

Information and Communications Technology new paradigm of probabilistic computing could inspire our thinking through a future World of uncertainty

-Part 3-



Prof. Eng. Ph.D. Victor GREU

Abstract

The paper analyses some aspects regarding the evolution and implications of the Information and Communications Technology (ICT) probabilistic computing paradigm. When the data uncertainty level is high, as the consequences of COVID-19 19 pandemic, the ICT support is more than useful. For evaluating the potential of ICT to face this challenge, first we have considered the actual and emerging ICT advances that could provide real instruments and associated results to approach the diversity of problems with high uncertainty. ICT trends are among the complex evolutions of the associated technologies and concepts that continuously bring innovations aiming the performance, efficacy and efficiency improvements for the ICT services, products and applications that support Information Society (IS) on the way towards the Knowledge Based Society (KBS). Probabilistic computing (PC) is the actual new paradigm which is implemented by the ICT industry leaders, in order to support the most performant advances of ICT, where artificial intelligence (AI) is first pointed, but also linked with Bigdata or other ICT advances, like quantum computing (QC). The link between these advances is given by the ICT struggle to continue Moore Law, but PC is in the same time an emerging trend to improve AI toward human brain unreached features, like using fewer data (than machines) in order to generalize and decide. To reach such purposes, ICT innovations are made in both hardware and software areas, but also in new models and algorithms, more and more inspired from human brain, as the paper presents by analysing some relevant examples, including PC, QC and biological substrates for computation (cellular computing). The analysis revealed the role of "learning" in the innovation process, as the actual aim of AI/PC is to achieve the human brain ability to learn and re-create, including probabilistic programming, which is in the stage of providing the ability to self-develop and create new programs without human intervention.

The analysis includes some elements which are linking the two emergent and unconventional computation concepts/technologies, i.e. probabilistic computing and quantum computing. Still, **it is important to analyze such advanced instruments from all relevant implications, because we have to admit that in the more and more sophisticated world of soft/ICT, the logical covering of all scenarios is still necessary, but in the same time more difficult to achieve.** All these challenges express the difficulty and complexity of innovation processes ICT/AI have to face toward further performance improvements, but also the high expectations from PC, just due to this context.

The paper stressed the inherent care that should be considered for a sustainable progress of ICT/IS/KBS, including the necessary monitoring of all consequences (benefic or not) that could appear at planetary scale from the proliferation of using their services and products everywhere and everytime. Here climate changes, Earth resource fading or social contrasts, affecting Earth ecosystem and humankind life/evolution are crucial problems that should be considered. **In this context, the learned lessons of ICT on the way of implementing the new paradigm of PC could bring benefic support also for people's everyday life, when facing the uncertainties of World evolution/challenges.**

Our point of view and the paper focus is that the essence of those evolutions of the context factors is the fact that one of the main mechanisms that lead to complexity and difficulty to optimize the progress solutions is the increasing level of uncertainty that characterizes associated data of the analyzed processes to be optimized at

planetary level, but at lower (individual) levels also. This way we agreed that **some approaches of the models and technologies, used by ICT to implement the new paradigm of Probabilistic Computing (PC) could bring benefic support and learned lessons also for people's everyday life, when everyone is facing the uncertainties and decision challenges in the general context of World evolution or of their own life context. The chances for maximizing the veracity of estimating the processes evolutions are given by trying to keep searching for the relevant data/information/knowledge, integrating the events results step by step and this way counting the average positive ones**, i.e in a manner that is very close to Bayesian approach which forms the PC main premise. Starting from one of the remarkable PC basic models, **<<to built reliable constructions from probabilistic parts>>**, our opinion is that this important approach is in fact **one of the pillars humankind could learn from ICT (but not exclusively from it), when facing the World uncertainties, everyday and everywhere on Earth and beyond**. It is clear that such apparent paradoxical approach must be discussed for every application area, where this idea from PC/ICT should be applied with the appropriate solutions (if they are identified!), in order to **find the approaches and algorithms that provide reliable constructions from probabilistic parts or at least lead to safer ensemble (by compensating the expected points of failure!), instead of simple using the probabilistic (not very safe) parts**. This basic PC model could be benefic for understanding the suggested approach/method which then should be applied from case to case, either in simple problems of decision or in probabilistic programming applications, but **always innovating something in the case model, i.e. using our imagination to estimate and compensate the probable risk of fealure and finally increasing the success probability**.

As a main conclusion, we just have to imagine how humankind could evoluate from the actual trends of using everyday ICT advances, including probabilistic computing/ programming, considering also the emergent changes in business models and jobs transformations AI/ICT have already started to produce, but eventually using the above ICT lessons to better face the World uncertainties.

Keywords: Probabilistic computing paradigm, Quantum computing, Probabilistic bits, Cellular computing, Bayesian programs, Probabilistic transistors, Probabilistic programming, Machine learning

JEL Classification: L63; L86; M15; O31; O33

**„The most important questions of life are indeed, for the most part, really only problems of probability”
Pierre-Simon Laplace**

1. Teaching machines to probabilistically learn

In spite of all daily evidences regarding World's general technological progress and wellbeing, we also could see how the challenges for people's lives and organizations/incumbents are also growing and become more complex, complicated and difficult to face, without considering the natural aim to optimally solve them.

Perhaps the COVID-19 19 pandemic could and will be one of the most relevant examples, adding to the main list of climate changes, Earth resources fading, social unbalances etc.

On the other hand, this World's major sanitary crisis, generating other extended or potentially crises, including here economical, financial and educational ones, is undoubtedly an opportunity for reconsidering development/progress strategies and generating innovation in all humankind activity fields.

Inherently, observing the words “all humankind activity fields” leads us to another item that greatly influences the same fields: Information and Communications Technology (ICT).

As we have repeatedly mentioned and detailed [9] [20], ICT is the main driving factor of the World progress and particularly of the Information Society (IS) on the way towards the Knowledge Based Society (KBS).

Now coming back to the above-mentioned major crisis, it is not just a coincidence that for most World's big problems, ICT is always a leveraging factor for the optimal solutions.

Further, we may consider that for the complex problems, where usually the data uncertainty level is high, as the consequences of COVID-19 pandemic, the ICT benefic support is more than useful.

For evaluating the potential of ICT to face this challenge, first we have to consider the actual and emerging ICT advances that could provide real instruments and associated results to approach the diversity of problems with high uncertainty.

Generally, these ICT trends are among the complex evolutions of the associated technologies and concepts that continuously bring innovations aiming the performance, efficacy and efficiency improvements for the ICT services, products and applications that support IS/KBS progress.

In fact, as we have presented in [3], *probabilistic computing* (PC) is the actual new paradigm which is implemented by the ICT industry leaders, in order to support the most performant advances of ICT, where artificial intelligence (AI) is first pointed, but also linked with Bigdata or other ICT advances, like *quantum computing* (QC).

The link between these advances is generally given by the ICT struggle to continue Moore Law, as we also have approached [20], but PC is in the same time an emerging way to improve AI toward human brain unreached features, like using fewer data (than machines) in order to generalize and decide.

Although it is not always true, usually fewer data mean a higher probability to introduce fewer errors or noise in the process, leading to models similar with human brain operation and performances.

To reach these purposes, ICT innovations are made in both hardware and software areas, but also in new models and algorithms, more and more inspired from human brain [16][17][19].

On this way, it is well known the role of “learning” in any developing process and the actual aim of AI/PC is to achieve the human brain ability to learn and re-create, including programming, as the next relevant example presents in detail [1]:

„ The actual learning takes place inside large data centers using many computer processors churning away in parallel for hours or days ...Many researchers start their adventures in machine learning by tinkering with the Modified National Institute of Standards and Technology (MNIST) database of handwritten digits, which is commonly used to train image-processing systems. One of the seminal publications in probabilistic programming came in 2015 from Brenden Lake, Ruslan Salakhutdinov and Joshua Tenenbaum, who described a computational model that can recognize, parse and re-create these handwritten characters. Their program learns quickly from limited samples and has an uncanny ability to use what it has already learned to create further new semantics, or meanings, much as a person would.”

Here the news is that, step by step, the impressive results provide the ability to self-develop and create new programs without human intervention:

“Their framework draws from three key areas in machine learning: compositionality, causality and “learning to learn.” Rich concepts are constructed compositionally from primitive elements (the most basic elements available in the programming language), which

serve as building blocks. Probabilistic semantics that are robust to noise — that is, are stable despite the addition of random elements — help this framework capture the causality inherent in real-world processes. The model learns to learn by using previous experience with related concepts to facilitate the mastery of new concepts, thereby constructing programs that best explain observations under a Bayesian criterion. These priors embody a learned inductive bias — a set of assumptions that the learner uses to predict outputs, given inputs that it has not yet encountered — that captures key regularities and variations across concepts, and instances of these concepts in a given data domain. New programs can be constructed reusing pieces of existing ones, exploiting the causal and compositional properties of real-world generative processes operating on multiple scales. New program types can be broadly generated by choosing primitive actions from a library and combining these subparts into larger components and relationships to define simple programs. Running these programs and rendering them as raw data can generate new program types...”

It is important to analyse such advanced instruments from all relevant implications, because we have to admit **that in the more and more sophisticated world of soft/ICT, the logical covering of all scenarios is still necessary, but in the same time more difficult to achieve.**

In this case, at least the benefic implications are very clear pointed as concerning the performance, further development and the human factor cost:

“One of the strengths of Bayesian probabilistic programs is that they are capable of writing new Bayesian programs themselves, with no need for human programmers. This so-called Bayesian program synthesis (BPS) framework separates modelling and inference, allowing the automatic synthesis of new programs via inference; the programs then feed into a modular framework and are integrated into larger models. Because Bayesian methods easily incorporate prior knowledge, effective inference can often be performed with a lot less data...”

Here we have to notice the crucial observation that using prior knowledge is essential, as in the case of human brain the experience role is, because this way we can design and optimize these programming tools for a sustainable progress when incorporating the refined knowledge resulted from global evaluation of all consequences of ICT/IS/KBS development.

As we have mentioned for years [18][6], the biological World will feed the scientist inspirations from nature’s million years research, which actually happens with impressive results, but these are also complex, iterative and long processes, where, fortunately, ICT with its advances are one of the main enablers, in a huge and benefic self-promoting circle. **Many of the biological innovations try to find an alternative for the actual (silicon) advanced technologies and go further with Moore Law.**

Like an iceberg tip, the next example could be one of these revolutionary innovations, although at the beginning and having relatively limited applications fields [2]:

“Synthetic biology uses living cells as the substrate for performing human-defined computations. Many current implementations of cellular computing are based on the “genetic circuit” metaphor, an approximation of the operation of silicon-based computers. Although this conceptual mapping has been relatively successful, we argue that it fundamentally limits the types of computation that may be engineered inside the cell, and fails to exploit the rich and diverse functionality available in natural living systems. We propose the notion of “cellular supremacy” to focus attention on domains in which biocomputing might offer

superior performance over traditional computers. We consider potential pathways toward cellular supremacy, and suggest application areas in which it may be found."

The practical results of this idea are provided by replacing silicon by new, biological, substrates for computation (*cellular computing*), but hopefully with benefits for other useful areas:

"Synthetic biology is a rapidly growing field of research which applies engineering concepts and principles to the rational engineering of living systems, such as bacteria and yeast. The promise of synthetic biology lies in its potential to provide new substrates for computation, production, pollution control and medical diagnosis (among many areas), and to harness the "wetware" inside the living cell for human-defined purposes. Synthetic biology is set to become a significant component of the multi-billion dollar bio-economy, but, in addition to tangible benefits such as cheaper drug production or more precise bio-sensing, many researchers in the field believe that the very process of re-engineering life will both require and inform a reexamination of our fundamental understanding of cellular processes"

The importance of this technology relies on the fact that, although limited, the beneficial applications fields include *bio-economy, pollution control, medical diagnosis, drug production or precise bio-sensing, for human-defined purposes*, i.e. some of the most needed directions for World sustainable progress.

In order to generally estimate the stage and the complexity of the PC/QC/AI/ICT advances, starting from the unprecedented "tops" where we are already are, but on the other hand comparing soft and hard fields on this line, the next examples could bring relevant and more detailed elements for the emerging, but on a long road, probabilistic computing and quantum computing development.

First, PC has the premises to bring reliable solutions and to improve performances just in the areas that are actually most needed for the progress of ICT, as it is next detailed[4]:

"The potential impact of Artificial Intelligence (AI) has never been greater but we'll only be successful if AI can deliver smarter and more intuitive answers. A key barrier to AI today is that natural data fed to a computer is largely unstructured and "noisy". It's easy for humans to sort through natural data. For example: If you are driving a car on a residential street and see a ball roll in front of you, you would stop, assuming there is a small child not far behind that ball. Computers today don't do this. They are built to assist humans with precise productivity tasks. Making computers efficient at dealing with probabilities at scale is central to our ability to transform current systems and applications from advanced computational aids into intelligent partners for understanding and decision-making. This is why probabilistic computing is one key component to AI and central to addressing these challenges."

We see that PC has relevant premises to push AI to the next step of its amazing evolution, aiming some of the long desired human brain features:

"Probabilistic computing will allow future systems to comprehend and compute with uncertainties inherent in natural data, which will enable us to build computers capable of understanding, predicting and decision-making. Today at Intel, we are observing an unprecedented growth of applications that rely on analysis of noisy natural data different and even conflicting information. Such applications aim to assist humans with a higher level of intelligence and awareness about the environments in which they operate. Cutting through this

noisy minefield is central to our ability to transform computers into intelligent partners that can understand and act on information with human-like fidelity”.

It is worth to notice the crucial role of PC/ICT *to assist humans with a higher level of intelligence and awareness about the **environments** in which they operate*, i.e. just what our paper aim is suggesting as a support for people when facing the World’s reality, where more and more they need a way to estimate and compensate the risk of failure caused by uncertainty.

If the general model of PC approach seems not very complicated and also the expected results could be limited, for revolutionary improvements expected when linking PC and QC the situation could be different, as it is presented by [5]:

<<Researchers from Purdue University and Tohoku University ... created and used probabilistic bits (p-bits) to factorize integers up to 945. The work, led by Kerem Casmari (Purdue) and Shunsuke Fukami (Tohoku), seems to be well suited for classes of optimization (energy cost) problems “The key role is played by a probabilistic bit (a p-bit)—a robust, classical entity fluctuating in time between 0 and 1, which interacts with other p-bits in the same system using principles inspired by neural networks. Here we present a proof-of-concept experiment for probabilistic computing using spintronics technology, and demonstrate integer factorization, an illustrative example of the optimization class of problems addressed by adiabatic and gated quantum computing. Nanoscale magnetic tunnel junctions showing stochastic behavior are developed by modifying market-ready magnetoresistive random-access memory technology and are used to implement three-terminal p-bits that operate at room temperature.”>>

Although it is just a simple application of the concept, the importance of this achievement for further development is huge:

<<According to the paper, the p-bits are electrically connected to form a functional asynchronous network, to which a modified adiabatic quantum computing algorithm that implements three- and four-body interactions is applied. “Factorization of integers up to 945 is demonstrated with this rudimentary asynchronous probabilistic computer using eight correlated p-bits, and the results show good agreement with theoretical predictions.”

The authors note decoherence and the current requirement for cryogenic operation, “as well as the limited many-body interactions that can be implemented” all pose challenges for typical quantum computers. “Probabilistic computing,” they write, “is another unconventional computation scheme that shares similar concepts with quantum computing but is not limited by the above challenges.”>>

Here we have to notice the relevant example of linking the two emergent and unconventional computation concepts/technologies, i.e. *probabilistic computing and quantum computing*.

It is also important to observe the advantages offered, at least in this case, by PC versus QC, where the *cryogenic* conditions will rise severe challenges for the versatility of QC applications, along with the limited useful *interactions*.

All these challenges express the difficulty and complexity of innovation processes ICT/AI have to face toward further performance improvements, but also the high expectations from PC, just due to this context.

Another reality we have to consider is the fact that all these research advances difficulties became natural, as the exponential evolution of ITC peaked such huge achievements with an unprecedented speed.

We have also to mention the inherent care that should be considered for a sustainable progress of ICT/IS/KBS, including the necessary monitoring of all consequences (benefic or not) that could appear at planetary scale from the proliferation of using their services and products everywhere and everytime. Here climate changes, Earth resource fading or social contrasts, affecting Earth ecosystem and humankind life/evolution are crucial problems that should be considered.

In this context, the learned lessons of ICT on the way of implementing the new paradigm of PC could bring benefic support also for people's everyday life, when facing the uncertainties of World evolution/challenges.

2. Facing a World of more and more uncertainty

All ICT advances are aiming the IS toward KBS progress, but the fast pace in the complex and dynamic context of these evolutions generates challenges which are more and more difficult to solve, at research, incumbents and even at the individuals levels.

Still, it is fair to mention from the beginning that these challenges are not caused exclusively by ICT evolution, but the IS/KBS context and even more, in the Earth ecosystem, where all the factors contribute in generating very complex and complicate decision problems which are associated with the political, economical, social or technological fields and also with the humankind behaviour and evolutions.

By our point of view, for the paper focus, **the essence of those evolutions of the context factors is the fact that one of the main mechanisms that lead to complexity and difficulty to optimize the progress solutions is the increasing level of uncertainty that characterizes associated data of the analyzed processes to be optimized at planetary level, but at lower (individual) levels also.**

This way we may agree that **some approaches of the models and technologies, used by ICT to implement the new paradigm of Probabilistic Computing (PC), could bring benefic support and learned lessons also for people's everyday life, when everyone is facing the uncertainties and decision challenges in the general context of World evolution or of their own life context.**

In order to approach or learn from the mentioned models and technologies, we should analyze some relevant details or conclusions from the ICT innovations in the general area of PC.

On a systemic approach, perhaps one of the most relevant observations has to be taken from the main efforts of the researchers and analysts to estimate just the directions where generally ICT is going to, as it is well pointed by [7]:

<< Twelve years ago, IEEE Fellow, Marconi Prize winner, and beloved Spectrum columnist Robert W. Lucky wrote about the difficulty of predicting the technological future. We've reprinted his wise words here...

"When I joined Bell Labs, so many years ago, there were two great development projects under way that together were to shape the future—the Picturephone and the millimeter

waveguide. The waveguide was an empty pipe, about 5 centimeters in diameter, that would carry across the country the 6-megahertz analog signals from those ubiquitous Picturephones. Needless to say, this was an alternative future that never happened. Our technological landscape is littered with such failed bets. For decades engineers would say that the future of communications was video telephony. Now that we can have it for free, not many people even want it. The millimeter waveguide never happened either. Out of the blue, optical fiber came along, and that was that. Oh, and analog didn't last. Gordon Moore made his observation about integrated-circuit progress in the midst of this period, but of course we had a hard time believing it. Analog switching overstayed its tenure because engineers didn't quite believe the irresistible economics of Moore's Law...">>

Further, the human experience from such events is also worth to notice and understand, because similar situations are often encountered in many fields and generally for many individuals in a diversity of contexts:

<<...The irony at Bell Labs is that we had some of the finest engineers in the world then, working on things like the integrated circuit and the Internet—in other words, engineers who were responsible for many of the innovations that upset the very future they and their associates had been working on. This is the way the future often evolves: Looking back, you say, "We should have known" or "We knew, but we didn't believe." And at the same time we were ignoring the exponential trends that were all around us, we hyped glamorous technologies like artificial intelligence and neural networks. Yogi Berra, who should probably be in the National Academy of Sciences as well as the National Baseball Hall of Fame, once said, "It's tough making predictions, especially about the future." We aren't even good at making predictions about the present, let alone the future.>>

Without considering all above mentioned examples, as artificial intelligence, which is now again on top, it is useful to observe the confirmed difficulty to precisely estimate all the possible evolutions of such "hurricane" as ICT is [11][14][13][12][15].

Our point about the similarity with individuals' lives also here could be observed, this time for journalists:

<<...Journalists are sometimes better than engineers about seeing the latent future embedded in the present. I often read articles telling me that there is a trend where a lot of people are doing this or that. I raise my eyebrows in mild surprise. I didn't realize a lot of people were doing this or that. Perhaps something is afoot, and an amorphous social network is unconsciously shaping the future of technology. Well, we've made a lot of misguided predictions in the past. But we've learned from those mistakes. Now we know. The future lies in quantum computers. And electronics will be a thing of the past, since we'll be using optical processing. All this is just right around the corner.>>

More than the clear connection with QC, the last conclusion is a good lesson for the best practice, i.e. to consider the relativity and probability of each analysed field/event and learn from those mistakes.

We consider also that **the chances for maximizing the veracity of estimating the processes evolutions are given by trying to keep searching for the relevant data/information/knowledge, integrating the events results step by step and this way counting the average positive ones**, i.e. in a manner that is very close to Bayesian approach which forms the PC main premise.

A confirmation of this approach, starting from simple innovation steps, is very relevant presented by [8]:

“Probabilistic computation is, in a way, not new. John von Neumann himself dedicated a fair amount of research effort to what he referred to as reliable computing from unreliable components. On the other hand, however, traditional approaches to silicon technology have assumed “deterministic” transistors whose behaviours have a very high level of predictability – so high, in fact, that computational models (e.g., multiplication) built on top of transistor gates assume deterministic gate-level behaviour. The research being investigated in this project within ISNE at NTU, together with international collaborators, aims to explore a new approach for the nanoscale era: reliable computing from probabilistic components.”

Here we have to observe that the main idea is not limited to Probabilistic Computing, but we can imagine that any construction (physical or virtual; hard or soft) could benefit from this approach: built *reliable constructions from probabilistic parts*.

Our opinion is that this important approach is in fact **one of the pillars humankind could learn from ICT (but not exclusively from it), when facing the World uncertainties, everyday and everywhere on Earth and beyond**. It is clear that such apparent paradoxical approach must be discussed for every application area, where this idea from PC/ICT should be applied with the appropriate solutions (if they are identified!), in order to **find the approaches and algorithms that provide reliable constructions from probabilistic parts or at least lead to safer ensemble (by compensating the expected points of failure!), instead of simply using the probabilistic (not very safe) parts**.

Further, the idea is detailed and applied when designing new models for probabilistic transistors:

“Several important pieces of research into probabilistic computation are under way. Professor Krishna Palem’s seminal work in this area serves as the first opening effort: the so-called Probabilistic CMOS (PCMO), a new theory of probabilistic transitions based on the physics of thermodynamics, and the mathematics of probabilistic logic (a recent thesis by Lakshmi Chakrapani). Associate Professor Xing Zhou aims to provide predictive compact models for probabilistic transistors. Associate Professor Vincent Mooney is working to link these predictive models to layout and gate-level design of computational primitives such as adders, multipliers and filters. Associate Professor Keck-Voon Ling is designing new models of probabilistic computation for these computational primitives and with these Voong primitives build commonly used DSP blocks. The ultimate goal is directed towards probabilistic computation: from algorithms to predictive circuit models and silicon realization.”

Here we have to notice the crucial step of progressing from Probabilistic CMOS to digital signal processors (DSP) based on PCMO.

Another practical observation is extracted from the fact that the advances of ICT in high-performance computing and deep learning algorithms could ease the progress of PC as it is mentioned in [4]:

“Research into probabilistic computing is not a new area of study, but the improvements in high-performance computing and deep learning algorithms may lead probabilistic computing into a new era. In the next few years, we expect that research in probabilistic computing will lead to significant improvements in the reliability, security,

serviceability and performance of AI systems, including hardware designed specifically for probabilistic computing. These advancements are critical to deploying applications into the real world from smart homes to smart cities. To accelerate our work in probabilistic computing, Intel is increasing its research investment in probabilistic computing and we are working with partners to pursue this goal...

In fact, the practical benefits of such evolutions are two-fold: first for the *improvements in the reliability, security, serviceability and performance* of AI and second for the practical applications closed to individuals and communities (*real world from smart homes to smart cities*).

Here the applications analyses could provide much more lessons and advices, for example just thinking how much the sensors and the security systems could benefit from such ICT advances, where people could further learn or be educated to act on such PC approach bases.

Considering the capacity of software innovations to provide ICT progress using human intelligence and imagination, i.e. the main unlimited resources, PC will naturally benefit of it, as it next presented [10]:

“What is probabilistic programming? How does it differ from other forms of programming? When people talk about Probabilistic Programming Languages (PPLs), they usually mean a system for building and reasoning about Bayesian models. Maybe the simplest way to think about this is as a way of reasoning about simulations. Say you have a simulation that you can run to make a simulated “world”. Every part of the simulation has some randomness. This includes the things you can actually observe, but also the underlying choices the simulator made for things that affect those observations. But those are random too, so they might depend on other random choices. Ok, so choices made along the way will affect the distribution of things downstream. But we can also use this to reason the other way! We observe some data, and ask “what choices along the way could have led to this?”

Going beyond *Bayesian models*, here we have to observe that the innovations in the simulation processes could consider a new point of view, i.e. linking the *choices made along the way* (parameters selection) with the *distribution of things downstream*.

Although both sides are random variables, just this way the probabilistic approach could be useful in studying and then selecting the optimal choices, as further is suggested:

“In the simplest case, say we have a simulation for biased coin flips where we pick a random probability of heads, say $p \sim \text{Uniform}(0,1)$, and simulate 20 flips. Then we observe 15 heads and 5 tails. We can’t say for certain what p was, but we can find a distribution that’s updated based on the observed data...”

It is sure that the real/life cases are more complicated, but the example could be benefic for understanding the suggested approach/method which then should be applied from case to case, either in simple problems of decision or in *probabilistic programming* applications, but **always innovating something in the case model, i.e. using our imagination to estimate and compensate the probable risk of failure and finally increasing the success probability.**

Further we just have to imagine how humankind could evolve from the actual trends of using everyday ICT advances, including probabilistic computing/programming, considering also the emergent changes in business models and jobs

transformations AI/ICT have already started to produce, but eventually using the above ICT lessons to better face the World uncertainties.

3. Conclusions

When the data uncertainty level is high, as the consequences of COVID-19 19 pandemic, the ICT benefic support is more than useful. For evaluating the potential of ICT to face this challenge, first we have considered the actual and emerging ICT advances that could provide real instruments and associated results to approach the diversity of problems with high uncertainty. ICT trends are among the complex evolutions of the associated technologies and concepts that continuously bring innovations aiming the performance, efficacy and efficiency improvements for the ICT services, products and applications that support IS/KBS progress.

As we have presented in [3], *probabilistic computing* (PC) is the actual new paradigm which is implemented by the ICT industry leaders, in order to support the most performant advances of ICT, where artificial intelligence (AI) is first pointed, but also linked with Bigdata or other ICT advances, like *quantum computing* (QC). The link between these advances is generally given by the ICT struggle to continue Moore Law, as we also have approached [20], but PC is in the same time an emerging trend to improve AI toward human brain unreached features, like using fewer data (than machines) in order to generalize and decide.

To reach such purposes, ICT innovations are made in both hardware and software areas, but also in new models and algorithms, more and more inspired from human brain, as the paper presents by analysing some relevant examples, including PC, QC and biological substrates for computation (*cellular computing*).

The analysis revealed the role of “learning” in the innovation process, as the actual aim of AI/PC is to achieve the human brain ability to learn and re-create, including probabilistic programming, which is in the stage of providing the ability to self-develop and create new programs without human intervention.

Another important issue is that the analysis presented some elements which are linking the two emergent and *unconventional computation* concepts/technologies, i.e. *probabilistic computing* and *quantum computing*.

Still, it is important to analyse such advanced instruments from all relevant implications, because we have to admit that in the more and more sophisticated world of soft/ICT, the logical covering of all scenarios is still necessary, but in the same time more difficult to achieve. All these challenges express the difficulty and complexity of innovation processes ICT/AI have to face toward further performance improvements, but also the high expectations from PC, just due to this context.

Anyway, we have to notice the inherent care that should be considered for a sustainable progress of ICT/IS/KBS, including the necessary monitoring of all consequences (benefic or not) that could appear at planetary scale from the proliferation of using their services and products everywhere and everytime. Here climate changes, Earth resource fading or social contrasts, affecting Earth ecosystem and humankind life/evolution are crucial problems that should be considered. **In this context, the learned lessons of ICT on the way of implementing the new paradigm of PC could bring benefic support also for people’s everyday life, when facing the uncertainties of World evolution/challenges.**

By our point of view and the paper focus, the essence of those evolutions of the context factors is the fact that one of the main mechanisms that lead to complexity and difficulty to optimize the progress solutions is the increasing level of uncertainty that characterizes associated data of the analyzed processes to be optimized at planetary level, but at lower (individual) levels also.

This way we may agree that **some approaches of the models and technologies, used by ICT to implement the new paradigm of Probabilistic Computing (PC) could bring benefic support and learned lessons also for people's everyday life, when everyone is facing the uncertainties and decision challenges in the general context of World evolution or of their own life context. The chances for maximizing the veracity of estimating the processes evolutions are given by trying to keep searching for the relevant data/information/knowledge, integrating the events results step by step and this way counting the average positive ones, i.e in a manner that is very close to Bayesian approach which forms the PC main premise.**

Starting from one of the remarkable PC basic models, <<**to built *reliable constructions from probabilistic parts***>>, our opinion is that this important approach is in fact **one of the pillars humankind could learn from ICT (but not exclusively from it), when facing the World uncertainties, everyday and everywhere on Earth and beyond.** It is clear that such apparent paradoxical approach must be discussed for every application area, where this idea from PC/ICT should be applied with the appropriate solutions (if they are identified!), in order to **find the approaches and algorithms that provide *reliable constructions from probabilistic parts* or at least lead to safer ensemble (by compensating the expected points of failure!), instead of simple using the probabilistic (not very safe) parts.**

This basic PC model could be benefic for understanding the suggested approach/method which then should be applied from case to case, either in simple problems of decision or in *probabilistic programming* applications, but **always innovating something in the case model, i.e. using our imagination to estimate and compensate the probable risk of feaure and finally increasing the success probability.**

As a main conclusion, we just have to imagine how humankind could evoluate from the actual trends of using everyday ICT advances, including probabilistic computing/ programming, considering also the emergent changes in business models and jobs transformations AI/ICT have already started to produce, but eventually using the above ICT lessons to better face the World uncertainties.

REFERENCES

- [1]Michael Kozlov, Ashish Kulkarni, *Probabilistic programming and the art of the possible*, May16, 2019, <https://www.weareworldquant.com/en/thought-leadership/probabilistic-programming-and-the-art-of-the-possible/>
- [2] Lewis Grozinger et al, *Pathways to cellular supremacy in biocomputing* Nature Communications volume 10, <https://www.nature.com/articles/s41467-019-13232-z>
- [3]Victor Greu, *Information and Communications Technology new paradigm of probabilistic computing could inspire our thinking through a future World of uncertainty - (Part 1)*, Romanian Distribution Committee Magazine, Volume 11, Issue 2, Year 2020.
- [4]George Rajna, *Probabilistic Computing for AI*,

https://www.academia.edu/36610944/Probabilistic_Computing_for_AI, <https://vixra.org/abs/1805.0240>

[5] John Russell, *Is Is There a Probabilistic Computer in Your Future*, September 23, 2019, <https://www.hpcwire.com/2019/09/23/is-there-a-probabilistic-computer-in-your-future/>

[6] Victor Greu, *Searching the right tracks of new technologies in the earth race for a balance between progress and survival*, Romanian Distribution Committee Magazine, Volume 3, Issue1, Year 2012.

[7] Robert W. Lucky, *Back To The Elusive Future We looked back for inspiration on looking forward*, IEEE Spectrum, Jan 2020.

[8]***, *Probabilistic Computation: Algorithms, Circuit Models and Silicon Realisation*, <http://www.ntu.edu.sg/ISNE/research/Pages/probabilistic.aspx>

[9] Victor Greu, *The information and communications technology is driving artificial intelligence to leverage refined knowledge for the World sustainable development – (Part 2)*, Romanian Distribution Committee Magazine, Volume 10, Issue 1, Year 2019.

[10] Javier Rodríguez Chatruc, Federico Carrone, *Probabilistic Programming with Julia An interview with its creator, Chad Scherrer*, <https://notamonadtutorial.com/soss-probabilistic-programming-with-julia-6acc5add5549>

[11] Will Knight, *Intel's New Chips Are More Brain-Like Than Ever*, January 9, 2018, <https://www.technologyreview.com/2018/01/09/67469/intels-new-chips-are-more-brain-like-than-ever/>

[12] Florin Enache, Victor Greu, Petrică Ciotîrnae, Florin Popescu, *Model and Algorithms for Optimizing a Human Computing System Oriented to Knowledge Extraction by Use of Crowdsourcing*, 2020 13th International Conference on Communications (COMM), (Politehnica University of Bucharest, Military Technical Academy, IEEE Romania), <https://ieeexplore.ieee.org/document/9141972>

[13] Vikash K. Mansinghka, *MIT Probabilistic Computing Project*, 2020, <http://probcomp.csail.mit.edu/>

[14]***, *Intel Scales Neuromorphic Research System to 100 Million Neurons*, March 18, 2020, <https://newsroom.intel.com/news/intel-scales-neuromorphic-research-system-100-million-neurons/#gs.8os7kd>

[15] Victor Greu et al, *Human and artificial intelligence driven incentive-operation model and algorithms for a multi-purpose integrated crowdsensing-crowdsourcing scalable system*, Proceedings of International Conference Communications 2018, (Politehnica University of Bucharest, Military Technical Academy, IEEE Romania), June 2018.

[16] Michael Irving, *Intel's new neuron-based computer matches brain of a small mammal*, March 19, 2020, <https://newatlas.com/computers/intel-neuromorphic-computer-pohoiki-springs/>

[17] Mudassir Khan, *Big data analytics emerging trends, technology and innovations for the future business in the global market*, International Journal of Scientific Research and Review, Volume 8, Issue 2, 2019.

[18] Victor GREU, *Information and Communications Technologies are Learning from Nature's "Research" to Push the Performance Limits*, Romanian Distribution Committee Magazine, Volume 5, Issue 1, Year 2014

[19] Sandeep Ravindran, *Building a Silicon Brain, Computer chips based on biological neurons may help simulate larger and more-complex brain models*, Apr 30, 2019, <https://www.the-scientist.com/features/building-a-silicon-brain-65738>,

[20] Victor Greu, *Extending information and communications technologies' impact on knowledge based society through artificial and collective intelligence – (Part 3)*, Romanian Distribution Committee Magazine, Volume 9, Issue 3, Year 2018.