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Prospects on Clouds of Quantum Machines

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Abstract: This theoretical work continues previous studies in Service-Oriented Architectures (SOA) on clouds of quantum computers, considering quantum entanglement and quantum teleportation of states of services as resources to deploy high production in IT environments and to guide studies on the implementation of intelligent behavior in server clouds. A way to preserve quantum entanglement is presented. Also, it proposes a metalanguage to organize the topology of orchestration of services. This topology is embedded in the states of services and takes part in the information to be teleported from server to server. The creation of entangled states of information with the aid of the concept of progenitor is reviewed with some details.

Key words: Cloud computing, quantum teleportation, quantum entanglement, tapestry, progenitor, SOA

Resumo: Esse trabalho teórico dá continuidade a estudos anteriores sobre Arquiteturas Orientadas a Serviço (SOA) em nuvens de computadores quânticos, considerando o emaranhamento quântico e o teletransporte quântico de estados de serviços como recursos para instaurar alta produtividade em ambientes de TI e fundamentar estudos sobre a implementação de comportamentos inteligentes em nuvens de servidores. Uma maneira de preservar o entrelaçamento quântico é apresentada. Além disso, propõe-se uma metalinguagem para organizar a topologia de orquestração dos serviços. Essa topologia é incorporada nos estados de serviços e participa das informações a serem teletransportadas de servidor para servidor. A criação de estados de informação entrelaçados com a ajuda do conceito de progenitor é revisada com alguns detalhes.

Palavras-chave: Computação em nuvem, teletransporte quântico, emaranhamento quântico, tapeçaria, progenitor, SOA

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1. Prologue

Some years ago, reflecting on the mysteries of quantum entanglement, I came to a couple of propositions as to the nature of this phenomenon: the first is philosophical, that is, it is a representation (I call it "quantum-imagineering"[1]) based on the refinement of ideas and images drawn from common facts; the second is a mathematical translation, or rather, it is meant to be an abstract transcription that can someway support what the first proposition stated. The essence of this work rests on an approach to quantum computation in which I raise some questions about the customary primacy attributed to unitary transformations. Also, the work started from an unconventional point of view about abstract spaces, in addition to introducing the concept of "progenitor" as a Kronecker operator to obtain two entangled qubits. Unfortunately, the last version of the article was published with some printing flaws that were not corrected by the publishers, so that I was forced to republish it, taking the opportunity to add these comments.

As quantum computers rely on qubits, and qubits are just quantum objects like subatomic particles or super-conducting electrons, it would be a very anthropic theory to suppose that such objects were limited to living in our narrow world. The common distance between two entangled particles is nothing more than a substructure of perception that forces us to think that all interaction must occur in ordinary spacetime. Entangled particles live on an imaginary quantumfold from which we may obtain an imaginary representation of entangled states. Unsurprisingly, this quantumfold is not constituted by parts, since parts are pieces of common space. Thus, to managing qubits one must first to understand this fact because the disruption of entanglement (called decoherence) is a fact that, for all practical purposes, occurs in common world (as a rule caused by macro-perturbations like noise and environmental vibrations) and entanglement is a fact that occurs in quantum world. This leads to huge scientific challenges!

One of these challenges comes from the process of measuring qubits, since such process, in a controlled environment colder than deep space (near absolute zero), forces them to collapse into common binary states, which makes it necessary to repeat a calculation routine several times to check the result. So, in a realistic view for a near future, facing the great physical and technological barriers, quantum computers shall work in cooperation with classical computers in combined devices, even though von Neumann's architecture of classic computers shows enough to handle the more trivial operations such as surfing the internet and editing spreadsheets. It is artificial intelligence that will enjoy the greatest benefits supposedly attributed to quantum computing; while quantum processors have to operate at near absolute zero, classical computers shall interface with them to carry out semantic tasks and send signals to the processors.

There is every reason to believe that we should operate with merged clouds of quantum and classical computers. Cloud computing has been one of the main technical achievements to galvanize service-oriented architectures (SOA). It summarizes the idea of a computing environment based on a massive network of virtual and physical servers. Hosting thousands of quantum servers, we shall establish a probabilistic approach of the physical state of each sever as well as its state of information. As in quantum mechanics, where the physical position of a particle is random-dispersed until the intervention of an observer, the information is "nowhere", and, at the same time, "everywhere" until an objective request is done. This probabilistic approach of the cyber states of the cloud and their components is consistent with a vector representation in Hilbert space, just as the latter is used in quantum mechanics. But, what about clouds of quantum machines? How can we expect to develop intelligent networks of servers working under quantum principles? How to preserve quantum entanglement, which is the main pillar of quantum teleportation? How far is a pragmatic quantum machine from our state of art in informatics? How to describe processes that occur through non-causal tracks and what trigger such a connection between two objects far from one-another? These are some of the questions tackled in present article.

[1] In fact, the term was inspired in a terminology applied by my friend and colleague Richard Cathcart referring to macro-engineering projects.

Strictly speaking, computation has evolved in terms of processing speed, storage capacity, and size reduction. But it's no longer about doing faster, it's about doing what cannot yet be done because of limitations of logic design and physical framework according to von Neumann's model. We still think within the standards of Intel's first 4-bits processor, the 4004 of 1971, only with more bits and much smaller devices. Indeed, we are waiting for a real computational revolution.

In conclusion, quantum computing is still in its infancy. I believe that some of the authors I have briefly interacted maintain a superficial view of quantum mechanics in the sense of merely repeating the theory that has long been known, disregarding the fact that we need to go further, if we want to move faster. All of us who work in this area want to know the extent to which a quantum computer for daily use will be feasible, how far its performance will bring real gains for the progress of mankind, and at what time, if this computer is really realistic, it shall surely change the world. Even though I consider myself an optimist, I think it's still a distant time.

2. Introduction

This work is a continuation of studies started at 2014. Since then, I improved some ideas about theoretical quantum machines interacting in cloud operation, as well as enhancements on the concept of quantum entanglement itself. Some recent works have been added to the original references, although the classic treatises remain in effect, given the slowness with which the subject progresses.

As we know, one of the great challenges in quantum computing is how to preserve quantum entanglement, since microphysical systems are extremely sensitive to external disturbances. It is one of my aims to show a way to minimize this problem. Moreover, a quantum orchestration metalanguage is introduced into a first schematic representation of the operation of a quantum cloud aiming to optimize further constructions of quantum algorithms. While it is essential that the reader becomes familiar with quantum mechanics, some parts of my first work are reproduced here in order to reduce the effort to understand the subject.

Background: Services and Clouds in a Contemporary Approach

Services are cybernetic replicas of human practices, being evoked by well-established environmental motivations. In turn, SOA is an architecture that integrates in a standard manner several service units, each of them sending their features as sets of tasks over the network. Only service interfaces are exposed to consumers as exported methods (Nakamura et al., 2004). Therefore, when services are requested, SOA seeks the best responses to those environmental motivations according to the internal logic of each service. In particular, this architecture is now strongly linked to the theme of "enterprise application integration" (EAI) in contexts where legacy applications already established are performed on different platforms.

The literature on SOA comprises several milestone contributions as the works of Nakamura et al. (2004), Erl (2005), Anderson & Ciruli (2006), Natis (2007), Sha (2007) and, markedly, Frenken et al. (2008) about device-level service deployment. On this latter subject, it is noteworthy that, in the process of architectural development, devices which access legacy applications are created and interact using a protocol defined by the system. In turn, the system returns the aggregated information from the various legacy applications, preferably without any additional code. The architectural development also takes care of the service interface, prescribing the information required to access the competences of that. It is worth remembering that the existence of interfaces and descriptions of accessibility is sine qua non for the implementation of SOA. More recent works show the state-of-art in services orchestration (MEF Forum, 2015; Lemos et al., 2015).

In SOA projects, the so-called Enterprise Service Bus (ESB) is thought to be the main component of the infrastructure layer. It is the mediator between provider and service consumers, and its responsibility is to provide integration and interoperability between different systems. Embedded in this responsibility is also the mission of cleaning the databases by a service that tracks and recognizes all of the systems which shall be linked. Connectors are created in the databases feeding a new datawarehouse [2] completely normalized, such that any updates made on the original basis are automatically computed and reflected in the standardized repository.

As a logical consequence of the advent of the Internet and the concept of SOA, we can say that cloud computing is a cybernetic implementation by which all IT resources (hardware, software, networking, storage, etc.) are provided as services on-demand to consumers via Internet, remaining managed to ensure fast delivery, high availability, security and quality. In short, cloud computing is a model of computation by which those IT resources are randomly dispersed in the network, being offered as services paid as they are consumed. Although this subject promotes a lot of controversy about information security, everything suggests that the process of agglomeration of servers in clouds is irreversible.

Cloud computing and SOA have contributed significantly with one another and should remain so for a long time. In the words of David Linthicum, "SOA can be used as a key technology-enabling approach to leverage cloud computing" (Linthicum, 2009). Thus, the use of SOA can be galvanized by the cloud structure, since it allows on-demand delivery beyond the limitations imposed by the firewall constraints of the enterprise environment. A cloud computing system, whether formed by quantum machines and evolving to the point of hosting thousands or millions of servers, leads to a probabilistic approach of the states of each component as well as the states of information. As in quantum mechanics, where the physical position of a particle is random-dispersed until the intervention of an observer, the information is "nowhere", and, at the same time, "everywhere" until an objective request is done. This probabilistic approach of the cyber states of the cloud and their components is consistent with a vector representation in Hilbert space, just as the latter is used in quantum mechanics. With respect to the theoretical foundations and not on the scale of physical phenomena, the above conceptual and formal analogy improves the ways to understand the behavior of a "quantum cloud", and, reversely, our understanding of quantum physics and its paradigmatic importance to modern informatics, a fact that certainly contributes to future advances in the field of cybernetics. In the next sections I will explain the representative basis to build quantum clouds, discussing the main outcomes expected from such a technology.

Probability and Symmetry in Quantum Mechanics

The concept of physical probability was really born with the adventure of quantum mechanics, even though in the core of this discipline it has been treated systematically as the expression of the inexact knowledge.

The focal point was to interpret the so-called wave function ψ — the amplitude of the wave itself — and Max Born was the prime to achieve it. As we know, ψ is solution of the famous wave equation for one particle with mass m, due to Schrödinger

$$-\frac{\hbar^2}{2m}\nabla^2\psi + V\psi = i\hbar\frac{\partial\psi}{\partial t}, \qquad (1)$$

where V is the potential and $\hbar$ is the Planck constant divided by 2π. The functions ψ are in general complex. The connection of such quantities to the "real" world (or, which came to be the same, the acquirement of quantities called "observables") is represented by means of operations such as $\psi_i^*\psi_i$, where ψ_i^* is the complex conjugate of ψ_i. It prays a fundamental postulate of quantum mechanics that $\left|\psi(r,t)\right|^2 = \psi.\psi$ is the density of the probability $P(r,t)$ for a particle of mass m to be found at the point r, on time t. Therefore, the likelihood to locate the particle inside an infinitesimal volume of space τ on that time t is

$$\left|\psi(r,t)\right|^2 d\tau. \qquad (2)$$

Only in the case of one particle, the configuration space of the function ψ is isomorphic to the tridimensional space of positions. For two particles, for example, the wave function of the system

[2] After Business Object and Big Data technologies, no one really talks about the old concept of datawarehouse.

($\psi(r_1, r_2)$) is defined in a configuration space of six dimensions.

Since the summation of the probabilities referring to events that are mutually exclusive is 1, it follows

$$\int P(r,t)d\tau = \int |\psi(r,t)|^2 d\tau = 1. \tag{3}$$

Once ψ is not an observable quantity, there is a certain freedom of choice of its form. Besides, the solutions of linear equations, like Schrödinger's equation, may be multiplied by complex numbers, remaining solutions, so that expression (3) turns possible to choose a correct amplitude factor. The point of view of the physical interpretation sustains that the probability $P(r,t)$ is in fact the reflection of an objective property of the "particle", which is that the possible eigenvalues coexist as propentions in a reference class until a macroscopic intervention (a measurement) takes place. Such intervention changes drastically the original reference class. Let us take a system with states $|\psi\rangle$ and $|\psi'\rangle$ respectively before and after the experimental intervention. It's clear that the function ψ is somewhat conjectural here, but, for all theoretical purposes, is ever possible to think this function as a set of states reducible to a unique state (the reduction of the "wave packet"). We must consider the set $|\psi\rangle$ while not specified any function ψ by the apparatus of measurement, in such manner that we have two distinct instances of the reality, one before and other after the observation.

Quantum measurements are represented by a collection { $\hat{\mathcal{O}}_{ќ}$ } of operators that act upon the phase space of the system under observation. The subindex ќ labels the possible results of measurement. Let us suppose that the system is in the initial state Ψ. The probability for a certain state ќ after the measurement is,

$$P(ќ) = \langle \Psi | \hat{\mathcal{O}}_{ќ}^{\dagger} \hat{\mathcal{O}}_{ќ} | \Psi \rangle, \tag{4}$$

where $\hat{\mathcal{O}}_{ќ}^{\dagger}$ is the conjugate transposed of $\hat{\mathcal{O}}_{ќ}$,

$$\langle \Psi | \Psi \rangle = 1$$

and

$$\hat{\mathcal{O}}_{ќ}^{\dagger} \hat{\mathcal{O}}_{ќ} = 1.$$

This is what mathematically signifies to be a normalized state in quantum mechanics. Now, let $|\epsilon_1\rangle, |\epsilon_2\rangle, |\epsilon_3\rangle, ..., |\epsilon_q\rangle$ be an orthonormal base. Thus,

$$\hat{\mathcal{O}}_{ќ} = |\epsilon_{ќ}\rangle\langle\epsilon_{ќ}| \tag{5}$$

is a quantum measurement. The intervention of the apparatus modifies the state of the system to

$$\frac{\hat{\mathcal{O}}_{ќ}|\Psi\rangle}{\left(\langle\Psi|\hat{\mathcal{O}}_{ќ}^{\dagger}\hat{\mathcal{O}}_{ќ}|\Psi\rangle\right)^{1/2}} = |\Psi'\rangle; \tag{6}$$

$$\frac{|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle}{\left(\langle\Psi|\hat{\mathcal{O}}_{ќ}^{\dagger}\hat{\mathcal{O}}_{ќ}|\Psi\rangle\right)^{1/2}} = |\Psi'\rangle; \tag{7}$$

$$\frac{|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle}{\left(\langle\Psi|\langle\epsilon_{ќ}|\epsilon_{ќ}\rangle|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle\right)^{1/2}} = |\Psi'\rangle; \tag{8}$$

$$\frac{|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle}{\left(\langle\Psi|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle\right)^{1/2}} = |\Psi'\rangle; \tag{9}$$

$$\frac{|\epsilon_{ќ}\rangle\langle\epsilon_{ќ}|\Psi\rangle}{|\langle\epsilon_{ќ}|\Psi\rangle|} = |\Psi'\rangle. \tag{10}$$

The Vectorial Backbone of Quantum Mechanics

The vector space of quantum mechanics is a Hilbert space, that is, an orthonormal vector space in which

1- The vector components are complex scalars;
2- The scalar product satisfies $\langle\psi|\psi\rangle > 0$ for $|\psi\rangle \neq 0$, otherwise $\langle\psi|\psi\rangle = 0$;
3- If a and b are complex scalars, them

$$\langle\chi|a\psi_1 + b\psi_2\rangle = a\langle\chi|\psi_1\rangle + b\langle\chi|\psi_2\rangle;$$

4- The space is complete in the norm

$$\|\psi\| = \sqrt{\langle\psi|\psi\rangle}.$$

Finally, the implementation of symmetries in generalized quantum mechanical coordinates [3] may be represented by a unitary operator in the Hilbert space, so that,

$$\mathcal{U}^{\dagger}\mathcal{U}=1,\ \left[H,\mathcal{U}\right]=0;$$

for the groundstate of the Hamiltonian

$$H=-\frac{\hbar^2}{2m}\nabla^2+V,$$

$$\mathcal{U}\left|\psi_0\right\rangle=\left|\psi_0\right\rangle;\ \text{(this is not so obvious!)}$$

$$H\left|\psi_0\right\rangle=E_0\left|\psi_0\right\rangle;$$

$$\mathcal{U}H\left|\psi_0\right\rangle=E_0\left(\mathcal{U}\left|\psi_0\right\rangle\right).$$

In fact, accordingly von Neumann theorem, a coordinate transformation that corresponds to a symmetry of the Hamiltonian let invariant the canonical commutation relations of the system and (here is the power of the theorem) may always be implemented by an unitary manner in the Hilbert space of the states. So,

$$\hat{q}_i'=\mathcal{U}\left(S\right)\hat{q}_i\,\mathcal{U}^{\dagger}\left(S\right)=\ S_{ij}\hat{q}_j;$$

$$\mathcal{U}\left(S\right)=e^{i\omega\hat{O}},$$

where $\hat{O}$ is an operator that defines a motion constant (thereby furnishing good quantum numbers for the states of the system) so that $\hat{O}^{\dagger}=\hat{O}$, and ω is the set of parameters defining the matrix S.

Of course, as an effect of the macroscopic intervention, $\epsilon_{\acute{\kappa}}$ shows some classic traces inherited from the apparatus. But quantum mechanics says nothing about de world out of the experiment. Also, it is important to clarify that it is not always possible to carry out a complete and decisive experiment in this area. For instance, with respect to gravity, an approach by quantum field theory would need 1) an understandable model of gravitation accordingly some quantization algorithm applied to general relativity, which seems little bearing, and 2) an experimental frame able to reproduce the physical conditions under which the hypothetical quantum nature of gravity may come about, such as in a black hole singularity. In fact, one reason to brush aside an experimental program in this way is the difficulty of formulating quantum theory in a cosmological context in which the observers must be part of the system. Although it appears out of the blue, we may suppose there is a real messenger of gravity and imagine a "metaframe" to render gravitation in a familiar figurative language with no a priori concerns whether the messenger and its supersymmetric partner follow Bose or Fermi statistics beneath lab apparatus. This was my proposal: a supersymmetric meta-field theory on gravity (Serpa, 2015). So, I define meta-field theory as a theory that introduces a supersymmetric metaframe to describe fields as sets of particular transformations between two types of entities, the supersymmetric partners in focus.

As in the supersymmetric meta-field theory, it is possible to build a similar metaframe to describe cloud computing in its continuous process of increasing complexity. I will try, so much as possible, to refine the presentation of the formalism in order to avoid time lost with unclear notations and conventions.

The Quantum Bit

The quantum bit, or qubit, is the quantum tile of information and differs from the classical bit by the fact that it is generally given in a superposition of two basic states, e. g., $\left|0\right\rangle$ and $\left|1\right\rangle$, so that the Dirac ket of the time-dependent state-function of a qubit is denoted by

$$\left|\Psi(t)\right\rangle=c_0(t)\left|0\right\rangle+c_1(t)\left|1\right\rangle,$$

[3] A symmetry in quantum mechanics is a discrete transformation or a group of continuous transformations that let invariant the Hamiltonian (or the Lagrangian) and the canonical commutation relations of the system.

where $c_0(t)$ and $c_1(t)$ are complex time functions. The binary assigned to the basic states are associated with discrete values assumed by physical degrees of freedom of elementary particles, such as the spin. The qubit state fulfills equation (1) in such manner that the Hamiltonian operator takes the form

$$H(t) = h_{00}(t)|0\rangle\langle 0| + h_{01}(t)|0\rangle\langle 1| + h_{10}(t)|1\rangle\langle 0| + \\ + h_{11}(t)|1\rangle\langle 1|.$$

Sometimes it is useful to rewrite Schrödinger's equation in matrix formalism as

$$i\hbar\begin{pmatrix}\dot{c}_0(t)\\ \dot{c}_1(t)\end{pmatrix} = \begin{pmatrix}h_{00}(t) & h_{01}(t)\\ h_{10}(t) & h_{11}(t)\end{pmatrix}\begin{pmatrix}c_0(t)\\ c_1(t)\end{pmatrix}.$$

Lastly, normalization condition applies

$$|c_0|^2 + |c_1|^2 = 1.$$

4. Quantum Teleportation

Quantum teleportation is a very different conception of their science fiction counterparts. Since the nineties authors have studied the subject in theoretical and experimental approaches (Deutsch & Jozsa, 1992; Braunstein, 1996; Bouwmeester, 1997; Zhang et al., 2002; Bowen, 2003).

The concept of quantum teleportation and the so-called quantum entanglement form the basis of cloud computing as conceived here. The latter is one of the biggest sources of confusion in science, since quantum entanglement became a paradox in quantum theory because of its conflict with causality. Two quantum objects are said entangled if they are linked in such manner that their behaviors are bonded never minding how much distant they are from one another. I will try to explain the central idea in the cloud context with a maximum of formal consistence on the previous sections.

We start with two state functions to be entangled at server A, $|\Psi_\uparrow\rangle_A$ and $|\Psi_\downarrow\rangle_A$. The entanglement is given by the instruction 0 (I_0) of the experiment

$$I_0 : |\Psi_\uparrow\rangle_A \# |\Psi_\downarrow\rangle_A \Rightarrow |\Psi_{(\uparrow\downarrow)(\downarrow\uparrow)}\rangle_A.$$

(11)

The two state functions are now non-causally correlated. After the entanglement, we apply by instruction 1 (I_1) a classical procedure P_1 to carry the second entangled state function on server B, that is,

$$I_1 : P_1|\Psi_{(\uparrow\downarrow)(\downarrow\uparrow)}\rangle_A \overset{\circ}{=}> |\Psi_{(\uparrow\downarrow)(\downarrow\uparrow)}\rangle_A (-) |\Psi_{(\uparrow\downarrow)}\rangle_A \equiv \\ \equiv |\Psi_{(\downarrow\uparrow)}\rangle_B.$$

Now we perform a measurement $|M\rangle$ in server A on the combined state which we gain putting $|\Psi_{\uparrow(\downarrow)}\rangle_A$ in contact with the unknown state function $|\chi\rangle$. Having done this interaction, server A transmits to server B, through a classical channel reachable by procedure P_2, a complete description of the results of the quantum measurement on $|\chi\rangle|\Psi_{\uparrow(\downarrow)}\rangle_A$ in order to enable server B to perform certain linear transformation $|\delta\rangle$ on $|\Psi_{(\uparrow)\downarrow}\rangle_B$; in fact, the measurement described annihilates $|\chi\rangle$, but the linear transformation $|\delta\rangle$ rebuilds the latter at server B from $|\Psi_{(\uparrow)\downarrow}\rangle_B$, so that by instruction 2 (I_2)

$$I_2 : P_2|M\rangle|\chi\rangle|\Psi_{(\uparrow\downarrow)}\rangle \overset{\circ}{=}> |\delta\rangle|\Psi_{(\downarrow\uparrow)}\rangle_B \equiv |\chi\rangle.$$

This is what we call teleportation of the state from server *A* to server *B*. Quantum teleportation refers to the "blind" teleport of the state $|\chi\rangle$ of a quantum system about which there was no information. The measurement does not provide any information from the state function $|\chi\rangle$. All of the quantum state information is passed by the non-causal link between the entangled states

$$\left|\Psi_{(\uparrow\downarrow)}\right\rangle_A$$

and

$$\left|\Psi_{(\downarrow\uparrow)}\right\rangle_B$$

The main consequence of the process is the annihilation of the initial quantum state at server A rebuilt at server B. It must be understood that it is the quantum states which are destroyed and recreated in the teleportation process, and not material components. Thereby, cloning is an impossible operation in quantum physics; we simply can generate an almost-perfect replica of the original destroyed after teleportation. It is also important to remember that quantum information within a state function is available only as probabilities or, as we commonly say, expectation values.

Entanglement: The Pictures on the Pool

It was pointed that quantum processing was born from "purely philosophically motivated questions" (Walther, 2006) on non-locality and completeness of quantum mechanics fomented mainly by Einstein from his collaborative work with Podolsky and Rosen in 1935. In fact, as once observed, it was Einstein whom restored in modern science the Cartesian metaphysical sense of philosophy, turning physics into a real theory of knowledge (Charon, 1967). This important note remembers to us that philosophy will always be present in the process of creation. It is precisely its absence that determines little creativity that prevails today in all fields. Thus, to understand what entanglement is it will be necessary a reflective process of reconstruction of the conceptual foundations of physics, which will lead to a comprehensive review of the applicability of the notion of causality.

The main controversies of quantum mechanics ever resided in the difficulty of the human mind to separate the physical fact from its perception or representation. Indeed we always work with our perceptions; we took from them the full potential of human development and survival offered, creating representations for all we observe. There was a time when I was a follower of a kind of fruitless and paralyzing materialism that insisted to reify the world. Later, influenced by some physicists adepts of the operationalism, I came also to sympathize with the dresser and foolish idea that the only thing that matters is the calculation and not the ultimate nature of things. Thanks to my growing interest in quantum computing, I could deepen those controversial discussions and reach my own conclusions about them. Of course, long before the seventies there were eloquent speeches from the great thinkers of modern physics. Weizsäcker, for instance, in the Spanish version of 1974: "*El átomo no es inmediatamente perceptible para nuestros sentidos, y cualquier experimento lleva sólo una determinada propiedad del átomo al ámbito de una perceptibilidad mediata*"[4] (Weizsäcker, 1974). But that was still little; not just to observe a predicate and describe it by means of classical concepts. It was necessary a phenomenal texture made by the experimental apparatus from which one could then extract useful measurements (information). In this it would lie a deepening of the famous complementarity of Bohr: the ultimate hidden object and its accessible and inseparable image.

Inspired by those philosophical texts from the first half of the twentieth century and early second half, I could refine my ideas and reach an understanding which I consider acceptable, although limited by the nature of human thought. Now I believe that the understanding of the quantum entanglement, one of the most intriguing phenomena of the quantum world, rises, for happiness of the philosophers, in a reflection on the edge of a pool. One summer night, I sat in a chair right in front of a lighted lamp whose flickering

[4] The atom is not immediately perceptible to our senses, and any experiment takes only a specific property of the atom to the ambit of a mediated sensibility.

light was reflected in the pool. The image of the lamp stretched like a rubber with the ripples of the water and sometimes came to double or even to quintuple depending on the swings of the water. Both, the lamp and its images in water, are real, belonging to the world of mater and perceptions. But imagine that we could not see the lamp, only their images reflected in the water. We would think that two objects born of a unique (duplicate picture) would be irrevocably united, although separated; any change in one of them would "cause" an instantaneous change in the other. With respect to the quantum world is passing up something similar. We have no direct access to the ultimate reality (as the hidden lamp), only to the images produced by our experiments. What we see are the "pictures in the pool" and these are as real as the object that produced them. Clearly, these images carry information from the ultimate object, which makes them tractable to control. Instead of using the ultimate object we use them with all their informational potential. This potential is the base of the teleport process, since we teleport physical states, not matter in itself. In short, the quantum world is so light and sensible to our presence that it would be impossible to get direct benefits from their objects. All we can do is work with "pools". As Weizsäcker said: "*Todo experimento es un acto material que es simultáneamente un acto de percepción*"[5] (Weizsäcker, 1974).

⚜

As it is known, to overcome the number of errors generated in a quantum system — a number resulting from the sensitivity of the system to macroscopic impacts — is a great challenge. My idea of quantum mirroring allows one to understand how to read a state without destroying the system. An "image" is created, a copy of a qubit from three molecular spins of trichloroethylene, on which measurements are taken. Considering the pictures on the pool as the imagineering representation of entangled objects, an indirect reading could be done by means of the "mirror" that reflects this image. This is what middling does nuclear magnetic resonance.

[5] Every experiment is a material act which is simultaneously an act of perception.

To get a slight idea of quantum entanglement we consider the process of creation and destruction of a pair of quantum bits called "pair of Einstein, Podolsky and Rosen" (EPR pair). So, let us suppose a quantum bit in a zero-state,

$$|\Psi_1\rangle = 1|0\rangle + 0|1\rangle = |0\rangle.$$

Now, let us take the Hadamard matrix H_2

$$H_2 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

and

$$U_2 = \frac{1}{\sqrt{2}} H_2.$$

We make

$$|\Psi'_1\rangle = U_2 |\Psi_1\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} =$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle.$$

Also we take another quantum bit in zero-state

$$|\Psi_2\rangle = 1|0\rangle + 0|1\rangle = |0\rangle.$$

Performing a tensor product between $|\Psi'_1\rangle$ and Ψ_2 we gain

$$|\Psi'_1\rangle \otimes |\Psi_2\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \otimes \begin{pmatrix} 1 \\ 0 \end{pmatrix} =$$

$$\frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}}|00\rangle + 0|01\rangle + \frac{1}{\sqrt{2}}|10\rangle + 0|11\rangle.$$

It is convenient to define certain unitary transformation, called “control NOT-gate” (*CNot*). Using Pauli matrices

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$$

we may write

$$CNot = \frac{1+\sigma_z}{2} \otimes 1 + \frac{1-\sigma_z}{2} \otimes \sigma_x =$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix},$$

so that

$$CNot\left|\Psi_1^{'}\Psi_2\right\rangle = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix} =$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\left|00\right\rangle + \frac{1}{\sqrt{2}}\left|11\right\rangle. \quad (12)$$

The point is that for entangled states, as expressed in the above result, decomposition does not hold, that is,

$$\left\{ \nexists(\varphi_1,\varphi_2) / \varphi_1 \otimes \varphi_2 = \frac{1}{\sqrt{2}}\left|00\right\rangle + \frac{1}{\sqrt{2}}\left|11\right\rangle \right\}.$$

The very strangeness of entanglement may be explained taking two distinct moments of experimental intervention. Just prior the *CNot* transformation we perform a measurement to obtain the probability of $\left|0\right\rangle$. The measurement operator is

$$M_0 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

Before the *CNot* transformation the system is in state

$$\left|\Psi_1^{'}\Psi_2\right\rangle = \frac{1}{\sqrt{2}}\left|00\right\rangle + 0\left|01\right\rangle + \frac{1}{\sqrt{2}}\left|10\right\rangle + 0\left|11\right\rangle.$$

Therefore,

$$p(0) = \left\langle \Psi_1^{'}\Psi_2 \right| M_0^{\dagger} M_0 \left| \Psi_1^{'}\Psi_2 \right\rangle =$$

$$= \left\langle \Psi_1^{'}\Psi_2 \right| M_0 \left| \Psi_1^{'}\Psi_2 \right\rangle =$$

$$= \frac{1}{\sqrt{2}}(1,0,1,0) \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \end{pmatrix} =$$

$$= \left(\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}}, 0 \right) \begin{pmatrix} \frac{1}{\sqrt{2}} \\ 0 \\ \frac{1}{\sqrt{2}} \\ 0 \end{pmatrix} = 1.$$

After measurement we get for the state of the system

$$\frac{M_0\left|\Psi_1^{'}\Psi_2\right\rangle}{\sqrt{\left\langle\Psi_1^{'}\Psi_2\right|M_0^{\dagger}M_0\left|\Psi_1^{'}\Psi_2\right\rangle}}=\frac{\begin{pmatrix}\frac{1}{\sqrt{2}}\\0\\\frac{1}{\sqrt{2}}\\0\end{pmatrix}}{1}=\left|\Psi_1^{'}\Psi_2\right\rangle. \tag{13}$$

We see that measurement had no influence on the first quantum bit that remains in a superposition of $\left|0\right\rangle$ and $\left|1\right\rangle$. This is not the case when we perform the same measurement just after the *CNot* application. Now we start from

$$\Psi_3=\frac{1}{\sqrt{2}}\left|00\right\rangle+\frac{1}{\sqrt{2}}\left|11\right\rangle.$$

Let us compute the probability of $\left|0\right\rangle$ by means of

$$p(0)=\left\langle\Psi_3\,|\,M_0^{\dagger}M_0\,|\,\Psi_3\right\rangle=\left\langle\Psi_3\,|\,M_0\,|\,\Psi_3\right\rangle=$$

$$=\frac{1}{\sqrt{2}}(1,0,0,1)\begin{pmatrix}1&0&0&0\\0&0&0&0\\0&0&1&0\\0&0&0&0\end{pmatrix}\frac{1}{\sqrt{2}}\begin{pmatrix}1\\0\\0\\0\end{pmatrix}=\frac{1}{2}.$$

Thereby, probability of $\left|0\right\rangle$ was changed to $1/2$. After measurement, the state vector of the system took the form

$$\frac{M_0\left|\Psi_3\right\rangle}{\sqrt{\left\langle\Psi_3\,|\,M_0^{\dagger}M_0\,|\,\Psi_3\right\rangle}}=\frac{1}{\sqrt{2}}\begin{pmatrix}1&0&0&0\\0&0&0&0\\0&0&1&0\\0&0&0&0\end{pmatrix}\times$$

$$\times\begin{pmatrix}\frac{1}{\sqrt{2}}\\0\\0\\\frac{1}{\sqrt{2}}\end{pmatrix}=\frac{1}{\sqrt{2}}\begin{pmatrix}\frac{1}{\sqrt{2}}\\0\\0\\0\end{pmatrix}=\begin{pmatrix}1\\0\\0\\0\end{pmatrix}=\left|00\right\rangle.$$

This is somewhat astonishing. Measuring one quantum bit we modify the probabilities of the other quantum bits of the system. However, as strange as the phenomenon is, the role of science is only to describe what happens, leaving aside ontological speculations about the "why" of the things being as they are.

5. Main Focus

Operators in quantum mechanics commonly provide representations of experimental interventions. But this does not mean that reality is determined by the observer. In fact, the experiment is just a physical intervention rationally controlled similar to the natural physical interventions occurring at random in the interactions between systems. Another important consideration to be made is about the clear representational role that mathematical constructs which serve to quantum mechanics must have, for example, the construct "quantum gate". According to McMahon (2008),

"*A gate can be thought of as an abstraction that represents information processing. [...] In a quantum computer, information is also processed using gates, but in this case the "gates" are unitary operations. Since quantum gates are just unitary operators, we'll often go back and forth between the words gate and operator --- so keep in mind they mean the same thing in this context*". (McMahon, 2008).

Then, we may say that quantum gates are connectors that allow us to building quantum circuits. They act upon quantum bits; thus, generalizing the concept, we may think of them as formal representations of particular circumstances imposed by the environment or the observer, never minding weather they are controlled or not. They are operators of certain type acting on quantum bits to do something, that is, to produce some specific quantum configuration.

Thinking About Non-Unitary Operations Embedded in Entangled States: Does It Make Sense?

In its current formal representation, quantum computation deals only with quantum gate operations which are necessarily unitary, a fact that turns difficult or even impossible to solve central problems such as decoherence and feasibility of measurements in the middle of the computation. From my theoretical background, the restriction to unitary gates and pure quantum states seems very arbitrary. Quantum gates can perfectly represent general quantum operations, not exclusively unitary, providing more flexibility and facility to building algorithms. Unitary operations can, at best, be elected to represent the evolution of a quantum system under observational control, but not necessarily to represent quantum systems free of human intervention. Many works were performed on quantum gates (Barenco et al., 1995; Raussendorf & Briegel, 2000; Wang et al., 2001), so that the reader can deepen his particular search as desired.

What I want to show is that, given two entangled quantum bits, it is not possible to know whether the entanglement arose from the interference of some non-unitary action on a given quantum bit in a pure initial state. This means that quantum bits separated by large distances may carry effects of primary out-of-measurement processes that originated them. So, could we embed quantum states with these non-unitary actions, that is, these out-of-measurement transformation rules? If so, how would be the protocol for that?

First of all, as already suggested, I assume that certain operators reflect environmental conditions that favor the creation of new qubits from a primary qubit. In my former works, I developed the math entity named "progenitor" as the Kronecker operator to obtain two entangled qubits. According to my considerations on Bohr's philosophical thinking, there must be an abstract quantum physical description of the natural process that leads to entangled qubits interacting through a quantum channel. I assume that if what connects two entangled qubits far from one another is a non-classical channel, that is, no transaction between entangled qubits occurs in common spacetime, so what triggered such a connection is an imaginary "operation". So, the transfer of information in a quantum system, based on the non-classic connection between qubits, is holding trough an imaginary "operation" like

$$\hat{G} := \frac{1}{\sqrt{2}}\begin{pmatrix} \imath\mathbf{i} & -\imath\mathbf{i} \\ 0 & -\imath\mathbf{i} \end{pmatrix}\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -\imath\mathbf{i} \\ 0 & -\imath\mathbf{i} \end{pmatrix},$$

where $\imath\mathbf{i} = \sqrt{-1}$, and

$$\begin{pmatrix} \imath\mathbf{i} & -\imath\mathbf{i} \\ 0 & -\imath\mathbf{i} \end{pmatrix}\begin{pmatrix} -\imath\mathbf{i} & \imath\mathbf{i} \\ 0 & \imath\mathbf{i} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

The object

$$\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -\imath\mathbf{i} \\ 0 & -\imath\mathbf{i} \end{pmatrix}$$

is the progenitor, that is, an operator which acting on a qubit by a Kronecker product on the left gives one two-qubit system in a certain configuration such that, under a control gate, it outputs a pair of entangled qubits. The Kronecker product protocol (KP) comes

$$\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & -\imath\mathbf{i} \\ 0 & -\imath\mathbf{i} \end{pmatrix} \otimes \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ 0 \\ -\imath\mathbf{i} \\ 0 \\ 0 \\ 0 \\ -\imath\mathbf{i} \\ 0 \end{pmatrix}. \quad (14)$$

Applying the correct imaginary gate, it follows

$$\begin{pmatrix} i0000000 \\ 0i000000 \\ 00i00000 \\ 000i0000 \\ 0000000i \\ 000000i0 \\ 00000i00 \\ 0000i000 \end{pmatrix} \times \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 0 \\ -i \\ 0 \\ 0 \\ 0 \\ -i \\ 0 \end{pmatrix} = \frac{-i}{\sqrt{2}} \begin{pmatrix} 0 \\ 0 \\ i \\ 0 \\ 0 \\ i \\ 0 \\ 0 \end{pmatrix} =$$

$$= \frac{1}{\sqrt{2}}|11\rangle + \frac{1}{\sqrt{2}}|00\rangle. \qquad (15)$$

The reader must remember that tensor product warrants the permanence of the superposition principle, i.e., there is a way to have a little of the $\widehat{G}-$ operator and a little of the original quantum state in the final state.

The advantage of this approach is the presumption of a genuine quantum channel through which imaginary transformations occur, even though we do not know the dynamic essence of the non-local phenomenon; so, the imaginary operations are the logical quantum channel paths (not physical paths in spacetime).

Preserving Quantum Entanglement

The question is not so much of mathematical theorems but appropriate representations for the physical phenomena examined here. Thus, all my effort was directed to set representations that can be implemented in quantum algorithms to solve or minimize decoherence problems.

The quantum world is very difficult to understand because of the lack of realistic correspondence with Euclidian world. But if we open our minds and enlarge common geometry to imagine the "geometry" of an object with no extension, we shall be very close to the language we need to describe quantum mechanical facts in quantum computing. For the sake of simplicity, we could call "point" any indivisible structure, not uniquely the point of geometry. Thus, two entangled particles would constitute a "point" in which refers their interactions. However, this point was called "tapestry" in my quantum language. It may sound strange to call "tapestry" an entity with no extension, but this is intentional. A tapestry is understood from the "onefold" coverage provided by unique progenitor tensor product on one qubit. This is like to define the element of a wool rug, the minimal knot that begins a complete Persian tapestry. Thereby, one simple knot is in fact a tapestry of one element[6]. A fundamental issue about entanglement is that, no matter how far apart two entangled particles are from one another, what happens to one brings instantaneous response from the other. I sustain that if we use the particle image of matter, it is impossible to conceive the phenomenon of quantum entanglement, since what affects the particle cannot propagate instantaneously to another particle. On the other hand, if we think about a continuous entity as a tapestry not made up by parts, then it is easy to see much more; to have no parts means to be indivisible in the space of configuration. In fact, two entangled particles constitute a physical monad as in the metaphysical Leibnizian sense. What is really missing is a rational form of expression suitable for such a phenomenon, both mathematically as literarily. We can well conceive the quantum monad as an imaginary tapestry of one element, cohesive, indivisible and intractable by common sense.

Our tapestry is an imaginary quantumfold, that is, a onefold that only exists in quantum descriptions of nature. From this quantumfold we may obtain an imaginary representation of entangled states by tensor operations applied on it. As the quantumfold is not geometrically thinkable because it is not composed by parts, it is covered, as I said, by unique progenitor tensor product to one qubit. To extract entangled states from this coverage, that is, to obtain real descriptions of states not separable from superposition principle, we logically need one imaginary gate, the only to transform (that is, to Wick-rotate) representations of imaginary objects into real ones. This gate builds

[6] The name may seem strange to a manifold with such a restriction; however, the idea of tapestry refers more to the image of numerous particles distant from each other only in conventional space.

a bridge between the two representations. So, let us take an important definition.

Definition 1 — a tapestry $\mathbb{T}$ is a map that carries a pair progenitor-cum-qubit $\left(\xi^{\dagger},\psi^{\pm}\right)$ on a column vector $\amalg$ with entries $(0,-\imath\mathbf{i})$ by a Kronecker product $\left\langle\langle...\rangle,\langle...\rangle\right\rangle$, so that

$$\mathbb{T}:\left\langle\xi^{\dagger}\right\rangle,\left\langle\psi^{\pm}\right\rangle\to\amalg_{(0,-\imath\mathbf{i})}.$$

This approaching is derived from Serpa's proposal on Wick-rotations (Serpa, 2015). In some sense, tapestry is the generalized geometrical locus of qubit transformations that lead to entanglements.

Definition 2 — a quantum channel is a manifold built by the connected sum of two or more tapestries such that the canonical representation of each tapestry is a word as

$$\Gamma_1\Gamma_2...\Gamma_g\Lambda_1\Lambda_2...\Lambda_h=1,$$

meaning that the tapestry has *genus* g and h holes.

Connected Tapestries over Servers in Cloud

But not everything is perfect, since the phenomenon of decoherence — the loss of entanglement by environmental interferences — haunts quantum computing labs and brings puzzles to theorists. The problem of decoherence tantalizes scientists since long ago. However, it was demonstrated that the existence of quasiparticle excitations named non-Abelian anions, neither classified as bosons nor fermions, is related to certain topological configurations that make immune to local decoherence the quantum information stored in such configurations (Sarma, et al., 2006). Also it was reported recently what would be the first experimental demonstration of a loss resilient entanglement-based protocol, probing that, in some circumstances, it's possible to preserve properties acquired by qubits at first in entangled states (Zhang, 2013). These findings encourage theoretical investigations, including progenitor's protocol. According to the last, when a pair of qubits is produced by progenitor's action on a qubit, the imaginary tensor "operation" is somewhat "memorable" inside the generated pair in tapestry. As we know, tensor product retains a little of the progenitor and a little of the original quantum state in the final state. To understand exactly where I want to go, let us consider the concept of measurement from the point of view of quantum mechanics.

Following von Neumann, we say that a consistent description of the measurement process in quantum physics must consider the interaction between the quantum system under observation and the quantum measurement apparatus (von Neumann, 1932). Thereby, a measurement is an intervention described by a unitary transformation that evolves the initial global state of the combined system. In this sense, the application of a certain controlled-gate builds a fact from what really happens. From the point of view of the model presented here, quantum entanglement precedes every physical measurement operation; two qubits are said entangled if they result of the transformation of a single qubit via progenitor, such that there must be at least one controlled-gate (a Wick-rotation matrix) capable of translating this entanglement as mathematically associated with an observable, albeit indirectly. The proposed protocol establishes the mathematical design of two entangled qubits from one qubit and one progenitor instead of two former qubits. Theoretically, from the notions of tapestry, imaginary quantum channel and progenitor, it is possible to reduce the loss of the amount of entanglement. Now we take the Kronecker protocol (14), from which we have the tapestry representation of entangled states

$$KP|10\rangle=0|01\rangle+0|01\rangle+0|11\rangle+0|11\rangle+$$
$$+0|00\rangle+0|10\rangle-\frac{\imath\mathbf{i}}{\sqrt{2}}|00\rangle-\frac{\imath\mathbf{i}}{\sqrt{2}}|10\rangle.$$

Relating the terms of last expression with the formalism of surface topology, we can imagine an algorithm that converts this representation into a string (or word) such that in server A we read

$$|\imath1\rangle_A=aaccbdef$$

with

$$a := 0|01\rangle; \qquad d := 0|10\rangle;$$

$$c := 0|11\rangle; \qquad e := -\imath\mathbf{i}/\sqrt{2}|00\rangle;$$

$$b := 0|00\rangle; \qquad f := -\imath\mathbf{i}/\sqrt{2}|10\rangle.$$

We can make $bdef \rightarrow b$, so that canonical representation gives

$$aaccb = 1,$$

which is a Klein bottle formed by two cross caps (aa, cc) and a hole (b) (see Figure 1).

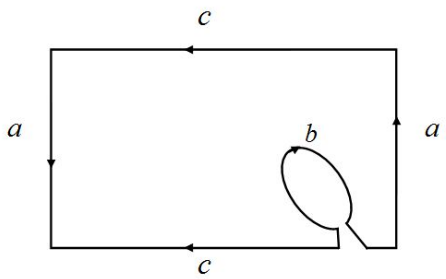

Figure 1. Topological planar model of $KP|10\rangle$.

Clearly, the topology shall depend on the initial number of entangled qubits. It is obvious that cyclic order is not important to identify the topology, but once determined this latter, the cyclic order operates as a part of the signature of the entanglement itself; we may fix the total additional information about the implicit manifold, including that signature, to be transmitted by a classical channel to server B into a complete topological information-state packet coupled to the qubit, so that we may ensure high efficiency and fidelity repairing entanglement. The number of possible anagrams (signatures) from a word in which there is repetition is given by

$$P_n^{(q_1, q_2, q_3 \ldots)} = \frac{n!}{q_1!.q_2!.q_3!\ldots},$$

where $q_1, q_2, q_3 \ldots$ are the numbers of times that repeated letters appear in the word. For the case of Klein bottle,

$$P_5^{(2,2)} = \frac{5!}{2!2!} = 30.$$

Thus, there are 30 possible signatures for the Klein bottle.

That information-state packet is the "memory" of entanglement and serves to preserve it from external perturbations. The connected sum (entanglement) $|i\mathrm{I}\rangle_A \# |i\mathrm{I}\rangle_B$ represents the physical connection — the quantum channel — between the qubits and is written as

$$|i\mathrm{I}\rangle_{A\#B} = a_1a_1c_1c_1b_1a_2a_2c_2c_2b_2.$$

Then, entanglement is a quantum phenomenon in which, through the quantum channel, the two tapestries in servers A and B are connected as the two *tori* in Figure 2. All we have to do is to transmit the topological information-state associated to the Kronecker protocol from server A to server B. If noise removes entanglement between two qubits, the reapplication of the control imaginary gate (the reconstruction of the quantum channel between the qubits) in server B through a quantum circuit will restore, in thesis, the entanglement from that memorized information shared by the two qubits.

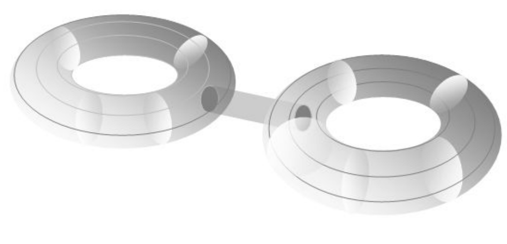

Figure 2. Connected sum of two tori:

$a_1b_1a_1^{-}b_1^{-}a_2b_2a_2^{-}b_2^{-}$.

Orchestral Metalanguage

To think about quantum cloud computing is a natural consequence when we investigate the potential of quantum machines. From here, it rises a plethora of interesting subjects, including security and privacy of computation by blind quantum computing based on the transmission of individual photonic qubits (Barz et al., 2012). Thus, it is a great challenge to understand the complexity of services to be orchestrated in quantum clouds.

The task of identifying and matching services is far from obvious. Potential applications of quantum mechanics in everyday life always bump into a linguistic modeling problem, a fact which greatly complicates the accurate understanding of what we want to do and what we can really do. For this reason, the structuring of an orchestral metalanguage is decisive for the correct construction of the topology of services, evidencing scalability and giving descriptive accuracy and, in the same breath, great facility of implementation of changes. In addition, as well observed by Metodi and Chong, a quantum computer of practical value must be up to storing and orchestrating a system comprising tens of millions qubits (Metodi & Chong, 2006). Therefore, that orchestral metalanguage would be an interesting tool to represent such complex dynamics.

With respect to the above introduced metalanguage and to make it clearer, it is important to consider the idea of orchestration as referring not only to the service composition, but also to the topology that determines the order in which the services occur in a given process. We begin by defining a functional f as a unique service for state analysis. It informs a given composite service S about the best orchestration of elementary services to be performed depending on demand and the current state of the environment or on a collection of orchestrations identified on the same basic services to be initialized in parallel, depending on the overhead consumption. There are two ways of doing work one functional on a composite service as we shall see.

The lexicon of the metalanguage, that is, its main catalogue of elementary connectors and words, is given by what we call a primitive base as follows:

Table 1- *Primitive Base*

S	Composite service
s	Elementary service
f	Functional
$\curlyvee$	Combined with (to compose services)
$\succ$	Call forward
$\prec$	Call backward
$\prec\!\succ$	Parallel running
$\curlywedge$	Defined as
$\langle f \vert$	Right functional
$\vert f \rangle$	Left functional
O^1	Orchestration in one dimension

Now we look at the grammar of the metalanguage, that is, the rules to combine connectors and words in such manner that we may build meaningful statements (axioms, definitions, sentences, etc.):

Definition 1 — it is called weak coupling the orchestration O^1 of elementary services s_i to which there is mutual communication among the orchestration component services.

Axiom 1 — for any set of elementary services s_i there is at least one weak coupling O^1 on s_i, such that O^1 on s_i is an application of the topology T^1 on s_i equivalent to the composite service S^1 :

$$\left\{ \forall \{s_i\} \exists O^1_{\{s_i\}} / O^1_{\{s_i\}} : T^1 \{s_i\} \Leftrightarrow S^1 \right\}.$$

Definition 2 — it is called agglomerate the meeting O^k of k weak couplings on the same basic services, being k = 1, 2, 3... n the size of the agglomerate and $O^k \Leftrightarrow S^k$.

Axiom 2 — for every set of basic services s_i, there is at least one agglomerate O^k on s_i, such that O^k on s_i is an application of the topology T^k on s_i equivalent to the composite service S^k :

$$\left\{\forall \{s_i\} \exists O^k_{\{s_i\}} / O^k_{\{s_i\}} : T^k \{s_i\} \Leftrightarrow S^k\right\}.$$

Definition 3 — it is called "left" functional action the initialization of the weak coupling O^1 which has the best performance among all identified weak couplings on the same basic services.

Definition 4 — it is called "right" functional action the initialization of the agglomerate O^k.

Corollary — all weak coupling O^1 is an agglomerate of dimension $k = 1$.

It must be understood that both lexicon and grammar can be enlarged as the representational complexity advances. For instance, let us take an example of a functional action at "left" and at "right",

$$|f\rangle S^1 \curlywedge \langle s_1 \succ \langle s_2 \curlyvee s_3 \rangle \succ \langle s_4 \curlyvee s_5 \curlyvee s_6 \rangle\rangle;$$

$$S^4 \langle f | \curlywedge \begin{Vmatrix} \langle s_1 \succ \langle s_2 \curlyvee s_3 \rangle \succ \langle s_4 \curlyvee s_5 \curlyvee s_6 \rangle\rangle \\ \langle s_1 \succ \langle s_2 \curlyvee s_3 \rangle \succ \langle\langle s_4 \curlyvee s_5 \rangle \succ s_6 \rangle\rangle \\ \langle s_1 \succ \langle s_2 \curlyvee s_3 \rangle \prec\succ \langle s_4 \curlyvee s_5 \curlyvee s_6 \rangle\rangle \\ \langle s_1 \succ \langle s_2 \curlyvee s_3 \rangle \succ \langle s_4 \succ \langle s_5 \curlyvee s_6 \rangle\rangle\rangle \end{Vmatrix},$$

$$S^4 \langle f | \curlywedge \begin{Vmatrix} O^1 \\ O^2 \\ O^3 \\ O^4 \end{Vmatrix}. \tag{16}$$

Expression (16) is called parallelism matrix and its dimension k depends primarily on the number of elementary services and the number of available qubits. It is understood that service combinations, expressed between kets, must precede external calls. Large service chains with related functions can be represented in this way, documenting all the required topologies. Considering two servers, A and B, and taking the last column-matrix, quantum teleportation of this four-dimensional agglomerate from server A to server B, by the instruction 2 from equation (6), would be given by

$$I_2 : P_2 |M\rangle \left|O^1 O^2 O^3 O^4\right\rangle \left|\Psi_{(\uparrow\downarrow)}\right\rangle_A \overset{\circ}{=}>$$
$$\Rightarrow |\delta\rangle \left|\Psi_{(\downarrow\uparrow)}\right\rangle_B \equiv \left|O^1 O^2 O^3 O^4\right\rangle.$$

Operating under metacomputation, B will perform the same task as server A could do, however, with no needs to repeat the process of topological analysis done by A. In server B, all topological possibilities can be used simultaneously to perform parts of a computation (service).

Figure 3 (in appendix) outlines the SOA overlay intermediating clients and quantum machines in a certain hypothetical production environment. Servers A, B and C are supercomputers originally sharing the same quantum channel. At the right of the ESB a client requests certain complex service. By means of a protocol translation hardware (*PT*) located at the left of the ESB, a query is addressed to the quantum machines B and C to know whether the requested service is already available. If the answer is negative, the request is forwarded to the quantum analyzer A. Until now, all we have done took place by means of classic channels. From now on, having defined the best orchestration, the quantum analyzer teleports the state matrix to both servers B and C; the probabilistic parallel processing begins in B and C at the same time that state matrix is destroyed at A. This diagram was inspired in a more general scheme called one-to-many teleportation. Due to entanglement, probabilities in B and C interfere with one another. The requested service results from the instantaneous "collapse" (see Figure 4 in appendix) of the copies of the state matrix into new states at *PT* (mathematically, this is a change of probabilistic reference class). Finally, service is really available for the client through ESB. While in machines B and C the service stays divided in probabilities, only manifesting as an effective product in daily world after protocol translation. With continuous reductions, that is, with unbroken chain of very fast reductions, availability and quickness are theoretically warranted in a level never seen before. Lastly, as pointed out by Schmidt and colleagues, the virtualized infrastructure of the bus allows it to grow or shrink according to the workload which it is supporting (Schmidt, 2005).

The one-to-many teleportation has become well known since the end of the nineties (Murao *et al.*, 2000), now considered by Ghiu (2012). Let us first establish the initial state in server A related to a half-spin particle,

$$|\psi\rangle_A = \alpha|0\rangle + \beta|1\rangle.$$

We want to broadcast the information of this state to servers B and C, so that they share the final state

$$|\Psi\rangle_{BC} = \alpha|\phi_0\rangle + \beta|\phi_1\rangle.$$

The general representation of a quantum channel shared by the three servers is given from

$$|C\rangle_{ABC} = N\left(|0\rangle_A|\phi_0\rangle_{BC} + n|1\rangle_A|\phi_1\rangle_{BC}\right),$$

where

$$N = 1/\sqrt{1+n^2}.$$

If we take parameter n = 1 we get one-to-many teleportation. Now considering Bell-states, it follows the whole system state

$$|\psi\rangle|C\rangle = \frac{N}{\sqrt{2}}\Big[\,|\Psi_a^+\rangle\left(\alpha|\phi_0\rangle + \beta|\phi_1\rangle\right) + |\Psi_a^-\rangle\left(\alpha|\phi_0\rangle - \beta|\phi_1\rangle\right) + \\ + |\Psi_b^+\rangle\left(\beta|\phi_0\rangle + \alpha|\phi_1\rangle\right) + |\Psi_b^-\rangle\left(-\beta|\phi_0\rangle + \alpha|\phi_1\rangle\right)\Big].$$

Lastly, servers B and C have to make local appropriate transformations to get final state

$$|\psi\rangle = \frac{1}{\sqrt{|\alpha|^2 + n^2|\beta|^2}}\left(\alpha|\phi_0\rangle + n\beta|\phi_1\rangle\right) = \alpha|\phi_0\rangle + \beta|\phi_1\rangle.$$

Now we apply the metalanguage defined above. Each elementary service has a complete state function, so that, with Bell-basis, we may write for the whole system

$$S^4\langle f\,|\,\curlywedge\frac{N}{\sqrt{2}}\left\|\begin{matrix}\langle\psi_1 \succ \langle\psi_2 \curlyvee \psi_3\rangle \succ \langle\psi_4 \curlyvee \psi_5 \curlyvee \psi_6\rangle\rangle \\ \langle\psi_1 \succ \langle\psi_2 \curlyvee \psi_3\rangle \succ \langle\langle\psi_4 \curlyvee \psi_5\rangle \succ \psi_6\rangle\rangle \\ \langle\psi_1 \succ \langle\psi_2 \curlyvee \psi_3\rangle \prec\!\succ \langle\psi_4 \curlyvee \psi_5 \curlyvee \psi_6\rangle\rangle \\ \langle\psi_1 \succ \langle\psi_2 \curlyvee \psi_3\rangle \succ \langle\psi_4 \succ \langle\psi_5 \curlyvee \psi_6\rangle\rangle\rangle\end{matrix}\right\|, \quad (17)$$

So we can say that the functional applied to the right in the above expression corresponds to the initialization of the quantum channel between the functions ψ_i that make up the orchestration S^4, so that, for each elementary service s_i we have

$$\psi_i = \Big[\,|\Psi_{i,A}^+\rangle\left(\alpha|\phi_0\rangle + \beta|\phi_1\rangle\right) + |\Psi_{i,A}^-\rangle\left(\alpha|\phi_0\rangle - \beta|\phi_1\rangle\right) + \\ + |\Psi_{i,B}^+\rangle\left(\beta|\phi_0\rangle + \alpha|\phi_1\rangle\right) + |\Psi_{i,B}^-\rangle\left(-\beta|\phi_0\rangle + \alpha|\phi_1\rangle\right)\Big].$$

6. Discussion

According to *Definition 1* and *Axiom 1*, S^1 has flexible nature enough to incorporate virtually any weak coupling O^1 on s_i services. Based on the *Definition 2* and the *Axiom 2*, this flexibility extends to n dimensions according to *Definition 4*, which states that in practice an array of identified weak couplings is executable under demand and according to the availability of resources. *Definition 3* requires logistical criteria previously established in the architecture itself. It is worth remembering that both auxiliary services and application services fall within the formal framework described above.

The word "agglomerate" was used rather than "cluster" precisely to avoid confusion with the concept of "cluster of machines". Based on quantum principles, Server A arrived at the best possible solutions in four dimensions. During the short period of processing, the computer repeated the test in hundreds of different ways to make sure that there was not a better selection of ways to perform the required task. Thus, given a cloud under a SOA overlay disposing services s_1, s_2, s_3, s_4, s_5, s_6, this agglomerate shall be analyzed in server B according to local environmental conditions. The advantage is that the teleported matrix already contains the best selections of orchestrations on the same services for a certain global task to be replied in a remote location.

Due to the uncommon nature of the qubit itself, in comparison with the classical bit, quantum computers are expected to prove in labs to be able to operate many times faster executing complex tasks of analysis and recombination. Nevertheless, as Nielsen and Chuang pointed out, "we do not understand what exactly it is that makes quantum computers powerful, or on what class of problems they can be expected to outperform classical computers" (Nielsen & Chuang, 2000). In fact, our example of orchestration was a simple one, but in reality quantum servers shall deal with a high number of services and dimensions, a situation now difficult to govern by common computers. In addition, quantum principles applied in computation should help to solve the most challenging problem in computer science: the construction of learning machines. By making computers select and analyze teleported agglomerates (as server B) based on previous experiences (server A), there is hopeless to improve artificial intelligence in clouds for complex decisions related to global scenarios of production. I think that there shall be not by way of individual processing but by metacomputation that we shall obtain the best performance gains and cyber intelligence with quantum machines.

Spontaneous Entanglement

In fact, the creation of a pair of qubits from one qubit, as presented previously, is understandable as an outcome of the growth in the complexity of cybernetic autonomous devices of information interchanging and their links, but changes of complexity stay obscure; they require spontaneous entanglement. This is what keeps physicists separate from the world outside the laboratory.

Quantum processors need to operate at superconductivity regime in order to make superposition happen. A viable way to achieve this is using metal niobium and lowering the temperature of the apparatus to -272.98ºC, close to absolute zero. This is a physical precondition to hold quantum phenomena. It happens that spontaneous entanglement is a response to complex stimuli from the environment; the more you induce the increasing required complexity of the system, the more you rise the chances of new entanglements. As the phenomenon of mutation useful for the survival of a species, or the emergence of new synapses in the brain, allowing connections between intellective processes, it is not known precisely how occurs spontaneous quantum entanglement between qubits from the incitement of the process until the conflagration of the fact itself; it is an evolutionary interval that remains confined to a black box. Spontaneous entanglements are not observed, in the same way that it is not feasible a snapshot of the natural extinction of a species.

A Metaframe for Clouds in Hilbert Space

Constructions of type-cloud are more than sets of devices. Clearly, there is a succession of scales if we agree that to be a member of the larger system (cloud), the element (server) must be enrolled in some metric with tier below the tier of the metric of the first. Altaisky (2001) understood very well the problem of formal description of complex cybernetic systems, including systems of type-cloud. A state function to describe the members x (servers) of an object X (cloud) would be

$$\{\Psi(X), \Psi(X,x)\},$$

being $\Psi(X)$ the global state function and $\Psi(X,x)$ the state function of the elements. Since the $\Psi(X,x)$ are in $\Psi(X)$, it is not valid the commutation rule

$$[\Psi(X), \Psi(X,x)].$$

This means that, in principle, we cannot apply operators on these functions such that we can measure both simultaneously; either we observe the overall behavior of the cloud, or the isolated behavior of one of its members. In theoretical terms, in a perfectly entangled quantum cloud, to measure the state of a server blurs the overall state of the cloud and vice versa. As the objects $\Psi(X,x)$ and $\Psi(X)$ inhabit different functional spaces, their signatures or sets of coordinates associated with them assume a hierarchical network. Each level of the hierarchy is described by the structure

$$\mathcal{M} = \left\langle \ell, \beta^{\ell}, \mathrm{T}^{\beta^{\ell}} \right\rangle$$

in which

$\ell \rightarrow$ the signature of scale,

$\beta^{\ell} \rightarrow$ the symmetry group at scale ℓ,

$\mathrm{T}^{\beta^{\ell}} \rightarrow$ some topology on β^{ℓ} (in other words, the coordinates at ℓ-th level).

In Hilbert space $\mathcal{H}$ of these hierarchical states,

$$\Psi_1, \Psi_2 \in \mathcal{H}; \alpha, \beta \in C \Rightarrow \alpha\Psi_1 + \beta\Psi_2 \in \mathcal{H},$$

where C is the set of the complex numbers, we would have for the general state, by definition,

$$\alpha\Psi(X) = \left\{ \alpha\psi_X^{\ell_1}\left(\tau^{\beta^{\ell_1}}\right), \left\{ \alpha\psi_{Xx_1}^{\ell_2}\left(\tau_1^{\beta^{\ell_2}}\right), \ldots, \alpha\psi_{Xx_n}^{\ell_2}\left(\tau_n^{\beta^{\ell_2}}\right) \right\}, \ldots \right\},$$

remembering that by the re-ingoing nature of $\Psi(X)$ there is no commutation.

The structure of $\mathcal{M}$ is enough to preach cybernetic systems of type "cloud", although here I have provided only a brief formalism. This structure includes complexities such as dynamic provisioning of computing resources, dynamic balancing of the workload and performance monitoring. The application of cloud computing is a reality on the Internet (Google and Yahoo). In 2008 the total of the clouds of the five largest Internet search companies amounted to around 2 million servers. The main advantage of this computational model is the significant reduction of the time-to-market for on-demand e-business and Web 2.0 applications, that is, the gradual allocation of resources by necessity.

The Beehive Effect

Quantum communication uses the informational content of entangled systems in order to obtain an extra resource. Quantum entanglement is essential to reach the exponential speed-up anticipated by some quantum algorithms. From the theoretical point of view, all the information in a state of maximum entanglement is contained in the joint properties of the systems and not in individuals separately. The so-called "beehive effect" originates from a large scattering of entangled states distributed across multiple quantum servers via broadcast channels. Aiming to make an effective distribution of information by entangled states we would have to build a linked set of transmitters like in the most stable going experiments in which we start from the distribution of entangled photons through glass fibers, since they are installed underground and thus, they are less vulnerable to external disturbances. Eventually, it will be necessary the use of satellite technology. Due to the spread of entangled states over arbitrary distances, the cloud assumes a global behavior from each stimulus locally introduced. The global response is resulting not only from the entanglement, but also from the state analysis promoted by auxiliary services of SOA architecture on the entangled states.

It is usual to expect that quantum computing comes to fruition in the next ten/twelve years, mainly solving problems about the transfer of large amounts of complex data by teleporting based on quantum entanglement. The evolution to an intelligent cloud of entangled quantum servers with the ability to send and receive large amounts of data analyzing and deciding what to do is a more distant win I suppose, but even so it would be risky to make estimates from the present stage of research.

7. Future trends

Physicists agree on that we are a long way off — decades, they suppose — from employing quantum features to build quantum hardware with practical applicability (Woo, 2013). The correlation quantumness between particles is in principle given by entanglement, and entanglement is very sensible to environmental perturbations, which turns impracticable to maintain superposition of states. Researchers are now working on new ideas to quantify the disagreement (the "discord") between quantum and classical ways of calculating the same property as a manner to solve the problem of sensibility to the environment, but it is still not clear if discord really fulfills general computing quantumness (Tyler, 2013). As Professors Hadjiivanov and Todorov said,

"Quantum mechanics, created during the first quarter of XX century is finding wide applications only after the invention of the transistor in 1948 and the development of the laser in the late 1950's. The true applications of the 'second quantum revolution' are yet to come". (Hadjiivanov & Todorov, 2015).

Currently, with the improvement of laser technology, there are several advanced experiments applying quantum entanglement/teleportation over distances of about 89 mi. We expect that computers endowed of quantum microprocessors shall develop capabilities to perform what I call "self-entanglement", transmitting packets of entangled states with embedded spinor-like gates to other computers in a cloud, interacting with high efficiency by teleportation of states. The "quantum cloud" will be many times faster to provide services than any conceived architecture now available. This is the beginning of an increasing intelligence, since entanglement and teleportation open doors to infinity of interactions from server to server.

In the future, clouds will be able to make global decisions supported by entangled states of information shared among all quantum servers, including via teleportation of entanglement itself. As well as, local decisions will be made after the beehive analysis of the situation, a complex task which requires multiple entanglements and teleportations. Quantum cloud computing is still in its infancies, but it is very far from science fiction.

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Key Terms

Beehive effect – the supposed global — and even intelligent — behavior of a cloud of servers acting under quantum principles.

Cloud computing – a model of computation by which IT resources are randomly dispersed in the network, being offered as services.

Progenitor – the gate generator of a two-qubit system which under the action of a control gate creates a pair of entangled states.

Quantum bit (or Qubit) – the quantum tile of information that can assume both states 0 and 1 at the same time.

Quantum entanglement – the matting of quantum states to which decomposition does not hold.

Quantum machine – a computer whose general operation follows the laws of quantum mechanics.

Quantum teleportation – the long-distance replication of a quantum state.

SOA (Service Oriented Architecture) – a computational architecture for the provision of services as packages of specific tasks over the network.

Appendix

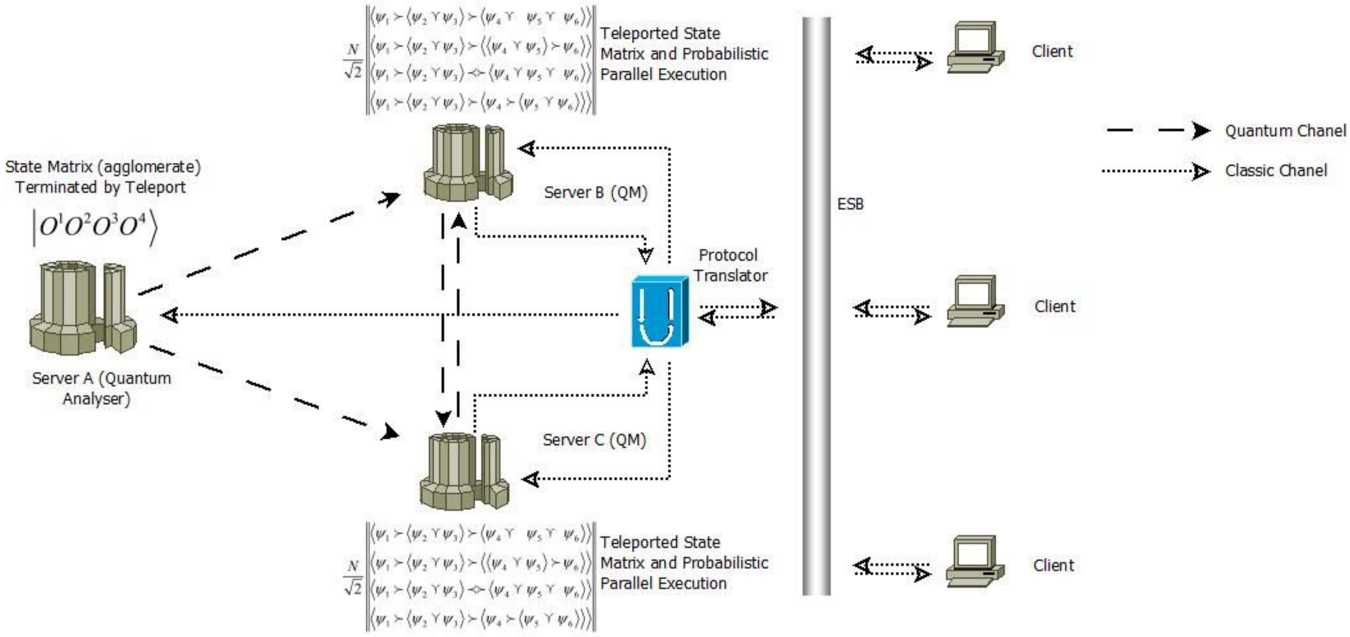

Figure 3. Operating sketch of a cloud of quantum machines, showing simple quantum cloud architecture linked to an Enterprise Service Bus through the protocol translator hardware.

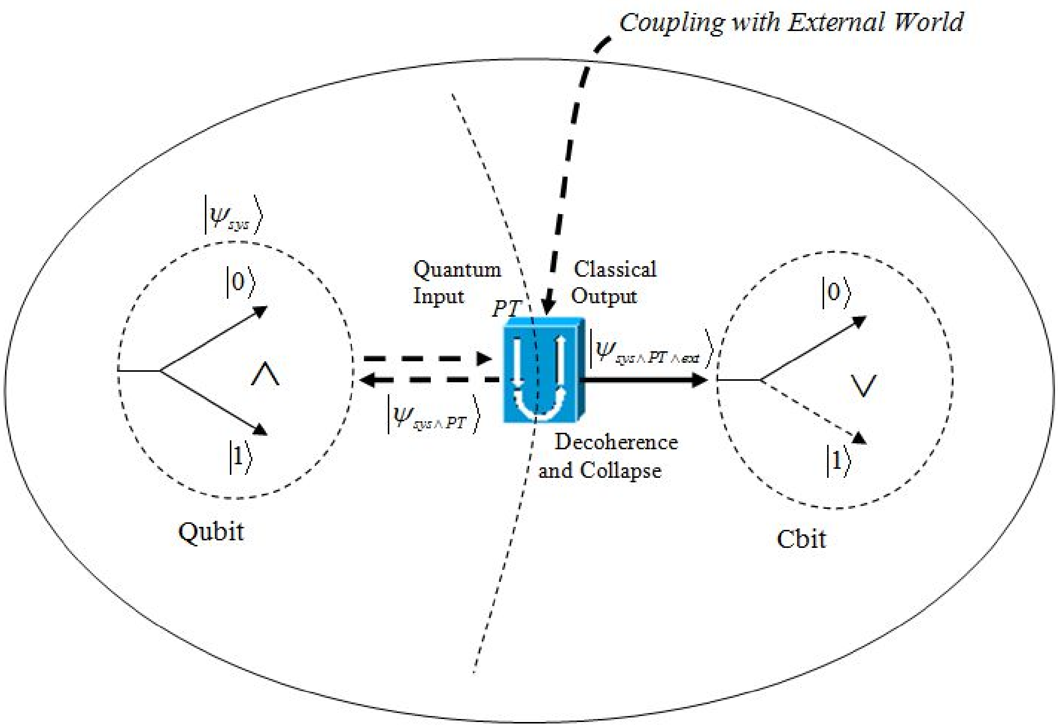

Figure 4. Detail of the interactions at protocol translator.