

Information and Communications Technology New Paradigm of Probabilistic Computing Could Inspire our Thinking through a Future World of Uncertainty

-Part 2-



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Abstract

The paper presents the premises of probabilistic computing context evolution, as it is essentially linked with the challenge to maintain the pace of Information and Communications Technology (ICT) development, but providing a sustainable progress for Information society (IS) toward Knowledge Based Society (KBS) and generally for Earth environment. On the other hand, the ICT economic and social impact, including the humankind behaviour evolution, is complicate and difficult to analyse, because of the high level of complexity and uncertainty, when dynamically facing the diversity and the different levels of ICT products and services and applications. In addition, Covid-19 pandemy consequences, far from being completely foreseen, will bring more and more uncertainty everywhere. One of the most complex and difficult challenge of such analyses is concerning the proper, responsible and opportune understanding of all ICT evolution consequences. Perhaps the most important care, for a sustainable progress of IS/KBS, is to have an efficient and efficacy response at the too fast changes induced by the ICT exponential evolutions, considering the states, organizations or people potential and will for complex and complicate analyses and eventually for expensive reactions/actions. This context could still provide benefic lessons for humankind, based on the ways ICT find new solutions to face the complexity and uncertainty which increase along with its products, services and applications. Such lessons could include more than the simple rules or habits to use ICT, but more than these, they eventually induce new and useful ways to think or approach the diversity of uncertainties that the fast pace and the complex evolutions of ICT and IS/KBS progressively induce in the real life and Earth ecosystem.

The paper first addressed the challenge to maintain the pace of ICT development, often linked with continuing Moore's Law, considering to provide a sustainable progress for IS/KBS, which is, naturally, an ever-changing condition, leading to probabilistic approaches for optimization. The analysis included, by relevant examples, the strategy of ICT leaders to adapt the goal of advancing performances to the new, more and more complex realities, by probabilistic approaches, aiming the highest performance of ICT, where the AI challenge is to further advance from the highest top of ICT in the more and more complex context of applications. The "highest performance" is actually linked with "autonomous systems", i.e. the most challenging field of ICT applications, where we could find, along with the diversity of robots, self-driving cars. Here the importance of sensors and their precisions, although in a continuous spectacular progress, represent key factors for the sustainable development of applications fields. The inherent limits/errors of actual AI/sensors are mentioned and we consider that it is worth to notice that this is one of the main features of future ICT development, given by the fact that continuously increasing the technology performance level is inherently very complicate and difficult, in a World that complicates with a speed higher than the ICT speed, because of the complex impact at Earth scale and of humankind nature.

As a consequence of these limits, it is necessary to build, on actual levels (waves) of AI, the next wave, but actually we have to observe the essential link between the AI/ICT development and the "human beings" needs. Here is included not only the fundamental rule of the sustainable development for AI/ICT/IS/KBS, i.e. de proper social need (command), but especially its specific evolution toward uncertainty, when "navigate the world" facing the technology errors risks. This conclusion is, by our opinion, fundamental for the sustainable development of AI/ICT/IS/KBS, because it is necessary to consider the risks of errors, as the humankind and all Earth ecosystem is tending to be too much depending on (mainly ICT) technology, especially when observing critical infrastructure like Internet, power grid, security, defence or ... robots. From this point of view, we have to agree that this new

paradigm of ICT leaders (i.e. probabilistic computing) is very opportune, realistic and responsible. On the other hand, the diversity of scenarios and the scientific/technical difficulties to implement this strategy will rise considerable problems for ICT applications involving probabilistic computing, although the idea is not very new, but the context, the aimed performance and the available technologies come with different challenges/benefits. On this line, the role of modelling and programming/software is continuously increasing, as a flexible and efficient instrument for updating and improving systems performances when using the available hardware technology to implement.

The analysis also presents that probabilistic modelling and inference are the key factors in improving ML and further DL toward automatization of inference processes using Bayesian theory, in order to optimally cover the probabilistic scenarios of complex and dynamic context of AI applications. Here we noticed that correcting and re-orienting ML could make of it „the art of the possible”, i.e. having the potential to obtain remarkable improvements of AI applications. Toward such aim, it is pointed the intrinsic capacity of humans to make connections and generalize based on experience/memory and intuition, which are this way identified as desired features for AI, considering the inherent noise behaviour and operation that could provide the desired functionality and performance as the brain.

An important conclusion resulted as innovating both modelling/software and hardware structure of the AI systems could provide more advanced performances when facing uncertainty. The examples confirmed the clear tendency and results toward using probabilistic computing AI/ICT for improvements when solving problems with high uncertainty data, approaching models which are inspired from human brain operational structure, but the way these advances could be useful for humans, beyond the main purpose of each application, is another, more complicate, issue. In fact, it is a complex ecosystem of processes where the ICT/AI progress solutions could generate lessons to be learned beyond the areas and aims they are native implemented or designed. That is why it is very important, but also tough, to deeply analyse the balance and consequences of the complex and mutual dependencies in the processes inspired from humans and for humans. Going further from the ethical dilemma of these highest AI/ICT advances, we have to further analyze how such solutions issued from some humans thinking could influence all other humans thinking, especially facing life/Earth uncertainties.

Considering the mentioned noise as a generic or perturbation factor for decisions (of incumbents or individuals), when facing uncertainty data, we can go further and imagine that regardless the nature of noise/perturbation, it is necessary to have a strategy that optimally matches the process/case and this will be based on probabilistic approaches issued from the above elements and then extended to other areas. The supposed useful elements could include models and algorithms, but most concrete, each decision process will have to identify the probability distribution that better suits the context and the performance level. All these applications/contexts will gradually generate, along with AI/ICT devices and services, added value learned lessons to be used in a diversity of areas and scenarios, where we have to recall that imagination is the limit. Consequently we have to consider again and again, the crucial importance of refining knowledge, as general model for IS/KBS, which generates such benefic „added value” in this complex ecosystem of Earth, where humans inspire ... humans, in processes that are distant in time, space and ... way of thinking.

As a final conclusion, due to their obvious difficulty, dynamic, levels and diversity of areas, such analyses needs further and timely continuation, for having efficacy results and useful conclusions in order to inspire people's way of thinking in the World increasing uncertainty.

Keywords: probabilistic computing, quantum computing, artificial intelligence, machine learning, deep learning, qubit, probabilistic inference, neuronal network, information society, knowledge based society, human brain

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

Ignorance gives one a large range of probabilities
— George Eliot

1. ICT is heading toward the third wave of AI by probabilistic computing

Watching the amazing ways Information and Communications Technologies (ICT) influence our daily life, offering a fast changing picture of products and services, where the incredible technological advances penetrates all the activity fields, we simply could agree that ICT is a prominent factor of the progress of the Information society (IS) toward Knowledge Based Society (KBS).

Even if we would consider only the benefic consequences of ICT exponential development, step by step the Earth complex realities prove that ... it is not enough!

Considering, for example, the prominent ICT advances, like Internet of Things (IoT), Artificial Intelligence (AI), Cloud, BIG DATA, 5G or the family of nanotechnologies, we have to observe that all their applications and associated processes at Earth scale, inherently will generate complex consequences and challenges.

Starting from this general approach, the principal challenge is to maintain the pace of ICT development, but providing a sustainable progress for IS/KBS and generally for Earth environment. Here we have to recall our repeated mentions [9] [6] of Earth challenges regarding climate changes, resources fading etc.

On the other hand, the ICT economic and social impact, including the humankind behaviour evolution, is complicate and difficult to analyse, because of the high level of complexity and uncertainty, when dynamically facing the diversity and the different levels of ICT products and services and applications. In addition, Covid-19 consequences, far from being completely foreseen, will bring more and more uncertainty everywhere.

More than these, we have to emphasize one of the most complex and difficult issue, although sometimes not so evident, concerning the **proper, responsible and opportune understanding of all these consequences and challenges of ICT evolution**.

With other words, perhaps the most important care, for a sustainable progress of IS/KBS, is to have an efficient and efficacy response at the too fast changes induced by the ICT exponential evolutions, considering the states, organizations or people potential and will for complex and complicate analyses and eventually for expensive reactions/actions.

This way it is obvious that the timely analysis and knowledge refining, regarding ICT development and impact on IS/KBS is more than necessary, although difficult and inherently always far from being complete.

The benefits of such analyses could include, as our paper title emphasizes, important lessons for humankind, regarding the ways ICT find new solutions to face the complexity and uncertainty which increase along with its products, services and applications.

It is important to recall [3] [25], that such “lessons” could include more than the simple rules or habits to use ICT, but more than these, they eventually induce new and useful ways to think or approach the diversity of uncertainties that the fast pace and the complex evolutions of ICT and IS/KBS progressively induce in the real life and Earth environment.

In order to have a concrete expression of these challenges and preoccupations which could also bring the necessary confidence of their real importance, some relevant examples and references will be useful.

With a systemic approach, among the first we should address the challenge to maintain the pace of ICT development, often linked with continuing Moore’s Law [3][18][10][11][20], but now we should consider to provide a sustainable progress for IS/KBS and generally for Earth environment, which is, naturally, an ever-changing condition, leading to probabilistic approaches for optimization.

This way, we can understand the strategy of ICT leaders to adapt the goal of advancing performances to the new, more and more complex realities, by probabilistic approaches [1]:

“Intel announced today that it is forming a strategic research alliance to take artificial intelligence to the next level. Autonomous systems don’t have good enough ways to respond to

the uncertainties of the real world, and they don't have a good enough way to understand how the uncertainties of their sensors should factor into the decisions they need to make. According to Intel CTO Mike Mayberry, the answer is "probabilistic computing," which he says could be AI's next wave."

This Intel point of view is very relevant and brings together many sides of the analysed context, as it focused on the actual main ICT advanced field: AI.

The relevance starts with the aim of highest performance of ICT, where the AI challenge is to further advance from the highest top of ICT in the more and more complex context of applications.

Perhaps less evident is the issue that, beyond a general pointing of AI, here we could observe that "highest performance" is actually linked with "*autonomous systems*", i.e. the most challenging field of ICT applications, where we could find, along with the diversity of robots, self-driving cars.

Here the importance of sensors and their precisions, although in a continuous spectacular progress, represent key factors for the sustainable development of applications fields.

In a concrete manner, this context is suggested by the huge area of sensors that will enable unprecedented applications and performances, where the data they will provide could definitely influence the involved complex decision processes.

This way, step by step, the main idea of "*probabilistic computing*" is naturally found as "*AI's next wave*", but this is obviously just the start of a *long and winding road* toward the desired optimal models and solutions, from field to field of applications.

As we already mentioned [3] [21], the complexity and difficulty of optimizing ICT development is generally an "iceberg tip", further detailed by Intel (one of the main players of ICT) as:

"We're trying to figure out what the next wave of AI is. The original wave of AI is based on logic and it's based on writing down rules; it's closest to what you'd call classical reasoning. The current wave of AI is around sensing and perception—using a convolutional neural net to scan an image and see if something of interest is there. Those two by themselves don't add up to all the things that human beings do naturally as they navigate the world. An example of this would be where you are startled by something—let's say a car siren. You'd automatically be thinking of different scenarios that would be consistent with the data you have and you would also be conscious of the data you don't have. You would be inferring a probability. Maybe the probability is figuring out whether the siren is coming from ahead of you or behind you. Or whether it is going to make you late for a meeting. You automatically do things that machines have trouble with. We run into those situations all the time in real life, because there's always uncertainty around what is the current situation."

This is a very relevant analysis, made at Intel, due to the multiple sides it suddenly reveals, in order to create a clear picture of realities we have to face in spite of our unprecedented progress we benefit.

First, by a systemic approach, the inherent limits of actual AI/sensors are mentioned and we consider that it is worth to notice that this is **one of the main features of future ICT development, given by the fact that continuously increasing the technology performance level is inherently very complicate and difficult, in a World that complicates with a speed**

higher than the ICT speed, because of the complex impact at Earth scale and of humankind nature.

After considering the limits, it is necessary to build, on actual levels (*waves*) of AI, the next wave, but here we have to observe **the essential link between the AI/ICT development and the “human beings” needs.**

In fact, this is the point where we can observe not only the fundamental rule of the sustainable development for AI/ICT/IS/KBS, i.e. de proper social need (command), but especially its specific evolution toward uncertainty, when “*navigate the world*”.

To understand the whole significations of this fundamental but complex reality, the simple but relevant example of the *siren* has the remarkable potential to realistically link the complex scenario/context (of traffic) with the main technological advances (autonomous cars/systems), starting from the human intelligence case, but clearly pointing the future design of AI case.

Quite from here we could observe the mutual relation, concerning the models and features, of the advanced AI or generally *probabilistic computing*, with the human brain.

With simpler words, the aim of *probabilistic computing* is to optimally solve the classes of problems AI systems could meet, in the complex environment of future World, with models and algorithms which could mimic the way human brain does.

As we have already mentioned [12][3][15], this strategy will change the paradigm of AI/ICT, i.e. using less data, because the Data Deluge could contain much uncertainty or ambiguity and on the other hand human brain has the capacity to take decisions from less data, even when containing incertitude.

A concrete expression of this limit of AI/ICT is also given, considering the actual typical case of machine learning applications:

“Currently AI and deep-learning systems have been described as brittle. What we mean by that is they are overconfident in their answer. They’ll say with 99 percent certainty that there something in a picture that it thinks it recognizes. But in many cases the probability is incorrect; confidence is not as high as [the AI] thinks it is.”

This conclusion is, by our opinion, fundamental for the sustainable development of AI/ICT/IS/KBS, because, as we have already presented [18] [6] and here is confirmed, it is necessary to consider the risks of errors, as the humankind and all Earth ecosystem is tending to be too much depending on (mainly ICT) technology, especially when observing critical infrastructure like Internet, power grid, security, defence or ... robots.

From this point of view, we have to agree that this new paradigm of ICT leaders (i.e. *probabilistic computing*) is very opportune, realistic and responsible.

On the other hand, the diversity of scenarios and the scientific/technical difficulties to implement this strategy will rise considerable problems for ICT applications involving *probabilistic computing*, although the idea is not very new, but the context, the aimed performance and the available technologies come with different challenges/benefits.

As above the challenges analysis was first considered, the benefits of the technology advances would, perhaps, complete the picture of *probabilistic computing* premises.

The role of modelling and programming/software is continuously increasing, as a flexible and efficient instrument for updating and improving systems performances when using the available hardware technology to implement [2]:

“Let us start, as we always should, with first principles. Probabilistic models help us to draw population inferences – that is we create mathematical models to help us to understand or test a hypothesis about how a system or environment behaves. Probabilistic reasoning is a fundamental pillar of machine learning (ML), whereas deep learning (DL) can be distinguished from machine learning through its employment of gradient-based optimization algorithms. Probabilistic programming languages are designed to describe probabilistic models and then perform inference in those models... As stated above, probabilistic programming languages and tools allow us to automate Bayesian inference. In other words, it allows us to code using probabilistic language-specific syntax to describe conditional probability distributions.”

Here we can observe that *probabilistic modelling and inference* are the key factors in improving ML and further DL toward automatization of inference processes using Bayesian theory, in order to optimally cover the probabilistic scenarios of complex and dynamic real context of AI applications.

As we already mentioned in [3], the hardware improvement is more difficult in the actual advanced stage of AI/ICT, but on the other hand, Moore’s Law foreseeable saturation has generated a deep research for revolutionary technologies, which will provide the highest performances required by AI progress.

More than these, quantum computing [4][13][16][17][19][23][24] proved to be very much linked with *probabilistic computing*, but here the progress is still very difficult and still slow, although the technology leaders (like Intel, NSF, IBM, AWS, M’soft) collaborate to advance faster [4]:

“We obtain single-qubit control via electron spin resonance and readout using Pauli spin blockade. In addition, we show individual coherent control of two qubits and measure single-qubit fidelities of up to 99.3 per cent. We demonstrate the tunability of the exchange interaction between the two spins from 0.5 to 18 megahertz and use it to execute coherent two-qubit controlled rotations. The demonstration of ‘hot’ and universal quantum logic in a semiconductor platform paves the way for quantum integrated circuits that host both the quantum hardware and its control circuitry on the same chip, providing a scalable approach towards practical quantum information processing.”

One of the main problems encountered by the researchers is to extend the capacity of processing system to control more qubits (up to millions), which leads to complex control electronics circuitry, but Intel started to solve this issue by integrating qubits and control on the same chip:

<<As Intel emphasized, “Applying quantum computing to practical problems hinges on the ability to scale to and control thousands – if not millions – of qubits at the same time with high levels of fidelity. However, current quantum systems designs are limited by overall system size, qubit fidelity and especially the complexity of control electronics required to manage the quantum at large scale. Having the control electronics and spin qubits integrated on the same chip greatly simplifies the interconnections between the two.”>>.

Of course, these examples are only tips of the icebergs involved in the technology advances, but it is important that they prove the importance and the dimensions of this new wave of AI we witnessing, with the confidence of unprecedented performances and the hope for **a sustainable progress that could be extended from technology to our life benefit and even reasoning against uncertainties.**

2. Probabilistically modelling and thinking AI, inspired from humans and for humans

With or without Moore's Law, ICT and generally the technology in many fields of activity have to learn from nature's research, as we repeatedly mentioned [18][3], but especially now, facing the challenges above presented, AI/ICT are truly involved in „mimicking” the human brain.

Obviously, this picture is changing as AI/ICT exponential evolution and performances are fast changing and also the ICT/IS/KBS in the Earth ecosystem is going more complex and difficult to optimize „sitting on top” technologies but facing challenges never encountered before.

On the other hand, the humankind evolution and behaviour is also changing, among other just due/because of the ICT benefits/consequences.

Last but not the least, entering the delicate field of „human thinking” changes, the averaged model to follow is more and more difficult to define.

With little words, these could be some prominent premises when analyzing how „probabilistically modelling and thinking AI” in the more general frame of *probabilistic computing* and AI/ICT performances increasing.

Without looking for references for all premises or involved factors, it is useful to observe, by some relevant examples, the ways this research, for higher performances and better efficacy/efficiency of future AI, could be achieved.

Although, generally, programming could be seen (by error) as a technical issue and having less potential for providing revolutionary improvements, now there are (partially above mentioned) prominent premises to reverse such opinion, as it is detailed demonstrated by [5]:

„Today machine learning is rigid and requires massive amounts of data. But AI researchers are attempting to emulate the low-data fluidity and rich representations of human thinking. Give credit to Thomas Bayes....Two aspects of conceptual knowledge have eluded machine learning systems. First, for most natural categories (birds, fish, dogs, people) and artificial categories (man-made cars, boats, smartphones), people seem to be able to learn new concepts from one or a handful of examples. Standard machine learning algorithms, on the other hand, require large numbers of examples... Second, humans master richer representations of the categories than machines can, even for simple concepts; that is, they understand what inherent features make a bird a bird and a rock a rock. Humans learn these inherent features without careful study or instruction and can use them for a wide range of functions. Even when objects in a category are quite diverse, humans can create new “exemplars” — generalized concepts stored in memory — parse objects into parts, relate them to similar objects and develop new abstract categories. In contrast, the best machine classifiers fall behind when they attempt these additional functions, even with deeper analysis and specialized algorithms.”

Here we have to notice, before entering into details, that correcting and re-orienting ML could make of it „the art of the possible”, i.e. having the potential to obtain remarkable improvements of AI applications.

Toward such aim, it is pointed the inherent capacity of humans to make connections and generalize based on experience/memory and intuition, which are this way identified as desired features for AI.

In order to achieve such objectives, some introspections into human brain behaviour and operation structure are given:

„A central challenge is to explain two characteristics of human conceptual learning: how people learn new concepts from just a few examples and how they generate such abstract, rich and flexible representations. An even greater challenge arises when you put the two together: How can machine learning use small amounts of data and produce rich representations? If this sounds paradoxical, it is, based on most current learning theories. Nonetheless, people seem to navigate this trade-off with remarkable agility, learning rich concepts that generalize well from relatively sparse data. The answer may lie with a long-dead Presbyterian minister who had a deep interest in probabilities...”

The way AI could benefit from (theorem of Thomas Bayes, a Presbyterian minister) Bayesian probability and ... thinking, is very well pointed, considering simple examples from real life, where human brain operates in a simple manner:

„This theorem is a means of updating beliefs in a hypothesis based on new evidence. It is rooted in probabilities: The more often you see the sun rise in the morning, the higher the probability that it will continue to happen in the future. The Bayesian approach captures a key aspect of how humans learn in an uncertain world. And although this learning can be quite complex, involving many hypotheses and multiple probabilities, it has led to a new form of AI that is improved by learning and inference.”

After suggesting how AI could achieve similar performances based on considering all relevant hypotheses and multiple probabilities, the improving of inference processes could come as:

„More recent developments in high-performance computing and deep learning algorithms suggest that probabilistic computing is entering a new era. In the next few years, experts anticipate research to produce significant improvements in the reliability, security, serviceability and performance of AI systems, including hardware designed specifically for probabilistic computing. There are certainly strong incentives for developing machine learning approaches that are easier to use and less data-hungry. Machine learning currently requires a large, raw dataset, which typically needs humans to manually label it, clean it and reduce “noise” — that is, meaningless or random data. The actual learning takes place inside large data centers using many computer processors churning away in parallel for hours or days. In general, the time and cost associated with this are material.”

Finally, the essence of such approach is pointed and reveals the main mechanisms which allow to use less data, but provide higher efficiency and effective inference, this way nearing the human model:

„Because Bayesian methods easily incorporate prior knowledge, effective inference can often be performed with a lot less data. This increases the efficiency of implementing new models and understanding data. Just as high-level programming languages transformed developer productivity by eliminating the need to deal with technical details of processors and memory architecture, probabilistic languages promise to free developers from the complexities of high-performance probabilistic inference. In short, BPS allows more efficient search to find

the optimum possibility. The constraints are probabilistic, and the output is a probability distribution that can then be further refined.”

Although anticipated and very desirable, *the reliability, security, serviceability and performance of AI systems*, which could be obtained implementing brain models, need also to face the challenges that arose from the complex cortical processes to mimic [7]:

„Probabilistic inference as a principle of brain function has attracted increasing attention over the past decades. In support of a sampling-based “Bayesian-brain hypothesis”, the high in-vivo response variability of cortical neurons observed in electrophysiological recordings is interpreted in the context of ongoing probabilistic computation. Simultaneously, it has been found that intrinsically stochastic neural networks are a suitable substrate for machine learning. These findings have led to the incorporation of noise into computational neuroscience models, in particular to give account for the mechanisms underlying stochastic computing such as sampling-based probabilistic inference in biological neuronal substrates. Note that the term “stochastic computing” refers to the idea that the variability required for this form of computing can be mathematically described as (or replaced by) quasi-stochasticity without altering the functionality of the network. It does not imply that its implementation is relying on truly stochastic sources of noise, neither in natural nor synthetic neuronal substrates.”

Consequently, the AI models design have to consider and implement the inherent noise behaviour and operation that could provide the desired functionality and performance as the brain:

„Neuronal network models of high-level brain functions such as memory recall and reasoning often rely on the presence of some form of noise. The majority of these models assumes that each neuron in the functional network is equipped with its own private source of randomness, often in the form of uncorrelated external noise. In vivo, synaptic background input has been suggested to serve as the main source of noise in biological neuronal networks. However, the finiteness of the number of such noise sources constitutes a challenge to this idea. Here, we show that shared-noise correlations resulting from a finite number of independent noise sources can substantially impair the performance of stochastic network models. We demonstrate that this problem is naturally overcome by replacing the ensemble of independent noise sources by a deterministic recurrent neuronal network. By virtue of inhibitory feedback, such networks can generate small residual spatial correlations in their activity which, counter to intuition, suppress the detrimental effect of shared input. We exploit this mechanism to show that a single recurrent network of a few hundred neurons can serve as a natural noise source for a large ensemble of functional networks performing probabilistic computations, each comprising thousands of units.”

Without other details we could notice that a very useful solution for these challenges is *replacing the ensemble of independent noise sources by a deterministic recurrent neuronal network*, which obviously has the advantage of an easier implementation, due to its simplified network along with performance increase.

Innovating both modelling/software and hardware structure of the AI systems could provide more advanced performances when facing uncertainty, as it is also confirmed by [8]:

“Traditional computers often seem brilliant and simpleminded at the same time. On the one hand, they can perform billions of high-precision numerical operations per second with

perfect repeatability. On the other hand, they fail catastrophically when their inputs are incomplete or ambiguous. These strengths and weaknesses flow from their mathematical foundations in deductive logic and deterministic functions. Navia Systems is working to change all this, by building the world's first natively probabilistic computers, designed from the ground up to handle ambiguity, make good guesses, and learn from their experience. Instead of logic and determinism, Navia's hardware and software are grounded in probability distributions and stochastic simulators, generalizing the mathematics of traditional computing to the probabilistic setting. The result is a technology as suited to making judgements in the presence of uncertainty as traditional computing technology is to large-scale record keeping."

All these examples confirm the clear tendency and results toward using *probabilistic computing* AI/ICT to improve performances when solving problems with high uncertainty data, approaching models which are inspired from human brain operational structure, but the way these advances could be useful for humans, beyond the main purpose of each application, is another, more complicated, issue [22].

In fact, it is a complex ecosystem of processes where the ICT/AI progress solutions could generate lessons to be learned beyond the areas and aims they are native implemented or designed.

That is why it is very important, but also tough, to deeply analyse the balance and consequences of the complex and mutual dependencies in the processes **inspired from humans and for humans**.

Going further from the ethical dilemma of these highest AI/ICT advances (**Who is worrying us most, the robots or the humans?**), we have to see first how such solutions issued from some humans thinking could influence all other humans thinking, especially facing life/Earth uncertainties.

Although it could seem that we come back to analysis starting point, now we have above presented elements/examples to observe what is new, or added value, when supposing to teach humans with lessons that apparently have been learned from ... humans.

To be more concrete, let's just consider the noise, as one of the most important sources of uncertainty/ambiguity for both machines and humans.

Here we have to recall, as a relevant example, from the above, that *replacing the ensemble of independent noise sources by a deterministic recurrent neuronal network*, which addresses the *models of high-level brain functions such as memory recall and reasoning*, is eventually an AI/ICT solution inspired from brain, but it could provide also better results in many areas of applications (including e-health), as a starting or way of thinking (idea).

If we consider noise as a generic or perturbation factor for decisions (of incumbents or individuals), when facing uncertainty data, we can go further and imagine that regardless the nature of noise/perturbation, it is necessary to have a strategy that optimally matches the process/case and this will be based on probabilistic approaches issued from the above elements and then extended to other areas.

The supposed useful elements could include models and algorithms, but most concrete, each decision process will have to identify the probability distribution that better suits the context and the performance level.

All these applications/contexts will gradually generate, along with AI/ICT devices and services, added value learned lessons to be used in a diversity of areas and scenarios, where we have to recall that ... **imagination is the limit**.

In other words, we have to consider again and again, as we have already presented [12][15][21][24], the crucial importance of **refining knowledge**, as general model for IS/KBS, which **generates such benefic „added value” in this complex ecosystem of Earth, where humans inspire ... humans, in processes that are distant in time, space and ... way of thinking**.

Due to their obvious difficulty, dynamic, levels and diversity of areas, **such analyses needs further and timely continuation, for having efficacy results and useful conclusions in order to inspire people’s way of thinking in the World increasing uncertainty**.

3. Conclusions

The analysis started from the premise that *probabilistic computing* context is essentially linked with the challenge to maintain the pace of ICT development, but providing a sustainable progress for IS/KBS and generally for Earth environment. On the other hand, the ICT economic and social impact, including the humankind behaviour evolution, is complicate and difficult to analyse, because of the high level of complexity and uncertainty, when dynamically facing the diversity and the different levels of ICT products and services and applications. In addition, Covid-19 consequences, far from being completely foreseen, will bring more and more uncertainty everywhere. One of the most complex and difficult challenge of such analyses is concerning the **proper, responsible and opportune understanding of all ICT evolution consequences**. Perhaps the most important care, for a sustainable progress of IS/KBS, is to have an efficient and efficacy response at the too fast changes induced by the ICT exponential evolutions, considering the states, organizations or people potential and will for complex and complicate analyses and eventually for expensive reactions/actions.

This context could still provide benefic lessons for humankind, based on the ways ICT find new solutions to face the complexity and uncertainty which increase along with its products, services and applications. Such lessons could include more than the simple rules or habits to use ICT, but more than these, they eventually induce new and useful ways to think or approach the diversity of uncertainties that the fast pace and the complex evolutions of ICT and IS/KBS progressively induce in the real life and Earth ecosystem.

By a systemic approach, the paper first addressed the challenge to maintain the pace of ICT development, often linked with continuing Moore’s Law, considering to provide a sustainable progress for IS/KBS, which is, naturally, an ever-changing condition, leading to probabilistic approaches for optimization.

This way, the analysis included, by relevant examples, the strategy of ICT leaders to adapt the goal of advancing performances to the new, more and more complex realities, by probabilistic approaches, aiming the highest performance of ICT, where the AI challenge is to further advance from the highest top of ICT in the more and more complex context of applications.

The “highest performance” is actually linked with “*autonomous systems*”, i.e. the most challenging field of ICT applications, where we could find, along with the diversity of robots,

self-driving cars. Here the importance of sensors and their precisions, although in a continuous spectacular progress, represent key factors for the sustainable development of applications fields. The inherent limits/errors of actual AI/sensors are mentioned and we consider that it is worth to notice that this is **one of the main features of future ICT development, given by the fact that continuously increasing the technology performance level is inherently very complicate and difficult, in a World that complicates with a speed higher than the ICT speed, because of the complex impact at Earth scale and of humankind nature.**

Considering these limits, it is necessary to build, on actual levels (*waves*) of AI, the next wave, but actually we have to observe **the essential link between the AI/ICT development and the “human beings” needs**. Here is included not only the fundamental rule of the sustainable development for AI/ICT/IS/KBS, i.e. de proper social need (command), but especially its specific evolution toward uncertainty, when “*navigate the world*” facing the technology errors risks.

This conclusion is, by our opinion, fundamental for the sustainable development of AI/ICT/IS/KBS, because it is necessary to consider the risks of errors, as the humankind and all Earth ecosystem is tending to be too much depending on (mainly ICT) technology, especially when observing critical infrastructure like Internet, power grid, security, defence or ... robots. From this point of view, we have to agree that this new paradigm of ICT leaders (i.e. *probabilistic computing*) is very opportune, realistic and responsible.

On the other hand, the diversity of scenarios and the scientific/technical difficulties to implement this strategy will rise considerable problems for ICT applications involving *probabilistic computing*, although the idea is not very new, but the context, the aimed performance and the available technologies come with different challenges/benefits.

On this line, the role of modelling and programming/software is continuously increasing, as a flexible and efficient instrument for updating and improving systems performances when using the available hardware technology to implement.

The analysis presented that *probabilistic modelling and inference* are the key factors in improving ML and further DL toward automatization of inference processes using Bayesian theory, in order to optimally cover the probabilistic scenarios of complex and dynamic context of AI applications. Here we noticed that correcting and re-orienting ML could make of it „*the art of the possible*”, i.e. having the potential to obtain remarkable improvements of AI applications. Toward such aim, it is pointed the intrinsic capacity of humans to make connections and generalize based on experience/memory and intuition, which are this way identified as desired features for AI, considering the inherent **noise behaviour** and operation that could provide the desired functionality and performance as the brain.

An important conclusion resulted as innovating both modelling/software and hardware structure of the AI systems could provide more advanced performances when facing uncertainty. The exemples confirmed the clear tendency and results toward using *probabilistic computing* AI/ICT for improvements when solving problems with high uncertainty data, approaching models which are inspired from human brain operational structure, but the way these advances could be useful for humans, beyond the main purpose of each application, is another, more complicate, issue. In fact, it is a complex ecosystem of processes where the ICT/AI progress solutions could generate lessons to be learn beyond the areas and aims they are native implemented or designed. That is why it is very important, but also tough, to deeply

analyse the balance and consequences of the complex and mutual dependencies in the processes **inspired from humans and for humans**.

Going further from the ethical dilemma of these highest AI/ICT advances, we have to further analyze how such solutions issued from some humans thinking could influence all other humans thinking, especially facing life/Earth uncertainties.

Considering **the mentioned noise as a generic or perturbation factor for decisions** (of incumbents or individuals), when facing uncertainty data, we can go further and imagine that regardless the nature of noise/perturbation, it is necessary to have a strategy that optimally matches the process/case and this will be based on probabilistic approaches issued from the above elements and then extended to other areas. The supposed useful elements could include models and algorithms, but most concrete, each decision process will have to identify the probability distribution that better suits the context and the performance level.

All these applications/contexts will gradually generate, along with AI/ICT devices and services, added value learned lessons to be used in a diversity of areas and scenarios, where we have to recall that **imagination is the limit**.

Consequently we have to consider again and again, as we have already presented [12][15][21][24], the crucial importance of **refining knowledge**, as general model for IS/KBS, which **generates such benefic „added value” in this complex ecosystem of Earth, where humans inspire ... humans, in processes that are distant in time, space and ... way of thinking**.

Finally, due to their obvious difficulty, dynamic, levels and diversity of areas, **such analyses needs further and timely continuation, for having efficacy results and useful conclusions in order to inspire people’s way of thinking in the World increasing uncertainty**.

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