Quantum computing a new paradigm in science and technology

Part Ia: Quantum computing. General documentary. A stroll in an incompletely explored and known world.

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Prolegomenon

Quantum computing (QC) and quantum information (QI) has been emerged as an extension of Quantum Mechanics (QM) to the problem of interaction of atoms and light (photons). It matured as a stand-alone branch of physics, in the much wider realm, already referred to as the Quantum Electrodynamic (QED) (e.g. Dirac 1948, Feynman 1949, Van Dyck, 1990, Ryder 1996). QED encompasses relativistic quantum field theory of electrodynamics. Essentially, it describes light and matter interaction in a context that assures agreement between quantum mechanics and special relativity, the latter in a format devised by Albert Einstein on the base of two postulates: *i)* the laws of physics are invariant when referred to non-accelerating frame of reference – inertial systems – and, *ii)* the speed of the light is invariant for all observers irrespective of the motion of the light source.

Special relativity implies physics effects which have been experimentally, scrupulously verified. Suffice to mention: length contraction, time dilatation, relativistic mass model which is a "bridge" between mass and energy, legitimizing the mass-energy equivalence ($E=mc^2$), where c is the invariant light speed limit and together with the principle of the relativity of simultaneity. For quantum computing is of relevance the latter concept of relativity of simultaneity or distant simultaneity, which implies that if two spatially separated events happen at the same time, the perception of the event is not absolute but depends on the observer's reference frame.

However, the tackling of QED, even in a superficial way, is beyond the scope of this essay and has limited practical relevance from the perspective of quantum computing to which is devoted this section.

Quantum computing pairs with Nanomechanics in the quest to master the realm of material world.

Quantum computing and the associated contrivances support, quantum computers, imply the explicit use of quantum mechanics effects, in order to perform computing operation on data. Here, it is meant by data any set of values of quantitative and/or qualitative variables. Sub-sets of data can be formalized as information entities. Quantum computing recourses, primarily, to few fundamental principles of quantum mechanics: quantum superposition, quantum entanglement and quantum tunneling effect.

Quantum superposition principle asserts that two or more quantum states can be merged, the result being another different quantum state. Usually, merged quantum states are entangled (on entanglement see further).

Reciprocally, a quantum state can be represented (decomposed) as a sum of two or more distinct quantum states. This handling derives from the linearity of the solution of Schrödinger's equation, i.e. any linear combination of solutions is also a solution of the equation.

1. Quantum computing. An incompletely explored world.

a) What is quantum computing?

Quantum computing studies engage in, theoretic research, and perform experiments, on computation systems (i.e. on quantum computers) making direct use of quantum-mechanical phenomena (effects), such as superposition, tunneling and states entanglement, in order to perform operations on data.

Figure 1.1 represent a pictorial suggesting the basic phenomenology underlying Quantum computing: the field of involved qubits, as mediators and partaking in quantum computing such as processes of coherence-decoherence of quantum states. There are also represented, in a suggestive pictorial, the human neurons and their inter-linking, as residence

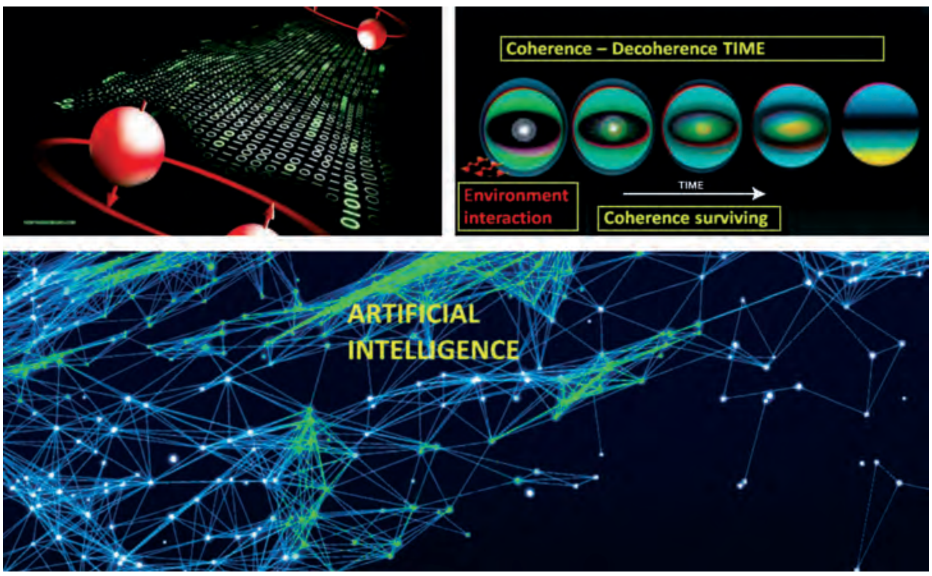

Figure 1.1. A pictorial suggesting the basic phenomenology underlying Quantum computing.

of the human mind, in the quest be mimicked by artificial intelligence; using the mathematical formalism of quantum theory also as a landmark in deciphering the nature of the human consciousness.

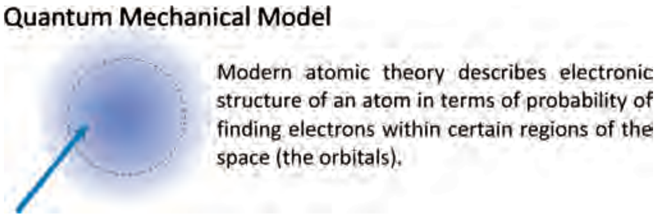

Figure 1.2. Cloud of the probabilities field.

Figure 1.2 is an illustrative outline of what is encompassed in the concept of a quantum mechanics model

b) Milestones in the developments of Quantum Mechanics and Quantm Computing

The advancement of science depends, in general, on the interplay between experimental studies and theory. Generally, theoretical physics primordially adheres to methods and formalism of mathematical sciences, while giving less weight to experiments and observations which involve availability of founding and competent personnel for manipulating the equipment. For instance, while developing special relativity, Albert Einstein was concerned with the Lorentz transformation which left Maxwell's equations invariant, but was apparently uninterested in the Michelson–Morley experiment on Earth's drift across the luminiferous "*ether*". The luminiferous ether is a immaginative concept hypothsizing that the Earth moves through a „medium", the ether, conceived as „light-bearing", or, otherwise stating, sustaining the propagation of light. It was in the late of 19th century, when it was tempted to explaain and, eventually, to simulate the propagation of the light.

Concurrently, at that time, Einstein was awarded the Nobel Prize for explaining the photoelectric effect, as well as, an experimental result, which was, lacking a theoretical formulation and explanation.

The simulation of light propagation has been tempted, recently, with The Monte Carlo simulation technique which, by its nature, is a flexible method, enabling the simulation of light propagation in vid in various media, organic tissues included. The simulation is based on the random walks mathematical model, applied to traveling photons. After the simulation of propagation of many photons, the net distribution of photons, evinces an reasonable approximation of the reality.

Quantum computing (QC) and, more generally, quantum information (QI) have been emerged as an extension of Quantum Mechanics (QM) to the of interaction of atoms with light (photons), otherwise stated, the interaction between elementary particles and radiative waves.

In the followings it is tempted an overview of the milestones in the developments in time of Quantum Mechanics Theory.

c) Parallel computing

Parallel computing method consists in dividing a large computational problem into many smaller tasks, enabling simultaneous computing execution on multiple processors. This can be achieved through two approaches: massively parallel processors (MPPs) and distributed computing (DC).

The MPPs systems combine multiple CPUs, ranging from a few hundred to a few thousand, in a single large cabinet sharing common memory (usually hundreds of gigabytes). MPPs offer enormous computational power and are used to solve complex problems such as global climate modeling and drugs design. As simulations become more and more complex, the computational power required to produce significant results, within reasonable amount of time, grows rapidly. Thus, parallel computing through MPPs has provided a practical approach to obtain large computational power beyond what the fastest sequential supercomputer can offer. MPPs systems typically require special design and thus demand high cost for their high computing performance. The second approach for parallel computing can be achieved by distributed computing. Distributed computing (DC)is is a process, whereby, computers connected through a network are used, collectively, and simultaneously to solve a single large problem. As more and more organizations have high-speed local area networks, interconnecting many general-purpose workstations, the combined computational resources may exceed the power of a single high-performance computer. In some cases, several MPPs have been combined using distributed computing to produce unequaled computational power. The most attractive feature of the distributed computing approach lies in its low cost. Networked workstations or PCs for distributed computing typically cost only a fraction of that for a large MPPs system with comparable performance. Both distributed computing and MPP can use message passing model to coordinate parallel computing tasks. In parallel computing processing, data must be exchanged between tasks. Several standards have been employed for this purpose, including shared memory, parallelizing compilers, and messages passing. The message-passing model has become the paradigm of choices for its wide support by various hardware and software vendors. Two major software packages and standards are currently used for message passing in distributed systems of paralleling computing. They are PVM (Parallel Virtual Machine) from Oak Ridge National Laboratory and University of Tennessee and MPI (Message Passing Interface), developed by MPI Forum (a group of more than 80 people from 40 organizations, including vendors of parallel systems, industrial users, industrial and national research laboratories, and universities). Both PVM and MPI support C/C++ and FORTRAN programming languages and can be used on MPP and distributed systems.

PVM enables a collection of heterogeneous computer systems to be viewed as a single parallel virtual machine. The PVM system is composed of two parts. The first part is a daemon (process) running on the background of UNIX system) called pvmd that resides on all computers making up the virtual machine. The daemon pvmd is designed so that any user with a valid login can install the daemon on a machine. A user can run a PVM applications, first starting up PVM to create a virtual machine. The PVM aplication can then be started from an UNIX prompt on any host.

The second part of the PVM system is a library of PVM interface routines. It contains a functionally complete set of primitives that are needed for coordinating tasks of an application, e.g., user-callable routines for message passing, spawning processes, coordinating tasks, and modifying the virtual machine. Arbitrarily complex combinational switching circuits by using an interconnection of a set of simpler combinational circuits are called primitives.

MPI is a software package that facilities message passing between different processors for either MPPs or distributed systems. Unlike PVM, MPI doesn't require an active daemon running on each processor. Version 1 of MPI standard (MPI-1) was released in summer 1994. Since its release, the MPI specifications have become the leading standards of message-passing libraries for parallel computing. More than a dozen implementations exist on a wide variety of platforms. Every vendor of high-performance parallel computer systems offers an MPI implementation for heterogeneous networks of workstations and symmetric multiprocessors. An important reason for the rapid adoption of MPI was the representation on the MPI forum by all segments of the parallel computing community: vendors, library writer and application scientists. MPI and PVM are compatible in the sense that they are both based on the message passing model and they can be ported easily from one to the other.

In summary, parallel processing on a distributed system with PVM or MPI is an efficient tool for large-scaled scientific computation and simulation. It can solve extremely computing-intensive scientific problems, which in the past can only be solved using MPPs, at an affordable cost.

d) Measurement process and the disturbance of quantum states

Measurement without disturbance: In classical physics a core assumption is that a measurement on a system could reveals the information without any disturbance to the measured system. All that is required to do this is to turn off the interaction ways involved in the measurement process. For example, if we want to determine the position and velocity of a particle all we must do is to use a weak light source turned on and off quickly for taking two snapshots of the particle. The first snapshot gives the initial position *xi*, and the second, taken at Δt , time later, gives its final position *xf*. We can thus determine particles velocity as v = (*xf* −*xi)*/Δt. According to classical physics, one can measure precisely both the position and velocity to an arbitrary accuracy, though, this assertion contradicts what is observed and is predicted by quantum mechanics relative to the system. Another aside philosophical matter is associated with classical assumption is that the position and velocity of particles in the system are well defined, simply awaiting the results of the process of our observation. Worth to mention that in quantum theory, these interrelated circumstances do not hold.

e) Determinism and Laplace's demon

Classical physics is based upon the deterministic differential equations models. Pierre-Simon de Laplace, was first to imagine a thought experiment known as "*Laplace's demon*". First published in 1814, it articulates, comprehensively, the causal or scientific determinism. In the framework of determinism, he states, conceptually, that if someone (the „*Demon"*) knows the precise location and momentum of every atom in the universe, their past and future parameters for any given specific time are entailed. It becomes possible to perform calculations on the base of the laws of classical mechanics.

If one knows precisely the initial values of the position and velocity of all particles in a system at one moment in time evolution, then all the future behavior of the system can be predicted. The universe is likened to a clock, which when set about running, deterministically, it evolves continuously. This concept is, suggestively, embodied by Laplace's demon.

As stated Pierre Simon Laplace in "*A Philosophical Essay on Probabilities, (1814)", w*e may regard the present state of the universe as the effect of its past history, and the cause of its future evolution. An intellect which, at a certain moment, would know all forces that set the nature in motion, and all positions of all items of which nature is composed, and, moreover, if the "intellect" is also vast enough to submit these data to analysis, it could embrace, in principle, in a single formula the movements of the entities evolving in the universe, no matter that they are the tiniest atoms. For such an intellect, nothing would be uncertain and the future just like the past would be present before its eyes."

Glossing on Laplace's demon, we can assert that uncertainty in classical physics was only due to our own ignorance of the position and velocity of all particles at a given instant in time. The universe was, simply, one in initial-value problem and if we knew the initial conditions at one instant in time, we could infer the outcome of every circumstance in the future, as well as looking back in the past and know all that has been!

f) Cracks in the foundational construct of Quantum Mechanics

The foundations of classical physics started to show cracks well before the advent of quantum theory. In the 1880s, Michelson and Morley performed a series of experiments that demonstrated the earth does not travel through the luminiferous ether that was thought to permeate the universe. Recall that if light were a wave, then it must be an excitation of some medium and as the earth travelled through the ether, it should have a different velocity depending on the relative velocity of the earth and ether. No difference was observed, and the resulting theory that describes this circumstance is none other than Einstein's special theory of relativity.

It is a common misconception in which physicists of the 1890s believed that the fundamental laws of nature had been already discovered and all that was left to do was to work out the consequences of these. In fact, that times were a tumultuous period in which several fundamental unresolved problems occupied some of the greatest minds of the time. For example, the kinetic theory of gases and the equipartition theorem put forth by Clausius, Maxwell, and Boltzmann was not widely accepted at that time. The atomic and molecular theory of the structure of matter came under attack, as the origin of the "resonances" in molecules, which were assumed to be the origin of spectral lines, was unknown. IT should be recallled that at that time there was no direct evidence for the existence of fundamental particles until 1897, when J. J. Thomson discovered the electron.

Many unexplained phenomena came about, aftermath, because of the availability of increasingly precise experimental results, which had slipped to previous generations because the observations of earlier times were not as precise as in more advanced times. However, this does not limited the applicability of classical physics, which works quite well in its realm of applicability. For example, the new physics that arose at the onset of the 1900s (relativity theory and quantum physics) were not required for the applications in the well established science and technologies of the times.

However, there were several observations and experiments that were oriented towards the development and consolidation of quantum theory, which are worth to be, briefly evoked.

g) Spectral lines

Starting with a Swiss schoolmaster known by the name of Johann Balmer who, in 1885, was trying to understand the spectral lines observed in the emission from hydrogen. He noticed that there were regularities in the wavelengths of the emitted.

It is useful to remind an assertion, already proclaimed here, that the relationship between increased measurement precision, technological advance, and discovery of new physical phenomena. When an experimentalist develops a method to measure some quantity with significantly increased precision, beyond what was capable before, this new capability enables to measure and manipulate systems on a more precise scale. This allows for the development of smaller, faster and more complex technologies that we use in our daily lives. Furthermore, these technologies can be used to probe new areas of physics previously unexplored. New discoveries from such experiments can then feed back into the development of new measurement techniques and related technologies.

When a metal surface is illuminated by light, electrons can be emitted from the surface. This phenomenon is known as the photoelectric effect, and was first discovered by Heinrich Rudolph Hertz in 1887 while investigating electromagnetic radiation. Einstein extends the work of Planck and applies it to describe the photoelectric effect. In 1902 Phillipp Lenard observed that the maximum photoelecton kinetic energies are independent of intensity but depend on frequency, which could not be explained by a wave theory of light (see also Original Lenard's writings: *Über Kathodenstrahlen* (Leipzig, 1906; 2nd ed., Leipzig, 1920); and *Über Äther und Materie*, Heidelberg, 1910; 2nd ed., Heidelberg, 1911).

h) Heat capacity of solids; Dulong-Petit law.

In the retrospective of the development of quantum physics theory, appeared another issue that needed fixing, in order to be put in consonance with the sense of the well established classical physics. This issue was the theory of heat capacity of solids, considered as a milestone in legitimizing Quantum Mechanics theory. It was legitimized the theoretical model of the specific heat capacity of a material system, C, defined as the amount of heat Q, required to raise the temperature of an known amount of material (typically one mole), by a given amount of temperature increase, ΔT:

$$C = Q/\Delta T \qquad (1.1)$$

The SI unit of specific heat capacity is a J/mol^{-K}. It is worth to recall that according to the equipartition theorem of classical statistical mechanics, the total energy contained in an assembly of a large number of individual particles exchanging energy amongst themselves, through mutual interactions, is shared equally on average by all the particles. In other words, at temperature T, each atom has an energy of $k_BT/2$ per degree of freedom, for both kinetic and potential energies. For an atom in a crystalline solid, there are three degrees of freedom, associated with the three directions they can wiggle about their equilibrium positions) and, thus, they have kinetic energy $K = 3/2k_BT$, and potential energy $U = 3/2k_BT$, giving total thermal energy stored in the system of $E = 3k_BT$. Thus, the amount of heat required to increase the temperature of one mole of atoms by, ΔT, is given by the difference between the final and initial energies $Q = 3k_B(T+\Delta T)-3k_BT = 3k_B\Delta T$. Thus, the heat capacity is given by C = 3kB, which is independent of temperature. This is known as the Dulong-Petit law after its French discoverers (1819), and derived theoretically by Boltzmann in 1876. This prediction of classical physics agrees fairly well with experimental observations for most materials near room temperature. However, this temperature independent behavior was not observed at low temperatures for certain materials, particularly diamond (carbon), boron and silicon. The carbon anomaly had been known since 1841. In experiments published in 1905 it was shown by the Scottish chemist James Dewar that the heat capacity of diamond essentially vanishes near 20 K, and as the temperature of any material approaches absolute zero, the heat capacity should approach zero as well. The solution to this problem was partially solved by Einstein in 1907 by extending the ideas of Max Planck, assuming that atoms are constrained to oscillated about their equilibrium positions in a lattice at frequency υ, and can oscillate having only discrete energies given by integer multiples of $h\upsilon$, where h is Planck's constant. Einstein's theory was further refined and gives excellent agreement with experiments as evinced the Dutch physicist P. Debye in 1912.

If an chemical element or an izotop is measured, its atomic weight can be approximated using Dulong-Petit empirical law; many atomic weights were originally so derived. Later it was modified to apply only to metallic elements, and later still low-temperature measurements showed that the heat capacity of all solids tends to become zero at sufficiently low temperature.

i) Einstein's contribution to specific heat theory.

The Law of Dulong and Petit assums that Maxwell-Boltzmann statistics and equipartition of energy could be applied even at low temperatures. Einstein recognized that for a quantum harmonic oscillator at energies less than kT, the Einstein-Bose statistics must be applied. This was the same conclusion that was drawn about blackbody radiation. The statistical distribution of energy in the vibrational states gives average energy:

$$\langle E\rangle = \frac{h\upsilon}{e^{h\upsilon/kT}-1} \qquad (1.2)$$

where the frequency, υ, is the frequency of a quantum oscilator There are three degrees of freedom per vibrator, so the total energy is:

$$E_{oscillators} = \frac{3h\upsilon N_A}{e^{h\upsilon/kT}-1} mole^{-1} \qquad (1.3)$$

The derivative of last equation gives:

$$C_V = \frac{\partial E}{\partial T} = \frac{3N_A k\left(\frac{h\upsilon}{kT}\right)^2 e^{h\upsilon/kT}}{\left(e^{h\upsilon/kT}-1\right)^2} mole^{-1} \qquad (1.4)$$

Blackbody radiation and the ultraviolet catastrophe: all played a role in the development of the quantum theory we know today. However, there was one key unresolved problem that led to the discovery of quantum physics and contributed to the resolution of many of the other.

j) The ultraviolet catastrophe and the blackbody

The ultraviolet catasrophy is related with the law of equipartition of energy. It states that, in a system in thermal equilibrium, on the average, an equal amount of energy will be associated with each independent energy state.

A blackbody is an idealized entity which absorbs and emits energy on all frequencies. Classical physics can be used to derive an equation which describes the intensity of blackbody radiation as a function of frequency at a constant temperature. The effect is formalized by the Rayleigh-Jeans law. Although the Rayleigh-Jeans law works for low frequencies, it diverges as υ^2; increases. This divergence effect for high frequencies is called the ultraviolet catastrophe.

Max Planck explained the blackbody radiation in 1900 by assuming that the energies of the oscillations of electrons which gave rise to the radiation must be proportional to integral multiples of the frequency, i.e.:

$$E_n = nh\upsilon \qquad (1.5)$$

Using statistical mechanics, Planck derived an equation similar to the Rayleigh-Jeans equation, but with the adjustable parameter h. Planck found $h = 6.626\times10^{-34}$

Nevertheless, Planck could not offer a good justification for his assumption of energy quantization. Physicicsts did not take this energy quantization idea seriously until Einstein invoked a similar assumption to explain the photoelectric effect (see further).

The law of equipartition breaks down when the thermal energy kBT is significantly smaller than the spacing between energy levels. Equipartition no longer holds because it is a poor approximation to assume that the energy levels form a smooth continuum, which is required in the derivations of the equipartition theorem mentioned above. Historically, the failures of the classical equipartition theorem to explain specific heats and blackbody radiation were critical showing the need for a new theory of matter and radiation, namely, the quantum mechanics and quantum field theory.

To illustrate the breakdown of equipartition concept, consider the average energy in a single (quantum) harmonic oscillator, as was introduced above for the classical case. Neglecting the irrelevant zero-point energy term, the quantum energy levels are given by $E_n = nh\upsilon$, where h is the Planck constant, υ is the fundamental frequency of the oscillator, and n is an integer. The probability of a given energy level being populated in the canonical ensemble is given by its Boltzmann factor.

Boltzmann's factor is $e^{-(E/kT)}$, which expresses the „probability" of a state of energy E relative to the probability of a state of zero energy. This factor can be used to introduce temperature into a wide variety of physics/computing problems and is often taken as a starting point in simulations.

In classical statistical mechanics, the equipartition theorem relates the temperature of a system to its average energies. The equipartition theorem also known as the law of equipartition of energy.

The original idea underlying of equipartition concept was that, in thermal equilibrium, energy is shared equally among all of its various forms; for example, the average kinetic energy per degree of freedom in translational motion of a molecule should equal that in that in rotational motion.

The equipartition theorem enables quantitative predictions. Like the virial theorem, it gives the total average kinetic and potential energies for a system at a given temperature, from which the system's heat capacity can be computed. In other terms, in mechanics, the virial theorem provides a general equation that relates the average, over the time, of the total kinetic energy, of a stable system consisting of N particles, bounded by potential forces.

However, equipartition also gives the average values of individual components of the energy, such as the kinetic energy of a particular particle or the potential energy of a single spring model. For example, it predicts that every atom in a monatomic ideal gas has an average kinetic energy of $(3/2)k_BT$ in thermal equilibrium, where k_B is the Boltzmann constant and T is the (thermodynamic) temperature. Thermodynamic temperature is the absolute measure of temperature and is one of the principal parameters of thermodynamics. Thermodynamic temperature is defined by the third law of thermodynamics in which the theoretically lowest temperature is the null or zero point. At this point, absolute zero, the particle constituents of matter have minimal motion and can become no colder.

Returning to equipartition theorem, more generally, this theorem can be applied to any classical system in thermal equilibrium, no matter how complicated. It can be used to derive the ideal gas law, and the Dulong–Petit law for the specific heat capacities of solids. The equipartition theorem can also be used to predict the properties of stars, in asstrophysics, even for white dwarfs and neutron stars, since it holds even when relativistic effects are considered.

Although the equipartition theorem makes accurate predictions in certain conditions, it is inaccurate when quantum effects are significant, such as at low temperatures. The circumstance is said to be „frozen out. For example, the heat capacity of a solid decreases at low temperatures as various types of motion become frozen out, rather than remaining constant, as predicted by equipartition theorem. Such decreases in heat capacity were among the first signs to physicists of the 19th century that classical physics was incorrect and that a new, more subtle, scientific model was required. Along with other evidence, equipartition's failure to model black-body radiation – also known as the ultraviolet catastrophe – led Max Planck to suggest that energy in the oscillators in an object, which emit light, were quantized, a revolutionary hypothesis that spurred the development of quantum mechanics and quantum field theory.

k) Quantum discord

In quantum information theory, quantum discord is a measure of nonclassical correlations between two subsystems of a quantum system. It includes correlations that are due to quantum physical effects but do not necessarily involve quantum entanglement.

2. Quantum effects involved in quantum computig and hystorical milestones of the scientific developments along this path

a) 1905, Photoelectric effect

Photoelectric effect has been clarified by Einsstein in the back waves/siage of the success of Planck's theory that accomplished to describe the observed spectral emission for blackbody radiation. At the base was an effect of constraining the absorption and emission of radiation to discrete energy values. This prompted a patent of young clerk working in Bern Switzerland, to apply this idea to an outstanding problem of the time, namely the photoelectric effect. Albert Einstein, one of the few scientists to take Planck's ideas seriously, advocated for the involvement in photoelectric effect the quantum of light (the photons), entities, which behave also like a particles. On the same path, Einstein developed in 1907, the theory the heat capacity of metals: Einstein assumes that the atoms in a solid are constrained to oscillated about their equilibrium positions in a lattice at frequency υ, oscillations being sustained only by discrete energies amounting only integer multiples of $h\nu$, where h is Planck's constant.

In 1911, appeared Nuclear model of atom: Ernest Rutherford infers the nucleus, according to results gathered in alpha-scattering experiments performed by Hans Geiger and Ernest Marsden it was proposed a nuclear model of atom, superseding Thomson's "plumb-pudding" model.

1913 Bohr's atom: Niels Bohr succeeds in constructing a theory of atomic structure based on Rutherford's nuclear planetary model of the atom and the quantum ideas of Planck and Einstein. The key insight was that there were only discrete energies that the system could have. The electrons were said to occupy stationary states at these energies, which do not radiate electromagnetic energy.

1914 Franck-Hertz experiment of James Franck and Gustav Hertz confirm the existence of stationary states through an electron-scattering experiment.

1923 X-ray - electron scattering: Arthur Compton discovers the quantum (particle), the nature of *x* rays, thus confirming photons as particles.

1924 de Broglie waves model: Louis de Broglie proposes that matter has wave properties.

1924 Bosons: Satyendra, Nath Bose and Albert Einstein find a new way to count quantum particles, founding, later, Bose-Einstein statistics, and, concurrently, they predict that extremely cold atoms should condense into a single quantum state, later branded as a Bose-Einstein condensate.

1925 Matrix mechanics: Werner Heisenberg, Max Born, and Pascual Jordan develop matrix mechanics, the first complete version of quantum mechanics theory. Initial step toward quantum field theory.

1925 Exclusion principle: Wolfgang Pauli formulates the exclusion principle for electrons in an atom.

1926 Wave mechanics: Erwin Schrödinger develops wave mechanics by trying to determine the equations of motion that describe also de Broglie's waves. Max Born gives a probability interpretation of quantum mechanics. G.N. Lewis proposes the name "photon" for a quantum of light.

1926 Fermions: Enrico Fermi and Paul A.M. Dirac find that quantum mechanics requires a second way to count particles, Fermi-Dirac statistics emerged, opening the way to the development of solid-state physics.

1926 Quantum theory of light consolidated: Dirac publishes the seminal paper on the quantization of electromagnetism and quantum field theory is born.

1927 Heisenberg Uncertainty Principle: it states that the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa (see: Heisenberg, W. (1927), „Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik", Zeitschrift für Physik (in German), 43 (3–4): 172–198.

1928 Paul Dirac combines quantum mechanics and special relativity to describe the electron.

1931 Paul Dirac realizes that the positively-charged particles required by his equation are new objects (he calls them "positrons" which he mistakenly believes is the proton). They are exactly like electrons, but positively charged. This is the first example of antiparticles.

1932 Carl David Anderson discovers antimatter, an antielectron called the positron.

Further developments: 1932-1995 Nuclear physics, quantum field theory, superconductivity, and spooky action at a distance.

1934 Enrico Fermi puts forth a theory of beta decay that introduces the weak interaction. This is the first theory to explicitly use neutrinos and particle flavor changes.

1934 Hideki Yukawa combines relativity and quantum theory to describe nuclear interactions by an exchange of new particles (mesons called "pions") between protons and neutrons. From the size of the nucleus, Yukawa concludes that the mass of the conjectured particles (mesons) is about 200 electron masses. This is the beginning of the meson theory of nuclear forces.

1935 Albert Einstein, Boris Podolsky, and Nathan Rosen raise concerns about the consequences of quantum theory for correlated quantum systems and put forth the EPR paradox.

1942 Richard Feynman puts forth his path integral formulation of quantum mechanics in his PhD thesis.

1946-48 Experiments by Isidor Rabi, Willis Lamb, and Polykarp Kusch reveal discrepancies in the Dirac theory of hydrogen.

1947 Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga develop the first complete theory of the interaction of photons and electrons, quantum electrodynamics, which accounts for the discrepancies in the Dirac theory, giving procedures to calculate electromagnetic properties of electrons, positrons, and photons. Introduction of Feynman diagrams.

1951 David Bohm introduced a simplified version of the EPR paradox consisting of correlated spins.

1957 Julian Schwinger writes a paper proposing unification of weak and electromagnetic interactions.

1957 John Bardeen, Leon Cooper, and J. Robert Schrieffer show that electrons can form pairs whose quantum properties allow them to travel without resistance, providing an explanation for the zero electrical resistance of superconductors. This theory was later termed the BCS theory (after the surname initials of the three physicists).

1959 Yakir Aharonov and David Bohm predict that a magnetic field affects the quantum properties of an electron in a way that is forbidden by classical physics. The Aharonov-Bohm effect is observed in 1960 and hints at a wealth of unexpected macroscopic effects.

1964 John S. Bell proposes an experimental test, "Bell's inequalities," of whether quantum mechanics provides the most complete possible description of a system.

1982 Alain Aspect carries out an experimental test of Bell's inequalities and confirms the completeness of quantum mechanics.

1995 Eric Cornell, Carl Wieman, and Wolfgang Ketterle trap clouds of metallic atoms cooled to less than a millionth of a degree above absolute zero, producing Bose-Einstein condensates, which were first predicted 70 years earlier. This accomplishment leads to the creation of the atom laser and superfluid gases.

b) Turing-type (TT) computing machines

The quantum computing construct is actively supporting Turing-types computing machines. *Turing machine* is an abstract machine that manipulates symbols on a strip of tape according to a table of rules. To be more specific, it is a mathematical model that defines such a contrivance. Despite the model's simplicity, given any computer algorithm, a Turing machine can be constructed that is capable of simulating that algorithm's logic.

In an alternate explanation, Turing's machines are conceptual/mind tools indorsing the reshaping our understanding of dimensionality both in the real universe and alternate parallel universes. According to the founders of D-wave, artificial intelligence project, TT machines are here to sustain the quest to quantum computation development, over long periods ahead. Understanding what it means, is to understand that the tough system, talked about appearing in the top scientist revelations, is coming about. This acts as a controlling empire, called, euphemistically the New World Order that can now encumbrance mankind beyond recognition because the demanded privacy is in train to be suppressed, and, if you think otherwise or wrong about – you are prone to be banned.

As, nowadays (in 2018), the development of quantum computers technology is still in its infancy, but experiments have been carried out, in which quantum computational operations were executed with relatively small number of quantum bits. Both theoretical and practical research continue, and, many national governments military and financial agencies are funding quantum computing in an effort to develop quantum computers for civilian, business, trade, economy, finances, environmental and national security purposes, cryptanalysis being, in the context, a fancy, but an outstanding example.

One purpose of quantum computation is to allow the performing of useful tasks, tackling also parallel realities (universes), developing computing machines able to exploit other worlds." – see, Geordie Rose, the Founder of D-Wave System.

Other purpose of QC is to solve complex problems that conventional computers cannot approach. Another important purpose is to build quantum computers is the pursuit to build "machines like us, i.e. mimicking humans behavior. The D-wave quantum computer "looks like a giant monolith" and, according to Geordie Rose, Founder of D-Wave, company, the machine has a "heart beat" which keeps the computational power behind D-wave unruffled. In other words this machine has a "heartbeat" making one step closer to human artificial intelligence (see the pictorial in Figure 1.1 for suggestive interpretational graphics).

The quantum computer plans strive to "to grab the shadows" of other parallel universes and bring them closer to our reality. These machines can be used to bring the "demons" from "parallel" universes into our world and to "communicate" with them via quantum physics on issues of practical interest.

The quantum computing field is actively supporting Turing-types machines. They are conceptual/mind tools for reshaping the understanding of dimensionality both in the real universe and parallel universes. According to the founder of D-wave, artificial intelligence project, TT machines are here to sustain the quest to quantum computation. Understanding what it means, is to understand that the tough system, talked about in the top scientist revelations, is coming about?. The controlling empire called euphemistically the New World Order can now yoke mankind beyond recognition because the privacy is in train to be suppressed, and if you think wrong about – you are prone to be banned.

Quantum information realm sub-sums information processing, covering quantum computing itself, quantum communications, quantum cryptography and even quantum games. What is referred, nowadays, as quantum information, in the meaning of a stand-alone branch, in the much wider context, has been explored since many years, as Quantum Electrodynamic (QED) (see, e.g. Dirac 1948, Feynman 1949, Van Dyck, 1990, Ryder 1996).

Special relativity refers to physics effects that have been experimentally, scrupulously, verified. Suffice to mention: length contraction, time dilatation, relativistic mass which "bridges" mass and energy, legitimizing mass-energy equivalence ($E=mc^2$), via an invariant parameter, light speed, c, as a limit, in the condition of relativity simultaneity. For quantum computing is of relevance the latter concept of relativity simultaneity or distant simultaneity, which implies that if two spatially separated events happen at the same time, the perception of the events are not absolute but depend on the observer's reference frame.

However, the tackling of QED, even in a superficial way, is beyond the scope of this essay, and has limited practical relevance from the perspective of quantum computing to which is devoted this writing.

Quantum computers are different from binary digital electronic computers based on transistors. Whereas common digital computing requires that data be encoded into binary digits (bits), each of which is always in one of two definite states (0 or 1). Quantum computation is analog and uses quantum bits, which can be in an infinite number of superpositions of states. A quantum Turing (1936) machine is a uncntroversial theoretical model of such a computer, and is known as prototyping the universal quantum computers. Quantum computers share theoretical similarities with non-deterministic and probabilistic computers. The field of quantum computing was initiated by the work of Paul Benioff and Yuri Manin in 1980, Richard Feynman in 1982, and David Deutsch in 1985.

Large-scale quantum computers would theoretically be able to solve certain problems much more quickly than any classical computers employing, even the best currently known algorithms, like integer factorization using Shor's algorithm or the simulation of quantum many-body systems. There exist quantum algorithms, such as Simon's algorithm, that run faster than any possible probabilistic classical algorithm. Given sufficient computational resources, a classical computer could in theory simulate any quantum algorithm, as quantum computation does not violate the Church–Turing thesis. On the other hand, quantum computers may be able to efficiently solve problems which are not practically feasible on classical computers.

Feynman (1982) in a seminal conference and ensuing publication asserted that anything what happens in the physics in the region of a finite volume of the universe is analyzable in a finite number of logical operations, performable by the simulation of the discrete natural effects, from macroscopic perception, down to the quantum size- and time-scale (Feynman conjecture). Moreover, the simulation of quantum mechanical systems would be impossible on classic digital electronic computers which, inherently, are unable to simulate quantum systems using abstract spaces with sub-exponential dimensions and be obliged to exponential growth of the amount of quantum states and associated characterizing data (see e.g. Strubell 2011).

Thus, by Feynman conjecture the viability of quantum computing has been legitimized.

Quantum computers, apart from limitations which will be further discussed, enable to explore non-classical attributes of quantum systems being able to process, exponentially, the information that is trackable in only a polynomial growing time. Obviously, by these attributes, quantum computers can, in principle, approach complex and very large systems in Newtonian mechanics, informatics, biology, language theory and semantics, cryptography, environmental, social and politic phenomena and, not-the-last, in cybersecurity.

Further, it is worth to mention that, along the path of historic developments, Deutsch (1985) speculated that Feynman's assertion could lead to versatile quantum computers and associated quantum computing algorithms since, in principle, any physical or mental process could be modeled, accurately, by quantum computers and, by the way of consequence, can outperform classical digital computers. It is not surprising that it followed many proposals of illuminated ideas on how to build and exploit such quantum contrivances, at the macroscopic level, by exploiting quantum effects.

On this line, Shor (1994, 1995, 2004), proposed a method for solving an intricate and highly computing-intensive, practical computation problem, namely, the factorization problem which arises in the theory of numbers, a paradigm example. He demonstrated that quantum computers, by using specific quantum algorithms, are prone to factor huge numbers in a very short time, outperforming possibilities of classic digital computers (see also controversial views on this matter in the work of Ekert and Jozsa 1997).

Quantum computing and the associated material support, quantum computers, imply the explicit use of quantum mechanics effects, in order to perform computing operation on data. Here, it is meant by data any set of values of quantitative and/or qualitative variables. Sub-sets of data are formalized as information entities. Quantum computing recourses to , primarily, only to few fundamental principles of quantum mechanics: quantum superposition, quantum entanglement and quantum tunneling effect.

Quantum superposition principle asserts that two or more quantum states can be merged, resulting another, different, quantum state. Reciprocally, a quantum state can be represented (decomposed) as a sum of two or more distinct quantum states. This handling derives from the linearity of the solution of Schrödinger's equation, i.e., any linear combination of solutions is also a solution of the equation.

A quantum state is considered entangled if it cannot be decomposed into its "more fundamental" constituents. Quantum entanglement is a quantum effect that occurs when pairs of particles or groups of particles are generated, or interact, in a way that the quantum state of each particle cannot be described independently of others to which they are entangled, even if particles are separated by large distances. In this circumstance, the quantum state of the system must be described as whole, in terms of physical observables, i.e. in entities of physical nature that can be recognized experimentally.

It is worth to say that quantum entanglement is not yet completely understood and the development of the concept is merely based on a mosaic of observations and *ad hoc* experiments, though imaginative, but not decisive.

However, in this matter it cannot be excluded sorts of theories which bring into play non-local hidden parameters which affect only parts of the system, parts arbitrarily distanced in the universe. This matter is attempted to be rationalized by Bell's theorem which sub-sums, under a collective denomination, a set of results suggesting the impossibility of "local realistic" interpretation of quantum mechanics (Bell 1964). Local realistic in Bell's interpretation is rather "hazy" implying or a heuristic prior guess or the allotment of probability to the result of measurements but not evading, apparently, the necessity of "hidden variables".

Bell's theorem is considered, nowadays, as a controversial matter and efforts are deployed for obtaining new experimental evidences. Decisive remains to find a compromise with the old EPR thought experiment in order to explore new ways of approach.

Quantum tunneling is referred as a quantum effect where a particle tunnels a classical energy barrier which, otherwise, is not surmountable. This effect plays a key role in quantum computing and scanning tunneling microscopy.

Worth to emphasize that, classically, the assessment of the state of a physical system implies the complete knowledge of what is needed to predict the future of the system (e.g. see the discussion in the publication of Susskind and Friedman 2014). The knowledge of the state, of a quantized system, specifically needs the knowledge of its associated four quantum numbers, n, l, m_l and m_s, as explained, in more details, at the beginning of the Chapter 3 in the monograph of Cioclov (2008c).

Quantum computing encountered from the beginning difficulties in understanding and material realization. The quintessence of difficulties are met in evidence by the EPR "thought experiment" proposed in 1935 by Einstein and his co-workers, Boris Podolsky and Nathan Rosen (hence "EPR" acronym). Lets now outline this historical "thought experiment".

In 1935 and 1936, Schrödinger published a two-part article in the *Proceedings of the Cambridge Philosophical Society* in which he discussed and extended an argument advanced by Einstein, Podolsky, and Rosen (The Einstein-Podolsky-Rosen (EPR) argument). This initiative, was, in many ways, the culmination of Einstein's critique targeting the orthodox Copenhagen interpretation of quantum mechanics, concurrently, suggesting that quantum theory, in the format that it is stabilized and widely accepted is incomplete. In classical mechanics the state of a system is essentially a list of the system's properties – more precisely, it is the specification of a set of parameters from which the list of properties can be reconstructed: the positions and momenta of all the particles comprising the system (or similar parameters in the case of fields). The theory of quantum dynamics specifies how properties change, in terms of a law of evolution of the the states. Pauli characterized this mode of description of physical systems as a 'detached observer' idealization.

It is not hard to notice that this interpretation introduces a paradox, namely, that the information is communicated at unlimited speed. This odd assumption has been, eventually, confirmed. This paradox, "chatted" by Albert Einstein and co-workers, Boris Podolski and Nathan Rosen in 1935 in a publication of a *"thought experiment"* referred, nowadays, by the acronym of EPR. Let now be more specifically.

Envisage a thought experiment in which an elemental particle, with zero spin is emitted by a source and then is converted into two entangled particles with spin. Particles fly apart and they must display opposite spins by virtue of one of quantum mechanics principles, which state that the spin of an elementary particle in any process is conserved. Consequently, if at an instant one measures the spin direction of one particle, instantly one knows that the spin direction of the other particle is opposite. However, following this logic, according to Bohr, this outcome is not defined until the measurement is performed, operation that instantaneously set free the collapse of the governing wave function, making, eventually, unstable the quantum process which may be implied in quantum computation process. To circumvent this hurdle, EPR conjecture claims, tacitly, that Schrödinger's wave equation does not assures a complete description of a quantum state, supposedly governed by Schrödinger's wave equation as is nowadays quasi-unanimously accepted (e.g. Daintith 2009). An easy-to-guess substitute comes into mind: there are implied hidden variables that need to be specified and taken into account. The supposition of existence of yet undiscovered hidden variables in quantum mechanics has, nevertheless, not advanced until now.

Moreover, the embarrassment deepens and it is not hard to notice that quantum computing is affected by a paradox of principia, namely, that the information is communicated at unlimited speed. This odd result, ought to accept, that is stemming from the oddness of primary quantum conjectures which have been, nevertheless, unambiguously confirmed by experiment. Under this perspective, it is not superfluous to attempt, perhaps, new specific rules, beyond classical QM, though not forgetting that existing rules have demonstrated an outstanding resilience and predictive accuracy and this achievement is worth to be conserved (see, e.g. a discussion of Nielsen and Chuang 2010).

The relationship of QM to specific branches of physics, at quantum size levels, analogizes, in some sort, the relationship between computers structure (hardware) to computers operating systems, adapted via specific basic parameters and modes of operation (software), leaving for specific tasks (applications) the occupation of personalized software.

In order to advance, quantum computing, facing impediments, some of them ostensibly insurmountable, it is needed, primarily, to assure, higher speed than the light speed, of signals instantaneous perception in any location in the universe. Obviously, this requirement is in flagrant contradiction with the Einstein's theory of relativity, contradiction with its basic postulates, already outlined above.

A non-controversial solution was sought in quantum effects which, by "smart" manipulations, gives chance to circumvent this embarrassing circumstance. One *ad hoc* way of approach has been imagined, namely, whether it is feasible to duplicate (*clone*) an unknown (arbitrary) quantum state, that is, to construct a copy of a quantum state. If cloning is possible, then it appears possible to signal faster than the light speed by using such a quantum effect.

Disappointingly, in the early 1980s, *no-cloning theorem* has been unambiguously demonstrated which cast doubts on the perspective to build quantum computers. No-cloning theorem proved by Wooters and Zurek (1982) enforces that it is not possible to copy rigorously the quantum information. This follows from Heisenberg's principle of uncertainty which implies that there are no means to obtain complete information about a quantum state, that is equivalent to duplicate quantum states.

For instance, if a photon of definite polarization encounters an excited atom, there it is always a non-vanishingly probability that the atom will emit (a sort of duplications), a second photon by stimulated emission.

In this stage of reasoning it is legitimate to ponder the question: Is it possible to produce by this way another beam?, having the same state as the original. If it were possible, for this purpose, it can be used for demonstration the duplicate photon to be instrumental in trying to asses, the exact state of the photon. Intuitively, it ought to have the same polarization as the initial one but, however, this is not possible, as evinced by Wooters and Zureck (1982), owing to the linearity of Heisenberg's wave equation which forcefully leads to no-cloning theorem. Moreover, if the investigation of duplicating quantum states is pursued, the quantum state is altered (collapses). Facing this evidence, there is, nowadays, accepted that quantum mechanics forbids quantum states replication, a ruling applicable to any quantum system in an arbitrary state, imposing/forcing prohibiting of cloning photons faster-than-light, i.e. the surpassing the light speed in any interaction and communication.

Related to the *no-cloning* theorem is the Bell's conjecture introduced above. However, Bell's theorem, since then, was meticulously analyzed, revealing how, even and imperfect quantum, but functional cloning device, should work. By back-reflex, this undertaking has helped to understand new facets of quantum mechanics.

It was obvious that the key information needed to be clarified in this endeavor was how to obtain complete control over singular quantum systems. After 1970s it was clear that to obtain a complete control over a single quantum system is not excluded but is, at least computationally, a Herculean task. Experimental tools, such as particles accelerators, enable only limited access to individual constituents of quantum systems and afford only a weak control over them. Nevertheless, "rogue" controlling techniques have been developed, a salient example are methods of trapping a single atom by "atoms/ions traps", thus enabling to isolate one atom of the rest of the world and, moreover, enabling to manipulate it, inclusive giving the possibility of exploring, with high accuracy, various aspects of its behavior. On this line, scanning tunneling microscopy (STM) has been developed as a device for imaging surfaces at atomic level (Nobel Prise 1986 for Gerd Binnig and Heinrich Roher) that assures a good resolution of 0.01 nm in depth and 0.1 nm on lateral. This resolution enables visualization of individual atoms in vacuum and air at temperatures between 0 K and some hundred Celsius degrees. Concurrently, by STM technology it becomes possible the atoms manipulation. STM is based on the demonstrated effect of quantum tunneling which is a QM effect where a particle tunnels through a classical potential barrier which otherwise is insurmountable. This effect is essential in astrophysics studies and diodes nanotechnology.

Tunneling at quantum level is explained on the base of Heisenberg's uncertainties principle and de Broglie wave-particle duality principles. When tunneling, it is possible, zero spin particles, conceptually, to be moved in another place in universe faster than the speed of the light.

The effect described above, apparently violates the principle of causality since it means that in a reference frame one arrives in a place before it is left! This paradoxical circumstance was tackled by Max Born who suggested that tunneling is, as whole, a quantum mechanics effect which, basically stems from the primary principles of Quantum Mechanics.

c) Quantum field theory (QFT)

In theoretical physics, quantum field theory (QFT) is a theoretical framework for constructing quantum mechanical models of subatomic particles in the physics of particles and quasiparticles in the more general realm of condensed matter physics. QFT treats particles as excited states of an underlying physical field, so these are called in the semantic context, field quanta.

How this construct is accomodated with all involved formal rules is in general *a posteriori* check. In principle the Lagrangian of the quantum system may depend on everything, but after having worked out the equations of motion you can realise that some constraints and dependences must be taken out to ensure the uniquiness of the solutions as well as the Cauchy problem[1] to make sense and so on. That the Lagrangian only depends on the value of the fields in one point, well, this just follows from the fact that it is a function of the fields, which in turns are maps from one point of the space-time onto the bundles. Moreover, the Lagrangian only depends on a finite number of derivatives because it is needed that the equations of motions to be a finite order differential equation which can be solved specifying a finite number of initial conditions. This requirement would not be fulfilled if there are allowed infinite order of derivatives related to the fields in dependency on the least action principle.

d) Causality and Locality

As itemized John Bell (1964), a paradox is hunting in Quantum Mechanics. It is known under the acronym EPR, which embodies the first letters of the proponents: Einstein, Podolsky and Rosen. This paradox is the reflection of the argument that that Quantum Mechanics, in many circumstances, behaves like as a non-complete theory, if it is not supplemented with additional variables to act as agents to take into account causality and locality.

Causality means that if something happens before in one reference frame of your choice, then it will happen before in any other existing reference frame in the whole universe.

Locality means that if two events are space-like separated then it exists at least one reference frame where they happen at the same time; if two events are time-like separated, then it exists at least a reference frame where they happen at the same point.

In order to preserve causality, to be preserved we have survey that the physical measurements and observables are of time-dependent types, which in QFT translates in turn into the statement that observables must commute if space-like separated.

General References

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1 A Cauchy problem in mathematics refers to a solution of a partial differential equation that satisfies certain conditions that are given on a hypersurface in the domain. A Cauchy problem can be an initial value problem or a boundary value problem (for this case see also Cauchy boundary condition), but it can be none of them.

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(It will continue in the issue 2/2018 of the magazine.)

Calendar of international and national events

2018			
March 20 - 22	Nordic Welding Expo	Tampere, Finland	https://www.nordicweldingexpo.fi/en/
April 10 - 12	Welding - Fair of Welding Technology and Equipment	Kielce, Poland	http://www.targikielce.pl/en/
April 10 - 13	Exhibition Welding and Cutting	Minsk, Belarus	http://www.minskexpo.com/
April 15 - 18	International Brazing and Soldering Conference (IBSC) 2018	New Orleans, Louisiana, USA	https://www.aws.org/events/detail/ibsc-2018
Aprilie 26 - 27	The conference "WELDING 2018"	Timisoara, Romania	http://www.asr.ro/index.php/news
June 11 - 13	International conference "Titanium 2018: Production and application in Ukraine"	Kiev, Ukraine	http://pwi-scientists.com/eng/titan2018
June 11 - 15	12th European conference on Non-Destructive Testing	Gothenburg, Sweden	http://www.ecndt2018.com
August 23 - 24	Nordic Welding Conference	Reykjavík, Iceland	http://nwc2018.is/
August 29 - 31	The 4th IIW young professionals international conference YPIC2018	Yutz, France	https://www.ypic2018.com; www.weezevent.com/ypic2018
October 10 - 12	The 4th IIW South-East Europe International Congress	Belgrade, Serbia	http://seeiiw2018.duzs.org.rs/