Lecture 4

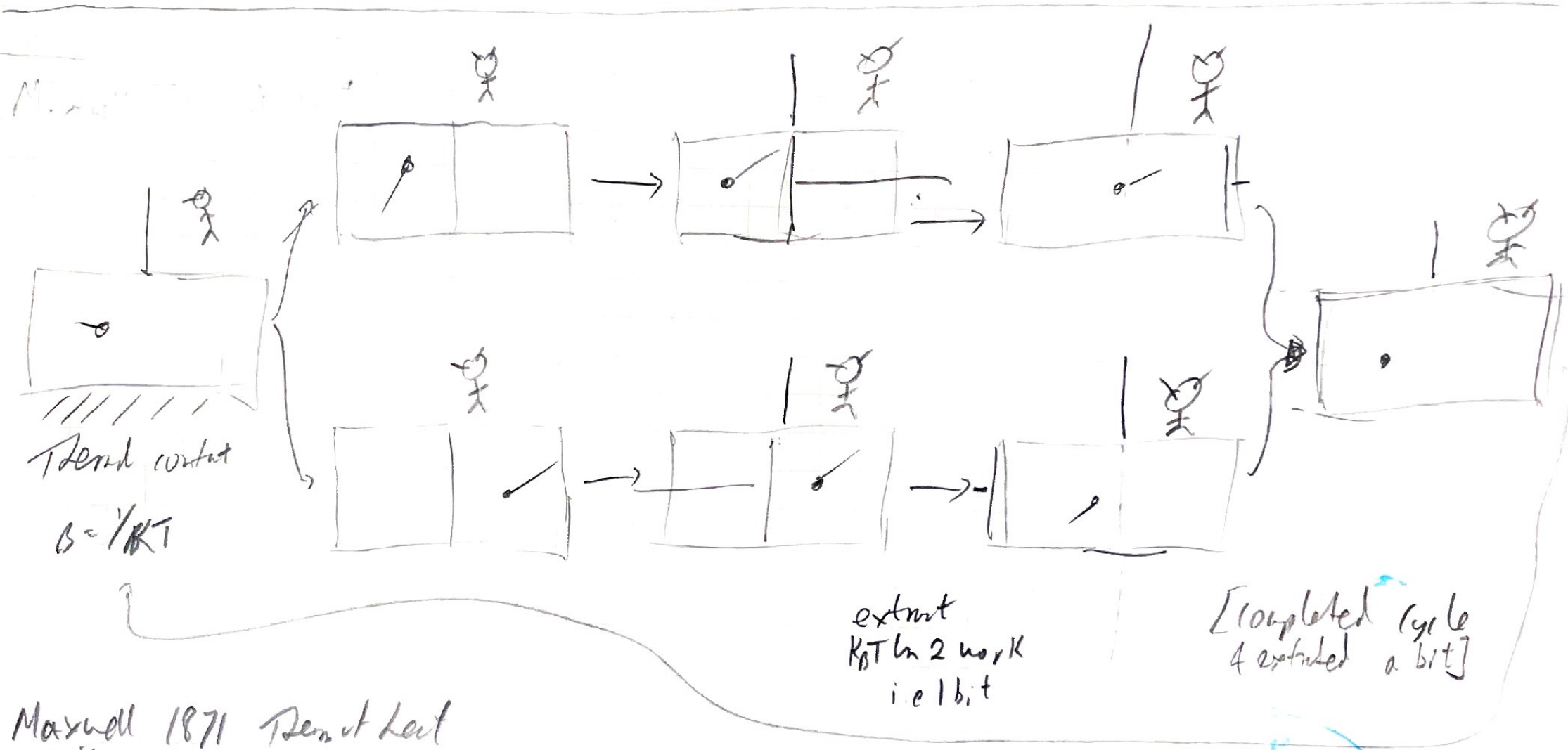
Good News Homework Due Fri Feb 2nd

Honor Code - Do it yourself
- encouraged to discuss homework on newsletter
- No cheating
- Obstacle of the exercise is that to find the right answer
  had to make sure you know how to find the right answer.

Email Adity a

Bette News UC Berkeley hiring

Lecture 4 — Maxwell's Demon & Szilard's Engine



Maxwell 1871 Demon Lecture
Szilard 1928

[The Demon's name is Max]
[like Frankenstein]

Info & Maxwell's Demon

4 pre

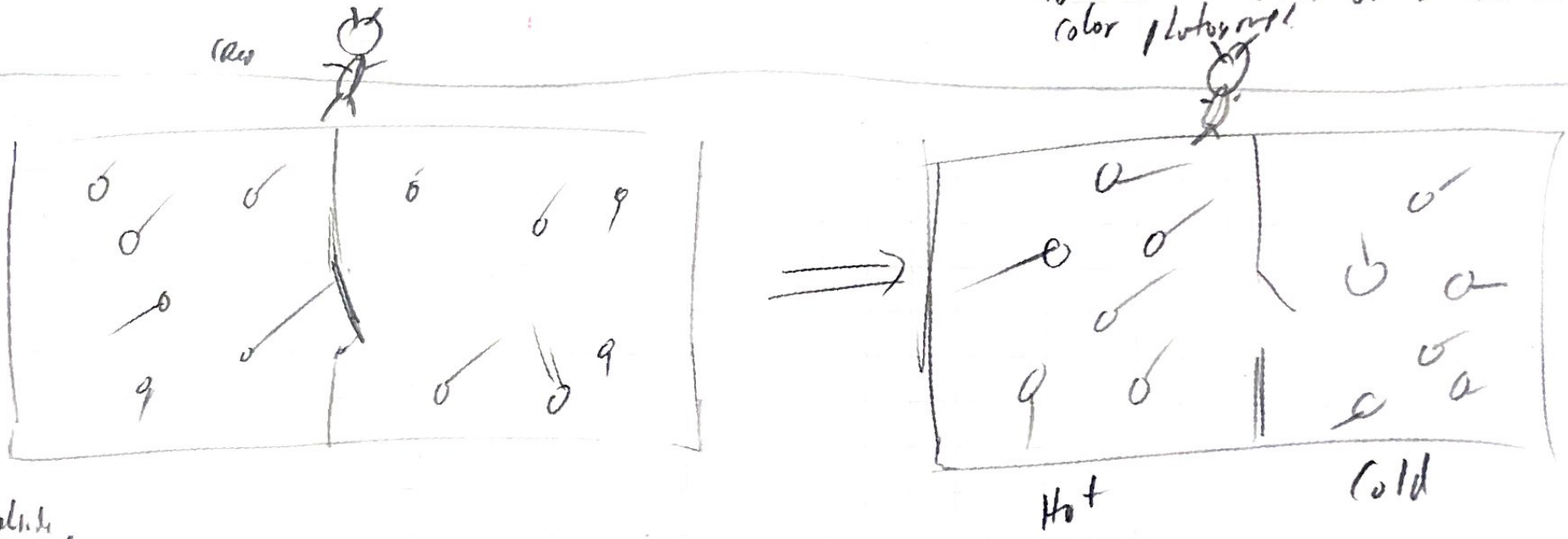
Intro Maxwell

electromagnetism

Thermodynamics - Maxwell relation

Stat mech - Maxwell-Boltzmann equation

color photography



(Goals:
3 Red
3 Blue.

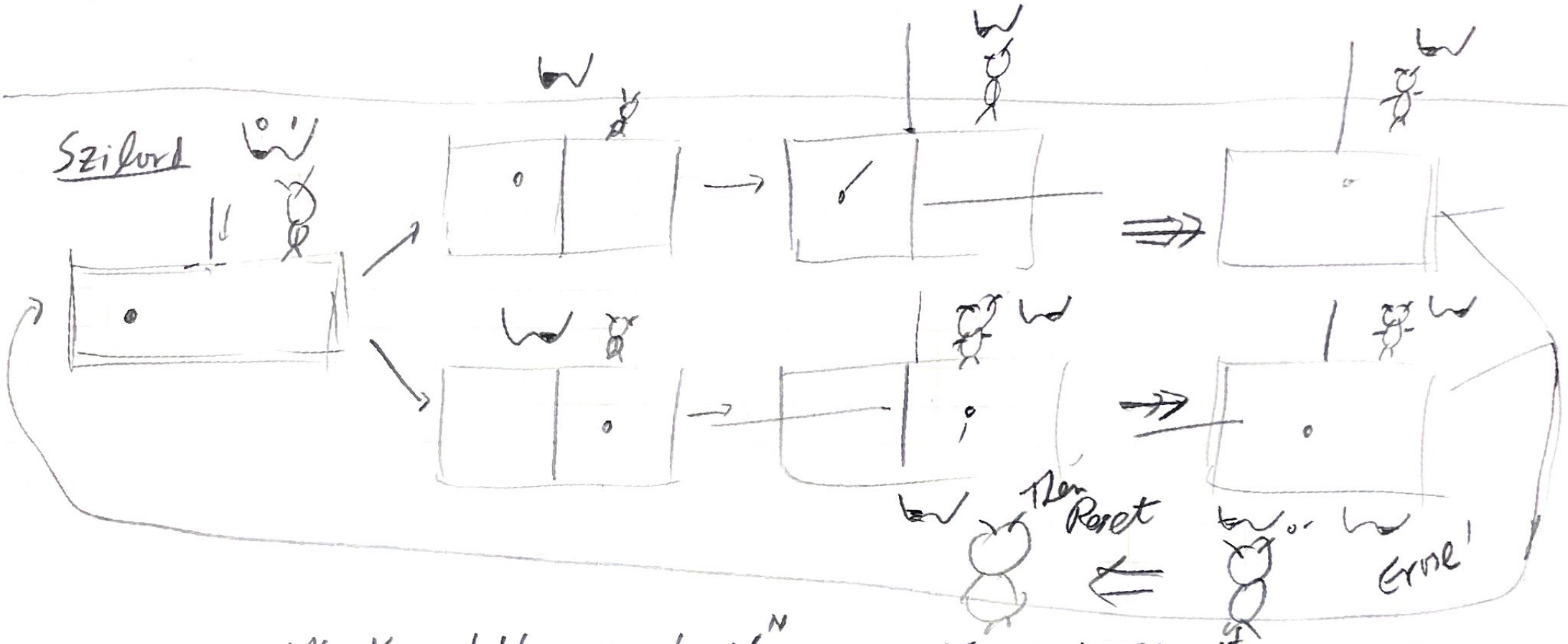
Why can't an intelligent machine violate the 2nd Law

→ Physical system. So why not? What is Re (ctd?)
Who specifically

Wrong answers - - Quantum
- Measurement
- Bend statistics & Trapdoor

→ Szilard Engine.

41rd

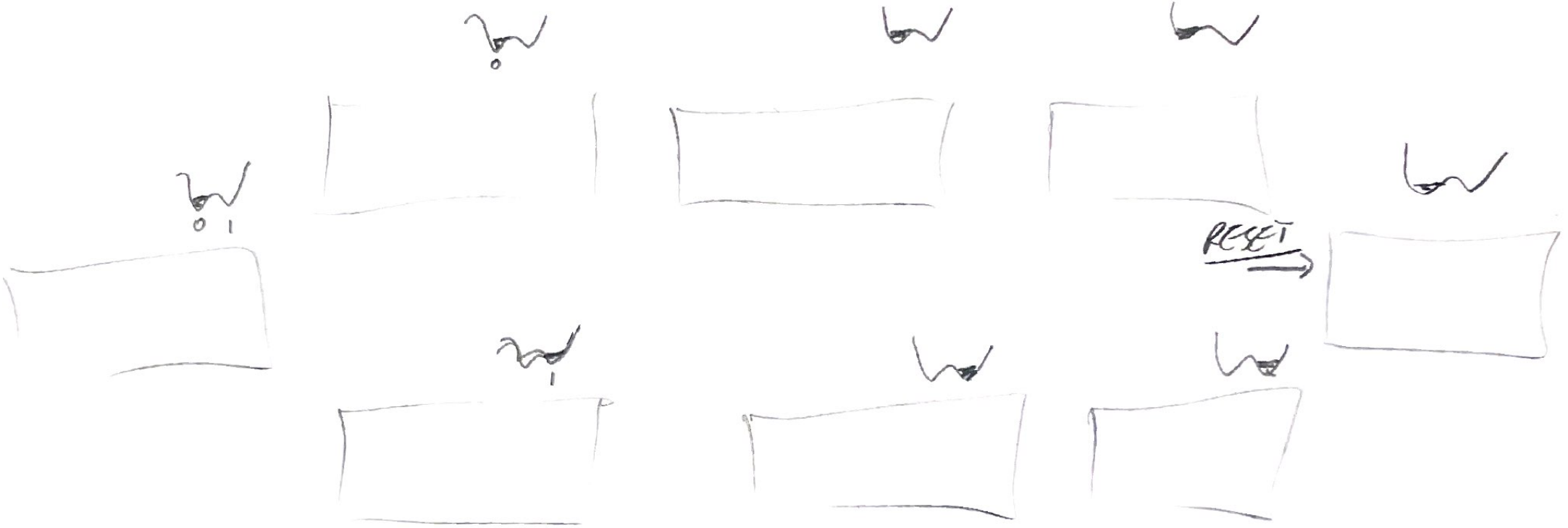


Work ideal gas $S = \ln \frac{V^N}{N!} + C$ $\Delta F = K_B T \ln \frac{V_f}{V_i} = K_B T \underbrace{\ln 2}_{0.7 \text{ nats} \atop 1 \text{ bit}}$

Reversible work

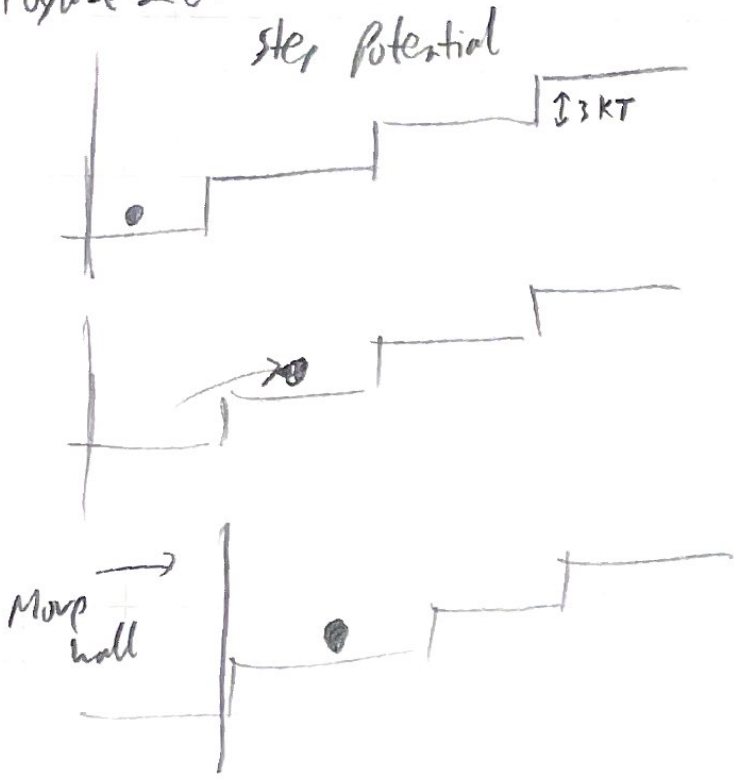
(Initial Volume)

There's a bit of another implicit operation.

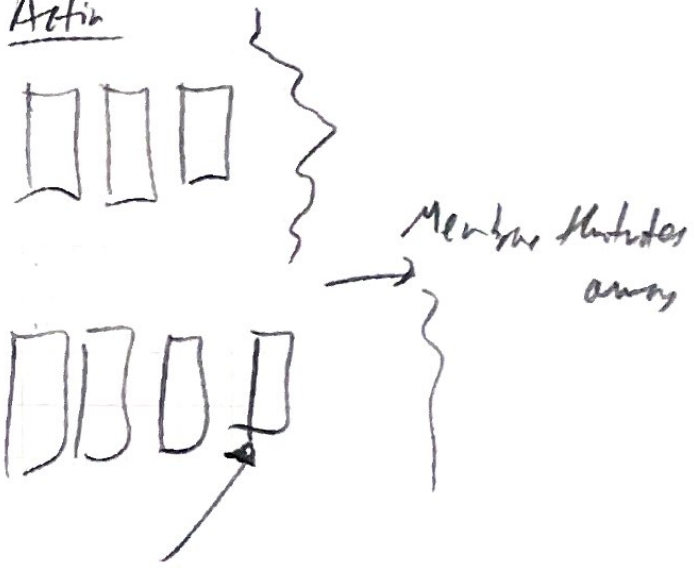


4 pre

Toyabe 2010

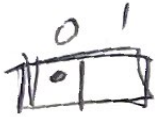


Actin



~~Motor Ratchet~~
Brownian Ratchet

Landauer's Principle

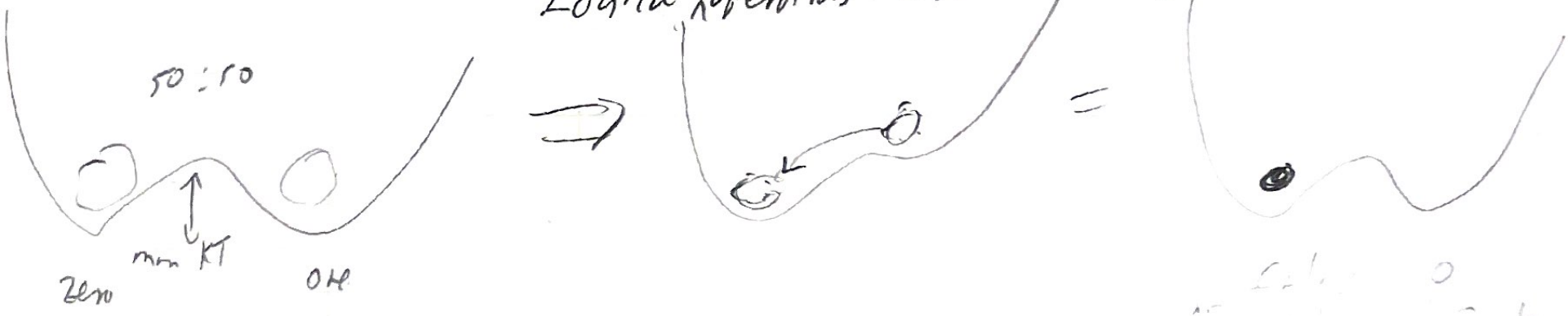
Information Theory 

$$I = \sum p(x,y) \ln \frac{p(x,y)}{p(x)\,p(y)}$$

Landauer's 101

A Bit is a physical system

Logical irreversible operations have thermodynamic costs



extra 1 bit = $\ln 2$ nats

cost to Reset is "erasure"

$\Delta F = k_B T \ln 2$

Berut 2012
Jun 2014

Landauer's Principle Experiments

Micron sized bead. Water

Bead sees a bumpy potential. Can Measure force

Laser Trap

Resonant tube

Multiplexed tube

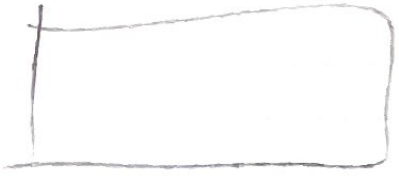
Bent 2012

Howb 2016 Nanomagnetic memory bits

Slow

Information & Erasure

[where is the information]



$I = 0$

$I = 1$ bit

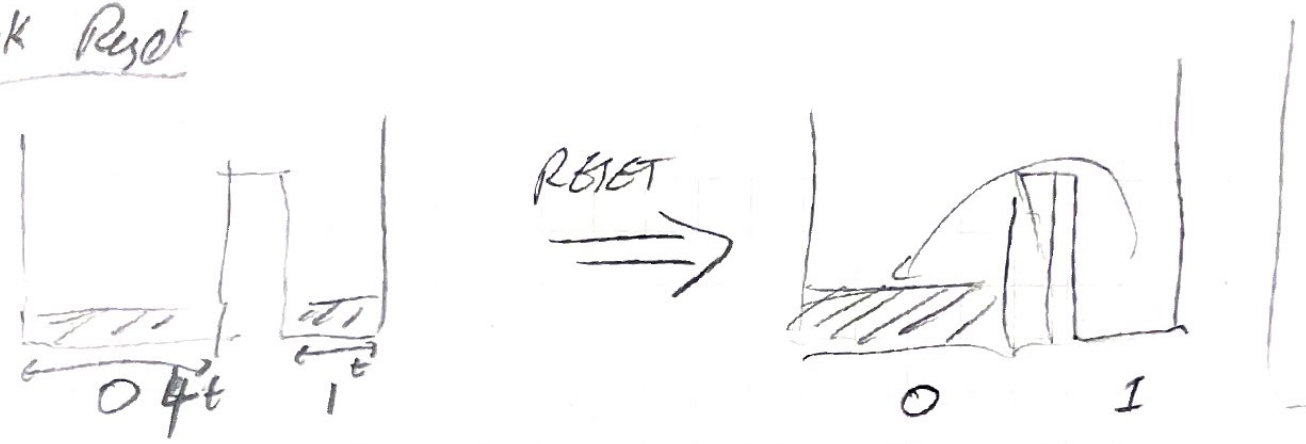
$I(C,D) = 1$ bit $\xrightarrow{\text{Erasure of information at some cost in work extraction}}$ $I(C,D) = 0$ bits

RESET $I = (C,D) = 0$ bits

self Information $I(C;D) = \sum_{cd} P(cd) \log \frac{P(c,d)}{P(c)P(d)}$ $\quad I(D,D) = \sum P(d) \log \frac{P(d)}{P(d)P(d)} = S(D)$

Erase ≠ Reset

Zero work Reset



COPY [Add copy]

C	D	→	C	D
0	0		0	0
0	1		0	1
1	0		1	1
1	1		1	0

XOR

logically Reversible.

Symmetric bit no work to copy

Bit operation work

Entropy 1 bit + $\frac{1}{2}\lg 4t + \frac{1}{2}\lg 1t$ 0 bits + $1 \lg 2\epsilon$

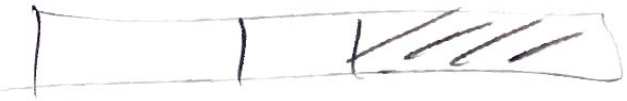
$$\Delta S = \underbrace{1 + \tfrac{1}{2}\lg 4}_{2} - \underbrace{1\lg 4}_{2} = 0$$

Bar Kessli 2006 [crabote]

Gavrilov & Bellhoefer 2016

Landauer's Principle

Reuse Book 3



[Landauer Principle Logically Reversible operations ⟷ Thermodynamically Reversible

[Loss emphasis on "Erasure", not Reset

⇒ It's The cycle that matters.

* Ongoing Research area.

Landauer Bound. ~~Reset~~ costs ≥ $k_B T \ln 2$ bits

What's This Number? $300 \times 1.4 \times 10^{-23} \times 0.7$ J

$\sim 3 \times 10^{-21}$ J Zetta Joules.

[Why Not Run computer in a dilution Refrigerator]

Refs Landauer 1961

Leff & Rex 2014 "Maxwell's Demon"

Thermodynamics of Computing

Charlie Bennett 1982

NOR 

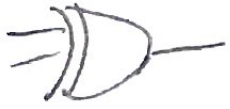
	0	1
0	1	0
1	0	0

AND 

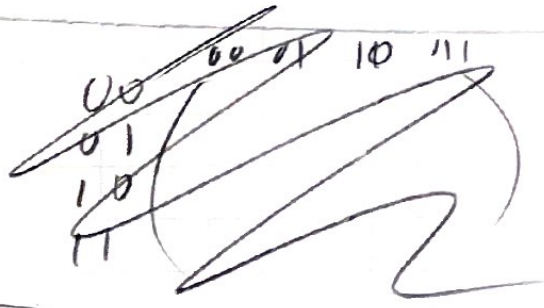
OR 

and ?	
0 0	0
0 1	0
1 0	0
1 1	1

OR	
0 0	0
0 1	p
1 0	q
1 1	1

XOR 

XOR	
0 0	0 0
0 1	0 1
1 0	1 1
1 1	1 0



Permutation Matrix

	00	01	10	11
00	1	0	0	0
01	0	1	0	0
10	0	0	0	1
11	0	0	1	0

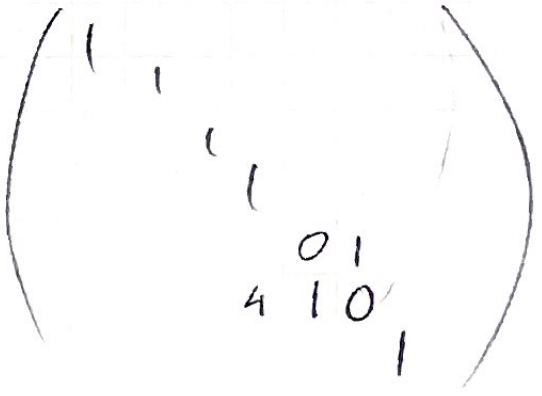
CNOT GATE

— Reversible Orthogonal Matrix $M^T = M$

[But XOR & NOT not universal. Need 3-bit gates]

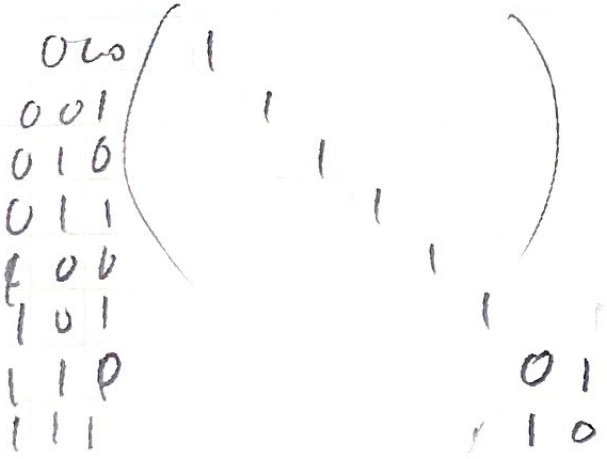
Toffoli Gate

Fredkin Gate
Controlled SWAP



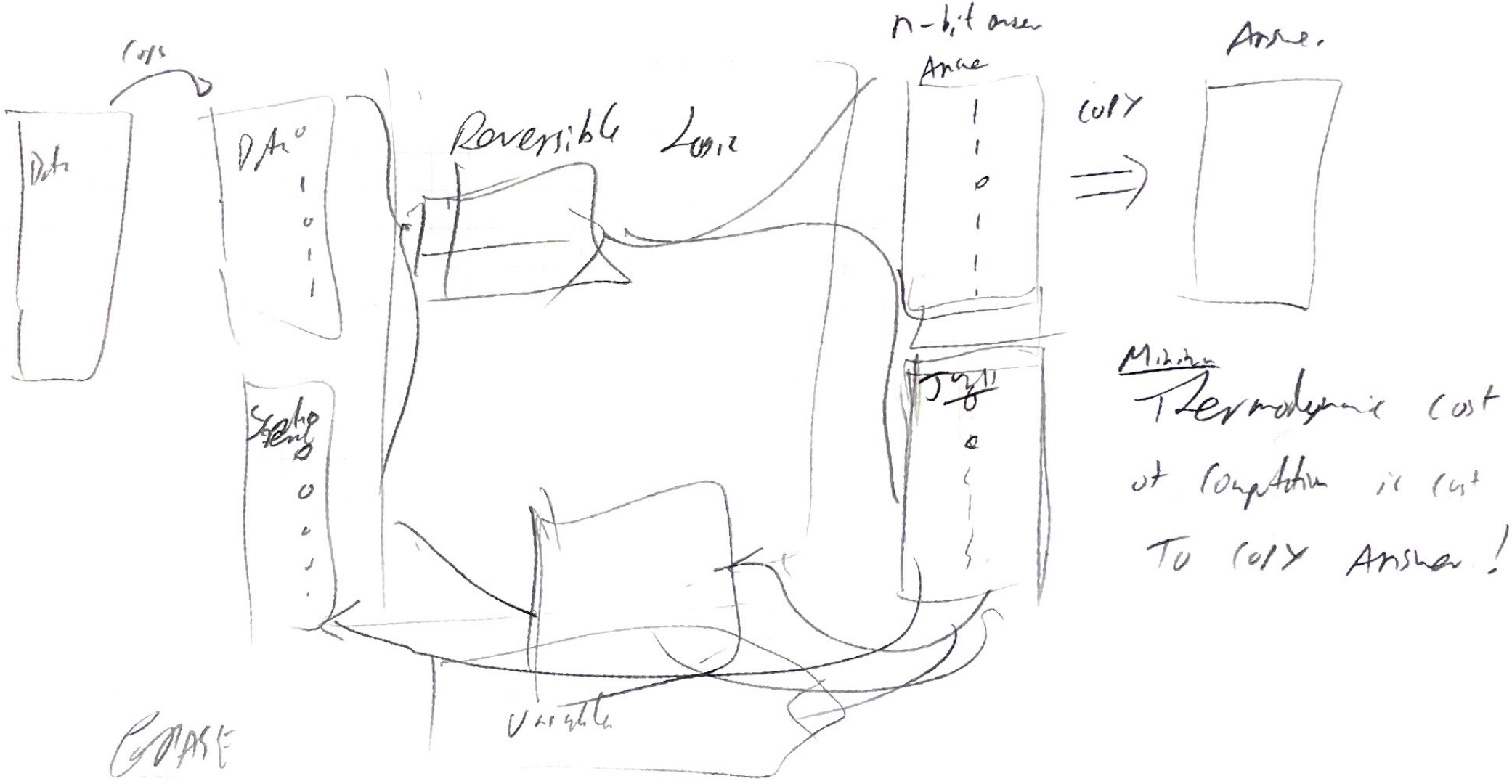
These are universal

Permutation



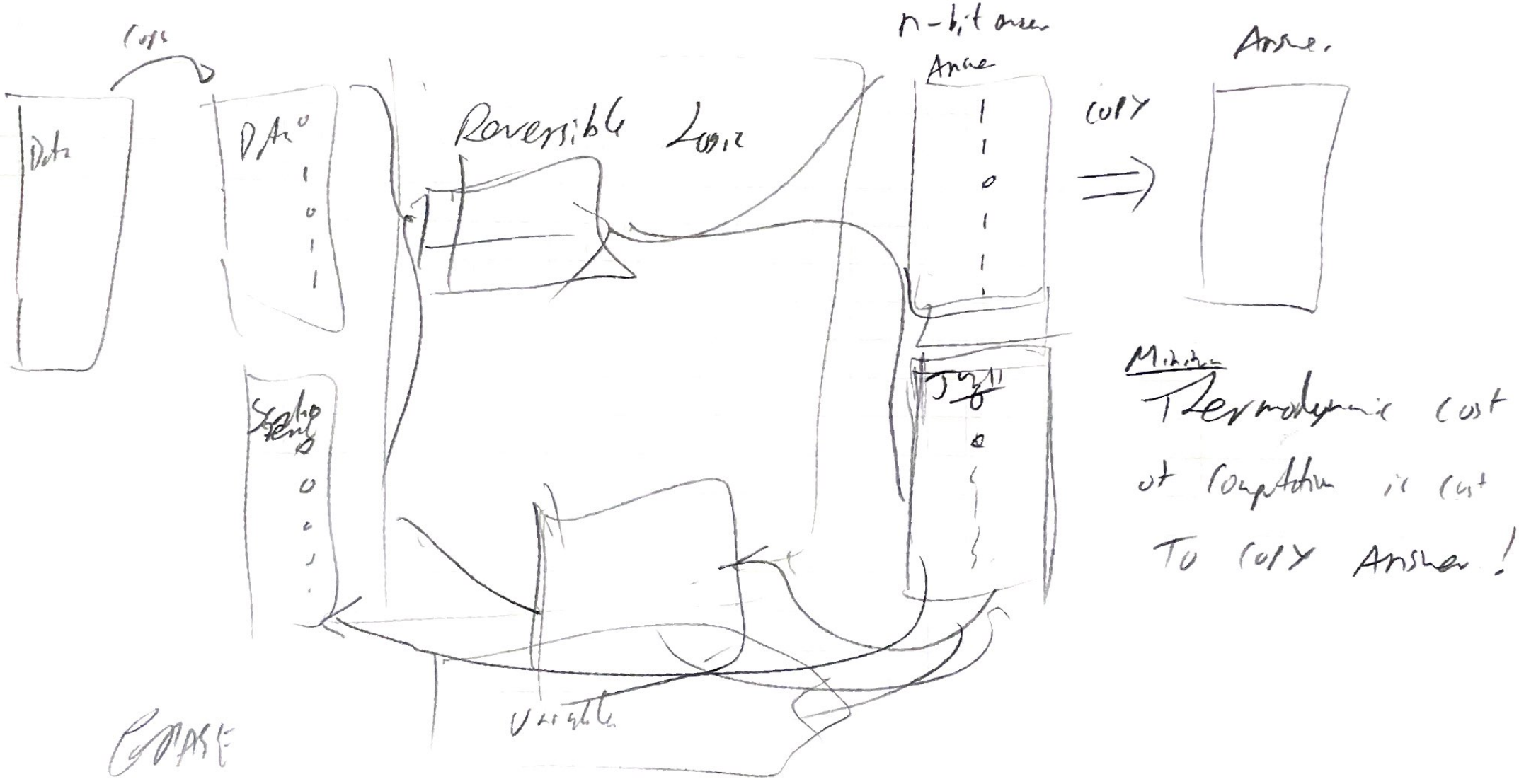
(Quantum

Reversible computation



Reversible computation

C



Minimum Thermodynamic cost of computation is cost To copy Answer!