from users, reply in natural language, and perform services on behalf of the user. But these tools simply retrieve information, and perform minor clerical tasks such as creating appointment calendar items. 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. 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.

This is quite different from the democratization of information we enjoy today. As an example, imagine a legal advice cog in the spirit of Langley's synthetic lawyer (Langley, 2013). Currently, to access expert legal advice, we must employ a lawyer skilled and knowledgeable in the area of the law pertinent to our case. The legal advice cog will train by consuming and studying millions of documents on laws and the legal profession and be fine-tuned by working with expert lawyers. When available as an app for the average person's phone or tablet, the user will be able to engage in a natural language discussion with the cog about a legal issue and receive expert advice and direction from the cog.

One may argue that this is no different than what we have today. A person can certainly search the Internet and find information about any legal issue they may be facing. However, the difference is where the "thinking" happens. Currently, a person is able to access information but they must read and understand the information and then reason about that information to arrive at a course of action. In this case, all of the thinking is done by the person (P_{person}). In the cog era, the cog will do most of the legal thinking (P_{cog}). The user will provide information to the cog about their particular issue but the cog will do the work normally ascribed to the professional lawyer (replacing P_{expert}). Therefore, instead of being partnered with a mere library of legal information, the user is partnered with an expert practitioner of the legal profession albeit an artificial construct.

5. The Cog Era

What will the world be like when most of us can perform as experts in any field? We are at the very beginning of the cog era and its evolution will play out over the next few decades. The cog era will, for the first time, give humans artificial systems to assist them in thinking. This cognitive augmentation will create a new industry and market and will change things for us culturally, legally, socially, and legally. If we let history be our teacher, we can expect the cog era to bring about changes we can only begin to imagine today. We now think of a time before electricity or a time before the telephone or television, or even before the computer and the Internet. We believe one day we will look back and think of a time before cogs. It's difficult to remember or imagine life without our modern technological conveniences and we believe one day we will say the same thing about cogs. This section contains some, but certainly not all, of the interesting factors that will come in the cog era.

The Cog Market

Large-scale cognitive systems we call *enterprise cogs* are being developed now. This will certainly continue and spread into every industry and will certainly become an economic force in the market worth many billions of dollars. However, enterprise cogs are not intended for purchase and use by the average person. We predict the emergence of *specialty cogs* and *personal cogs* intended for the mass-market. 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. We will both

be able to purchase or rent our own cogs and also be able to subscribe to Cloud-based cog services and information.

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 (we call this 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, we predict the commoditization of expertise.

Teacher Cogs

We expect cogs to become a new form of intelligent tutoring systems. 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 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. 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 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.

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, like a spouse, coworker, or a friend, 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 assistants.

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 such as in Figure 1. Such *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.

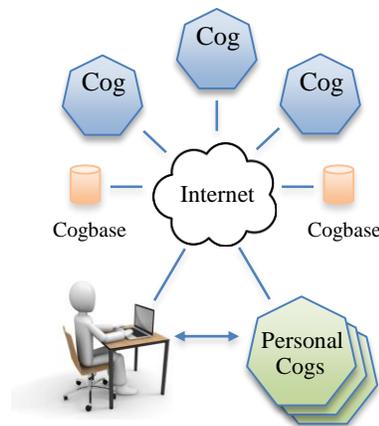


Figure 1: Human Partnering with Multiple Personal Cogs and Collaborating with Other Cogs via the Internet

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 research cog and ask "So what is the current state of the art in <insert domain here>." The cog will have already consumed all existing material about the subject, will have recognized patterns and trends, and will be able to answer questions and even suggest lines of thought.

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 imagine 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 both economically and socially.

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 and even 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 [40]. 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.

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