Quantum problem solving as simultaneous computation

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Abstract
I provide an alternative way of seeing quantum computation. First, I describe an idealized classical problem solving machine that, thanks to a many body interaction, reversibly and nondeterministically produces the solution of the problem under the simultaneous influence of all the problem constraints. This requires a perfectly accurate, rigid, and reversible relation between the coordinates of the machine parts – the machine can be considered the many body generalization of another perfect machine, the bouncing ball model of reversible computation. The mathematical description of the machine, as it is, is applicable to quantum problem solving, an extension of the quantum algorithms that comprises the physical representation of the problem-solution interdependence. The perfect relation between the coordinates of the machine parts is transferred to the populations of the reduced density operators of the parts of the computer register. The solution of the problem is reversibly and nondeterministically produced under the simultaneous influence of the state before measurement and the quantum principle. At the light of the present notion of simultaneous computation, the quantum speed up turns out to be "precognition" of the solution, namely the reduction of the initial ignorance of the solution due to backdating, to before running the algorithm, a time-symmetric part of the state vector reduction on the solution; as such, it is bounded by state vector reduction through an entropic inequality.

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1 Introduction
This work is about the notion of simultaneous computation, a fundamental computation mechanism implicit in quantum computation. It can also be seen as an application of the notion of Gestalt to computation. The following is a summary by section.

Section 2. I review the definition of Gestalt as truly simultaneous dependence between all the quantitative variables describing a physical situation.
Section 3. A perfect simultaneous dependence between all computational variables enables a simultaneous form of computation in the idealized classical framework. The problem addressed is solving a simultaneous system of Boolean equations. The Boolean variables are mapped by real non-negative variables (coordinates of the machine parts) submitted to idealized physical constraints (perfectly accurate, rigid and reversible) representing the simultaneous system of Boolean equations. The solution of the problem is reversibly and nondeterministically produced under the simultaneous influence of all equations – in fact through an idealized many body interaction. This machine can be seen as the many body generalization of another perfect machine, the bouncing ball model of reversible computation.

Section 4. Simultaneous computation turns out to be a representation of quantum problem solving, an extension of the quantum algorithms that comprises the physical representation of the problem-solution interdependence. The simultaneous dependence between the coordinates of the machine parts is transferred to the populations of the reduced density operators of the parts of the computer register. Simultaneous dependence becomes quantum correlation. Infinite precision is replaced by quantization (Finkelstein, 2007). The solution of the problem is reversibly and nondeterministically produced under the simultaneous influence of the state before measurement and the quantum principle.

Section 5. The quantum speed up turns out to be ”precognition of the solution” – the reduction of the initial ignorance of the solution due to backdating, to before running the algorithm, a time-symmetric part of the state vector reduction on the solution; as such, it is bounded by state vector reduction through an entropic inequality.

Section 6. The notion of simultaneous computation is positioned within the development of quantum computation.

2 The notion of Gestalt

In the definition of the Vienna circle, Gestalt is an organized coherent whole whose parts are determined by laws intrinsic to the whole rather than being independently juxtaposed or associated. Moreover, if the whole can be described by quantitative variables, Gestalt is defined as truly simultaneous dependence between all variables (e.g., Mulligan and Smith, 1988).

It can be argued that ”truly simultaneous dependence” is only between the variables related by a fundamental physical law. An example in classical physics is Newton’s law in the idealized case of a point mass: it establishes a truly simultaneous dependence between force, mass, and acceleration since the change of any one variable is correlated with an identical change of the product, or ratio, of the other two. In view of what will follow, I should remark that simultaneous dependence between variables is mutual, like correlation, and can be non-functional, in the sense that the perturbation of any one variable does not univocally ”propagate” to the others. This is the case of Newton’s law that, correspondingly, can host in principle a nondeterministic many body
Identified with the notion of physical law, Gestalt becomes a revisitation of the Platonic notion of Form, or Idea (the Greek word Eidos translates into Form, Idea, or Vision): "Ideas are objective perfections that exist in themselves and for themselves, at the same time they are the cause of natural phenomena, they keep phenomena bound together and constitute their unity.

The concept of objectively perfect simultaneous dependence can be clarified by resorting to the concept of mechanism. A fundamental law should be seen as a perfect mechanism (perfectly accurate, rigid, and reversible) whose degrees of freedom are the continuous variables related by the law – it is not the case that this mechanism gets deformed because of flexibility or jams because of friction or irregularities. As we will see, an underconstrained perfect mechanism, characterized by a non-functional relation between its degrees of freedom, can host a nondeterministic many body interaction.

3 Simultaneous computation in an idealized classical framework

By using the definition of Gestalt as absolutely simultaneous dependence between all the quantitative variables describing a physical situation, one can see in the first place that there is no Gestalt in classical computation. Let us consider the idealized bouncing ball model of reversible computation (Fredkin and Toffoli, 1982). The variables at stake are the positions and momenta of each and every ball. Outside collisions, there is no simultaneous dependence between the variables of different balls, which are independent of each other. In the instant of (idealized) collision, there is simultaneous dependence between the variables of the colliding balls, but this is limited to ball pairs (there can be several collisions at the same time, but involving independent ball pairs, with no simultaneous dependence between the variables of different pairs). The simultaneous collision between more than two balls is avoided since it would introduce the many body problem.

This lack of Gestalt raises the question whether there is a form of computation endowed with it. By assuming a perfect simultaneous dependence between all computational variables, one can devise an idealized classical machine that – thanks to a many body interaction – nondeterministically produces the solution of a system of Boolean equations under the simultaneous influence of all equations (the same simultaneous dependence will represent quantum correlation).

We can start with the simplest "problem" represented by a single unconstrained Boolean variable \(x\) – we will also use the auxiliary variable \(y = \overline{x}\). The problem solutions are of course \(x = 0, y = 1\) and \(x = 1, y = 0\). Let \(X, Y, Q\) be real non-negative variables. The Boolean problem can be transformed into the problem of finding the solutions, for \(Q > 0\), of the simultaneous equations...
\[
\frac{X}{Q} + \frac{Y}{Q} = 1, \quad (1)
\]

\[
\left(\frac{X}{Q}\right)^2 + \left(\frac{Y}{Q}\right)^2 = 1. \quad (2)
\]

\(Q = 0\) implies \(X = Y = 0\). With \(Q > 0\), \(\frac{X}{Q} \equiv x\) and \(\frac{Y}{Q} \equiv y\); one can see that \(X = 0, Y > 0\) corresponds to the Boolean values \(x = 0, y = 1\) and \(X > 0, Y = 0\) to \(x = 1, y = 0\).

In this real variable representation of the Boolean problem, the solutions can be computed by a many body interaction, as follows. Equation (1) can be represented by an idealized hydraulic circuit where \(Q\) is the coordinate of a piston feeding in parallel (through an incompressible fluid) two pistons of even section and mass, and coordinates respectively \(X\) and \(Y\). Equation (2) is represented by a differential mechanism with non-linear (parabolic) cams applying to pistons \(X, Y\), and \(Q\) (I use the same symbol to denote the piston and its coordinate). The initial configuration of the machine is \(X = Y = Q = 0\); it can be argued that any movement of piston \(Q\) from \(Q = 0\) to \(Q > 0\) instantly produces a solution in a nondeterministic way. This motion could be obtained by applying a force to piston \(Q\), then there would be no reason that either \(X\) or \(Y\) (in a mutually exclusive way) move with \(Q\), as either movement offers zero static resistance to the force (there is only the inertia of the pistons). This reversible, nondeterministic many body interaction should be postulated in the present idealized classical framework, in the quantum framework it becomes a representation of measurement. I should note that simultaneous dependence is nonlinear in the nondeterministic transition from \(Q = 0\) to \(Q > 0\), and linear in the deterministic movement of the pistons in the interval \(Q > 0\) – in fact, with \(Q > 0\) and, say, \(X = 0\), the two equations (1) and (2) make a redundant linear system in the positive interval.

Unlike deterministic reversible processes, the present process is not invertible – in general one cannot go back and forth along the same process. For example, we can think of connecting the input piston to an ideal spring charged when \(Q = 0\). On the one side, there would be oscillations without dissipation. On the other, at each oscillation, the movement of the input piston from \(Q = 0\) to \(Q > 0\) would randomly drag either \(X\) or \(Y\) in a mutually exclusive way.

This idealized computation mechanism can solve any system of Boolean equations, namely of \(N\) NAND equations \(x_{i,3} = \text{NAND}(x_{i,1}, x_{i,2})\), with \(i = 1, \ldots, N\) and \(x_{i,j} = x_{h,k}\) for some assignments of \(i, j, h, k\). The hydraulic circuit becomes the series of an input branch/piston \(Q\) and \(N\) quadruples of parallel branches/pistons \(X_{i,j}\), \(j = 1, \ldots, 4\). The four branches/pistons of each quadruple are labeled by the Boolean values that satisfy the corresponding NAND equation. For example, branches/pistons \(X_{i,1}; X_{i,2}; X_{i,3}; X_{i,4}\) are labeled by, respectively, \(x_{i,1} = 0, x_{i,2} = 0, x_{i,3} = 1; x_{i,1} = 0, x_{i,2} = 1, x_{i,3} = 1; x_{i,1} = 1, x_{i,2} = 0, x_{i,3} = 1; x_{i,1} = 1, x_{i,2} = 1, x_{i,3} = 0\). "Fluxes" \(X_{i,j}\) in the branches of the same quadruple are made to be mutually exclusive with one another by nonlinear transmissions between the corresponding pistons and the
total flux across branches labeled by the same value of the same Boolean variable is made to be conserved across different quadruples by linear transmissions between the corresponding pistons. By applying a force to the input piston $Q$, the machine’s motion from $Q = 0$ to $Q > 0$ instantly produces a solution under the simultaneous influence of all the problem constraints (in each quadruple, there is only one branch with flux $> 0$, the series of all these branches is labeled by a Boolean assignment that solves the system). By using the partial OR (POR) gate instead of the NAND gate, quadruples can be replaced by triples.

This idealized machine has the only purpose of introducing the idea of simultaneous computation, namely of a computation mechanism that, thanks to a perfect simultaneous dependence between many continuous computational variables, nondeterministically produces the solution of a problem under the simultaneous influence of all the problem constraints.

4 Quantum computation as simultaneous computation

To see that quantum computation is simultaneous computation, we should replace the configuration space of the idealized classical machine by the phase space of the quantum machine. Simultaneous dependence between the coordinates of the machine parts becomes simultaneous dependence between the populations of the reduced density operators of the parts of the computer register. Let us consider for example the simplest problem of section 3, of finding the solutions of a single unconstrained Boolean variable $x$. The motion of the idealized machine from $Q = 0$ to $Q > 0$ is analogous to measuring two qubits in the entangled state $|0\rangle_X |1\rangle_Y + |1\rangle_X |0\rangle_Y$. Let us represent the populations of the reduced density operator of the first (second) qubit by the variables $x_{11}, x_{22}$ ($y_{11}, y_{22}$). The state before measurement corresponds to the assignment $x_{11} = x_{22} = y_{11} = y_{22} = \frac{1}{2}$, the state after measurement to $x_{11} = 1, x_{22} = 0, y_{11} = 0, y_{22} = 1$ or, in a mutually exclusive way, $x_{11} = 0, x_{22} = 1, y_{11} = 1, y_{22} = 0$. The correspondence between the coordinates of the idealized classical machine and the populations of the quantum machine is:

$$\frac{X}{Q} = x_{11} = 1 - x_{22}, \frac{Y}{Q} = y_{11} = 1 - y_{22}. \quad (3)$$

The transition imposed by the quantum principle is isomorphic with the transition from $Q = 0$ to $Q > 0$ of section 3 and can be represented in exactly the same way by adding, to equations \((3)\), equations \((1)\) and \((2)\), repeated here for convenience:

$$\frac{X}{Q} + \frac{Y}{Q} = 1. \quad (4)$$
We can see that the infinite precision required by the classical machine is replaced by quantization (Finkelstein, 2007).

More in general, the nondeterministic production of the solution under the simultaneous influence of all the problem constraints of the idealized classical model becomes the nondeterministic production of the solution under the joint influence of the state before measurement and the condition established by the quantum principle, that the state before measurement is projected on the eigenspace of one eigenvalue of the measured observable, with probability the square of the modulus of the corresponding amplitude. State vector reduction performs the computation (symbol handling) that transforms the symbolic description of the state before measurement into the symbolic description of the state after measurement. The computation is performed by simultaneously solving a system of Boolean equations – not by the causal propagation of an input into an output (Castagnoli, 1999).

I should note that simultaneous dependence encompasses the whole sequence preparation/unitary evolution/quantum measurement. In fact there is simultaneous dependence between any two populations at any two times $t_1$, $t_2$ along the sequence, as follows. As before, populations should be seen as variables that switch from an assignment to another in correspondence of state vector reduction. We can take as independent variables the amplitudes $\{\alpha_i\}$, $i = 1, 2, ..., N$, of the basis vectors in the preparation of the quantum system. During unitary evolution, the amplitudes of the basis vectors evolve into linear combinations $f_{i,t}(\{\alpha_i\})$ of the independent variables. Setting the independent variables to the values they have in the preparation yields the usual quantum evolution (the forward evolution). Quantum measurement changes this evolution into the backward evolution, which undergoes the same unitary transformation but starts with a different preparation and ends with the state after measurement. There is simultaneous dependence between any two populations at any two times $t_1$, $t_2$ since the change of one population from the forward to the backward value (in correspondence with the transition from $Q = 0$ to $Q > 0$) is correlated to the change of the other. Simultaneous dependence is like between the polarizations of two photons in a polarization entangled state; the determination of one polarization determines the other, also at a previous or subsequent time along the sequence preparation/unitary evolution/measurement, and vice-versa.

5 An explanation of the speed up

Simultaneous computation offers a way of explaining the speed up of the quantum algorithms. In the years 1997-2000 I published, with others, a few papers that ascribe the quantum speed up to the non causal joint-determination of the measurement outcome by the state before measurement and the quantum principle (Castagnoli 1997, 1999, Castagnoli et al., 2000, Castagnoli and Finkelstein, 2000). We showed that the joint-determination associated with entanglement
and disentanglement, the former due to quantum parallel computation, the latter to quantum measurement, was responsible for all the speed-ups discovered until then. Soon afterwards (Raussendorf and Briegel, 2000) there was the first paper on cluster computing, where the use of entanglement and disentanglement by quantum measurement becomes explicit. The notion propounded in the following, that the speed up depends on backdated state vector reduction and is therefore entropically bounded by state vector reduction, is new, although already implicit in (Castagnoli and Finkelstein, 2000).

We have seen that, in the quantum context, simultaneous computation becomes the nondeterministic production of the solution under the joint influence of the quantum principle and the state before measurement. This is evident in the algorithms of Simon (1994) and Shor (1994). Here "function evaluation" produces an entangled state of the form $\sum_{x=1}^{N} |x\rangle_X |f(x)\rangle_F$, with $f(x)$ a periodic function of $x$. The final measurement is equivalent to measuring the value of the function immediately after function evaluation, for the retroactivity of state vector reduction in a reversible evolution. Joint-determination extradyynamically filters, out of an exponential number of arguments, all the arguments corresponding to a common value of the function. By applying the quantum Fourier transform to the superposition of such arguments, one extracts the period of the function.

On the contrary, joint-determination is completely hidden in Deutsch’s (1985) and Grover’s (1996) algorithms, which yield their speed ups through unitary evolutions – I am presently considering Cleve’s et al. (1997) revisitation of Deutsch’s algorithm and Grover’s algorithm for a database size that provides no probability of error. Apparently, there is no entanglement between computer registers and no nondeterministic production of the solution. However, this can be ascribed to the fact that these algorithms physically represent only the procedure that leads to the solution, whereas the interdependence between the problem and the solution is disregarded.

We are dealing with quantum games. One player chooses at random one of the four functions in Deutsch’s problem, or a data base location in Grover’s problem, the other player must find out the choice of the first player (a character thereof in Deutsch’s problem), but the physical representation does not comprise the random generation of the move of the first player. Simultaneous computation (problem-solution interdependence) does not appear since the problem is not represented physically.

Let us focus on Grover’s algorithm and let the size of the database be $N$. In the conventional algorithm, the quantum database is represented by a quantum computer that, given an input $x$, computes $\delta(k, x)$, where $\delta$ is the Kronecker function and $k$ is the database location randomly chosen by the first player. For each input $x$ provided by the second player, the computation of $\delta(k, x)$ tells whether it is the database location chosen by the first player. The second player prepares the input register $X$ in an even superposition of all the possible values of $x$. To find out the choice of the first player, the algorithm has to compute $\delta(k, x)$ the order of $\sqrt{N}$ times, instead of $N$ like in the classical case.
To physically represent the problem, it suffices to represent the random generation of $k$ on the part of the first player – then the computation of $\delta(k, x)$ copes for problem-solution interdependence. To this end, we add an ancillary register $K$ prepared in a superposition of all the possible values of $k$. The extended algorithm repeatedly computes $\delta(k, x)$ as before but now for a superposition of all the possible combinations of values of $k$ and $x$. This entangles each possible value of $k$ with the corresponding solution (the same value of $k$) found by the second player at the end of the algorithm. For example, with database size $N = 4$, the state before measurement is:

$$\frac{1}{2\sqrt{2}} (|00\rangle_K |00\rangle_X + |01\rangle_K |01\rangle_X + |10\rangle_K |10\rangle_X + |11\rangle_K |11\rangle_X ) (|0\rangle_F - |1\rangle_F)$$

(6)

Measuring the content of registers $K$ and $X$ determines the moves of both players – also representing the random choice of the value of $k$ on the part of the first player. The content of register $K$ is known to the first player, that of register $X$ to the second player. The state vector reduction induced by measuring the content of register $K$ can be backdated to before running the algorithm. This leaves the initial preparation of register $X$ – a superposition of all the possible values of $x$ – unaltered (because of the unitary transformations in between) and brings that of register $K$ to a sharp value, thus representing exactly the original Grover’s algorithm. In view of what will follow, I should note that the state of the computer register also represent the state of knowledge of the value of $k$ on the part of the second player. The initial state of the register – where $K$ is in an even superposition of all the possible values of $k$ – represents ignorance of the value of $k$. The fully entangled state (6) at the end of the algorithm, as well as the outcome of final measurement, represents knowledge of it.

Thus, by completing the physical representation of Grover’s algorithm, one finds again a succession of entanglement and disentanglement, and simultaneous computation through joint-determination of the measurement outcome by the state before measurement and the quantum principle. Joint-determination can be seen as mutual determination between the contents of the two entangled registers $K$ and $X$, which justifies the square root speed up with respect to a classical database search, where the content of the former register determines that of the latter and not vice-versa. By ascribing the speed up to mutual determination between register contents, one finds that it is bounded by state vector reduction through an entropic inequality, as follows.

Mutual determination is symmetrical, it can be represented by saying that the contents of the two registers are determined by the measurement of the first (second) bit of register $K$ and the second (first) bit of register $X$. Thus Grover’s algorithm is equivalent to the following game. We should think to arrange the $N$ database locations in a matrix of $\sqrt{N}$ columns and $\sqrt{N}$ rows – with $N = 4$ the row can be identified by the first bit of either register, the column by the second bit. At the end of Grover’s algorithm, the first player determines, say, the row by measuring the first bit of register $K$ in state (6). This is equivalent
to determining the row before running the algorithm, for what said before. The second player determines (and knows) the column by measuring the second bit of register $X$. The related state vector reduction can be backdated to before running the algorithm, namely to the initial preparation of the two registers $K$ and $X$, each in an even superposition of all the possible values of, respectively, $k$ and $x$. This leaves the initial preparation of register $X$ unaltered (because of the unitary transformations in between) and reduces that of register $K$ to the superposition of all the values of $k$ ending by that bit (determining the column before running the algorithm). In this picture, Grover’s algorithm searches just the row randomly chosen by the first player, which justifies the $O\left(\sqrt{N}\right)$ computations of $\delta(k, x)$, i.e. the square root speed up (of course the picture should be symmetrized for the exchange of columns and rows).

The same justification holds in the case that the value of $k$ is already determined before running the algorithm, like in virtual database search; this situation is indistinguishable from the random generation of $k$ at the end of the algorithm, since state vector reduction can be backdated so that $k$ is already determined before running the algorithm. With $k$ predetermined, the preparation of register $K$ in an even superposition of all the possible values of $k$ represents the initial ignorance of the value of $k$ on the part of the second player. Since there is no more determination of the column on the part of the second player, mutual determination between the contents of registers $K$ and $X$ becomes "precognition" of the column on the part of the second player. "Precognition" corresponds to backdating, to before running the algorithm, the state vector reduction induced by the measurement of (say) the second bit of register $X$, which leaves (as said before) the initial preparation of register $X$ unaltered and determines the second bit in the initial preparation of register $K$ (determines the column), reducing the initial ignorance of the second player about the value of $k$. The related information gain is

$$\Delta S = \frac{1}{2} \lg N,$$

one bit with $N = 4$. Besides database size, $N$ is the ratio between the size of the superposition before measurement (8 terms with amplitudes even in modulus – see eq. 6) and the size of the subspace on which the superposition is projected by quantum measurement (the 2 dimensions of the Hilbert space of register $F$).

I should like to quote the question raised by Grover in his 2001 paper: "What is the reason that one would expect that a quantum mechanical scheme could accomplish the search in $O\left(\sqrt{N}\right)$ steps? It would be insightful to have a simple two line argument for this without having to describe the details of the search algorithm." The "precognition" explanation might provide this argument. Casting it in two lines: "the speed up is the reduction of the initial ignorance of the solution due to backdating, to before running the algorithm, a time-symmetric part of the state vector reduction on the solution".

A similar extension of Deutsch’s algorithm yields the state before measurement:
\[
\frac{1}{2\sqrt{2}} [(|00\rangle_K + |11\rangle_K) |0\rangle_X + (|01\rangle_K + |10\rangle_K) |1\rangle_X)] (|0\rangle_F - |1\rangle_F)
\]

(8)

where \(k = 00, 01, 10, 11\) specifies the function randomly chosen by the first player and \(x\) is the answer provided by the second player (whether the function is balanced or constant). State (8) is reached by invoking the computation of the function only once instead of the two times required in the classical case. Although things are less symmetrical than in database search, as the two registers have different length, there is still a succession of entanglement and disentanglement, and mutual determination between the contents of the two registers \(K\) and \(X\). The information gain \(\Delta S = \frac{1}{2} \lg N\), associated to backdating a time symmetric part of the state vector reduction on the solution, is one bit – the ratio of Hilbert space sizes before and after measurement is still \(N = 4\). This is consistent with the fact that the speed up of Deutsch’s algorithm consists in having to check the value of one bit rather than two in the classical case.

Equation (7) can be rewritten by noting that \(\lg N\), the logarithm of the squeeze of Hilbert space size, is the von Neumann entropy of the reduced density operator of register \(K\) in state (6):

\[
\Delta S = \frac{1}{2} \Delta R.
\]

(9)

I call this entropy \(\Delta R\) since it is also the decrease of entropy of register \(K\) during state vector reduction – before reduction \(K\) is maximally entangled, after reduction it is in a sharp state and its entropy is zero. \(\Delta R\) can be used as an entropic measure of state vector reduction. It is more general than the logarithm of the ratio of Hilbert space sizes, with which it coincides in the case of even modulus amplitudes.

Similarly, the information gain \(\Delta S\) associated with partial backdated state vector reduction can be used as a measure of the speed up. This means defining the speed up – when applicable – as the reduction of the logarithmic size of the problem such that: the time taken by the quantum algorithm to solve the problem is the same as the time taken by the classical algorithm to solve the reduced problem.

For example, in the case of Grover’s algorithm, if database size is \(N = 4\), the logarithmic size of the problem is \(\lg 4 = 2\) (the number of bits of register \(K\)), the logarithmic size of the reduced problem is \(\lg 2 = 1\). The time taken by the quantum algorithm to solve the problem of 2 bits is the same as the time taken by the classical algorithm to solve the problem of 1 bit – in both cases \(\delta (k, x)\) is computed once.

Equation (9) states that this measure of the speed up is 50% of the entropic measure of state vector reduction in both Grover’s and Deutsch’s algorithms. These algorithms concern unstructured problems. More in general, the notion that the speed up is partial backdated state vector reduction implies:
\[ \Delta S \leq \Delta R. \] (10)

where \( \Delta R \), the entropic measure of state vector reduction, can be defined in general as the entropy of the reduced density operator of the observable being measured. We can do without the details of the quantum algorithm by considering the state immediately before the measurement projection, when the observable is maximally entangled with the pointer of the measurement apparatus. In particular, inequality (10) states that, when the problem-solution interdependence is physically represented, there is no speed up without state vector reduction.

6 Conclusions

I would like to conclude by positioning simultaneous computation within the development of quantum computation. It took a fundamental computation model to describe computation in the quantum framework (Bennett, 1973, 1982, Fredkin and Toffoli, 1982). It was naturally the model of deterministic reversibility. The early works of Benioff (1982) and Feynman (1985) were quantum mechanical models of deterministic reversible computation. I argue that all quantum algorithms, starting with the first work of Deutsch (1985), call for the extension of the early notion of deterministic reversible computation to simultaneous computation. Summing up, this extension can be segmented into the following steps: (i) replace the idealized (deterministic, two body) bouncing ball model of reversible computation by the idealized (nondeterministic, many body) classical model of simultaneous computation, (ii) notice that the simultaneous dependence between the coordinates of the machine parts can be replaced, in the quantum framework, by the simultaneous dependence between the populations of the reduced density operators of the parts of the computer register, (iii) complete the physical representation of problem-solving by comprising the problem-solution interdependence, and (iv) see that the speed up is the gain of information due to backdating, to before running the algorithm, a time symmetric part of the state vector reduction on the solution.

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