Knowledge in 2020

What will "knowledge" mean in 2050?

By Roberto Saracco

Introduction

During the first half of 2022, I was involved in an IEEE group inspecting the crystal ball to imagine what the world will be like, and concerns IEEE landscape and business opportunities may be interested in by the year 2050. The core biz of IEEE today, as it was for the last 60 years, is sharing peer reviewed information in the form of articles, conferences, and education courses (there is more, but that is the real core).

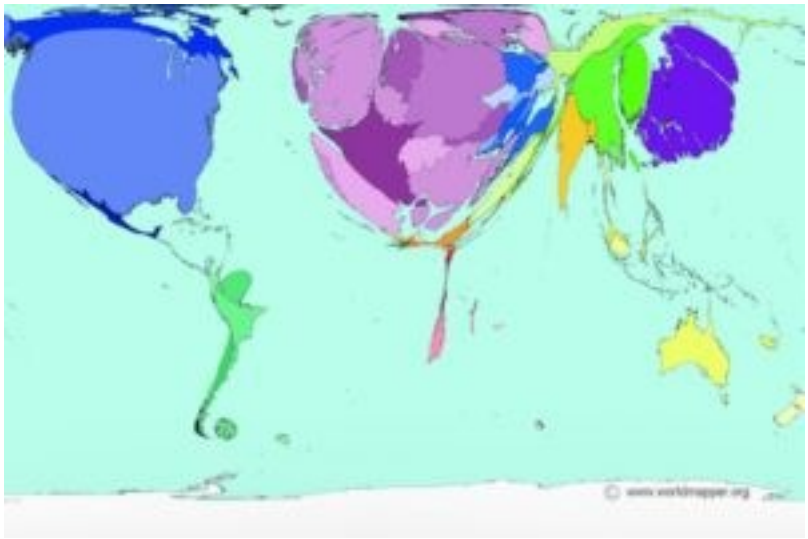

Figure 1. A very "old" (2001) but interesting graphic representing the relative size of world Countries with respect to number of scientific papers published in 2021. Notice that the size/shape of Australia is quite similar to its geographical size area. This means that the average of papers published by Australian authors are in line with the world average. The US shape is way larger than the one that corresponds to the area, meaning that on average there are more US authors than the average. On the other edge, Africa has a much smaller shape, signaling lower than average publication by authors from Africa. Image credit: worldmapper.org

1. Too Much Information

A major problem already visible today is that there is TOO MUCH information, to the point that digesting it is impossible on a human scale. Yes. in these last decades IEEE has endeavored to make information more easily accessible, but that does not solve the problem of the overload of information (in a way, it makes it worse). Notice, also, that the flooding of articles and the likes is a consequence of Goodhart's law:

"When a measure becomes a target, it ceases to be a good measure."

Academia has decided that the evaluation of merit should be based on the number of articles published, then supplemented by the number of references to those articles. That has been a force in stimulating paper production (there are also other reasons). For example, it is easier to write a paper, more opportunities to publish it, there are more people all over the world writing them, etc. Whatever the reason, the result is that we are drowning in information. This is when companies like Gartner become more valuable: sorting, distilling, and customizing information to fit a specific need at a specific time.

The creation of information will only increase in the coming years. Soon, machines will start creating "papers," i.e. information, and machines will become the largest user community of information. Machines don't go to conferences or subscribe to education courses. Most likely they don't need peer-reviewed information since they have a way to review it by themselves. Additionally, machines are lightning fast, so you can expect information to grow even more than today.

I may be talking about machines, but it is obvious that the engine is artificial intelligence (AI). AI natural language understanding, syntheses, and creation has enabled enhancement to an impressive level. Add to this a better than good translation capability, voice syntheses, image recognition and

creation, meaning extraction, and you have the perfect storm. The world of knowledge will not be the same by the end of this decade.

This will have profound impacts on education, business, the job market, and even on the "meaning" of knowledge.

Figure 2. Photo of the Rhind papyrus. It goes back to 1550 BC, approximately, and it is a testimony of the ancient Egyptian mathematical knowledge. Image credit: British Museum

2. Transmission of Knowledge

Knowledge must be sharable and must be understandable. Knowledge in a brilliant brain that does not communicate with anyone else is not useful (for all practical purposes, it is non-existent). Similarly, knowledge stored in data centers that have never been accessed is completely useless. Accessing knowledge is not enough, it needs to be understandable. Ancient Egyptian knowledge faded away in the first centuries of the last millennium as humanity lost the capability to understand hieroglyphs. The Rhind papyrus shares with us the ancient Egyptian knowledge on math (at least part of it), but this sharing was possible only because Champollion provided the key to decipher the hieroglyphs in 1824.

Today, the English language is a tool most people use to share knowledge in the scientific domain. However, important pockets of knowledge are represented in other languages, Chinese being the most used after English. The barriers created by languages are fading away thanks to artificial intelligence. Today I read articles originally written in Chinese, courtesy of Google translator. Of course, I must trust the translation as I do not, in practice, have any way to verify the accuracy. In other words, I am content if I feel what I am reading makes sense and if it gives me food for thought.

In a way we can say that the language barrier to knowledge access is fading away.

What I often do is look at graphics. I like the ones created by the World Economic Forum (WEF), Gartner, and McKinsey ... Notice that all these companies are in the business of making knowledge meaningful and easily understandable. Since an image is worth a thousand words, they often publish their meaning extraction in a form of graphics.

One of the problems with these images is that they "hide" the precise knowledge on which they are based. Often you have access to that, but most of the time people process knowledge just by looking at a graphic. A caption usually explains how to interpret the graphic and helps re-enforce knowledge sharing and understanding.

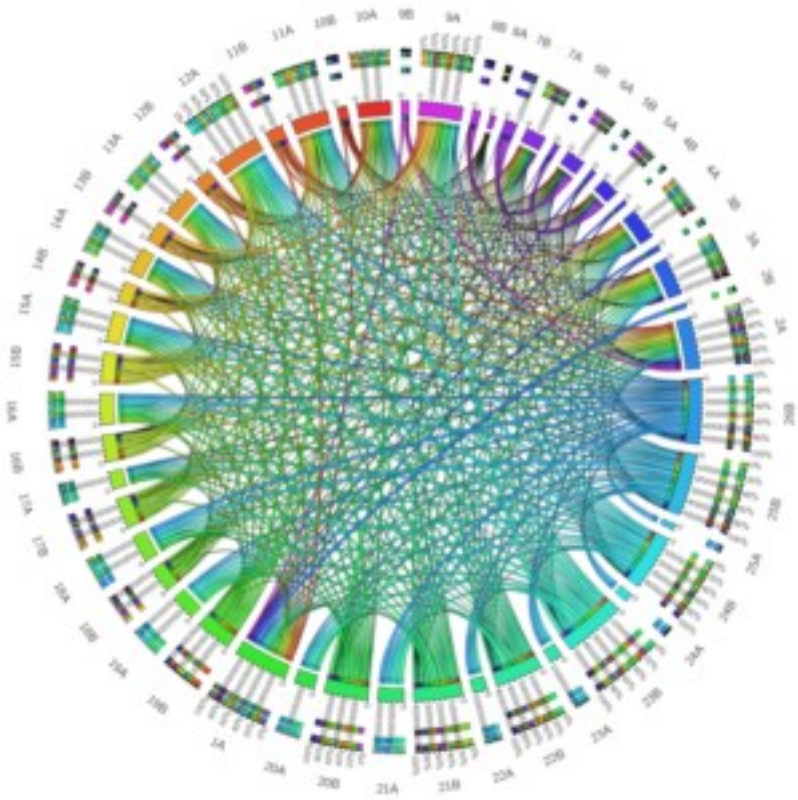

Figure 3. A graphic I generated to show the correlations among different factors influencing the future of jobs. Data has been created by an IEEE group I participated.

Another way to use graphical representation is by having knowledge emerge from them. For example, you may see a table with an abundance of data, so much so that it is basically impossible to digest. By transforming data into a graphic, you often succeed in having knowledge emerge. Graphics can be both a shorthand notation for knowledge representation, and a way to stimulate thinking, thus leading to the "creation" of knowledge.

For example, look at the circular diagram on the left-hand side of the page. This is a graphic I created from a table reporting correlations (in the form of numbers up to the 8th decimal point). This can be much more effective than trying to understand thousands of numbers.

However, and this is the interesting part, when I shared the resulting diagram, a discussion started amongst some of the group participant on "what is the meaning" of the graphic—what knowledge can we derive from it.

I am pointing this out because if it is true that graphic representations can be easier to grasp, making them more meaningful, it is also bound to generate "different" interpretations. This will create different, subjective knowledge spaces.

It is true that you should always be able to go the data source to try and understand the true meaning, but in practice we never do that.

All this rambling is to highlight a new wave of knowledge transfer, based on the computation of raw data. This is what we will be seeing more and more of as knowledge is accessed "through" machines that are responsible for rendering the raw data in ways that can be understood and can provide “meaning." The rendering requires intelligence, and, more so in the future, artificial intelligenc is and will be a crucial component of knowledge transfer, and in a way, of knowledge creation.

Virtual Reality (VR) and Augmented Reality (AR) are just two technologies that we will be using to access knowledge. As discussed, they will also create knowledge, and these creations are bound to be biased.

Following this discussion, we can state that:

- Knowledge represented by "raw" data is becoming impossible to digest due to the sheer volume of incoming data.
- There is value in the rendering of data using AI, AR, VR. In the future, a significant chunk of the perceived value will be derived from these three technologies.
- The very act of rendering is crucial, but it is subject to potential bias and errors. Trust in the rendering (i.e. in the organization/software that perform the rendering) will be an essential component of the perceived value.

The corollary is that IEEE will need to transition from being a trusted repository of knowledge to a trusted transfer knowledge service provider.

3. Knowledge Contextualization

Figure 4. Scrolls disrupted the transmission of knowledge making it possible to kill space and time barriers. Image credit: Barakat

Since the invention of writing, knowledge sources have been decoupled from the knowledge consumer. This, actually, was a great step forward in the dissemination of knowledge since it killed space and time barriers in one stroke. A parchment could be sent thousands of miles away and read at a later time. Additionally, this decoupling also made it possible to consume the same knowledge over and over by several recipients (as long as they could access the parchment and, of course, know how to read it!).

As good as the invention of parchment was, the printing press was ten times better, slashing costs and making it possible to produce multiple copies, thus reaching a much broader audience.

Now, lets jump to the Internet. Knowledge is potentially accessible by anyone, anywhere, anytime. Still, with few exceptions, the paradigm of one source multiple users have has remained unchanged. Yes, the decrease of cost and the tremendous expansion of the capabilties have allowed customization, for example, “books for kids,” courses for graduates in a specified university … Different users (market segments) can choose what they like better.

Technology is promising a change in knowledge access that is likely to be as disruptive as the invention of writing and the printing press by enabling the possibility of customi.ation. To the point of becoming the so called “market of one.”

Enter the world of Personal Digital Twins—this technology is just taking its first steps. It derives from Digital Twins technology applied in industry and has been focused on personalized healthcare. The basic idea is to create a digital mirror of a set of a persons characteristics (creating a digital model of those characteristics), and through the use of sensors (like wearables for healthcare applications), we can keep these models in synch with the “real” person. Moreover, the Personal Digital Twin can keep a record of the evolution and status of the person (an extended EHR in healthcare).

What can really make a difference is the embedding intelligence that can ebable Personal Digital Twins to make sense of the context and the status of the person and to suggest (or even take) corrective actions.

Cognitive Digital Twins are an extension of the Personal Digital Twin to the knowledge area. They mirror the knowledge of a person, and an embedded intelligence could spot gaps and shortcomings of the knowledge owned by its physical twin (the person). Spotting gaps requires an understanding of the owned knowledge, the existing knowledg,e and, crucially, the needed knowledge. A gap will exist only if the knowledge needed is broader than the one owned, and if such knowledge exists … somewhere.

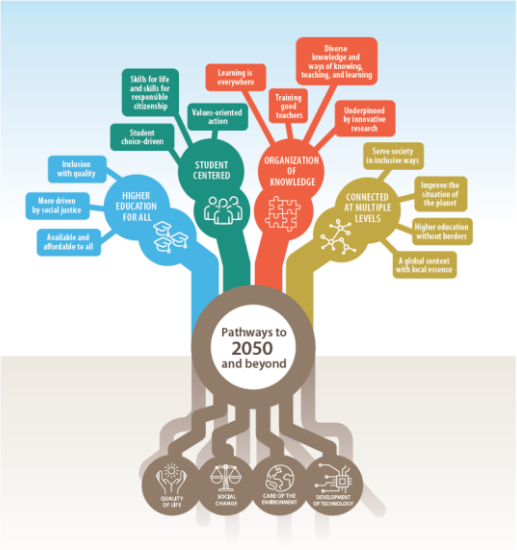

Figure 5. Education is most likely to change in terms of tools and goals by 2050, taking a much more global approach. Knowledge, as such, will be considered available, and the main point of education will shift to make use of this distributed knowledge. Image credit: UNESCO

4. From Knowledge Access to Augmentation

Now, lets take a time machine into the future—Welcome to 2050, a time when we are all (or most of are) living in the Metaverse consisting of a continuum of both digital and physical entities. It is perceived as a single space because the co-presence of digital and physical entities are seamless. Our eyes, and our minds' eye, can roam both. Barriers stil exist in the physical space, but often these can be overcome through the digital space.

If we are all living in the Metaverse in 2050, the young generation will have grown up in the Metaverse (those completing today's equivalency of an undergraduate degree). We had to learn it, and they need to grow "in it."

Knowledge continues to grow at an exponential rate. We were overwhelmed by it a few decades ago, but now we see it as an integral part of our living space. Marvin Minsky's explanation of common sense from the early 2000s is now embedded everywhere—in people, devices, and environments.

In the future, recent university graduates will have grown their Cognitive Digital Twin (CDT) throughout college and early academia. It is essentially a curriculum vitae on steroids!

Similarly to how a cv provides a record of ones' learning and professional experiences, down the road, people will have them in the form of a CDT that can be used, and even transferred (under the physical persons control) in specified scenarios. It will become a knowledge avatar that the physical person can use when engaging in activities within (the digital part of) the Metaverse, which will have grown to embed experiences gained through exercises, projects, interactions with other students, professors, industry professionals, and more. Even more fascinating is the broad set of trusted relationships that have grown to provide access to massively distributed knowledge, one of which connects to IEEE.

Previously, the connection was in the form of membership which providied access to the IEEE knowledge base, but now, in 2050, it will become an educational subscription service for distributing knowledge. Many students will maintain their IEEE membership throughout this transformation since IEEE enables connecting and networking with like-minded people.

By subscribing to IEEE, as opposed to other knowledge providers, a person can empower their CDT to access knowledge from that provider. The CDT can negotiate services with the knowledge provider, for example if there are changes in the knowledge base.

Embedded Artificial Intelligence (AI) will manage the interaction and make "sense" of the outside knowledge space, picking up parts that are of interest (while remaining connected to the whole knowledge space), and will implement the additional knowledge if needed by a specific person, at a specific time. The rendering, or the presentation of knowledge, will be fully customized to the person, place, and the occasion so that it can be leveraged immediately.

Does this mean that every one will know everthing and there will be no cognitive differences among people? Absolutely not! The specific training, attitudes of a person, their character, and so much more will determine the effectiveness and use of the available knowledge. Similarly to how things were in 2020—Every one had access to the internet, but the way this access is leveraged is unique to each user.

What happens with students will happen for every one, even for companies. Actually, a company is more likely to have its own CDT that will set up links to IEEE and other knowledge providers. The name of the game, for the providers, is the ability to deliver relevant chunks of knowledge in a usable manner, and, of course, to be recognized as a trusted party.

Some knowledge providers started developing CDTs of their clients in the previous decades creating both a de facto standard and a dominant position in the knowledge market. Eventually, these CDTs migrated under person (or client) ownership, with the knowledge provider supporting them through platforms that are open to third-party services (used as plug-ins by the CDT).

This did not come easy, nor cheap. Significant, incremental investment over the years in software, particularly in AI, has proven crucial. More than that, this has required a change of mindset and business relations. Bisomesses needed to transform from knowledge warehouses into a knowledge service providers with continuous and specific relation to their clients.

The end result, however, was worth the effort. Now their clients are augmented with knowledge at the tip of their fingers, without the need to access it.

4.1 Pervasive Knowledge

In the 2050 scenario described above, I pointed out that knowledge will no longer be perceived as overwhelming, but rather as a property of the space (metaspace) we live in. In other words, knowledge becomes pervasive—It is available when and where it is needed.

Figure 6. Isn't a restaurant QR code an example of pervasive knowledge that can be seamless accessed? Image credit: Emrah Sıtkı Yılmaz

Think about it, we are taking the first few tiny steps in that direction: when we dine at a restaurant, a QR code tells our smartphone where to go to look at the menu, and thanks to the pandemic, this has become a seamless experience. Simply point your smartphone camera to the QR code and start browsing the restaurant menu. Similarly, many every day devices no longer come with a printed instruction manual—the "manual" is either built-in, like in modern cars and televisions, or it is as close a QR code is to the nearest smartphone.

Yes, these are indeed "tiny" steps, but they're clearly showing the way. Knowledge is out there, and what we need is a way to grab a link bring knowledge to your fingertips. AR devices will become an integral part of our every day

life, and 2050 is a given! The better question is “when,” nott “if,” knowledge will be readily available.

A crucial component for this transformation is contextualizing knowledge that you “see and digest” tailored to your context. Therefore, it will be quite different from today’s restaurant QR code that brings the same menu to every one. In the future, one person will be seei a menu that takes into account their taste preferences and possible allergies, listing only the items that best fulfill their needs, and there may even be a second section included advertising other items that the person might want try. I understand that this example may seem out of place when talking about “knowledge,” but it is interesting because it shows that knowledge in the future will not be something abstract and unrelated to whom needs it.

Rather, in the future. “knowledge” will be:

- Seamlessly available;
- Presented in a way that can be effectively used (takes the user experience into account);
- Related to specific needs (it will take into account “why” a person is asking);
- Fit in the context (it will be applicable at a particular time, and in a particular context)

The knowledge adaptas to the user, the context, and also to the device, and can be mediated through a Cognitive Digital Twin... At least we think this is the most promising technology that we see today. However, in thirty years, it might be something different, but alas, the functions performed will consist of adaptation and contextualization.

Interestingly, the ambient will also be part of the global knowledge, and in many situations, people won’t have to explicitly access knowledge, it will automatically become available in the ambient.

Typically, the working environment (including robots on the shop floor) will be pervaded by knowledge that is available within a certain vicinity of that ambient. Of course, it will be tailored to that ambient and to the specific needs of people and machines.

With one hand. the pervasive presence of contextualized knowledge is seamlessly augmenting peoples’ knowledge, or their capability to execute tasks, both manual and intellectual. This is fostering knowledge transfer through continuing education, and it is going to reshape the way we “learn.”

4.2 What Happens to Formal Learning

I recently read a thriller by Robin Cook, *Charlatans*. As usual, he created an engaging plot, while at the same time, it makes you think of the unexpected twist brought forward by the evolution of technology. In this (fiction) story, one of the characters is an anesthesiologist that is hiding a secret (revealed at the very end, of course) that she did not graduate from medical school and never completed a medical residency, but managed to get hired by a prestigious hospital by doctoring her resume online and forging paperwork to demonstrate that she completed all of the required education courses. The point, however, is not about the forging, but rather about her capability to perform in her role. She had proven to not just be good, but perhaps even better than all of her colleagues as nobody ever suspected that she was not adequately trained.

What got me thinking was her explanation and response to another character/colleague when he discovered that something was not right and questioned her about it:

"The Web is providing all the knowledge you need, and you can learn at your own pace, way better than following a course. You have everything at your fingertips, it is up to you to decide how much you want to learn, and more than that, if you embark in this way of learning you'll discover that you will keep learning every single day—spending time every day to enhance, and update, your knowledge. In addition, there are simulators that will allow you to practice, as long as you need or want, telling you how close you are getting to perfection. There is no need anymore for formal training, you can have it, and have it better on the web. When you will engage on a job you will be asked to prove that you have the knowledge and the skills, not what type of formal training you have. What really matters is how you can perform, not how you acquired the needed skills."

I feel I can relate to this, yet most of our world is still based on formal papers. Possibly because they can provide an a-priori assessment of your skills. However, it is becoming much easier to test, document, and demonstrate your skills via software (artificial intelligence in many cases). This way, an employer can gauge first-hand on the specific task you will be required to address.

I guess this type of evolution is inevitable as the number of formal employers will shrink, giving space to one shot jobs, possibly requested from the other side of the world.

For example, Google started using AI to screen job applicants (they receive so many that this has become the only way to process all of them). More recently, they released *Interview Warmup*, an AI-based software helping applicants prepare for real interviews. It is a short step from letting AI screen applicants to carrying out the interview (at least in the beginning), but I bet that in the future, AI may be leveraged to make decisions on which applicant to hire, and for what role.

Formal learning remains useful for many people (students and professionals alike) when there is a need to for teaching and stimulating learning, or what I would call "forced education." In addition, in this scenario, we can hypothesize that by 2050 software will have progressed to mimic teachers, and provide personalized learning/tutoring experiences. We can also expect an evolution in the culture and traditional customs that "force" people to learn as their social duty.

Enhancing technology is not the only big hurdle in this evolution—we must also take into account that this may result in millions of teachers losing their jobs.

I expect the transition from formal to informal (although reviews) learning will evolve from the expansion of continuous learning-focussed professionals. This is going to become an integral part of many professions, and it will require customization both in terms of what to learn, and how to learn (at a specific person's pace). This will evolve and become increasingly software-supported throughout this decade (Cognitive Digital Twins will likely be an important tool), and emerging sws will start contaminating "formal" learning. By 205,0 I expect a significant share of all learning will no longer follow today's formal channels.

4.3 Executable knowledge

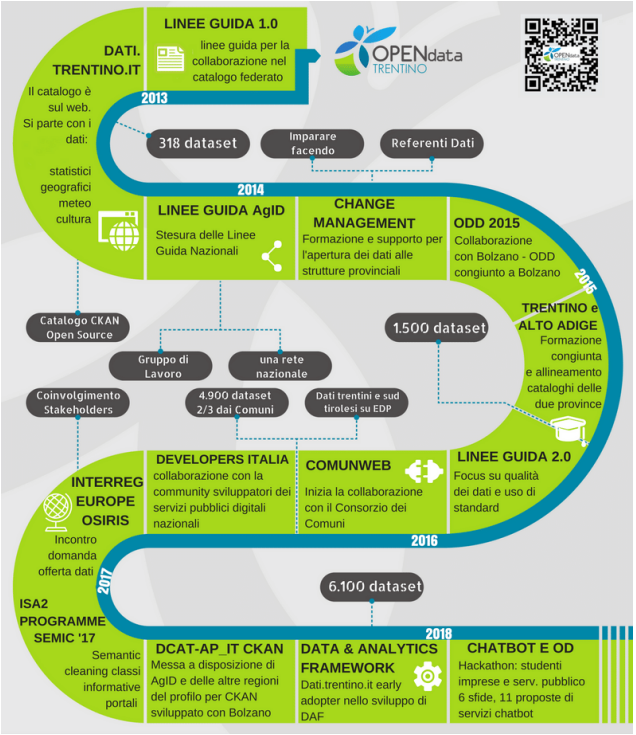

Figure 7. The roadmap followed by the Trentino Region in the development of their Digital Platform. Image credit: Francesco Flammini

If you go back to the web in the last century, and, partially, to the first decade of this century, you'll notice that you accessed the web via a browser. The web was a gigantic, and growing warehouse of documents (similarly to how IEEE eXplore is a warehouse of articles). Ever better browsers flanked by search engines gave you the capability to find and look at what you wanted.

The landscape changed dramatically with the advent of apps (and the iPhone was surely a breaking point in this respect). Nowadays, we are still using browsers and search engines, but a significant portion of our web usage occurs via apps. Apps are mediating our needs with service providers of some sort.

Apps are evolving and becoming smarter. They learn about us as we use them and thus are able to finely tune the interactions to our needs. Some apps work in the background by acquiring data that might be of interest to have available in the backend, ready for the next time we use the app. Some go even further, generating messages to capture our attention.

The appearance of intelligent assistants began in the last decade. They were moved from being a curiosity to taking a centerstage in our daily interaction with cyberspace, and even with other people (socially and in the business environment). The progress in artificial intelligence has been the enabling factor.

A very similar path will be taken by knowledge and knowledge access. Knowledge services embedded in apps will provide the knowledge that we need, when we need it, and in a form allowing us to apply it. This is what is called executable knowledge.

The packaging of "data," with an interpreter of those data that can interact with an access agent, is transforming the knowledge landscape. Data in a data center, a company repository, in a research center, and in academia will no longer be a static entity. I know I will generate some discussion and opposition with what I say next, but they will become, in a way, self aware of their potential "usefulness."

I have seen this happening, although on a smaller scale, with the initiative "Open Data Trentino[1]" provided by the Province of Trento when I was at the EIT Digital Italian Node. The idea was to make all data stored in the many (some 120) data bases of the Province available to anyone interested. The data was encapsulated and made accessible only via Application Programming Interfaces (APIs), or pieces of software that will respond to a query by a user, not providing the raw data, but rather the meaning that is significant to that specific query, a meaning that could be

[1] https://www.interregeurope.eu/good-practices/open-data-trentino-increasing-data-culture-in-the-innovation-ecosystem-for-a-data-driven-economy

derived by performing data analytics on all the data sets (potentially). The idea was that as more data becomes available and data analytics evolve (read inclusion of artificial intelligence), it would be possible to offer more and more meaning to a growing variety of users—in other words, ideally allowing us to extract more and more value from data. The Open Data Trentino initiative intended to stimulate the sharing of private companies data as well, and to my knowledge, it was the first, basic attempt to develop a system capable of delivering executable knowledge.

The following, notable aspects were tackled:

- Providing a meaning that was derived from many data sets – the system tried to "understand" the query and worked out the necessary actions to retrive the meaning disseminated in the data;
- Providing a framework that was preserving the ownership of data;
- Protecting the data owners from potential undesired issues of misuse of their data
- Providing a mechanism to extract value from the data and share the economic value resulting from the use of data with the owner(s).

To my knowledge, the Open Data Trentino initiative has proven its value in stimulating the opening of data by private companies. However, its full potential has not been pursued (i.e. it is still looking like a more advanced data center rather than a knowledge service center).

4.4 The "Softwarization" of Knowledge

Executable knowledge is both something that can be put into action by a person as well as something that can be executed by a machine. i.e. a piece of software, hence the requirement to be understandable and applicable to the present situation).

There is a major trend in the software production area, often referred to as "low code-no code." Basically, as the name suggests, moving from the description of the solution to a problem to the development of that solution in software is becoming possible even with very limited programming knowledge (ideally with no programming at all). Clearly, software still needs to be created, assembled, and integrated into a working system, but the assumption is that there will be a growing amount of software snippets available that, like Lego bricks, can be assembled into a working system (with very limited programming capabilities), like Lego bricks, can be assembled into a working system.

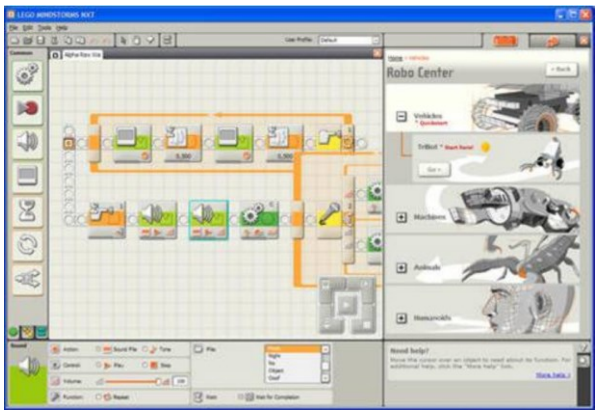

Figure 8. The Lego Mindstorms programming language, NXT, was designed for kids and people with no programming background. It is a matter of joining blocks, and their shape tells you if they can fit together or not. Image credit: MIT

I am making a reference to Lego bricks because the first example I saw of low code - no code was in the Lego Lab at Massachusetts Institute of Technology (MIT). MIT was asked by Lego to develop a new generation of "bricks" that could engage an audience that has become more demanding (kids adapted to Nintendo and other video games and started to favor them over Lego). This resulted in the Lego Mindstorms—using Lego bricks, children can create a variety of robots and make them perform different tasks by programming them with a graphic language created in shape of 2-dimensional bricks. Each brick was a

piece of software that, when assembled with other bricks, resulted in a system operating the robot. It turned out that Lego Mindstorms created a new audience, grown up kids like myself, pretending to teach their sons and having fun at the same time.

This approach is now being used for industrial applications, and it will soon permeate many business and production environments. As software becomes pervasive, there is a need to enable people that have very limited to no skills in software development to use it.

My bet is that many researchers, both in academia and industry, will develop their "knowledge", i.e. the result of their endeavors, in the form of software snippets that could be combined and assembled in many ways to create a functioning system. These executable knowledge chunks will transform the knowledge market by providing a much higher value to users.

4.5 Knowledge Augmentation

4.5.1 Machines Expand the Knowledge Space

Machines and Artificial Intelligence will play a crucial role in creating, managing, and making knowledge usable. In some areas, like genomics, we are already seeing how AI has become indispensable not just for managing an overwhelming volume of data, but also to extract knowledge from this data. The hope of connecting the genotype (the sequence of codons making up the genes and the expression of genes) to the phenotype (who we are) is based on AI. It is already difficult and time consuming to associate a specific gene to a phenotype characteristic, and associating the hundreds of genes and their expressions that can influence a specific phenotype characteristic is an impossible feat. To name one example, try to understand the role of genes in Autism Spectrum Disorder (ASD) as a starting point. Look for a remedy would not be possible without AI (notice that AI is a tool, it is not a solution—we are not going to solve ASD just by applying AI to it, but we won't be able to solve it without AI).

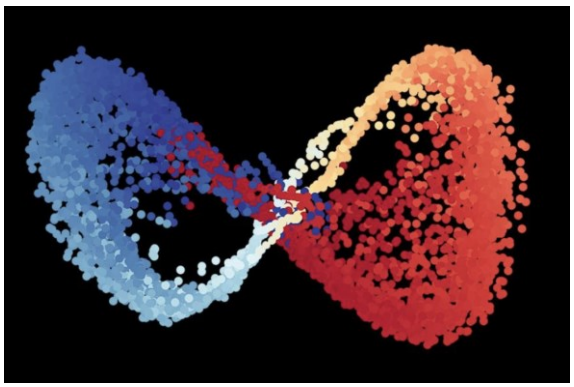

Figure 9. Through observation of physical phenomena, AI has extracted a number of (unexpected) variables that can be used to develop a physics theory. Image credit: Boyuan Chen/Columbia Engineering

AI is already augmenting our knowledge from the design of alloys, to the evaluation of safety in large urban environments, and even from logistics to financial markets. Notice that I am not talking about the use of AI to "solve" a problem, rather using AI to "create" knowledge.

Researchers have been using AI to enable robots, for example, to become aware (to develop knowledge of their environment and take decisions), and evaluate the impact of those decisions, which basically is creating knowledge about possible futures…

We have seen AI proving math theorems,[2] and we also have AI creating new theorems[3], therefore, new knowledge[4]!

[2] https://www.it.uu.se/edu/course/homepage/ai/vt05/AI-theorem.html
[3] https://www.iflscience.com/researchers-create-ai-that-can-invent-brand-new-math-theorems-61816
[4] https://scitechdaily.com/artificial-intelligence-discovers-alternative-physics/

By the end of this decade, we can expect that knowledge creation by AI, and through AI, will start to exceed knowledge creation by humans.

Add to this the creation of knowledge by humans made possible through the use of AI, and you get a picture of the crucial role that AI will be playing in knowledge augmentation.

However, when I am talking about knowledge augmentation, I am not *only* talking about the knowledge "created" by AI, but rather about the flanking of AI to make knowledge available when and where a person needs it.

4.5.2 Intelligence Augmentation

How many times do you pick up your smartphone to search for a restaurant? obtain directions for an address or find the age of an actor? Perhaps the date of occurence for a historical event? Try calculating a percentage—I bet so many times that you don't know how many. Besides, most times you did not even perceive you were delegating to a third party, or a machine, the role of "knowing."

A pilot has a host of information about the engine status, the route, and so much more at their fingertips. This is more than information—it is knowledge derived from a variety of sensor data and communications with other machines (software), presented in a seamless way. The cockpit is the ambient of a pilot, and it is full of machine generated knowledge. In the past, the cockpit only presented data, but today what you see is the knowledge developed by software that receives data from thousands of sensors, often many times per second, and transforms this data into knowledge. In fact, flying a modern aircraft would likely be impossible without this "knowledge." Interestingly, you and I won't be able to use that knowledge because we do not have the "knowledge" required to match the one provided by the machine. The pilot's knowledge on how a plane works and what is needed to fly it from A to B is flanked by additional knowledge that makes their task possible or even easier.

We are moving towards a world where ambient knowledge will seamlessly flank our knowledge, augmenting it. We are going to become smarter because of this, similarly to how we become more intelligent by reading books and listening to/learning from our teachers.

Unfortunately, while some people, including a few school teachers, consider the leveraging of machine's generated knowledge as a diminution of our mental capability. Similarly to how, for a while, the invention of writing was considered to be diminishing human memorization capabilities since one could rely on written text as memory. Most agree that because of the increasing complexity of out ambient and capability offered by machines, this is not an inevitable evolution, but it is a tool to augment our intelligence (as writing proved to be).

The knowledge provided by machines enables us to do more, and that includes more reasoning and sharpening our intelligence in the same way that listening to another person stimulates our reasoning. This is a crucial point—Intelligence augmentation goes beyond the access to an extended knowledge space...It provides, through our brain, food for though.

An amazing, and possibly very human characteristic, is the abstraction capability (being able to build ever more complex reasoning and taking a set of knowledge and thought processes (such as when a child sits on an adults shoulders to gain a better view). Today, the average high school kid is likely more "intelligent" (as measured by IQ tests) than Aristotle and Leonardo da Vinci, simply because of the stratification of knowledge that has sedimented in the ambient through the centuries. An Aristotle's mind today would be able to rise way higher than in the past simply because it can take so much knowledge as a given.

A growing number of AI experts are now stating that the real goal of AI is to enable IA: Intelligence Augmentation.

4.5.3 Leveraging from Intelligence Augmentation

As pointed out we are *already* augmenting our intelligence with a variety of tools, the smartphone and its apps being an everyday experience. Workers on the shop floor augment their intelligence using knowledge that is provided in the work ambient, by robots, by processes (before doing this check that….). Future looking companies are leveraging on these possibilities to provide continuous education.

We are also seeing an evolution from a "static" knowledge (and related static intelligence) where tasks are allocated among humans and machines on the bases of who can do what, to a dynamic landscape where both humans and machines learn from doing and from each other.

In this new landscape the allocation of tasks is both steered by the need to accomplish them and by the aim of increasing the overall system intelligence. It is continuous education on steroids and it can be organised in such a way that the system self-learns and improves. This has been the case in a few companies that stimulate the professional growth of their workforce and translate that growth into a continuous re-engineering of the company (it is not easy since most management dogma insist on stability, don't change what works!).

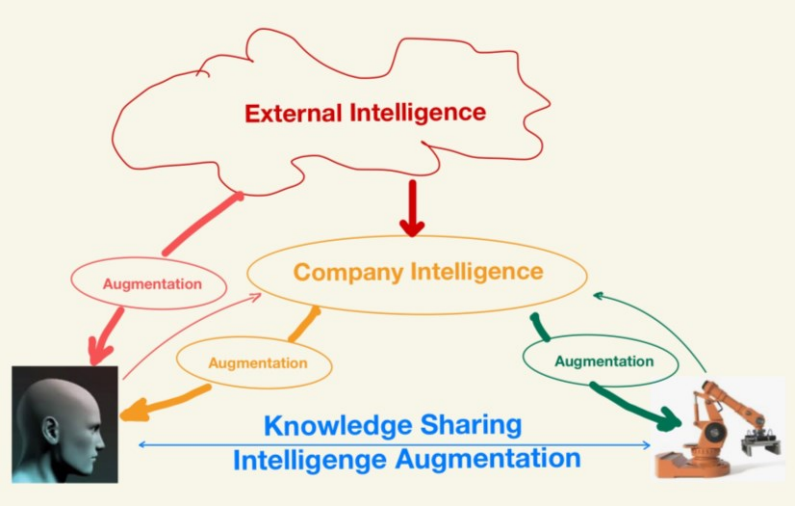

Figure 10. Both Knowledge and Intelligence are distributed and it becomes possible for both humans and machines to leverage on this distributed asset to augment their own intelligence. A company may have its own formalised knowledge and intelligent space (often creating a competitive biz advantage) that is used to increase local intelligence and manage knowledge resources.

It is also the case, lately, for machines: these have acquired the capability to learn as they operate and can self-adjust based on results so that they get better and better.

My bet is that the next frontier in intelligence augmentation is the capability to leverage from it: by augmenting the overall company intelligence (as the personal one) the company fine tunes its processes and its products in a path of continuous amelioration. Of course a corollary to this is that a company needs to know what its current intelligent is, how it compares to their competitor intelligence and how it can grow further its intelligence. Notice the paradigm shift from "knowledge company" to "intelligent company", with the latter emphasising on how to increase its knowledge and how to leverage/apply it.

What goes for a company goes for the individual. The augmentation of intelligence should not lead to a delegation of intelligence to the external ambient, rather it should be a lever to increase the internal (brain based) intelligence. This is what, I feel, will keep preserving differences among different people. There will be some that will see the access to intelligence augmentation as a way

to lay back and delegate; others will see this as an opportunity for continuous improvement of their capabilities. These latter will be able to increase the value of the intelligence augmentation, since their internal intelligence will keep growing to make the most out of the external one.

This is the fundamental reason why I do not share the concern of some observers that artificial intelligence will kill natural intelligence. This is also the reason why most people will not lay-back: competition will force everybody to become smarter, i.e. to grow their "brain" based intelligence, taking advantage from intelligence augmentation to keep growing their own. The external intelligence providing augmentation will become a sort of commodity (anybody can use a smartphone) but the value delivered, i.e. the amount of augmentation, will depend on the brain based (internal) intelligence.

As represented in figure 11, there is a difference between the presence of intelligence in the ambient (that in the cyberspace co-exist in proximity to all other ambient) and the one embedded in a company. The former is unstructured, owned by different entities and becomes visible once the owners share it -explicitly or implicitly; the latter is -or should be- structured (hence the representation of the former using a cloud and of the latter using a well defined set). The augmentation through this intelligence is structured, i.e. it happens through tools (like a smartphone, connected software, …) and processes (mental processes on the human side, organisation defined processes on the company side).

The challenge for humans is to learn to leverage from this available intelligence and for a company to use intelligence as a resource managed by company's processes.

4.5.4 Intelligence by proxy

A crucial point, and a stumbling block, in this idea of intelligence augmentation (and knowledge sharing) on the human side is:

> how can a person leverage on external intelligence?

that, in turns prompts the question:

> how can this external intelligence "merge" with the person intelligence, effectively augmenting it?

The answer to the first question requires that a person has seamless access to the external intelligence that applies to the current situation, the answer to the second question requires that the external intelligence is delivered in such a way to couple with the existing intelligence, i.e. it should make sense to the person. This is particularly important

as we consider the responsibility aspect that in the end will remain on the person's shoulder. Hence, the person needs to understand the intelligence booster provided.

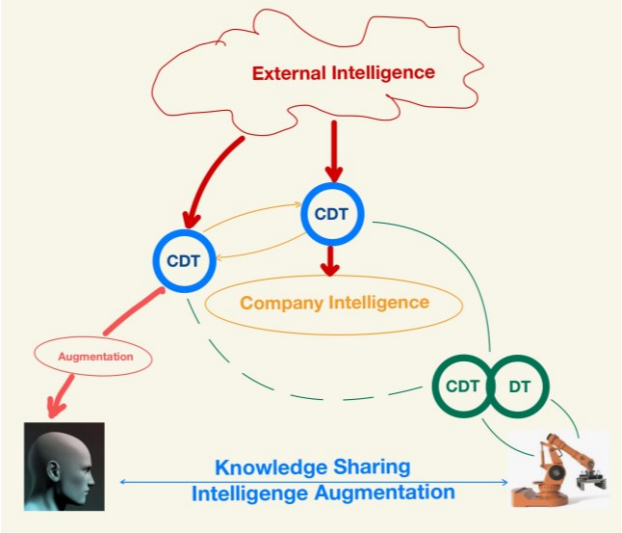

Figure 11. The Cognitive Digital Twin, CDT, can be used both for the human and for a machine (they have been proposed first for application to smart robots by IBM). The CDT of a human can interact both with the Company CDT, embedding the company wide intelligence, and with the external intelligence. The human intelligence augmentation is the result of the "use" of the external intelligence by the human brain. In turn this contributes, via the Person CDT>Company CDT to the company intelligence. In case of machine the augmentation is mediated by the Company CDT and affect the Digital Twin of the machine, i.e. its behaviour. In case of smart, self-learning machines, it will also contribute to the company CDT intelligence.

Satisfying both is challenging. As already pointed out access to external intelligence (and knowledge) once there is so much of it available may be beyond our human capability. The fruition of intelligence requires an adaptation that has to take into account ourselves and what our needs are here and now. What is needed is a proxy that can intermediate the external space with the internal (brain) space.

The Digital Twin and the Cognitive Digital Twin may play this "proxy" role.

As shown in figure 11, the Cognitive Digital Twin, CDT, is intermediating the access to knowledge and intelligence, making both available as needed by the person. The whole mechanism of searching, assessing and customising the knowledge is taken care by the CDT. From the human perspective this knowledge is transformed into a flanking intelligence, ideally seamlessly present whenever and wherever needed. You are looking at your car and find out a light beam is broken. Your augmented intelligence is there to let you know how to access the lamp and replace it (I can tell you that replacing a beam light on my BMW turned out into a nightmare and I had to resort to YouTube and watch a video with instructions provided by some bird of feather . That required a search, watching and rewatching the clip as I progressed in the task all the while wondering who in heaven designed the beam without any concern for the lamp replacement!). Have I had my CDT handy and seamlessly interacting with me it would have been a piece of cake.y CDT

As shown in the graphic, the person CDT, when in the context of a working environment will connect to the company CDT (assuming that company had developed one, something that in the future is most likely the case), will be getting intelligence from the company and provide intelligence to the company.

In case of machines these will have their own Digital Twin that could have been extended to include the mirroring of the knowledge and of the capabilities (intelligence) of the machine. In the graphic this is represented by the partially overlapping DT and CDT. The machine DT/CDT will draw intelligence from the company CDT and will be "de-facto" an integral part of that CDT. In some cases, when the machine is an autonomous system and

has self-learning capabilities the machine CDT will augment the intelligence of the company as it acquires more intelligence itself.

The dashed line connecting the person and machine CDTs is to represent the situation of emerging intelligence deriving from swarm interaction, swarm intelligence, where there is not an explicit communication among the different parties but the changing context resulting from the behaviour of one entity creates ripple effects on the others giving rise to the swarm intelligence.

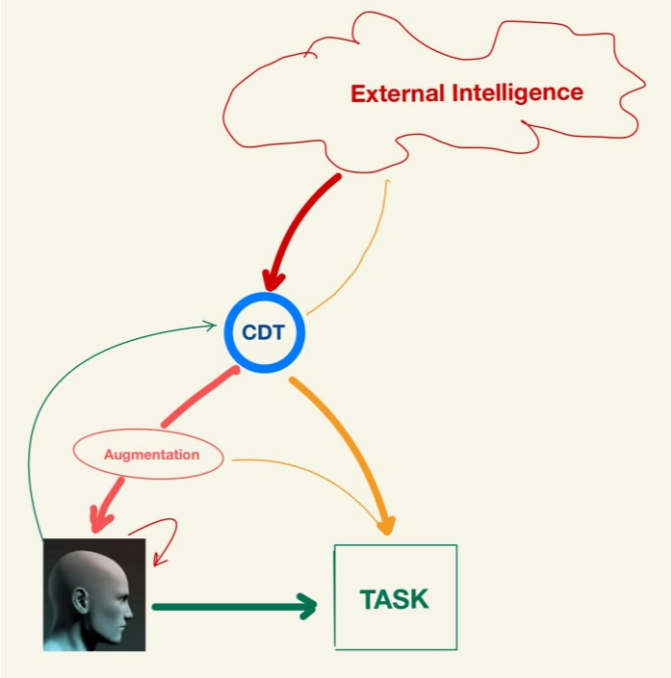

Figure 12. The Cognitive Digital Twin, CDT, intermediates external knowledge and intelligence to the internal (brain) one. The person can make use of the CDT to augment her intelligence in performing a task (yellowish lines) and/or taking advantage of the CDT to keep increasing her knowledge, in a sort of seamless continuous education "on the job".

4.5.5 Augmenting "my" intelligence

Having a Cognitive Digital Twin, seamlessly connecting external intelligence (and knowledge) with the owned one (brain enabled), could be an effective way to augment our own intelligence. It is also providing a competitive advantage, like having a college education provides an advantage towards those who haven't had one but is not enough when competing with those having a university education, who in turns are at a disadvantage versus those having a Master/PhD education. In other words: the more educated you are the better you (at least potentially) can fare in the labour market. Of course your education has to be in line (useful) with respect to the work area (having a PhD in philosophy does not provide any significant advantage if you are a mason…).

A CDT can provide intelligence, and knowledge augmentation, contextualised to your needs (area of work) here and now. This does not mean that your basic education/experience has no value. The keyword here is "augmentation" and it works by leveraging on what you already know. The more you know the more effective the augmentation will be.

Actually, augmentation can serve two purposes:

- help you in performing a task (like, turn that screw, use that tool, contact that expert, …);
- increase your "brain"knowledge (like, turn that screw because …)

This is no small difference. There is clearly a trade-off between augmenting your knowledge/intelligence by delegation (first situation) and "educating". The former is more effective in the short term, the latter is leading to more lasting effects. It is also a matter of evaluating what is the value of augmentation, If it just relating to a specific task that will not need to be tackled in the future most likely the first "transient" augmentation makes more sense. If, on the other hand, that

task (or similar one) is going to be faced more and more in the future an approach based on "education" might be better. Of course, education is more time consuming and places a burden onto the educated party. I can imagine that part of the decision on the way to augment one's knowledge and intelligence will have to rest on the "augmented" person. On the other hand, the augmentation service provider will also have its saying and can greatly influence the decision of the augmented party. This observation is to say that competition on education and difference in people knowledge/intelligence will remain unchanged. The CDT is not a plug in brain prosthetic, is a tool, a very powerful one indeed but just a tool.

However, let's not underestimate the power of "tools" in changing ourselves, our understanding of the environment and the value we associate to knowledge. Once a tool has become so pervasive and "seamless" that people take it for granted without paying it a second thought the tool has managed to change who we are. The knowledge we value today (and we seek to acquire) is very different from the one of our ancestors (lighting fire and knowing how to fracture a stone to create a blade were a matter of life and death) and even from the one of our grandparents (we find easier to buy something new to replace what does not work anymore whilst our grandparents needed to know how to fix "things").

In the continuous process of abstraction, that has characterised the homo sapiens evolution, we pay attention to the higher levels of knowledge, taking the lower ones for granted, in part becoming structured into the ambient we live in, in our society and in part embedded in tools, like the computer I am using to write this text. What I need to know is not how to build a computer, only how to use a word processor. Give it a few more year and I will no longer need to know how to use a word processor, since talking to some kind of interface will be sufficient to generate a text for someone else to read.

Take a few more years and my knowledge will be captured by my Cognitive Digital Twin that will be able to use it as needed, with just a loose control from my part. That same CDT will also embed contextual knowledge (just to make a trivial example, the fact that I will be in a location where people speak Chinese) and will contextualise that to my "brain" knowledge (converting Chinese into Italian, to stay on the example). Once this becomes seamless, how much would the capability to understand and speak Chinese (from my point of view) be valued? Will I dedicate years to learn that language or will I be content with the adaptation provided by my CDT?

4.5.6 Augmenting an Organisation Intelligence

If it is obvious the advantage derived from augmenting our own intelligence, knowledge, at a personal level -to become more competitive on the market (or just for self-esteem)- it is also evident the interest of a company to increase its own intelligence/knowledge and to harvest, effectively, the ones of their resources (humans and machines alike).

Here again a Cognitive Digital Twin, this one set up to mimic the company/organisation knowledge and intelligence, can become a tool that supports that organisation goals through an augmentation of its knowledge/intelligence.

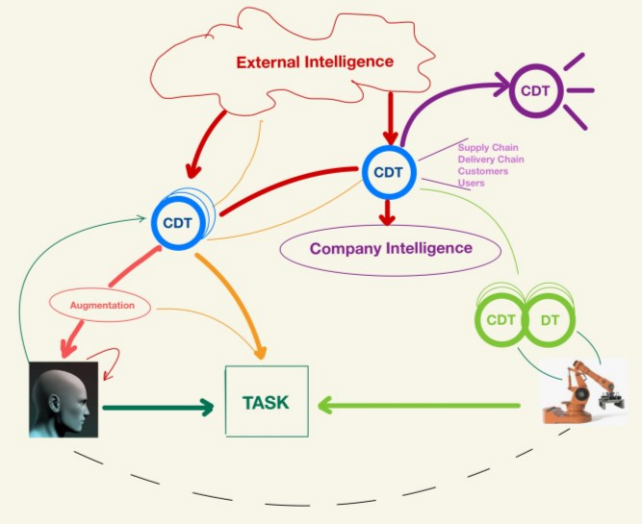

Figure 13. A company can create its own Cognitive Digital Twin, CDT, to mirror the whole set of company's knowledge and support its exploitation, hence the company "intelligence". This CDT interacts with all companies resources CTDs, in the graphic represented as instances. In addition it derives knowledge (and intelligence) from the supply, delivery chains, from customers and users, sometimes via their own CDTs. In perspective, the company CDT can be used to export the company knowledge and intelligence, via provisioning of services, thus enriching the company offer portfolio (represented by the purple CDT).

The organisation knowledge, intelligence, is the combination of the ones embedded in its components:

- human resources
- machines (in a broad sense, including sw)
- processes

In addition, the organisation may harvest, indirectly and -more and more- directly, the knowledge/intelligence of its suppliers, distributors and even of its customers/products-services users. Indirectly, since a good portion of the (relevant) knowledge of these constituencies can be derived from the interactions the organisation has with them, directly because, at least in some cases (growing over time) these constituencies will start sharing their knowledge to facilitate interactions and fruition of their "wares" or fruition of the organisation's products/services (from the customer / user side).

Interestingly this knowledge that refers to the company boundary can be embedded in the company CDT or it can be construed in such a way to be embedded in a CDT mirroring, with respect to the company, that particular entity, e.g. a supplier, a customer.

It might be the case (at least for a supplier, most unlikely for a customer, although in the 2050 timeframe the situation might be very different) that the external entity has its own CDT and it becomes possible to extend the company knowledge/intelligence, simply through the connection to the external entity CDT. As an example a supplier can embed in its own CDT its expertise and by making the connection to that supplier's CDT a company's CDT may "extend" its knowledge and intelligence (making use of the other CDT knowledge intelligence). Of course, in general, this augmentation is a service that will generate value and a corresponding fee to be used.

This is symmetrical, in the sense that a company's CDT may also be used to deliver knowledge and intelligence of the company, as a service. This is represented in the graphic by the purple CDT that is an instance of the company CDT to deliver services (it may also be in the form of instances, each one delivering a set of services to a specific "customer").

Notice how this way of using a CDT (and all the effort in creating and embedding it inside the company's processes) is both a result of the Digital Transformation and a strong tool to foster the Digital Transformation.

What I described in terms of possible architecture for managing the augmentation through the external knowledge by either connecting to other CDTs outside the company boundary or mirroring

the outside by embedding it inside the company's CDT is also applicable to the internal knowledge provided by human resources and machines. Whilst for these latter in general it does not make a difference to embed the machine knowledge in the company's CDT or leverage that knowledge through the interaction with the machine's CDT (there are exception to this, when a machine is provided as a "service" by a third party: in this case the third party may enforce the separation of the machine's CDT from the company's CDT to keep control of the services being provided) in case of leveraging the knowledge of human resources the most appropriate architecture should be the one indicated in the graphic, where the worker's CDT remains under her control and can be leveraged through interactions, thus ensuring the separation of ownership.

4.5.7 Knowledge - Intelligence Providers

Over the last 20 years knowledge has become a valued asset and, as might be expected, a number of companies have endeavoured, and are endeavouring, to capitalise on this value converting it into revenues.

Since its foundation, IEEE has been a facilitator of knowledge exchange among its members first and then opening up to a worldwide audience. Conferences (thousands of them), journals/magazines (in the hundreds) and peer-reviewed paper archive (in the millions) have been the tools offered to a worldwide market to share and access knowledge. In the last 20 years as its members, and the world audience, moved on line the paper medium has been fading away, replaced by electronic media. The sheer volume of data (and related embedded knowledge) has pushed IEEE to develop tools to facilitate access and sharing, like IEEE Xplore and Collaboratech.

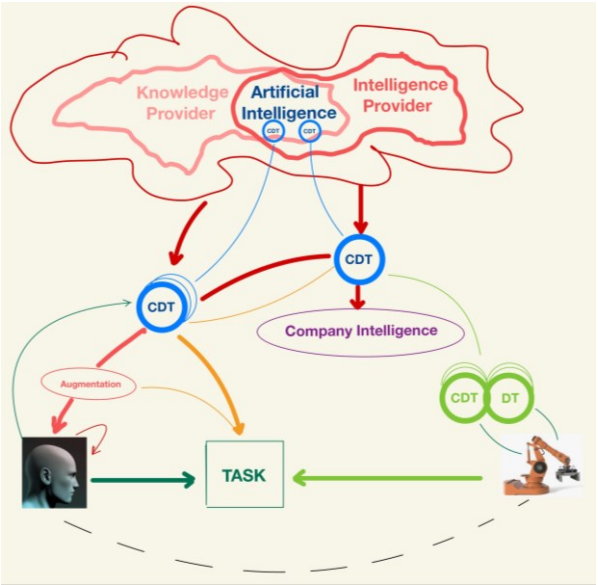

Figure 14. Knowledge and Intelligence Providers are on a collision path with a growing overlapping of service offering. This is fostered by the application of Artificial Intelligence, helping in customisation and delivery "here and now". CDTs can be a tool used/created/offered by Service Providers to keep a competitive edge on the market.

In parallel, intelligence agencies, like Gartner, McKinsey and the likes, have created knowledge services to deliver intelligence crafted to the individual customer (matching its business space with the relevant knowledge space).

Artificial Intelligence is taking these two market spaces on a collision course, as knowledge and intelligence becomes one and the same. Moreover, a growing portion of knowledge search, assessment, analyses and intelligence can be fuelled by artificial intelligence.

The world based on archived knowledge and the world based on specific vertical knowledge derived from interaction with key players and self-feeding through consultant services can leverage on different sets of data. However, this difference is fading away as more data (articles and live conference interactions capture) on one side and data accrual from the increased space of consultancy is reaching a point where artificial intelligence can create the metadata, the knowledge and intelligence that is sought by the end customers.

Clearly, the competitive advantage shifts from the raw ownership of data to the capability of processing these data, contextualising their interpretation and their delivery to target a specific customer need.

The latter implies a growing knowledge of the customer and, possibly, the evaluation of the impact of the past knowledge/intelligence transfer to keep fine tuning the delivery.

There are, obviously, many ways to achieve this. For sure one would be to apply the concept of Cognitive Digital Twin. The intelligence provider (knowledge is morphing into intelligence, so even if the knowledge part remains the crucial, essential, starting point, the intelligence is what is valued and perceived by the end user) can start developing a set of CDTs to deliver the service:

- The CDT embedding the knowledge owned by the provider (this includes the knowledge on where and how to retrieve additional knowledge owned by third parties);
- The CDT embedding the knowledge space of a given vertical sectors (like what knowledge is needed in the energy, or agricultural, or pharmaceutical, or automotive …. sector);
- The CDT instances, one for each customer/potential customer, that inherits from the relevant vertical sector adding the specific knowledge of that specific customer.

The interplay of these CDTs leads to knowledge gap analyses and to the creation and delivery of the needed intelligence to a specific customer.

The architecture supporting these CDTs and their interplay can differ and can become a point of competitive advantage.

As an example, a provider may enter into a partnership framework with its customer and provide the tools to create the CDT instance of that customer (even develop it in house) and then hand it over to the customer. Another provider, possibly claiming that the customer life will be easier if the CDT instance is completely managed by the provider, can just enable the customer to access the relevant CDT instance …

5. A novel knowledge landscape

Let’s try to pull all the threads I developed so far into a tapestry, the one forming a (possible) novel knowledge landscape in 2050:

- knowledge will keep growing at an exponential rate. This growth will partly expand existing knowledge and partly replace it,
- knowledge grows fuelled by better human interconnections, by tools supporting human knowledge creation / sharing, and increasingly by machine/AI that by 2050 will be, most likely, the major knowledge creators,
- we have already reached the human (brain) limit in terms of capability to absorb the knowledge being created,
- the “Knowledge Society” is struggling to make sense (to apply) all the knowledge potentially available,
- the value is already shifting from “knowledge” to the capability of getting and applying the knowledge that is relevant “here and now”,

- “knowing what” and “knowing how” are merging into intelligence as a service,
- intelligence augmentation is already a reality that is taking the upper hand, both as continuous augmentation of brain’s capabilities and as external knowledge that flanks brain’s one,
- knowledge providers and intelligence providers are on a collision course merging their services well before 2050
- humans capabilities may not suffer from this external intelligence, as long as that intelligence is used to grow the human intelligence.

All these threads can be used to create the new knowledge tapestry, however, as for any tapestry the result depends on the way the various threads are processed in the loom. Problem is, we do not have, yet, an agreement on the loom to use, i.e. to an accepted framework. The basic problem is in the definition of intelligence: the capability to provide an approach/solution to a problem (reaching a goal is part of this) making use of the available resources and taking constraints into account. Different cultures may have different problems/goals and different set of constraints.

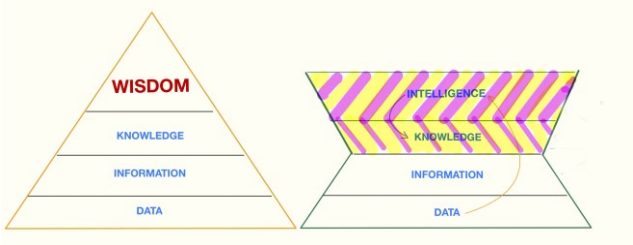

Figure 15. On the left hand side the classic representation of the knowledge pyramid, rooted on data, processed to become information whose meaning creates knowledge. The purple lines highlight the role of machines, greater in the intelligence space but significant in the knowledge space. The yellow lines highlight the role of humans. Notice that in this new landscape raw data, through AI, have a direct impact on Intelligence.

This is represented in Figure 15 by the graphic on the right hand side. The one on the left is the well known representation of the “knowledge pyramid”. The advent of AI and machines generating and embedding knowledge is changing the pyramid.

First notice how in the past knowledge was, in a way, a distillation of information, now knowledge is building on information often creating a larger set of entities (by connecting several entities). Think about the genome sequencing. The genome data generate information and this information generates an ever expanding set of knowledge that connects and is fed by many other streams.

Second, notice that whilst the pyramid on the left was all about humans, the graphic on the right involves, and will involve more and more, machines (represented by the purple areas) in the creation of knowledge and intelligence. Obviously, today machines have the upper hand in the harvesting of data (IoT communication networks and storage -cloud).

It should also be noticed, as shown in the graphic, that machines (read AI) is making use of “raw” data directly to create intelligence, i.e. it does now follow the human path of moving from data to information to knowledge than will be converted into executable one demonstrating “intelligence”. A machine can well demonstrate an intelligent behaviour without necessarily having the knowledge that is required by a human. Take the example of language translation. A human needs to know the meaning to translate from a language to another. A machine does not need this intermediate step. By the way this is also one reason some people claim that machines are not “intelligent” since they miss the underlying knowledge.

5.1 Knowledge obsolescence and up-keeping

Another crucial aspect of knowledge today, and more so in the 2050, is the pace of substitution. We always had new knowledge replacing old ones but that occurred over long time spans measured in centuries. Now knowledge, in some areas, is being continuously updated with new one killing the older one. However, there is no single "stack" of knowledge, it is distributed and "knowing" the state of the art is a challenge. Areas like healthcare are particularly exposed to this knowledge deluge and to knowledge obsolescence (others are the areas of security/cybersecurity, math, physics, chemistry, biology, …).

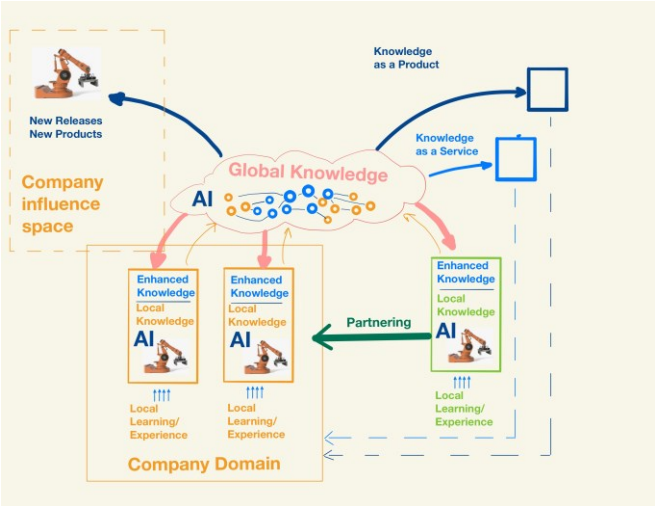

Figure 16. This picture represents the variety of knowledge sources that a company should consider when planning for its knowledge asset up-keeping. Internal knowledge within the company domain (i.e. under its full control), the fuzzier one that can be derived from the use of its products/services, the one that can be relied upon through partnering with other companies and the one that can be harvested from the cyberspace. More and more the use of this latter can be facilitated through knowledge services and through knowledge as a product that can be acquired on the marketplace.

An area that is particularly affected by obsolescence is the application of technology, because of the ever growing offer of products, their shorter lifetime and the mismatch between a product offering lifetime vs that product usage lifetime. Here, a new branch of knowledge, the one of roadmapping, will become a basic tools for most decision makers in their everyday decision of what to buy, what architecture to adopt, how to deploy.

A sideline, but an important one for both individuals and companies/organisations, is that the "source" of knowledge is shifting very rapidly. A leading edge company that was leveraging on an advanced technology may find itself pushed on the sideline by a new company that has been betting on a different technology (or the rise of a technology that is becoming the competitive advantage of a new company). Similarly, a leading edge expert in a technology may be rendered "obsolete" by the technology shift that favours other experts.

This is symmetrical, in the sense that a company that was relying on another one (or on some experts, both internal and external to the company) will need to change its relations from the "old" ones to "new" ones.

The crucial point for a company is that of ensuring it has the knowledge it needs at any time, and as it plans for a new product line it has to plan for its knowledge availability. For this latter the company has to consider what it would make more sense in terms of "synchronising" its knowledge to its needs:

- creating a turn over whereby new employees, with the required knowledge are replacing existing ones;
- pursuing continuous education to increase current employees knowledge;
- acquiring machines (software) that can provide and share the required knowledge;
- partnering with other companies to access the needed knowledge;
- using knowledge as a service from a variety of knowledge service providers;
- creating a swarm intelligence through processes, people and machines orchestration.

Of course all of the above is not “either-or”. Besides, different situations (biz, contexts) may lead to different approaches.

Take a very easy case: a company needs to enter a new market where a different language it is spoken, hence it needs to adapt their products interfaces to the new language. What should the company do?

- hire a person with that language skill and dismiss another person
- hire a temp to do the job
- ask a third party to do the job
- use machine translation
- create an open interface so that it can be adapted by the end users in an ecosystem-like approach (swarm intelligence)

The key point is that companies (as individuals) have and will have more and more ways to augment their intelligence (to evaluate, take decisions, “do” things…). Intelligence no longer needs to be an internal capability, it can reach out to harvest what is needed (in a seamless way). The focus shifts from “owning” to “leveraging”.

5.2 Knowledge Framework

Having to rely on external knowledge/intelligence is already a reality. It will be even more so in the future and a company, as for an individual, will need to trust the knowledge/intelligence provider.

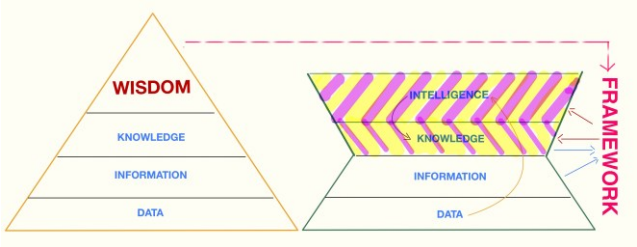

Figure 17. We knew that knowledge has to be filtered through wisdom (guiding in its application). Here, on the right hand side Wisdom is becoming a Framework and it is no longer the end point in a hierarchy of values. It lays outside and changes over time as new information and knowledge becomes part of the cultural landscape (often intertwined with the regulatory landscape). Also notable in the shift is that the framework, affects both knowledge and intelligence.

In the past, and by large today, we also had to rely on trust. Mechanisms have been developed to verify the correctness of information and the derived knowledge. We actually trust a knowledge provider because we trust the underlying mechanisms. As an example, I trust the information I get from papers in Xplore because there is a well oiled procedure to certify the papers that end up in Xplore, based on peer-review.

The responsibility, and the burden of understanding that information, converting it first into knowledge and then into intelligence (how to apply that knowledge) is on me.

However, by 2050 the landscape will be quite different. Knowledge and intelligence will likely be one and the same (at least in most areas). This corresponds to a new layer of abstraction. Yesterday I trusted, implicitly, the ball pen to give me the exact amount of ink I needed to write, today I trust my computer to create a digital representation of the letters I am writing and to send that digital representation to another computer that will interpret those digits as the letter I typed. Tomorrow, I might need to trust an entity that *writes* on my behalf!

This is an amazing change, not an incremental one. We have been used to develop better and better tools to help us in menial activities, now we have tools that can help, even substitute, mental activities. This is a major leap that influences the very meaning of trust bringing societal and ethical aspects into the equation.

As shown in figure 17 the Wisdom that used to crown the hierarchy of data-information-knowledge will be morphing into a Framework in a future where humans and machines will share intelligence.

In a way it is not a brand new issue. The way I solve problems, take decision, is part of my intelligence. However, my approach to solution and to decisions may differ significantly from your approach: the reason is rooted in cultural differences (as well as several other factors like experience, propensity to take risks, …). Likewise, a machine (artificial intelligence) will approach solutions and decisions within a set of constraints, set up by the regulator and implemented by the programmer (including a program generated by a machine or self-generated).

We have been calling "Wisdom" the broad set of capabilities to make use of knowledge in a sensible way. Of course different people will differ in evaluating what is sensible, hence what is wisdom. We are facing the same problem with machines although with machine it would seem peculiar to talk about Wisdom!

How do I know (how can I trust a machine) that the intelligence provided by the machine, merging with mine, is aligned with my set of values, with my culture? The concept of Framework comes handy. A Framework is the space of operation of the machine, that has been defined a-priori. A framework is what will constrain the decision of a self-driving car in choosing an action over another because of an a-priori defined value (the well known challenge in choosing among hitting a kid, an elderly person or a wall resulting in harming the car passengers).

The Framework needs to be defined and needs to be transparent, i.e. people using that external intelligence should be aware of its operation space.

The choice of providing a set of knowledge vs another, a given intelligence versus another, is going to change my perception of the world (of the issue at stake and of the possible ways to address it), hence my "intelligence" will be deeply affected by the external one.

Having a trusted provider of intelligence (executable knowledge) will become crucial; to an extent it will be even more important than having a trusted information provider today, since the external intelligence will have an immediate effect, whilst in the case of information I usually have time to digest, compare and make up my mind.

5.3 Swarm Intelligence

My view of Knowledge in 2050, hence, is along the line of:

- continuous, and accelerating, creation of knowledge by humans and machines
- merging of knowledge and intelligence
- massively distributed knowledge, among humans and the ambient
- education has shifted from knowledge acquisition to knowledge transfer tools and knowledge application: from "knowing what" to "knowing how to"

- knowledge services (and value perception) have shifted from access to application - knowledge execution

- distributed awareness leading to adaptive interaction among humans and the ambient

- emerging intelligence as result of the ever changing mutually influenced interactions (swarm intelligence)

- system wide self-assessment of the impact of interaction leading to a continuous fine tuning within a given Framework.

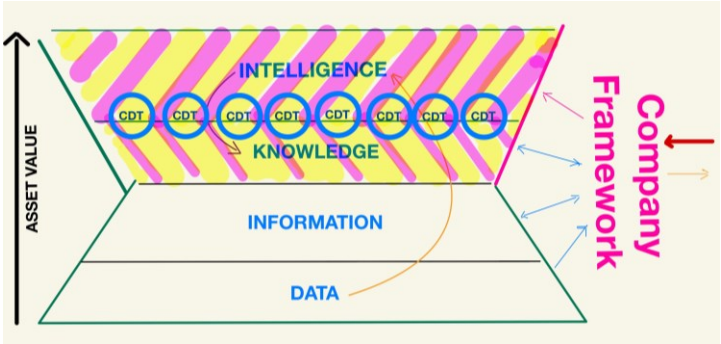

Figure 18. Representation of an organisation knowledge asset value. The value increases from data to information to knowledge up to intelligence. Notice that the emergence of intelligence is regulated by that organisation framework, that most likely has to comply to an external framework set up by the regulation entity. CDTs are embedding the executable knowledge, bridging knowledge and intelligence.

Knowledge has mostly implied education as the way to transfer it from one person (who knows) to another (who needs to know). We are starting to see a change in this paradigm with self-education where machines (as repository, facilitators, simulators) can become the tools for transfer knowledge. The rising need for continuous education will push the offer of customised "just-in-time" education again involving more and more machines (AI). Actually, the transfer of knowledge will become a commodity, the value is in the capability to apply knowledge, in the "intelligence".

As humans we have also been "educated" by the ambient we have been growing in. This will continue in the future with the difference that the ambient will keep evolving much more rapidly and the learning experiences provided by the ambient will be far greater than they were in the past.

Companies will both acknowledge this new distributed knowledge and ambient embedded knowledge and many will start to leverage on the possibility for continuous education offered by the company environment. When we work in a company we are implicitly subject to a continuous learning -aka experience-. As the company becomes a cluster of knowledge (and intelligence) that keeps expanding employees will benefit from this and the organisation of the company will evolve towards the exploitation of the overall emerging intelligence. Again. there is nothing significantly new in this. HR departments are there to allocate the best available resources to tasks (where "best" refers to the capability of performing in that specific task) AND at the same time to grow the capability of each resource preparing them to the next task. What changes is speed of intelligence growth required to remain competitive in a business, hence the need to grow the overall company intelligence by organising the company's processes so that they can at the same time deliver effectiveness and efficiency on one hand and keep increasing the company intelligence on the other.

The Digital Reality Initiative has created a first prototype enabling the development of Knowledge Services and has partnered with HRCoffee to develop a first example of service. The choice of involving a company focussed on the future of HR is in line with the points just made. They are

supporting the evolution of HR in companies that are executing the Digital Transformation, supporting the knowledge management seen as a continuously evolving asset.

Knowledge boundaries are fading, intelligence is the competitive differentiator in the future, that is the capability to apply knowledge. Artificial Intelligence will be permeating the whole area of knowledge.

IEEE will need to evolve from a repository of raw information to a knowledge service first and then to a catalyser of intelligence able to foster the exploitation of the knowledge derived from its activities.