

Nonlocal Quantum Computing Theory

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1. INTRODUCTION

As we are entering the centennial year of quantum mechanics theory, a new kind of science from non-local concept is emerging to supplement the existing local theory for science and engineering problems through the investigation of quantum parallel computing. It has been more than 340 years since Issaic Newton and Gottfried Leibniz developed the Calculus/Differential equation approach, from classical mechanics to quantum mechanics, to supplement the algebra approach before that. It is a local theory because an operator is to operate on a function (or a state) at the same location. In addition, the concept of time is introduced as an independent variable as dynamics. This local theory is based on Euclidean geometry imposed by the condition from the addition of two numbers, the starting point of computing. In essence, algebraic computation, matrix operation and differential equation are all local theory and based on Euclidean geometry.

The emerging new kind of science is a non-local theory in the sense that an operator can operate on a function (or an eigen-state) at a proper distance away from each other. Of course, the quantities at two different locations are linked. This non-local concept is to move away from Euclidean to a piece-wise-Euclidean geometry and thus the computation is no longer “addition-rule compatible” for most of the quantum computing, save one. Therefore “universal computer” is not a valid concept. This is realized when we investigate the quantum parallel computing. Computing deals with huge spatially distributed numbers, in a digital or analog numbering system. Thus, spatial relations among those numbers form the rules of computing. In algebraic operations, starting from the addition operation on two strings of numbers, the concept of “carry” was introduced to make the computing a “local” approach. That means with 8 computation states employed, a local (and man-made) processor can sequentially generate two outputs,

“carry” and “sum”, at each step to complete the 16 needed outcomes.

2. ARGUMENTS

Generally, 16 Boolean operations are achieved using transistors to build the 16 logic gates (or through the equivalent minimum-gate approach). Thus, the logic-gate concept is for sequential computing and a von-Neumann (or Charles Babbage) computing architecture is employed. For massive parallel computing, billions of processors are interconnected. The number of interconnections must be at a minimum. This requirement reduces the computer architecture to only one: cellular automata architecture.

Quantum computing is “parallel” computing. All spatially distributed numbers (or the states) are altered in every step through the 16 needed spatial rules to replace the 16 Boolean operations in sequential computing. So, what are those 16 rules? However, the first step is to realize that quantum computing is “rule-based”, not “quantum logic-gate-based”. In this new concept, we can view the entire universe as a giant parallel computer. Spatial relations change the contents of the universe as human beings start observing it.

Non-local operator-state rules can also be viewed as “symbolic substitution” or “pattern transformation/recognition” rules. The graphical transformation process in classical computing already moves us into a GPU concept from the original CPU concept. This is because computing was originally rule-based. But the pattern transformation operation is still performed sequentially. In quantum computing, pattern recognitions are performed simultaneously. Instead of using graphical description, we describe this concept in terms of “non-local operator-state relations” because this is from the terminologies used in quantum mechanics, operators and eigen-states. But it also means an operator is a state at the same time. Thus, the standard textbook notations of local quantum mechanics description cannot be used. With

the understanding that we need 16 nonlocal operator-state rules operated under a cellular automata architecture, we are now able to place the “superposition and entanglement” of electrons into actions for quantum parallel computing.

There are many different types of computing (because there is no such thing as “universal computer” as stated earlier), and they are all to be compared at the Fourier space, the momentum space of atoms. The non-local nature implies “time” is associate with the “space” under consideration and is not an independent variable. This is in sharp contrast with Schrodinger’s differential equation description.

Quantum computing is a parallel “phase” computing from the nature that is executed in the Fourier space. From a chain of atoms in superposition and in entanglement conditions, all eigen-vectors of the same energy across the atomic chain are phase-coupled through the external Fourier transform, the entanglement condition. All the eigen-vectors of different energies within the atom are internally Fourier transformed, in superposition condition. So indeed, superposition and entanglement together establish multi-channel superconducting chain in the atoms, because of the phase relations established across the chain. This can be achieved through photons, instead of phonons in BCS theory.

3. DETAILED DESCRIPTION

First, we provide an equivalent qubit description of quantum computing and then point out the incompleteness of the qubit theory. In a chain of two-level atoms of energies E_1 and E_2 and eigen states, $\bar{S}_1(\ell)$ and $\bar{S}_2(\ell)$, located at position ℓ on the chain, as in Fig. 1, the computation states, $S_1(\ell)$ and $S_2(\ell)$ are from the superpositions (or the Fourier transform) of the two eigen-states and can be written as:

$$\begin{array}{c} \ell \\ \leftarrow a \rightarrow \ell-1 \\ \begin{array}{c} \text{---} \\ \text{---} \\ \text{---} \end{array} \begin{array}{c} E_2, \bar{S}_2(\ell) \\ E_1, \bar{S}_1(\ell) \end{array} \quad \begin{array}{c} \text{---} \\ \text{---} \\ \text{---} \end{array} \begin{array}{c} E_2, \bar{S}_2(\ell-1) \\ E_1, \bar{S}_1(\ell-1) \end{array} \end{array} \quad \begin{pmatrix} S_2 \\ S_1 \end{pmatrix} = \begin{pmatrix} -1 & 1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} \bar{S}_2 \\ \bar{S}_1 \end{pmatrix}$$

Fig. 1: Hadamard transformation, internal Fourier transform in an atom of two energies.

This is also known as the Hadamard transformation. That simply means at the internal Fourier-transform space, the two eigen-vector form a π and 2π phase difference to generate two computation states. The entanglement between eigen-vector, $\bar{S}_1(\ell)$ and its neighboring one, $\bar{S}_1(\ell-1)$, is π phase difference and between the eigen-vectors, $\bar{S}_2(\ell)$ and $\bar{S}_2(\ell-1)$ has a 2π phase difference. This entanglement is achieved if there is a minimum separation distance, the focal distance, a , such that $\hbar a = \pi$, where $\hbar$ is the wave vector of the lowest energy E_1 . That means entanglement is simply an external Fourier transformation. So, for a small chain

of atoms prepared in an initial configuration of computation states in $S_2 S_1 S_2 S_2$ can be illustrated as in Fig. 2.

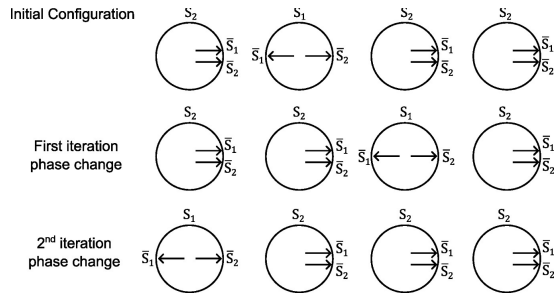


Fig. 2: Computation state phase-changing sequences.

That means in Fourier space, a plane wave is not prepared by a single electron of one energy. Rather they can be two plane waves, extended to infinities with two energies E_1 and E_2 and are prepared by a chain of N atoms under the Fourier transform. Thus, each atom contributes only part of the plane wave for that energy in Fourier space. Say, we have just a pair of electrons ($N=2$) in entanglement at the lowest energy level E_1 . If it is just one atom alone, then it occupies the entire infinite space with a well-defined momentum vector. That would be fine. But it is now occupied only half of the space on the left side and another half space on the right side is occupied by another electron of the same energy and between the left space and right space has a separation distance, a , the focal length, such that $\hbar a = \pi$ is achieved, that is called the entanglement condition. Now both sides of the electron waves can extend to the other side because an electron with well-defined momentum can extend to an infinite space. The net result is eigen-vector, $\bar{S}_1(\ell-1)$, will extend the wave over the distance, a , and gain an additional phase of π and interacts with the eigen vector $\bar{S}_1(\ell)$ such that a non-local operator-state relation, $\bar{S}_1(\ell-1)\bar{S}_1(\ell) = \pi\bar{S}_1(\ell)$, at time, τ , is achieved. In a coherent particle picture, an electron at energy E_1 at $\ell-1$ can travel over the focal distance, a , and gain an additional phase π before interacting with the state, $\bar{S}_1(\ell)$, the eigen vector of the same energy, after a time of τ is consumed. So, τ is just a parameter related to the focal distance, a . Similarly, electrons at energy E_2 can interact at half value of τ . So, a chain of atoms with a sequence of S_1 and S_2 computation states will change the phases according to the four following rules:

- 1) $S_1(\ell-1)S_1(\ell) = S_1(\ell)$
- 2) $S_1(\ell-1)S_2(\ell) = S_2(\ell)$
- 3) $S_2(\ell-1)S_1(\ell) = S_2(\ell)$
- 4) $S_2(\ell-1)S_2(\ell) = S_1(\ell)$

Similarly, for the four time-reversal relations.

Even though non-local operator-state relations can be established, there are only four relations that exist, and we need a complete 16 simultaneous relations to replace the 16 Boolean sequential operations. This points out the deficiencies or the incompleteness of qubit computing theory. A qubit forms a quantum processor at the smallest size and the bit-content of the processor is too small to provide the 16 needed instruction capabilities. Because with two computation states used in a processor, there requires eight instruction capabilities on the tiny processor. This is then not possible to construct.

But this non-local concept described here does show an extended non-local Schrodinger description. Namely, in Fourier space, a Hamiltonian operator (of the kinetic energy part) moves the electron energy located at position $\ell - 1$ over a focal distance, a , to location ℓ and operate on the eigenvector $\bar{S}_1(\ell)$. The net result is a phase of π is added to $\bar{S}_1(\ell)$ after time, τ . The relative phase difference of π value is maintained for $\bar{S}_1$ eigenvectors between two atoms. Similarly, for $\bar{S}_2$ eigenvectors, the phase value is maintained at 2π to complete the external Fourier transform.

Thus, an initial computation state configuration will keep changing the phase values over an entire atomic chain and perform perpetual computing. The result is a generation of a space-time Sierpinski triangle of fractals. Sierpinski triangle is where this new kind of science is anchored in. Time crystals, birth-and-death of space-time structures and the development from microscopic structure to mesoscopic and then to macroscopic structure can all be answered by examining the Sierpinski triangle.

But before that, we need to present a proper quantum parallel computing theory with the proper 16 non-local operator-state rules. First is to understand what the proper number of computation states is needed. This is not a trivial question. In local theory when eight computation states are used, there needs two instruction capabilities on the processor. With two computation states employed in qubit theory, there is a need for eight instructions that is too much for a two-state processor to provide. That is obvious problem appeared the Turing adder has already appeared. The correct method is four computation states with four instruction capabilities imposed on the processor. The four computation states are in two layers; computation result is at the lower level and a nutrition level at the top. They are shown in Fig. 3.

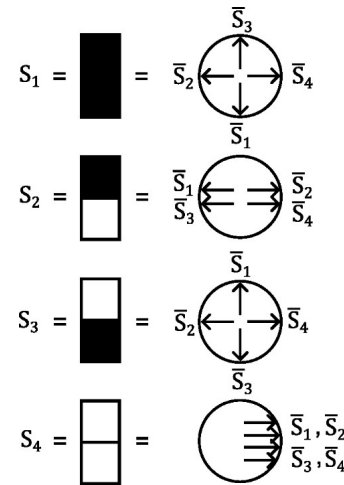


Fig. 3: Superposition of four eigen-states $\bar{S}_1, \bar{S}_2, \bar{S}_3$, and $\bar{S}_4$ to form four computation states S_1, S_2, S_3 , and S_4 in one atom.

4. RESULTS

The four computation states, S_1, S_2, S_3 , and S_4 , needed means they are generated from the superpositions of four energy levels, or four eigen states, $\bar{S}_1, \bar{S}_2, \bar{S}_3$, and $\bar{S}_4$ of an atom as shown. The entanglement conditions imposed additional four non-local operator-states relations, tensorial relations shown in Fig. 4(a) and labeled as Rules I, II, III and IV. Fig. 4(a) extends the local theory of quantum mechanics to non-local quantum mechanics in the sense that there exist two mixed-conjugate relations as indicated by Rule II and Rule III. The corresponding computation-state relations are shown in Fig. 4(b) in four possible cyclic distribution of the 16 outcomes.

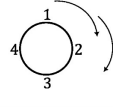
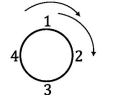
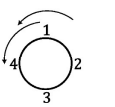
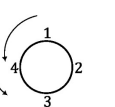
	A) Four Orthogonal Operations	B) Four Computation-State Transition Rules
Rule I	Operator $\bar{S}_1(\ell-1)$ $\begin{matrix} \bar{S}_1 & \bar{S}_2 & \bar{S}_3 & \bar{S}_4 \\ \bar{S}_1 & i\bar{S}_1 & 0 & 0 \\ \bar{S}_2 & 0 & -\bar{S}_2 & 0 \\ \bar{S}_3 & 0 & 0 & -i\bar{S}_3 \\ \bar{S}_4 & 0 & 0 & 0 \end{matrix}$ State $\bar{S}(\ell)$	$S(\ell-1)$ $\begin{matrix} S_1 & S_2 & S_3 & S_4 \\ S_1 & S_1 & S_2 & S_3 \\ S_2 & S_2 & S_3 & S_4 \\ S_3 & S_3 & S_4 & S_1 \\ S_4 & S_4 & S_1 & S_2 \end{matrix}$ $S(\ell)$ 
Rule II	Operator $\bar{S}_1^*(\ell-1)$ $\begin{matrix} \bar{S}_1^* & \bar{S}_2^* & \bar{S}_3^* & \bar{S}_4^* \\ \bar{S}_1^* & i\bar{S}_1^* & 0 & 0 \\ \bar{S}_2^* & 0 & -\bar{S}_2^* & 0 \\ \bar{S}_3^* & 0 & 0 & -i\bar{S}_3^* \\ \bar{S}_4^* & 0 & 0 & 0 \end{matrix}$ State $\bar{S}(\ell)$	$S(\ell-1)$ $\begin{matrix} S_1 & S_2 & S_3 & S_4 \\ S_1 & S_1 & S_2 & S_3 \\ S_2 & S_2 & S_1 & S_4 \\ S_3 & S_3 & S_4 & S_1 \\ S_4 & S_4 & S_3 & S_2 \end{matrix}$ $S(\ell)$ 
Rule III	Operator $\bar{S}_1(\ell-1)$ $\begin{matrix} \bar{S}_1 & \bar{S}_2 & \bar{S}_3 & \bar{S}_4 \\ \bar{S}_1 & i\bar{S}_1^* & 0 & 0 \\ \bar{S}_2 & 0 & -\bar{S}_2 & 0 \\ \bar{S}_3 & 0 & 0 & -i\bar{S}_3^* \\ \bar{S}_4^* & 0 & 0 & 0 \end{matrix}$ State $\bar{S}(\ell)$	$S(\ell-1)$ $\begin{matrix} S_1 & S_2 & S_3 & S_4 \\ S_1 & S_1 & S_4 & S_3 \\ S_2 & S_2 & S_1 & S_4 \\ S_3 & S_3 & S_2 & S_1 \\ S_4 & S_4 & S_3 & S_2 \end{matrix}$ $S(\ell)$ 
Rule IV	Operator $\bar{S}_1^*(\ell-1)$ $\begin{matrix} \bar{S}_1^* & \bar{S}_2^* & \bar{S}_3^* & \bar{S}_4^* \\ \bar{S}_1^* & i\bar{S}_1^* & 0 & 0 \\ \bar{S}_2^* & 0 & -\bar{S}_2^* & 0 \\ \bar{S}_3^* & 0 & 0 & -i\bar{S}_3^* \\ \bar{S}_4^* & 0 & 0 & 0 \end{matrix}$ State $\bar{S}(\ell)$	$S(\ell-1)$ $\begin{matrix} S_1 & S_2 & S_3 & S_4 \\ S_1 & S_1 & S_4 & S_3 \\ S_2 & S_4 & S_3 & S_2 \\ S_3 & S_3 & S_2 & S_1 \\ S_4 & S_2 & S_1 & S_4 \end{matrix}$ $S(\ell)$ 

Fig. 4: (a) Four fundamental diagonal non-local operator-state relations for and operator $\bar{S}_1(\ell-1)$ at location, $\ell-1$, to operate on the state $\bar{S}(\ell)$ at location, ℓ , on the chain. The diagonal results are the states located at ℓ . (b) The four corresponding computation-states are in four complete cyclic form as shown in the four sequences. The inner arrows first and then the outer arrows. The four 16-rule sets are shown as Rule I-IV.

In this new kind of science, the implications of left-right symmetry and time-reversal symmetry are important enough to change our thinking of time symmetry for past and future. Fig. 5 shows the difference between local and non-local concepts of the symmetries.

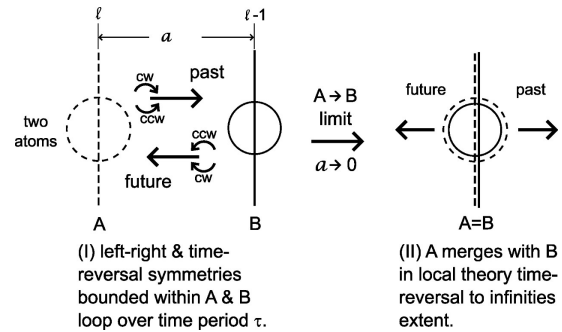


Fig. 5: Origin of time and the change of time symmetry concept from non-local theory to local.

In other words, in Fig. 5 (I), the time arrow from B to A (future) can be constructed clockwise (cw) or counterclockwise (ccw), to establish Rule I and Rule II of Fig. 4. Similarly, the time arrow from A to B (time reversal) can also be constructed through the cw and ccw distinctions to establish Rule III and Rule IV of Fig. 4. Those four symmetries are concurrently applied between two locals, A and B, and they exist at that space scale only. However, when this non-local theory is approaching to the local theory limit, $A \rightarrow B$ as one point as shown in Fig.5(II), the two-time arrows now move to two infinities as past and future. There is an important conceptual change when a non-local concept is reduced to a local concept.

5. CONCLUSION

A nonlocal quantum computing theory is presented here with four parallel 16-rule sets under cellular automata architecture. The deficiencies of the qubit theory are shown and several new physical concepts and consequences are presented to point out the arrival of a new kind of science.

6. REFERENCES

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