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Information without Information:
Quantum physics and the nature of reality

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Quantum Physics as Information

❑Physics all about predictions
❑Information about the system crucial
❑How much information?
❑What is the speed of processing?

Laplace: Gimme all positions and velocities of all particles and I will tell you the future exactly.
Maxwell: Gimme all positions and velocities of all particles and I will violate the Second Law.
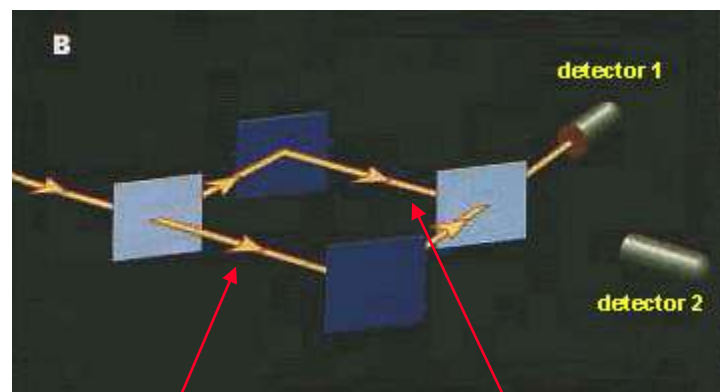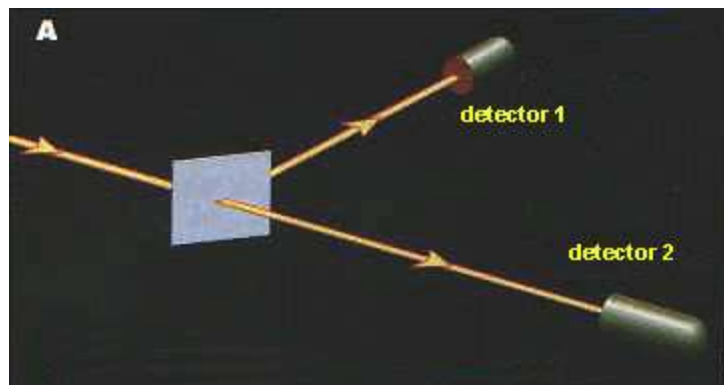
Catalogue of Information

❑ States of physical systems are betting portfolios

❑ Laws of physics: how does the portfolio change in time?

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$
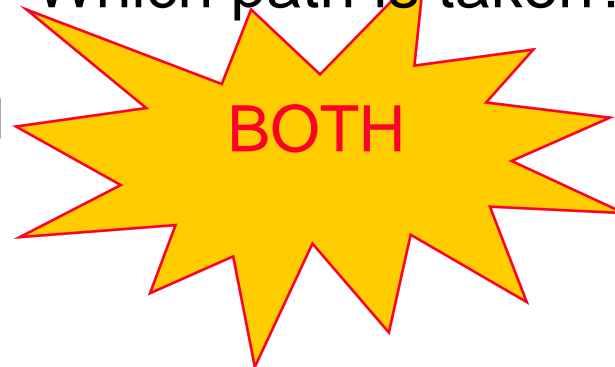
Quantum betting: Two things at once

Which path is taken?

SUPERPOSITION ⬅ BOTH

Superposition principle

Suppose we want to encode a bit of information into a state of photon after the beam-splitter.

Classical bit can be in only two possible states 0 or 1; qubit can be in any superposition as above.

$$|\psi\rangle = a\begin{pmatrix} 1 \\ 0 \end{pmatrix} + b\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} a \\ b \end{pmatrix}$$

Quantifying Information

All we need is probability for something, p.

$$I = \log 1/p$$

Construct everything from probabilistic events.

Kelly's betting:
$$W = 2^{n(1-I)}$$

Classical Versus Quantum Physics

Classical physics describes large (slow) objects. Crucially it is deterministic.

Quantum physics was introduced to describe small objects. (but we know it also applies to large ones!). It is indeterministic.

Schrödinger: Entanglement is the key difference!

Entanglement

E.Schrödinger, ``Die gegenwärtige Situation in der Quantenmechanik'',Naturwissenschaften, **23**, 807-812 (1935).

$$\left| \Psi_{ab} \right\rangle \neq \left| \Psi_a \right\rangle \otimes \left| \Psi_b \right\rangle$$

Information about "a" and "b" is not the same as information about "a" and information about "b"!

Not in the mind of God!

Einstein: "Spooky Action at a Distance."

$$\left|\psi^-\right\rangle = \left|\uparrow\right\rangle\left|\downarrow\right\rangle - \left|\downarrow\right\rangle\left|\uparrow\right\rangle$$

$$\left|\psi^-\right\rangle = \left|\rightarrow\right\rangle\left|\leftarrow\right\rangle - \left|\leftarrow\right\rangle\left|\rightarrow\right\rangle$$

Measure one of the spins – know immediately the value of the other.

Key conclusion: the value of spin does not exist before it is measured! Randomness and breakaway from causality.

Bohr-Einstein Dialog

Bohr and Einstein in the twenties, at the house of Paul Ehrenfest.

Einstein:
„Out there is this huge world, which exists independently of us human beings and which stands before us like a great, eternal riddle, at least partially accessible to our inspection."

Bohr:
„There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about nature."

Universe as Information

- The Universe is fundamentally made up of bits of information, not matter and energy;

- The same information at the root of various physical, biological, computational and even economical and sociological phenomena;

- Ultimately, information is quantum…

- Reality emerges through an interplay between the random and deterministic.
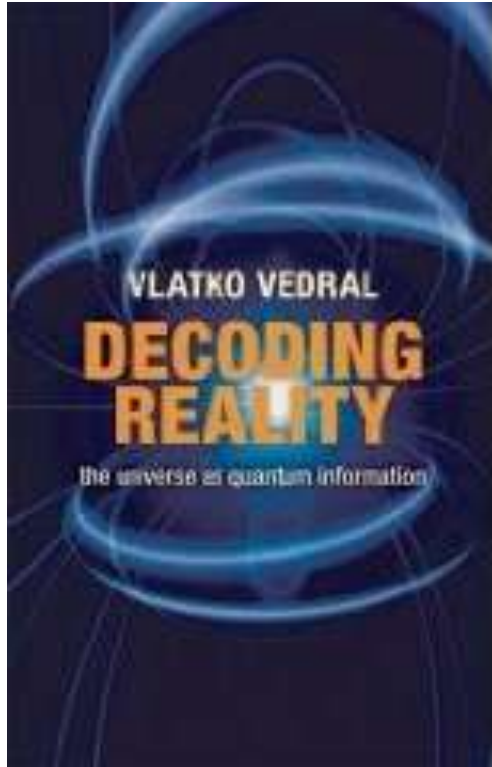
Reality as a Game of Cards

Have:

Want:

Two rules:
1. You can only ask for a card if you have one of the same kind;
2. If asked and you have this type of card you must give it up.

Amazing conclusion: DON'T NEED CARDS TO PLAY THE GAME!

Further reading

www.vlatkovedral.org

More formal reading:
1. Vedral, Rev. Mod. Phys. (2002);
2. Amico, Fazio, Osterloh, Vedral Rev. Mod. Phys. (2008);
3. Maruyama, Nori, Vedral, Rev. Mod. Phys. (2009).