Quantum Entanglement, Bell's Theorem, and *Reality*

in 12 minutes

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Randomness in QM: Subjective or Objective?

- **Uncertainty Principle** predicts **incompatible observables** (e.g., position and momentum)
- Measuring one **randomizes** any subsequent measurement of the other
- **But before the first measurement, don't both have definite values?**

But before the measurement, don't both have definite values?

Partial Answer: **Bell's Theorem** (JS Bell, 1964):

Two possibilities…

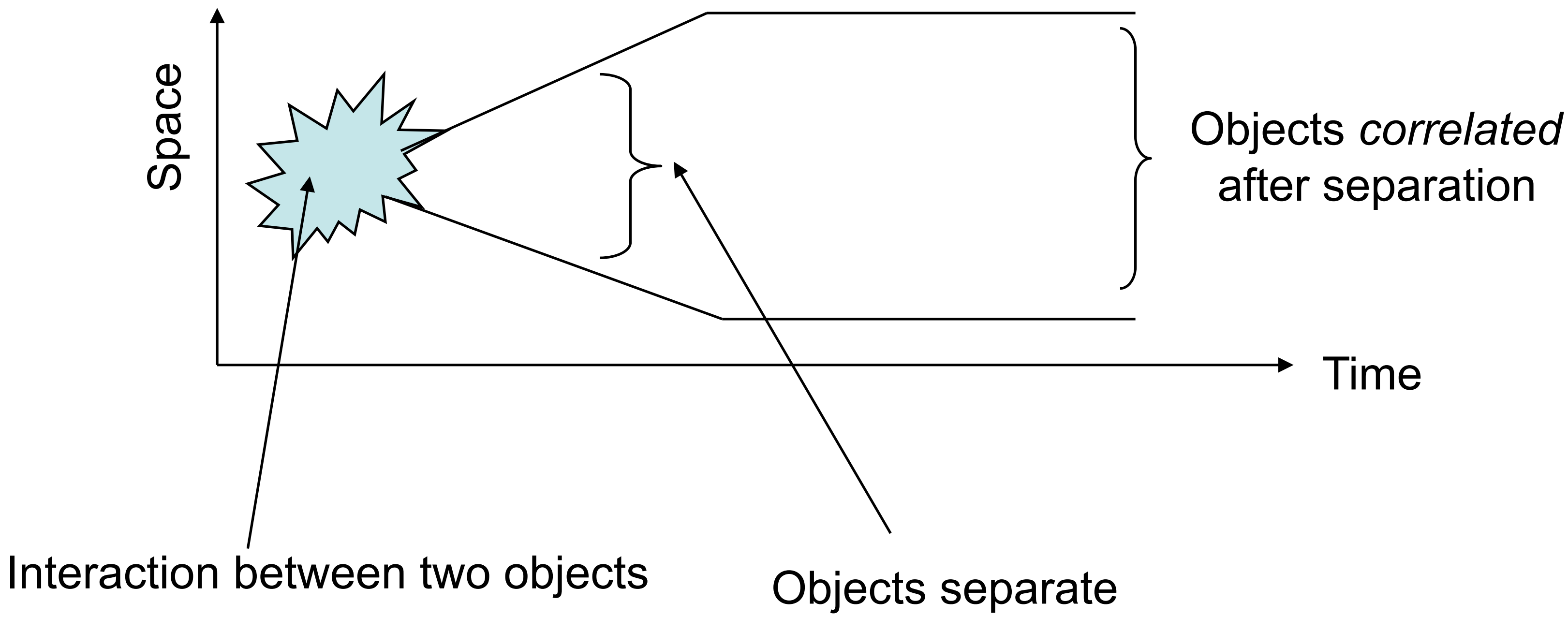
either:

Incompatible observables **don't** both have definite values

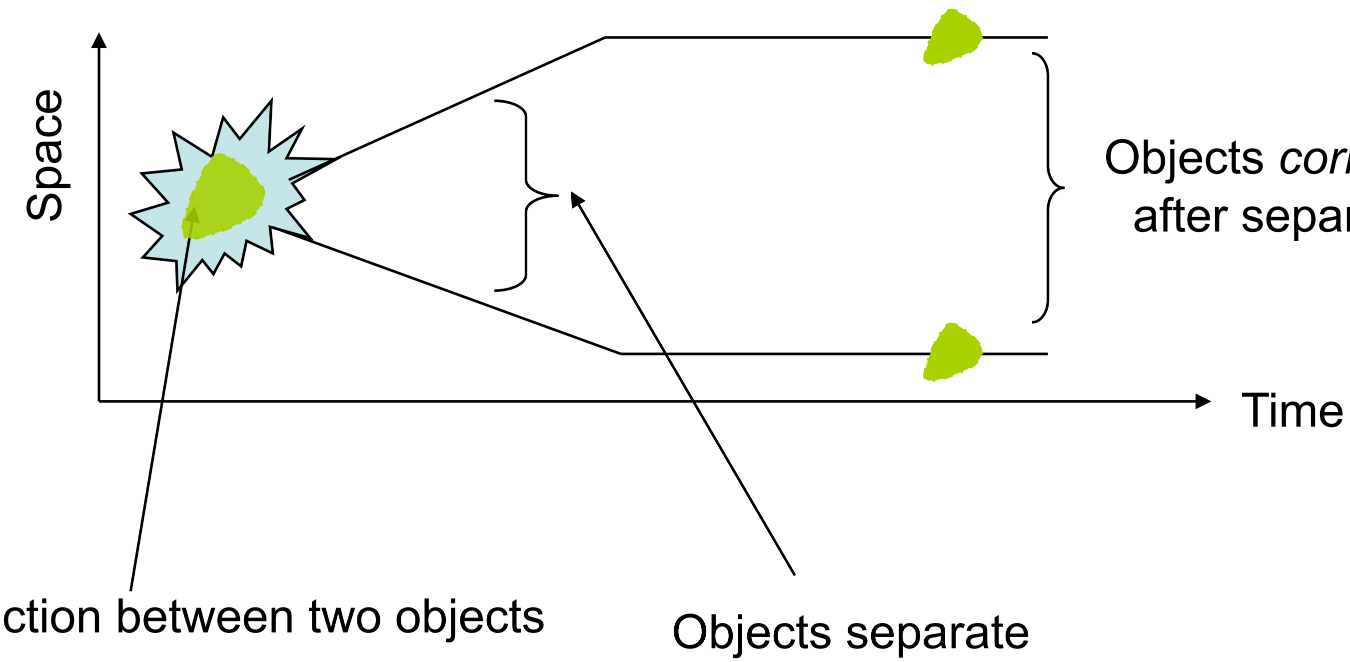
or:

Incompatible observables **do** both have definite values, but, those values **depend on simultaneous events, at far away locations**

Quantum Entanglement

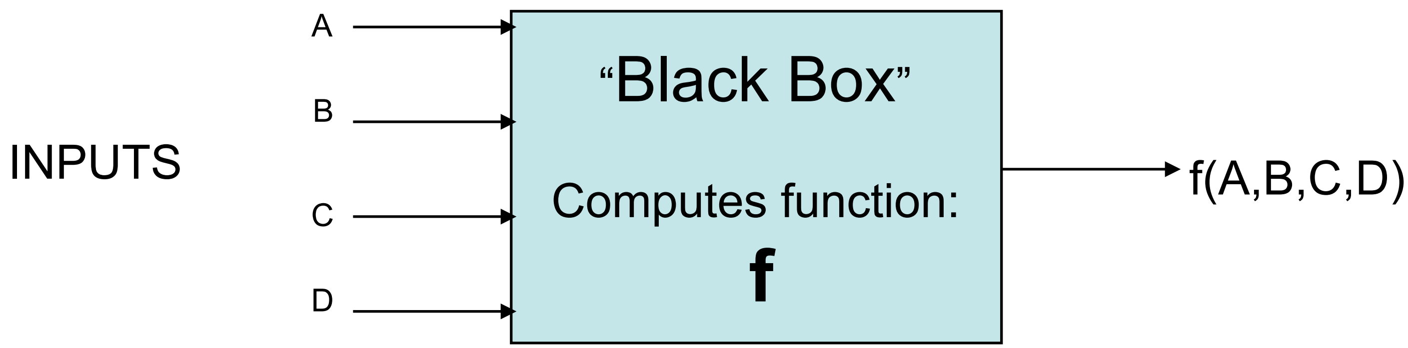


Quantum Entanglement



If the interaction includes **quantum entanglement**, then: after separating, the objects are **more strongly correlated** than any separated non-quantum objects can be.

Making linear operations nonlinear, with entanglement

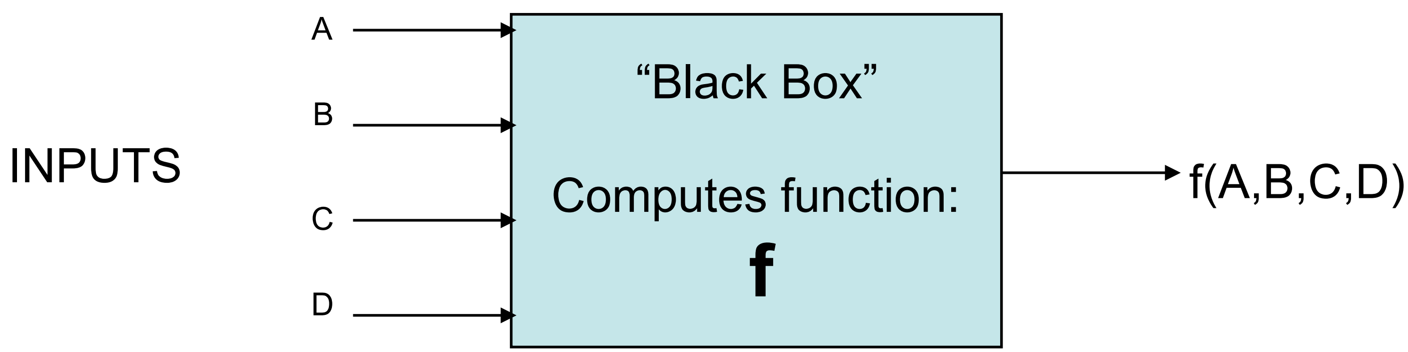


Box is a simple quantum computer. Need linear algebra to understand its operation.

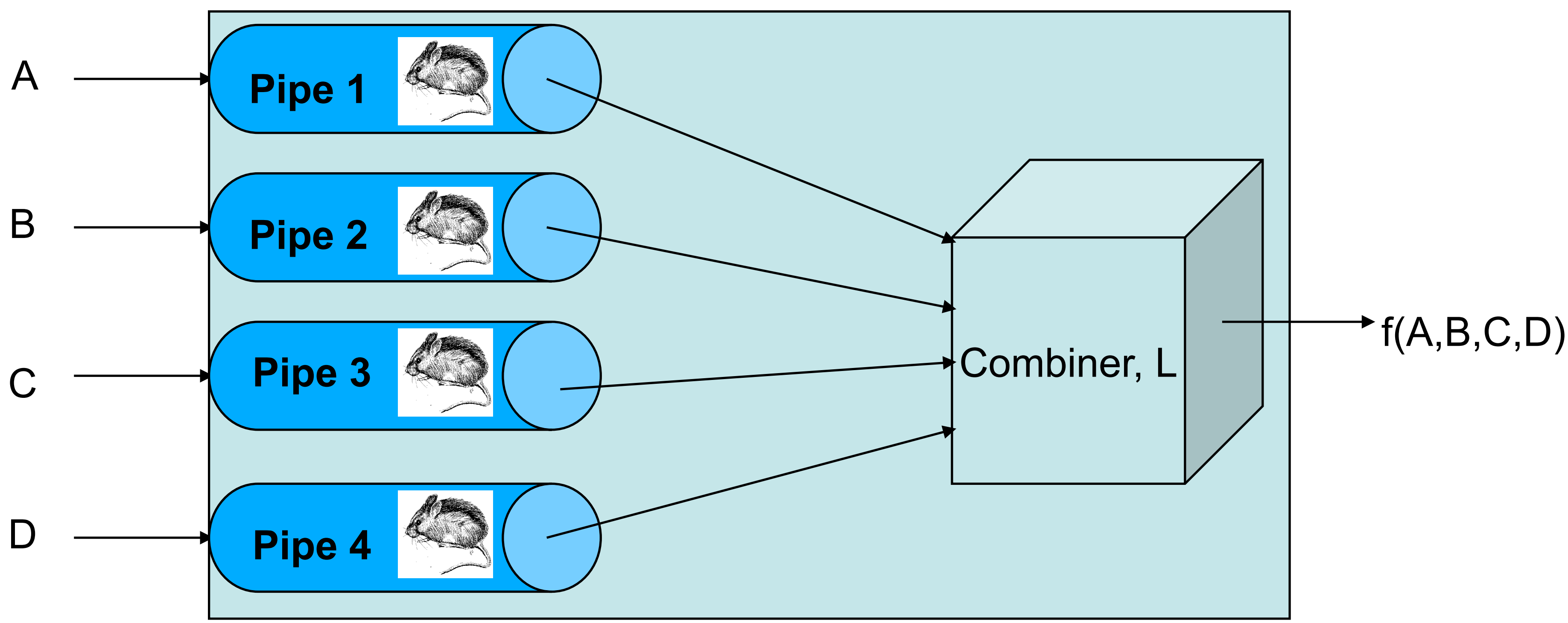
Therefore we make an analogy:

Quantum computational process →
Flow of information through **separate pipes** where the information is altered by **machinery**; followed by a **coupling stage**.

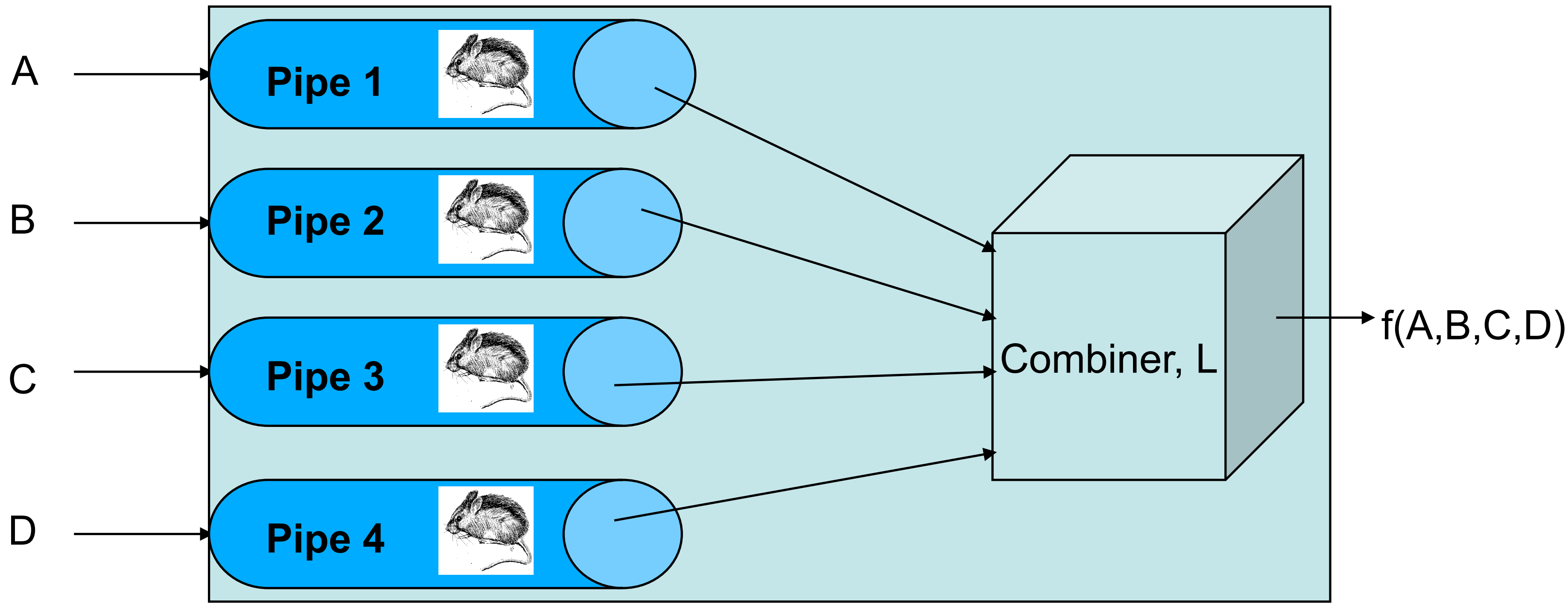
Quantum randomness in the computation →
Mice are stuck in the pipes. They cause random fluctuations in the pipe-machinery. But the box is **designed to work anyway** (it computes f).



Inside the black box: Pipes isolate input streams, then combine



Inside the black box: Pipes *isolate* input streams, then combine



Assumption: Mouse behavior is deterministic

There are "random" fluctuations in the pipes **from use to use**, but, **during any given use**, **each pipe outputs a definite function of its input**.

(Note: Mouse behavior too complex to predict ***which*** function.)

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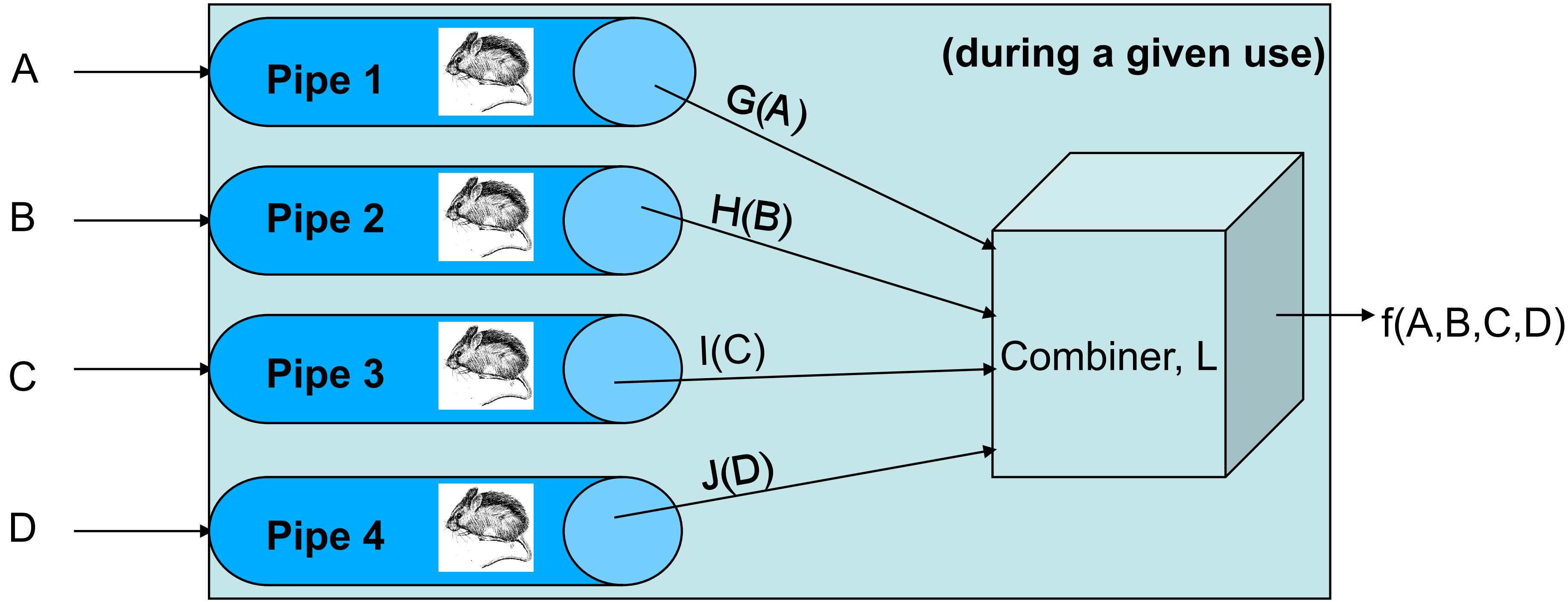

During any single use:

Each pipe has one, determined output, for a given input.

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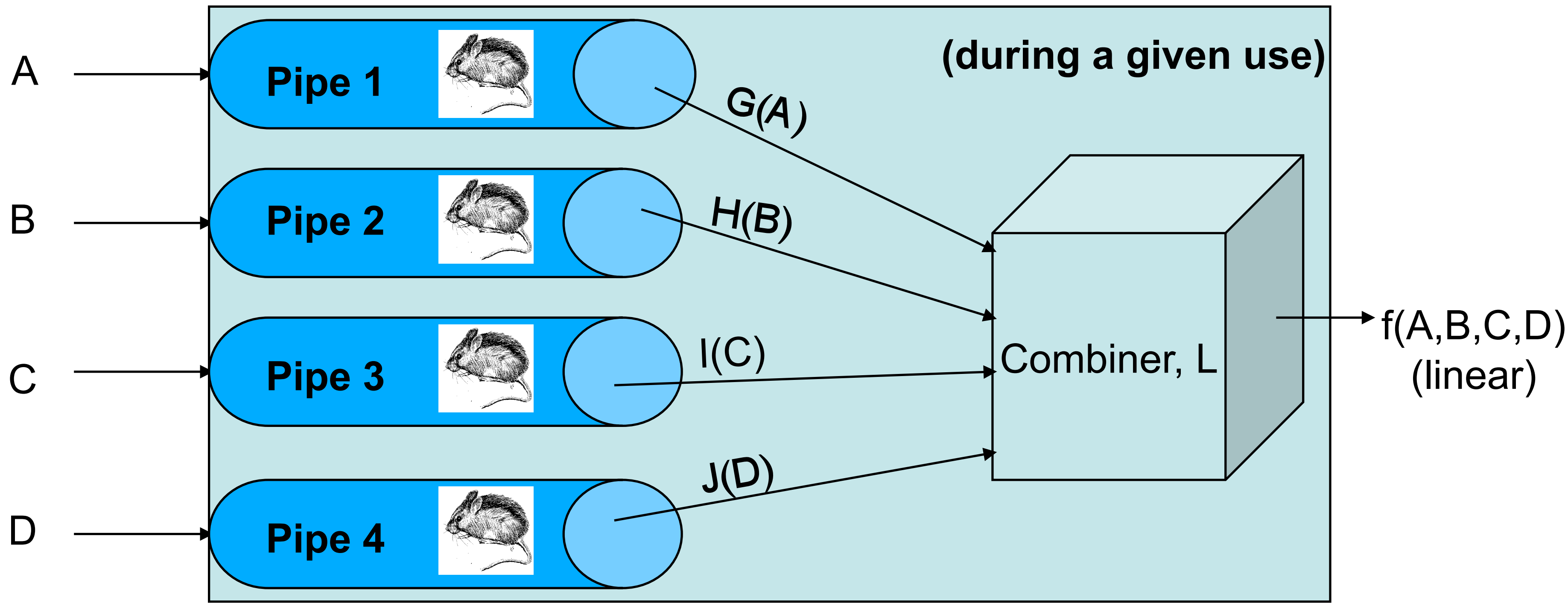

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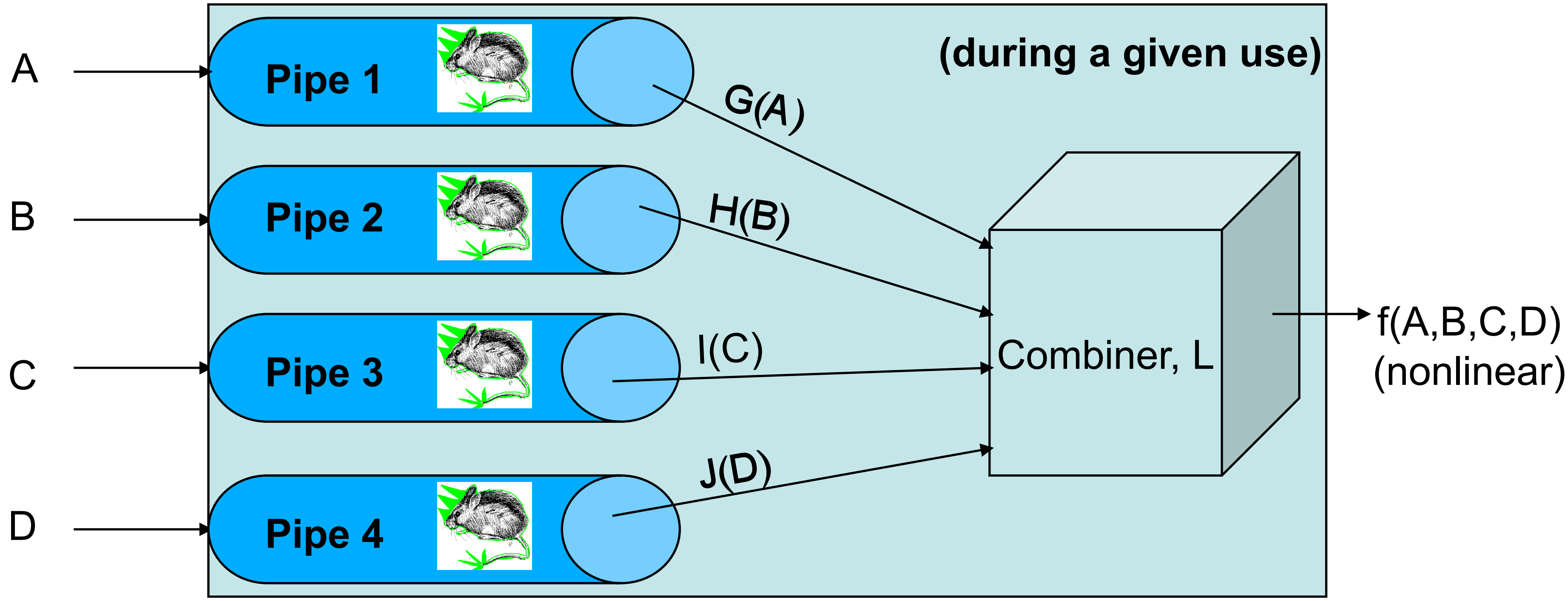
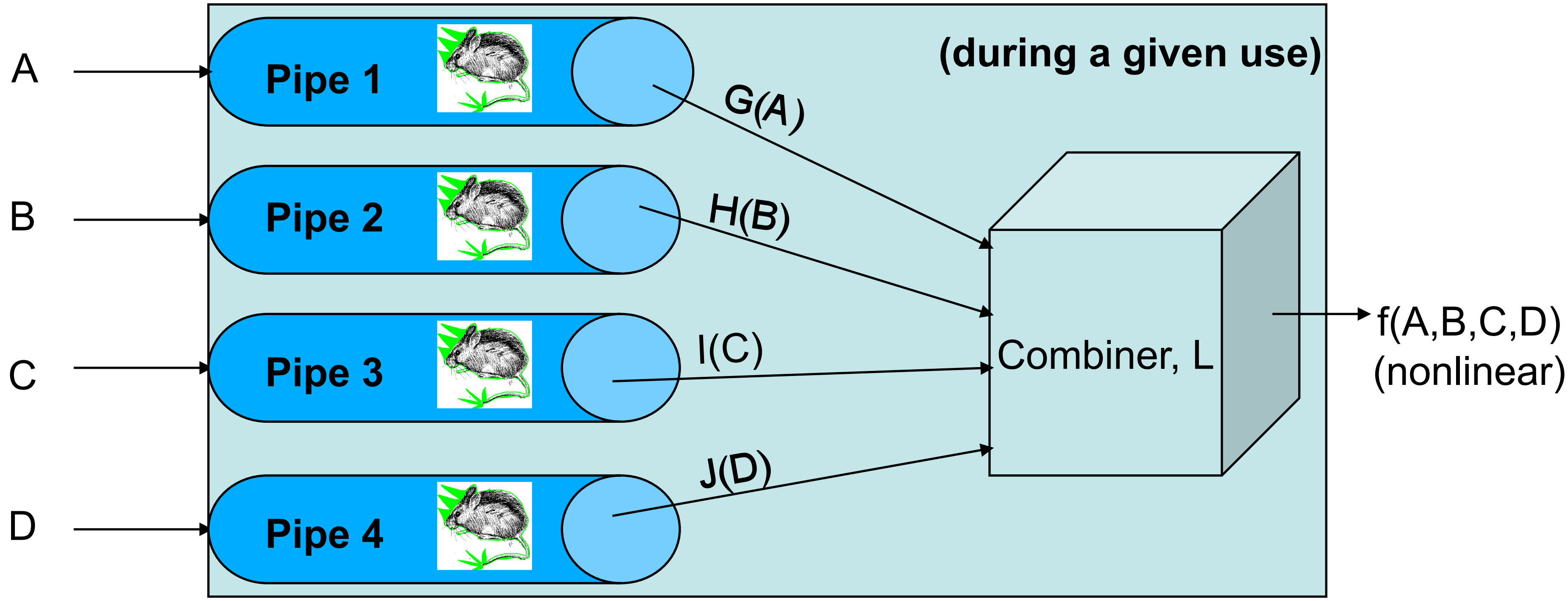


BUT: In our box, the mice have been entangled with one another in the past, and f becomes a nonlinear function of A, B, C, D

Even if we don’t change the nature of the combiner at all….

L DESIGNED SO THAT: No matter what functions G, H, I, J are, L outputs a linear function of A, B, C, D



If the mice have been entangled with one another in the past, L outputs a nonlinear function of A, B, C, D…

… even though the mice never interact after the machine is constructed.

A PARADOX?

No matter what *functions* G, H, I, J are:
L always outputs a linear function of A, B, C, D

BUT: If the mice have prior entanglement,
L outputs a nonlinear function of A, B, C, D….
Even though the mice never interact after the machine is constructed

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Made one key assumption:

*"There are random fluctuations in the pipes from **use to use**, but,*
***during any given use**, each pipe outputs a **definite function** of its input."*

i.e., mouse behavior deterministic

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Resolutions of Paradox?:

1) **Behavior of mouse in one pipe is affected by input to other pipes.**
   Therefore a pipe's output is a function *both* of its own input and of the inputs to other pipes.

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2) **Behavior of mouse is non-deterministic.**
   No definite function maps pipe input to pipe output.
   i.e., randomness in the computational process is *objective*

We’ve designed such a quantum-computational “box”, thus proving a variant of:

Bell’s Theorem:

Either:

1) **The hidden determinants of measured values in one location are *instantaneously* affected by events elsewhere.**

Or:

2) **Quantum randomness is *objective.***

   There are no hidden determinants of the values of all observables ……