# Applying Cognitive Digital Twins to Professional Education

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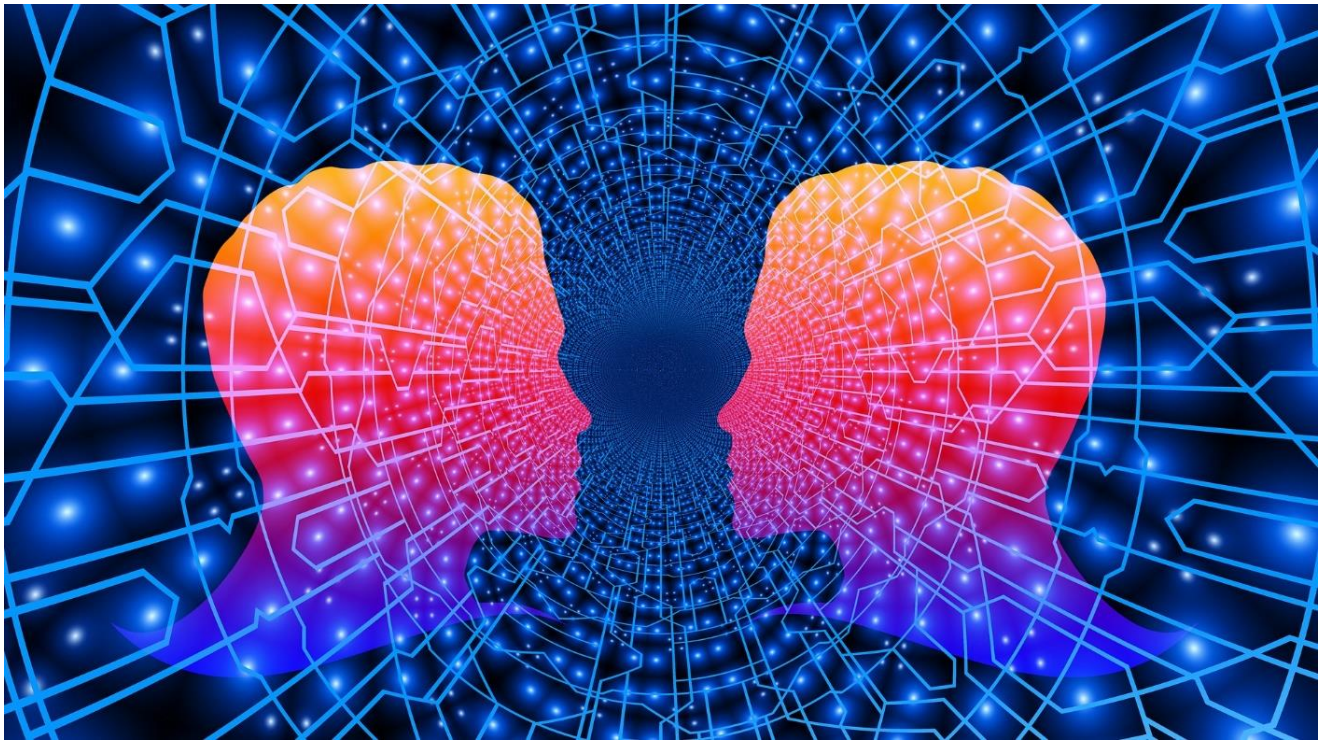

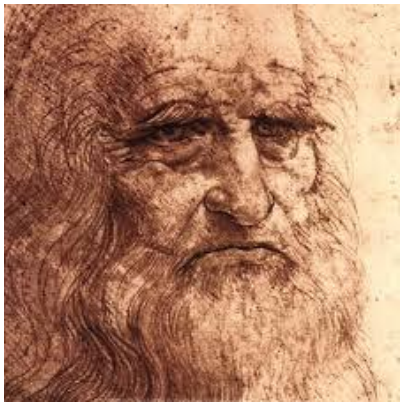

*Figure 1 A "selfie" of Leonardo da Vinci. A person like him, able to excel in many disciplines and having a comprehensive global knowledge, would be unthinkable today. Image credit: Fulcrum Gallery*

It is clearly impossible to keep up with the advance of knowledge. A novel Leonardo da Vinci is no longer possible given the breadth and depth of knowledge built in these last centuries and particularly in these last decades. Connectivity and digital processing (that used to comprise storage and access but now is evolving into analysis, correlation, and creation) have created, paradoxically, a sort of black hole of knowledge. We know that there is a huge wealth of knowledge potentially available, but in practice it remains beyond reach to the single person and more to the individual company.

And it is getting worse. In several (technical and scientific) areas, the knowledge gap is widening, and in spite of the abundance of good and accessible courses, staying up to date has become impossible. Even obtaining a general awareness of what knowledge is available is challenging.

Among institutions, organizations, companies, and professionals, there appears to be some frustration in those that really would like to invest in the upkeep of their knowledge and a sense of inadequacy in others that translates into a loss of interest in remaining up to date.

These latter are increasing due to a number of (sensible) reasons, like:

- the business is too competitive; there's no time left but to focus on daily tasks
- I am missing the foundation to learn what is new
- it is useless; by the time I have learned the latest it will no longer be the "latest." It is a pointless effort or a never ending story.

Several companies are -de facto- acting like they have lost hope in staying on the leading edge of knowledge. There are plenty of examples of companies that just twenty years ago were on the leading edge of knowledge and were actually actively working in pushing the knowledge boundaries forward and that today have completely lost their knowledge having delegated it to providers. One of the big issues of several incumbent telecommunications operators is their loss of technical knowledge; for too many years they have outsourced their information systems and have shifted the planning and operation to their suppliers. Now they have trouble steering their own future.

It made economic sense to outsource activities to specialized providers. At that time these activities seemed menial, but some of them have become crucial to today's business. The problem, common to most business shifts, is that change seems to be far away. For the time being the feeling is that one could operate as in the past: we were successful in the past and are still making quite good money today, why should we worry? If there is something new, there are new, usually small companies, focusing on novelty, pursuing technology evolution, and experimenting with new business models. Unfortunately, if it is true that most of these new companies will fail, and only a few will succeed, it is also true that they are disrupting the market decreasing its value (independently of having or not having success).
What is now becoming clear is that the knowledge gap and the "offshoring" of knowledge is hampering the evolution of companies' business. It has become clear that knowledge is a strategic lever, and companies need to be very careful in delegating knowledge elsewhere.

So, it is a fact that knowledge is expanding faster than ever. Part of this knowledge is not immediately applicable to business; some is theoretical and is most interesting to researchers. However, a portion of this knowledge growth is derived from experiences scattered around the world; some knowledge that has found application in one area might be just what is needed in a different area; and other knowledge needs just a little push to become usable and benefit business.

Even if we restrict to types of knowledge that have a proximity to maturity in a given field, the amount is very large, possibly exceeding the capability of a single person to acquire and digest. However, before even attempting the acquisition of knowledge one has to be aware of its existence, of where it is accessible and dedicate time and effort to digest it. This is the challenge for both professionals and companies.

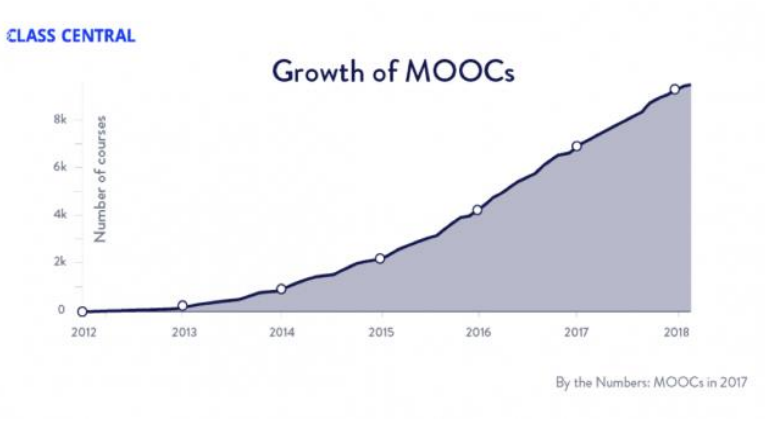


*Figure 2 Numbers of MOOCs as of end of 2018. Image credit: Class Central*

Notice that the problem, in most cases, is not the lack of education material, quite the contrary since we are facing an explosion in the area of education material as well. There are, as of the end of 2018, some 800 universities around the world that have developed on-line courses (Massive Open Online Courses - MOOCs) easily accessible from any place. The total number of MOOCs published in 2018 was 9,400, the previous year, 2017, the production totaled 6,850 MOOCs. The number of active MOOCs in 2018 reached 11,400. [1]This is not just an indication of the increase in on-line education material, it is also an indication of the short life spans of MOOCs.

Also, the number of people accessing these MOOCs keeps rising: Coursera had 30 million attendees, edX 14 million, XuetangX 9.3 million, Udacity 8 million and FutureLearn 7.1 million.[1] About 101 million people attended a MOOC in 2018, up from 84 million in 2017. These, although huge, represent the tip of the iceberg. Professional education fostered by companies and public administrations all around the world through specific initiatives leads to a staggering investment in education.

Unfortunately, a common denominator is a general dissatisfaction, both from professionals and from companies, in terms of effectiveness and return on investment (in time and money).

In summary, the professional education space has evolved in the following ways:

- the growing wealth of knowledge that is practically beyond the grasp of a single mind,
- the obsolescence of knowledge that is directly connected to its growth (older knowledge gets rapidly superseded by new one),
- the sense of frustration at the individual level for not being able to remain abreast of what is brewing,
- the economic motivation of companies to outsource knowledge and how it has backfired and is continuing to backfire,
- the growth in the education offerings, resulting from the increased knowledge available and increased need to master that knowledge leading, however, to a further increase in the knowledge space, paradoxically increasing the hurdles rather than easing them.

There are other factors that should be considered:

1. We are accessing information and knowledge in new and different ways; it is obtained now more and more in a quick and dirty on-demand way and via our mobile devices, whether we are on the move or not.

[1] https://www.classcentral.com/report/mooc-stats-2018/


*Figure 3 Data, information and services on the web keep growing exponentially and they are accessed more and more through mobile devices. This is a representation of what happens in terms of mobile access in a minute based on 2018 statistics. Image credit: Mobcl*

Based on the latest data from 2018, mobile access to the Internet has overtaken fixed access, and, according to Google, 58% of the search requests in 2018 came from mobile devices. Mobile access keeps growing and the increasing adoption of artificial reality (AR) will further push the use of mobile devices (smartphones and tablets). The growing pervasiveness of networks, their increased capacity and the trend towards creating local data bases (embedded in devices) and data bases at the edges provides the underpinning for effective availability of knowledge on demand.

2. The meta-data / information / knowledge created by machines themselves, through machine learning and adversarial neural networks is introducing a further exponential growth and, more importantly, leads to some knowledge that will need to be taken in an empirical form (you see it and you trust it, without understanding the processes through which it has been created). This second aspect signals a crucial departure from the knowledge we have been used to for millennia, i.e., acquired through the capabilities of the human brain. Now, and in the future, we will have to accept and manage knowledge that is beyond the human brain capability (for sure practical capabilities but possibly also beyond its structural capabilities, quantum computing being an example). This brings to the fore not just the convenience of leveraging machines in dealing with knowledge but also on the need to rely on them.

The new landscape of knowledge, characterized by

- continuously expanding data and metadata, partly fueled by humans and partly by machines, working asynchronously and only loosely connected,
- a tremendous ease to access data and at the same time an impossible task to reach all potentially relevant data (think about the ease of googling information and the impossibility to look at all of the answers provided!) and,
- the fact that the access to knowledge can, and most of the time do, increase knowledge,

creates a perfect storm.

An interesting approach to tackle the new landscape (not necessarily to solve all the associated problems) is by using machines (soft machines) and connecting them, seamlessly, to organizations and single persons through *cognitive digital twins* (CDT). We already have machines for searching the web, the proprietary –enterprise and personal– webs and the dark web. These tools, most of the time, open the door to a large subset of data that can be potentially relevant to the needs at hand. The visibility afforded is usually skewed to facilitate skimming of what can answer a need. This is based on automated profiling (complemented, in a few occasions by filtering requested by the user). A cognitive digital twin is a tool that can boost current profiling and act as an intermediator of knowledge, in both directions.

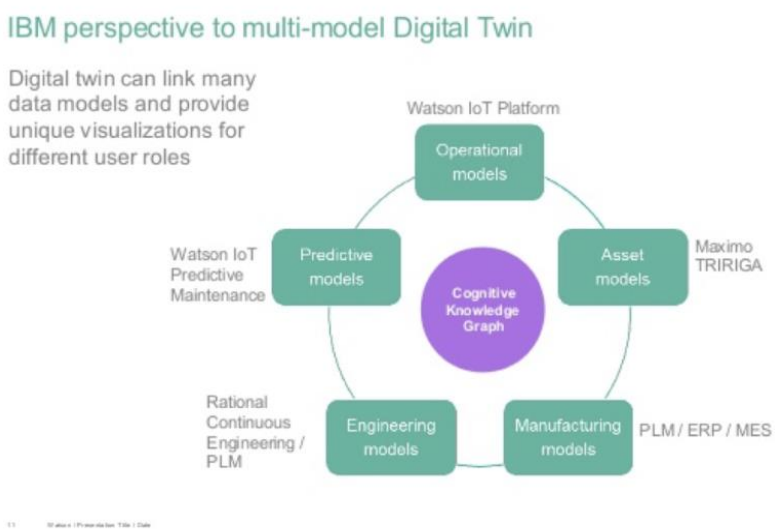


*Figure 4 A Digital Twin used to link data models and offer a single visualization based on a specific user. Image credit: IBM*

Invented some 15 years ago, digital twins have been developed in this decade and in the last five years have found application in manufacturing and operation. Now they are rapidly expanding in other areas.

Firstly, a digital twin is a digital model of an entity, be it a device, an engine, a product, a process, an organization. It can represent a simple entity like a hydraulic pump or a complex aggregation of entities (hard and soft) like a building or a city.

Secondly, a digital twin shadows the real entity, being connected to the real entity in a variety of ways that allow the digital model to remain in sync with the real entity (e.g. through sensors picking up the changes).

Thirdly, a digital twin contains the digital thread, basically the history of the evolution of the real entity over time. This digital thread can be used for reverse engineering of a situation, for example to understand when something happened to affect the current behavior (an excessive stress on a component might lead to a future malfunction).

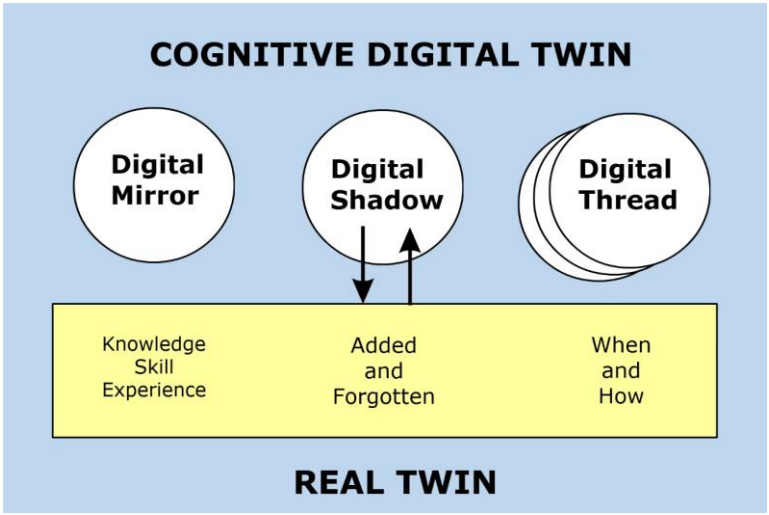


*Figure 5 A Cognitive Digital Twin can be seen as composed of three parts: one mirroring the present knowledge, skill and experience, one shadowing the processes of learning and forgetting and the third keeping track of when and how knowledge changes.*

As said, a digital twin can be applied to a variety of entities, so why not apply the concept of digital twin to a person or to an organization? Indeed, we are seeing the first attempts in this direction. As an example, a digital twin may become very useful in healthcare, mirroring some genetic characteristics of a person, shadowing its situation (by monitoring health parameters, like heart beats, breathing, blood pressure, glucose, metabolism) and its evolution over time (what has been eaten, the kind of physical exercise taken, medical exams and drugs). It can also be applied to a community detecting the overall health status, the presence of pollutants, monitoring the upstart of epidemics, the effect of prophylactic measures.

The next step, to address many of the issues raised above, is to apply the concept of digital twin to knowledge, to create a cognitive digital twin serving both a person and an organization.

What could a cognitive digital twin be? Taking the three aspects of a digital twin and instantiating them on a cognitive digital twin we could have:

- **Cognitive digital mirror**: it mirrors the knowledge, skill, experience of a person (or an organization). The development of this mirror entails gathering the information as it

currently stands. Based on this mirroring one could analyze the present level of knowledge, skill and experience and evaluate the gap determining what additional knowledge would be required facing a certain activity, project, or environment

- **Cognitive shadowing**: it provides the means to update the digital mirror as new knowledge, skills, and experience are acquired. Different from the shadowing of a machine, the shadowing of human knowledge needs to factor in the fading away of knowledge because it is being forgotten and the fading out of a skill because it is not being exercised. Notice that the shadowing may generate "hints" that point towards the depletion of existing knowledge and skill. It can also provide hints on the most effective way to learn and retain knowledge for that particular person (physical twin) or organization (digital twin clustering multiple digital twins).
- **Cognitive thread**: it records the evolution of skills, knowledge and experience as well as how those have been acquired (e.g. through courses, attending a conference, being active in a project team, operating in a certain environment). It also records the effectiveness of acquisition: a person may be more inclined to learn by doing, another by reading, another by interacting.

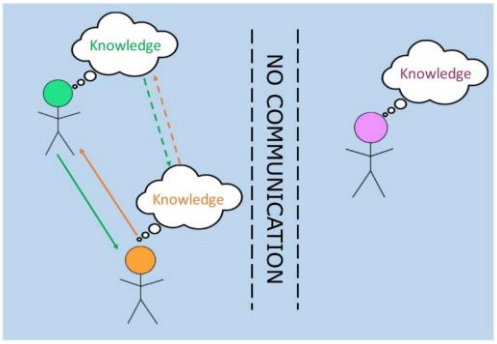


*Figure 6 In the past, knowledge was exchanged by word of mouth which made it quite complicated to have knowledge spread over great distances*

As more and more knowledge is accessed online, it is becoming easier to track the interest of a person and with some advanced software application, to detect the level of acquisition and "understanding". One could imagine a "big-brother" scenario, and be concerned. Actually, our current queries are monitored and are already finely tuning our profile. The cognitive digital twin can be at the service of its physical sibling. It is not a matter of recording everything; of course the more that is captured, the more accurate the overall picture and possibly the better the services that can be delivered. However, just a partial accumulation of data can create a meaningful mirror of a person's knowledge space (and interest).

By tracking the types of devices used in the interaction, as well as the location (shadowing and threading), it is also possible to infer the preferred way of interaction which can help the cognitive digital twin provide the best way to interact and display information for education services.

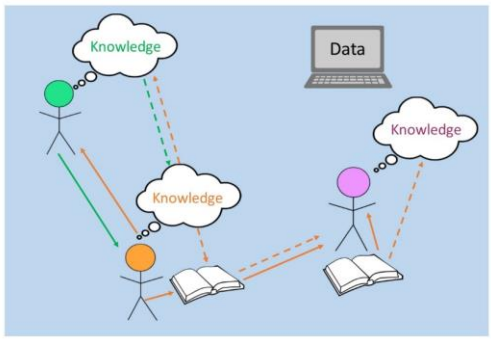


*Figure 7 Writing and communications provided a boost to knowledge exchange, and lately computers enter the arena exponentially improving communications exchange.*

A Cognitive Digital Twin, as it is the case for a Digital Twin, becomes a bridge between the person and cyberspace, in this case the "personal knowledge space" in cyberspace. Being made of bits and part of cyberspace, it enjoys the low transaction cost and the possibility to be at the same time local (with its physical twin) and global. The manipulation of bits can occur quickly and at very low cost. Exact copies can be created and simulation can be performed on a copy to evaluate different scenarios. This evaluation, in the case of a cognitive digital twin, can take into account cost in terms of efforts needed to fill a knowledge gap, and determine different strategies to fill the gap, either through various forms of education delivered at different times and in different ways or by making knowledge available through interaction (with other people/colleagues/consultants or with machines/AI).

A cognitive digital twin can be used to provide that person's knowledge to an avatar, allowing the avatar to engage in cognitive exchange within a certain context. This is what UBS, a Swiss Bank is doing by offering some of its clients the opportunity of discussing investment

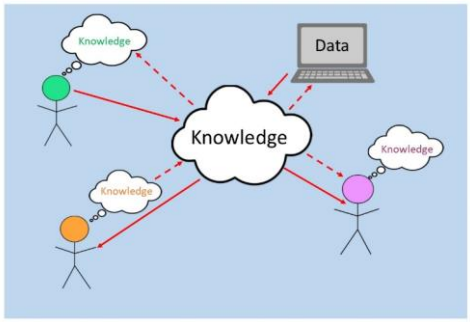


*Figure 8 Nowadays most knowledge exchange is mediated by the Internet/Web.*

opportunities with the avatar of their senior investment consultant. The avatar exploits the knowledge mirrored by the cognitive digital twin. Several cognitive digital twins operating in an environment, like a consulting company, can be made to interact among themselves in the same way as consultants in the company interact. Copies of these cognitive digital twins can simulate different kinds of interactions, i.e. interactions using different tools and operating in different organizations.

An interesting issue arises as the cognitive digital twin is endowed with learning capabilities. In this case, it will learn as it interacts with other cognitive digital twins, other digital twins and real entities. This leads to a divergence of that instance from the digital twin mirroring the person. This issue may be tackled in two ways:

1. Use the cognitive digital twin to increase a person's knowledge or experience by making this knowledge or experience available when needed or prompting the person to become aware of that increased knowledge space;
2. Keep the cognitive digital twin in sync with the person by separating the additional experience/knowledge into the avatar, i.e. the service that is exploiting the cognitive digital twin.

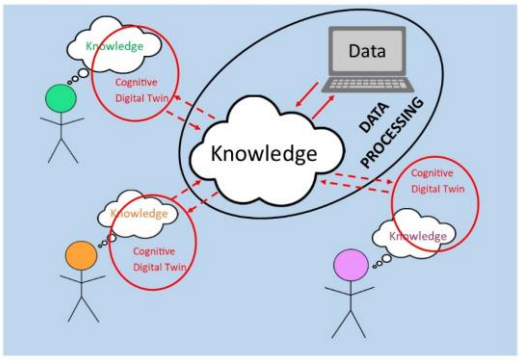


*Figure 9 Knowledge is no longer produced by humans alone; machines are starting to generate knowledge by collecting and analyzing data.*

Of the two, the former seems the more attractive, however it may become impossible to "update" the person with experiences gained by its cognitive digital twin as it roams cyberspace. The way out may be the establishment, and acceptance, of a super-self where the cognitive digital twin is no longer a mirror of the real twin (although it keeps mirroring it) but an autonomous entity that only exists in symbioses with its real twin, as it happens in many symbiotic lives in nature.

This is also leading towards a new paradigm of knowledge/skill/experience: a distributed symbiotic knowledge space.

One of the strengths of the human race, possibly its most important one, is the capability to share knowledge. The oral language was an enabler (or it might have been a consequence…,) making it possible both to transfer knowledge as well as to transfer "problems" to someone else who possessed the knowledge to tackle them. The invention of the written language made possible to transfer knowledge (and problems) beyond the barriers of space (you no longer needed to be face to face with the other person) and time (knowledge and problems could be transmitted to future generations in a much more effective way than using the oral tradition).

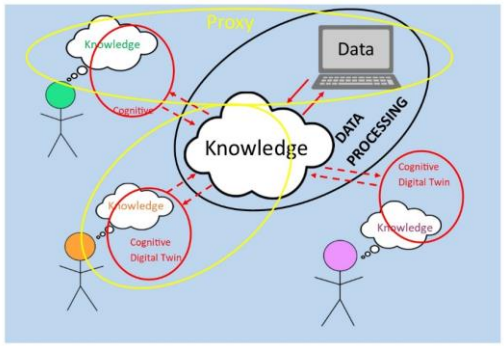


*Figure 10 A cognitive Digital Twin (red circle) shares part of the human twin knowledge and extends into cyberspace aggregating additional knowledge that is customized to fit the needs of the human twin. The CDT may act as a proxy (yellow circle) of the human twin roaming cyberspace to acquire knowledge.*

Notice that the transfer of knowledge and problems did not occur among humans only but also between a person and a tool or a machine. Was the stone block too heavy? Let's defer the task of pulling it up to rolling logs and using pulley. This might seem trivial but it is not! The knowledge to build tools required a leap in human intelligence, the capability to imagine various future steps that could be taken to address an issue and imagine what can be used to help and

then build the tool. This kind of knowledge became more and more sophisticated, and at the same time the tools became more effective and widespread to the point they started to be taken for granted. Over the centuries the knowledge required for tool building became an asset of few people with the majority happy to use the tool without knowing how to build it. The tool was becoming a sort of cognitive commodity in that people using it do not know how to build it, and most of the time they don't even know how it works. Think about extracting a square root: you know how to type in the number in your calculator (your smartphone) and you know how to read the result but most likely you don't know (remember) how to perform the calculation, nor how the calculator is performing it.

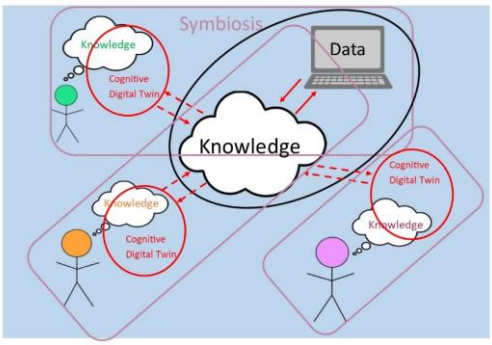


*Figure 11 Provided there is a seamless access to the knowledge mediated by the cognitive digital twin, e.g., by seamless AR, voice recognition, and syntheses, the person shifts into a symbiosis with that knowledge space (including skills). Already today we feel we are able to do nice diagrams because we are using a rendering program like Excel. Yet, we never say: Excel did that diagram, rather, we say, I did it!*

Additionally, our societies, communities, cities, and nations have embedded knowledge in their processes and in their organization. You may not know how to fix your car but you know that there is a number you can call to get directions to a car repair shop, and the person fixing your car most likely does not know how to manufacture that needed spare part, nor the person who used the lathe to produce that part would know how to build a lathe and so on in a very long chain of distributed knowledge. This is what psychologists call the "transactive memory networks[2]". For many centuries we have been living in this symbiotic distributed cognitive space with our tools and our social organization. Do you know how to build a fork? Most likely no, yet you can use a fork without giving it a second thought.

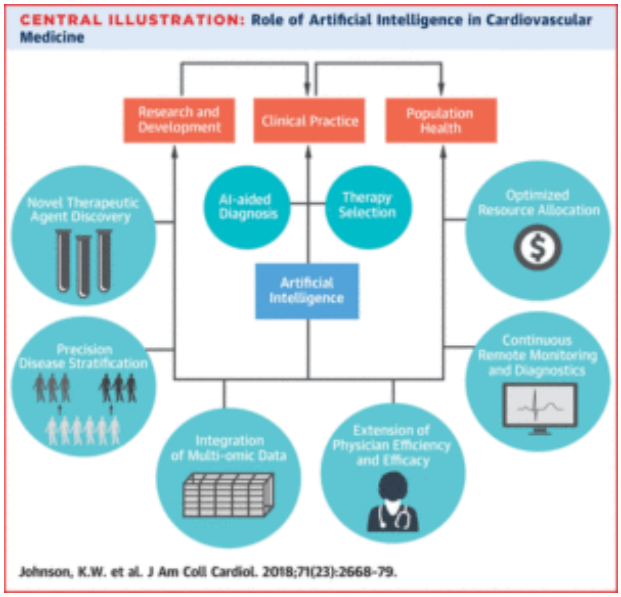


*Figure 12 Artificial Intelligence can play a major role in many professions by flanking the knowledge of humans with additional knowledge as well as facilitating the cooperation among different "knowledge" owned by human and machine players. The cognitive digital twin may act as an intermediator providing data to AI applications and making use of some of the results from these applications. Image credit: Johnson K.W. et al, JACC*

Books (and previously clay-tablets, parchments and the papyrus) are means to transfer both knowledge and problems. So are computers. In these last decades and increasingly, computers (machine learning and its siblings) have started to learn by themselves and, more than that, in these very last few years they have started to produce knowledge. We now are confronted with knowledge we inherit from the past, the knowledge we create, the one created by other people regardless of their location, and the knowledge created by machines.

The crux of this lengthy discussion is such: the knowledge space is far too broad (and getting broader) to be manageable by our brain. We need tools, and this is nothing new since we have become accustomed to using tools, to the point that they have become part of ourselves: "look at the nice diagram I created!" Well, as a matter of fact, it was created by some software I would have no idea how to write and doing computations I would not be capable of doing.

The cognitive digital twin can be such a tool, of course, leveraging itself with a variety of other tools. The goals of my cognitive digital twin are:

- to know what I know here and now

[2] https://psychology.iresearchnet.com/social-psychology/interpersonal-relationships/transactive-memory/

- to know what I should know to do what I am planning/supposed to do
- to share some knowledge with me by "educating" me
- to perform some cognitive activities on my behalf
- to act as my proxy, doing some cognitive tasks using part of my knowledge
- to share knowledge with other cognitive twins for cognitive team-working

Let's analyze each of these goals one by one.

1. ***Know what I know here and now***
   This is easier said than done. My cognitive digital twin needs to learn what I know at this particular time and in this particular context. Knowing that I know how to take a photo with a correct digital exposure is irrelevant if the situation requires analyzing the symptoms of a patient that is looking for a diagnosis and a cure. My cognitive digital twin should be much more focused on what I learned at medical school, what kind of experiences I gained through my hospital internship, what medical papers I've read. It should also, ideally, know what I have likely forgotten. There are means to infer this knowledge by looking at what I am doing every day, what patients I have, the prescriptions I write, my interactions with other doctors. Notice that I am taking the medical profession as an example but I could have chosen any other profession. Clearly, some professions involve a much higher level of digital interaction and it is simpler to intercept them and extract inferences. As a professional enrolled in an IEEE membership I am declaring every year what my areas of interest are by downloading technical papers, attending conferences, interacting with my peers in technical communities, submitting papers for review, giving lectures that are announced and sometimes recorded and presented in cyberspace.

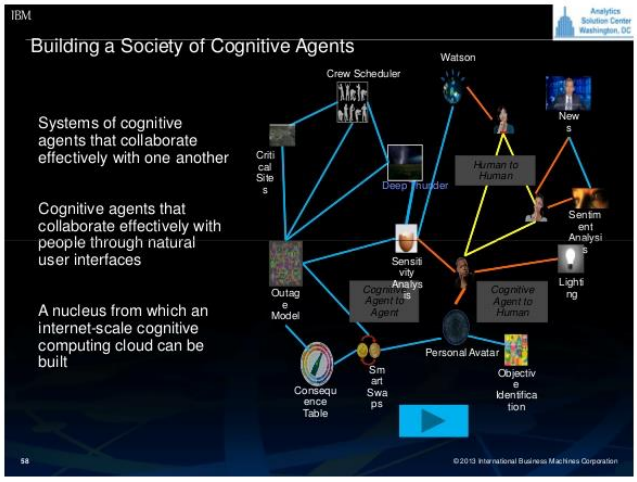


*Figure 13 Cognitive Avatars interacting with one another. The Cognitive Digital Twins can become the "engine" of avatars providing the cognition framework. Image credit: IBM, AAAI 2013*

For every job there are plenty of clues on the type and level of knowledge a specific person has. If we are looking at Industry 4.0 where more and more activities are performed in cyberspace, there is clearly plenty of behavioral and cognitive data that can be used to create a sort of knowledge map of a person. Also, many companies' human resource (HR) departments have this sort of (limited) knowledge map of their employees. Automated tools can make these maps much more accurate and effective. Clearly, in the case of a knowledge map used by HR, there are issues of privacy just as there are if some automatic system is in place to track your knowledge.

2. ***Know what I should know to do and what I am planning/supposed to do***
   The cognitive digital twin must have knowledge of what is required to perform an activity or a job, and this can entail some very basic "have-to-know" specs or can become very sophisticated, such as in the case of a medical doctor where the sky is the limit to the desirable knowledge. For example, what is the latest knowledge provided by research papers, what has been tested in similar cases bringing good results, who are the practitioners that may help in this situation and so on. It gets also more complicated since in most cases knowledge transfer takes time which then requires looking forward several months. Am I planning to change jobs? How can I leverage my present knowledge and how should I update it and complement it to become appealing for the type of jobs to which I am going to apply? From a company point of view what is the mix of knowledge skills that will be required next year as business demands change, and where does it make the most sense to invest in training?

3. ***Share some knowledge with me by "educating" me***
   As my cognitive digital twin interacts with other CDT there may be some knowledge that it is acquiring and that with limited effort can be transferred to me. My CDT will need to evaluate the what, when and how to make this transfer efficient. This is about me and my learning capabilities, but it is also about the time available (the one I am willing to dedicate) and the cost involved considering possible alternatives.

   This goal is of high interest in a company where the set of employees CDTs could come up with some proposed team mix that will both serve the task at hand by providing the right ensemble of skills and knowledge and at the same time lead to a growth of knowledge in (some part of) the team.

   A crucial part in achieving this goal is the how, both in terms of effectiveness in learning and in cost of learning. By customizing the way knowledge gets exposed one can make the transfer more effective.

   These first three goals are clearly directed to improve "my knowledge", the first one being more generally applicable to any learning, including school learning, while the second and the third more specifically tailored to the need of a professional (the second is clearly oriented to provide knowledge "pills" functional to a specific activity, the third to the sharing of knowledge harvested in the interaction with CDTs of people I will need to interact with as part of an activity). Let's now consider the goals aiming at flanking my knowledge with additional knowledge "owned" by the CDT to increase the effectiveness of my professional activity:

4. ***Perform some cognitive activities on my behalf***
   At a very basic level, some of the applications we are using today already perform few cognitive activities on our behalf: we provide some data and they perform some analyses, do calculation, render data into graphics and so on. Today it is normal, when applying for a job, being asked if you know how to use some applications, like Office, SAP ERP and so on. They are considered an integral part of your professional knowledge and expertise. In a near future your CDT may also be subject to inquiries. How much does your CDT know? How effective is it in extending your professional capabilities? Will there be a certification of competence of your CDT as there are of yours? Will there be services to improve your CDT capabilities? Notice that a CDT is not operating independently of you. It is not a neutral application of some sort. A CDT is flanking you. Your knowledge, skill and experience are part of it, so you are, and will remain, an integral part of it. It is actually "your" specificity that makes your CDT unique and competitive compared to another CDT. Again, this is nothing really new. Today, at a different level, companies may hire a person because that person "knows" other people that can be used as access gateways to market opportunities (a portfolio of clients). A person's network of colleagues can be valuable for as long as those people remain in the network.

5. ***Act as my proxy, doing some cognitive taks using part of my knowledge***
   Recall the example of UBS that has developed an avatar impersonating their Chief Financial Analyst, meaning impersonating his knowledge on the investment market and investment opportunities and risks. That avatar is a digital instance of the Chief Financial Analyst, and the company can have as many instances as it needs operating in parallel. One issue with proxies is the divergence of the proxy knowledge from the real person knowledge, if the software has self-learning capabilities (which is more and more the case). In a little while the proxy will no longer be a proxy but an entity impersonating a different knowledge set. To remain a proxy, it should be able to transfer the acquired knowledge to its (real) twin which may be difficult, and some may claim it is impossible since it involves the recreation of a context (telling you what I saw when I went to see the temples in Chiang Rai transfers only part of my knowledge to

you; a good deal of the experience –and feelings that will later on condition my decisions- is not transferred and cannot be transferred since it requires exposure to that full context).

6. ***Share knowledge with other cognitive twins for cognitive team-working***
   A CDT can independently, or acting as a proxy, entertain relationships with other CDTs to engage in a cognitive task requiring a mix of knowledge and experiences distributed among several CDTs. This occurs every day in human teams; the transposition at the CDTs level enormously increases the sharing of knowledge since in cyberspace there is no geographical separation nor, in practical terms, a limited number of interacting parties (which is basically dependent on processing power). As digital twins, CDTs can also create instances of themselves and interact among these instances to explore a variety of scenarios and converge –quickly- on the most effective one. Technologies like Bidirectional Generative Adversarial Networks (BIGANs) can support self-learning. We have seen versions of BIGANs being used by machines for self-learning (like AlphaGo learning to play Go and learning it so well to be able to devise new winning strategies). This machine learning has tremendous potential that will become available to professionals as well as companies. Beginning with the knowledge they have as a human being (or collection of human beings) and moving it to cyberspace generates new knowledge that would have taken a very long time to emerge through traditional human interactions.

These latter three goals, where the CDT is delegated to act on our behalf, raise some interesting issues, like:

- Who is responsible for the activity performed by the CDT?
- Who "owns" the rights (both intellectual and practical) for the result of those activities?
- Could my CDT (or part of it) be cloned and used by the company I am/have been working with?
- Could my CDT become the cognitive brain of a robot?
- Who is checking the appropriateness of the interaction of my CDT in cyberspace (suppose it endeavors to "steal" knowledge from other CDTs)?

Apart from those issues and others that may arise as a cognitive digital twin picks up autonomy (a life of its own), it is obvious that a CDT may provide significant support to, and to a certain extent, change professionals and their need of applying the latest knowledge to a task at hand.

This is why the IEEE Future Directions Symbiotic Autonomous Systems Initiative, along with IEEE Education Activities and some IEEE Societies, proposed to investigate the possibility of creating cognitive digital twins to harvest the wealth of knowledge available in the IEEE *Xplore* repository. This repository contains millions of peer reviewed papers and keeps expanding. IEEE members having a CDT could use it to access the repository. IEEE services may be developed to:

- Help in developing a CDT: IEEE already harvests information from members on their area of interest and background education on a voluntary basis. This set of information can be expanded, at the member's request, to include articles downloaded from IEEE *Xplore*, searches, tutorials, webinars, workshops and conference attendance;
- Help members to create a context describing the knowledge needs (not in terms of knowledge but in terms of the tasks to be addressed or the appropriate career path of interest). The context can also be generated through the instantiation of existing contexts, some of them developed by companies seeking specific expertise;
- Identify knowledge gaps, given a CDT and a specific context, and suggest learning pathways by prompting with articles to read, conference to attend, MOOCs to take, other members to get in touch with, and so on;

- Subscribe to a personalized and continuously updated learning path, signaling new articles and providing synopses tailored to the person's need, pointing to upcoming presentations at conferences, webinars and so on;
- Complement answers resulting from searches to IEEE *Xplore* with additional pointers to relevant material fitting that person's context and CDT;
- Signal opportunities to leverage the available personal knowledge by responding to market demand as well as showing career opportunities based on market demand that can be taken by extending the personal knowledge in specific areas with minimum effort.

Obviously, these services could also be extended and adapted to meet the needs of companies in search for specific skills, like preparing customized continuous education plans to meet new company challenges based on the available resources.

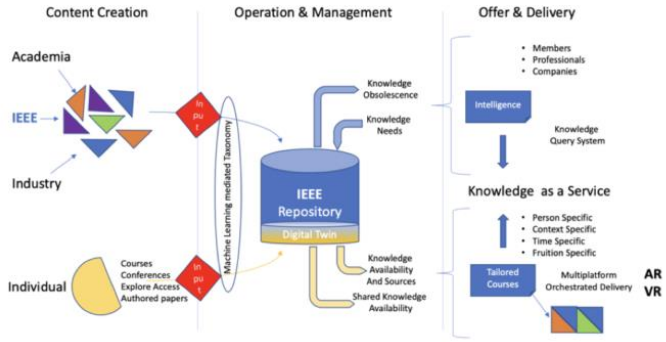


*Figure 14 Schematics for delivering services through cognitive digital twins in the IEEE Xplore context. Image credit: Roberto Saracco and Witold Kinsner*

All of the above is but a first goal, clearly a challenging one that, however, can be pursued in tiny incremental steps. Beyond that one can foresee services of Knowledge on Demand, Distributed-Cooperative Knowledge as well as, in the longer term, of Knowledge Creation.
It is an exciting scenario rich in opportunities, but it is also opening up several issues, having to balance openness with privacy and ownership, innovation with accountability, professional growth with automation.

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