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Potential of Cognitive Computing and Cognitive Systems

Abstract: Cognitive computing and cognitive technologies are game changers for future engineering systems, as well as for engineering practice and training. They are major drivers for knowledge automation work, and the creation of cognitive products with higher levels of intelligence than current smart products.

This paper gives a brief review of cognitive computing and some of the cognitive engineering systems activities. The potential of cognitive technologies is outlined, along with a brief description of future cognitive environments, incorporating cognitive assistants - specialized proactive intelligent software agents designed to follow and interact with humans and other cognitive assistants across the environments. The cognitive assistants engage, individually or collectively, with humans through a combination of adaptive multimodal interfaces, and advanced visualization and navigation techniques.

The realization of future cognitive environments requires the development of a cognitive innovation ecosystem for the engineering workforce. The continuously expanding major components of the ecosystem include integrated knowledge discovery and exploitation facilities (incorporating predictive and prescriptive big data analytics); novel cognitive modeling and visual simulation facilities; cognitive multimodal interfaces; and cognitive mobile and wearable devices. The ecosystem will provide timely, engaging, personalized / collaborative, learning and effective decision making. It will stimulate creativity and innovation, and prepare the participants to work in future cognitive enterprises and develop new cognitive products of increasing complexity.

Keywords: Cognitive computing, Cognitive systems, Cognitive products

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1 Introduction

The history of computing can be divided into three eras ([1, 2], and Figure 1). The first was the tabulating era, with the early 1900 calculators and tabulating machines made of mechanical systems, and later made of vacuum tubes. In the first era the numbers were fed in on punch cards, and there was no extraction of the data itself. The second era was the programmable era of computing, which started in the 1940s and ranged from vacuum tubes to microprocessors. It consisted of taking processes and putting them into the machine. Computing was completely controlled by the programming provided to the system. The third era is the cognitive computing era, where computing technology represented an intersection between neuroscience, supercomputing and nanotechnology.

In a little more than a century computing shifted from numbers to data then from data to knowledge. The shift was not about having one system replacing the other but enriching it. Programmable systems enabled the creation of data by processing numbers, and cognitive computing allowed making sense of data. Sense is what stands between raw data and actionable data.

Cognitive computing has attracted attention since 2011 when the IBM Watson computer (of the IBM DeepQA project) played against two champions of the US game show Jeopardy and won. Watson was able to respond directly and precisely to natural language prompts with relevant responses. It had access to 200 million pages of structured and unstructured information consuming four terabytes of disk storage.

Whereas in the programmable era, computers essentially process a series of 'if then what' equations, cognitive systems learn, adapt, and ultimately hypothesize and suggest answers. With the advent of big data, which grows larger, faster and more diverse by the day, cognitive computing systems are now used to gain knowledge from data as experience and then generalize what they have learned in new situations ([3] and Figure 2). They unlock the insights that the new wealth of data generated holds. Delivering these capabilities will require a fundamental shift in the way computing progress has been achieved for decades.

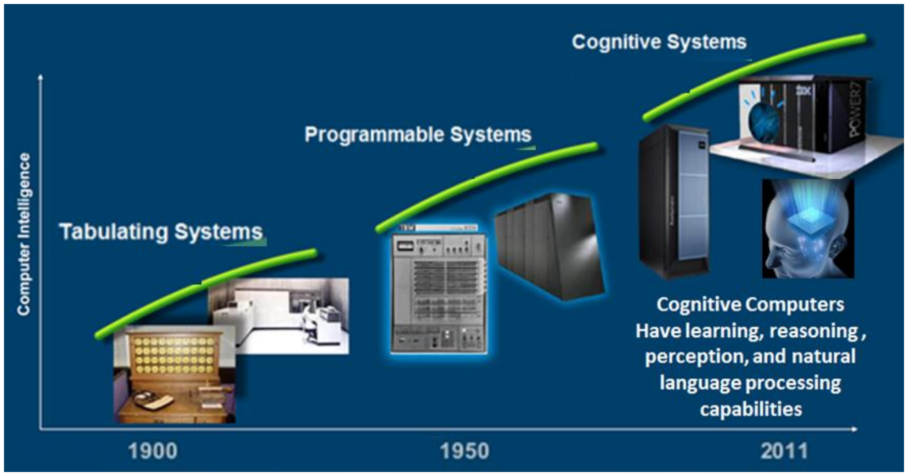

Figure 1: Three Eras of Computing (based on [1]).

2 Definition and characteristics of cognitive computing

2.1 Definition of Cognitive Computing

Cognitive computing refers to the development of computer systems modeled after the human brain, which has natural language processing capability, learn from experience, interact with humans in a natural way, and help in making decisions based on what it learns [2–4]. All cognitive computing systems are learning systems. They incorporate embedded data analytics, automated management and data-centric architectures in which the storage, memory, switching and processing are moving ever closer to the data. Their way of processing massive amounts of data is neither linear nor deterministic.

Originally referred to as artificial intelligence, researchers began to use the modern term cognitive computing instead in the 1990s, to indicate that the science was designed to teach computers to think like a human mind, rather than developing an artificial system. This type of computing integrates technology and biology in an attempt to re-engineer the brain, one of the most efficient and effective computers on Earth.

However, with major advances in cognitive science, researchers interested in computer intelligence became enthused. Deeper biological understanding of how the brain worked allowed scientists to build computer systems modeled after the mind, and most importantly to build a computer that could integrate past experiences into its system. Cognitive computing was reborn, with researchers at the turn of the 21st century developing computers which operated at a higher rate of speed than the human brain did. Its major asset is being able to accelerate the rate of learning in order to support humans in their work. Cognitive computing and cognitive technologies can be considered as the third phases of the AI evolution, from traditional Artificial Intelligence (AI) to Artificial General Intelligence (AGI) to cognitive systems [5].

2.2 Relation to Neural networks

Cognitive computing integrates the idea of a neural network, a series of events and experiences which the computer organizes to make decisions. Neural networks mimic the behavior of the human brain. Like the brain, multilayered computer networks can gather information and react to it. They can build up an understanding of what objects look or sound like. They contribute to the computer's body of knowledge about a situation and allow it to make an informed choice, and potentially to work around an obstacle or a problem. Researchers argue that the brain is a type of machine, and can therefore potentially be replicated. The development of neural networks was a large step in this direction.

As the body of knowledge about the brain grows and scientists experiment more with cognitive computing, intelligent computers are the result. Smart computers which are capable of recognizing voice commands and acting upon them, for example, are used in many corporate phone systems. Cognitive computing is also used in many navigation systems onboard aircraft and boats, and while these systems often cannot handle crises, they can operate the craft under normal conditions.

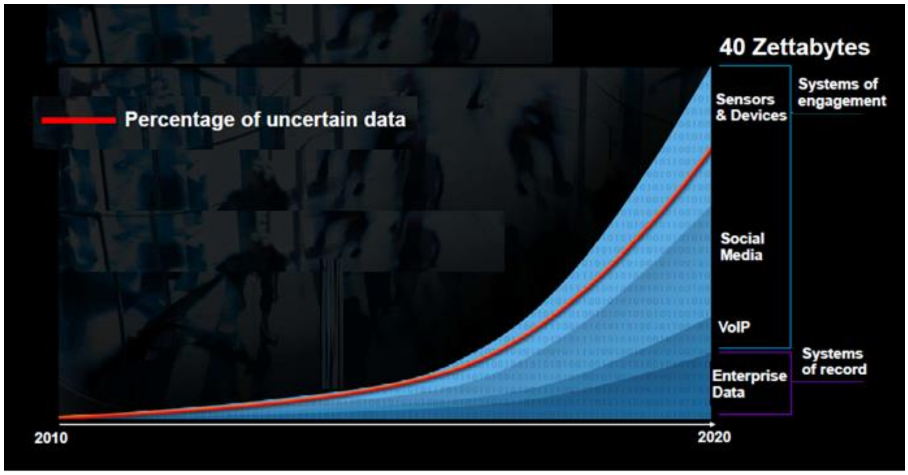

Figure 2: Projected Growth of Big Data (based on [1]).

At the turn of the 21st century, many researchers believed that cognitive computing was the hope of a near future. By replicating the human brain in computer form, researchers hope to improve conditions for humans as well as gaining a deeper understanding of the biological reactions that power the brain. Computers capable of reason were beginning to emerge in the late 1990s, with hopes for consciousness following.

2.3 Major characteristics of Cognitive Computing

The major characteristics of cognitive computing systems are [6]:

- Information adept—being able to integrate big data from multiple heterogeneous sources and then synthesizing ideas or answers from them.
- Dynamic training and adaptive—learning and changing as they receive new information, new analyses, new users, new interactions, new contexts of inquiry or activity.
- Probabilistic—discovering relevant patterns based on context, statistically generating and evaluating series of evidence-based hypotheses, predicting the probability of valuable connections, and returning answers based on learning and deep inferencing. This includes finding unexpected patterns—a kind of machine-aided serendipity.
- Highly integrated— has automated systems / workload management through which all modules contribute to a central learning system and are affected by new data, interactions and each other's historical data.
- Meaning-based— performing natural language processing and using embedded analytics to leverage language structure, semantics and relationships.
- Highly interactive—providing tools and interaction designs to facilitate advanced communications within the integrated system and incorporating stateful human-computer interactions, data analysis and visualizations.

Cognitive computing systems are able to handle ambiguity and a shifting set of variables. They can constantly re-evaluate information based on changes in the user, task, context, goal or new information. They must understand the question or context before seeking answers. They may offer multiple useful answers that are weighted for confidence or closeness to the query or topic. They turn big data into smart data and useful knowledge. Users are able to interact with the system easily in a kind of continuing "conversation." Like humans, cognitive computing systems must be dynamic, and they must learn. Four layers of Cognitive Computing Systems can be identified, namely

- Static and dynamic Learning Systems
- Data organization and interpretation
- Architecture / Design of the system
- Core components

2.4 Cognitive Computing Building Blocks

To usher in a new era of cognitive computing, novel hardware, programming languages, applications and simula-

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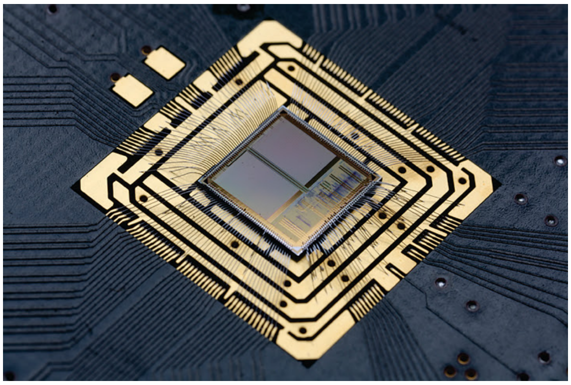

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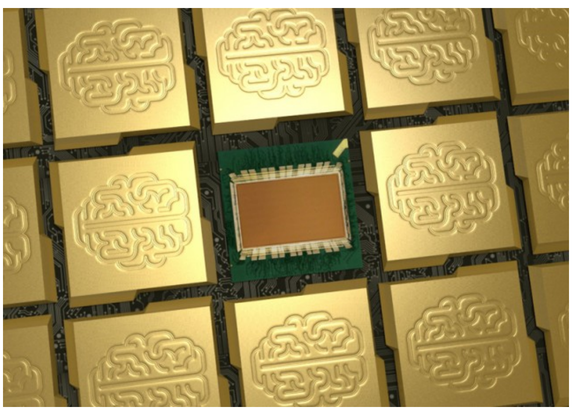

Figure 3: Neuromorphic Chips designed by Heidelberg group and IBM. (a) The Heidelberg Chip features 384 neurons, 100,000 Synapses and operates at a speed of approximately 100,000 times biological real time; (b) The new IBM chip, called TrueNorth, consists of 1 million programmable neurons and 256 million programmable synapses across 4096 individual neurosynaptic cores.

tors are currently being developed. The new hardware includes new electronic neuromorphic machine technology for processing sensory data, such as images and sound, and responding to changes in data in ways not specifically programmed. This technology breaks path with the traditional von-Neumann architecture used for the last 70 years [7, 8].

The DARPA's SyNAPSE (Systems of Neuromorphic Adaptive Plastic Scalable Electronics) program initiated in 2008 to model in silicon the massively parallel way the brain processes information as billions of neurons and trillions of synapses respond to sensory stimuli. The neurons also change how they connect with each other in response to changing images, sounds or patterns. The program is being undertaken by IBM, HRL labs, along with a number of universities. Neuromorphic chips have the potential of overcoming the physical limitations and considerably reducing the power requirements of the traditional von Neumann processors.

In 2011, a prototype neuromorphic chip containing 256 neurons and 262,144 synapses was developed by IBM. In August 2014, IBM built a new chip with one million neurons and 256 synapses. The new chip has 5.4 billion transistors and an-chip network of 4,096 cores. The chip consumes only 70mW during real-time operation — orders of magnitude less energy than traditional chips (Figure 3). The goal is to simulate one trillion synapses using only 4 kW of energy [9].

The neurosynaptic cores are distributed and operate in parallel. The cores integrate memory, computation, and communication. Individual cores can fail and yet, like the brain, the architecture can still function. Cores on the same chip communicate with one another via an on-chip event-driven network. Chips communicate via an inter-chip interface leading to seamless scalability like the cortex, enabling creation of scalable neuromorphic systems (Figure 4). The neurosynaptic chip technology opens new computing frontiers for distributed sensor and supercomputing, and robotic applications (Figure 5).

3 Cognitive / Smart Engineering Systems

A Cognitive system is one that performs some of the functions of human cognition – learning, understanding, planning, deciding, communicating, problem solving, analyzing, synthesizing, and judging. Some smart systems use "brute force" computation to perform their tasks (like some of the early concepts of driverless cars), others use machine (deep) learning to adapt to changing situations, detect novelty, seek out data, and augment human cognition. Emerging cognitive systems are being equipped with broad abilities in pattern recognition, natural language processing, complex communication, learning and other domains that used to be exclusively human. They cover a broad spectrum ranging from cognitive devices (e.g., neurocam, and OrCam systems) to robotic machines and large socio-technical systems (e.g., cognitive grids, cognitive infrastructures, and cognitive / smart cities). The cognitive socio-technical systems are managed in a more holistic and intelligent way, using lean operational practices and cognitive technologies that can ultimately contribute to improving the reliability and responsiveness of customer service and the whole economics of the systems. Cognitive

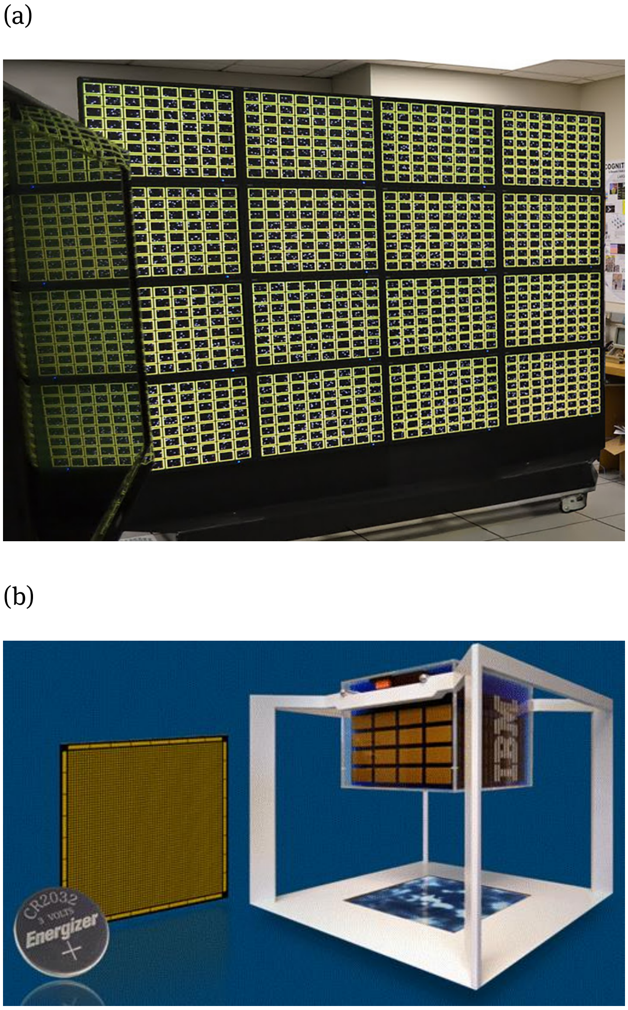

Figure 4: The Brain Wall and Brain Cube. (a) The brain wall is a neural network visualization tool built by SyNAPSE project researchers at IBM; (b) The brain cube will have 256 million neurons, and 64 million synapses.

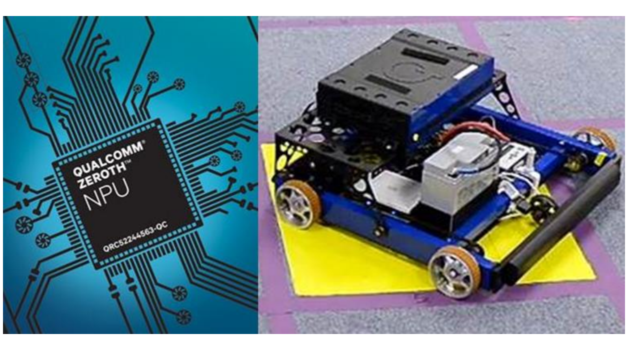

Figure 5: Qualcomm Neurochip and a robot using the chip (Neuro Bot).

systems will eventually impact every industry and every enterprise. They will significantly increase human productivity through assisting, advising, and extending the capabilities of humans.

Examples of some of the emerging cognitive engineering systems are given subsequently.

3.1 Cognitive Materials

Increasing interest has been shown in the development of cognitive material concepts through integrated sensing and intelligence (sensorial material concepts), beyond self-healing materials. The motivation for this work is drawn from biological systems [10, 11]. The goal is to develop a system that can inform engineers about how it is feeling, where it hurts, how it changed its shape, and what loads it is experiencing. Such materials are capable of real-time self-monitoring, as well as using information on their internal state to autonomously change major properties (including thermal, electrical and acoustical properties). The change in the internal state may not be predictable in the design phase, since it may occur during the service history of the component.

Structures using cognitive material systems will have the analog of a nervous system through the network of sensors and communication facilities that link them.

3.2 Cognitive (smart) Cameras

A cognitive camera can understand and interact with the surroundings, intelligently analyze complex scenes, and interact with the users. A prototype is being developed by a multidisciplinary team from Penn State and Stanford universities (Figure 6). The project is inspired by biological vision, particularly the human visual cortex, and builds on previous research at the University of Southern California, and M.I.T. A major goal of the project is to build a low-power cognitive devices that can replicate, and possibly exceed, the human vision in a wearable form. The prototype will have embedded computation, and does not need to be connected to the cloud (like Google glass).

Among the possible applications of cognitive cameras are warning distracted drivers, when they have taken their eyes off the road for a long period, and assisting the visually impaired.

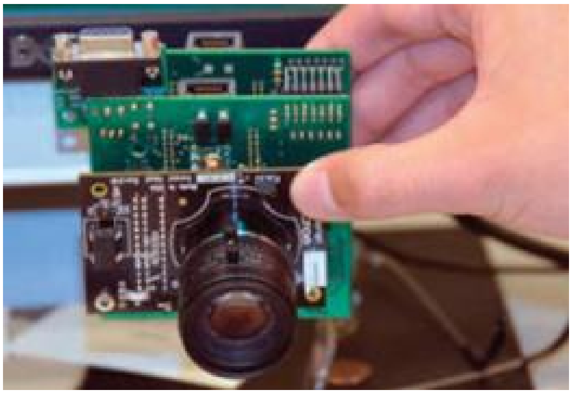

Figure 6: Cognitive Camera developed by a research team led by Penn State. The camera has an on-board computational power for intelligent video processing.

Figure 7: Myon the child-like cognitive robot developed by the Neuro Robotics group at Humboldt university.

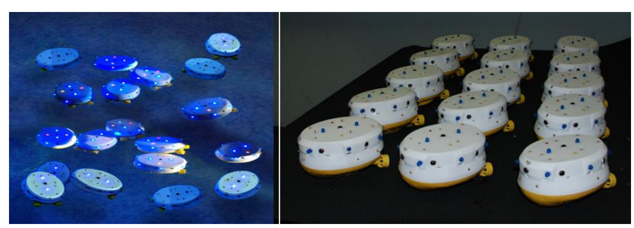

Figure 8: Collective Cognitive robots of the Artificial Life Laboratory of Graz, Austria. A swarm of autonomous underwater vehicles (AUVs) that are able to interact with each other and which can balance tasks (interactions between/within swarms).

3.3 Cognitive Robots

Significant work has been done in attempting to incorporate brain processing technologies into robots for better autonomy. The work was done under several titles, in addition to cognitive robots, including neurobiologically-inspired robots, neurorobots, and neuromorphic robots. Much of the work is being funded by DARPA and NSF in the US, the Human brain project in the European Union, and the Australian Research council.

As the interaction and cooperation of robots with humans increase, so does the demand for sophisticated robotic capabilities associated with deliberation and high-level cognitive functions. These include deep learning, on-time decision, robustness and adaptability. Future cognitive robots will be equipped with advanced perception, dexterity and manipulation to enable them to adapt to reason, act and perceive in changing, incompletely known, and unpredictable environments. These capabilities enable the robots to serve as effective human assistants or companions [12, 13].

An early generation of cognitive robots is the human-like robot Myon, developed by the Neurorobotics research lab of Humboldt University in Germany (Figure 7). All the body parts of Myon can be completely removed during the operation and flange-mounted again. The body parts retain their separate functionality because each one has its own energy supply and computational ability. The neural network is distributed over the decentralized robot.

A European consortium, led by the University of Graz and including both biological and technical institutions, is creating a swarm of cognitive, autonomous underwater robots (Figure 8). The goal of the project is to develop robotic vehicles that can interact with each other and cooperate in tasks. They could be used for biological monitoring, or for searching, maintaining, and even harvesting in underwater environments.

The swarm will need the robustness and stability to function under dynamically changing conditions. The vehicles will interact with each other and exchange information, resulting in a cognitive system that is aware of its environment, of local individual goals and threats, and of global swarm-level goals and threats.

As shown by natural swimming fish swarms, such mechanisms are flexible and scalable. The usage of cognition-generating algorithms can allow robots in the swarm to mimic each other's behavior and to learn from each other adequate reactions to environmental changes.

The plan includes investigating the emergence of artificial collective pre-consciousness, which leads to self-identification and further improvement of collective performance. In this way, several general principles of swarm-level cognition will be explored to assess their importance in real-world applications.
The results can be exploited for improving the robustness, flexibility, and efficiency of other technical applications in the field of information and computing technology.
In June 2014, the European Commission, along with 180 companies and research organizations (under the umbrella of euRobotics), launched the world's largest civilian research and innovation program in robotics. Covering manufacturing, agriculture, health, transport, civil security, and households, the initiative is called SPARC and aims at developing technologies including smart industrial robots, autonomous cars, and drones.
A cognitive / autonomous spherical robot concept has been proposed by IBM. The robot has multi-modal sensing, including image and sound, and could be deployed in a disaster area for search and rescue missions. An internal mechanism would allow it to roll around an environment to survey areas and identify persons in need, the condition of the zone and possible hazards. It could also communicate with people it finds and guide them to safety through speakers and a video display.

3.4 Cognitive Cars

Cognitive cars are equipped with integrated sensors, cameras, GPS navigation system and radar devices that provide coordinates and information gathered on the road to other cars, equipped with the same car-to-car communication system. Automakers and their research partners are currently working toward creating cars that think on behalf of drivers and passengers and act proactively, serving up infotainment and driver assistance features in anticipation of what's needed or wanted. The basic elements in every infotainment or telematics UI are a touchscreen display in the dashboard, voice recognition, control buttons or wheels on the steering wheel.
The new technologies are intended to serve and protect drivers and passengers, and ultimately render the human drivers superfluous. Driver assistance systems are laying the groundwork for autonomous (self-driving or driverless) cars.
The advanced technologies that make cognitive and self-driving cars have been filtering into commercial products at a fast rate [14, 15]. Some of the recent developments in driver assistance facilities, and driverless cars are described subsequently.

- GM introduced driver assist package into their 2012 Cadillac for detecting road hazards, and drawing the attention of the driver to them. The package uses long-range radar that scans for objects up to 150 meter away, short range radars, video and other cameras, ultrasonic sensors, a central embedded computer for processing information and identifying objects around the car.
- Texas Instruments has introduced a family of advanced driver assistance system devices (ADAS) that can implement a number of driving features, including pedestrian detection, emergency braking, traffic sign recognition, lane departure assistance, cross traffic alert adaptive cruise control, blind spot detection, high-beam and park assist.

Information from multiple cameras (front-facing, side, and rear), and various sensors are processed by the ADAS hardware simultaneously. The data then provides driver assistance for enhanced safety and driving. For example, headlights can be aimed and adjusted dynamically based on external driving conditions.

- Volvo began testing semiautonomous cars on city streets. By 2017, a fleet of 100 cars will be part of an experiment for autonomous handling of lane following, speed adaption, and merging traffic in the Swedish city of Gothenberg.
- A number of companies, including Audi, Mercedes, GM, and Nissan, are working on ways to automate the entire parking process. First , the car moves past a parking area, scanning for the marked edges of parking slots and for obstacles (such as parked vehicle). Different vantage points are provided by the several cameras and ultrasound sensors in the cars. The information is processed to classify the parking area according to its structure. Then the car moves to the next vantage point, and continues the process in order to offer a selection of possible parking slots.
- GM is working on crash-proof (crash-avoiding) car concept. The concept relies on the use of active safety systems, instead of the passive safety features used in modern cars (including air bags, and frames that absorb the impact to protect the occupants during crash). The active safety systems use, in addition to the passive safety tools, visual alerts, loud sound, and seat vibrations to alert the driver to imminent danger (e.g., approaching cross traffic).

Figure 9: Google's two-seater self-driving car prototype eliminates steering wheel, accelerator and brake pedals.

– Nissan recently unveiled its neuro car concept- a car equipped with a Nismo smart watch that can monitor a driver's biometric information. Nippon Sangyo (Japan Industries) plans to monitor not just the car but also the drivers' vital signs, including brainwave activity and skin temperature. The company plans to use electrocardiograms (ECG) and electroencephalograms (EEG) in the future to capture a range of heart and brainwave data of the driver.

The watch and car will be in constant communication, the car can update the driver via his watch whenever it needs an oil change or its tires rotated. It will remind the driver when it needs to be serviced.

Since it is impossible to plan ahead for every single scenario that an autonomous car might have to handle, one of the key requirements of autonomous (self-driving) cars is to have cognitive capabilities (being able to learn and make decisions on the fly). Recent self-driving car activities include o Google self-driving cars, which in April 2014 have surpassed 700,000 autonomous accident-free miles. This was done by improving the software that can detect hundreds of distinct objects simultaneously. The self-driving cars can ingest massive amounts of data in a very short amount of time, explore multiple scenarios, and eventually run simulations to insure that their decision are as safe as possible. The cars pay attention to pedestrians, buses, stop signs, and a cyclist making gestures that indicate a possible turn, in a way that a human driver cannot, and they never get tired or distracted. The cars can deal with changing environments and some level of dynamic uncertainty. The fully autonomous, two-seater electric car prototype, recently unveiled by Google, with the steering wheel, accelerator and brake pedals eliminated. The cars can go up to 25 mph. Google is building about 100 prototypes of this sort and plans to conduct tests in versions that retain the manual controls later this summer (Figure 9).

o A new autopilot tool, Cruise RP-1, to enable hands free driving on highways has recently been advertised. The tool, which is slated for use in California starting in 2015, can be fitted for nearly any vehicle. It includes two cameras, a radar mechanism, GPS, inertial sensors and an onboard computer, as well as actuators that control the car's steering, acceleration and braking actions. Using this software/hardware combination, the Cruise RP-1 constantly scans the road to keep the car operating within safe parameters in relation to other cars and the boundaries of the driving environment.

3.5 Cognitive Aircraft / Unmanned Aerial Vehicles (UAVs)

A paradigm shift is taking place in the design of UAVs – from automated to autonomous and cognitive UAVs. Whereas automated UAVs have deterministic, or pre-determined behavior, and are controlled by humans, cognitive UAVs make decisions that involve non-deterministic, stochastic, and emergent behavior. They behave in ways that are not pre-planned and preprogrammed.

In August 2014, BAE Systems has unveiled four futuristic technologies they believe could be incorporated in military and civil aircraft in 2040 or even earlier. The four technologies are autonomous UAVs, aircraft parts that can heal themselves in minutes - called the Survivor, a new type of long-range aircraft which divides into a number of smaller aircraft when it reaches its destination, dubbed the Transformer, and a directed energy weapon that could engage missiles at the speed of light, destroy them, and protect the people on the ground.

The Survivor is a lightweight adhesive fluid built inside the aircraft which allows jets to quickly heal themselves from damage sustained in flight. It is released to quickly 'set' in mid-flight and heal any damage.

The Transformer is a flexible aircraft system that combines smaller jets for more efficient travel, before having them split apart to quickly adapt to any scenario. BAE researchers feel that by combining the jets on longer journey there could be potential gains to be made in terms of increased range and fuel savings by cutting the amount of drag, scientists claim. All the four technologies are still at the drawing-board stage, but BAE Systems is confident about the prospects of them becoming a reality.

3.6 Cognitive Production Systems

Today's manufacturing is facing many challenges, including uncertainties of continuously and unprecedented abrupt-changes in market demands, increasing number of product variants, smaller lot sizes, enhancement of product quality, increasingly shorter time-to-market, and low cost production requirements. Manufacturing value chains are distributed and dependent on complex information and material flow requiring new approaches inside and outside the factory both on process and product lifecycle levels. They have to respond faster and more efficiently to higher complexity and frequently changing designs. Cognitive production systems concepts, including cognitive machines and processes and cognitive factories, can be applied to address some of challenges [16]. This is accomplished through applying the principles of cognition into every aspect of industrial production – from design to final assembly and quality control, and potentially to the end of the product life cycle.

The cognitive capability in production systems can be accomplished through the development of cognitive reasoning engines, or distributed intelligence agents, that are deployed throughout the production system at three different hierarchical levels: a) the manufacturing process level, b) the manufacturing system level, or factory level, and c) the production system logistical level, or supply chain level.

Actions must include validation/demonstration elements and involve stakeholders covering the whole value chain. In addition, mobile transportation robots are used to enable flexible routing – A team of robots can produce new products from a number of semi-finished products.

Researchers at Harvard and MIT have recently build a robot that assembles itself into a complex shape in four minutes flat, and crawls away without any human intervention. The advance, demonstrates the potential to quickly and cheaply build sophisticated machines that interact with the environment, and to automate much of the design and assembly process. The method draws inspiration from self-assembly in nature, such as the way linear sequences of amino acids fold into complex proteins with sophisticated functions.

Among the possible applications of this concept is that of a swarm of robotic satellites sandwiched together so that they could be sent up to space and then assemble themselves remotely once they get there-they could take images, collect data, and more. The concept is complementary to 3D printing, which also holds great promise for quickly and inexpensively manufacturing robotic components. The longer term could be changing the way we think about manufacturing in that the machines fabricate themselves. For example, cognitive 3D printers could receive data and automatically design and build bespoke products to meet individual demands.

Cognitive machines could improve their performance and develop new capabilities through mining data and applying learning algorithms that are specific to their applications. They could also exchange information with other systems and provide updates to higher-level control system, helping to create more efficient and flexible factories. Within all of this, the cognitive machines would remain aware of their capacities, as well as their limitations. Cognitive manufacturing is characterized by capabilities and visions for moving beyond "smart" manufacturing toward cognitive factories and systems that have the capacity to monitor and evaluate manufacturing performance and then propose process and operations improvements based on using sensing technologies and multifaceted data for real-time observation of human workers in industrial organizations to increase the understanding of human cognitive processes and transfer this knowledge to cognitive factories.

Cognitive factories are industrial autonomous systems that introduce artificial cognitive capabilities to the dynamic allocation of production services, and the control of production systems in order to overcome today's boundaries [17]. These include autonomous machining, automated programming of industrial robots, human –robot-cooperation, knowledge –based quality assurance and process control. The use of cognitive factories has the potential of enhancing the adaptivity of production systems, as well as the quality of products.

3.7 Cognitive Wireless Technologies

Cognitive (or smart) radio networks like xMax system of xG technology, Inc. represents an innovative approach to wireless engineering in which radios are designed with an unprecedented level of intelligence and agility. It enables more efficient use of scarce expensive wireless spectrum though using a number of technologies, including dynamic spectrum access (DSA), interference mitigation, full mobile handoff and software defined radio (SDR) capabilities [18].

Cognitive radios have the ability to monitor, sense, and detect the conditions of their operating environment, and dynamically reconfigure their own characteristics to best match those conditions [19].

They automatically detect available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. They provide a smarter, faster, and more efficient way to transmit information to and from fixed, mobile, other wireless communication devices. They have significantly improved the wireless communication performances, in a cost effective way, by exploiting underutilized licensed bands

3.8 Cognitive Flight systems, Airspace Systems, and other infrastructures

Cognitive Flight and aerospace systems are examples of cognitive socio-technical systems, which attempt to amplify the human capability in performing cognitive work through integrating the technical functions with the human cognitive processes [20, 21]. Other examples include healthcare systems, energy, transportation and other large scale infrastructures.

The issues addressed in socio-technical systems include decision making in complex and dynamic information environments, distributed collaboration, and management of extensively networked systems. For example, cognitive energy grids use variety of technologies in conjunction with big data to anticipate and smoothly meet the rapidly changing needs of different load centers distributed around the grid. They intelligently source and allocate energy from renewable sources (like solar, wind and hydro), and non-renewable sources, as required to ensure smooth and reliable delivery.

3.8.1 Cognitive / smart data for flight systems

Among the recent activities on cognitive technologies for socio-technical systems is the work on "cognitive / smart data" technologies by researchers at the Rensselaer Polytechnic Institute. The work is funded by the Air Force Office of Scientific Research, and aims at turning passive data systems into active ones by enabling them to search for patterns and relationships, discover knowledge in data streams, as well as incorrect data generated by faulty sensors, or other hardware failures, such as those that contributed to the Air France 447 crash in June 1st, 2009. During that flight, important sensors failed, and reported erroneous airspeed data. But the autopilot didn't know that, and it acted as if the data were correct.

The smart data system uses mathematical and programming elements that searches for patterns and relationships that indicate hardware failure. Active data has been incorporated into a software system called the "Programming Language for spatiO-Temporal data Streaming applications," or "PILOTS," which treats air speed, ground speed and wind speed as data streams that sometimes exhibit errors that can be automatically corrected and reproduced so that the pilot receives the correct readings and can adjust accordingly.

In addition to its benefits in making flight systems safer, smart analytics could also be helpful in other applications that rely on sensors, such as healthcare. Analyzing the patterns of data collected from sensors attached to the human body could detect, ahead of time, early signs of seizures or heart attacks.

3.8.2 Cognitive Airspace System

The airspace is a distributed and heterogeneous system comprising diverse human and technological functions. Enhancing the effectiveness of air traffic control and management, and extension of the airspace system to handle UAVs, requires equipping the facilities and resources in the system with cognitive capabilities.

Modernization of air traffic management is already under way. The new systems envisioned in Europe and the U.S. would begin automating a pilot's tasks even before submission of a flight plan. From a hotel room, hours before a flight, the pilot could plug an electronic flight planner into a tablet computer, automatically linking to the plane's flight management system and the FAA air traffic network center. He could choose one of several routes, from the fastest to the least expensive. He would receive weather information, including the wind's speed and direction. Within seconds, an optimal route would be calculated and a touchdown time determined, accurate to within two seconds. Two out of three flights would be flown automatically: A plane's own systems, linked to the airline's operations and FAA computers, would operate the aircraft, from the closing to the opening of the passenger cabin doors. Schedule disruptions caused by late passengers or sudden changes in weather would be managed by the networked computer systems, with the pilot alerted to the changes. Very rarely would a pilot have to intervene during an automatic flight, and usually only because the network offers faster or more fuel-efficient routing.

It is somewhat clear what the key enabling technologies and procedures will be, how much they will cost to introduce and what benefits they will bring. However, what is less clear is how the global network will be able to operate when parts of it are degraded, how soon all aircraft operators will adopt compliant technologies, how controllers will accept their changing roles, and how a global net-centric traffic management system will be regulated and certified.

Although significant technological advances have been made by the Unmanned Aerial System (UAS) community, critical research is needed to fully understand the impact of UAS operations in the National Air Space (NAS). There has also been little research to support the equipment design necessary for UAS airworthiness certification. In the near- to mid-term, UAS research will need to focus on technology deemed necessary for UAS access to the NAS.

4 Emerging Cognitive technologies and Environments

4.1 Cognitive Interfaces

The next phase of user interface architecture is multisensory and multimodal, so the machine is capable of recognizing a gesture while interpreting the user's voice simultaneously. Some of the recent work is devoted to creating machines that has pattern and object recognition capabilities, and can think on behalf of their users and act proactively, serving as user assistance features in anticipation of what's needed or wanted.

Future user interfaces and human machine interface systems are likely to be deceptively simple, yet so pioneering they could easily pass for special effects in a science fiction film—including neural interfaces, steering wheel sensors in cars capable of reading a driver's mind and touchscreens that morph into physical buttons and switches.

Cognitive interfaces will allow new decision-making experiences, such as making a critical maintenance decision on a gas pipeline. The power of these decision spaces is that they give users real insights, not just information; by providing valuable insight, users are one step closer to taking action.

4.2 Cognitive Assistants (Cogs)

Since the beginning of the 21st century, a number of AI activities were devoted to developing intelligent personal assistants (beyond Question / Answering systems). Among these activities is the large AI project funded by DARPA-the Personalized Assistant that Learns (PAL) program. The Cognitive Assistant that Learns and Organizes (CALO) project led by SRI was part of this program. A number of personal assistants on mobile devices resulted from CALO, including Apple's Siri, Google Now, Dragon Mobile Assistant, Nina Mobile, and Microsoft Cortana.

Recently, the creators of Siri, have announced a smart assistant successor Viv (the global brain), that is currently being developed and which can recognize the user's personal preferences and a near-infinite web of connections to answer almost any query and perform almost any function. Google is working on a more ambitious cognitive assistant called the "Google Brain" that melds computer science with neuroscience.

Emerging cognitive assistants are proactive autonomous agent systems (Cogs), a class of more advanced software programs, which are designed to follow and interact with people (and other cogs and services) inside and across cognitive environments. Cogs use cognitive analytics to process natural language and do pattern recognition.

4.3 Cognitive Environment

Research on cognitive environments is moving from overcoming physical, connectivity limitations to overcoming productivity and complexity limitations through enhanced cognition [22]. Among the recent developments are integrated sensor system for environmental and user activity monitoring, wearable technologies (including, annotated-reality glasses), advanced telepresence and visualization facilities, tools for reducing cognitive load, and Symbiotic cognitive systems incorporating Cogs.

Future cognitive environments will include learning and training facilities which can predict performance and learning needs, and distributed healthcare networks that could draw on vast quantities of medical data to help physicians in providing the right treatment to patients with unusual conditions.

4.4 Cognitive enterprise

Future enterprises will have cognitive environments, incorporating variety of cognitive assistants and cognitive tools and facilities. Their workforce will be engaged in complex applications requiring in-depth data analysis and adaptability. The algorithms used in these applications will be very hard to design and require processing extensive and complex big data sets (using big data predictive and prescriptive analytics).

5 A look at the future

Cognitive computing is a transformative area of computing, and a major driver for knowledge automation work,

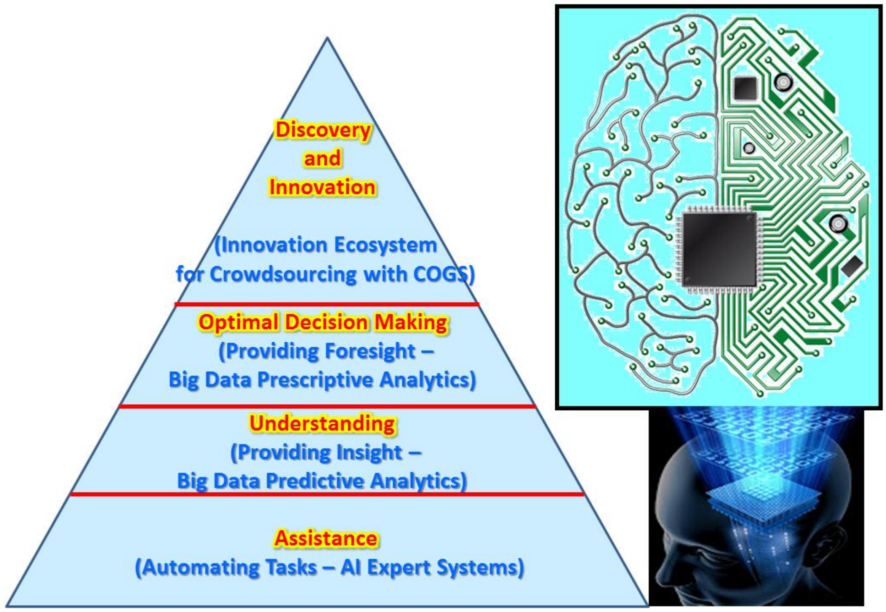

Figure 10: Augmenting and Amplifying human capability through cognitive computing and cognitive technologies.

both as an emerging enterprise disruptor, and future cognitive enterprise enabler. The confluence of Cognitive technologies with technologies such as cloud, mobile, wearable devices, Internet of Things (IOT), big data and visual analytics will amplify their impact. A new generation of cognitive devices, facilities and systems will be developed. The coming years will witness the infusion of cognitive technologies, devices, tools, facilities into decision support systems, engineering processes, practices and systems. Humans and machines will be working together to amplify human capabilities, particularly those associated with insight, finding relevant patterns in dynamic big data, making optimal choices, and discovery of new generation of cognitive products ([23, 24], and Figure 10). A radical shift in engineering software and engineering practice will occur. Engineers will use generic cognitive assistants (cogs) to build customized cogs for various applications (such as modeling, simulation, and knowledge capture and representation in product design).
The field of Cognitive product engineering will be developed as a new procedural paradigm, and a framework, for describing, designing, manufacturing, operating, and servicing cognitive products [25]. It will incorporate deep learning, predictive and prescriptive analytics, emergent engineering concepts, adaptive multimodal human-machine interfaces, along with other visuo-spatial cognition, computational and collaboration tools to enable symbiotic interaction with the environment, drive innovation, flexibility, and cost reduction.
The new products will have higher level of intelligence than current smart products, and include cognitive cyber-physical systems, with embedded intelligence, mechatronic and adaptronic components, that can monitor their own state, and are able to self-configure, self-optimize, self-protect, and self-heal. They will be able to communicate with other cognitive products.

6 Concluding remarks

In this paper a brief review is given of cognitive computing and some of the cognitive engineering systems activities. The potential of cognitive technologies is outlined, along with a brief description of future cognitive environments, incorporating cognitive assistants - specialized proactive intelligent software agents designed to follow and interact with humans and other cognitive assistants across the environments. The cognitive assistants engage, individually or collectively, with humans through a combination of adaptive multimodal interfaces, and advanced visualization and navigation techniques.
Cognitive computing, technologies and systems are a passage through a world yet to be imagined, and future developments in these areas will continue to push the limit of what is possible. Planned and future activities include

neuromorphic chips that monitor the performance of engineering systems (using data generated by variety of sensors) and provide early warnings of potential problems, and suggest possible remedial actions; cognitive systems which use image and speech recognition as their eyes and ears to recognize patterns, understand their environment, and interact more seamlessly with humans; cognitive products that are capable of knowing their operational environments and can act autonomously; and smart cities that can optimize their infrastructures, networks and other facilities.

A holistic perspective and a comprehensive strategy are needed to develop the discipline of cognitive engineering and to put its various activities on an ambitious trajectory that pushes the frontiers of innovation, discovery, and economic development. A step toward implementation of that strategy is the development of a cognitive innovation ecosystem for the engineering workforce. The continuously expanding major components of the ecosystem include integrated knowledge discovery and exploitation facilities (incorporating predictive and prescriptive big data analytics); novel cognitive modeling and visual simulation facilities; cognitive multimodal interfaces; and cognitive mobile and wearable devices. The ecosystem will provide timely, engaging, personalized / collaborative, learning and effective decision making. It will stimulate creativity and innovation, and prepare the participants to work in future cognitive enterprises and develop new cognitive products of increasing complexity.

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