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Abstract

This paper reports on enhancing cognition through the co-evolving developments of (1) genetic engineering and, (2) unawareables (in-the-body processors). Biological approaches for improving intelligence are: (a) gene modification using tools such as CRISPR and, (b) iterated embryonic selection.* Indirect intelligence amplification will be realized through (a) implantable bioengineered devices: (i) brain-machine interface prosthetics, (ii) embedded synthetic DNA constructs and, (iii) neural nanotechnology. Within the next 20 years, increased human intelligence will lead to a distinct demographic, where discrete populations will be benefactors and others will lag behind, creating social tension and geopolitical competition for the best technology as a means for maintaining intelligence parity with other countries.[1]

Keywords- Genetic editing, CRISPR, IES, IVF, technology law, science policy, evolution, human enhancement, transhuman, artificial intelligence, telemetry, molecular computer, unawareable, in-the-body technology, synthetic DNA, IQ, neuralnanorobots, brain-machine interface, brain/cloud interface, brain-computer interface, brain-to-brain interface, technology ethics.

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* Clustered Regularly InterSpaced Palindromic Repeats (CRISPR/Cas9) is a breakthrough technology enabling the correction of errors in the genome. With CRISPR scientists can alter gene composition, as well as turn them on or off, cheaply and with relative ease, potentially curing or preventing the effects of viruses, cancers, birth defects, and other genetic conditions. (See What is CRISPR/Cas9? https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4975809).

Introduction

Many species exhibit extraordinary abilities in applying know-how, but only humans engage in complex thought that leads to new fields of science, inventions, mathematics, or functional languages under the rubric "software." Our thought-based behaviors produce useful products and processes, but also solutions to illnesses, injustices and safeguarding national defense. The drive to solve problems coupled with our passion for the humanities has contributed to a thriving and complex civilization, one where a most valued feature centers around "intelligence," which manifests in a variety of ways, not the least which fuels an exponential rate of technological development. Ironically, as we ascend into the future, technological progress and improved intelligence will coexist in a sympathetic oscillation, each amplifying an ever compounding effect on the other.

For centuries nations have recognized that skill and education are highly valued, given their effect on trade and standards of living. The aligned value of intelligence serves to realize this objective, and thus nations will undoubtedly support policies and initiatives directed toward innovation in artificial intelligence, machine intelligence and means to enhanced human brainpower, either through alteration of genes that express for intelligence or via direct connection to the brain, either through physical attached peripherals or anatomically internalized products. [*, 2, 3] Although some of these advances may lag or lead during the course of the next 20 years, sufficient progress will be made in this sector demanding consideration of how to deal with what may prove socially destabilizing developments throughout the world.[4]

Understanding the broad outlines of what constitutes the pertinent technology of 2020, helps to put the state of Warfare 2040 into its proper perspective. Thus this paper focuses on co-evolving technological paths related largely to genetic enhancement, neural adjuncts in the form of nanotechnology, and neural interfaces, each of which stands to dramatically impact human intelligence up to and beyond the year 2040.[†,5]

Big Data Constructs

For decades data bases have been collecting information on academic achievement, psychological testing (e.g. IQ), life expectancy, encounters with the government acquired through census data and military service, and information related to consumption, insurance,

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[*] By the weight of authority, "median estimates," predict that human level machine intelligence (HLMI) will come to fruition in the next 55 to 60 years, based on a spread of estimates that vary from 10 years to over a century. Futurists Vernor Vinge and Ben Goertzel put it in the relative short term, i.e., 2025-2030 timeframe, whereas Ray Kurzweil puts the arrival time in the vicinity of mid-century as does Nils Nilsson;.See, https://futurism.com/kurzweil-claims-that-the-singularity-will-happen-by-2045/; See, Bostrom, N, (2014), Superintelligence, Paths, Dangers and Strategies, p. 22-23, Oxford University Press.

[†] Intellectual enhancements may also be achieved using other technologies, or combination of technologies such as psychopharmacology, advanced information management tools, memory enhancing drugs, and cognitive influencing products and processes such as augmented and virtual reality. These are not addressed here.

and medical interventions. These records are consolidated and used by businesses, institutions, and government for planning, organizing and decision making relative to academic trends, healthcare objectives, and other social purposes. Big Data has become, and will remain for the foreseeable future, a primary resource, where population statistics, the information for enhancing human performance, resides.

Genetic- based Intelligence

Big Data includes genome-wide association studies (GWAS) that are being used to discover genetic links, not only to a variety of health disorders or birth defects, but to the heritability of personality and other traits, such as intelligence.[6]

Intelligence may be defined as the competency of a system, including a biological system, to adapt its behavior to meet goals in a range of environments.[7, 8] As related to humans, an intelligence quotient, popularly known as IQ, has developed from standardized testing of abstract-reasoning, arithmetic, vocabulary, and general knowledge. [*] IQ as a refined concept relates to Spearman g-factors, or mental abilities such as: fluid intelligence (Gf), crystallized intelligence (Gc), visuospatial processing (Gv), working memory (Gwm) and quantitative reasoning (Gq).[†,9] Variations in individual g-factors range from brain size and density to the synchrony of neural activity and overall connectivity within the cortex. Nonetheless, a multiplicity of different genes undoubtedly affect each of these features, as well.

Genotyping on a large scale coupled with Big Data analytics adds to the power of GWAS initiatives, thus allowing scientists to compare DNA gene sequences and their associations with disease and other traits, such as intelligence. Using this data, an aim of cognitive neuroscientists and geneticists has been to investigate gene sequences that determine the genetic codes determinative of mental disease and to identify those genes implicated in the expression of intelligence.[10,11] Given that intelligence or IQ has been shown to have a high degree of heritability, it is likely that governments, commercial interests and individuals will pursue objectives that lead to the enhancement of human intellect between the present and year 2040.[12]

GWAS initiatives have identified genomic loci linked to variation in intelligence.[13,14,15] For example, in 2017, a meta-analysis of intelligence involving 78,308 individuals reported associations between intelligence and specific genes.[16] It identified 336 single-nucleotide polymorphisms ((SNPs) in 18 genomic loci, of which 15 had not previously been discovered. Overall the SNPs accounted for a non-negligible 5% difference in intelligence. Since in children, the heritability of intelligence is 0.45, and rises to 0.75 for

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[*] IQ scores have a normal distribution with a mean of 100 and a standard deviation of 15; 50 percent of individuals score above 100, and 50 percent score below 100. The average IQ is 85 to 114, and 68 percent fall into this range. Only 16 percent have scores of 85 or lower, and 14 percent have scores between 115 and 129. The top two percent of individuals have IQ scores between 130 and 145; these scores are higher than 98 percent of the population. IQ scores over 145 indicate the top 0.1 percent.

[†] I list five of ten broad categories of g, which can be subdivided into seventy more narrow abilities.

late adolescents and adults, scientists have a way to go to identify the genes that fully account for the known levels of heritability.[17]

GWAS data and multifactorial polygenic scoring thus far indicates that intelligence improvement traits will depend on multiple genes, each having only small effects.[*,18,19] Polygenic scoring puts the matter of improving IQ through gene manipulation into what may be a longer term realizable objective. The effort to discover a 5% difference in intelligence took about 3 years, so it would seem plausible that significant progress will be forth coming during the next 20 years.

Embryo Screening for Intelligence

Direct genetic modification presents but one option for enhancing intelligence, one of which because the various intelligence traits as defined by IQ are all likely polygenetic, will take several years, but likely not longer than a generation. A proposed offshoot of in vitro fertilization (IVF) technology uses stem cell-derived gametes and iterates embryo selection (IES), which promises to accelerate enhanced intelligence. This appears to be a quicker solution to increasing intellect based on utilizing embryos selected for the collection of prescribe genes that are known to express intelligence traits, and then using stem cells from these embryos to produce gametes. In essence, the selected gametes would in turn produce embryos, which would be used to repeat the process, until the desired level of specific intelligence was likely reached. Such a scheme was first proposed by Robert Sparrow in 2013, by using stem cell-derived gametes, understood here as gametes or gamete-like cells created in the laboratory from human pluripotent stem cells.[20] More particularly, egg and sperm cells would first be created from existing or pluripotent stem cell lines. The eggs would be fertilized using the sperm to create zygotes and finally embryos. Embryonic stem cells would then be harvested, from these embryos to create new egg and sperm cells, to be used to fertilize one another in creating additional embryos.

Shulman and Bostrom, from the Future of Humanity Institute, Oxford University, claim that IES, through the compression of multiple generational selections, will lead to improved IQ given that expanses in IQ gain will depend on the number of embryos used in selection.[21] For example, a 1 in 2 embryo selection protocol would yield a 4.2 point IQ gain, and 1 in 10 embryo selection would result in an 11.5 point gain. Over five generations, a 1 in 10 embryo selection protocol would max out at a 65 point gain, due to diminishing returns; and a 10 generation protocol would likewise max out at a 130 point gain. It is plausible that during the next generation we might see enhanced intelligence within a relatively unconstrained society. Assuming a low end effect produced by a 1 in 2 embryo selection, it would add a modest 4.2 point IQ gain, which if sufficiently widespread for any population could remarkably empower human capital.

[*] If an SNP association is found for IQ on the order of 0.01 % (i.e., a .01 change in the average IQ of 100), it means that to account for heritability in the 50% range, theoretically requires at least 5,000 SNPs be found to show the sought after trait. Some traits are well below 0.01 %, by orders of magnitude, and therefore require enormous numbers of associations.

Mapping the Brain

Other than gene therapy or IES, enhancing intelligence will co-evolve with novel prosthetics, which improve neurological features, such as increasing one's memory storage capacity, speed of mental calculation, or sensory acuity. Brain imaging technology is essential in understanding how the brain works.[*]

Brain imaging assists in the identification of genes and tissue structure associated with intelligence. In 2018, a group of scientists reported a study where 1,475 adolescents, part of the IMaging and GENetics (IMAGEN) sample, showed that general IQ (gIQ) is associated with (1) polygenic scores for intelligence, (2) epigenetic modification of DRD2 gene, (3) gray matter density in striatum, and (4) functional striatal activation elicited by temporarily surprising reward-predicting cues.[22]Studies such as these inform scientists where to direct their efforts, some of which will implicate biochemistry and others will involve brain mapping.

It's theorized that the steady increase of *Homo sapiens*' productive output is due to an increase in the number of cortical connections during evolution. [23] Following along these lines, scientists have embarked on various projects to map neuronal circuits, called connectomes. By the mid-1970s researchers already had mapped the connectivity of all 302 neurons or the full atlas for the roundworm *Caenorhabditis elegans.*[†, 24] Since then, a partial connectome of a mouse retina and mouse primary visual cortex have also been reported. Along similar lines, a complete 3D connectome of a portion of the central brain (referred to as the hemibrain) of the fruit fly Drosophila melanogaster was reported in October 2019.[25] The reconstruction comprised 25,000 neurons and 20 million synapses, the largest synaptic-level connectome model to date, of a large fraction of the fruit fly's brain.

When the human brain has been completely mapped it will involve over 80 billion (10^9) neurons and over a quadrillion (10^{14}) connections. As pertains to human intelligence, brain maps will shed additional light on the heritability of cognition, such as computation, visual acuity and linguistic skills. Efforts also are proceeding apace as witnessed by the large numbers of scientists working to advance the *in silico* simulation of the mammalian brain.

Brain Modeling

Through the structural emulation of the biological brain, intelligent software is believed to be achievable through uploading the brain's process to a computer. Termed Whole Brain Emulation (WBE), it has the potential to aid the further development of novel

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[*] For several decades neuroscientists and others in the medical profession have been studying the brain using instruments, such as the electroencephalograph (EEG) and those which permit imaging: magnetic resonant imaging (MRI), positron emission tomography (PET), functional MRI (fMRI), diffusion tensor imaging (DTI).

[†] C. elegans was the first multicellular eukaryotic organism to have its genome sequenced (C. elegans Sequencing Consortium, 1998).

computer architectures. These designs will advance computer technology from the classic von Neumann constructs, i.e., separate memory and computation/logical processing domains to paradigms that incorporate both memory and processing into an integrated whole. The subject of WBE is vast, taking one into discussions about artificial general intelligence. For our purposes, brain modeling, rather than WBE is intrinsically useful as a vehicle to further inform neuroscientists of brain features and improve our knowledge to move toward cognitive prosthetics for enhancing human intelligence.

Specially configured supercomputers tasked with modeling cognitive processes, have the dual purpose of better understanding how we think, but also bringing us closer to WBE.[26] The rate of progress will in part depend on the continued success of semiconductor miniaturization, which appears to be slowing, as transistor size reaches into the single digit nanometer domain.[*,27] Computer technology mileposts are being achieved at increasing rates, which will continue to advance the science of brain emulation.[†] For example, Intel claims its Intel Stratix 10 FPGAs are capable of 10 teraflops (10^{13}). It contains about 30 billion transistors. Semiconductor technology soon will commonly use 11 nm, shrinking to below 2 nm technology, and incorporating fifty-cores allowing 100 simultaneous hyper-threads. Transistors, but a few atoms wide, will populate state-of-the art processors housing upwards of 13 billion transistors. Additionally, manufacturers are producing new processors and memory to incorporate greater numbers of cores, as well as vertical, 3-D architectures.[‡]

Coming ever closer to integrating computers into the brain, scientists working at IBM's SyNAPSE in 2014 created the world's most advanced neuromorphic (brain-like) computer chip to date. Funded by DARPA, the chip combines the functions of both the left and right sides of the human brain to create a "holistic computing intelligence." It consists of one-million programmable neurons and 256 million programmable synapses, across 4,096 individual neurosynaptic cores. Built on Samsung's 28 nm process, it contains 5.4 billion transistor count, it remains incredibly efficient consuming 72 milliwatts power at loads that equate to 400 billion synaptic operations per second, per watt —176,000 times more efficient than a modern CPU running the same brain-like capacity."[28]

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[*] According to Moore's law, the number of transistors incorporated into integrated circuits double approximately every 24 months, which implies that computing power doubles as well, but a strong consensus among experts is that we are reaching a physical boundary limitation between 2022 and 2029. In semiconductor manufacturing, the 3 nm process is the next die shrink after the 5 nm MOSFET technology node. As of 2019, Samsung and TSMC have announced plans to put a 3 nm semiconductor node into commercial production. It is based on GAAFET (gate-all-around field-effect transistor) technology, a type of multi-gate MOSFET technology. In December 2019, Intel announced plans for 1.4 nm production in 2029. Wikipedia.

[†] Researchers estimate that it would require at least a machine with a computational capacity of 36.8 petaflops (a petaflop is a thousand trillion floating point operations per second) and a memory capacity of 3.2 petabytes, to fully replicate the human brain.

[‡] In 2017, Samsung Electronics combined 3D IC stacking with its 3D V-NAND technology (based on charge trap flash technology), manufacturing its 512 GB flash memory chip with eight stacked 64-layer V-NAND chips. In 2019, Samsung produced a 1 TB flash chip with 16 stacked V-NAND dies. As of 2018, Intel is considering the use of 3D ICs to improve performance. As of April 2019, memory devices with 96-layer chips can be bought from more than one manufacturer; with Toshiba having made 96-layer devices in 2018. See, Three-dimensional integrated circuit, Wikipedia.

In 2018, Hewlett Packard Enterprise announced that it had been chosen by EPFL Blue Brain Project to build a next-generation supercomputer for the modeling and simulation of the mammalian brain.* The National Institute of Mental Health has funded a multidisciplinary team of investigators across 15 research institutes, referred to as the PsychENCODE Consortium, to create an integrative atlas of the human brain by analyzing transcriptomic, epigenomic, and genomic data of postmortem adult and developing brains, at both the tissue and single-cells, across 2,000 samples. The requisite enabling technologies for a fully operational human WBE may not be realizable until about mid-century according to most experts.[29]

IBM's Blue Brain Project moves in another direction, using supercomputers programmed to simulate neural micro-circuits having neocortical column functionality, to achieve a greater understanding of its composition, density, and distribution of the numerous cortical cell types.[30] The density of each cell type and the volume of the occupied space provide clues for cell positioning and constructing the cortical circuits. These studies have led to the construction of models of neuromodulators to analyze different forms of plasticity, gap-junctions, the neuro-vascular glia system, and coupling of these bio-artifacts to neuro-robotic systems, which in the long run will assist in the simulation of perception, cognition and behavior. To this end, scientists have been collecting data on the neuron morphology and electrical behavior of the juvenile laboratory rat for years. The project in 2015 reported that it sought to simulate a rat's brain, which contains over 100 million neurons and one trillion synapses.[31]

Modeling the human brain provides scientists with a better appreciation of how a brain might function, but other projects underway are more in line with the subject of this paper, such as prosthetics that aide human intelligence directly. Key to success is interfacing electronic and biological artifacts to the brain's neurological system.

Brain/Computer Interface

In 2001, a U.S. government sponsored team headed by Theodore Berger, conducted experiments using an implantable biomimetic electronic device installed into a rat's hippocampus, where they succeeded in replicating the pattern of interaction between two subregions of the hippocampus, CA1 and CA3. [32] The experiment provided for a better understanding of the interface and functional requirements for a brain prosthetic, whether employed for enhancement or therapeutic effect.

In 2002, a microchip was implanted into a chimpanzee giving it control over a neuro-motor, allowing the chimp to move a computer cursor using its thoughts.[33] In 2005, a tetraplegic became the first person to control an artificial hand using a brain-computer-interface as part of the first nine-month human trial of Cyberkinetics Neurotechnology's 96-

* The Blue Brain, research initiative, aims to create a digital reconstruction of the brain by reverse-engineering mammalian brain circuitry. It was founded in May 2005, by the Brain and Mind Institute of the École Polytechnique Fédérale de Lausanne (EPFL).

electrode BrainGate-chip-implant. The chip implant, installed in the patient's right precentral gyrus (area of the motor cortex for arm movement), allowed the individual to control a robotic arm by thinking about moving his hand to control a computer cursor, lights, and a TV.[34]

In 2007, Duke University Center for Neuroengineering in North Carolina recorded the activity of more than 200 cortical neurons in a rhesus monkey as it walked a treadmill. It transmitted via the Internet the corresponding signals to a robotics laboratory in Japan, whereupon in receiving the transmission, a robot mimicked the monkey's walk. In 2012, a 58-year-old paralytic unable to move her arms or legs, sipped a cinnamon latte with the help of a mind-controlled robotic arm and an implanted sensor. The device, about the size of an 80 mg aspirin, bypassed and replaced nerve circuits. Also in 2012, two tetraplegic individuals, had nearly 100 electrodes implanted in their motor cortex, which allowed them to guide a robotic arm and grasp objects using their thoughts.[35,36]

Scientists are prototyping cortical prostheses that mimic the brain's natural patterns in the information encoding phase of learning and memory. Today, cortical prostheses can 1) monitor input patterns to the hippocampus, during the information encoding phase, 2) predict associated hippocampal output patterns and 3) deliver stimulated electrical pulses, during the same phase of the task in a pattern that conforms to the normal firing of the hippocampal output region. The utility of cortical prosthetics is established by their capacity to substitute encoding stimulation, when for example, a hippocampal ensemble cannot generate the necessary codes to successfully perform memory functionality. [37]

Commercial entities are currently developing entirely implantable wireless systems that utilize feedthrough pins to an intracortical neural recording microelectrode array. The implications for BMI are enormous, as it leads to the possibility that in the future, it may allow individuals to directly control robots working in dangerous assignments, fly aircraft, or allow individuals with implanted intracortical neural microelectrode arrays to transmit and receive physiological data. The technical hurdle that must be crossed involves the development of a noninvasive interface, which will not require the insertion of probes into the body proper. If this obstacle can be traversed, it is likely that BMI technology will be available for commercial and military applications within the next two decades.

Much of the technology relating to BMI employs conventional electronics to control and interface the biological substrate, whether at a macro-level such as the cortex, or the cytological level of a cell network. Rather than utilizing standard electrical connections, other more elegant solutions will evolve in the form of synthetic DNA systems. Regarding BMI prosthetics or efforts to diagnose and treat disease, especially products and processes that penetrate the neuroanatomical structure of the brain, compatibility with natural biochemical anatomical environments, such as the bloodstream and living cells would seem preferable as they will potentially reduce the side effects of an immune system intent on rejecting non-biological bodies.[38]

Synthetic DNA and its Promise

Synthetic biology aims to create novel genetic devices to carry out well-defined uses, such as genetically engineered micro-organisms to improve crop yields, fight bacterial infections, detect pollutants, or convert sunlight into energy.[39] Synthetic DNA digital constructs particularly have demonstrated effectiveness in replacing semiconductor counterparts for eventual application in larger biotechnology systems. As applied to the maintenance of one's wellness and quality of life, synthetic biology will play a role in the amelioration of disability, such as brain prostheses that empower individuals with spinal cord or cognitive dysfunction to live fuller lives.[*]

In 2008, synthetic biology was brought into prominence, when Craig Venter impressed a TED forum on his work in creating living bacteria from synthesized molecules.[†,40] However, concerning applications directed toward computation, signal processing and communications that may utilize bio-computers for instantiation into the anatomy, engineers have achieved proof of concept for a full catalog of devices, which are analogous to electronic digital components. These analogous components are comprised of enzyme logic gates, which provide Boolean operations such as combining the presence of two chemical inputs into an output resulting in chemical fluorescence. Engineers refer to these logic constructs as "AND" and "NOT AND" or "NAND" functions. This type of logic underpins the digital computer. [41,42] In 2007, researchers demonstrated a universal logic evaluator that operates in mammalian cells; and then in 2011, demonstrated proof-of-concept for a therapy that used biological digital computation to detect and kill cancer cells.[43]

Over 20 years ago, 1998, an invention was filed for a Multi-State Genetic Oscillator that worked inside *E. coli* cells, by altering its DNA sequence, causing the cells to blink predictably—that is, turn on and turn off. Six years ago scientists at Stanford University constructed a bio-transistor from genetic material that worked inside of living bacteria. [44, 45] These products use genetically encoded logic, data storage, and cell-cell communication to reprogram living systems and improve cellular therapeutics.

Chris Voigt and his team, at the University of California—San Francisco engineered a bacterial system to regulate gene expression in response to red light and another system to sense the bacteria's environment and conditionally invade cancer cells. As reported in Nature: "[T]he system consists of a synthetic sensor kinase that allows . . . bacteria to function as a biological film, such that the projection of a pattern of light on to the bacteria produces a high-definition two-dimensional chemical image (about 100 megapixels per

[*] Although not directly related to "enhancing intelligence" the main focus of this paper, synthetic biology is being employed to invent new life forms. In 2003, Nobel Laureate, Hamilton Smith was part of a group that synthetically assembled the genome of the virus, Phi X 174 bacteriophage.

[†] J. Craig Venter Institute created a man-made DNA structure by synthesizing and assembling the 582,970 base pair genome of a bacterium, Mycoplasma genitalium JCVI-1.0.

square inch). The spatial control of bacterial gene expression could be used to 'print' complex biological materials and to investigate signaling pathways." [46]

With advances spurred on by CRISPR-type developments, Voigt and his colleagues reported that they are employing new forms of Cas9, RNA-guided DNA endonuclease enzyme, such as dCas9, which uses small guide RNAs or sgRNAs, to repress genetic loci via the programmability of RNA:DNA base pairs for building transcriptional logic gates to perform computation in living cells. [47] In 2017, other researchers similarly demonstrated a Boolean logic and arithmetic system to engineer digital computation processes in human cells.[48]

To fully develop computer systems on biological platforms, engineers will need computational components, as well as circuits that transform continuous physical states, such as temperature, motion, pressure, and analog electronic signals.[49] One such example of this technology resulted in U.S. Patent 9,697,460 ('460), entitled "Biological analog-to-digital and digital-to-analog converters," issued (2017) to J. Collins and T. Kuan-Ta Lu.

The '460 disclosure describes an artificial cell that performs a standard conversion between the analog and the digital world, a function extant in the operation of complex electronic systems today. It employs a binary number system that directly corresponds to its electronic counterpart, the digital computer.* Biological switches convert analog inputs into digital outputs, and vice versa. Devices such as these are the future of embedding processors into the anatomy to realize sophisticated computer mediated applications—applications that will be directed toward enhancing IQ, memory and cognition generally.

The biological calculation is found in various forms, for example in cytology, but also in applications utilizing proteins.[50, 51] In the past few decades the idea of computation has focused on DNA.[52] However, defining necessary and sufficient conditions for "computation" is a complex subject, without straight forward answers.[53] A 2019 paper reports on a synthetic DNA hybrid device capable of calculating square roots to the number '900.'[54] Utilizing the manner of calculation does not place any theoretical constraint on the upper limit of the number whose square root is sought.

Synthetic DNA technology remains rudimentary, but no more primitive than computer technology of the 1950s. Given the rate of technological advancement, one might anticipate that the next quarter century would be ample time where synthetic computers would be more than comparable in computing power of the small digital processors of the early 1970s, such as the Intel 4004, 4-bit processor.

In addition to utilizing synthetic DNA for computational and signal processing, synthetic bio-engineered technology is now being employed to engineer compact digital memory devices. DNA digital data storage is the process of encoding and decoding binary data to and from synthesized strands of DNA.[55] Using this approach, scientists have stored full computer operating systems, movies, and other files with a total of 2.14×10^6 bytes in DNA oligos, which were perfectly retrieved.[56]

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* For example, a combination of three genetic toggle switches produce outputs 00000000, when all genetic toggle's are "off," and 00000001 00000010, and 00000011, when 1, 2 and 3 genetic toggle switch, respectively are "on."

Because a DNA-like computer and memory devices use organic chemistry materials they should better interface with human physiology than silicon based computers. DNA may supply analogous programming information, but mechanisms are required to alter the biochemistry of tissue in computationally meaningful ways. For example, scientists at UCLA are advancing protein engineering to effectuate better drug delivery or artificial vaccines, and building nanostructures by assembling computer designed protein domains in novel configurations.[57] As applied to the brain, biochemical alterations would involve protein production and epigenetic expression—a mechanism, for controlling gene expression.

Synthetic DNA has the potential for constructing entirely new genomes, in the form of a chromosome, and allow the incorporation of a 47th human chromosome. The wisdom of adding another chromosome will be determined through an analysis of gains and risks, both social, ethical and medical. For example, in eradicating disease or improving human intelligence, does it provide some advantage, perhaps greater efficacy over techniques that are underway? Gene therapy as applied to combating birth defects, or cancer currently will increasingly employ CRIPSR. This involves using modified viruses to insert the desired genetic twist of DNA into a cell's genome. But viruses are limited to relatively short sequences of DNA, and additionally risk off-target complications, causing unintended disabilities or disease.[58] On the other hand, a novel artificial chromosome stands to reduce, if not eliminate off-target likelihoods, and offer a relatively unlimited sequence length of SNPs.[59]

Manufactured from synthetic DNA and likely constructed from the rootstock of current nucleotide bases, it leaves open the possibility to draw from other elements extant in the periodic table.[60] In short, adding designed gene sets may open up an endless array of diagnostic and therapeutic possibilities, yet to be conceived. We do not intend to attempt to flesh out the implications of synthetic DNA insofar as serving to amplify intelligence, beyond what has already been described, but it certainly contributes one more tool and an intriguing parallel path in reaching that objective.

Nanoneural Brain Interface/Internet

Unawareables, whether synthetic DNA or semiconductor driven devices, likely will employ, within the next generation, microelectromechanical systems (MEMS), such as nano-sized robotic-motors to course through arteries for drug delivery, and eventually to provide a direct connection from the brain to the Internet. These devices will range in size from 10^{-9} meters (a few hundred atoms across) to 10^{-5} meters or the diameter of a white blood cell. The extent science and engineering realize this ambitious undertaking remains uncertain, especially the magnitude of improving computer-generated intelligence, i.e., information communicated to the brain, not intercepted by the human senses of sight or sound, but bi-directionally between computer and human thought. And, similarly, but more having to do with uncertain timing about when science will succeed in enhancing various anatomical elements that bear on the g-factor complexes for: improved visuospatial processing (Gv), working memory (Gwm), and fluid intelligence (Gf).

What makes nanotechnology revolutionary is that it allows engineers to assemble atom-by-atom and molecules-by-molecule, computational and signal processing architectures. In practice, the atom-by-atom constructions will take place using replicators, devices capable of growing themselves into usable supra-molecular structures, complexes or composites—much as has been the case in crystal growth for decades.[*] In the future these replicated artifacts, such as diamonoid structures, will house new synthetic biological modules, comprising sensors and logical arrays for measuring physiological activity or carrying out therapies. These modules may be put into position by MEMs or other means that operate as nanorobots. The latter may be used alongside sensors to measure conditions within metabolic pathways, that is, the series of chemical reactions occurring within a cell. Apropos to the topic of this paper, these devices will also be employed to transform how we gain and communicate information directly from the anatomy, specifically via neurons within the brain's cortex. This level of sophistication will be underway by 2040, but the timing of its practical realization is uncertain.

Synthetic DNA logic constructs, as compared to analogous semiconductors, are capable of novel morphological configurations, which are mechanically conformable, i.e., pliable and deformable, enabling cells or whole networks to adapt their form and fit within the context of an environment's biophysical constraints. These would be likely embedded into nanorobots (NNB). Considerable research is afoot in the NNB engineering sector, as exemplified by numerous examples that have risen through proof of concept.[61] One application of sDNA would be to instantiate sensing and transducer mechanisms into NNBs for pursuing, among other objectives, diseases or enhancing intelligence.

An international consortium of biologists, engineers, and physicians, led by researchers at UC Berkeley and the US Institute for Molecular Manufacturing predicts the development of a "Human Brain/Cloud Interface" (B/CI), that connects brain cells to cloud-computing networks in real time.[62] Significantly the central mechanism proposed would be based on NNB technology, which would connect between direct monitoring of the brain's neural activity and external data storage.

The BC/I consortium proposed that the NNB will materialize in three assortments: endoneurobots, gliabots, and synaptobots. The NNB's would be designed to: (1) breach of the blood–brain barrier (BBB), (2) enter the brain parenchyma, i.e., the functional tissue in the brain, which is comprised of cells for cognition and motor control, and then (3) ingress into brain cells, where they would autoposition; each type NNB taking their station within the proximity of a neuron. Along the axon initial segment the proposal is to develop an endoneurobot. Likewise, glial cells would be aligned with gliabots, and synapses aligned with synaptobots. How the NNBs would situate in the neuronal structure is discussed by Freitas in his treatise, The Alzheimer Protocols: A Nanorobotic Cure for Alzheimer's Disease and Related Neurodegenerative Conditions.[63]

These NNBs would wirelessly transmit up to $\sim 6 \times 10^{16}$ bits per second of synaptic processed and encoded human–brain electrical information via fiber optics. The conception of such a device would have obvious implications for enhancing intelligence in a multiplicity

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[*] Discovered by Buckminster Fuller, a buckyball is a form of carbon having a large molecule consisting of an empty cage of sixty or more carbon atoms.

of ways, such as by enabling access to supercomputing storage and processing, including artificial intelligence systems, all of which constitute goals mentioned by the researchers and by implication many of the subjects mentioned throughout this paper.

The concept of a synthetic biological module communicating over a wireless channel via nanoneural brain interface will not come without security concerns and social consequences. First it raises the potential that a multiplicity of sensing and control devices instantiated in individuals seconded by a government that would have the potential for the surreptitious acquisition of one's innermost thoughts. It exposes individuals in communication with external databases, which may lead to greater intrusiveness raising privacy concerns. The combination of supercomputers and databases, may play a role in human decision making or at a certain level of complexity control an individual's actions.

These potentialities will be certain to compromise individual autonomy. Hypothetically, Big Data could store one's interiority at the neurological level, where thinking and feeling originates. In addition to opening a window into one's psychological state, a two-way communication between a subject and a remote computer could become a tool or weapon to alter the subject's perception and level of intelligence (e.g., mental acuity, processing speed, memory). This kind of technology will expose populations to increased corporate and governmental abuse, well beyond the malfeasance we experience with hackers and the damage done by breaches in organizational security involving personal records.

But, it's not if or when these developments will intrude upon civil society, for progress will continue unabated during the next 20 years, when at a minimum we can expect to confront a changed milieu. It's incumbent on policymakers to plan, organize and prepare to deal with how these technologies will effect world order going forward.

Conclusion

More than a few projects as mentioned, such as brain modeling or WBE are in the exploratory stage, and as of yet, an effort to integrate the various approaches into a single technological field of study, does not exist.[64] For example, projects such as brain modeling are tangential to, yet add to human intelligence development. Through co-evolving science and technology, engineers, mathematicians, and biologists will learn much about the construction of the full workings of the brain, its neurons, whether excitatory, inhibitory, its axons, synaptic connectivity, the action of dendrites and other auxiliary anatomical constructs.

Overtime innovation seeking a narrow range of objectives often converges. By 2040, the advances discussed will take many technology forms, such as anatomically embedded semiconductors networks, synthetic DNA adjuncts to brain function, as well as the direct communicative integration of the brain to supercomputers. The past offers parallels to predict the future: between 1960 and 1980, many ideas were floated and modeled as to a wide range of solutions related electron tube-driven large computers, discrete transistor-driven minicomputers to finally integrated circuits in the form of microprocessors. Except for mini-computers (supplied by Data General, Digital Equipment Corp., and Varian Corporation), most data processing was done on large framed computers, until the mid-70s when personal and commercial applications began to converge. Through years of winnowing and absorption the most efficacious ideas survived. Those that did brought products such as the personal computer, the Internet and the smartphone into confluence.

It's likely that enhanced human intelligence regardless how it might be achieved will create a new social reality, a new pluralism. Depending on how society assigns significance and status to those that may incorporate a wide assortment of enhancements, individuals and classes of individuals may find themselves more generally in different modes of being. This would influence cultural modalities or status norms, such as where one fits into a particular commercial or social structure, such as a military, workplace or family unit. This may manifest in some segment of society having a knowledge base or reasoning ability superior to those with which they interact, or simply developing idiosyncrasies or heightened sensibilities regarding tastes in art, music or some other intellectual pursuit.[*]

More specifically, societal pressures can be anticipated to escalate as individuals of higher IQ pursue educational opportunities and careers consistent with their potentialities and aptitudes. This could force a realignment of members of society, into disparate groups, those who would not have the intellect to meaningfully participate and those, even a relatively few, who might dominate the intellectual and political spheres within a society. This may result in segments of a population that would oppose augmentation of human intelligence and others of whom would celebrate its arrival. Such possibilities would put local political and geopolitical forces in play.

What is known is that human level machine intelligence, artificial intelligence, and intelligence enhancement via gene adjustment, synthetic DNA processors, neuralnanorobotics, and human brain/cloud interfacing, will change the worldwide social, and cultural landscape, including world alliances, such as NATO over the next 15 to 25-year timeframe.

Acknowledgement

The author acknowledges Bioengineer Christine Vi for her technical/editorial support in the production of this paper.

Funding

This work was supported by NATO Headquarters, Supreme Allied Commander Transformation, Innovation Hub, Warfighting 2040 Study.

[*] Status norms explain the widespread recognition of differences in social order and value, differentiating age, sex, physique, education, occupation, neighborhood, and as genetic engineering of physiology and psychology take hold, there will anticipated differences in these norms, as a consequence of those who will exhibit extraordinary potentials to live longer, healthier lives, and superior intellect.

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