ABOUT TIME

The "Problem" of the 2nd Law

closed system $\langle \Delta S^{TM} \rangle \geq 0$ Clausius Jaynes 1957

① ~~Why~~ Origin of 2nd Law?

② Why does entropy increase at all? (why no Maxwell demons?)

③ Consequences of 2nd Law? → Thermodynamics
→ Stat Mech
→ Stochastic Thermodynamics

(Bread & butter)

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#2 ABOUT TIME

② Why does entropy only increase? (on average)

Or why no effective Maxwell demons?

Stochastic dynamics → Trivial

Markov chain distribution

stationary distribution

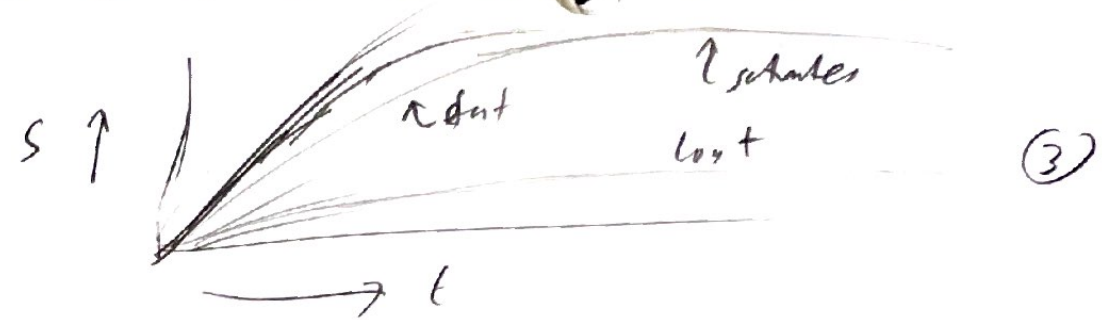
$$D(P_n \| \pi) \geq D(P_{n+1} \| \pi)$$

Cover & Thomas

$$\beta \Delta F = \beta F^{neq} - \beta F^{eq}$$

boundary → total entropy goes up

But? ~~Deterministic, reversible dynamics, information never lost?~~



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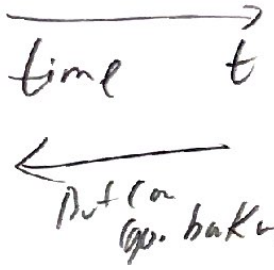
But? Deterministic, reversible dynamics → No information lost
(& not just invertible)

"low entropy



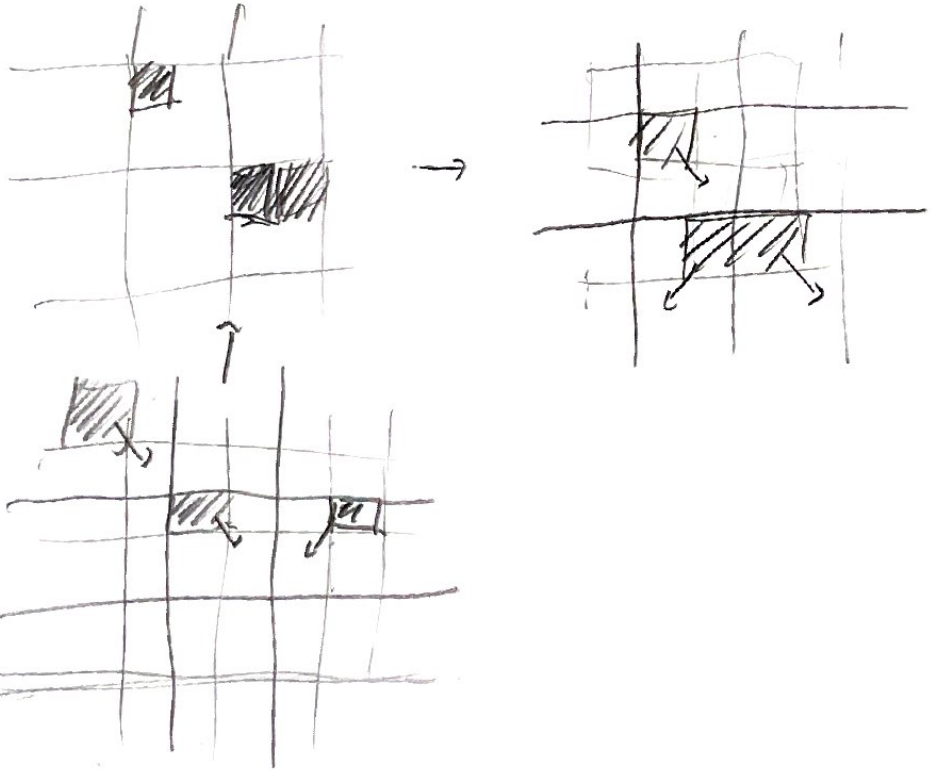
"High entropy

$S_{initial} + S_{gained} = S_{final}$

↳ entropy can increase at most ... by Landauer's principle !?

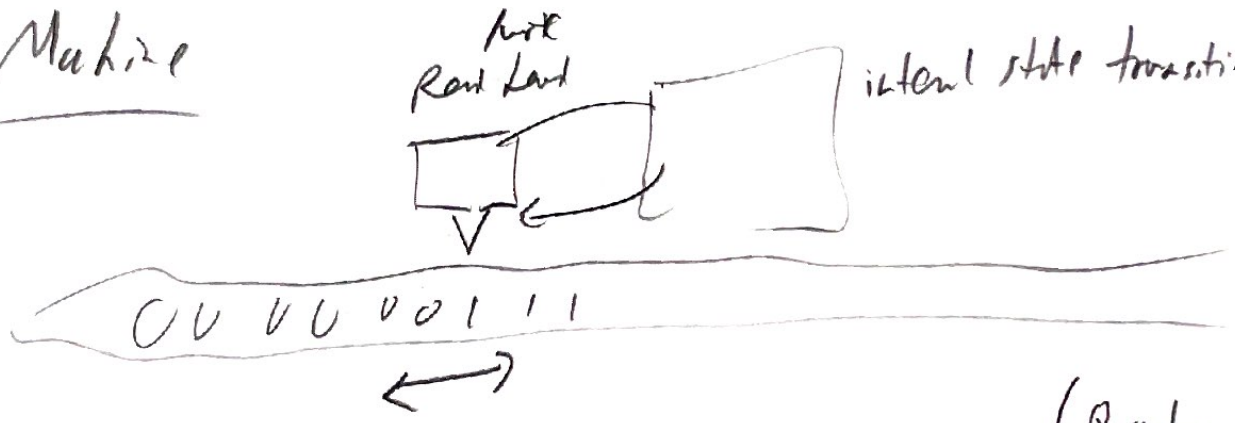
Solutions: Quantum? Chaos?

NO, → Cellular Automata bcs. Deterministic
Reversible
Discrete time & Space



(In a Reversible CA
colliding at 2 moving objects
~~don't annihilate~~ (or + create
static structure alone)

Universal Turing Machine



→ Computes "computable functions" (Quantum computers do not change what's a computable function)

Church Turing Thesis → Any computation (double) can be performed on a Turing complete

"Turing Complete" (e.g. C language print statement)

Recursion

If dynamics is Turing complete, then computationally irreducible to compress configurations (?)

→ See Stephen Wolfram "Computational Foundations of Quantum Law"

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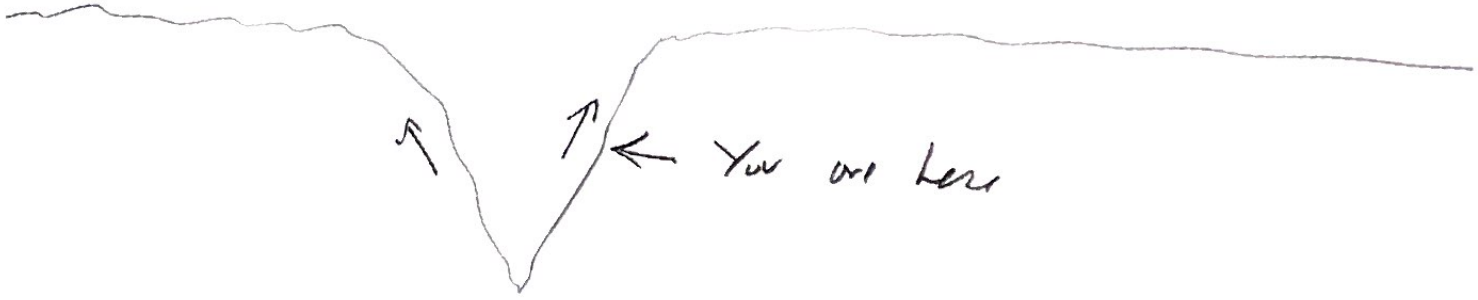
(1) Why is entropy low? (Entropy can't increase unless it's less than maximum)

Problem: Laws of physics are time reversal symmetric) *

Normal Situation? ⟷ time



Increase in entropy dictates time's arrow

⇒ Boltzmann Brain Paradox

*(not really CPT)

27, 28, 29

Past Hypothesis   David Albert 2000

Entropy increases into the future, [illegible]

because it was lower yesterday

⇒ Brief History of the universe.

⇒ Because Big Bang was low Entropy!

why are we located so close to ~~end~~ boundary of Universe?

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Lorentz Physics covariant Symmetries ($\Rightarrow$ conserved quantities)

Big Bang breaks Symmetries!

Time

Matter / Antimatter

(Atome?)

No rest frame

Why? Dunno.

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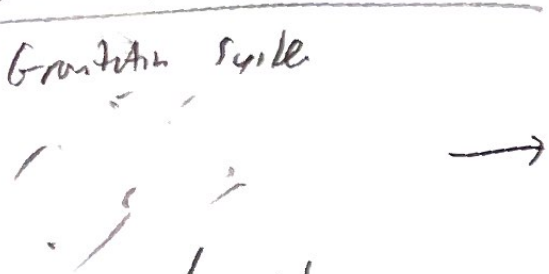
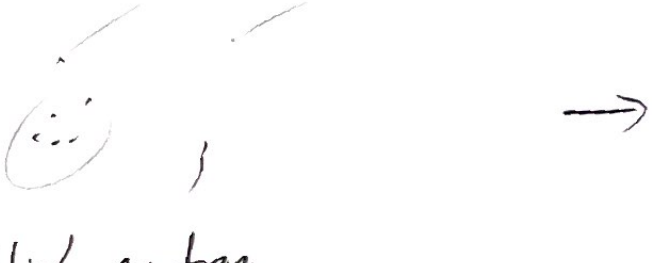
BEKENSTEIN-HAWKING

Gravity & entropy

Gravitating system



low entropy



High entropy
(so much energy released by
clumping mass, total entropy increases)

Black Hole!

Most entropy is black holes!

$$S_{BH} = \frac{A}{4}\left(\frac{K_B c^3}{G\hbar}\right) \qquad \text{Area} = m^2 \times 8\pi\left(\frac{G^2}{c^4}\right)$$

Planck units
$K = C = G = \hbar = 1$

length	10^{-35} M
mass	10^{-8} Kg
time	10^{-44} S
temperature	10^{32} K

other possibilities

Big Rip
Big Crunch

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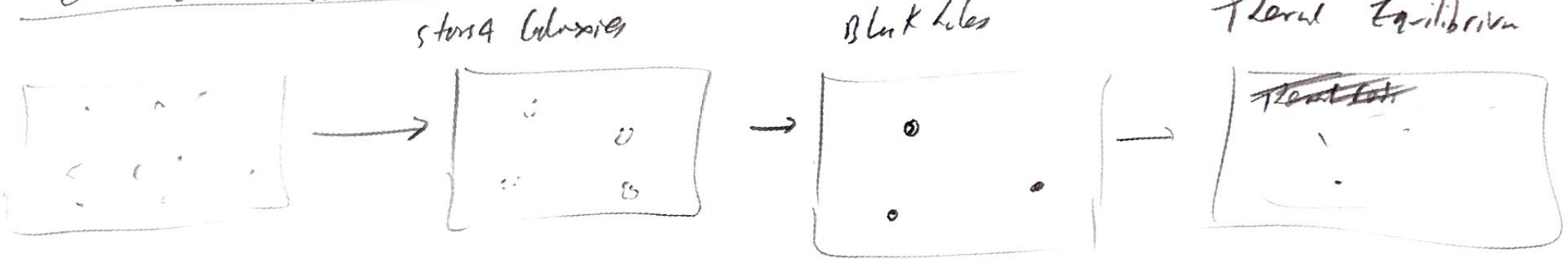
Heat death of Universe

10^{100} (googol years)



Hawking radiation, black holes evaporate

Have finite temperature

$\frac{1}{8\pi}$ Planck Mass, Planck Temperature

→ Smaller the black hole, hotter it is