Reversible Computing

Theory of reversible computing : expressing all computations as invertible functions. Laws of Physics are reversible but computations are irreversible.

Author gives us motivations as to why we should explore reversible computing:

Bridge the gap between computation and physics. Physics is reversible but computations are not. So how can we bridge this?

Entropy is used as a measure of uncertainty of probability distribution. Entropy is used as a measure of chaos/randomness.

No-hiding theorem - Information cannot be created or destroyed. Information can be made more ordered or disordered, but if we choose to make it more ordered then an energy cost has to be paid.

Correlations: relative entropy.

Power dissipation: the energy released when for instance, we clear memory.Information cannot be destroyed. So, it has to be evicted. The process of eviction releases heat.

Paper proposes a technique where this power dissipation is zero.

Fan-out and XOR are not bijections (they do not go from unique x to unique y). But both can be expressed as a single invertible function. Fan out has extra inputs and xor has extra outputs. Garbage: the bits that are not used for the functions.

Fundamental theorem of paper: every finite function can be expressed as an invertible realization by embedding it in a larger space.

NAND gate - universal gate. Every operation can be expressed using a number of NAND gates.

Reversible universal primitive: We get both NAND and AND gates by building an invertible realization of the AND gate.

Boolean ring: A ring is like a vector space with 2 operations: addition and multiplication.

NAND is universal for regular logic and for reversible computing.
Temporary storage: Storage and computation can occur at the same time - which is a new property of this technology.

Every invertible function can be represented as a combination of theta 1, theta 2 and theta 3.

Turing Machines, conservative logic : invertible operations can be embedded in these reversible structures.

Quantum computing is essentially all reversible operations. Quantum computing is an approximation of an unitary operator. Every q. Computer is a reversible computer. An unitary operator can be thought of as a hermitian conjugation operation on a matrix which gives a new matrix which when used with the original matrix gives an identity matrix.

In Quantum computing, quantum states are used to represent bits. Evolution of a Quantum state can be represented by an unitary operator.Unitary operators describe an operation.

Why is this technology not implemented in CMOS?

We ideally want everything to be integrated into CMOS. However everything needs to be very slowly integrated in CMOS which makes it a practical barrier.We could theoretically implement it in CMOS but won’t really benefit us because of garbage and constant bits. And also because it cannot mitigate all power dissipation. We can make CMOS reversible but it will not make it 0 energy.

Why is there so much hype around Quantum computing?

Shor’s algorithm to bypass cryptography algorithms has generated a lot of interest.Using Shor’s algorithm one can find the solution in log time rather than using bruteforce solutions to find keys.

How much energy is used in storage?

Author argues that one can add bits in sources and sinks for free. However in practise, it will add energy. The author has assumed storage is free but that is not so.