Simulated Time Travel, Teleportation without communication, and How to conduct a Romance with Someone who has fallen into a black hole

QUPON
Wien
24 May 2005
in honor of Prof
Anton Zeilinger

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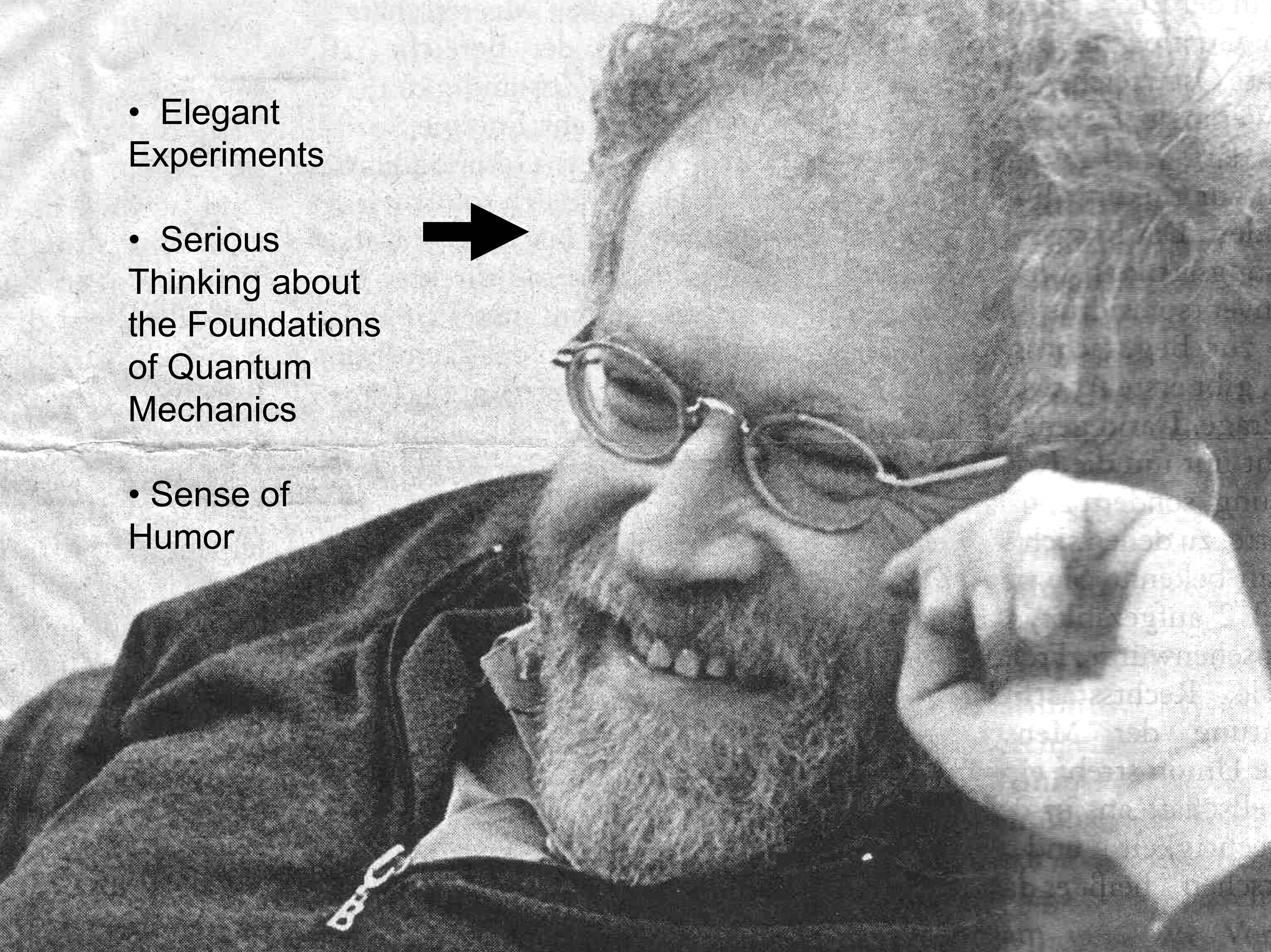
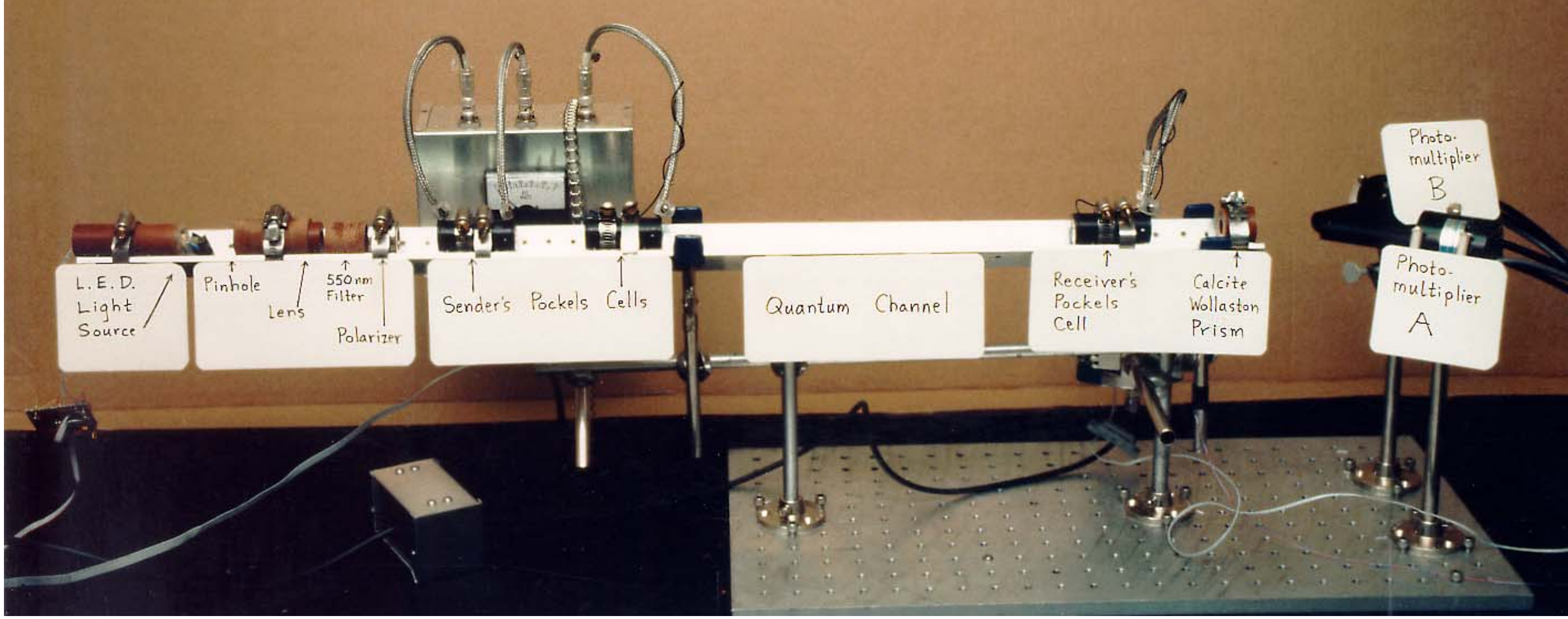
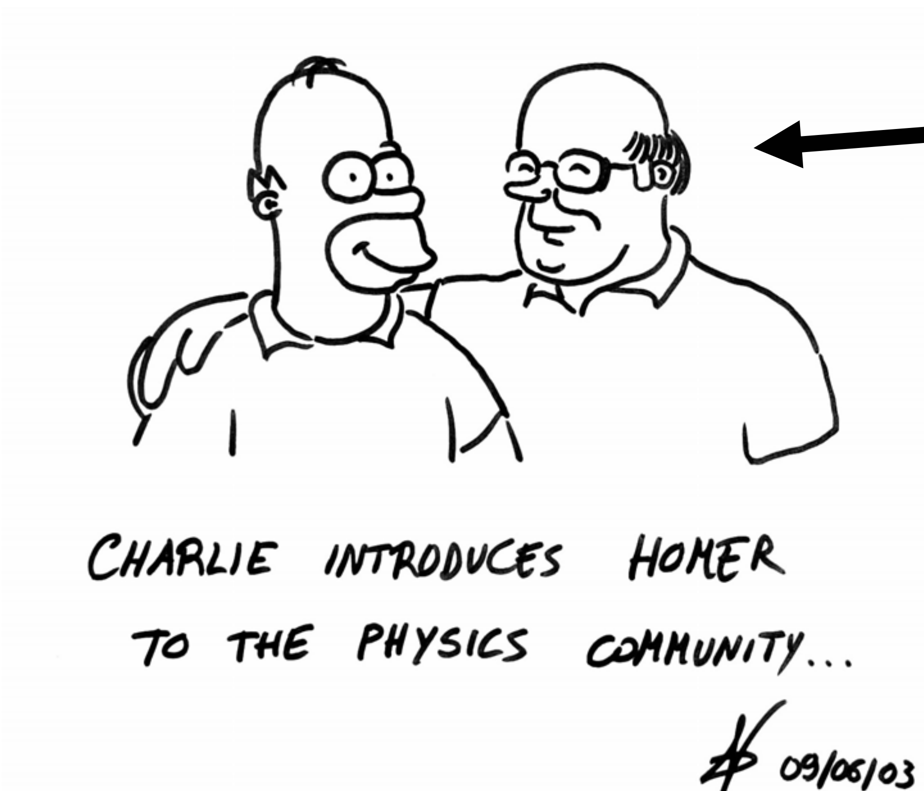
- Elegant Experiments
- Serious Thinking about the Foundations of Quantum Mechanics
- Sense of Humor







- Very Crude experiments

- Looking for Quantum Metaphors in the realms of Commerce, Love, Religion, and Popular Culture.

- Today I will add Ethics.

- The Metropolis Monte Carlo Method

- Simulated Time Travel, classical and quantum

- The Black Hole information problem.

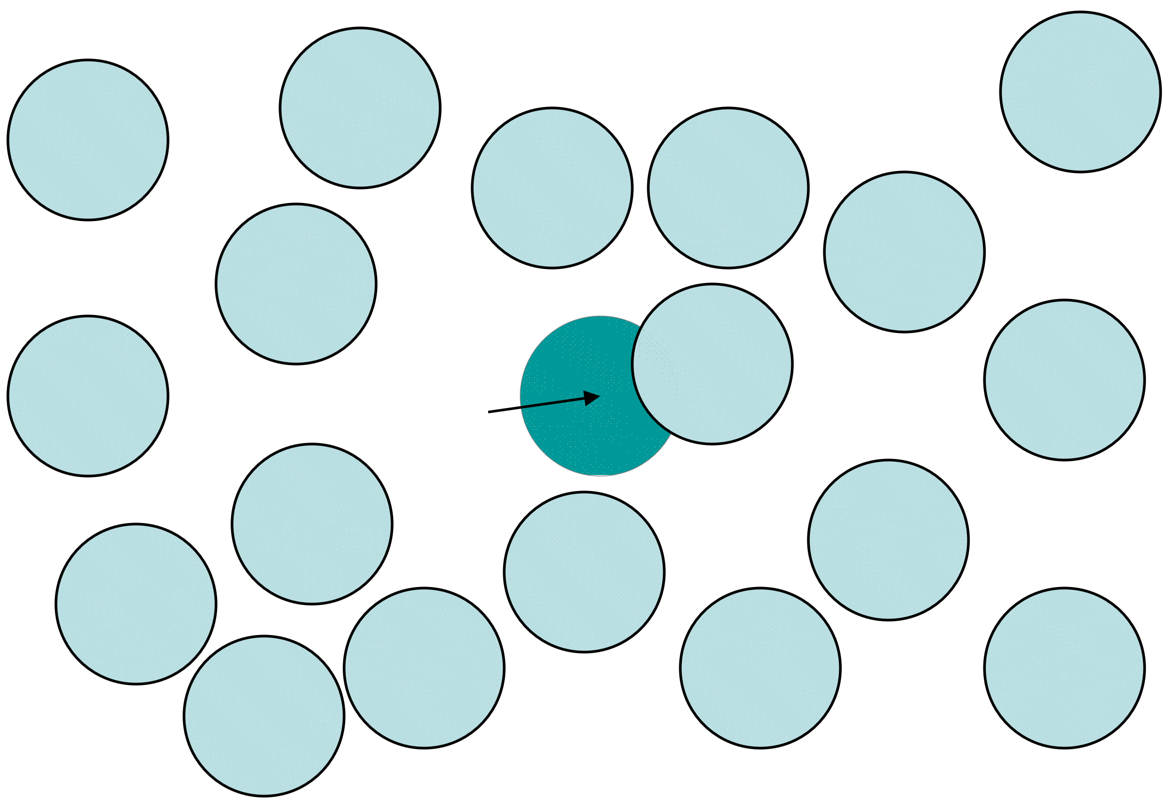
- Teleportation Without Communication as a possible solution to it.

- What romantic possibilities remain for a couple one of whom has fallen into a black hole, and what is the technology and etiquette for conducting such a doomed romance?

In perhaps the second most important scientific paper of 1953, Metropolis, Rosenbluth, Rosenbluth, Teller, and Teller, then all alive and mostly married to each other, introduced their "Monte Carlo method" for fairly sampling configurations of a classical mechanical system at thermal equilibrium, and applied it to a dense 2 dimensional gas of hard disks.

The MMRTT or Metropolis Monte Carlo method works by generating *trial moves*, e.g. random small displacements of a single particle, which are then accepted or rejected according to whether they increase or decrease the system's potential energy. Energy-decreasing trial moves are always accepted, while energy-increasing trial moves, which are typically far more common, are accepted with probability $\exp(-\Delta E/kT)$ where ΔE is the energy change, T is the absolute temperature, and k is Boltzmann's constant.

The usual MRRTT Monte Carlo method is not afraid of failure. If a trial move is rejected, one wastes no further time on it, but generates another in hopes that that will be accepted, or if not that the next…



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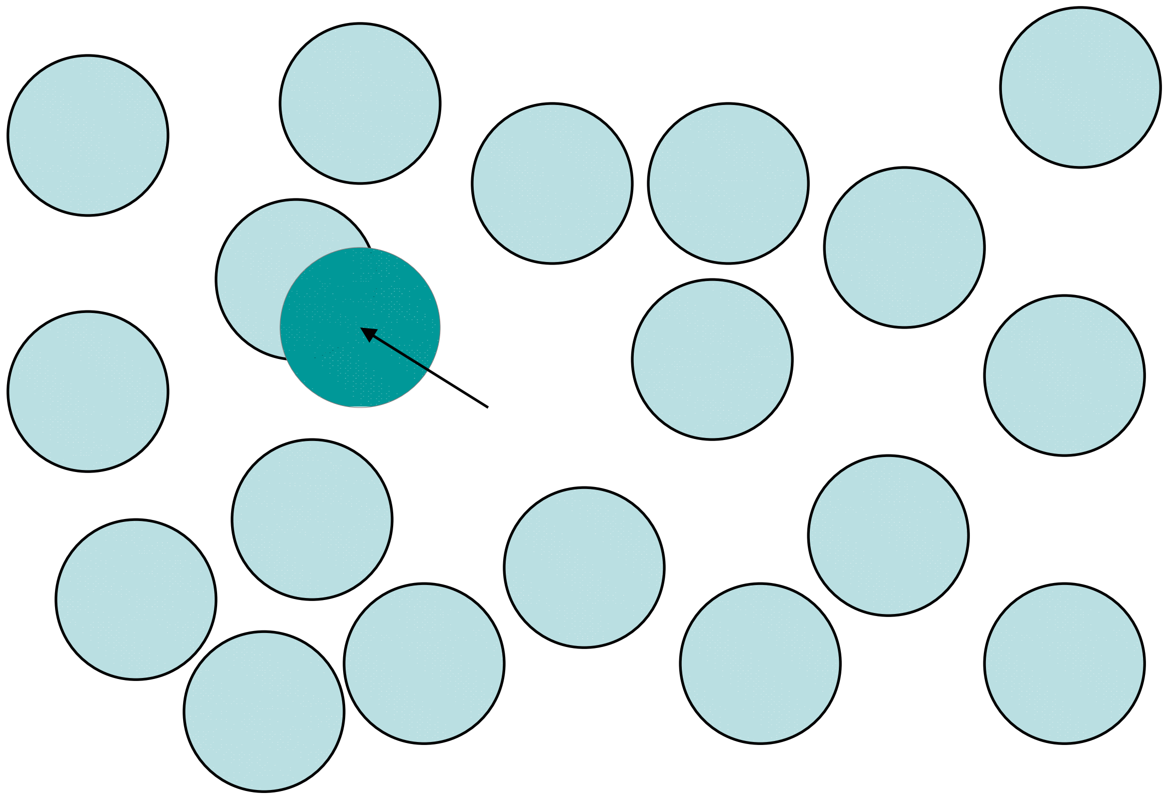

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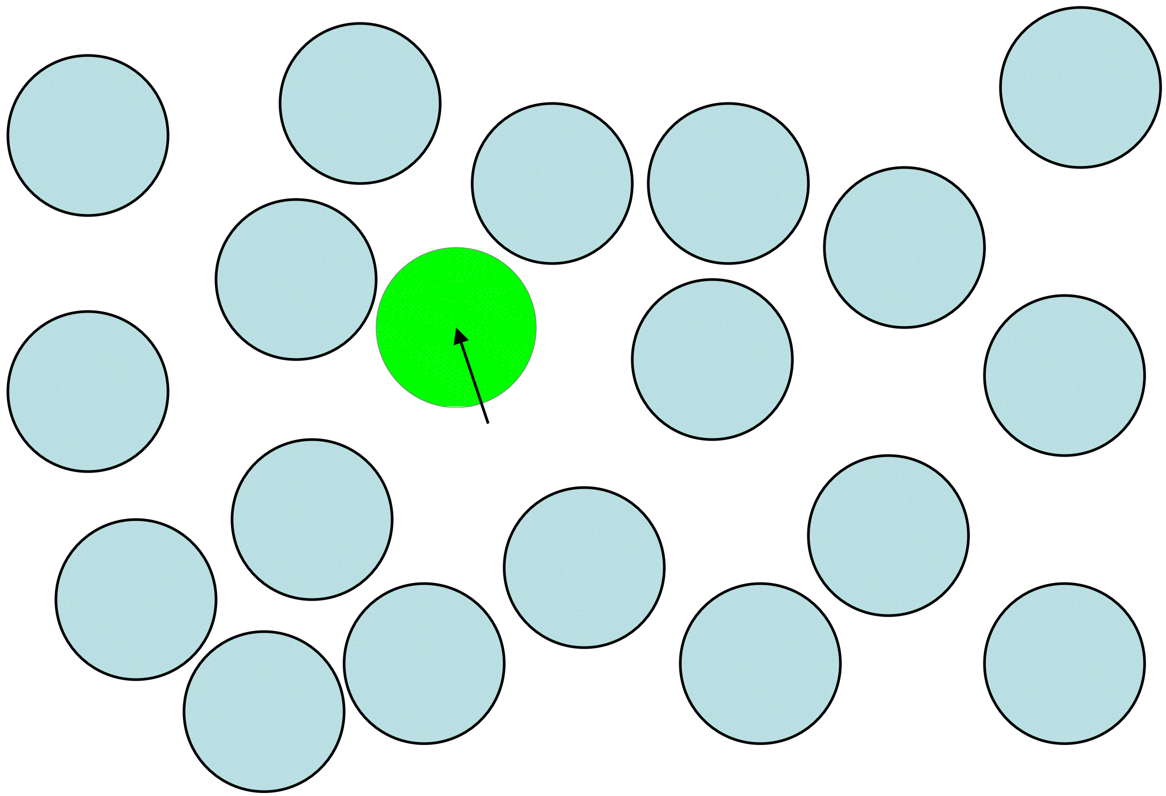
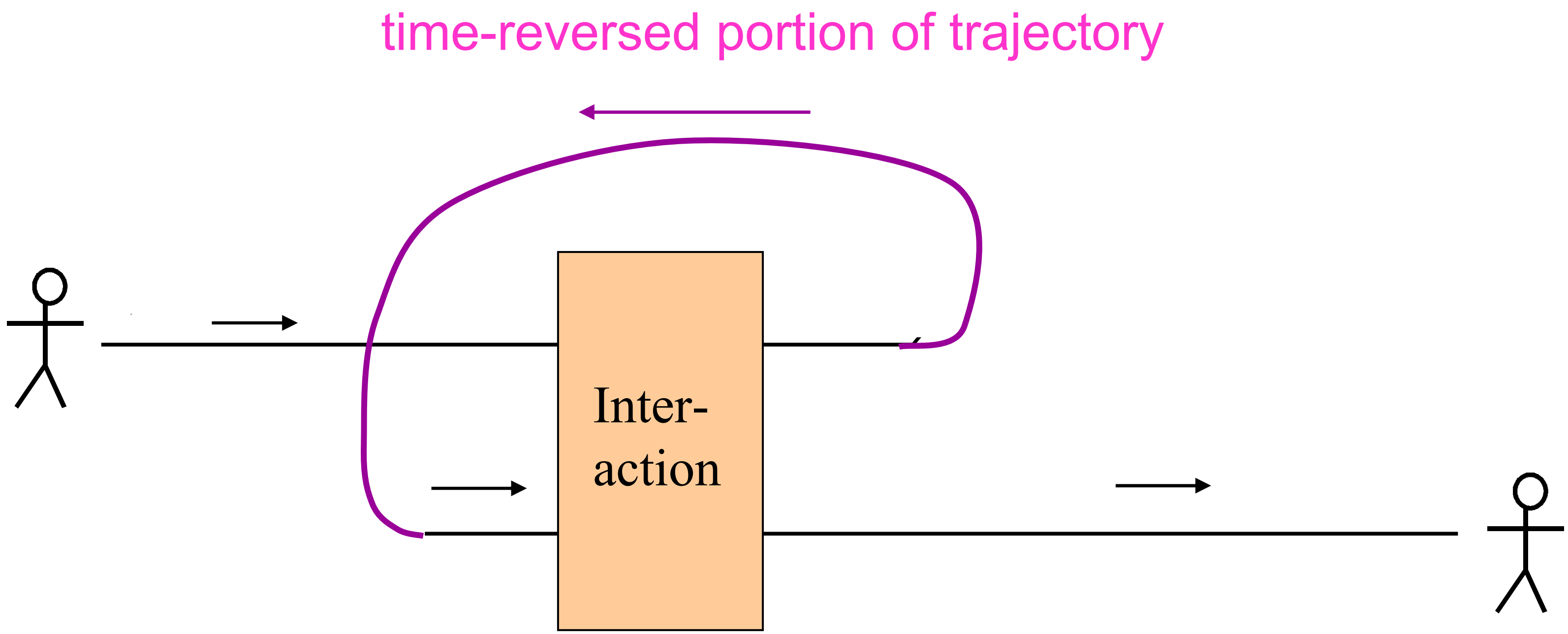


But all this failure can be bruising to the ego. In what might be called the Woody Allen version of the Monte Carlo method, testing is delayed to the end of the run, so as to postpone failure, even at the cost of increasing its likelihood.

"An optimist is a person who goes to an expensive restaurant, planning to pay for his dinner with the pearl he might find in his oyster."

(Unpublished "work" with Ben Schumacher)*

Interaction with one's past self using an exotic physical time machine, such as a Wormhole

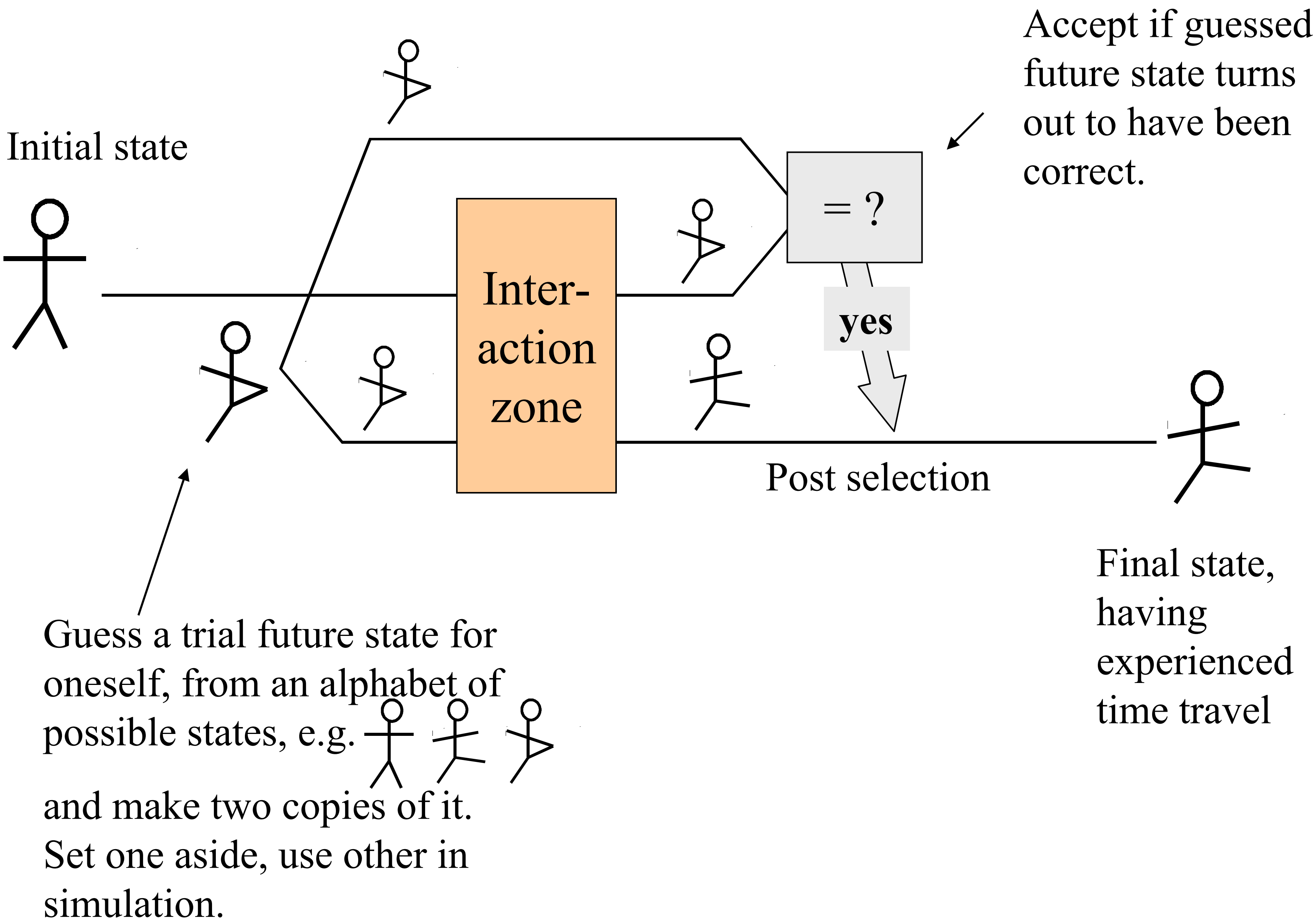


For some initial conditions, no future is possible (the so-called grandfather paradox).

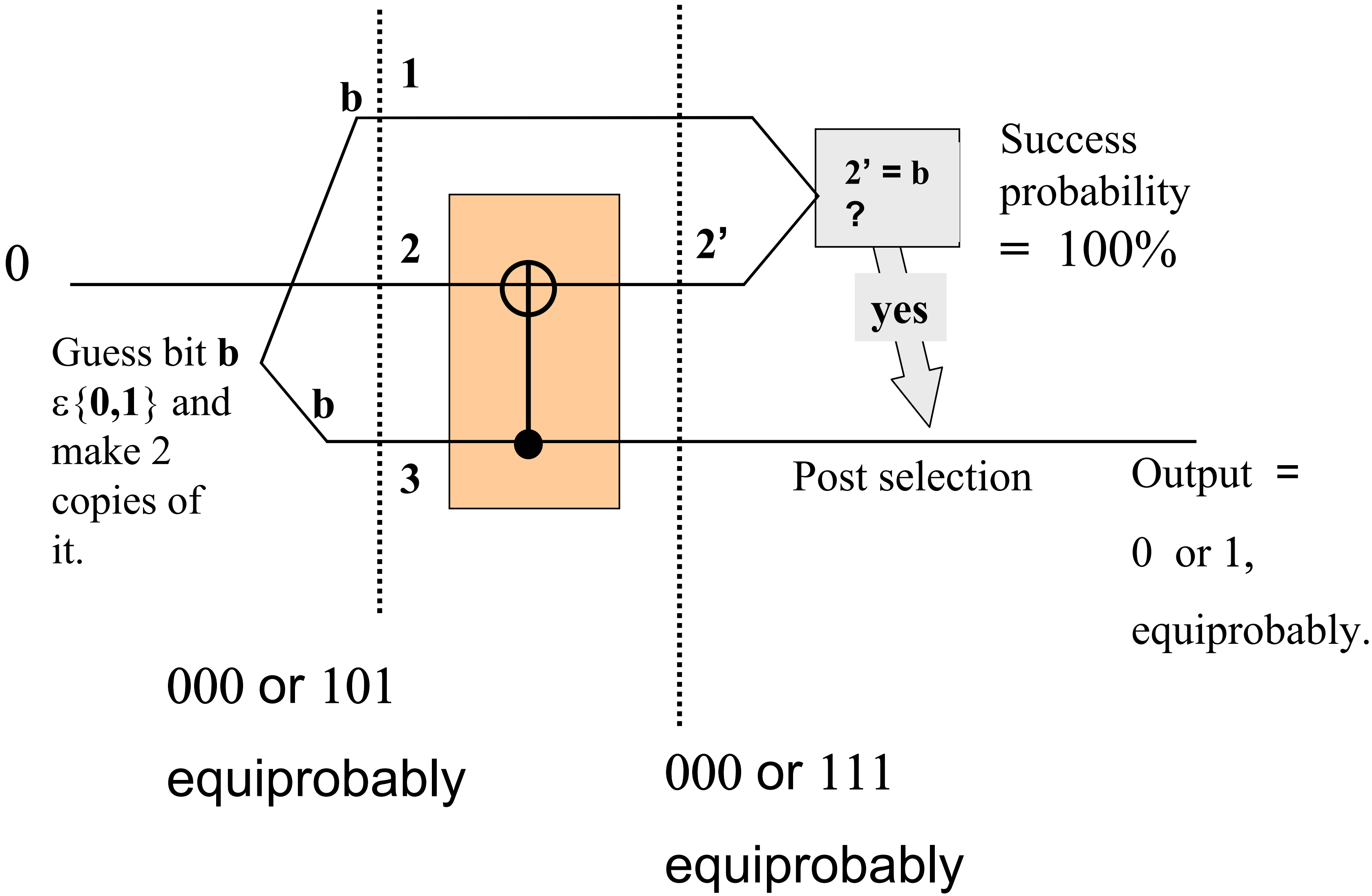
For others, multiple futures are possible.

*cf D. Deutsch, *QM near closed timelike lines* Phys.Rev. **D44,** 3197–3217 ('91)

Woody Allen MC can be used to simulate time travel without need of any exotic physical equipment.



Consider the case of a single bit, with an XOR interaction.
If initial state is 0, multiple futures are possible.

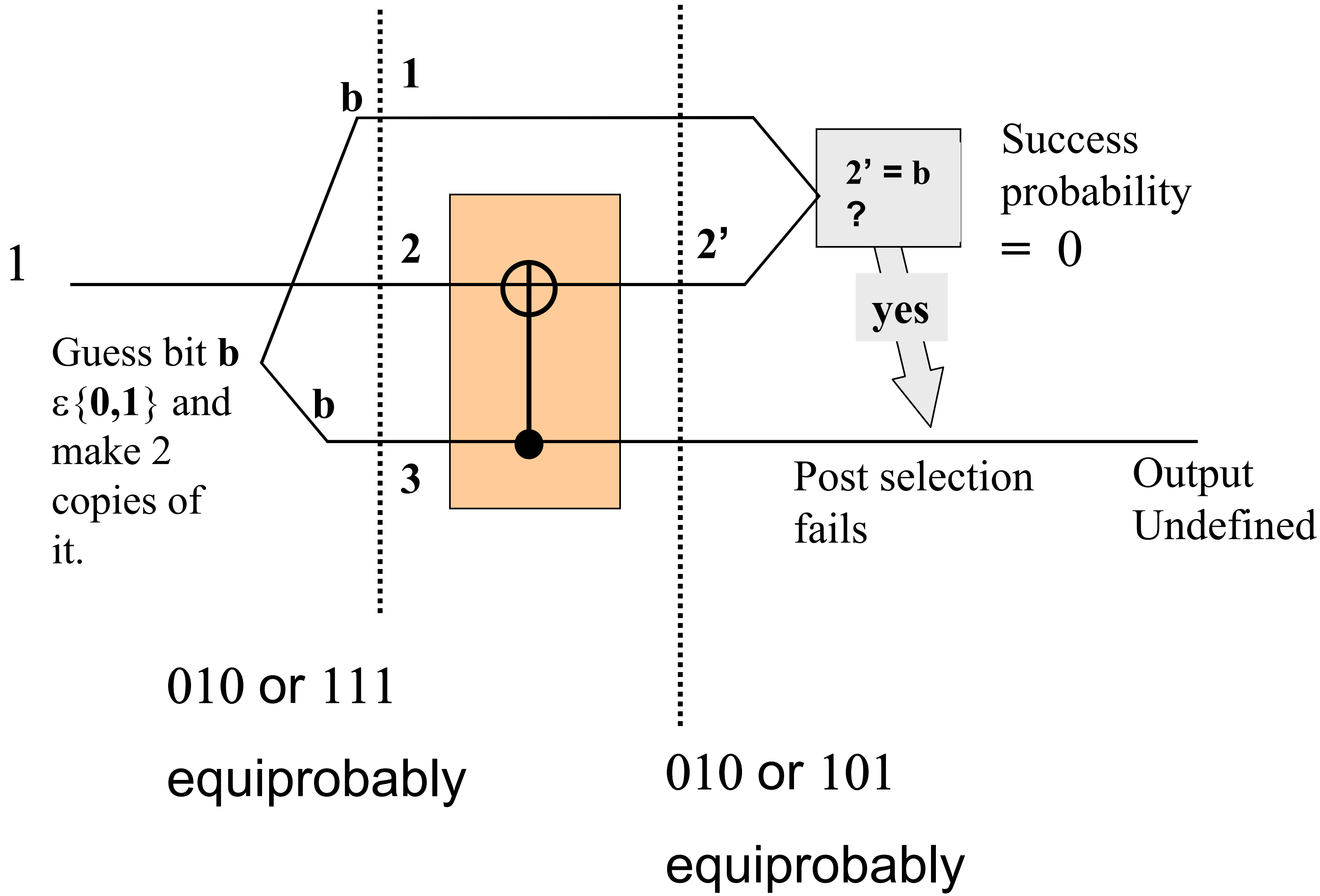


Ben Schumacher's story exemplifying multiple futures:

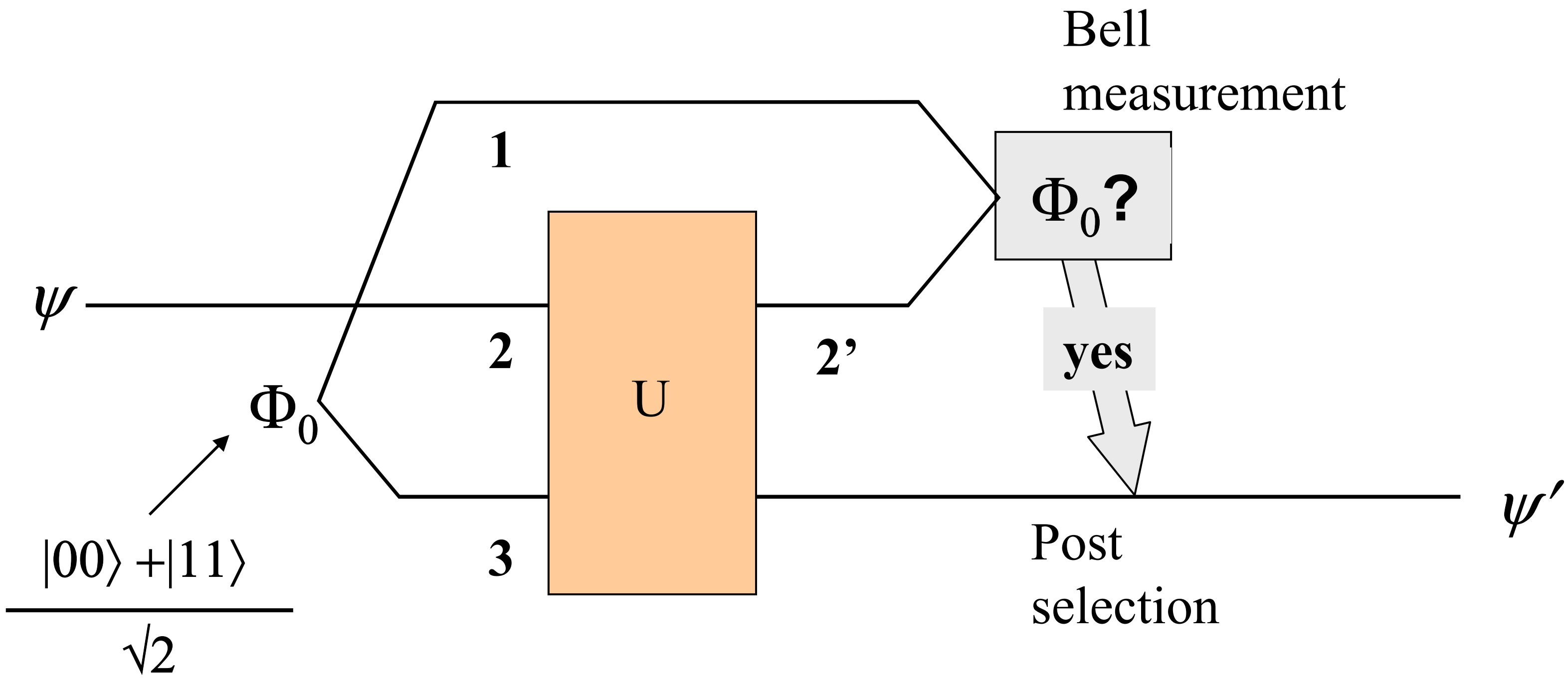
A: The time traveler, on his way to work one morning, meets a stranger who looks rather like him. The stranger smiles at the time traveler, who smiles back, and the two continue on their way. Later the time traveler, in the course of his duties, meets the same guy and smiles back at him.

B: The time traveler, on his way to work one morning, meets a stranger who looks rather like him. The stranger, for no reason, punches the time traveler and escapes down an alleyway. Later the time traveler, in the course of his duties, meets the aggressor and punches him back, escaping down an alleyway to avoid a more serious fight.

If initial state is 1, ***no future*** is possible (grandfather paradox).

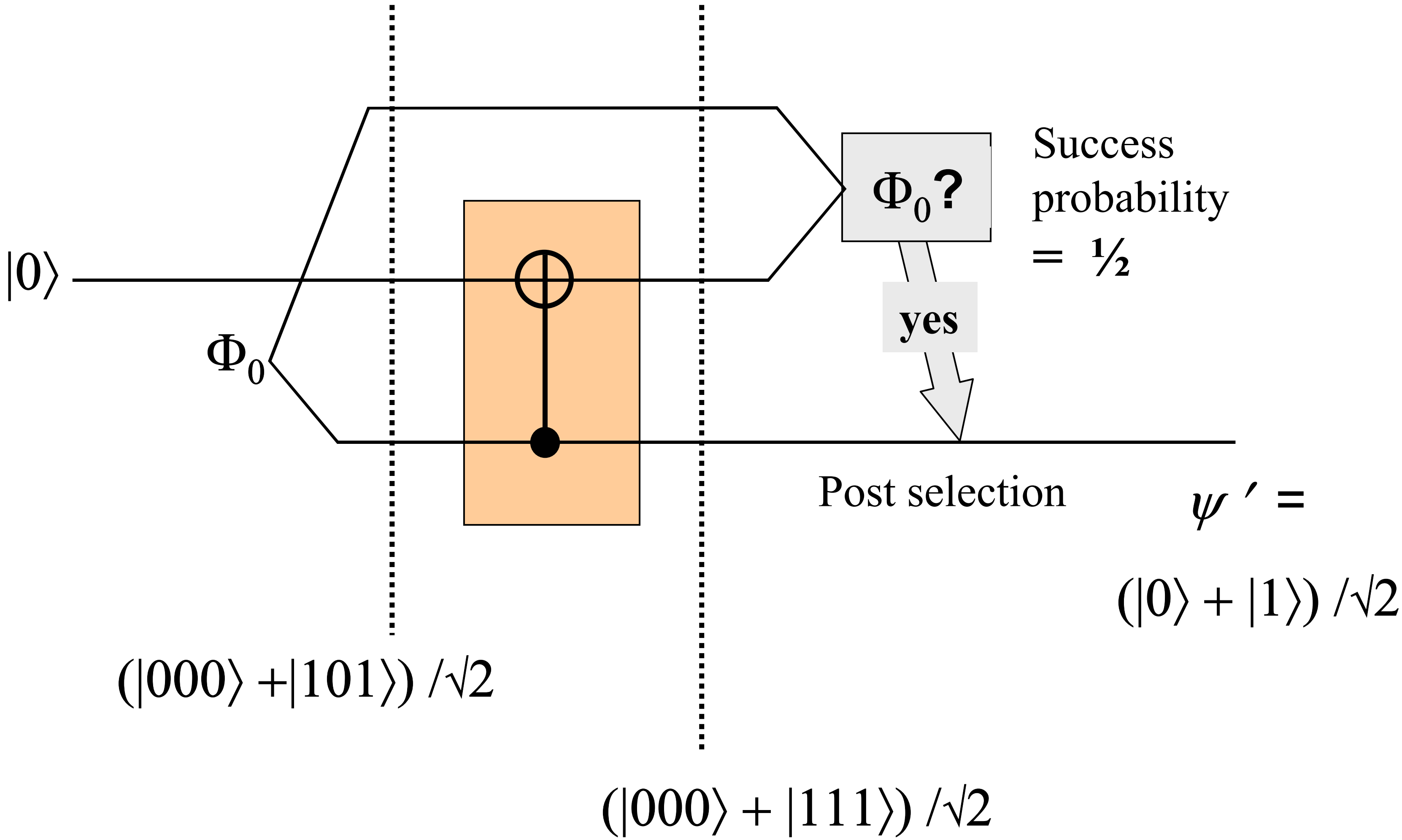


Quantum version of Woody Allen MC uses an entangled state *(deterministic)* instead of the *random* guessed future.

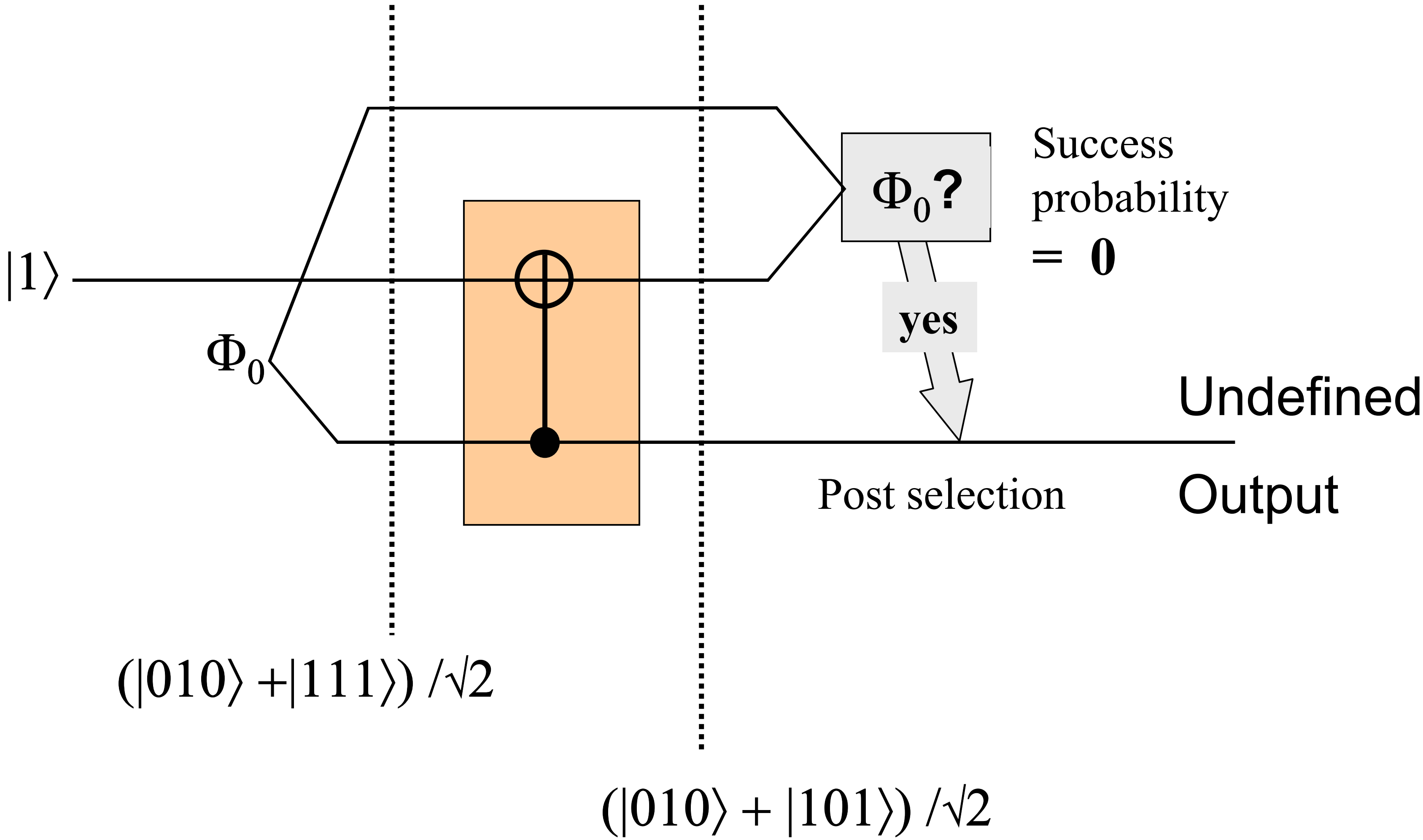


If the post selection was successful, qubit 1 may be viewed as a time-reversed version, and qubit 3 may as a time-traveled version of qubit 2'. The overall input-output state mapping is what it would have been with a physical time machine, for 0,1 basis states, and for arbitrary superpositions. Pure inputs are mapped to pure outputs.

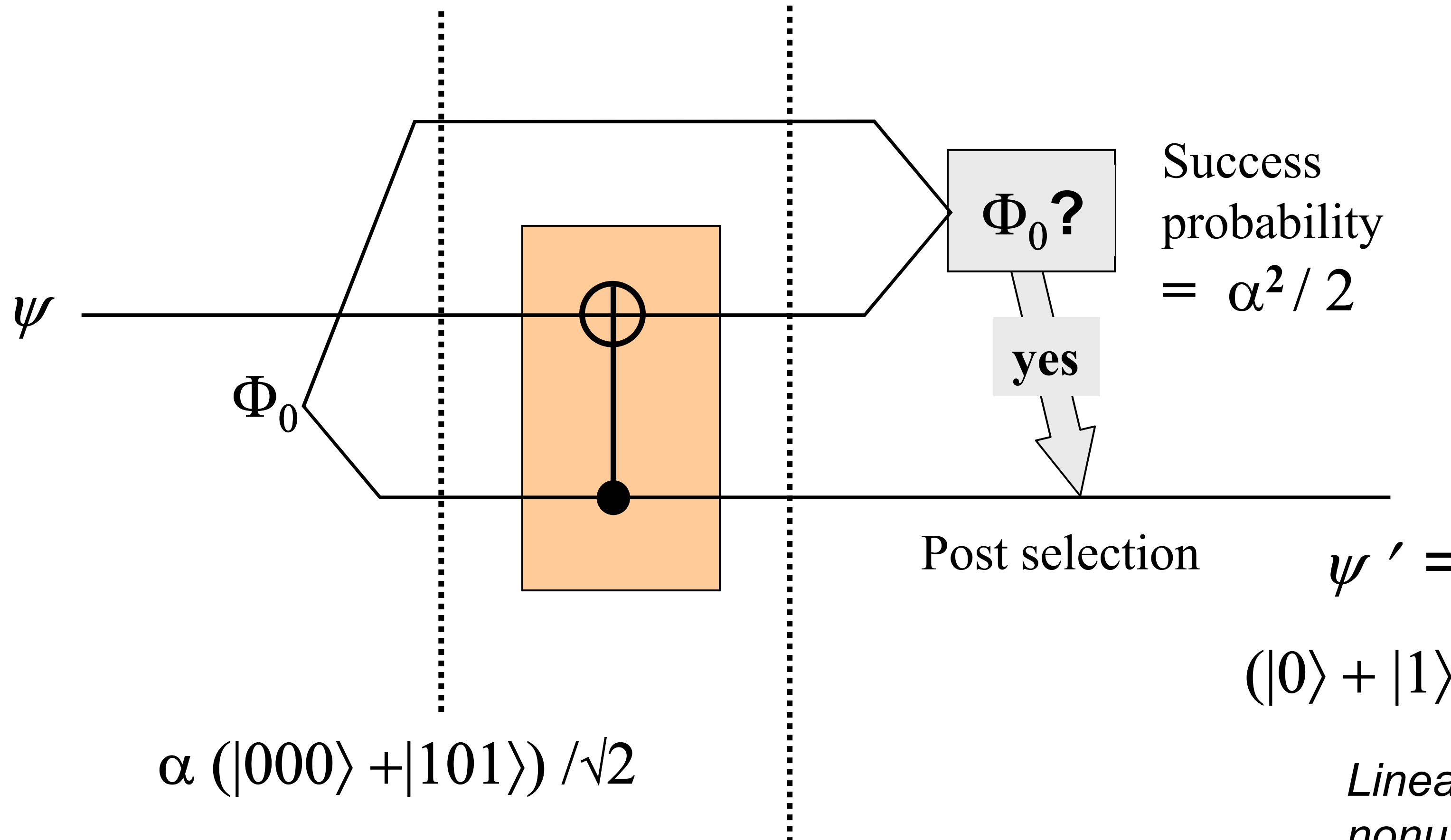
Quantum Version of multiple futures case gives deterministic superposition state as output, not a probabilistic mixture.



$U = \text{CNOT}, \ \psi = |1\rangle$ gives rise to Grandfather paradox.



General input $\psi = \alpha|0\rangle + \beta|1\rangle$ always gives same deterministic output, failing only when $\alpha = 0$. Grandfather paradox is confined to a set of initial conditions of measure 0.



$(|0\rangle + |1\rangle)/\sqrt{2}$

$\alpha\,(|000\rangle + |101\rangle)/\sqrt{2}$

$+\beta\,(|010\rangle + |111\rangle)/\sqrt{2}$

$\alpha\,(|000\rangle + |111\rangle)/\sqrt{2}$

$+\beta\,(|010\rangle + |101\rangle)/\sqrt{2}$

Linear but nonunitary function of input state

Q. Is it time travel?

A. It depends on what your definition of "is" is.

Q. Doesn't it imply cloning?

A. No. The older and younger versions of same qubit are not independent and cannot be separately measured to get a better state estimate. By measuring the younger, the older is affected.

Q. What is the output state when the post selection fails?

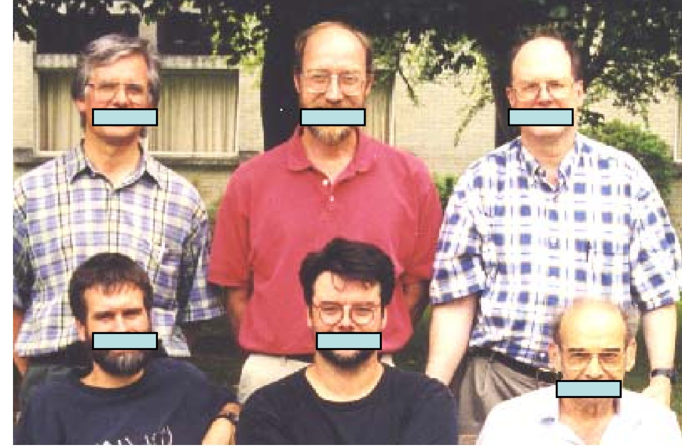
A. Shut up! (More seriously, the output state of the procedure is defined as what it would be if the post selection succeeded, so it is only undefined when the success probability is zero.)

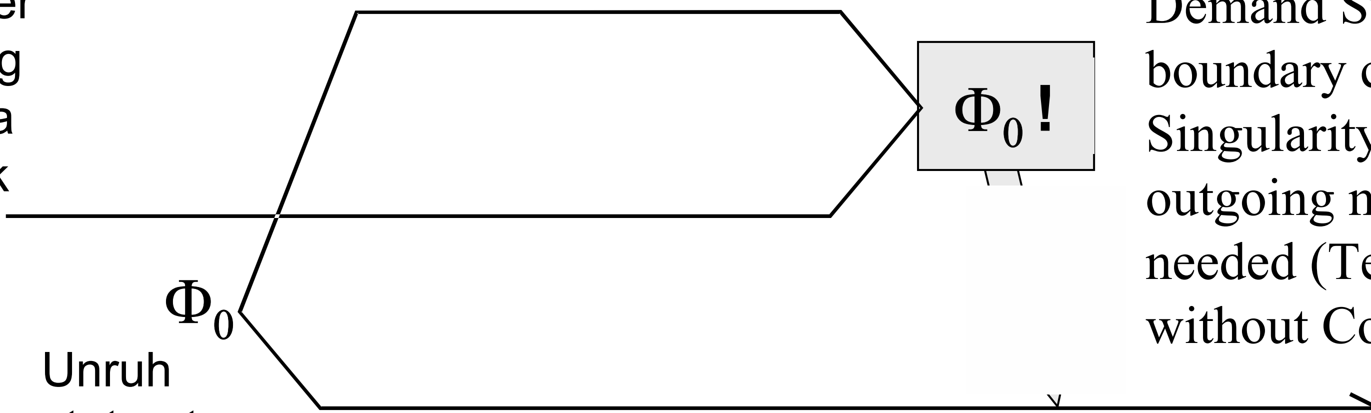
The Black Hole Information Problem

When a black hole forms, then evaporates, is the Hawking radiation that comes out truly random, or is it a unitarily transformed version of what fell into the black hole?

Hawking himself used to believe the former, and many experts still do; but now he believes the latter, as do many other experts.

Horowitz and Maldacena hep-th/0310281 *have proposed an idea like simulated time travel to resolve the black hole information problem.*

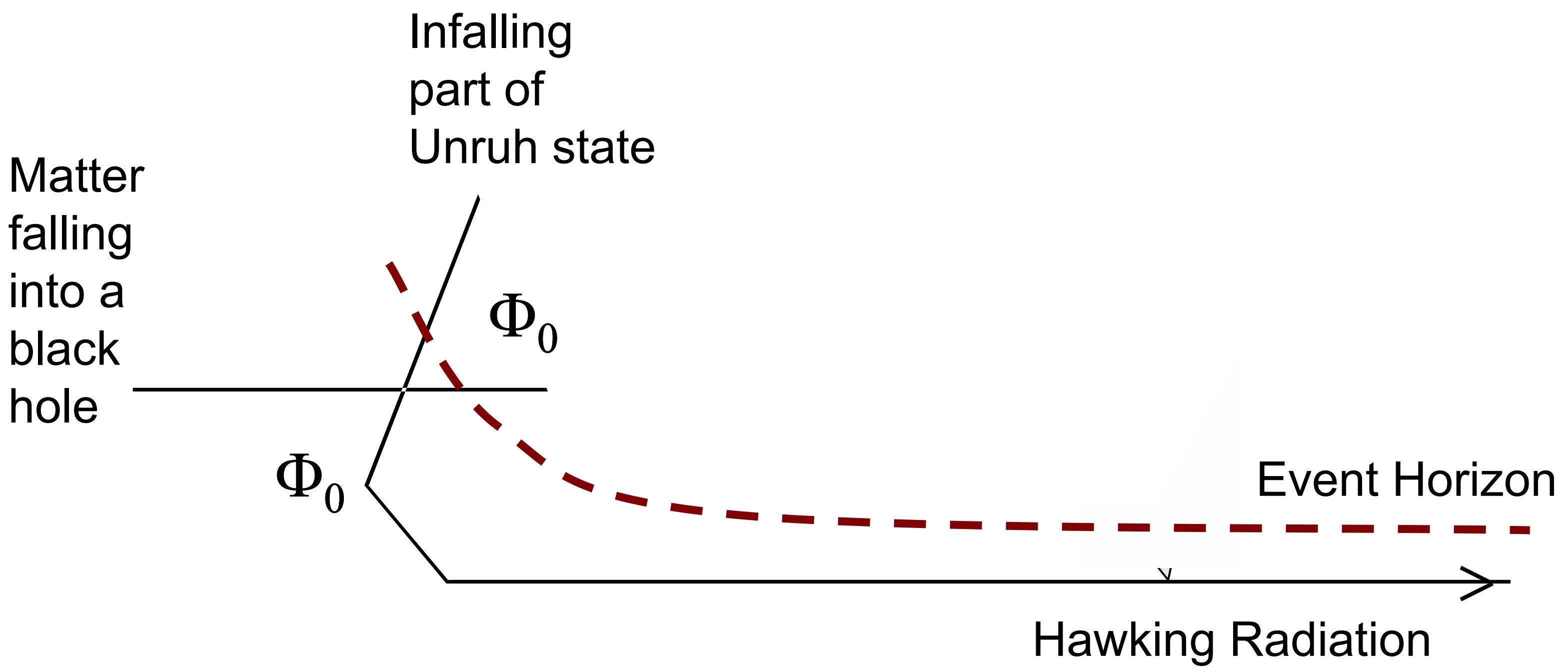




Demand Success as a boundary condition at the Singularity, so no outgoing message is needed (Teleportation without Communication).

The Bell state initial and final conditions establish a unitary relation between infalling matter and outgoing Hawking radiation.

But Gottesman and Preskill observed that if the infalling matter and Unruh radiation interact on the way in, the induced mapping will no longer be unitary.



Possible resolution: apply the Bell boundary condition not at the singularity but at the event horizon, thereby preempting interaction & restoring unitarity.

Principal objection to a boundary condition at the event horizon:

The event horizon is not locally distinguished from other places, so there is no reason to expect any unusual physics there. A person falling through the event horizon of a large black hole would not even notice.

Answer: the difference is not physical but *legal*. As soon as you cross an event horizon, I am no longer responsible for what you happens to you or what you think. From my viewpoint, matter and radiation lose their obligation to behave lawfully as soon as they cross a horizon.   (“Black hole complementarity”)

Real Estate metaphor for Black Hole Complementarity

Alice buys a luxury house from Bob, a friend of a friend, but agrees to let him continue living there for another week.

The hour of sale passes uneventfully, but for some reason the house begins to fall apart as soon as Bob is no longer the owner.

When new owner Alice complains, occupant Bob says “What damage? Everything looks OK to me.”

The BH information paradox is a controversial topic, to which all I bring is my own strong but poorly-informed opinion in favor of unitarity.

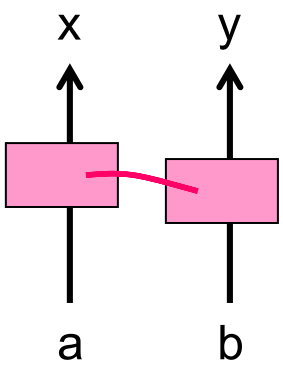
So let’s turn to a more productive topic:
Romance across an event horizon.
Suppose Alice has fallen into big black hole
and Bob, though unwilling or unable to join her,
still wishes to flirt with her.

How technically, can such a doomed romance be conducted, and what is the proper etiquette for doing so?

Natural Outdoor Vortex,

in a beaver pond,

showing surface-wave event horizon



Popescu-Rohrlich nonlocal boxes have been used by theorists to investigate hypothetical kinds of nonlocality stronger than entanglement, but still incapable of superluminal communication. However, as everyone knows, their main importance is as a popular Valentine's Day gift.

A nonlocal box (or more properly *pair* of nonlocal boxes) is a distributed 2-input 2-output device such that the outputs (x,y) are individually random, but have an XOR equal to the AND of inputs (a,b).
$x \oplus y = a \wedge b$.
A bidirectional channel with *no capacity* in either direction.

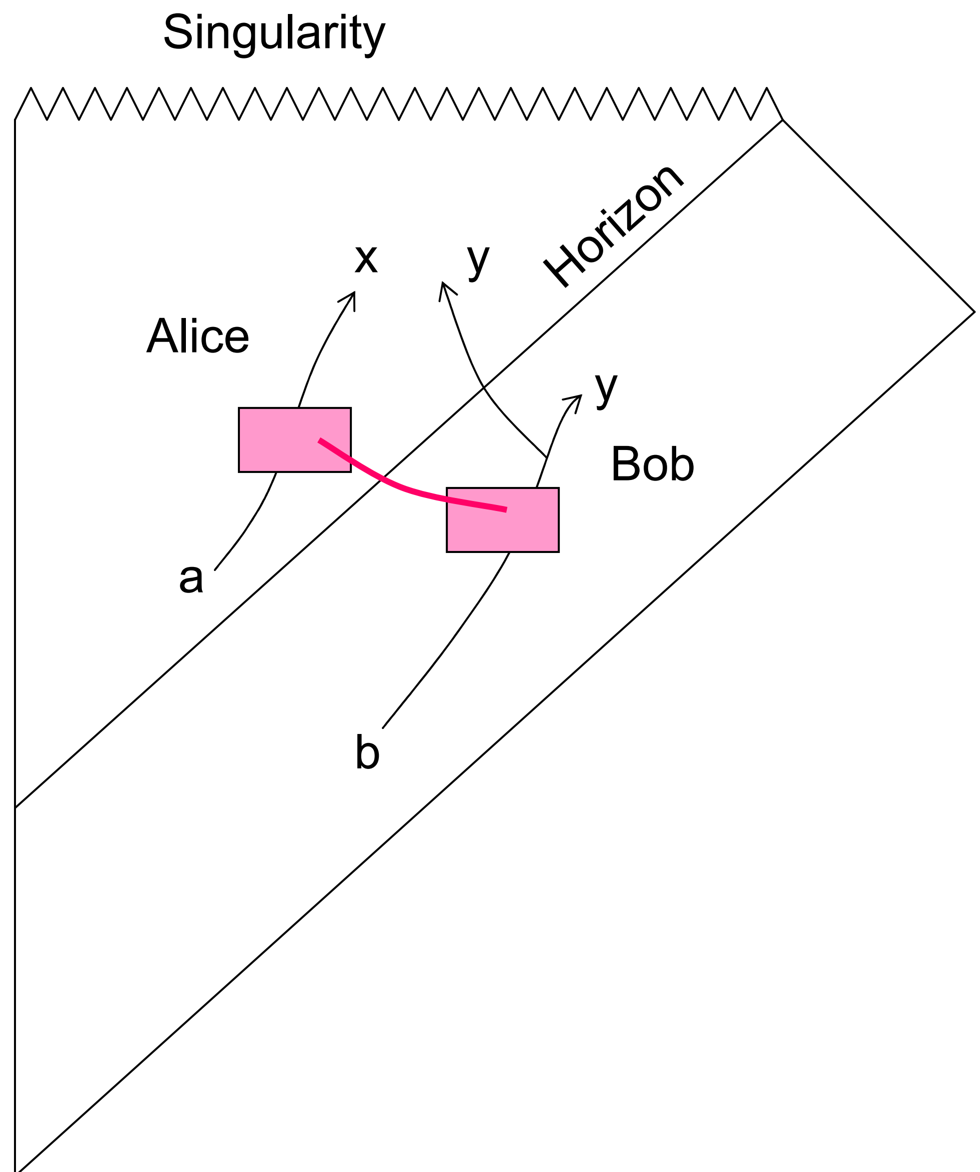
By each privately inputting their desire (1) or lack thereof (0), then exchanging outputs, Alice and Bob can answer the perennial question "Does he/she love me?" with minimum hurt feelings.

For example if Alice inputs 0 (No) and the two outputs are equal (No), she doesn't learn whether Bob loves her or not, sparing him some embarrassment.

Technology of Cross-Horizon Romance:

The Good News:
Nonlocal boxes have no communication ability in either direction. Therefore they could exist across a horizon without inflaming religious passions.

The Bad News:
Followup communication is only possible in one direction (from outside in), so, regardless of his input, Bob never learns whether Alice loves him or not.



Penrose diagram of Black Hole

Cross-Horizon Flirting, using nonlocal boxes.
Bob learns nothing of Alice's feelings for him, so w.l.o.g. we consider only the results from Alice's viewpoint, as a function of her NLB output and the followup message from Bob.

Dear Alice,

My NLB output was 0. I thought you'd like to know.

Goodbye Forever,

Bob

Alice's NLB input, output

1,1	0,0	1,0
Alice thinks: He loves me! I only wish I could tell him I love him too, forever!	Alice thinks: I don't like him, so I knew the output would be 0. But I wonder if he likes me--too bad I'll never know. But I have worse problems.	Alice thinks: Alas, my love for him is unrequited. ☹ At least he will never know how I felt.

Cross-Horizon Etiquette:
Other notes Bob could have sent.

Dear Alice,

Never mind the damned discreet NLB. This is no time for discretion. I love you!

Missing you forever,

Bob

Result:

Alice learns of Bob's love even if she is cool toward him. In fact she learns that he loves her so much he doesn't mind her finding out, even if his feelings are unrequited. Short of joining her in the black hole, this is the most comfort he can give her.

Cross-Horizon Etiquette:
Other notes Bob could have sent.

Dear Alice:

Never mind the NLB. I see no reason to hide my feelings. I never liked you.

So long, loser

Bob

Result:

Alice learns of Bob's lack of interest even if she is also cool toward him. This note is just plain cruel, adding insult to misfortune.

Ethical question: Is it wrong to offend or injure someone gratuitously after they have fallen into a black hole?

All this has strayed pretty far from hard science:

Unlike black holes, nonlocal boxes are not even known to exist physically. Moreover, the subjects of ethics and etiquette, if they can be considered science at all, are certainly a very soft science.

However, the last question, of whether it is wrong to hurt someone who has fallen into a black hole, is related to a real open question in hard science, namely the black hole information problem.

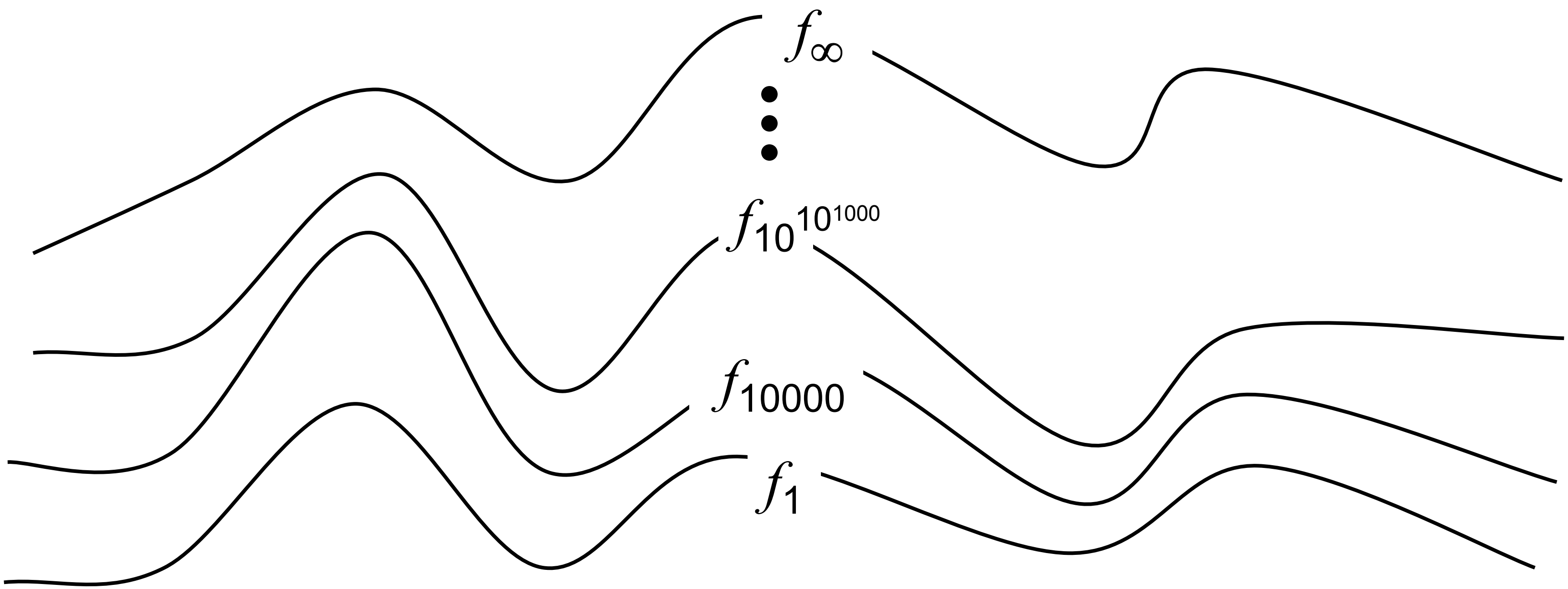
If black holes really destroy information, the cruel Bob of the last slide could comfort himself by saying that he has done no lasting damage, and that his “cruelty” was as temporary and ontologically dubious as the “path” taken by an unobserved photon through an interferometer.

But if black hole evaporation is unitary, then Bob can be held responsible both for his cruelty to Alice (which is real because evidence of it remains in the Hawking radiation) as well as for any additional damage caused by the Hawking radiation itself, e.g. bad “luck” in a Hawking-radiation-driven lottery.

A Scientific Question: If black hole evaporation is unitary, what is its computational complexity?

Could the process be unitary but uncomputable?

(A deterministic function can be uncomputable if, for example, it is the limit of a sequence of computable functions that converges with uncomputable slowness.)




The End