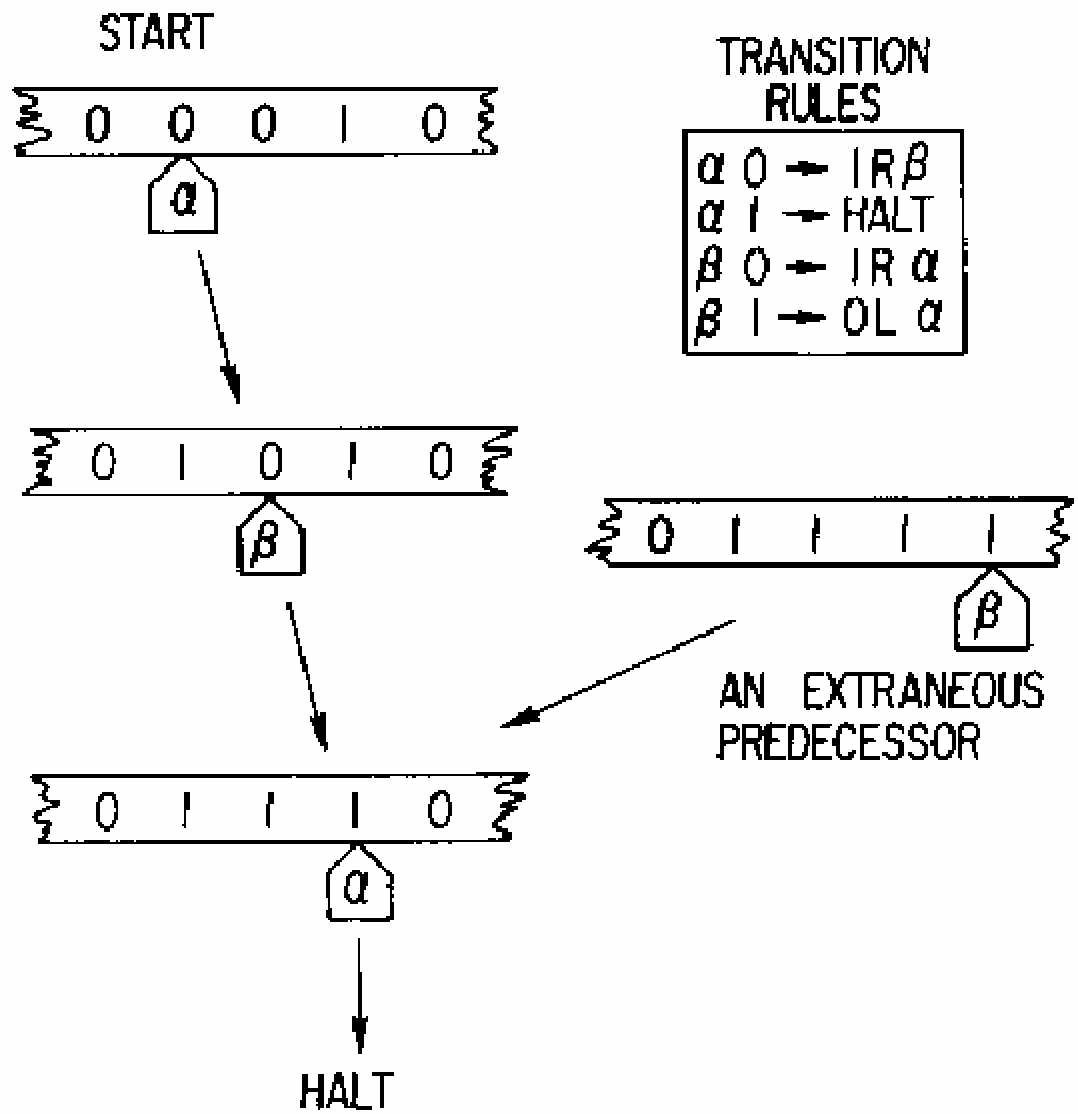
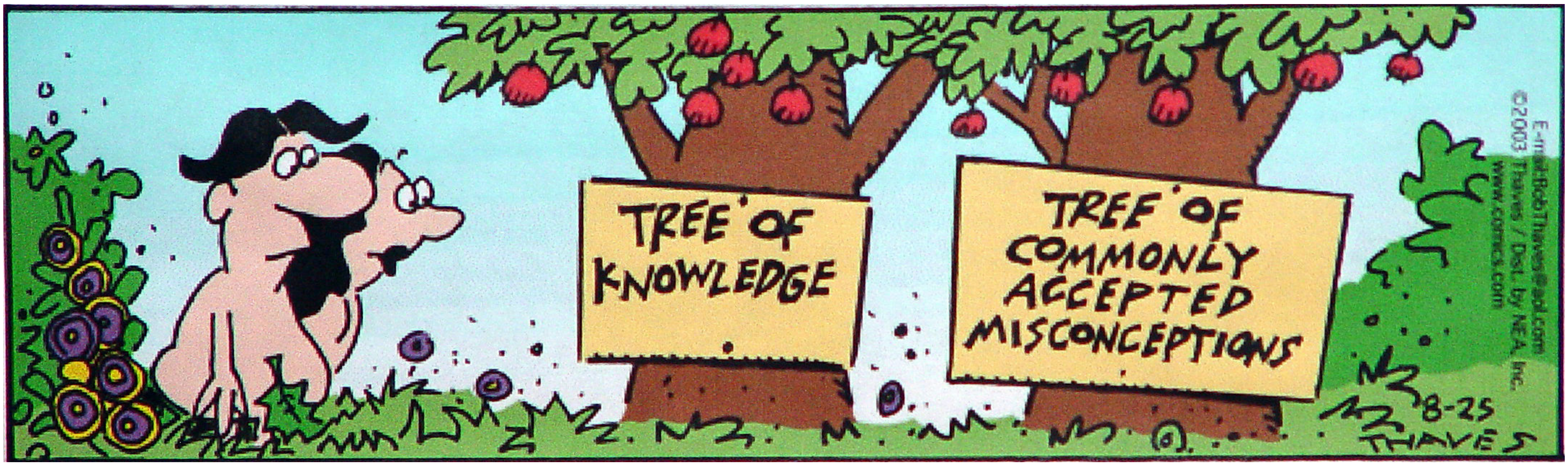
Turing machine, illustrating logical irreversibility

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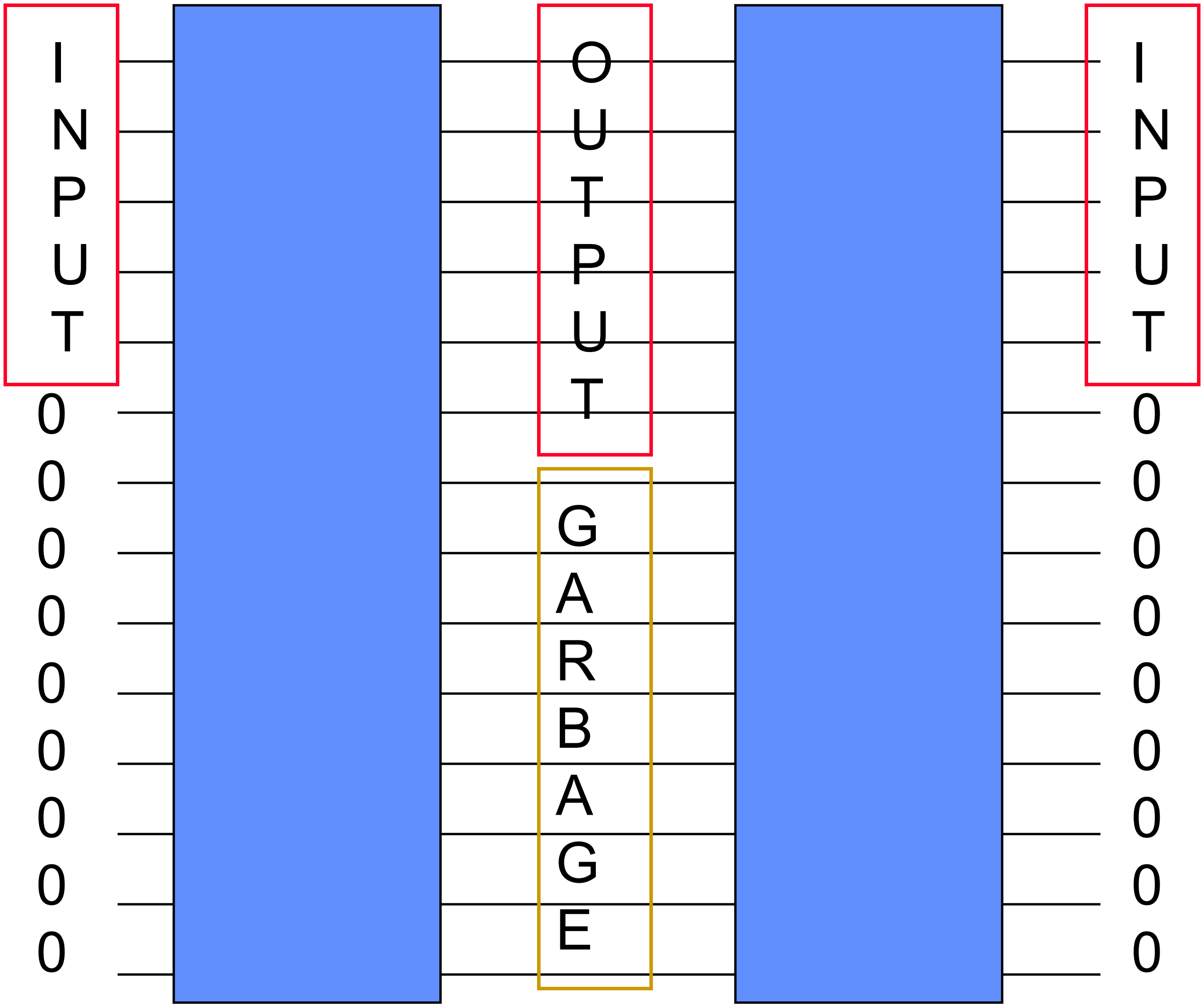
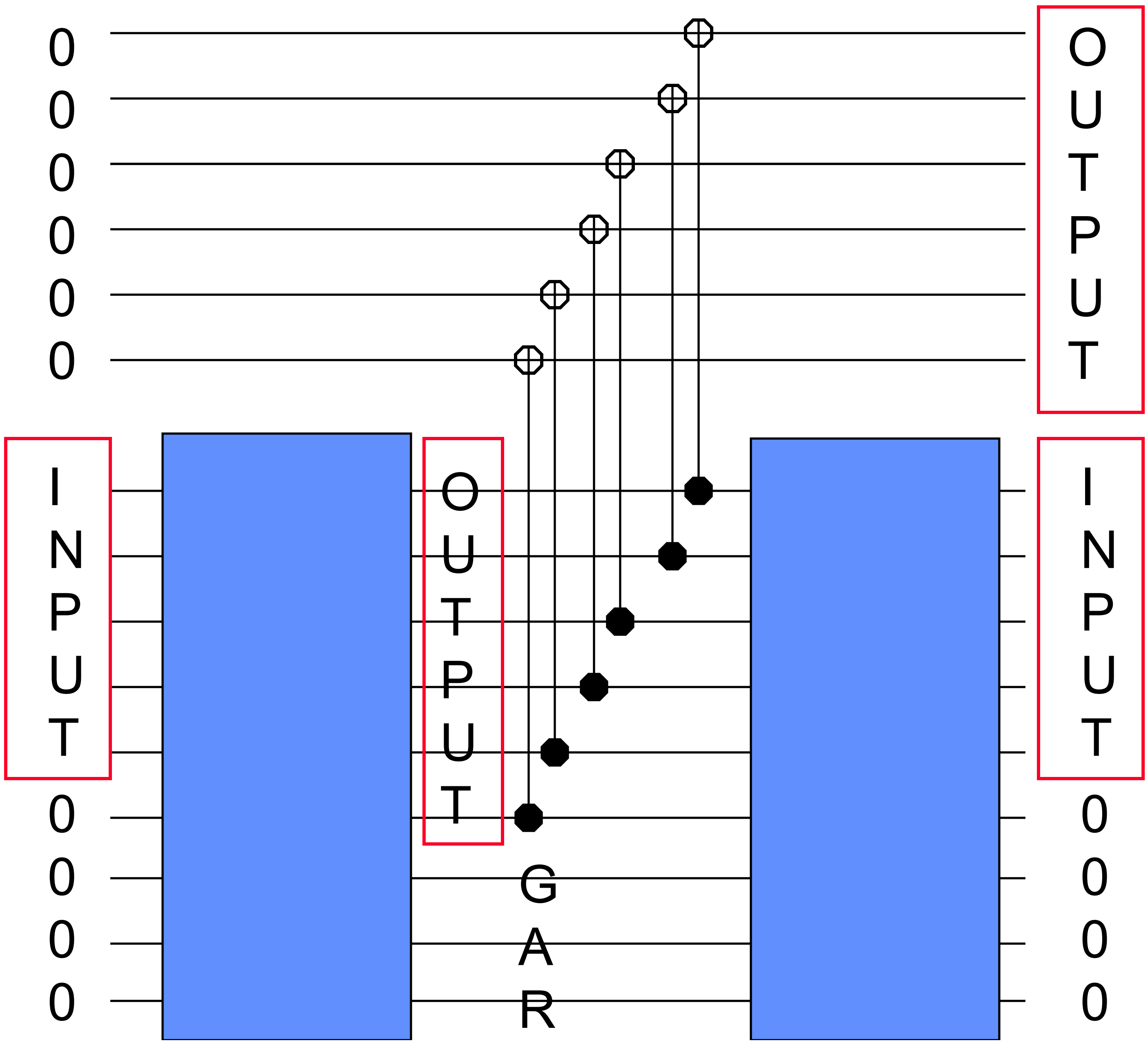
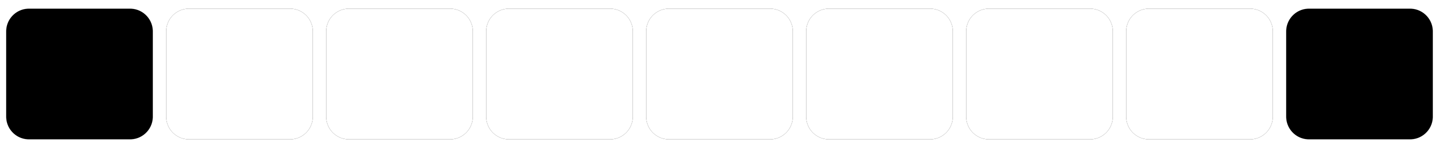
Time-Efficient Space-Inefficient reversible simulation of an irreversible computation



Using CNOTs to copy output before undoing computation



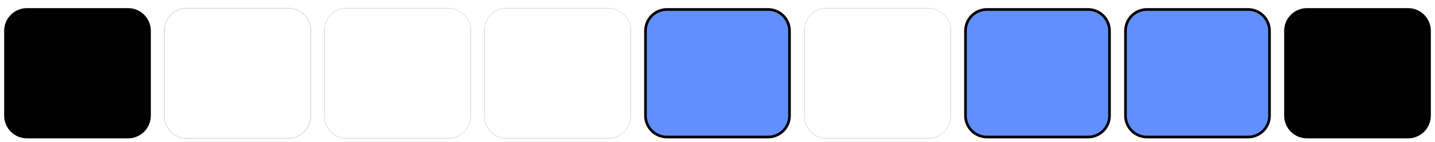
Another view of the Time-efficient, space-inefficient simulation



T steps of irreversible computation are simulated in 2T steps of reversible computation, using O(T) extra memory for temporary storage of intermediate results.

Like laying down a row of stepping stones to cross a river, then removing them. A stepping stone may be placed or removed only when its predecessor is present.

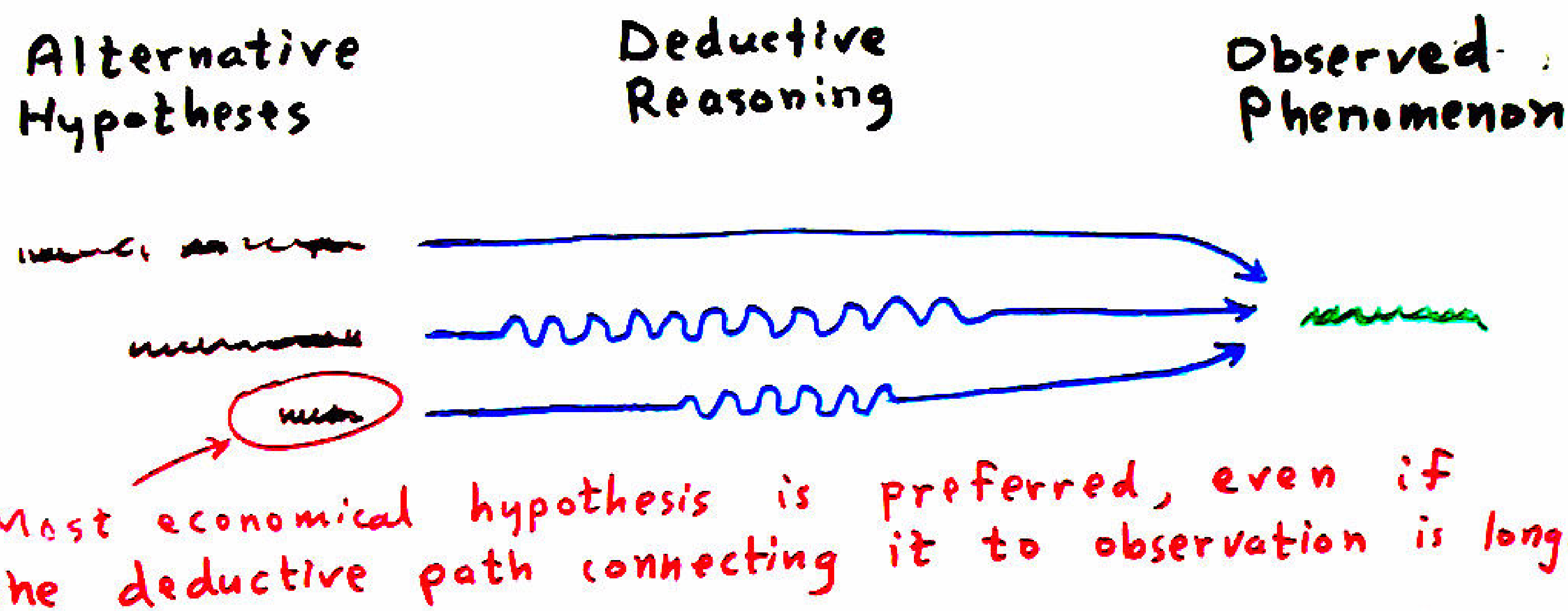
Trading time for space: By doing and undoing steps in a hierarchical manner, $T=2^m$ steps of irreversible computation can be simulated in 3^m reversible steps using $O(m)$ temporary intermediate storage.

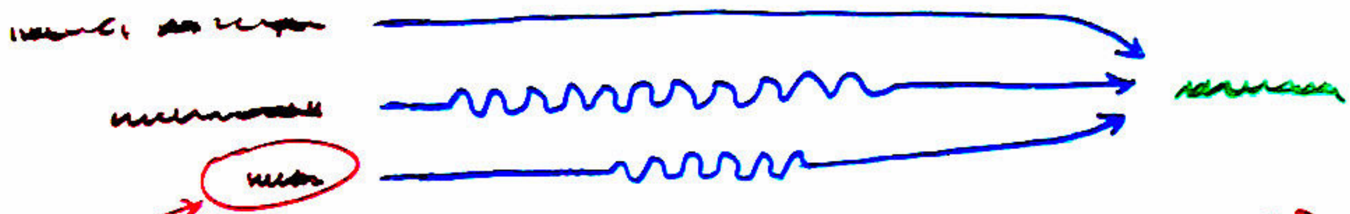


More generally, this type of argument shows that for all $\varepsilon > 0$, an irreversible computation using time T and space S can be reversibly simulated in time $\propto T^{1+\varepsilon}$ and space $\propto S \log T$. A still more space-efficient simulation runs in exponential time and linear space.

Occam's Razor & the notion of Logical Depth

In the philosophy of science, the principle of Occam's Razor directs us to choose the most economical hypothesis able to explain a given body of observed phenomena.

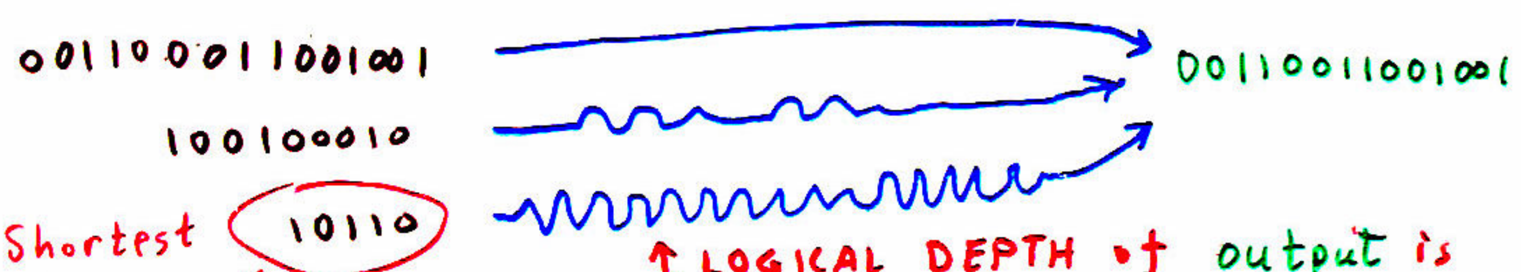




Most economical hypothesis is preferred, even if the deductive path connecting it to observation is long.

This idea is formalized using a universal computer (a device versatile enough in principle to follow any deductive path, or derive the consequences of any physical laws):

Alternative Inputs (Programs) | **Standard Universal Computer** | **Output to be explained**



Shortest Binary Input ↗

↑ LOGICAL DEPTH of output is time required to compute it from shortest input that generates it.

What did "Information is Physical" mean to Landauer?

1. We ought to think more about physical principles like the 2nd law when we are developing a theory of information processing.

2. It is a waste of time for mathematicians to think about things like the $2^{1,000,000th}$ digit of pi, which have no chance of being calculated in the physical universe.

But what about the $2^{1,000,000th}$ digit of 1/7?