How Much Does NOT Cost?

Mikhael Semaan

Project Presentation

PHY 256B Spring 2018

How Much
Does NOT Cost?

OR,

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PHY 256B Spring 2018

How Much Does NOT Cost?

OR, “The Thermodynamic Cost of Information Processing.”

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The broader question…

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For a particular logical operation,

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For a particular logical operation,
what is the tradeoff between accuracy and energetic cost?

Why Care?

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Answering this question would…

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- place bounds on information-processing efficiency,

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- do so as a function of desired accuracy, and

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Answering this question would…

- place bounds on information-processing efficiency,
- do so as a function of desired accuracy, and
- (perhaps) shed light on approaching those bounds.

How to start?

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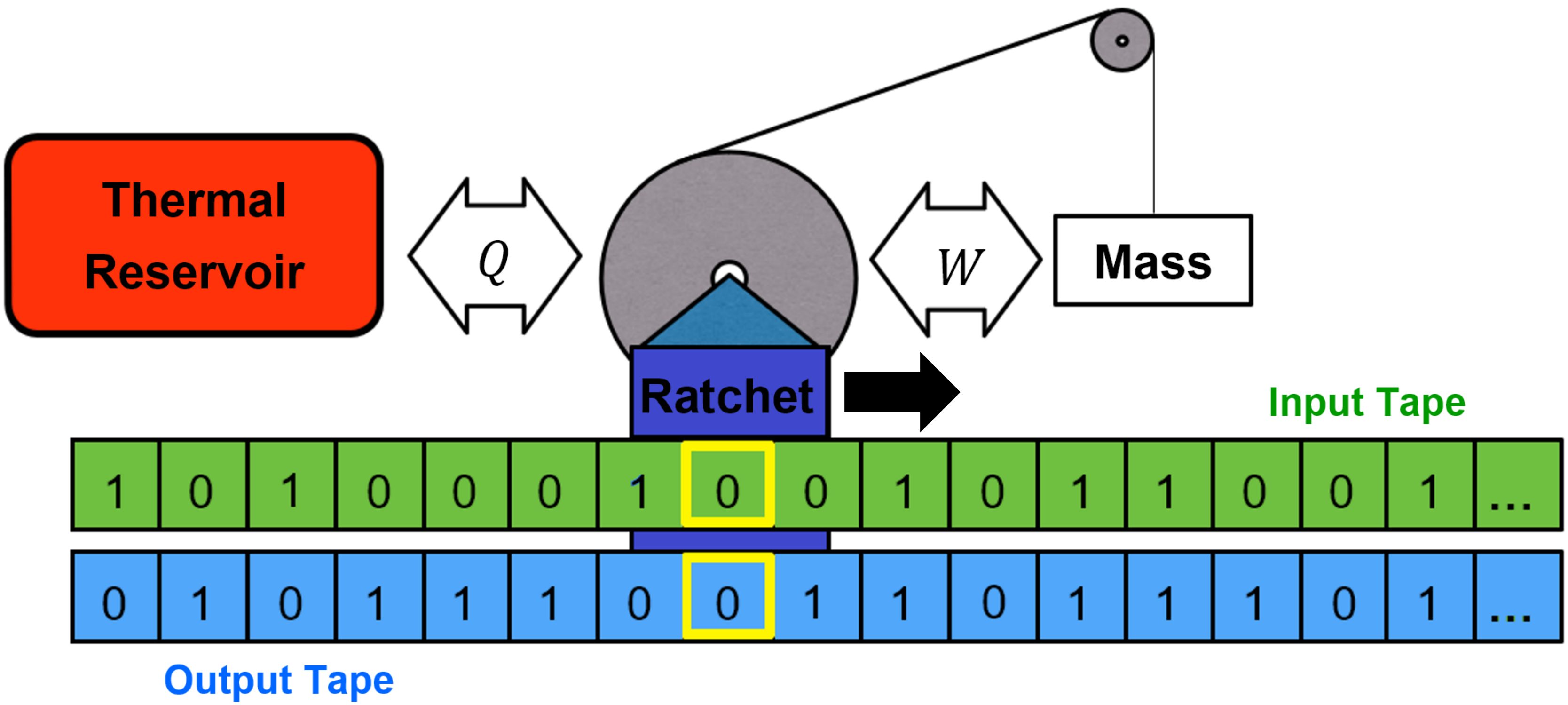
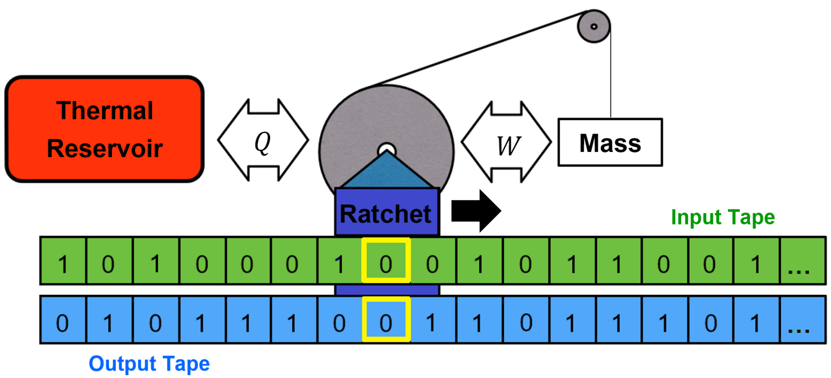
Information Ratchets!

Modified Information Ratchet



Some Assumptions…



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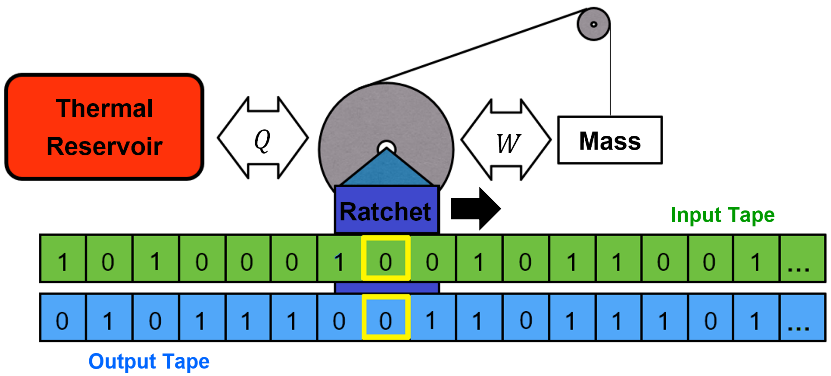
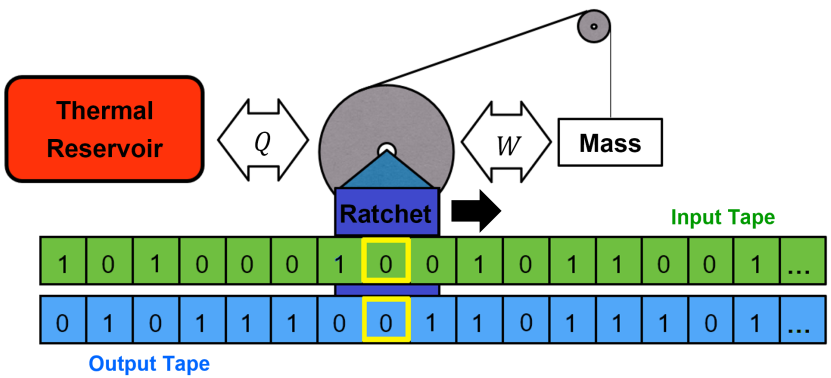


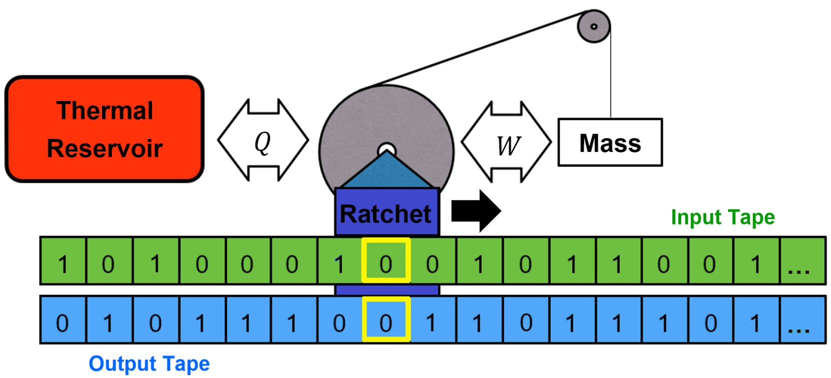
- Internal state transition takes τ.

Some Assumptions…



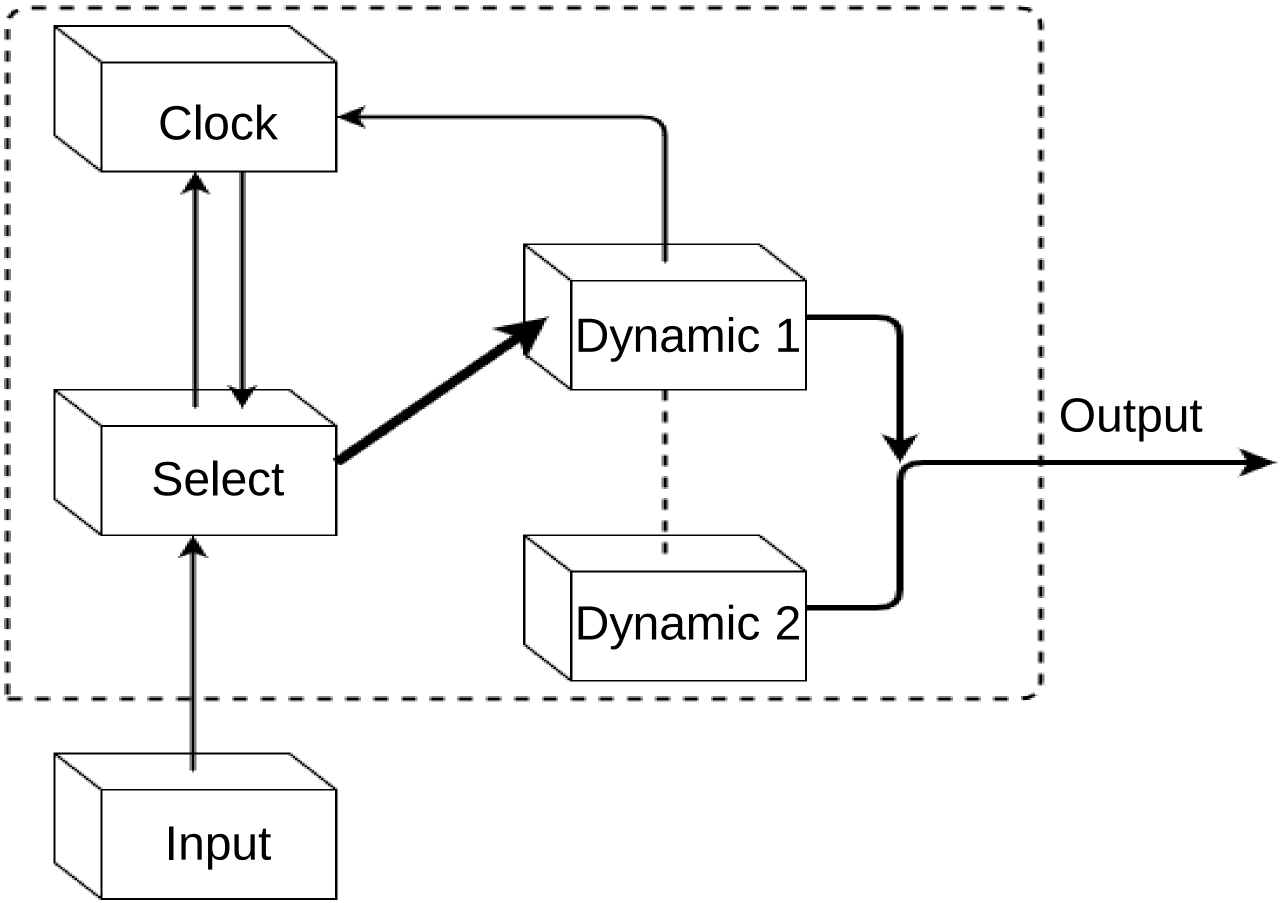
- Internal state transition takes τ.
- Initiate move/read every T.

Some Assumptions…



- Internal state transition takes τ.
- Initiate move/read every T.
- Each move/read takes $T - \tau$.

Inside the Ratchet



A NOT Gate

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Dynamic 1: Input Reads “0.”

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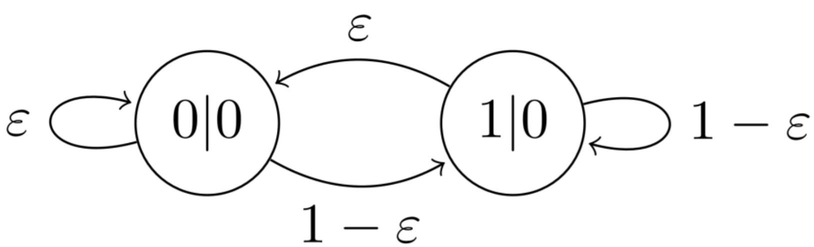

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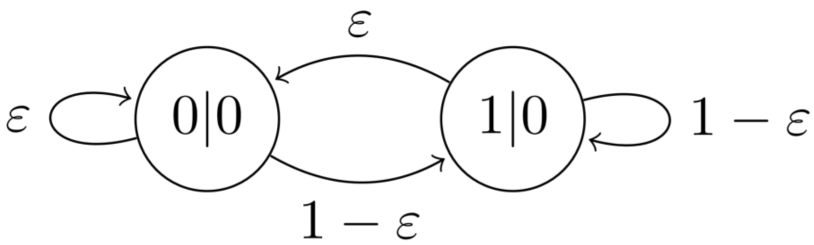

Dynamic 2: Input Reads “1.”

A NOT Gate

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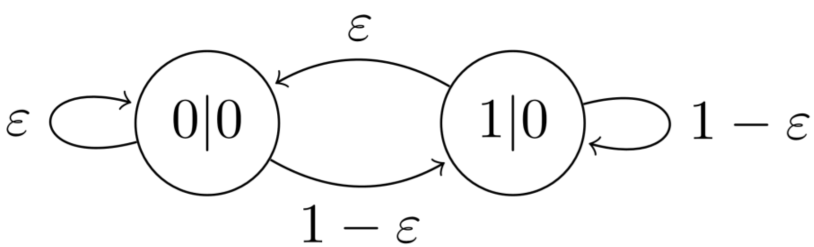

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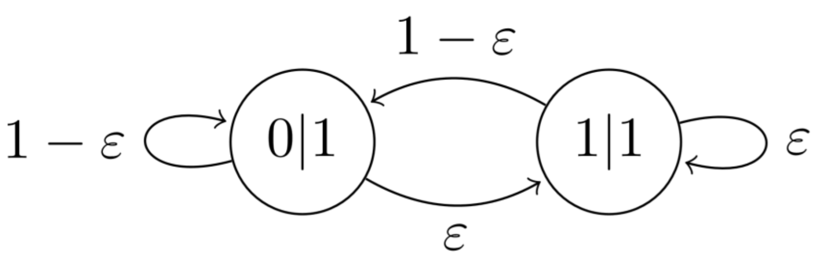

A NOT Gate + Detailed Balance!

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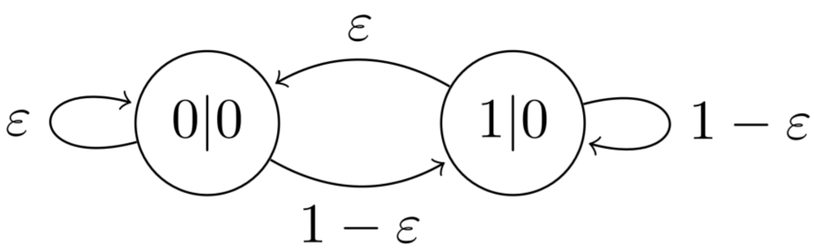

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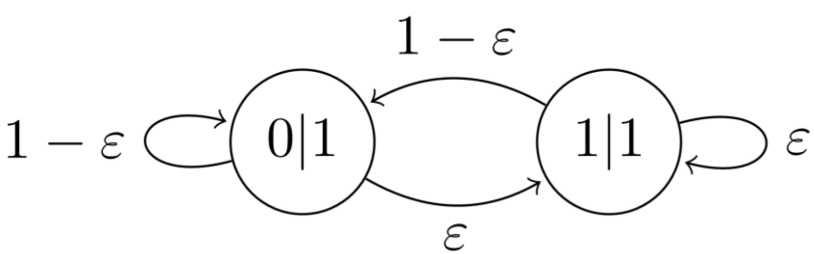

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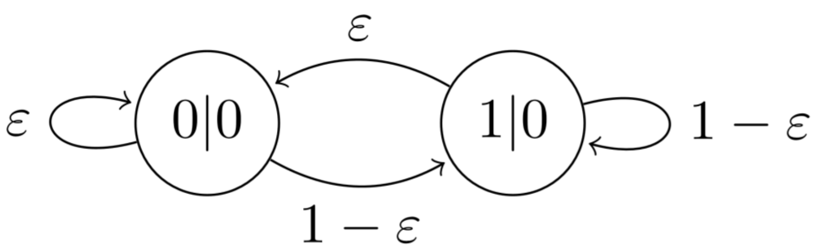
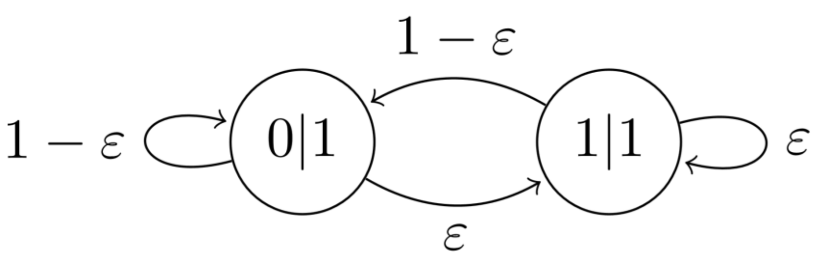


$$\frac{\Pr(A \to B)}{\Pr(B \to A)} = \mathrm{e}^{\Delta E / k_{\mathrm{B}} T}$$

Dynamic 2: Input Reads "1."



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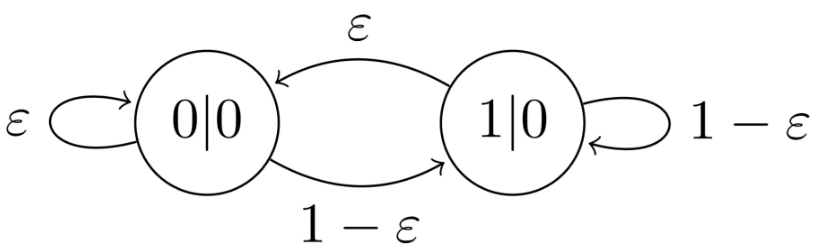

$$\frac{\Pr(A \to B)}{\Pr(B \to A)} = \mathrm{e}^{\Delta E / k_\mathrm{B} T}$$

⇒Reversible

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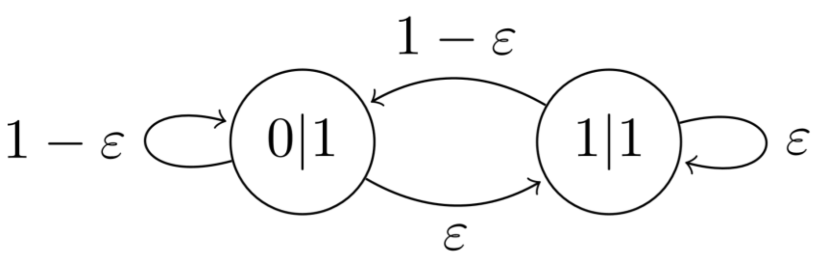

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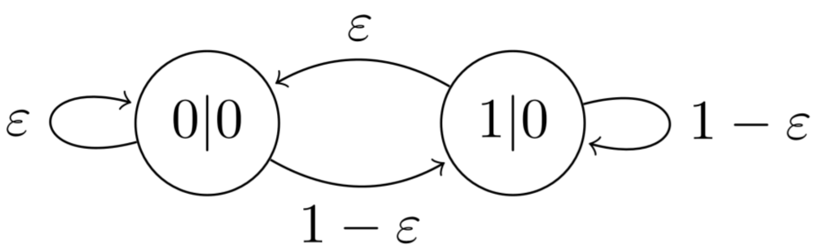

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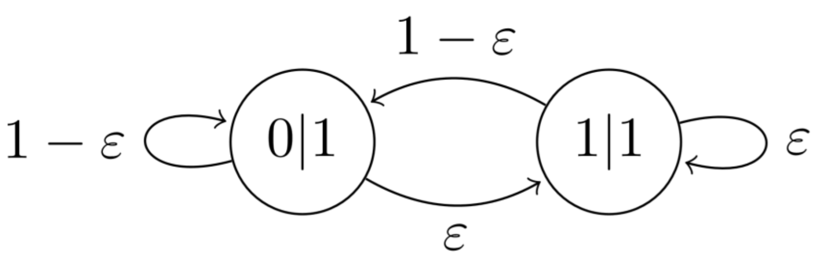

$$\frac{\Pr(A \rightarrow B)}{\Pr(B \rightarrow A)} = \mathrm{e}^{\Delta E / k_{\mathrm{B}} T}$$

⇒Reversible

⇒No 100% accuracy

A NOT Gate + Detailed Balance!

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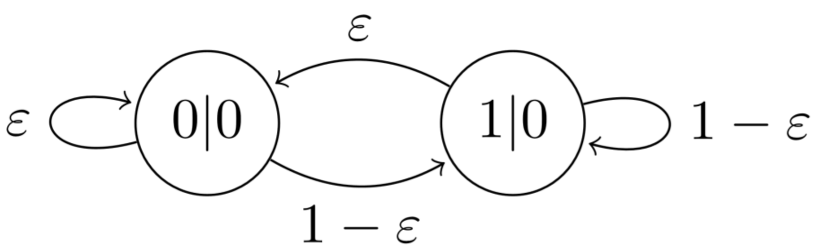

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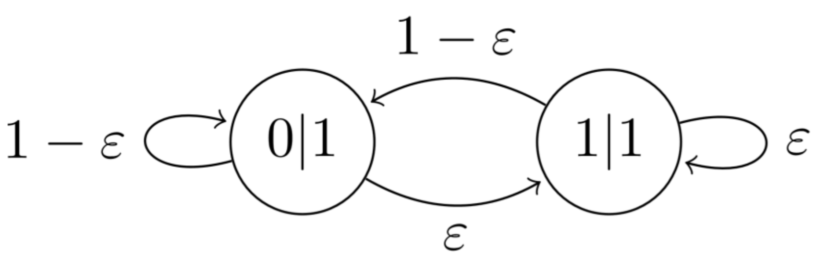

$$\frac{\Pr(A \to B)}{\Pr(B \to A)} = \mathrm{e}^{\Delta E / k_{\mathrm{B}} T}$$

⇒Reversible

⇒No 100% accuracy

⇒Tradeoff!

Baby Steps

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Consider Dynamic 1.

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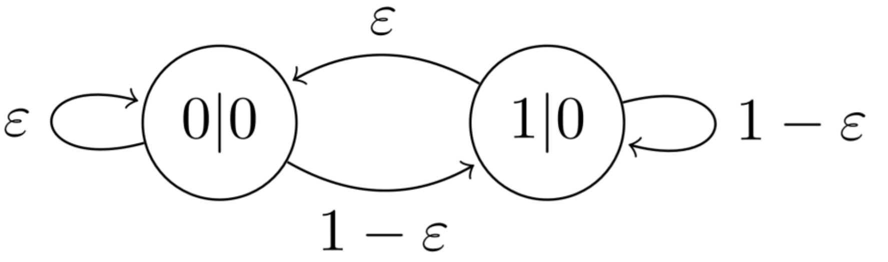

Baby Steps

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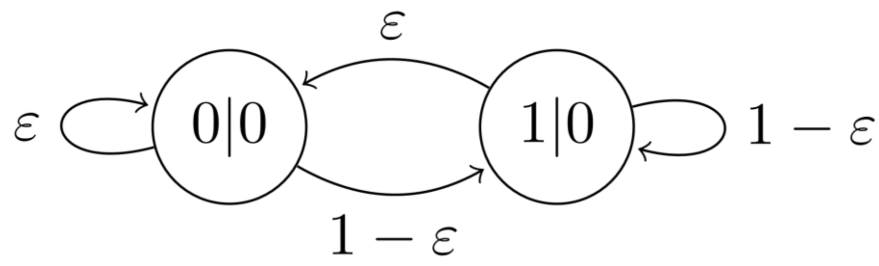

$$\frac{\Pr(0|0 \to 1|0)}{\Pr(1|0 \to 0|0)} = e^{\Delta E / k_B T}$$

Baby Steps

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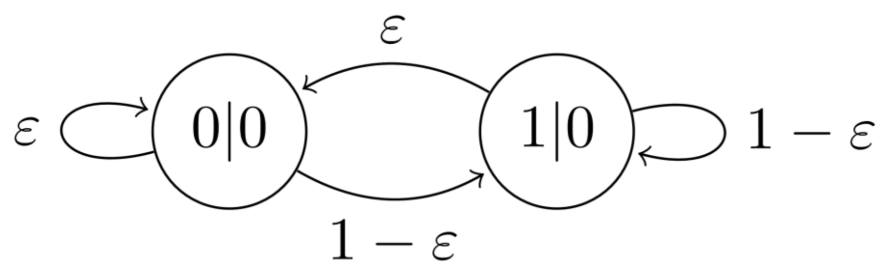

$$\frac{\Pr(0|0\to 1|0)}{\Pr(1|0\to 0|0)} = \mathrm{e}^{\Delta E/k_\mathrm{B}T}$$

$$\Longrightarrow \Delta E = k_\mathrm{B}T\ln\left(\frac{1}{\varepsilon}-1\right).$$

Baby Steps

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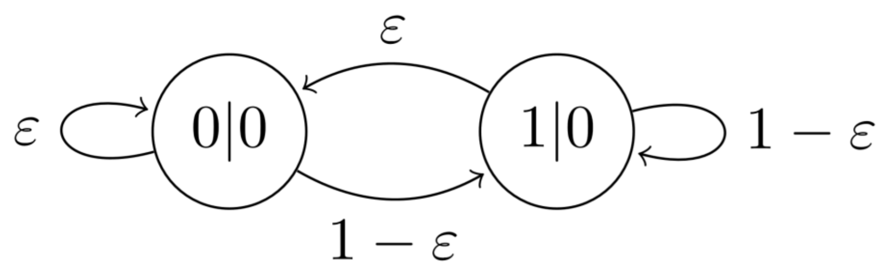

$$\frac{\Pr(0|0 \to 1|0)}{\Pr(1|0 \to 0|0)} = \mathrm{e}^{\Delta E / k_\mathrm{B} T}$$

$$\Longrightarrow \Delta E = k_\mathrm{B} T \ln\left(\frac{1}{\varepsilon} - 1\right).$$

As $\varepsilon \downarrow$, $\Delta E \uparrow$.

Next Steps

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- When convinced of approach: do NAND.
- Physical embedding / scheme for operation?
- Formal transducer representations of other blocks.
- Think about modularity dissipation.
- Nature? (Evolutionary Dynamics?)

Thanks!

Thanks!

Special thanks to Alec, Greg, Ryan, Dany, Sam, David, and Dr. Crutchfield, for useful discussion and guidance.

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Questions?

Special thanks to Alec, Greg, Ryan, Dany, Sam, David, and Dr. Crutchfield, for useful discussion and guidance.