Particle Quantum Computation and Information on a String

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ABSTRACT

▶ The promise of quantum computation and information arises from the quantum interference of amplitudes of mutually exclusive events.

▶ This quantum effect cannot be simulated or implemented in any classical setting. This frustrates efforts at understanding these quantum effects since there is little intuition into their origin.

▶ Here I suggest computation with the exactly solvable quantum system, “delta interaction,” interpretable within conventional quantum mechanics and thus, in principle, implementable in the real quantum universe.

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THE CLASSICAL STRING
The classical string is a tool of Classical Mechanics.
a Haircut in Horse Town...
and Other Great Car Talk Puzzlers

Tom and Ray Magliozzi
aka Click and Clack,
The Tappet Brothers
with Doug Berman

Some Classical Mechanics
From the classical garage
Classical strings are composed of PARTICLES that can be seen, or located with one COORDINATE.

- Motion can be induced in ONE coordinate direction.
- Observe trajectories (momentum and energy transfer along the string)
- Particles can interact, their motions are determined by “Newton’s Laws", and are not independent.
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Particles can interact, their motions are determined by “Newton’s Laws”, and are not independent.
Two coordinate open string (infinite air-track)
Impossible classical gate
Three coordinate gate
The Fredkin Gate

\[ \begin{array}{ccc|c}
A & B & C & \text{OUT} \\
0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 \\
1 & 0 & 0 & 1 \\
0 & 1 & 1 & 1 \\
1 & 0 & 1 & 1 \\
1 & 1 & 0 & 0 \\
1 & 1 & 1 & 0 \\
\end{array} \]

- Without \( C \), \( A' = A \) and \( B' = B \)
- When \( C \) is present, \( A' = B \) and \( B' = A \)

Computing with particles
THE QUANTUM STRING
Operates by the rules of Quantum Mechanics
SOME QUANTUM MECHANICS

David Saxon
Quantum strings are composed of PARTICLES that can be seen, or located with one COORDINATE.

- Motion can be induced in ONE coordinate direction.
- CAN’T Observe trajectories No Newton’s Laws
- CAN MEASURE RANDOM VARIABLES
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I excerpt a remarkable paragraph from page 29 of Saxon’s “Elementary Quantum Mechanics”:

$$\psi_p(x, t) = \exp[i\left(\frac{px}{\hbar}\right) - \omega(p)t]$$  \hspace{1cm} (1)

The identification of that particular state function which describes a particle with definite momentum is an absolutely crucial step in our method of development. . . . So there will be no misunderstanding we state as emphatically as possible that the quantum mechanical rabbit is already in the hat, once equation (1) is accepted and understood . . . all else follows from the correspondence principle alone.
DeBroglie waves in space time
\[ f(k_a, k_b)(e^{ik_ax} e^{ik_by} e^{-i\omega(k_a,k_b)t}) \]

is a complex valued function and is the amplitude (a function of random variables \(x, y\)) for coordinate \(x\) to be associated with “rapidity” \(k_a\) and \(y\) to be associated with rapidity \(k_b\) before the encounter. The sign is chosen so that the amplitudes of the mutually exclusive events destructively interfere if \(k_a = k_b\), so that rapidities are necessarily distinct.
INTEGRABILITY

\[
\begin{pmatrix}
    f'_{ab} \\
    f'_{ba}
\end{pmatrix} = \begin{pmatrix}
    T_{ab} & -R_{ab} \\
    -R_{ab} & T_{ab}
\end{pmatrix} \begin{pmatrix}
    f_{ab} \\
    f_{ba}
\end{pmatrix},
\]

where \( T_{ab} = T(k_a - k_b) \). The encounter is continuous at \( x = y, t = t_0 \) if \( T - R = 1 \). The system is “integrable” if the system of equations is unitary,

\[
\frac{T}{R} = -\frac{T^*}{R^*},
\]

and a condition of no diffraction (a Yang-Baxter equation) is met

\[
\frac{T_{ab}}{R_{ab}} + \frac{T_{bc}}{R_{bc}} = \frac{T_{ac}}{R_{ac}}.
\]
The star-triangle condition implies:

\[
\frac{T_{ab}}{R_{ab}} = \rho_{ab} = \frac{i(k_a - k_b)}{g}
\]

The continuity requirement gives a complete form for the reflection and transmission coefficients of delta interaction

\[
R_{ab} = \frac{1}{\rho_{ab} - 1}, \quad T_{ab} = \frac{\rho_{ab}}{\rho_{ab} - 1}
\]
A PARTICULAR SINGLE QUBIT GATE

Suppose

\[
\rho_{ab} = -i
\]

\[
R_{ab} = \frac{1}{\sqrt{2}} e^{-i \frac{\pi}{4}}, \quad T_{ab} = \frac{1}{\sqrt{2}} e^{i \frac{\pi}{4}}.
\]

IN state is prepared so that

\[
f_{ab} = T_{ab} = \frac{1}{\sqrt{2}} e^{i \frac{\pi}{4}}, \quad f_{ba} = -R_{ab} = \frac{1}{\sqrt{2}} e^{-i \frac{\pi}{4}}
\]

then OUT is

\[
f'_{ab} = T_{ab}^2 + R_{ab}^2 = 0, \quad f'_{ba} = -2T_{ab}R_{ab} = -1
\]
THE PARTICULAR GATE

probability 1/2

probability 1/2

probability 1
Implementation of this single qubit gate with three coordinates
gives a “quantum Fredkin gate"

Quantum Fredkin
I have suggested “universal” computation with the exactly solvable quantum system, “delta interaction”.

The key to this computation is the quantum interference of amplitudes of mutually exclusive events.

There is nothing to prevent discussion of more interesting computation on a closed string.
SOME CONCLUSIONS

- I have suggested "universal" computation with the exactly solvable quantum system, “delta interaction".
- The key to this computation is the quantum interference of amplitudes of mutually exclusive events.
- There is nothing to prevent discussion of more interesting computation on a closed string.
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