Towards Evolving Symbiotic Education Based on Digital Twins*

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Abstract

The industrial revolution has accelerated the need for many skilled individuals that could not be produced by the personalized master-student educational system of the old. What was needed was a well-organized one-fits-all educational system that could produce expected numbers of individuals with expected skills within a fixed period of time. The Prussian classroom education system of 1770 produced magnificent results. At that time, the acquired knowledge and skills lasted for at least a lifetime. The industrial revolutions since then have accelerated the pace of knowledge doubling from a lifetime to months. Are we capable of adjusting to that pace? Furthermore, since the resilience of jobs has also been below a single lifetime, young professionals are expected to have more than one job. How can they learn all of that in the old educational system? The time has come to revamp the educational system at the core. The new system must be personalized to match the diversity of individual abilities and styles of learning. The new system must also be based not only on the body of knowledge (BoK), but body of experience (BoX). We envisage that the new personalized system of education being sufficiently agile and interactive so that it would become evolving in its symbiosis with humans. For that to happen, we must coexist with symbiotic autonomous systems, specifically involving digital twins. This paper addresses some aspects of this view.

Sommario

La rivoluzione industriale ha aumentato la necessità di disporre di molte persone con uno skill elevato che non potevano essere "prodotte" attraverso un insegnamento personalizzato quale quello utilizzato precedentemente. Diventava necessario passare ad un

*Those interested in getting a more in depth vision could refer to the documents available in the Symbiotic Autonomous Systems Initiative Education website: https://symbiotic-autonomous-systems.ieee.org/education

sistema educativo in grado di gestire elevati volumi in tempi contenuti con un approccio “un solo sistema adatto per tutti”. Il sistema educativo Prussiano del 1770 basato sulla educazione in classe portò a risultati eccellenti. A quell’epoca le conoscenze acquisite duravano per tutta la vita. La rivoluzione industriale ha accelerato la crescita di conoscenze diminuendo al contempo la sua durata, da una vita a qualche anno/mese. Siamo in grado di adeguare il nostro sistema educativo a questa nuova situazione? Inoltre anche la durata dell’impiego non è più coincidente con la durata della vita lavorativa, i giovani devono aspettarsi diversi mestieri nel corso della loro vita. Come possono imparare questo con sistemi educativi pensati per rispondere ad esigenze diverse? È arrivato il momento di ripensare il sistema educativo dalle sue radici. Il nuovo sistema dovrà essere personalizzabile alle diverse capacità e necessità di apprendimento. Deve essere basato non solo su di un Body of Knowledge (BoK) ma anche su di un Body of Experiences (BoX). Occorre pensare ad un sistema educativo in simbiosi con le persone e l’utilizzo di tecnologie e paradigmi come i Digital Twin possano realizzarlo. Questo articolo riflette su questi aspetti.

Keywords: Symbiotic education; digital twins; symbions; body of knowledge - BoK; body of experience -BoX; life-long learning; learning ecosystem; knowledge pyramid; closed-loop education; symbions self-organization

Digital Twins

Digital Twins in Industry

A number of industries like General Electric (GE), Tesla, NASA, are creating digital twins defined as digital replicas of their products like airplanes, cars, and satellites. The idea is to mirror a physical analog object in bits (i.e., a physical digital system, not resembling the original object in shape, but in its behaviour) keeping the bit replica synchronized with the physical one. This allows various types of retrospective and predictive analyses on the digital twin that can provide a better insight into the analog one, and lead to corrective actions, when required. In this sense, digital twins are new tools for education: rather than studying and training on the analog object, one can study on its digital representation first. Many technologies like virtual reality can further enhance training and education.

The usefulness of a digital twin goes beyond that scenario. The digital twin can develop far beyond our physical and physiological limitations, and find proper ways to be helpful in our adaptation to the untenable challenge of doubling of knowledge over a decreasing time period. Another challenge is the need to educate individuals for more than one job due to automation, mechanization,

and the unprecedented growth in deep learning (DL) [1] and artificial general intelligence (AGI), as described in the White Paper I and II. Some challenges in developing better engineering education in cognitive systems are described in [2], [3].

Is There a Digital Twin of Me Already?

In a way, each of us has already several fragments of our own digital twin. Social media like Instagram and Facebook, LinkedIn and Twitter are collecting parts of our “self”. Governments and municipalities are also collectors of parts of our “self.” The health-care system "knows" much about our body and mind. Large physical department stores, as well as digital merchandise systems like Amazon "know" much about our purchasing needs and interests (electronic products, mechanical gadgets, books, music) so that they often suggest new and related products. Google has a deep insight into its users' interests ranging from scientific, technical, conceptual, philosophical, artistic, political, social, to theological. Travel companies know our interests about the world and our disposable income. In addition, the companies where we have been working and where we work now have other fragments, representing our acquired skills and habits. Insurance companies know much about our health risks. The educational institutions that we have used are also collecting records of what we have learnt, how good we are at specific subjects, and can assess our intellectual potential. All of those fragments approximate of what and who we are. They are distributed elements of our digital twins.

At this stage, all those fragments are dispersed. Some countries are developing rules to establish ownership of those fragments. For example, Italians have the right to access these data and information, and the companies physically storing the data have to grant them access. Having the right and actually being able to access them easily, are quite different stories.

Digital Twin: Aggregation of Fragments

In perspective, we should be able to aggregate those fragments into a more comprehensive one in order to represent our “self” better. In addition, it is most likely that the number of collected observations, data, and extracted information about ourselves will grow in time, thus leading to more and more accurate representation of our “self”.

If we imagine a symbiotic relationship between a person and the corresponding digital twin, the symbiotic counterpart could form a very good understanding of who we are, sometimes through direct access to what we do jointly, some other times through the access to other digital twins.

A Symbiotic Digital Twin

In a formal way, our digital twin could come to represent both our skills, knowledge, and wisdom. It can also be flanked by applications taking into account the fading away of skills (what we lose when not practising) and knowledge (when we forget). This information of our degrading skills/knowledge can be the starting point for a proactive education program.

Writing an article and presenting it at a conference, or attending a conference to listen to colleagues presenting their papers can also be mirrored by our digital twin. The same applies to the process of reviewing papers. Many publishers allow ongoing discussion on their published papers that could be monitored by our digital twin. Educational institutions, including IEEE, could contribute to the mirroring of their “students”, “members” into digital twins. These might come handy in creating customized and personalized education programs. An example of such a program is the *personalized system of instruction* (PSI) by Fred S. Keller (1899-1996; 97) []. Since the manual administration of Keller’s PSI is very tedious, we have developed a *Computer-Aided PSI* (CAPSI) that has been running at the University of Manitoba, Canada for many years [5].

In a symbiotic autonomous system (SAS), the skills, knowledge and wisdom should be shared among its component subsystems to enhance the overall performance of the system. Furthermore, the digital twin could start increasing (or decreasing) interaction between its component parts. Notice that in dynamical complex systems, the whole is not necessarily the sum of its part. Through such nonlinear interactions, an emergent quality may appear that may not be found in any of its parts.

How Can a Symbiotic Digital Twin Help Me in Skill and Concept Learning?

If I live in a symbiotic relation with my appliances at home or at work, the knowledge of what specific selection/action/effect (a "program" for short) I would most likely to be interested in at a give time becomes part of the global knowledge of the symbiotic digital twin. However, the knowledge about what programs are available and would fit my interest may lie in an appliance. Notice that Amazon's Alexa, Apple's Siri, Microsoft's Cortana are all moving in this direction. There are now thousands of programs (such as streaming contents) to choose from and be of serious interest to me, but they are just too many for me to be aware of at any given time. The same applies to the millions of YouTube clips, tweets, and other pieces of information that could become an integral part of my education process, but I will never know that they even exist.

The same scenario can be envisaged with studying magazines, white papers, reports, textbooks, monographs, and research papers. Another scenario emerges with all the courses and MOOCs (massive open online courses) that are available at Coursera launched in 2012 by Stanford University (over 2,000 courses), EdX launched in 2012 by Harvard University (over 1,200), Udemy (over 2,500), Udacity (200), MIT OpenCourseWare (2,200), XuetangX founded in 2013 by Tsinghua University (over 500), Lynda (3,300), Khan Academy started in 2006 by Salman Khan, TED (1,890), The Great Courses (500), and over 700 universities offering MOOCs (e.g. [6] [7]). Designing of online courses is discussed in [8] and improved comprehension in [9].

A similar scenario emerges when doing research. Finding and reading relevant research papers, technical magazines, technical reports, white papers, technical books is very time consuming. These are all examples of the "where can I find it?" problem in education. A digital twin could help in these situations.

More Reasons for Symbiotic Digital Twins: Knowledge Doubling and Its Half-Time

With the explosion of data, information, knowledge and wisdom, we would have to spend all our available time searching for what is needed for our education and work. We cannot just ask a teacher of professor to answer our questions outside their class or research area. Today, search engines still provide millions of hits that have to be reviewed for relevance. Finding the relevance in the sifted out and even prioritized material takes time. Since our reading and comprehension abilities are slow (the average reading speed is around 300 words per minute), it might take up to four hours to keep up with daily emails, news digests, blogs, magazines, and books. This keep-up time reduces the time for creative work.

According to Buckminster Fuller's "knowledge doubling curve" in 1982, all human knowledge generated and transmitted doubled in size around year 1500. It doubled again by 1750 (only 250 years), and doubled again by 1900 (just 150 years). With those rates, humans were able to adapt to the growth and change. It became harder to adapt when the doubling took 25 years around 1950. The knowledge doubling today is much shorter (around 13 months). As an example, the number of annual patents increased from about 50,000 to more than 325,000 over the last 50 years. Many in IBM predict that in not-too-distant future (2020), the knowledge doubling will happen in 12 hours. It is not feasible for a human to adapt to that rate. The concept and implementation of a digital twin seems to be a necessity now [10].

There is another reason for digital twins: the knowledge half-life. In his book Future Shock [11], Alvin Toffler stated that “the illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn.” The knowledge and skills acquired in our schools and successive jobs diminishes in value, and requires continuous updating, not once but throughout our lives.

How long does it take for knowledge to become outdated and irrelevant, or even incorrect? The half-life of knowledge (i.e., the amount of time it takes for knowledge to lose half its value) is often used to indicate the devaluation of knowledge in various disciplines. As might be expected, the knowledge half-life in aggressive disciplines like science, engineering and technology is shrinking fast.

Knowledge Tsunami and Organizations

The conditions when knowledge-doubling occurs exponentially, while the knowledge half-time decreases may have a tsunami effect on any society, organization, company or other organizational unit. The SAS with digital twins could be very helpful in increasing our resilience in some of the following areas: (i) Curation of knowledge (organizing and filtering according to agreed-upon criteria to eliminate irrelevant knowledge); (ii) Knowledge fusion (to discover and clean errors present in sources, as well as mistakes made in the process of knowledge extraction from sources); (iii) Plagiarism management (to generate new knowledge); (iv) Knowledge vetting (to identify and verify sources for quality of the content used in the organization); (v) Intellectual property management

(separating intellectual property, trade secrets, and copyrighted information from generic and public-domain content); (vi) Knowledge sunsetting (to identify knowledge that cannot be used any longer); (vii) As traditional libraries dwindle, creation of a digital twin "librarian" that knows the needs of the organization and its members would be beneficial; (viii) As traditional publishing also dwindles, creation of a suitable digital twin "publisher" could benefit the organization.

From Competition to Cooperation and Knowledge-Sharing Society

In the past, individuals and teams in companies and organizations worked independently, competing in the quest for reaching the finish line first. Competition has been recognized as healthy, but leaves many in the dark.

The emerging possibility of educational digital twins in the SAS environment creates a set of new opportunities for knowledge to be uncovered and discovered, distributed widely, and then enhanced by the same individuals, but now working in the SAS environment. In fact, new knowledge is now developed mostly by collaborating or even cooperating teams rather than individuals.

What Prevents Us from Having the SAS in Education Today?

There are at least three missing links to create a SAS in education: (i) a reasonable digital twin itself, (ii) symbiotic interconnects, and (iii) rigorous modelling of SAS.

While the concept of a digital twin is not new, the concept of a digital twin of a human is fairly new. While attempts are being made to develop machines and systems capable of acting in a manner that could be described as: adaptive, autonomous, intelligent, perceptual, cognitive, conscious, and symbiotic with humans and the environment, digital twins are not here yet.

The second missing link is the connectivity between the different parts of the symbiotic system. When the Internet has been developed sufficiently, we thought, happily but mistakenly, that education could be improved on a dime by delivering many online courses (in different forms such as the massive open online courses, MOOCs) to many people at any time and any place. Of course, this helped, as millions of new individuals obtained access to education that was not available to them before. However, the interconnections were not symbiotic. We must develop a new class of symbiotic interconnects.

The third missing link is proper rigorous modelling of SAS based on brain-inspired and socially-inspired processes. This modelling also implies quintessential changes in signal processing in the simulation of the processes. In the past, the majority of signal processing was done on a single scale (mono-scale). More advanced models of reality included multi-scale signal processing. Cognitive system and SAS require not only more elaborate multi-scale, but also poly-scale modelling and signal processing. Some of the definitions will be provided in the next subsection, and summaries of the modelling techniques may be described in SAS White Paper III.

How Can We Get There?

The missing links can be addressed by some innovators, including some specific initiatives by IEEE or ACM or other organizations (obviously not related

to the above case on how to learn using a photographic camera to make aesthetic photographs in a reasonably short time, but, as an example, to support careers path of its IEEE members).

Towards Evolving Symbiotic Education

Summary of Reasons

As discussed already, the knowledge tsunami and automation has put much pressure to change the current classroom/workshop model in vocational training. More students and workers learn “just-in-time”, and often just enough to solve a problem or get a job completed. Teachers and trainers can no longer be the main sources of knowledge about the world of work, but need new forms of technology to help find and manage the increasing amount of information. No single person, no matter how brilliant, can handle the knowledge, even in one field of study.

Consequently, the roles of teachers, trainers and consultants need to change – from mostly presenters of information to guides, mentors, curators of knowledge, critical thinkers, and problem solvers. They will have to use digital learning skills and literacies.

I have been making the case that the next generation of education would benefit much from the development of symbiotic digital twins capable of being in relation with human beings in a symbiotic system. This intimate knowledge of the personal needs and abilities could allow the digital twins to deliver both the BoK and BoX in a personalized way that has a chance to compete with the best model of the Oxford Master of the past.

Model of a Digital Twin in Education

A model of the digital twin that could be used in the symbiotic education is illustrated in Fig. 1.

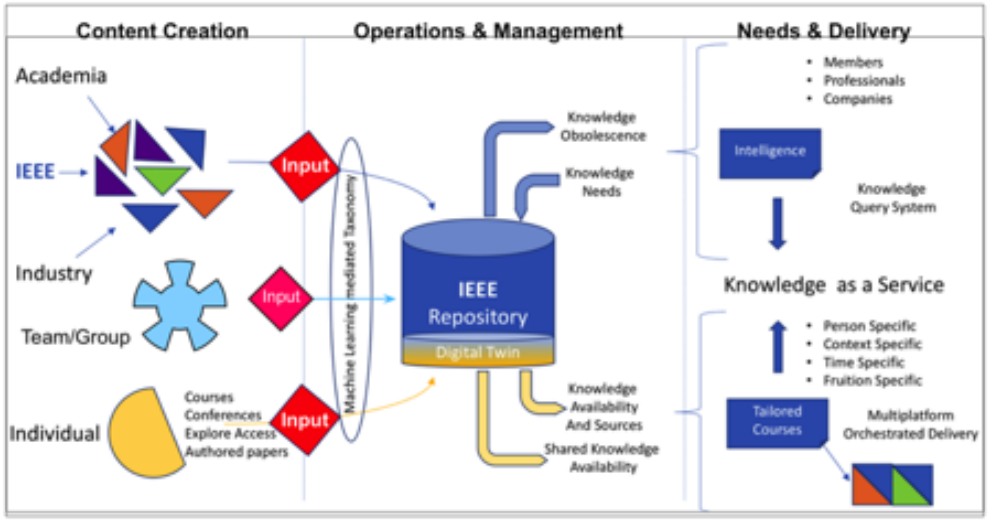

Figure 1
A digital twin model for symbiotic education.

For clarity, the digital twin is segmented into three parts: (A) content creation, (B) operations and management, and (C) needs and delivery. Each part is also subdivided into several groups of activities. For example, Part A has three distinct important content creators: (1) organizations, (2) groups, and (3) individual.

A. Content Creation

The first content creator (A1) includes: (i) the academic research and education, (ii) industrial research and development, together with the cumulative experience in the corresponding field, (iii) business modelling and analysis, and (iv) technical and scientific organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the Institution of Engineering and Technology (IET, formerly the Institution of Electrical Engineers, IEE), the Association of Computing Machinery (ACM).

The second content creator (A2) includes (i) teams and (ii) groups of individual whose objectives and driving forces may be fundamentally different from the corporations and organizations of Class A1. Their impact may also be very different in scope. Disruptive technologies and ideas often start at that level.

The third distinct content creator (A3) is the individual who operates differently from the other two content creators. Individuals do research, write papers, read papers, access IEEE Xplore, connect dots or relations not seen by others before, create courses, contribute to conferences, contribute to teams, as well as contribute to corporations, countries, and societies.

What is not shown in Fig. 5 is a content creator that is larger than corporations and organizations: the society and its culture, together with both the environment that the society exists and its humanity. Without closing this loop between the individual and humanity, the process may become unsustainable and meaningless. But it has never been so, in the long run.

B. Operations and Management

This operations and management part of the digital twin model includes three key constituents: (i) a repository of all that is known, (ii) a master analyzer and taxonomy creator (MaX), based on the inputs from Part A and from the knowledge repository, and (iii) the part of the digital twin that is visible to the outside world.

Based on the current needs, the digital twin provides the BoK and BoX that is available and suitable to the individual recipient. Using the best available machine learning mechanisms, the MaX categorizes the enormous influx of new knowledge and experience, and evaluates obsolescence and possible sunsetting of parts in the current BoK and BoX.

The MaX concept has the potential to induce new approaches, methods and techniques to learn by machines to help learning by humans. Why deep learning has improved the level of sophistication in machine learning, much more has to be considered from the perspective of an individual digital twin and the society of digital twins.

C. Needs and Delivery

This part of the system is responsible for identification of individual needs and personalized methods of delivery. The needs may be related to individuals, professionals, practitioners, members of an organization, companies, businesses, governments, countries, societies. The needs may stem from either personal or team interests and may be identified based on the specific (a) context, (b) time and (c) expected outcomes or any combination of the three.

There is another possible outcome of using digital twins. Business intelligence gathering in cyberspace from individuals, companies, organizations, governments, countries and economic systems is already practiced today. Unchecked and unethical practices may, however, lead to a collapse of the system itself, as individuals may select to see the profitable part of the system only. We see an opportunity for the digital twins to help in resolving this age-old problem. Digital twins may actually enforce the ethical use of the system by operating ethically.

Expected Outcomes from Using Digital Twins: Symbions

The result of such an evolving symbiotic educational system is illustrated in Figure 2. This figure shows the digital twin as an inverted pyramid. This is to emphasize the **complementary symbiotic relation** between an individual and the DT system. Such an intertwined DT and a person could be called a **symbion**. The diagram is also intended to imply that the symbions could penetrate the environment even deeper that the human alone. The system could participate in the data mining and processing to extract information more relevant to the individual and to the environment. It could possibly see more patterns in the information and extract more significant knowledge that could be used in the decision-making process. This layer is now the widest because the digital twin would be connected symbiotically to all the relevant other digital twins for consultation.

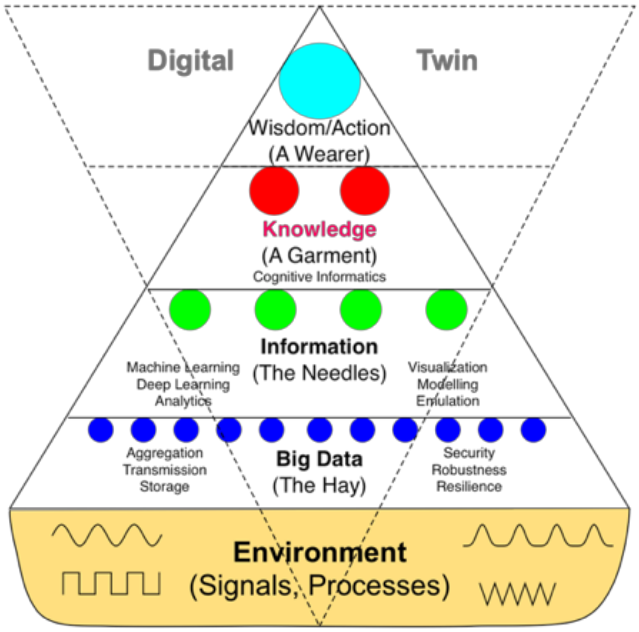

Figure 2
The impact of symbiotic education: Symbions.

Possible Outcomes from Symbions: Deeper Insight and Purpose

Learning through the symbiotic relation between an individual and a digital twin is potentially much more beneficial to the individual than alternative learning methods. The symbiotic pair (the individual and the digital twin) is called here a symbions. It should be very clear that such individual symbions are connected with other symbions through the fundamental construct of a digital twin. The individual symbions can enter into symbiotic relations with other symbions, forming teams, communities, and societies, as shown in Fig. 3b.

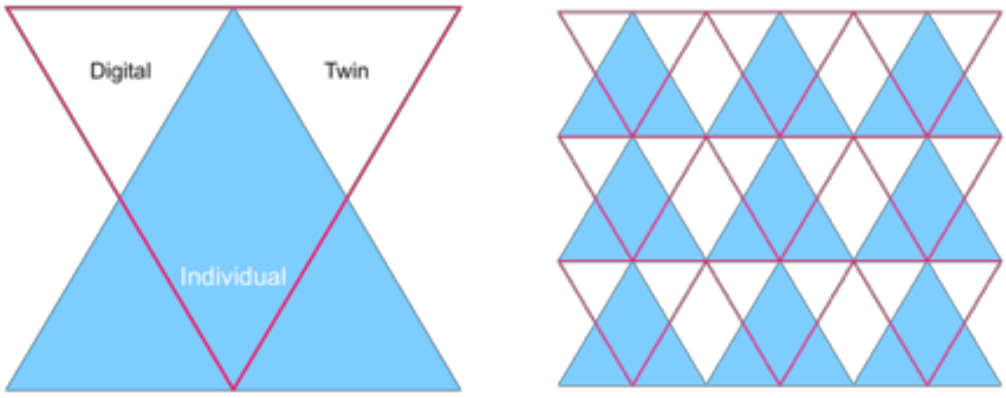

Figure 3

The impact of symbions: New societies and new knowledge. (a) A single symbions. (b) A small self-affine team.

The team shown in Fig. 3b is uniformly symmetrical. This pattern can be resized and repeated at different scales. It forms a self-similar object. The symbions can be displaced, flipped and rotated in either a deterministic or a random fashion, thus forming a self-affine structure, as shown in Fig. 4.

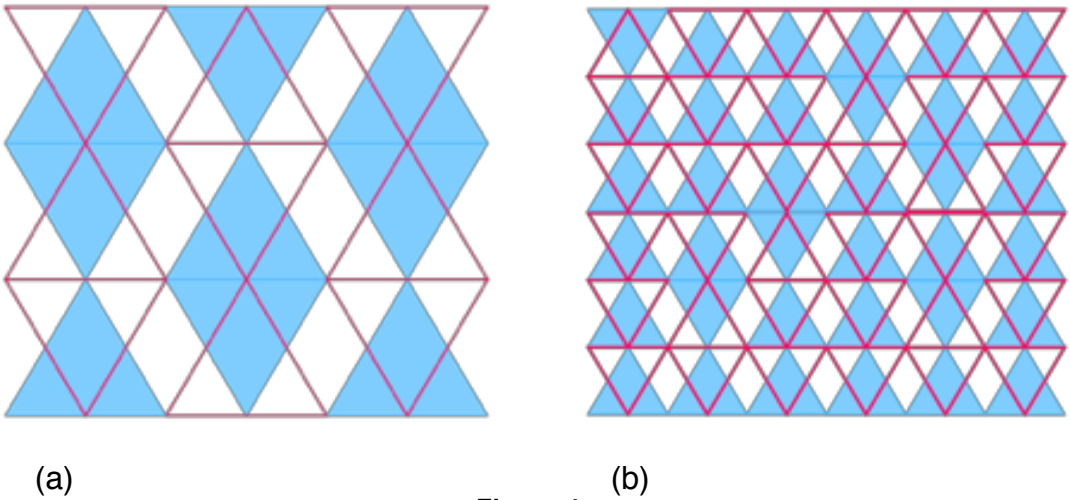

Figure 4

*Symbions groupings: (a) Self affine, *b) Stochastic self affine.*

The structures can be further altered to achieve even different topologies, as shown in Fig. 5.

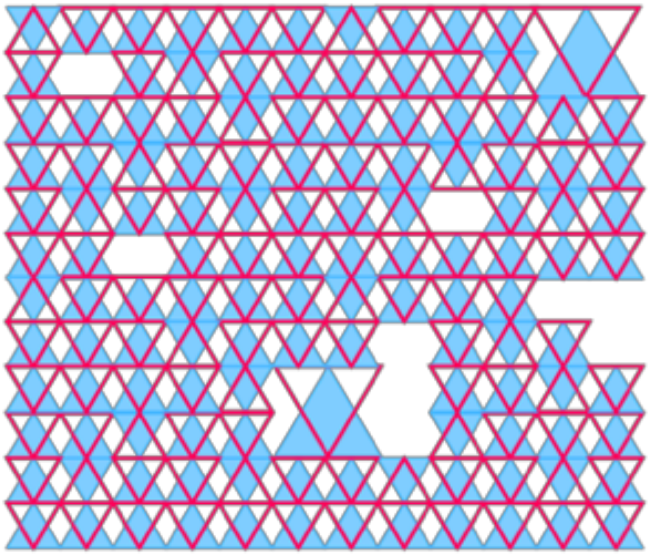

Figure 5
Stochastic topological groupings.

The advantage of this modelling is the ability study the dynamic behaviour of such teams and societies, using multiscale and polyscale techniques capable of identifying long-range dependencies, that are critical in predictive control in cognitive systems.

Closing Remarks on Symbiotic Education

- Symbiotic education has the promise of great impact on how we study, learn, acquire skills, interact with people and machines, discover new things, learn how to operate new things, and how to see reality much deeper.
- Symbiotic education can open up a new landscape for exciting new concepts and research projects.
- We already know how to compete. Symbiotic education might help us how to compete fairly.
- While competition could improve in fairness , we might also learn how to cooperate better.
- To succeed, symbiotic education must use the most sophisticated algorithms available today, and might accelerate development of better algorithm including:
    - Deep learning and machine learning [12];
    - Cognitive systems [13], [14];

- Web intelligence [15];
- Higher0order (HO) statistical signal processing [16], [16];
- Intelligent signal processing [54, [18]];
- Compressive sensing [19];
- Fuzzy and granular computing [20];
- Multiscale (wavelet) analysis [21], [30];
- Polyscale and fractal analysis [58], [30];
- Long-range-dependence patterns in the data [22], [23];
- Nonlinear time series analysis [59];
- Emergent dynamical systems concepts [24], [25].

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Biography

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