# Augmented Machines and Augmented Humans Converging on Transhumanism

**June 2019**

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We have experienced a significant evolution in the capabilities of machines over the last 250 years with an incredible acceleration in the last 50 years, thanks to electronics and software. This evolution is going to continue and accelerate in the coming two decades leading to machines as "smart" as humans.

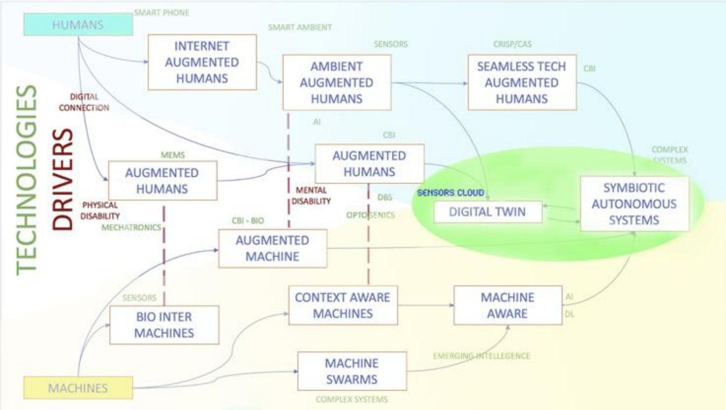


*Figure 1 A representation of the concurrent evolution of human and machine augmentation eventually merging into a symbiotic relationship mediated by digital twins. Credit: IEEE SAS Initiative*

At the same time the human species has augmented its capability in various areas more than doubling life expectation over the last 100 years, and individuals have learned to leverage machines as never before to improve their life, their performances and extend their knowledge. This is also expected to progress in the coming two decades to the point that the boundary between humans and machines will become, in many instances, fuzzier and fuzzier, partly due to the growing use of digital twins. The progress seen in the last decades and the one expected is reshaping the idea of transhumanism, making it much more concrete.

The IEEE Future Directions Committee had an Initiative, IEEE Symbiotic Autonomous Systems (SAS), that worked on these aspects. This initiative is now gaining steam by joining the Digital Reality Initiative aiming at fostering the Digital Transformation in its many facets.

As a matter of fact, the Digital Transformation is shifting the focus from a micro to a macro view of business, hence taking a global view at machines involved in business (production, transportation, delivery, and end user) processes. Whereas in the past innovation focused on a single machine, the Digital Transformation shifts the focus to the overall process, to the many machines involved, their mutual interactions, and their interaction with humans. The resulting effect is that the augmentation of a machine is no longer an internal aspect, rather it derives from its interaction from the operational context (and other machines/humans active in that context). Although hardware improvements remain important, they are more an enabler of machine augmentation. Rather, the functionality relies more and more on software, data analysis (including artificial intelligence) and communications.

The hardware is improving in many aspects, such as using raw materials that are no longer off-the-shelf but rather designed to deliver certain characteristics to the production processes, like additive manufacturing. This allows for creation of structures that were simply not possible in the last century. New "hardware" is also multiplying number crunching capabilities, stretching Moore's law to its physical (and economic) limit and circumventing it by moving to different computational architectures and new processing substrata. In turn, this ever increasing number crunching capability coupled with the ever increasing volumes of data enables data analytics, reasoning and the emergence of "intelligence". This leads to smarter machines embedding awareness and intelligence, able to share and learn through communications and evolve through adaptation and self-replication.

*Awareness*

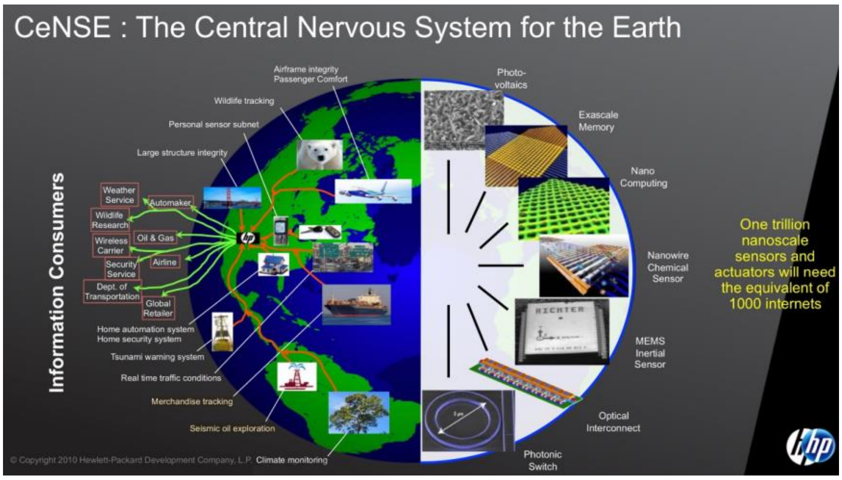


*Figure 2 CeNSE, a Central Nervous System for the Earth, as pictured by HP, in a vision of trillions of sensors moitoring the pulse of our Planet. Image credit: HP*

One cannot be smart without understanding the context one is operating in, and the very first step is to become aware of what occurring by sensing the environment.

The vision of a world that can be understood by scattering sensors all around was articulated by HP in the first decade of this century with the project CeNSE[1], Central Nervous System for the Earth. The project had Shell, the oil company, as the first customer, interested in using sensors to detect oil reservoirs by measuring vibration patterns induced by micro explosions. HP was foreseeing a world where every object had sensors embedded, and these sensors were forming a network, a nervous system, collecting data that could be processed centrally. Every bridge and every road would be a part of it. Bolts and nuts connecting the various parts of a bridge would embed sensors communicating with one another about the local stress and pressure; these data would be used to monitor the bridge and the movement of the connected banks. Sensors embedded in the tarmac would capture the vibration created by vehicles, and signal processing would be able to tell traffic patterns and even differentiate distinct types of vehicles: a micro sensing that could provide the data for a macro assessment of the environment.

Notice that this vision that was demanding a top down approach is becoming reality through a massively distributed bottom up approach. As an example most new buildings developed by big constructor companies are designed with embedded sensors to support remote monitoring and control, appliances are embedding a variety of sensors and come equipped with internet connectivity, even the latest models of digital cameras are embedding sensors and rely on internet connectivity to enhance their functionalities.

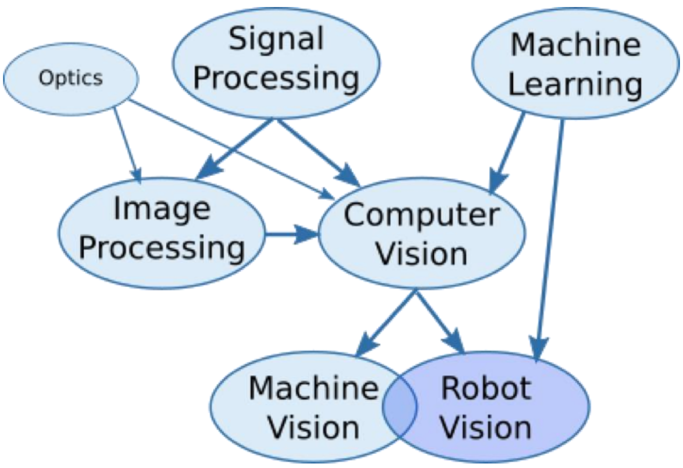


*Figure 3 A variety of technologies are at work to enable machines' awareness. The starting point is the capturing of the environment, more frequently making use of image detection capabilities. This information is processed in software. Credit: IEEE SAS Initiative*

A different approach to sensing is the one we are using every day and has been perfected through million years of evolution: sight. Image detectors have become extremely effective (high resolution and low cost) and computer vision, in these last years, has progressed enormously. It leverages image processing for detection of edges and identifying shadows and machine learning to analyze the image. It is now being used in machine vision[2] to recognize objects, like a rusted pole needing maintenance, or a vehicle plate number and in robot vision (e.g. to move in an ambient).

[1] CeNSE: https://www8.hp.com/us/en/hp-information/environment/cense.html

[2] https://blog.robotiq.com/robot-vision-vs-computer-vision-whats-the-difference

Lately, and more so in the future, smart materials have acquired sensing capabilities[3] so that any object will embed sensing in a native way. Smart materials can sense and react to a variety of stimuli, with piezoelectricity being the most common. Piezoelectric materials sense pressure, including touch, and release an electrical current that is proportional to the pressure applied, hence measuring that pressure.

All this enhanced and distributed sensing is creating data that can be processed both locally and at various hierarchical stages. And the processing is what can deliver value.

A digital copy mirroring the physical world can be used to analyze the data as it is (mirror), to compare it with what it was (thread), and to keep it in synch as the physical entity evolves (shadow). Through data analytics on the digital copy and on other digital entities loosely connected with it in the physical space we can assess what is going on and find out "why". Then we can infer what might be happening next and work out ways to steer the evolution in a more desirable direction (or at least limiting the negative aspects).
The sequence:

- what is going on,
- why,
- what will happen,
- changing the predicted evolution creates value.

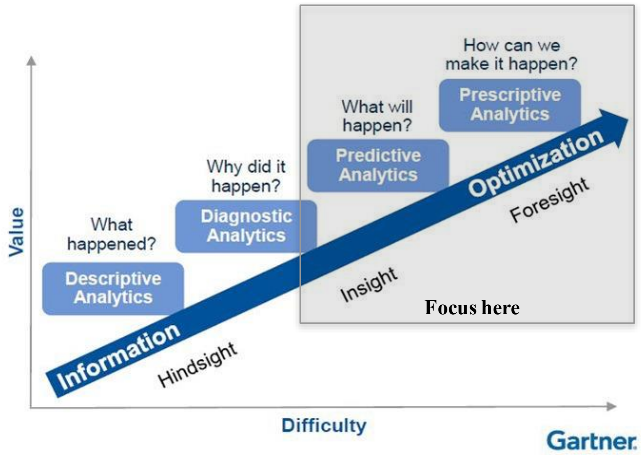


*Figure 4 The increased value in the processing of data. From monitoring the real world to analyzing the probable causes leading to a change, moving on to predicting what could be the evolution, reaching the highest value when implementing actions that can steer the evolution towards the desired outcome. Credit: Gartner*

Making sense of data is crucial, opening up the door to have data representing reality, creating a digital model of reality. Reality exists only in the present, however, data can represent the present and the past and can be used develop a thread to forecast the future. This is what digital twins are all about. Of course mirroring reality into a digital representation creates a snapshot that has a very short life. In order to keep the mirror faithful to reality it needs to be continuously synchronized. Digital shadows need to be created to keep the digital model up to date. This makes the digital twin useful, since it can be trusted to represent the physical reality.

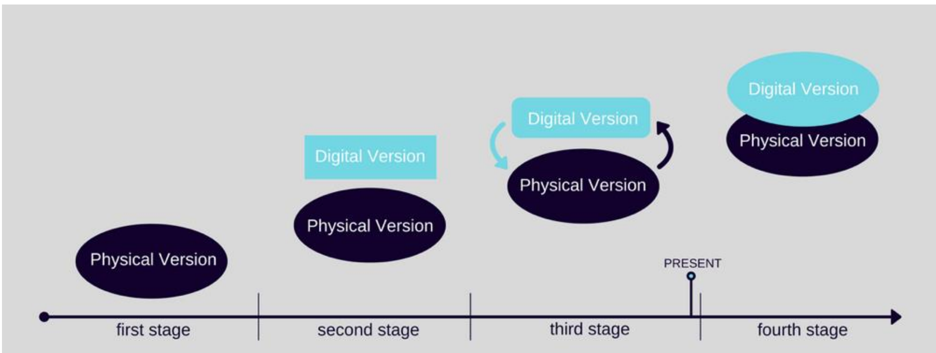


*Figure 5 Starting in the last century industry has begun to design products by creating digital model through CAD (computer-aided design). This digital model has been used more and more in the manufacturing phase through CAM (computer-aided manufacturing). Now the embedding of IoTs in the product makes possible the synchronization of the digital model with the product throughout its lifecycle. We are starting to see the first examples of operation through the sharing of functionality across the digital model and the product. Credit: Medium "How Digital Twins are completely transforming Manufacturing"*

Digital twins have been evolving over the last ten years from being simple representations of a real entity at a certain

[3] https://www.mdpi.com/journal/sensors/special_issues/ssnbsm

point (like at the design stage) to becoming shadows of the physical entity kept in sync through IoT (sensors).

In the coming years a (partial) fusion between a digital twin and its physical twin can be expected. The resulting reality, the one that we will perceive, will exist partially in the physical world and partly in cyberspace but the dividing line will get fuzzy and most likely will not be perceived by us. To us cyberspace and physical reality will be our perceived reality.

*Intelligence*

The huge, growing amount of data available is powering data analytics, and artificial intelligence is taking advantage of that. Notice how digital twins have embedded some of the "Vs" characterizing big data:

- *Volume*: the volume of data aggregated in a digital twin varies considerably depending on the mirrored physical entity, but quite a few physical entities are bound to generate a significant amount of data;
- *Velocity*: the shadowing of a physical entity again varies considerably but here again can have a significant "change rate";
- *Variety*: a digital twin may aggregate different streams of data (like the actual modelling of the entity –static-, the operation data –dynamic-, the context data -static and dynamic-), and in addition it can harvest data from other interacting or connected digital twins;
- *Veracity*: internal and external functionalities can authenticate data and ensure their veracity;
- *Value*: digital twins are a way to create value in the digital transformation.

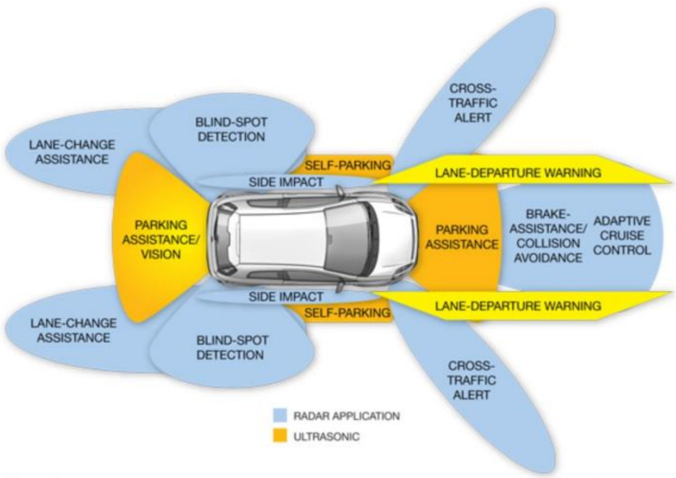


*Figure 6 A self-driving vehicle needs to be aware of its surrounding. This is achieved through a variety of sensors and the processing of the data against a knowledge background "owned" by the vehicle, i.e., its intelligence. Credit: Industrial WSN Blog, Analog Devices*

The first three characteristics support analytics and the emergence of intelligence.

There are four ways to "create" intelligence once in the world generated by the digital transformation and leveraging digital twins:

- *Embedded intelligence*: it is possible to embed processing capabilities resulting in intelligence in both the physical entity as well as in the digital entity (digital twin). These processes can be an integral part of the entity itself, or they can be intimately tied with it (an external intelligent function that is external in terms of hosting but it to all effect an integral part of the entity functionality). Notice that in the future this might be the result of a superposition of a digital twin on its physical twin. In the graphics of a self-driving car it can be the intelligence residing in the car, providing the required awareness and understanding of the context and of its evolution.
- *Shared intelligence*: it is possible to cluster single distributed intelligence into a whole that is intelligent (or more intelligent) that its single components. In the example of a self-driving car, communications among cars can result in an increased intelligence allowing the cars to navigate in a safer way since every car now can have broader knowledge derived from the sharing of individual knowledge.
- *Collective intelligence*: an ensemble of entities creates a group intelligence that is the result of sharing and operation at a collective level, e.g., by employing common rules or being part of a common framework. This may be the case of self-driving cars once a common framework is established and all individual decisions are taken based on that framework. Notice the difference between a shared intelligence where knowledge is

shared but intelligence is local, hence decisions can differ from one entity to another, from the collective intelligence where a framework ensures that all decisions are aligned. Bees are an example of collective intelligence, since each bee take decisions according to a predefined, common framework. A team of humans operates in a shared intelligence model, each one taking independent decisions although each one is “influenced” by the shared knowledge.

- *Emerging intelligence*: the intelligence is not present in the individual entities (although each one may have its own intelligence) but rather in the derived global behavior. This is the case in our brain where the intelligence emerges out of the independent, yet correlated and mutually influencing, activities of neuronal networks and single neurons. It is also the kind of intelligence shown by a swarm of bees (bees have a collective intelligence when they operate in a hive, then when they swarm in the thousands the swarm creates an emerging intelligence, seeming to know where it has to go). In the example of self-driving cars their mutually influencing behavior gives rise to a dynamically regulated flow of traffic in a city that optimizes travel time and use of resources seeming to be orchestrated by an intelligent controller, while it is the result of an emerging intelligence deriving from the application of few very basic rules.

An emerging intelligence can be the one generated by clusters of IoTs, once they reach certain thresholds. Most likely, IoTs can be seen as sensors whose data provide awareness. These data may be raw, simple data, or may be the result of an embedded processing (that in some complex IoT can generate some sort of “embedded” intelligence). Also, these data can be processed externally creating intelligence. One can take the smartphone as an example. Most advanced smartphones may have as many as 19 different kind of sensors[4] (see image) and additionally can act as aggregation hubs harvesting data generated by wearables (like smart watches, smart bands, smart clothing). Smartphones have the processing and storage capacity to analyze these data and create intelligence out of them. They can also connect to processing in the cloud (or any server) where data collected by hundreds of thousands of smartphones confluence. This might be the case of location data that can be used at a city level to understand traffic patterns and spot anomalies and traffic jams. For its characteristics of communication hub and processing/storage capabilities, the smartphone is becoming a component to interface and provide intelligence to a broad variety of everyday appliances, from lawnmowers to smart homes.

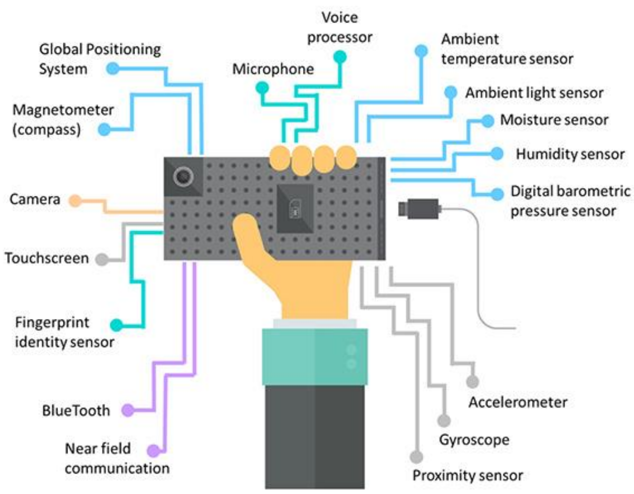


*Figure 7 Common sensors in a smartphone. Obviously top-of-the-line smartphones have more sensors embedded but the general trend is an increase of embedded sensors and of embedded software to make sense of data in all smartphones. Credit: ICON*

The processing of data aimed at the creation of intelligence (including meaning, understanding, and decision making) can be eased by specifically designed chips: neuromorphic

[4] https://study-volunteers.iconplc.com/icon-views/blog/2017/06/16/leveraging-smartphone-potential/

chips[5], so called because their architecture mimics, to a point, neural circuits in a brain. It is not just a matter of hardware; it is very much a matter of software. In general, neuromorphic chips come equipped with specific software components that can be used as building blocks. There are now several examples of neuromorphic chips, the first commercial one probably being SyNAPSE by IBM. More recently, NVIDIA and Intel have designed neuromorphic chips. In fact, the whole area of graphic processors units makes for a very good starting point in creating neuromorphic chips.


*Figure 8 The neuromorphic chip market will be expanding at an outstanding 20.7%CAGR throughout 2016-2026, which is the forecast period. Apart from this, the neuromorphic chip market will be touching an evaluation of nearly US$ 10,810Mn by 2026-end. Credit: Future Market Insights*

The market[6] for these chips is expected to grow at a 20.7% CAGR over the 2016-2026 period with Asia taking the lion's share with over $600M followed by US with over $450M (and the latest forecasts indicate an even greater growth pushed by China, Japan and South Korea).

*Communications*

Communications is an integral part of any smart entity. Without communication an entity cannot be smart (it won't be aware of its context, hence it would not be able to adapt to it). Better communications fosters smarter behavior; it is an integral component of smart machines (and smarter human/machine cooperation/interaction).

There are many forms of communications broadly split into direct and indirect communications, the former implying an explicit exchange of information among parties, the second being the result of an awareness of a party of the dynamics of its ambient leading to a change in its behavior.

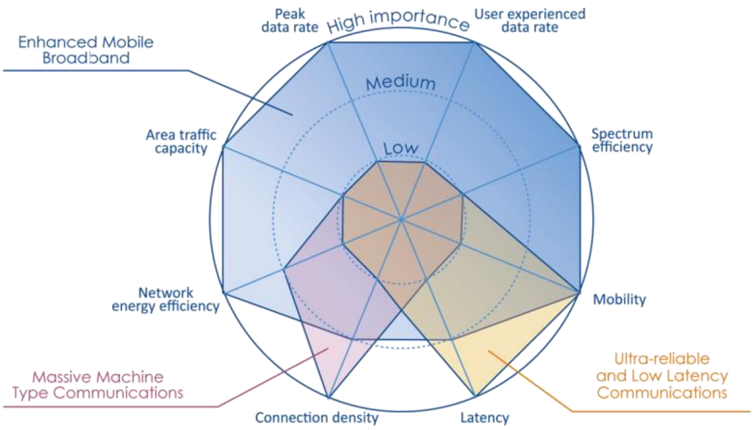


*Figure 9 Comparison of key capabilities of IMT-Advanced (4th generation) with IMT-2020 (5th generation) according to ITU-R M.2083*

Humans, have created very sophisticated communications and communication tools that in the last decade have formed an interconnected web on the planet making it possible to communicate seamlessly across distance and more and more enabling communication beyond the human species, with objects, machines and artificial intelligence. Depending on the needs[7], (see figure) different communication tools (infrastructures, protocols, interfaces and devices) can be used. This goes both for human and for machines.

[5] http://jetprime11.blogspot.com/2015/04/neuromorphic-chips-replacement-for.html
[6] https://www.nextbigfuture.com/2018/01/artificial-synapse-for-neuromorphic-chips.html
[7] https://www.etsi.org/technologies/5g

Machine communication has a greater variety than human communications. We are constrained by our senses (capabilities) which places both an upper and lower boundary to the volume of information (data) and their quality (form). Sensors, in general, require higher network energy efficiency (since powering sensors is not always easy, particularly for ambient sensors based on energy scavenging), however, on the other hand they do not need to transfer a large bulk of data and often latency is not consequential (a delay of 500ms in most situations is acceptable). In some applications there may be a high density, hence requiring pervasive coverage and management of thousands of IoTs in a single area (such as an IoT application in an industrial environment like an assembly line).

Human-machine communications rely on human senses thus far, creating machine interfaces that our senses can detect and interact with (such as screens, keyboard, and voice control). In the last decades, research has been focusing on creating direct Brain to Computer Interfaces[8] (BCI), leveraging sensors that can detect the brain's electrical activity and software able to interpret it. However, in spite of some amazing demonstrations (people able to control a robotic arm with their thoughts) real meaningful communication is still far from being realized. The most progress has occurred in virtual motorial communication, like directly controlling a pointer or robot movement with thoughts. This is because it is relatively straightforward to pinpoint the areas of the brain controlling our limbs, and therefore thinking "I need to move the hand to pick up that glass" sends an electrical pattern to the area controlling the movement of your arm and hand. This pattern can be detected by signaling processing software and translated into commands to a robotic arm.

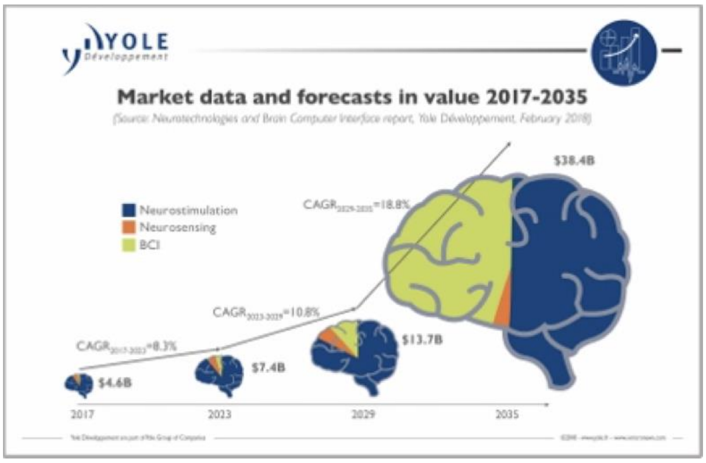


*Figure 10 The intersection of neurosciences, advanced micro technologies and rapid adoption of wearables stimulates the emergence of innovative start-up companies and increases the market value. Credit: Yole Development*

On the other hand, technology cannot currently detect a thought like "I am thirsty". One of the stumbling blocks is that there are significant similarities in the patterns generated by people when they want to move a limb but not in the patterns generated by a general thought like "I am thirsty". Even in the case of similarity for the movement of a limb, the signal processing software needs to be trained in order to detect the pattern specific to that particular person. As a matter of fact, the training goes both ways: the person also needs to be trained to "think" in such a way that the computer could understand.

[8] http://www.yole.fr/Neurotechnologies_BCI_IndustryEvolution.aspx#.XKxioS2B1p8

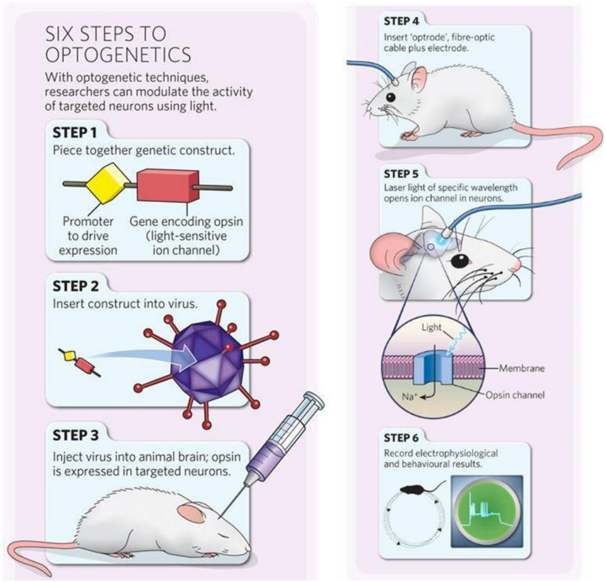


*Figure 11 Optogenetics, controlling the brain with light. Credit: http://optogenetics.weebly.com/why--how.html*

The reverse communication, from the computer to the brain, is today limited to micro commands, since it is based on electrical spikes that can be delivered to certain micro areas of the brain or on optogenetics[9] –still at experimental stage- using genetically modified neurones and light pulses delivered through optical fibers implanted in the brain. Both require invasive surgery and obviously are restricted to relieve specific pathologies (like epilepsy). The figure provides an explanation of the steps involved in the construction of an optogenetics interface.

Today, all communication from a machine (computer, robot, cyberspace) can only take place through the mediation of our senses. Implants are possible at the sensory level, like electrical stimulation of the aural nerve or a retinal chip implant (like ARGUS II). Haptic feedback is also being used in interfaces. Virtual Reality and Augmented Reality technologies can link humans to cyberspace, but that happens through the senses.

Indirect communications is valuable among life forms (a living being detects the ambient situation and changes its behavior accordingly, like in swarms, see figure), and with computer vision and other types of ambient sensors it is becoming important in machine to machine communication as well as for human-machine communication.

*Figure 12 A starlings swarm. No one particular bird is in charge; the choreography emerges out of few simple rules each individual abides to. Credit: Pinterest*

Indirect communication is based on:

- awareness
- adaptation
- influence.

*Awareness* includes not just the awareness of the situation but also the awareness of how the situation might evolve and what can condition the evolution in a specific direction. Both the awareness of the situation and of its possible evolution (even more this second than the former) can be done at different levels of intelligence. There is some interesting evolution in the capability of machines to become aware of the emotional state[10] of a person, and even of a crowd, by observing their faces and behavior. In this sense we can say that a machine can "read our mind".

*Adaptation* follows, at different degrees of effectiveness, the understanding of the situation and aims at changing the behavior of the entity. Clearly, adaptation is a continuous process constantly re-evaluating the benefit it brings to the entity. As machines (robots) are becoming more and more software driven, flexibility becomes possible and, a new technology area, that of evolutionary robotics, is looking into this.

[9] https://www.nanalyze.com/2016/11/optogenetics-explained-simply-investors/
[10] https://onix-systems.com/blog/emotion-sensing-technology-in-the-internet-of-things

At higher levels of intelligence, it is expected that machines can come to understand how the environment and its components react to specific actions and may be come able to *influence* the behavior of the environment components in the direction that is most beneficial to that entity. Clearly this is a cat and mouse game, since each entity in the long run will acquire this capability, and the interaction will become ever more complex.

*Technologies for Augmented Humans*

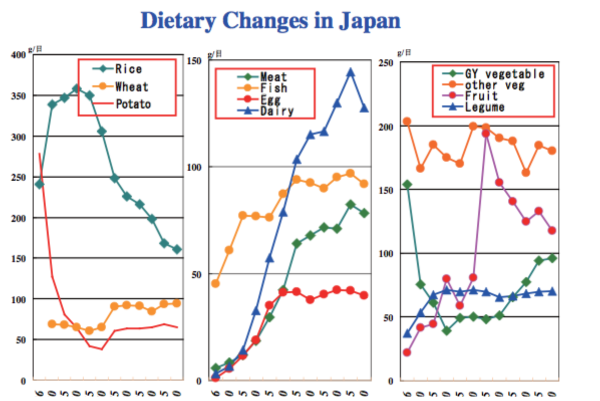


*Figure 13 Source:*
Fig.: *www8.cao.go.jp/syokuiku/data/eng_pamph/pdf/pamph3*
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The goal of augmenting human capabilities has always been present, as far as we can tell. The control of fire was a tremendous augmentation that had deep consequences on our species.

Cooking food opened up new ways of nourishment and made our species more adaptable to hostile environment and even changed the phenotype (this can be seen also in modern times, when the change of protein intake, by changing the diet, has made us taller[11] and stronger). In the figures above, see the increase of the average stature of Japanese over the last hundred years (left) and the change in their diet.

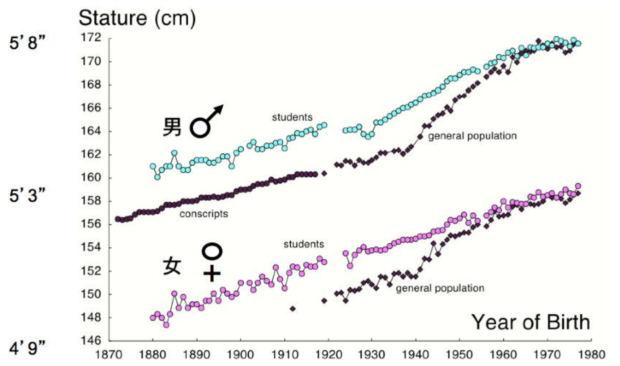


*Figure 14 Changes in the Japanese population stature. Source:* *http://www.dh.aist.go.jp/en/research/centered/anthropometry/*

The invention of tools to harvest and to convert and use forms of energy (from water/wind mills to steam and electricity) has multiplied our capabilities as single individuals and as a species. Actually, it is important to notice that as our tools have become more complex and require more and more capital and cognitive investment the augmentation has shifted from the individual to a larger and larger community, sometimes becoming the trademark of a region or a country (industrialized world). This makes a departure from the evolution of other species to the human species where the overlaying of artefacts and infrastructures has changed the phenotype and the extended phenotype of our species, something that, as far as we can tell, has never happened to other species. More recently, the evolution of hard technologies, that in the past resulted in an augmentation of physical performance, has been flanked by technologies that are augmenting our cognitive performances.

[11] https://blog.uvm.edu/cgoodnig/2013/04/29/the-phenotype-and-evolution-more-on-defining-evolution/

Take, as an everyday example, the smartphone. The phone, originally creating to provide communication across distance, has increased our capabilities. The smartphone today is only marginally used to communicate with other people; most of the time the services it provides are used instead, including communication with cyberspace to bring data and information to our fingertips, the variety of applications processing data, or its sensing capability (like taking a photo). With a smartphone, access to information and knowledge has become unlimited, and through augmented reality[12] apps, there is a seamless overlapping of the cyber world onto the physical world. The smartphone is a crucial component of the digital transformation, and it is possibly today the most important tool in the augmentation of our extended phenotype.

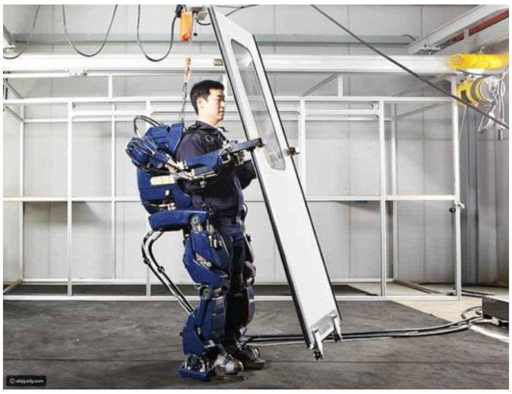

*Figure 15 A Hyundai wearable robot, or exoskeleton, relieving workers' fatigue by carrying of the weight. Credit: Engadget*

Technologies like exoskeletons (see image) are augmenting human strength, and relieving us from fatigue. They are now being used in car industry assembly lines[13], in the military, and in healthcare to overcome disabilities. Wearables like smart contact lenses[14] will be able to create a continuum, through seamless augmented reality, between the physical and the cyber world. Smart goggles are already commercially available but they are not delivering a seamless experience; smart contact lenses are still in the prototyping stage but it seems reasonable to expect their commercial availability within the next ten years.
Implants connected to our sensory termination can expand the range of our capabilities, like seeing in the infrared, hearing higher frequencies and even detecting electromagnetic fields. This is not happening through an extension of our brain capability but by leveraging the plasticity of the brain that can accommodate new sensory patterns including them in the existing processing of meaning (synesthesia).

*Human Augmentation*

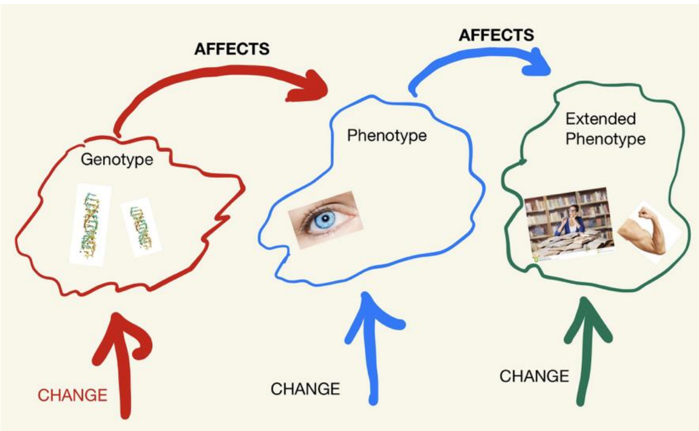


*Figure 16 Three stages of human augmentation, through genotype modification, phenotype change, and extended phenotype creation. Credit: IEEE SAS Initiative*

There are basically three ways to augment humans:

- Modifying the genotype
- Modifying the phenotype
- Modifying the extended phenotype

*Genotype modification*

Individuals inherit the genotype (the set of our genes contained in our chromosomes, each of us has 22 pairs of chromosomes –autosomes- plus the sex chromosomes, either X-X, or X-Y, female or male respectively). So far scientists do not agree on the exact number of genes, the estimate is between 19,000 and 20,000. Each gene is composed by a number of base-pairs (A:T –Adenine, Thymine- and C:G –Cytosine, Guanine-). The number of base pairs per gene varies significantly and it is not, generally speaking, an indication of the

[12] https://www.techradar.com/news/goodbye-smartphone-hello-augmented-reality
[13] https://www.technologyreview.com/the-download/611827/ford-is-deploying-exoskeletons-in-15-of-its-factories-around-the-world/
[14] https://www.visiondirect.co.uk/blog/smart-contact-lenses

sophistication of the living being (at least in the perception we have of "sophistication"). As an example compare the 20,000 genes (probably less than that) in a human genome with the 164,000-334,000 genes estimated in wheat[15]. In general scientists tend to look at the number of base-pairs, rather than at the number of genes.

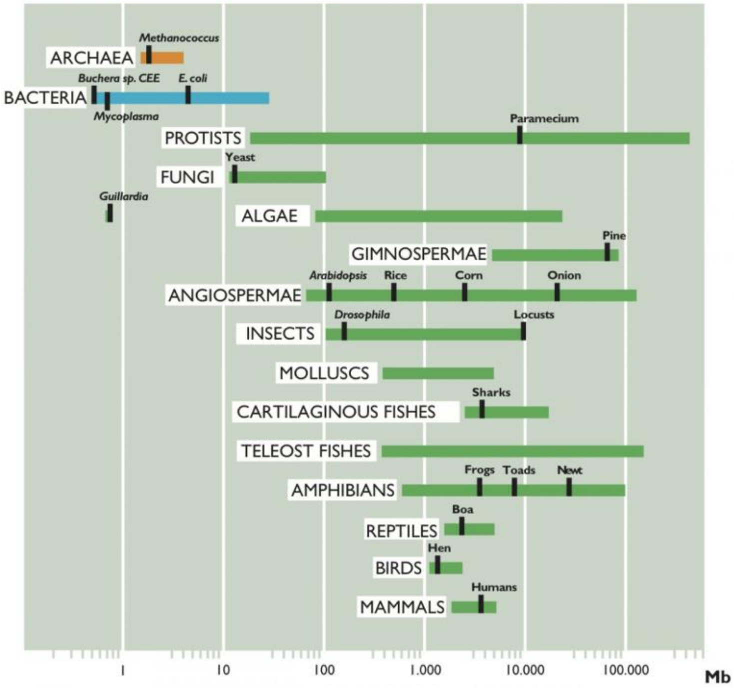


*Figure 17 Range of genome size in organisms of the three domains of life. Credit: Mètode*

The figure[16] provides an overview of the number of base pairs in different life forms (expressed in millions of base-pairs). As you can see mammals do not have the highest number of pairs, and humans are an "average" mammal in this sense. So, having many genes, or having many pairs, does not necessarily match our perception of "smartness".

By changing a gene there is the potential of changing the phenotype (change includes also deleting as well as adding a gene). The problem is that it is not known in general how a change in a gene affects the phenotype, so in spite of having the technology for changing genes (CRISPR/Cas 9 and more recent, more precise ones, like CRISPR/Cas 12a[17]), it is not possible to start from a desirable phenotype and reverse-engineer it into a change in the genotype. Someone commented that today's gene modification technology is comparable to having an extremely precise gun and being blindfolded when using it.

Some researchers are planning to use artificial intelligence (AI) to create this link between the genotype and the phenotype. This is becoming more and more a possibility given the growing number of sequenced genomes onto which machine learning can be applied.

There are already some clear correlations between genes and their expression in the phenotype, and companies like Genomic Predictions[18] are exploiting them to steer in-vitro fertilization towards a higher probability of avoiding disorders like diabetes, osteoporosis, schizophrenia and dwarfism. Among these correlations are the color of the eyes, and this is being exploited by companies like The Fertility Institute[19] that are offering future parents the possibility to "design" some aspects of their future child, including the sex and the color of the eye.

Augmenting human intelligence[20] through gene modification is still a big question mark, although there is a feeling that this should be "technically" possible (leaving aside the big ethical issues that, of course, should not be disregarded). Recently, in February 2019, there was a report[21] of a gene deletion performed in China to create HIV immunity that may have an increase of learning capability as an unexpected side effect.

[15] https://coloradowheat.org/2013/11/why-is-the-wheat-genome-so-complicated/
[16] https://metode.org/issues/monographs/the-size-of-the-genome-and-the-complexity-of-living-beings.html
[17] https://www.genengnews.com/topics/genome-editing/crispr-cas12a-more-precise-than-crispr-cas9/
[18] https://genomicprediction.com
[19] https://www.fertility-docs.com/programs-and-services/pgd-screening/choose-your-babys-eye-color.php
[20] http://nautil.us/issue/18/genius/super_intelligent-humans-are-coming
[21] https://www.technologyreview.com/s/612997/the-crispr-twins-had-their-brains-altered/

*Phenotype modification*

*Figure 18 Model of a bacterial CRISPR/Cas9 complex bound to target DNA. Credit: Merck, Barewalls*

Augmentation through changes in the genotype is fraught with ethical issues[22], both rooted in the lack of knowledge on the consequences and on general considerations, including the unfair advantage that may be gained by a restricted few (among these extremes there are plenty of additional ethical considerations).

In the coming decade(s) we can expect our knowledge to grow significantly but it will take quite some time before we can understand the implication of genome modification on all phenotypes (notice that the whole landscape is extremely complex because gene editing in different species has the potential for cross species effect due to virus infection).

A more conservative approach modifies RNA[23], instead of the DNA, since this will not affect the offspring, i.e., the future generations. This is now becoming within reach (at the moment is still in the research labs) using CRISPR/Cas13d, a variation of the technology of DNA editing.
Our phenotype changes continually through our life (e.g., aging), and scientists have understood that this depends in part on the activation of specific genes. By controlling this activation, it would be possible to change our genotype. Our genome consists of many "programs"; several of them lay dormant, and some may even stay that way throughout our life. By understanding the outcome of their activation on a phenotype, it would be possible to activate them (or keep them dormant stopping their natural activation) to shift the phenotype in a certain direction.
While we are getting closer to this from a technology point of view, we still do not fully understand the implications, and it might be quite some time before we do.

It is clear, however, that there is a huge potential in changing the phenotype by mastering this approach. An obvious application is in the area of extending our life span, and there are a number of companies, like Calico[24], doing research in this area. The Fountain of Youth, a myth originating as far back as in Herodotus accounts, is becoming an active, scientific, research area.
Notice that if and when (unlimited) life extension becomes possible, huge ethical and societal issues will need to be addressed.

It is likely that within this century epigenetics[25] will provide the tools to influence the phenotype leading on the one hand to defeating several diseases that are afflicting humanity and on the other hand to augment us in both physical and cognitive capabilities.

*Extended phenotype modification - physical*

We are likely the only species that have the capability of extending our phenotype (at least in such a significant way). We learn, and what we learn changes who we are. We learn from books, from experience and from being immersed in a specific culture.

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[22] https://news.harvard.edu/gazette/story/2019/01/perspectives-on-gene-editing/
[23] https://techcrunch.com/2018/09/20/scientists-have-moved-one-step-closer-to-rna-editing-which-could-be-the-next-stage-of-crispr/
[24] https://www.calicolabs.com
[25] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1392256/

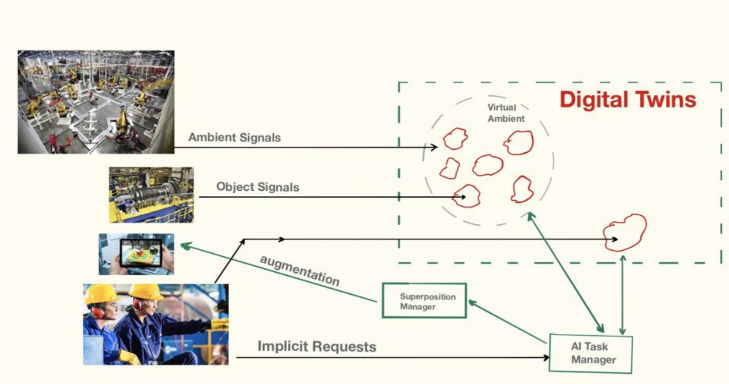


*Figure 19 Extended phenotype modification using Digital Twins. Credit: IEE SAS Initiative*

More recently we have created prosthetics, first to compensate for an acquired deficit (like losing a limb) and then to augment our capabilities (like a microscope). For a long time, these were physical prosthetics, and the cognitive improvement they made possible was totally mediated by our senses. More recently we are starting to have the possibility to increase our cognitive capabilities (e.g. using drugs).

What lays ahead is an ever-increasing sophistication of prosthetics both in the physical and in the cognitive space (mediated and in the long term direct).

Think about the increasing use of the smartphone to connect to knowledge in cyberspace, the seamless use (coming in the next decade) of augmented reality, and the ever-increasing reliance on distributed knowledge, mediated by seamless connectivity. Think about the emergence of personal digital twins that will augment our capability to improve health care and cognitive space.

Notice that it is not just about "us": the overall ambient we live in is improving and this changes the relationship we have with it, and along with it, our extended phenotype is changed. All discussion on the have and have-not is, actually, a discussion on the (widening) gap among the extended phenotype of people living in different ambient, resulting in the acquisition of different capabilities.

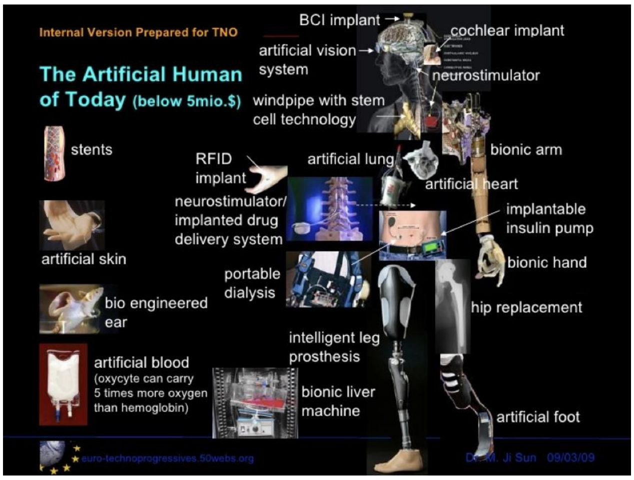


*Figure 20 Human enhancement technologies available today. Credit: MJSL 2050*

It is interesting to notice that the extended phenotype applies to the individual as well as to a community. There are plenty of companies "relocating" or opening a branch in an area having a rich distributed knowledge fabric, relevant to that company business. Likewise, at a micro level, companies try to create a distributed knowledge environment, both by keeping a crucial number of experts in contact with one another (in a physical space) or using tools to break distance barriers recreating contiguousness in cyberspace (with the present tools this is less effective than having people operating in the same physical space).
As mentioned, the availability of prosthetics is extending our phenotype. We can see an evolution in this area in 5 steps:

1. Replacement of missing or malfunctioning parts
2. Pro-active replacement to prevent failures
3. Replacement to sustain adverse conditions
4. Replacement to provide enhancement to specific features
5. System-wide enhancement, including life extension

Steps 1 and 2 are obvious and are already in the clinical practice today although the types of prosthetics are increasing and their capabilities are improving (sometimes becoming better than the part they are replacing).

Step 3 is already reality for plants, where at the genomic level changes are made to have them producing crops in certain types of soil, with low water availability and so on. However, this is a change at the genome level while here we are focusing on the extended phenotype. In the coming decades humans (some of them) will need to inhabit areas that are not suited for living, like outer space, and research is going on to find ways to create "augmented versions of humans" that can endure those situations. More simply, think about using prosthetics to allow firefighters to see the "heat" by using smart contact lenses, or workers in dangerous environment needing heightened sensory capability to anticipate problems. These prosthetics may be a mixture of hardware implants and signals generated by software, possibly by their digital twin.

These examples lead into the step 4, enhancing specific features (like heightened senses). Another example of a type 4 prosthetics may be the addition of an artificial sensor, like a radio antenna able to capture specific radio frequencies connected to a transducer that can process the radio signals converting them into electrical signal that can be conveyed to the brain (either to the cortex or more likely to some nerve, like the aural nerve, and let the plasticity of the brain learn how to process these new signals. After a while that person might be able to recognize radio frequencies and associate a meaning, in other words, to capture a different representation of the world.

Type 5 would lead to a complete human body/person enhancement, affecting the whole set of capabilities. Notice that some persons are already using (in many cases illegally) chemical compounds that enhance their overall performance, including resistance to stress, improved alertness, removal of fatigue, higher muscular efficiency and so on. The more we learn about the working and physiology of our body, the more likely we are to devise ways of improving on it (of course the risk of side effects remain high).

*Extended phenotype modification - cognitive*

Improving alertness or focus can contribute to improving the cognitive capability of a person (utilizing coffee, for example), but it is not really changing the rules of the game. However, in the last few years there has been a boost of our cognitive capabilities by flanking cyberspace with our brain.

The amount of data, information, and knowledge existing in cyberspace is so huge that it won't be an overstatement saying it is unlimited. At the same time the ease of accessing this supplementary "brain" makes it part of our extended phenotype.

In the coming years this ease will keep increasing and will make the flanking even more effective, seamless and customized to the person and to the specific immediate context. We can say that the equation: "brain+computer = enhanced brain" has become true.

*Figure 21 A human through the use of a computer becomes an augmented human. Credit: IEEE SAS Initiative*

Cognitive augmentation has started with education and has improved with the use of computers and more recently with the seamless use of smartphones to access cyberspace. It will be further improved with:

- the presence of digital twins (contextualization and personalization)
- the use of artificial intelligence to distil knowledge and create information
- the use of swarm intelligence leading to the emergence of applicable knowledge
- the creation and adoption of seamless interfaces (augmented reality)

Interestingly, as happened in the past with mass education, this flanking of cyberspace to the cognitive space provided by the brains is extending the phenotype of enterprises, communities and the world's societies to an extent that can be compared to the invention of writing first and to the movable printer characters of the XV century. Actually a few sociologists are claiming that the growing pervasiveness of cyberspace in our society is going to have an even greater impact on our species' cognition capabilities.

The development of closely tied societies has shifted the relevance of knowledge from the individual to the society. Today companies are looking for areas where the level of education and experience is high, rather than to the knowledge of a specific individual, implicitly recognizing that the exposure to knowledge is even more important than the knowledge possessed by a single individual.

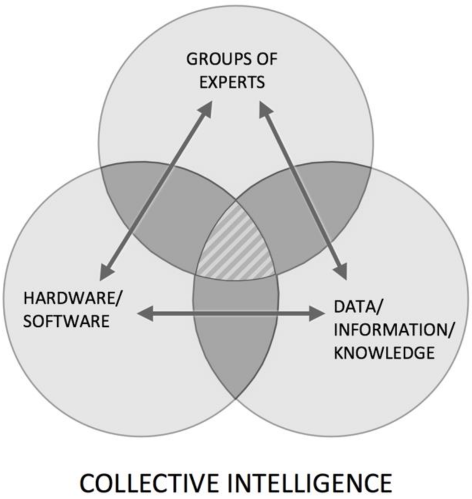


*Figure 22 Several initiatives are leveraging the increasing communications capabilities to create a collective intelligence, beyond the sum of individual intelligences. Credit: Millennium project*

One of the reason is the explosion of knowledge that can no longer be captured by a single individual. The possibility to access a distributed knowledge may change this. Companies like Unanimous AI harvest knowledge from people and complement it with knowledge harvested and created by Artificial Intelligence. Specifically, Unanimous AI is looking at medical knowledge, an area where both scientific and pragmatic knowledge is crucial and where both are expanding beyond the capability of a single doctor to manage.

By collecting experiences (practical knowledge) and autonomously browsing hundreds of thousands of articles in all medical areas, correlating them and distilling information to apply to specific cases, Unanimous AI provides (through a seamless interface) a powerful consulting mechanism to MDs to bring the collective practical experience and scientific knowledge to their specific case.

Similar approaches are being taken in a variety of industries, and the paradigm of Industry 4.0 is aligned to this, by flanking atoms and bits throughout the value chain and aggregating the competence of several companies, from row material harvesters to the end customers.

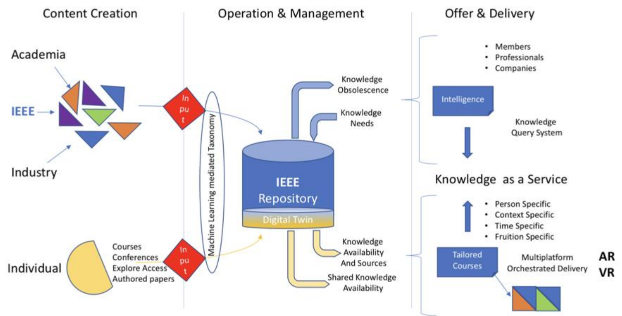


*Figure 23 Use of cognitive Digital Twins to increase the effectiveness of knowledge in the IEEE repository. Credit: IEEE SAS Initiative*

In IEEE Future Directions, as part of the studies carried out in the Symbiotic Autonomous Systems Initiative, there is a proposal to create cognitive Digital Twins to provide a tool to people accessing the IEEE *Xplore* repository for customizing the information and knowledge to their immediate needs. This can be a first step in a revolution of knowledge management, transforming knowledge from a product (hard to manage and slow to adsorb) into an effective service both at individual (professional) and at company/institution level.

Indeed, several sociologists are pointing to the flanking of cyberspace as an epigenetic factor that is influencing the individual, the culture, the society as a whole and the ambient we are living in (hence the epigenetics effects).

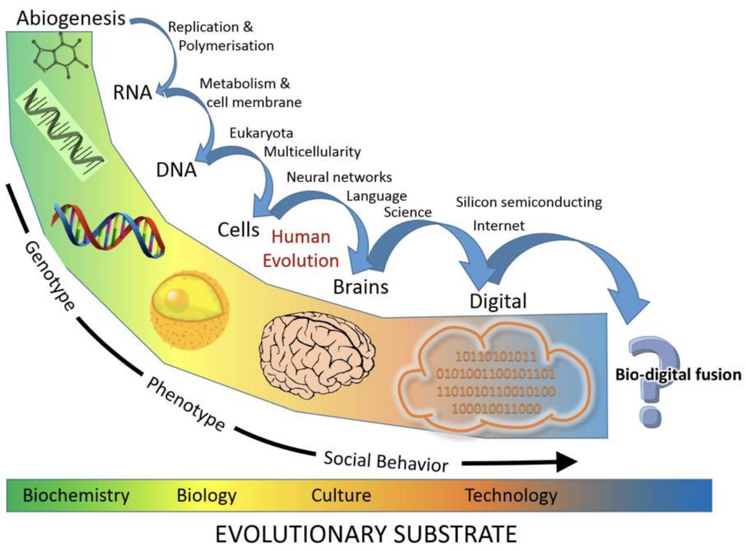


*Figure 24 Information in the Biosphere: Biological and Digital Worlds. Credit: M.R. Gillings, M. Hilbert, D.J. Kemp*

More and more effective, seamless communication (provided through 5G) is bringing minds together through a connection with data and through artificial intelligence and autonomous, evolving and self-learning systems and is creating a new species (from an evolutionary perspective). This is a sort of collective augmentation, leading to the emergence of a collective intelligence through a society-wide extended phenotype. In this, AI is going to play an important role and, it is likely to provide the glue for a symbiosis of humans and machines.

*Human Machine Symbiosis*

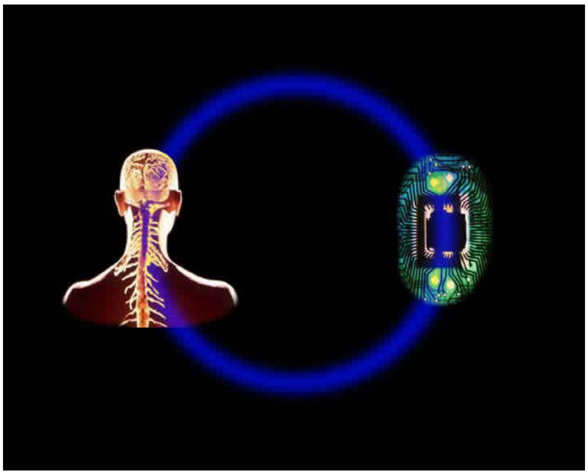

*Figure 25 The 10X MIT Media Laboratory program, aiming at increasing human's capabilities tenfold, by creating a symbiosis between human and machine. Credit: MIT*

The conclusion of the study carried out in 2018 by the IEEE-FDC Symbiotic Autonomous Systems Initiative projects that by 2050 it will be difficult to separate living from non-living things. Today there is on on-going debate regarding considering a virus a living thing. Some claim that since a virus cannot replicate without infecting a living cell it is not a living being but just an aggregation of molecules with some characteristics.

Some robots are showing an increasing level of empathy; however, they are not empathic - it is us who are perceiving them as empathic, intelligent, making autonomous decisions, learning and in the near future replicating themselves by creating offspring that inherit part of their characteristics and improve them. It may become, perceptually speaking, more and more difficult not to consider them "alive".

However, what matters here is that there will be a continuum among us and autonomous systems, sometimes a continuum between my "self" and cyberspace (and this latter is likely to happen sooner than the former). In a way, we are already seeing some social signs of this. Think about losing your photos because of a disk breakdown (or a smartphone that you forgot to back up or being stolen or falling into the swimming pool). It feels like you are losing a part of your "self". Smart prosthetics are becoming so seamless that they are no longer considered artificial parts, they become part of the person and the brain includes them in the body map.

We are living in symbioses with bacteria; we take lactic ferments to restore the bacterial flora in our guts. In a few years we might take bacteria supplements to change and improve the way our guts assimilate food; scientists might manufacture genetic variations of bacteria to improve our health. These can be seen as living prosthetics, that are actually artefacts made possible by technology. There are even some studies suggesting that a variation in the intestinal bacterial flora might relieve some symptoms of autism[26] and other brain disturbances.

Medical implants to monitor our health are bound to become more common as medicine becomes more customized and there is a need to monitor the effect and the possibility of dynamically changing the release of some drug molecules. These implants will become a symbiotic presence in our body, to the point that it will be difficult to live without them.

Our cognitive space will extend into cyberspace, in a continuum where it will be difficult to place a boundary separating the cognitive "self" from the extended self taking advantage of cyberspace. In a way it is already happening! Aren't companies hiring people on the basis of their capability to access distributed knowledge on the Internet? A person's value is a result of her personal knowledge and experience as well as the web of relationships she has and can acquire. Nowadays this web of relationships includes, as a crucial component, the familiarity with cyberspace.

In the coming decades the relationship with the cyberspace will become seamless, a sort of sixth sense. This will create a gap between those who have it and those who don't. Having an implant seamlessly connecting to cyberspace may become a competitive advantage compared to those who don't have it (as having a driving license was a competitive advantage in the past, as it is now a competitive advantage to know how to use a computer or by having a smartphone). In turn, this will push people to *require such implants*, quickly leading to mass adoption.

Welcome to the individual and societal extension on the phenotype changing what it means to be human. Human augmentation and machine augmentation are converging creating a new symbiotic creature.

Notice how more radical augmentation derived from genomic/phenotype modification has not been considered. Just by limiting the analysis to the extended phenotype, the symbiosis is demonstrated.

| | 2018-2034 | 2035-2050 |
|---|---|---|
| **AS as Objects** | Unemployment<br>Machine Ethics<br>Algorithms Fairness | Uploading values to SAS<br>Agents dominated<br>Dealing with AGI ASI |
| **AS as Beings** | Legal status of AS<br>Controlling Learning<br>Sharing<br>Responsibilities | Legal status of SAS<br>Consciousness ?<br>Mind Upload, Rights,<br>Accountability |

*Figure 26 Ethical Legal and Societal challenges framework for the coming decades. Credit: IEEE SAS Initiative*

If genome and phenotype modification are fraught with ethical and societal issues let's not fool ourselves into believing that extended phenotype modification does not create significant ethical and societal issues. Quite the contrary and in a sense, since the transformation is smoother and falling below most people's perception, it might be raising even bigger issues.

A few of the ethical and societal issues deriving from augmentation have already been addressed (specifically the widening gap between those who can afford to be augmented and those who cannot – notice that it is not just about economic affordability, it can be cultural or technology access as well). Augmentation is a two sided coin. Someone may complain because they do not have the opportunity to become augmented; others may complain because they are *forced* to become augmented. This latter aspect shall not be brushed aside. A few companies may de facto hire only augmented people (they can choose to hire people with a PhD today, tomorrow they may insist that only people with augmented cognitive capability can apply); others may require their current employees to take specific

[26] https://www.sciencenews.org/article/gut-microbes-autism-symptoms

professional courses to remain current. Consider the companies that will require people to wear smart contact lenses to become seamlessly connected to the internet thus able to access augmented reality at any time on the job (it might become essential for certain companies that will be splitting their manufacturing processes between the physical workshop floor and cyberspace). What about firemen being required to have their senses augmented to detect hot objects or the presence of dangerous substances? They are required today, for safety reasons to use certain devices to become alert of dangers. In the future those devices might be implanted and provide direct sensorial alert so there might be a case for a company to require employees to have those implants. And yet, how will people react? Even supposing you will have the option to opt in (and eventually opt out), will the social context be such that you will be forced to go along? There are plenty of situations where today we are forced to behave in a certain way, from dressing up according to an accepted "standard" to speaking in a certain way. And that might seem natural to us, but it is not. Societal rules are mostly taken for granted, and you may realize the imposition only when you find yourself in a different social context you are not used to.

Will a symbiosis between a human and a machine result in a symbiotic being that is legally recognized as such, where the two symbiont components (the human and the machine) lose their individuality? What kind of rights might a symbiotic being have, different from the ones of its parts?  It is clearly premature to address these kinds of issues but they are not black and white. The evolution will occur one tiny step at a time, and our grandchildren may find themselves in a new world resulting from technology we are developing today. Thinking about the consequences and how they should be addressed is clearly called for.

*Acknowledgement*

The editing and polishing of the text of this paper by Theresa Cavrak is gratefully acknowledged.