

Thermodynamics: ENTROPY

By JinChen and Yinuo

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What is entropy

- “disorder” and randomness
- probability

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Literature review

- Where did entropy come from?
- key scientists

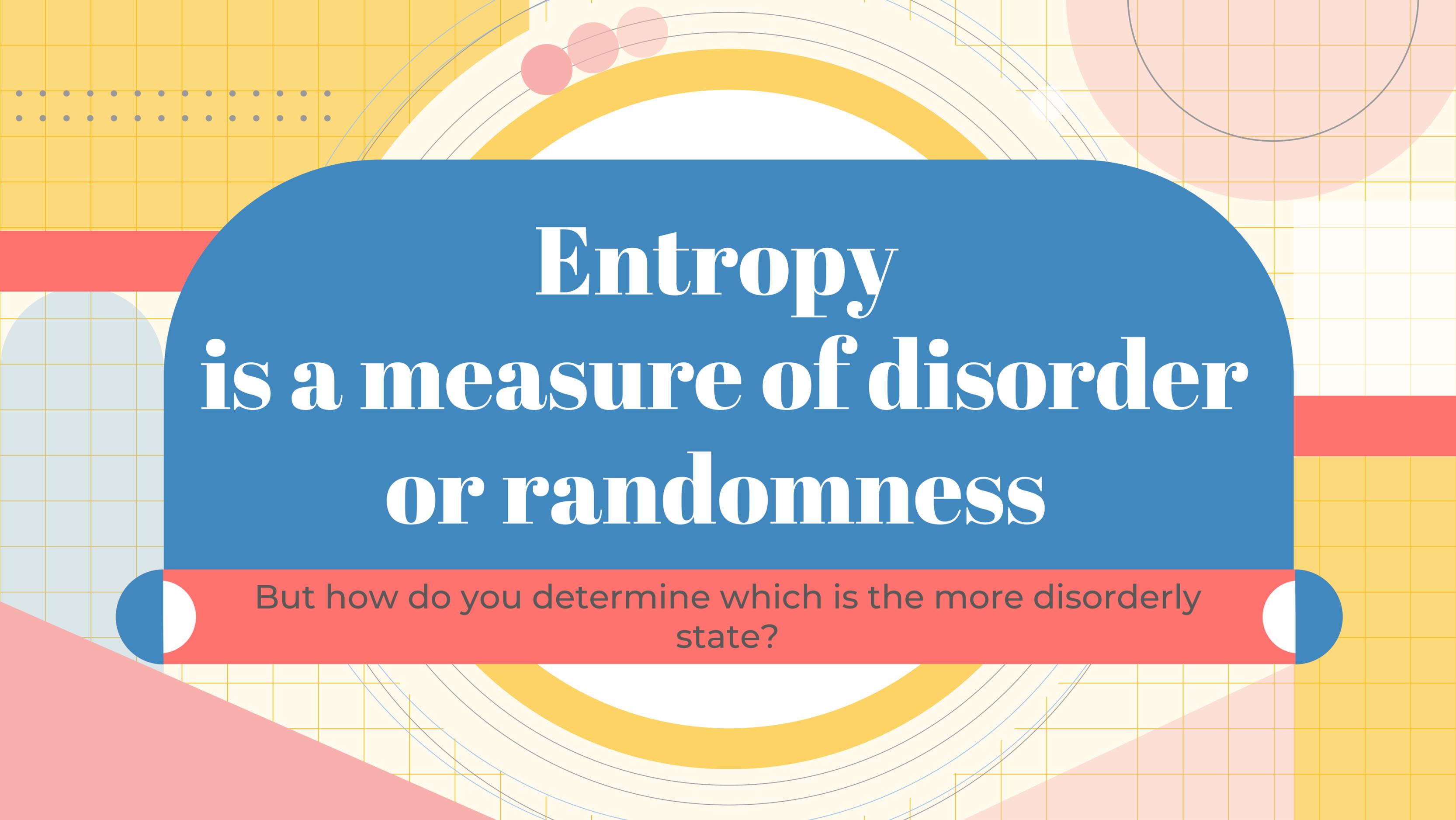
03

Second law of thermodynamics

- entropy always increases
- time
- heat death

04

Summary



Entropy

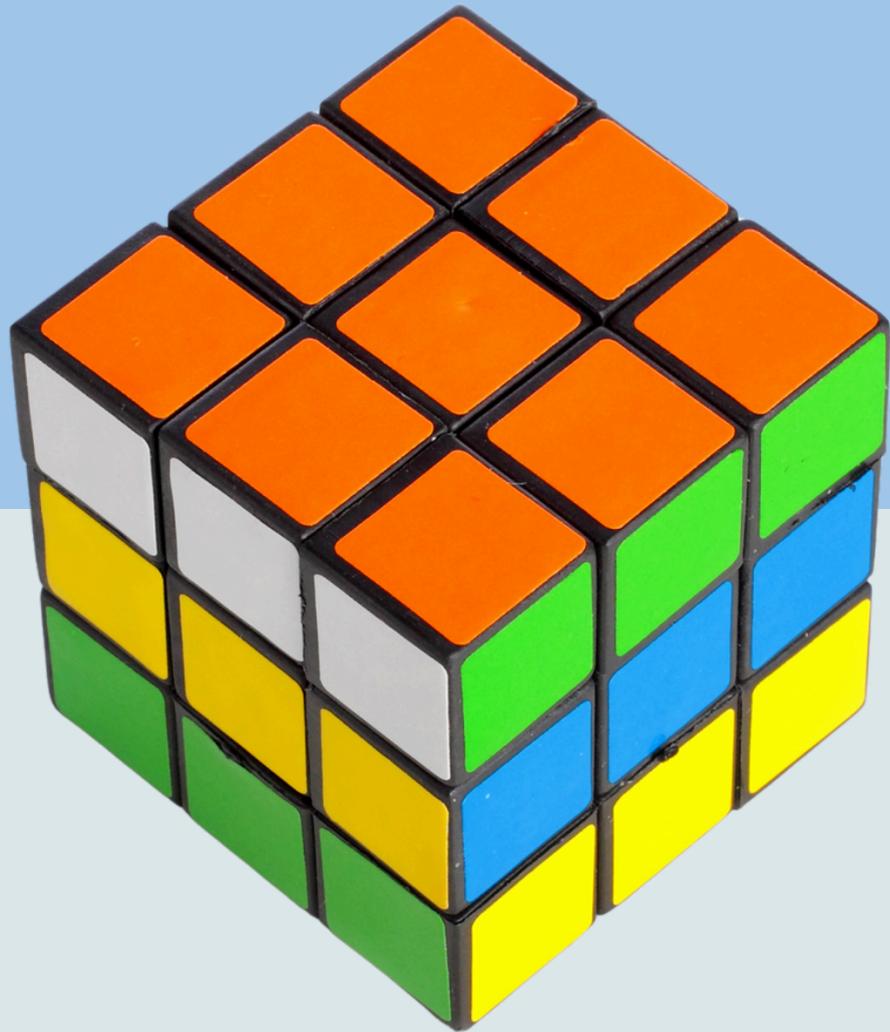
is a measure of disorder
or randomness

But how do you determine which is the more disorderly state?

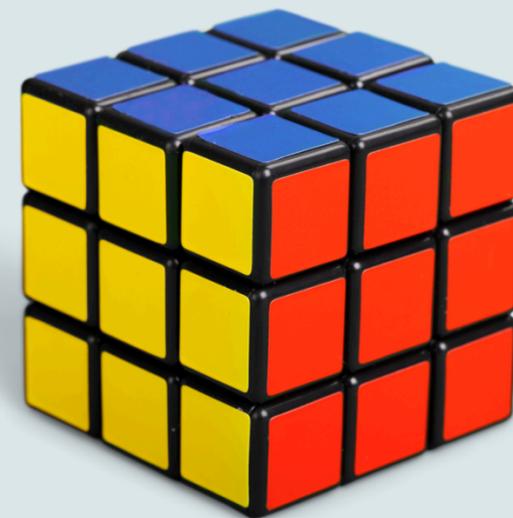
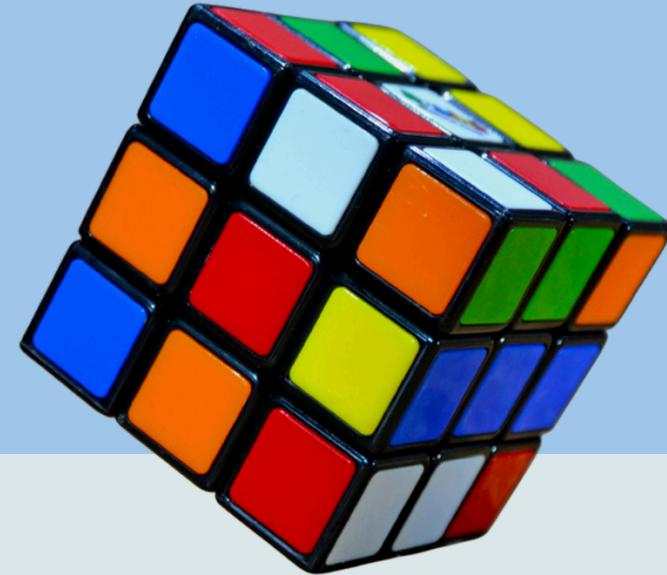
Neat room vs messy room



Rubix cube



99.999%



0.001%

Lazare Carnot - 1803

- Studied: pulleys, ramps, and simple machines
- Key insight: shocks and jerks waste energy
- This hinted at the second law of thermodynamics



Sadi Carnot

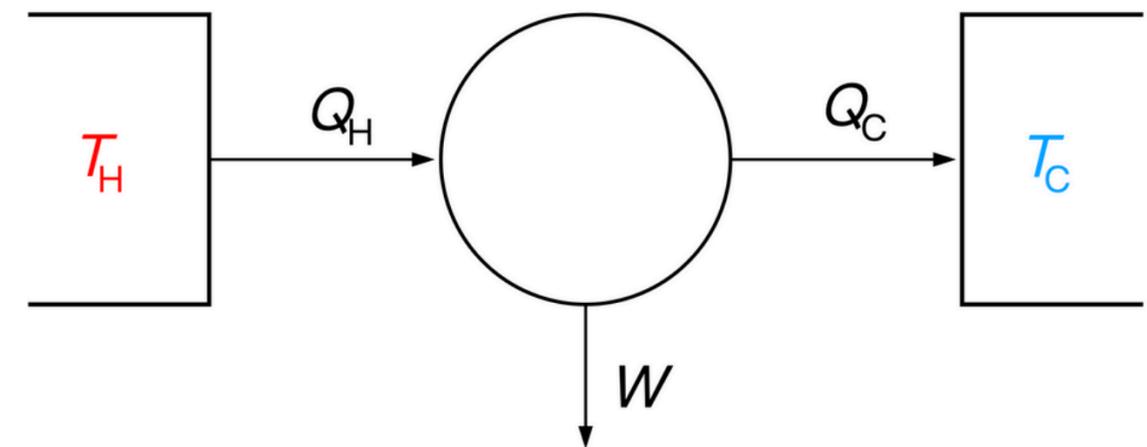
- Early 1800s: steam engines were everywhere but very inefficient
- Most heat from fuel was wasted
- Imagined a perfect heat engine which is a theoretical machine that had no friction, no leaks, no wasted motion, and transferred heat flawlessly.



regarded as the
father of
thermodynamics

Perfect Engine

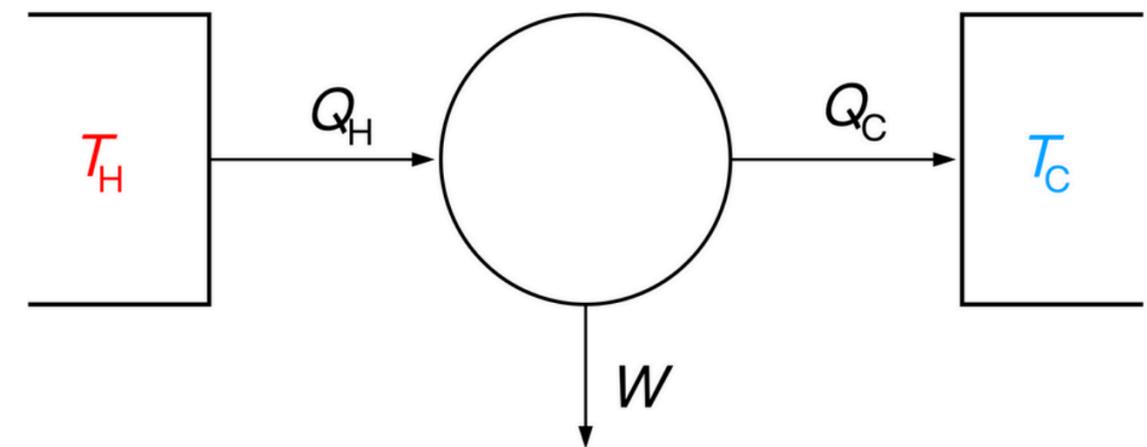
- Achieves the maximum possible efficiency allowed by thermodynamics
- How it works:
 - Runs in a reversible cycle between two heat reservoirs:
 - Hot reservoir absorbs heat Q_H at temperature T_H
 - Part of the heat is converted to work
 - Remaining heat Q_C expelled at temperature T_C



$$\eta_I = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H}$$

Perfect Engine

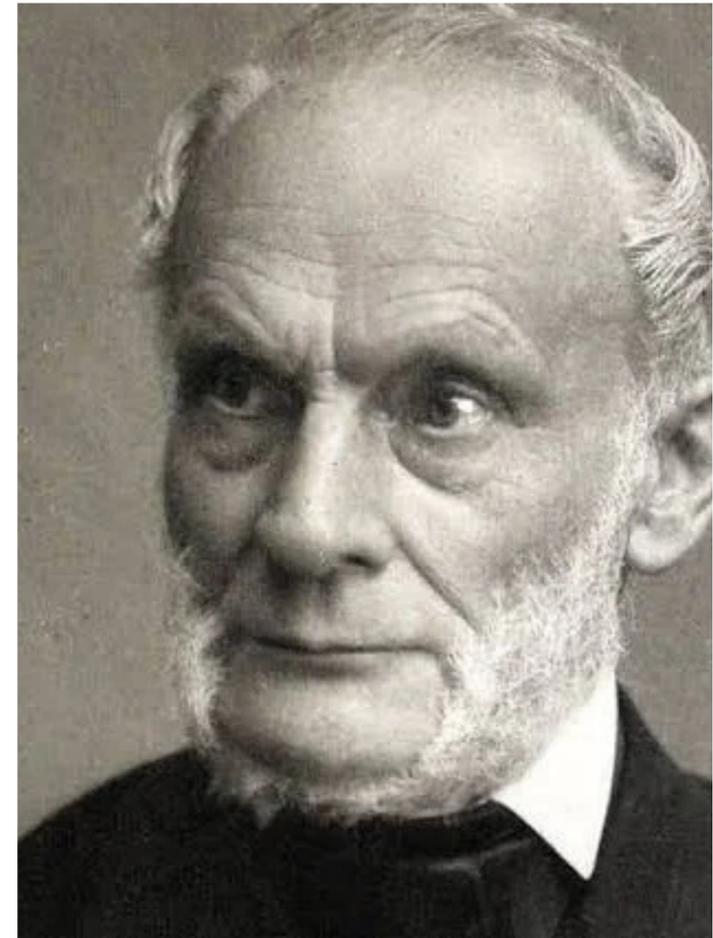
- Key Ideas:
 - Even if you remove *all* practical imperfections, some heat must always escape to the cold sink
 - No engine, not even the “perfect” one, can turn all its heat into work.
 - The efficiency of such an ideal engine depends only on the temperatures of the hot and cold reservoirs—not on the materials or the design of the machine.



$$\eta_I = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H}$$

Rudolf Clausius - 1854

- Introduced interior work and exterior work and formulated the concept of equivalence-value, an early version of entropy
- Developed mathematical formulations for reversible and irreversible heat transfer



History of discovery

$$\Delta S = Q \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

Q is the heat being transferred.

T_1 is the starting temperature.

T_2 is the ending temperature.

$$\int \frac{\delta Q}{T} = 0$$

$$\int \frac{\delta Q}{T} \leq 0$$

δQ means a tiny amount of heat energy that is transferred into or out of a system.

History of discovery

- Reversible process:
 - without friction, waste or imperfections
- Total entropy does not change

$$\int \frac{\delta Q}{T} = 0$$

History of discovery

- Irreversible process:
 - Some energy is always wasted as heat, friction, or disorder.
- For example

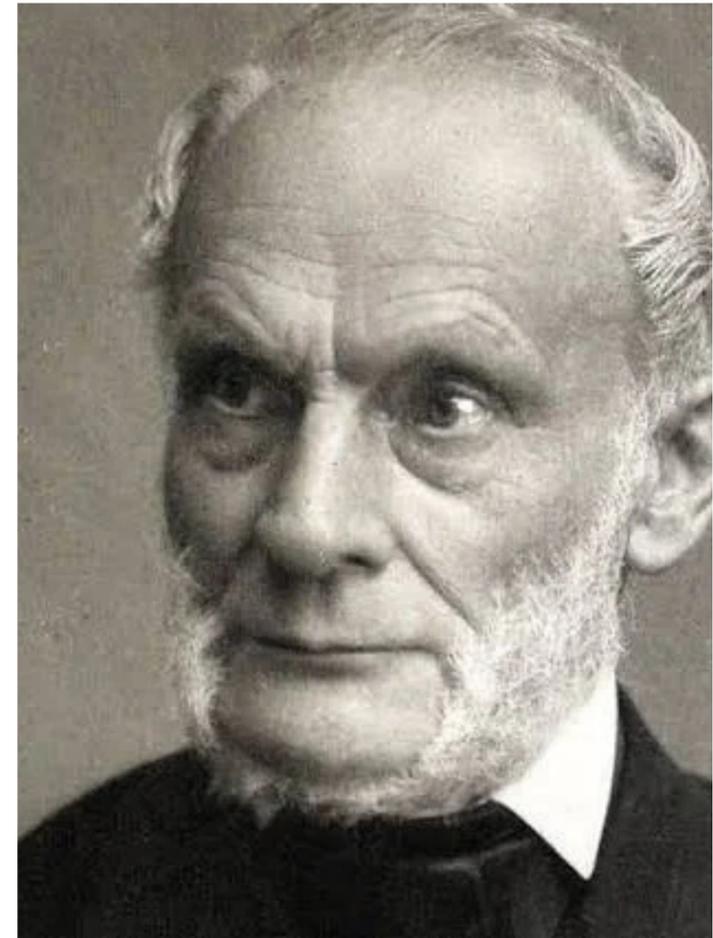


AI Generated

$$\int \frac{\delta Q}{T} \leq 0$$

Rudolf Clausius - 1865

- He coined the term entropy (S) to explain:
 - the tendency of heat
 - pressure
 - density
- to gradually disappear with time, or similarly, the inevitable generation of heat when work is done on a system by changing temperature.



Ludwig Boltzmann - 1877

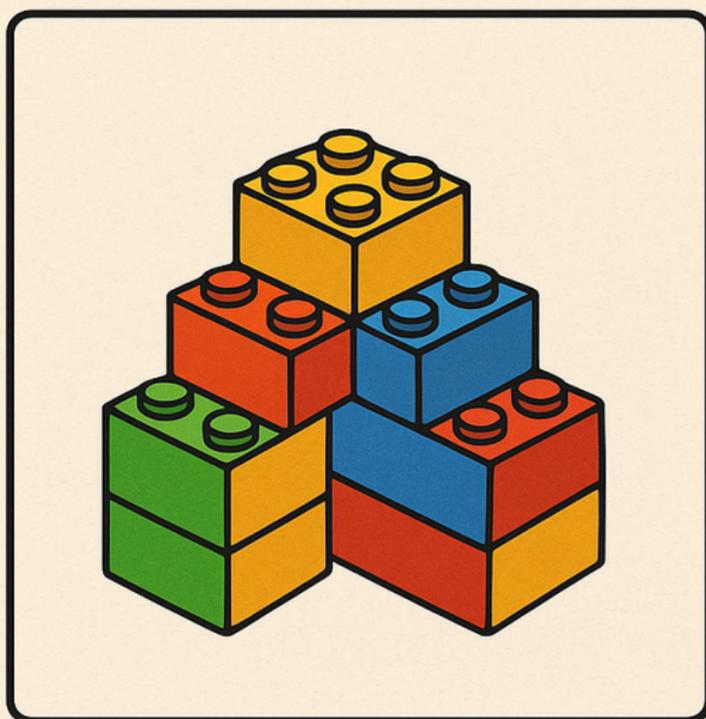
- Ludwig Boltzmann: Connected entropy to probability and microscopic particle arrangements with the famous equation:

$$S = k_B \ln \Omega$$

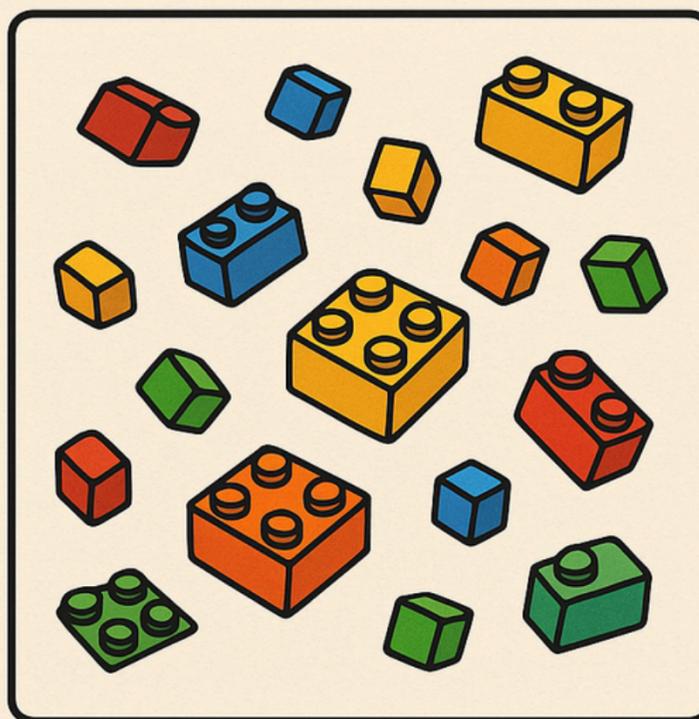
where S = entropy, k_B = Boltzmann constant, Ω = number of microstates.

History of discovery

LOW ENTROPY

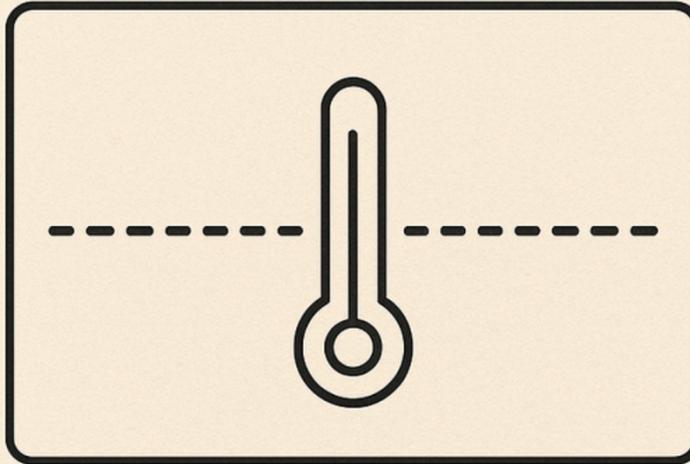


HIGH ENTROPY

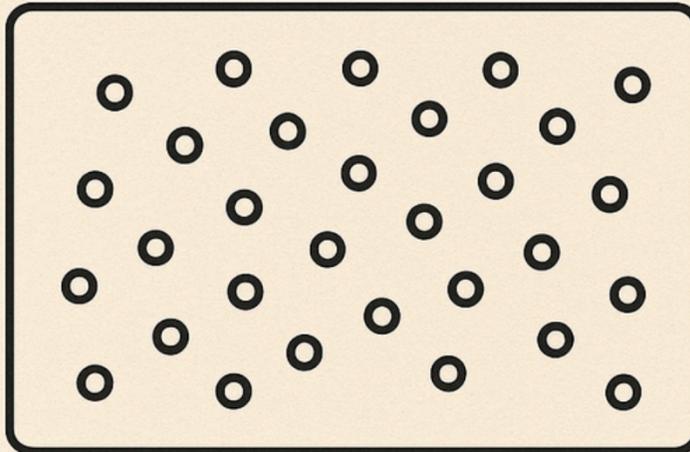


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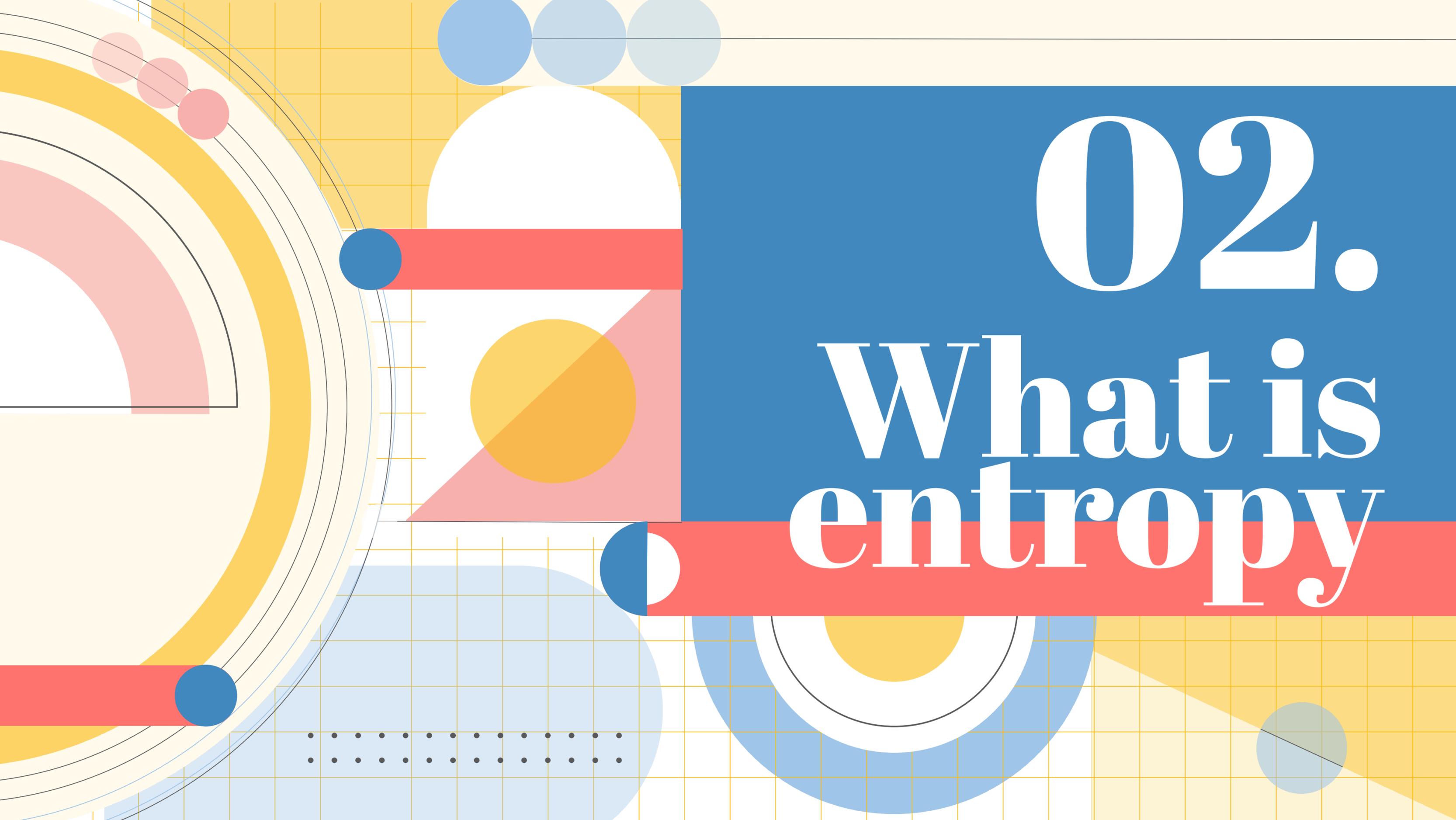
MACROSTATE



MICROSTATE

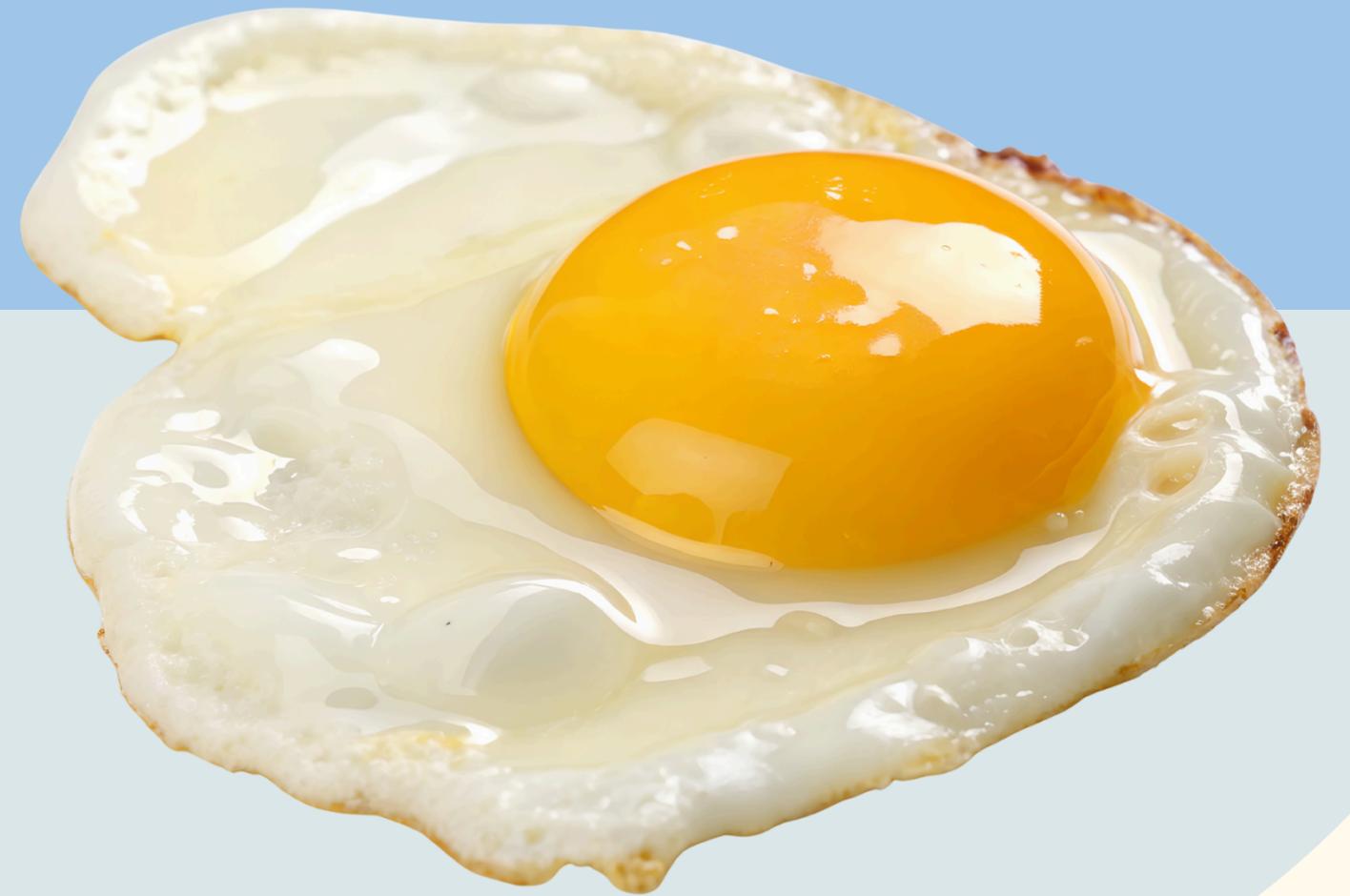


Entropy tells us how many microstates belong to one macrostate



02. What is entropy

Raw egg vs cooked egg

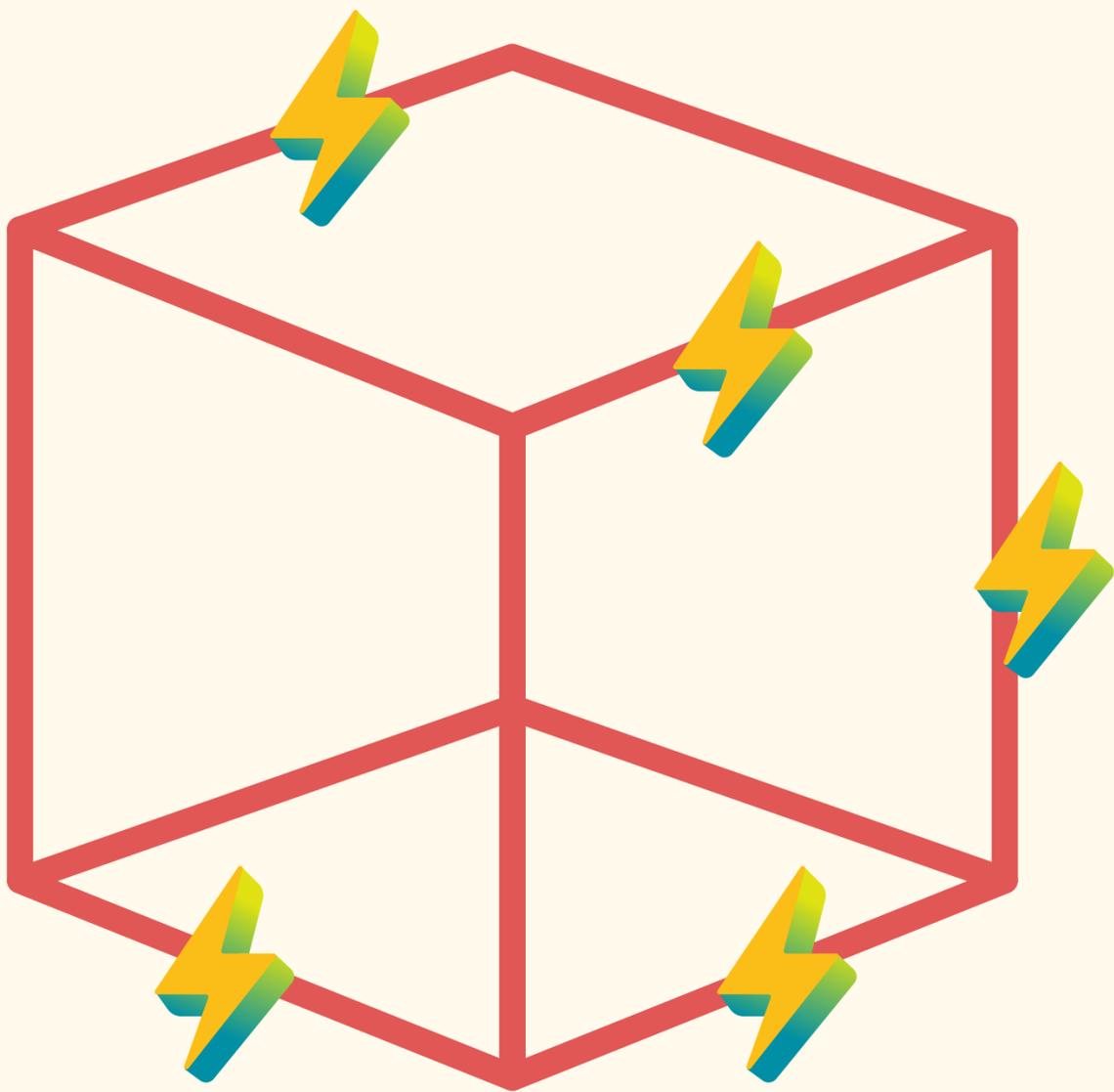


Higher possibility, higher entropy

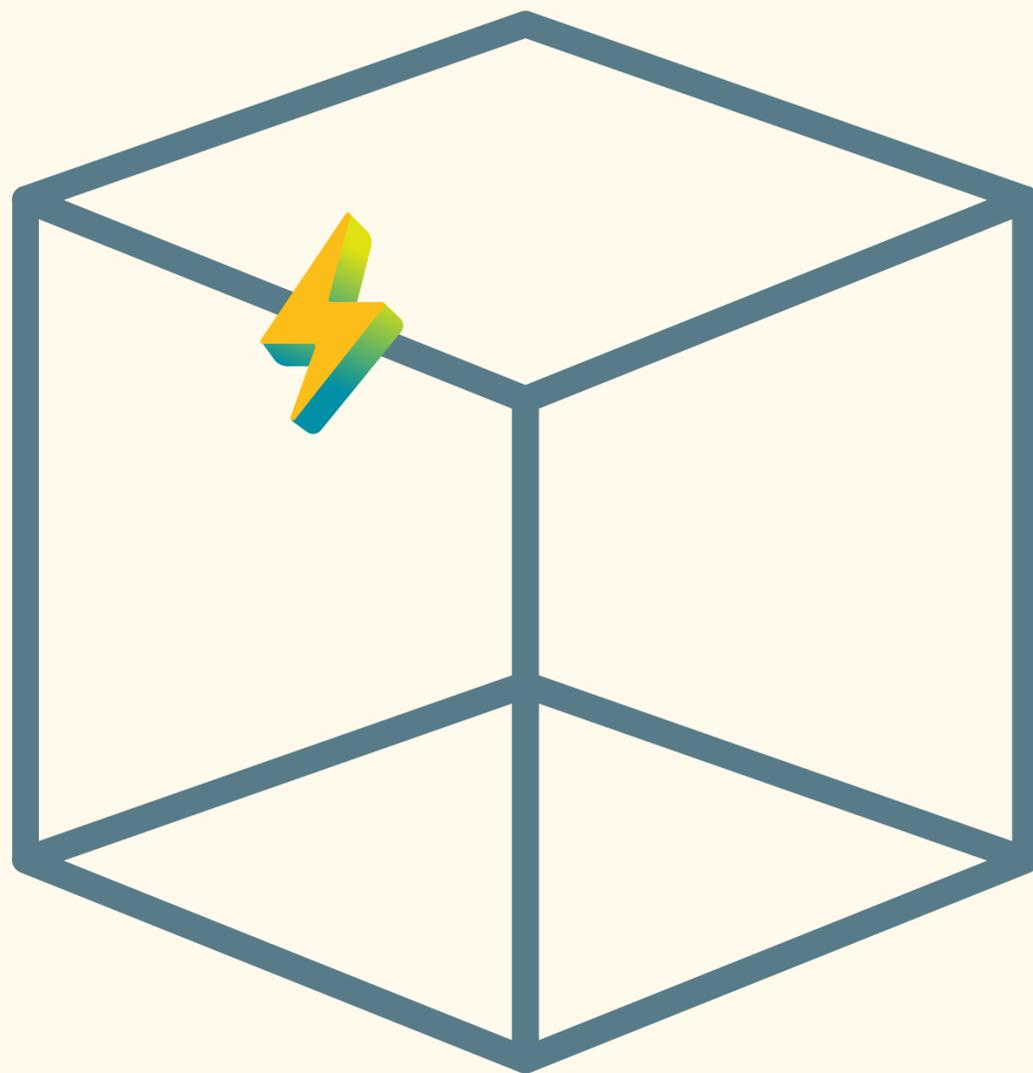
Entropy is a measure of how many possible microscopic arrangements (microstates) a system can have while still looking the same overall (macrostate).



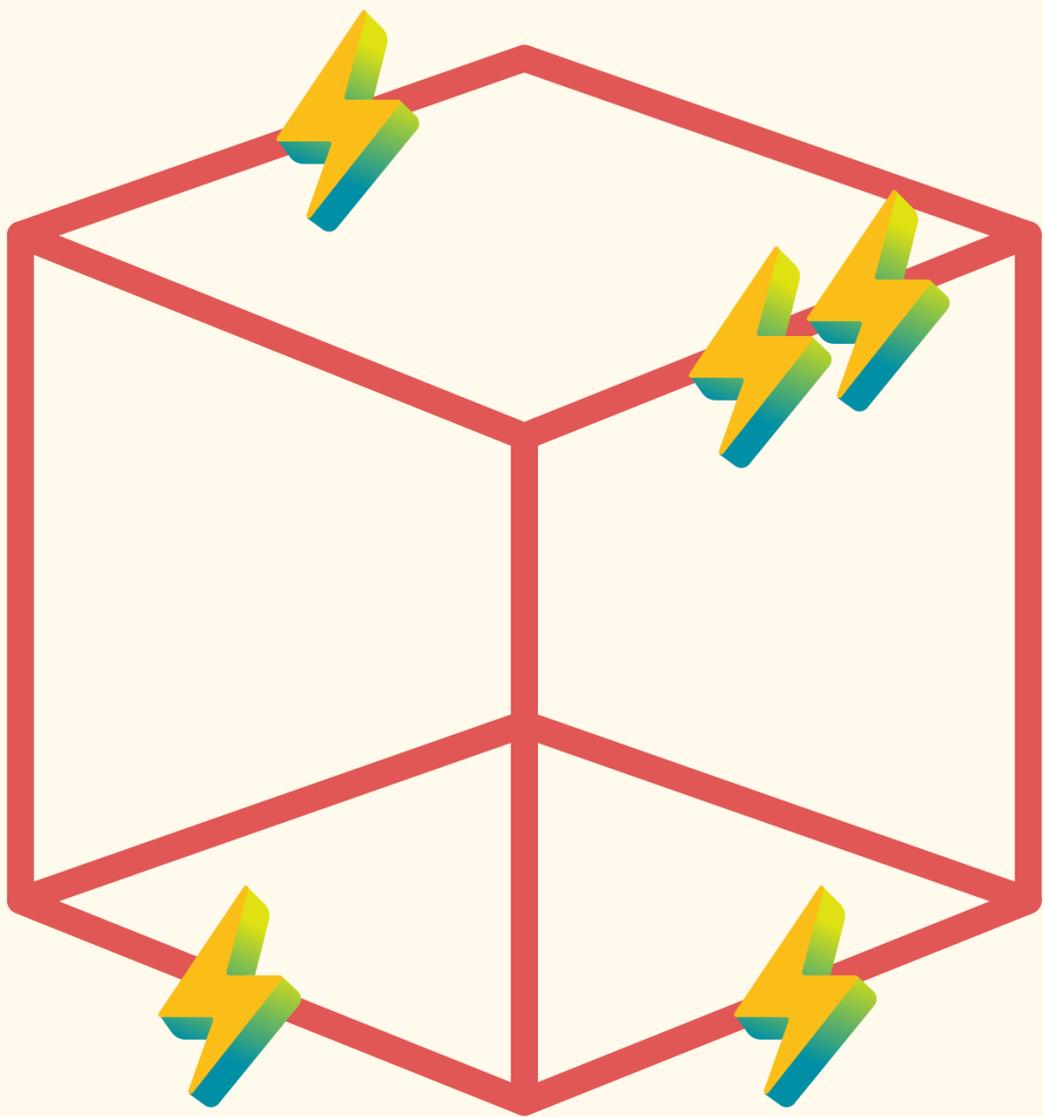
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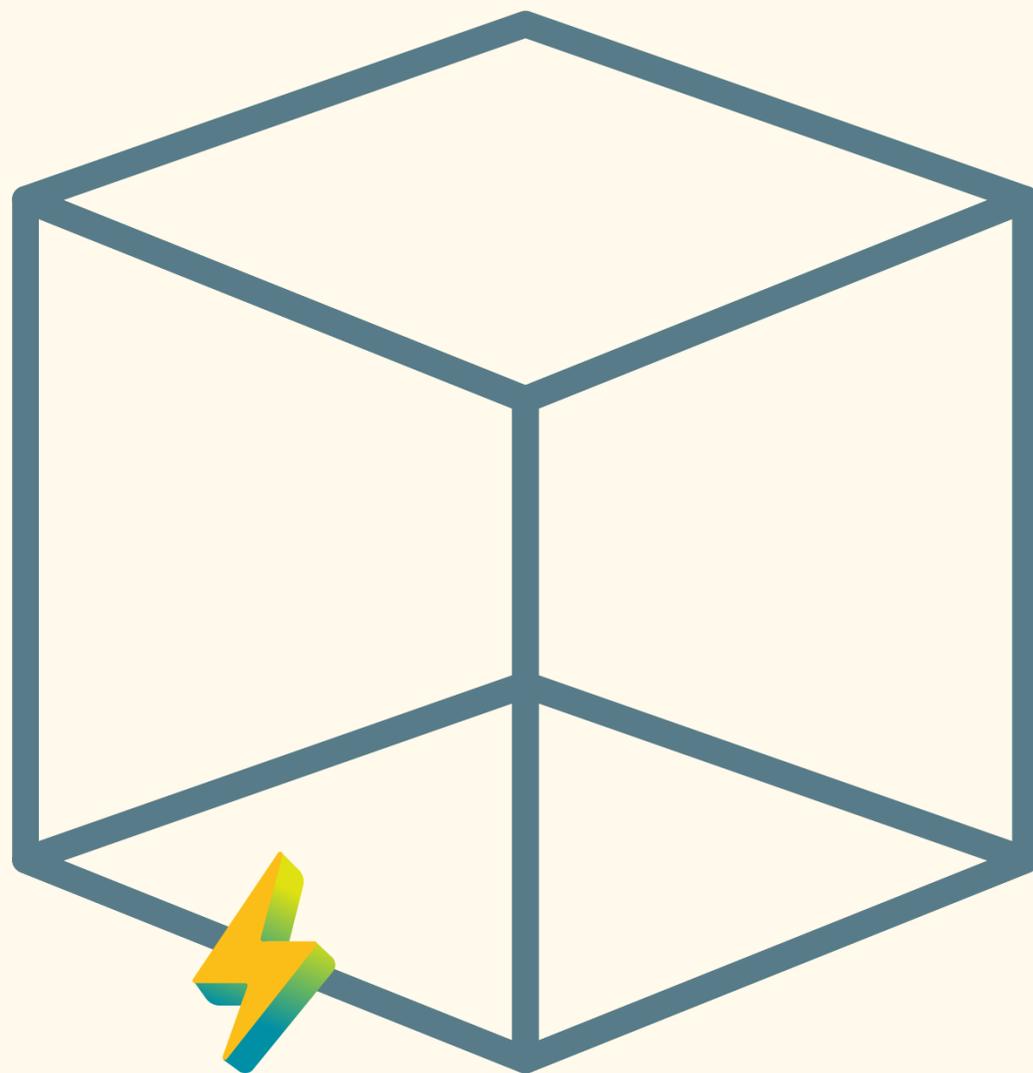
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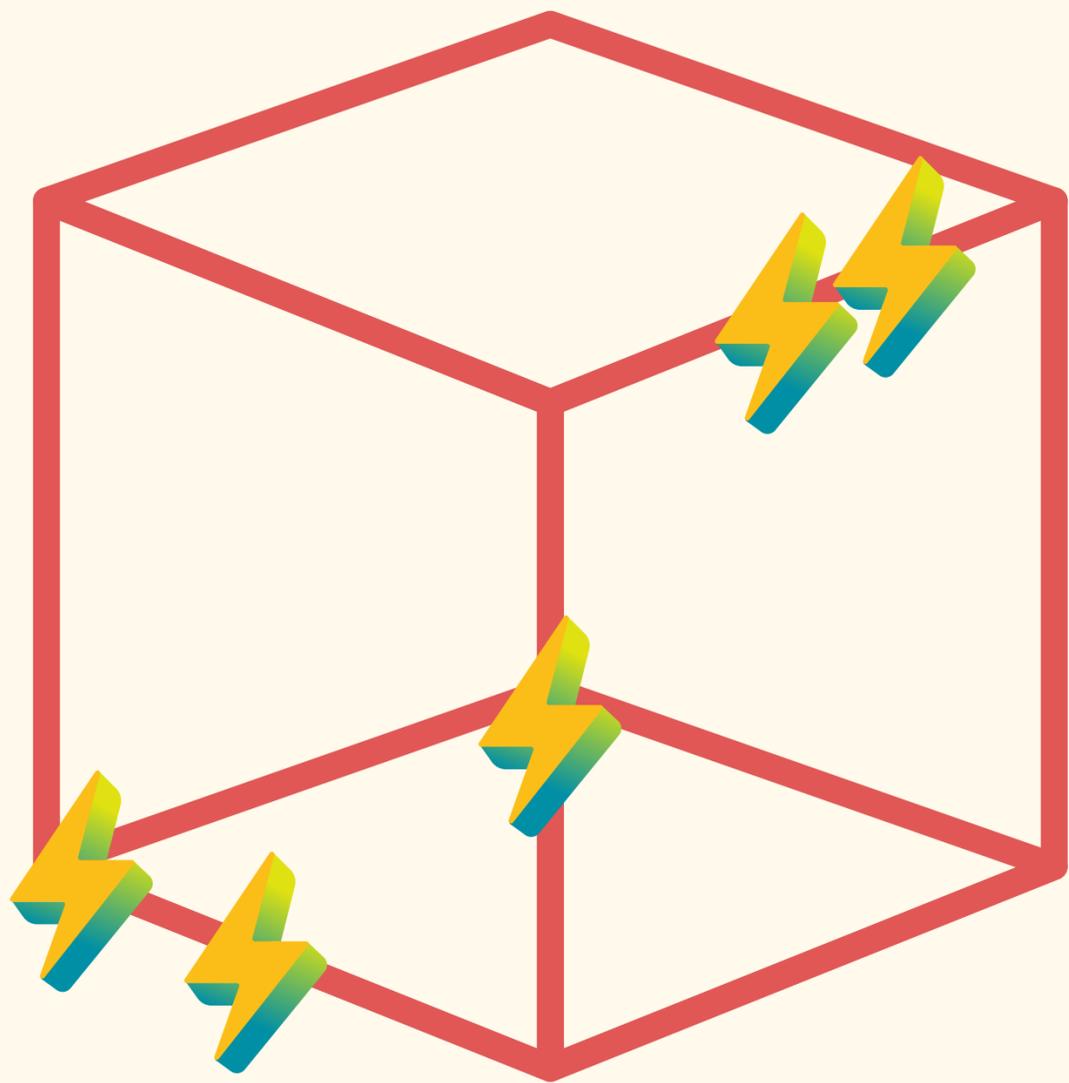
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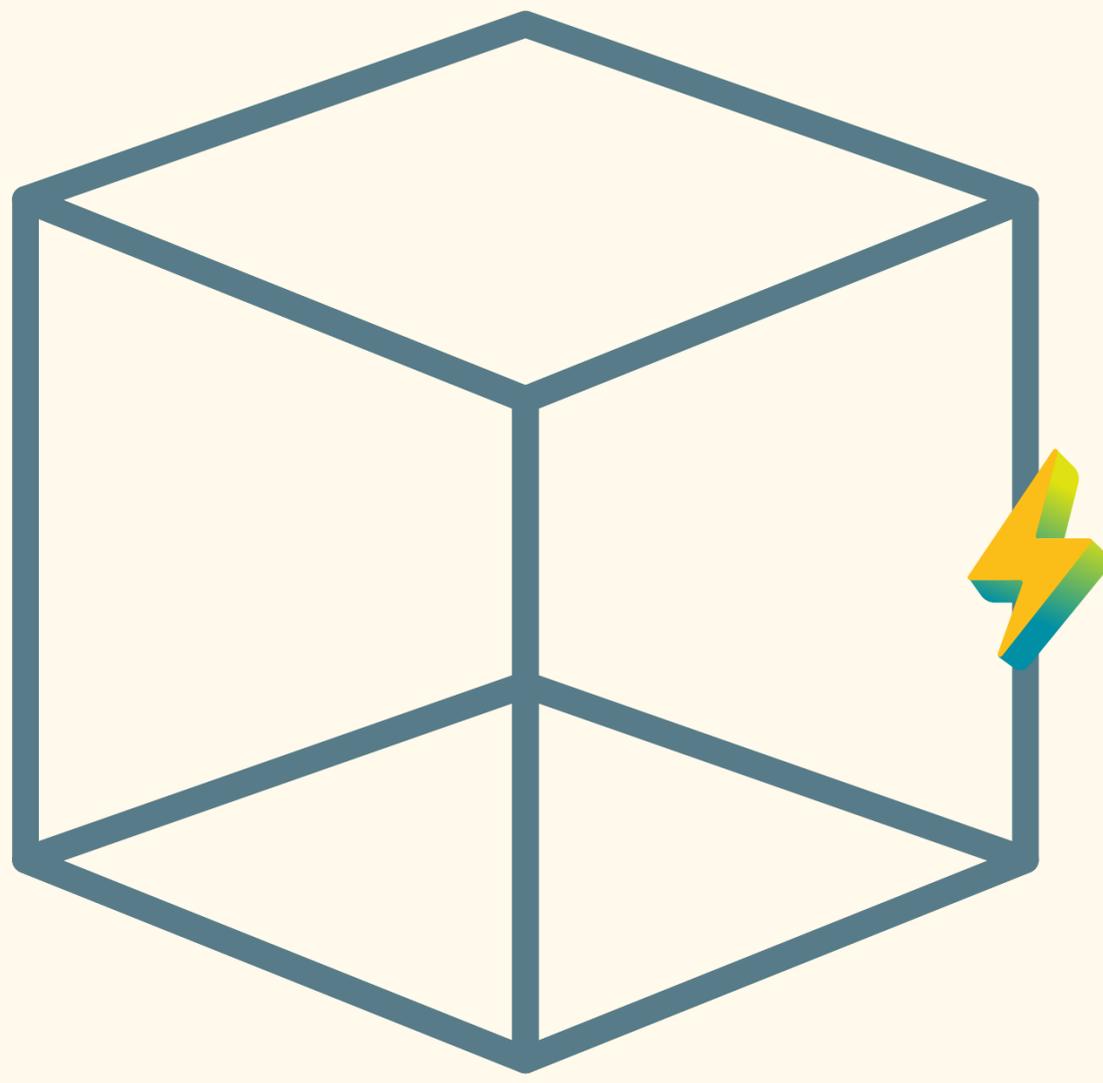
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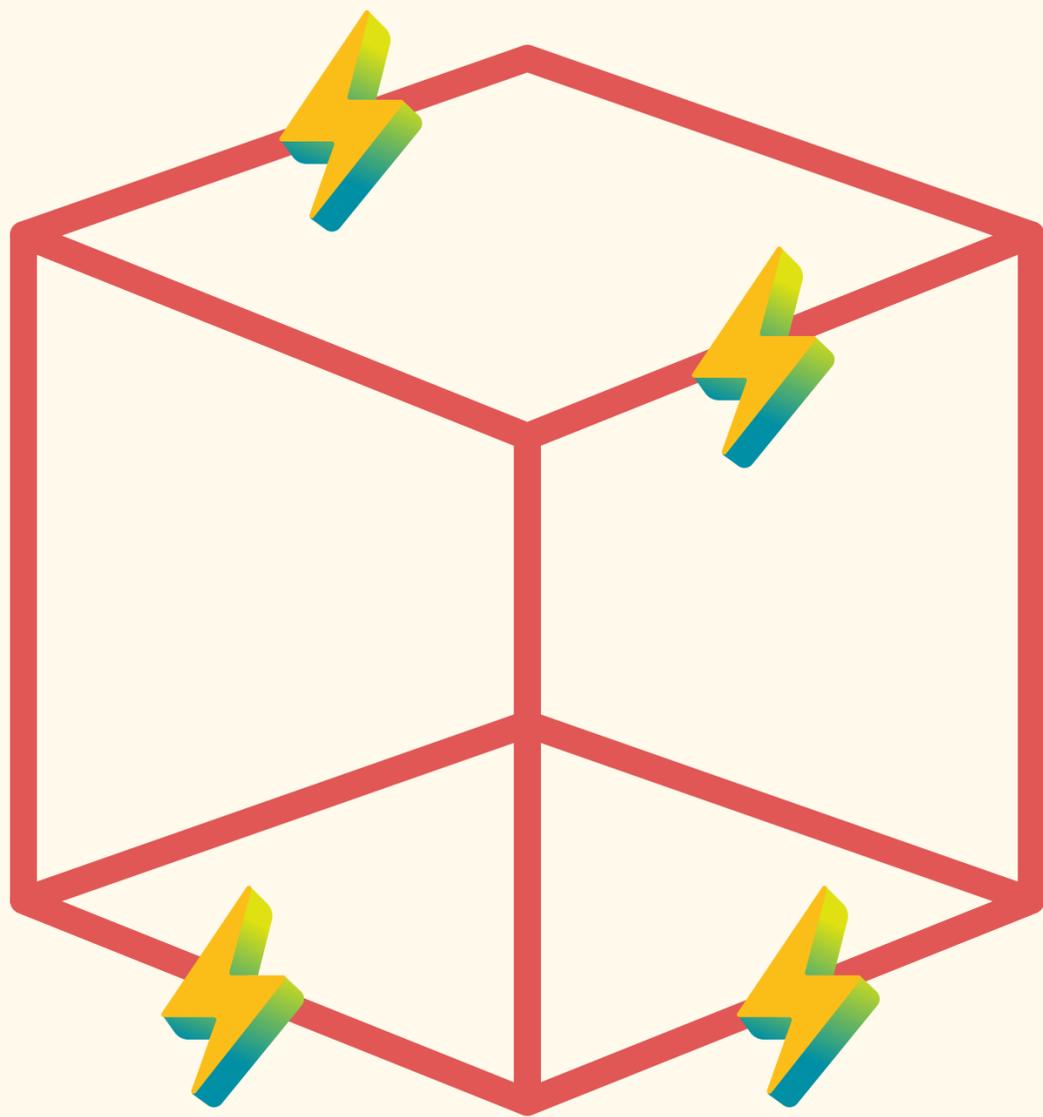
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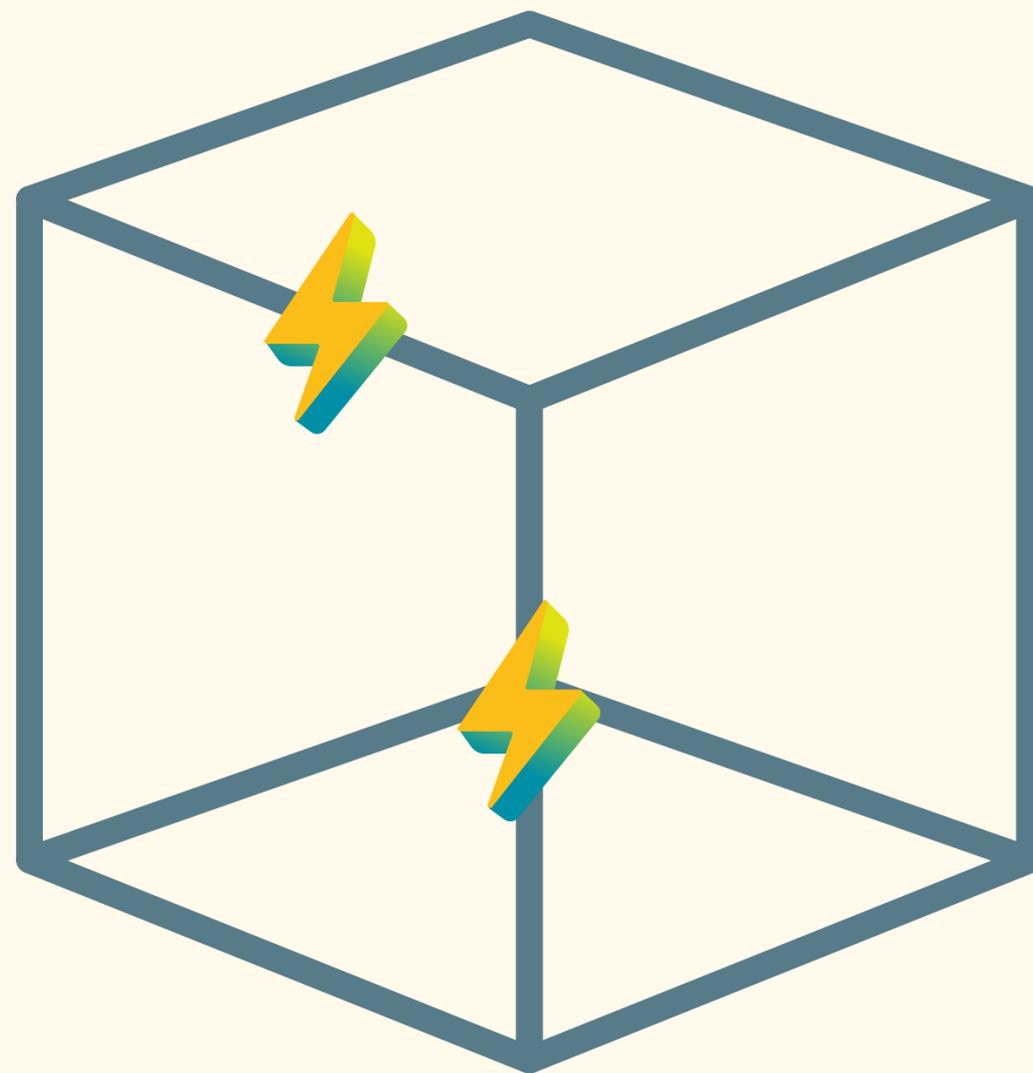
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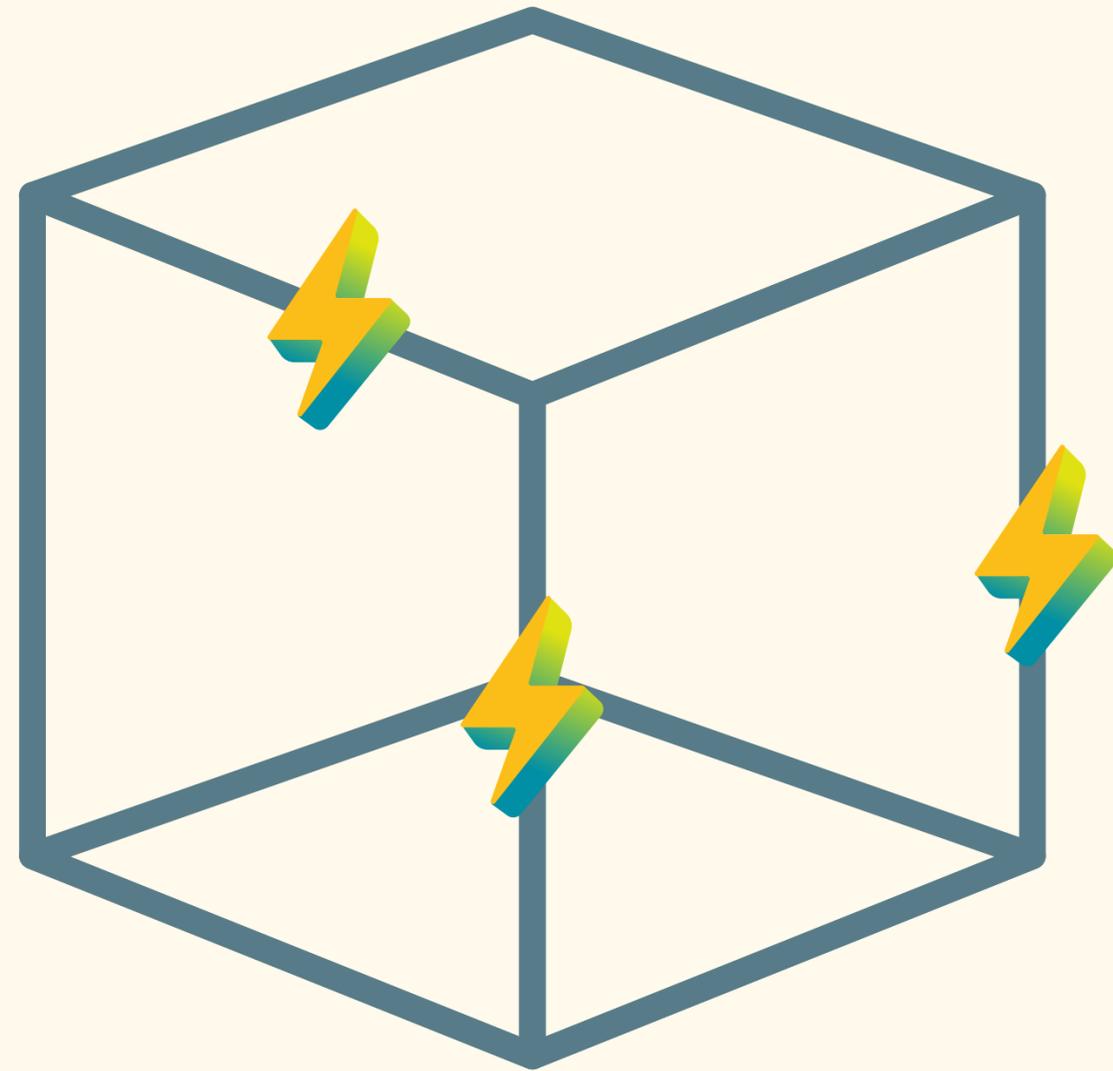
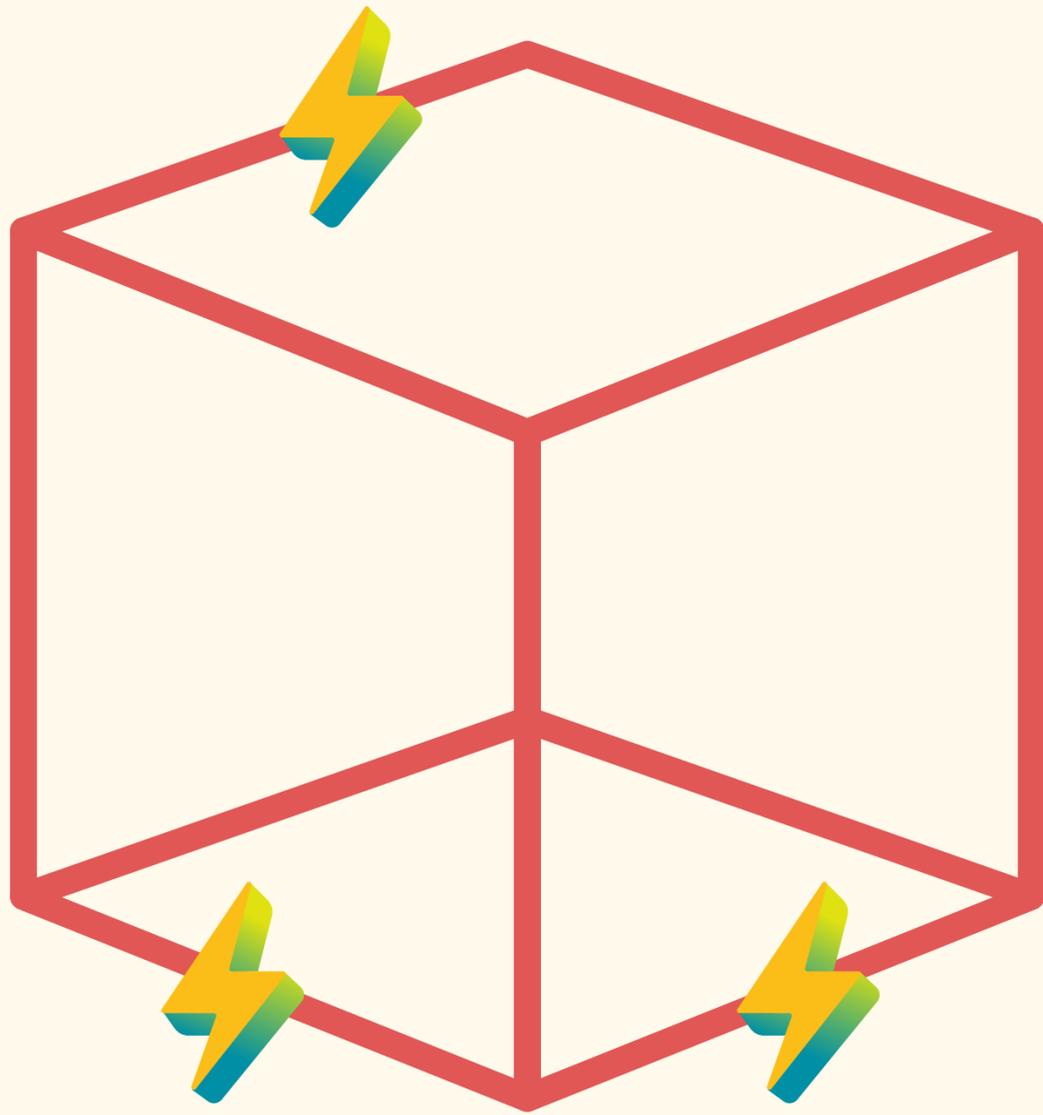
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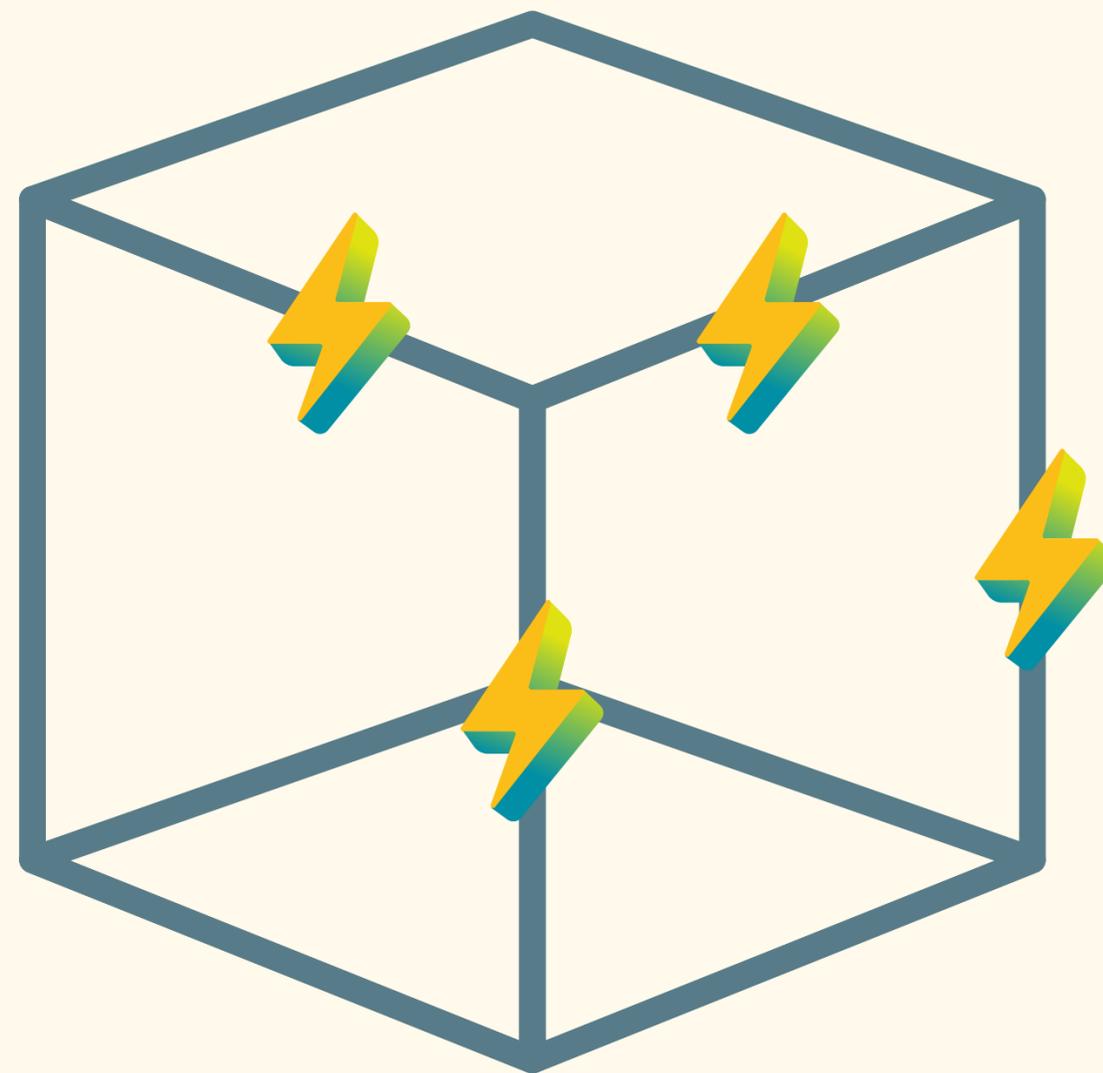
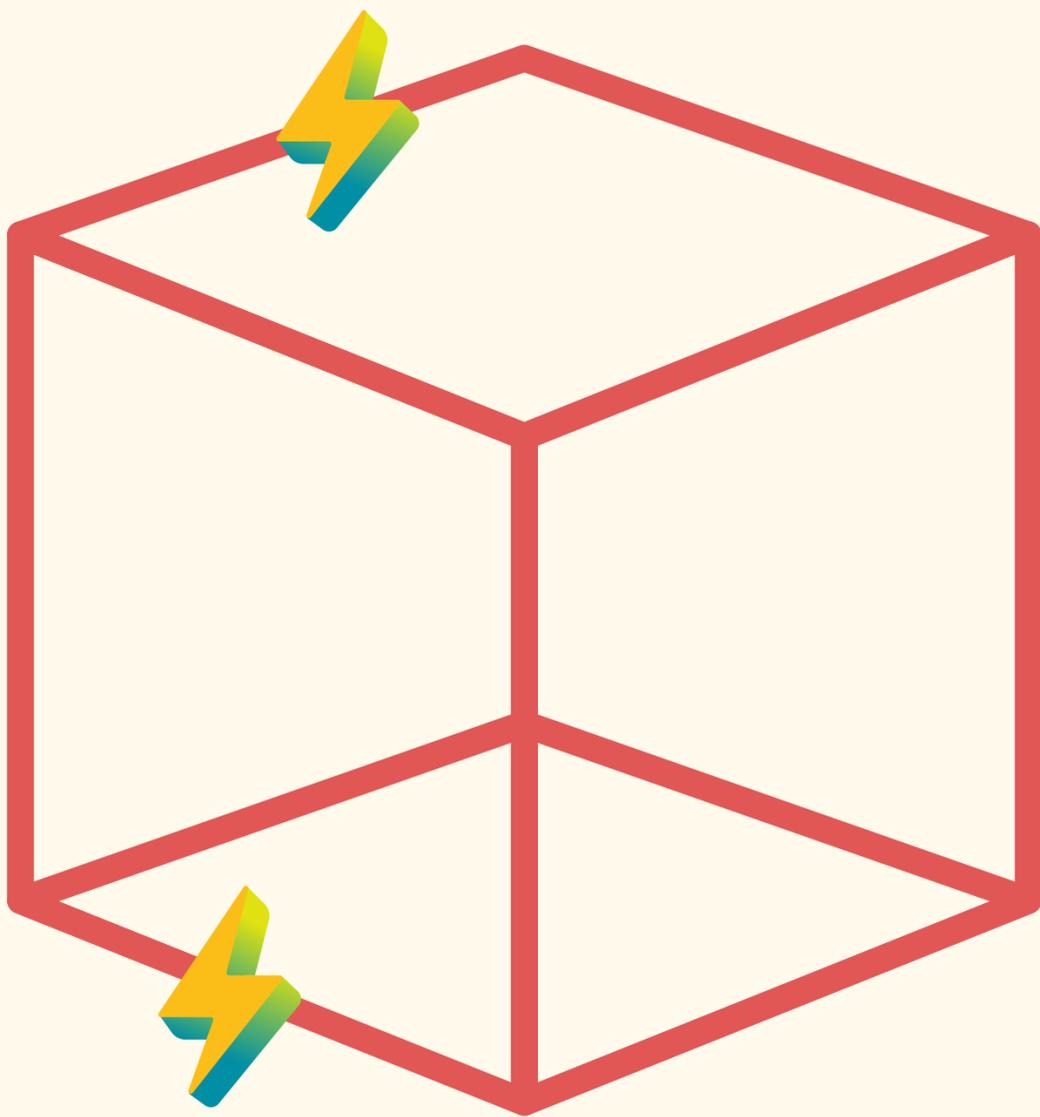


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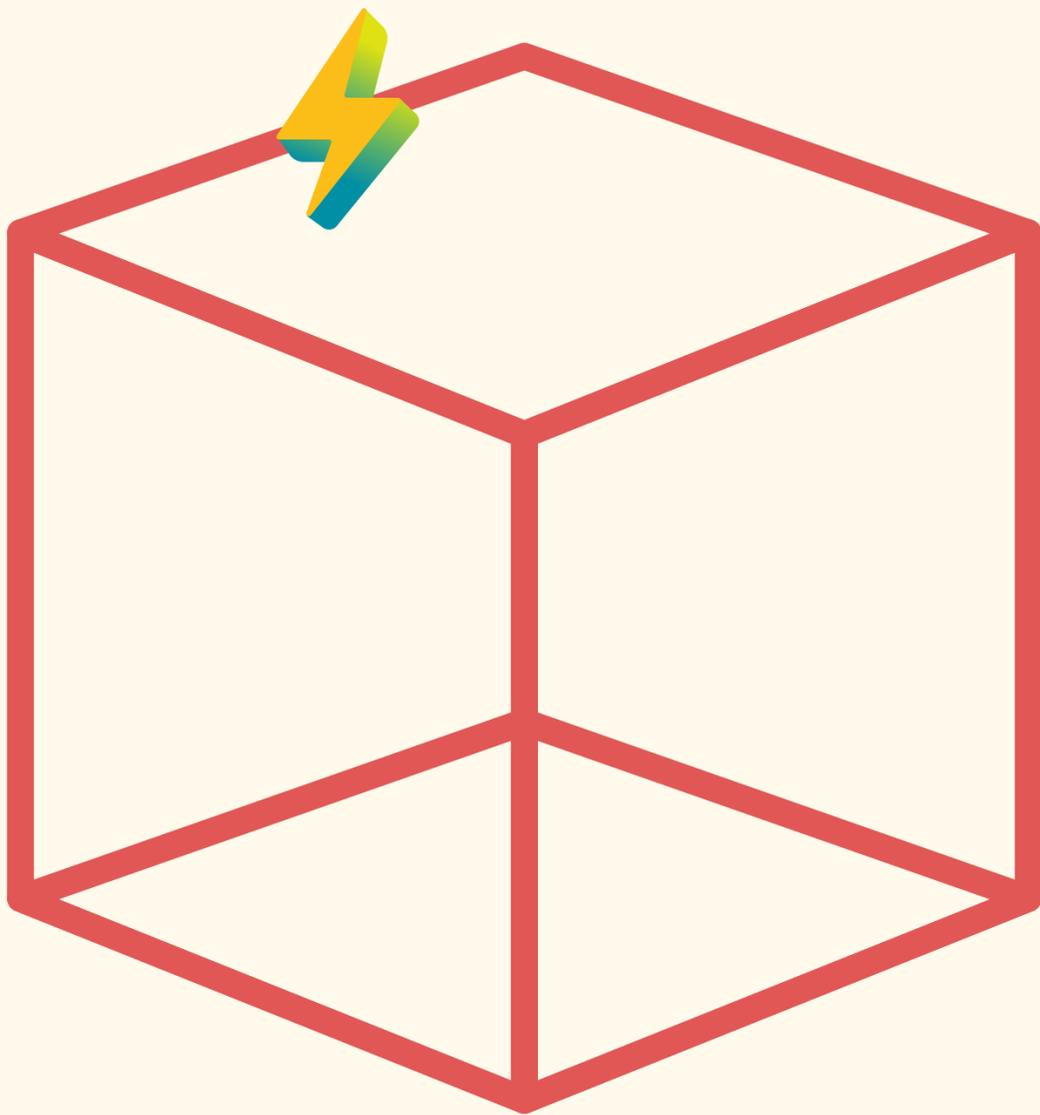
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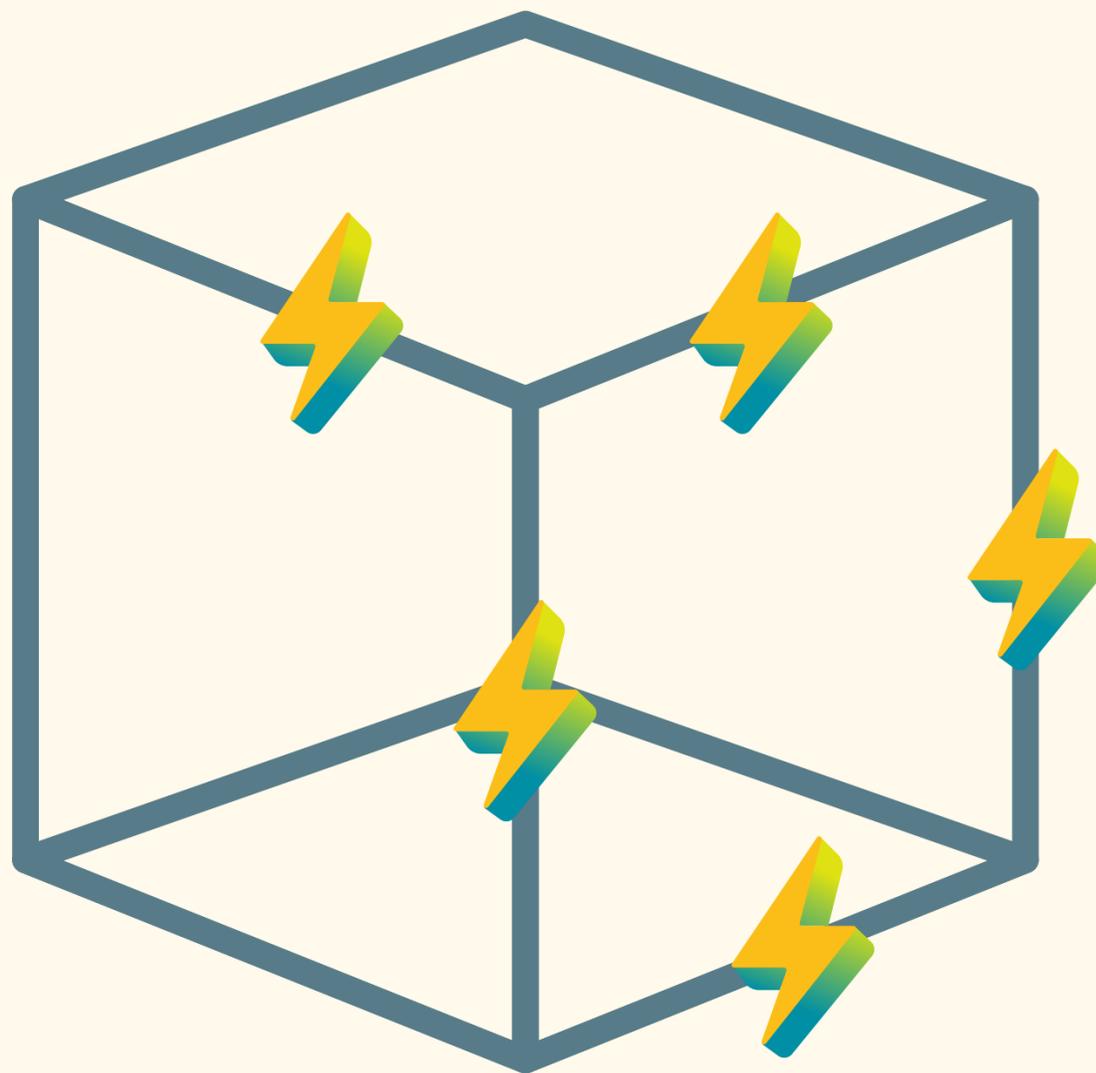


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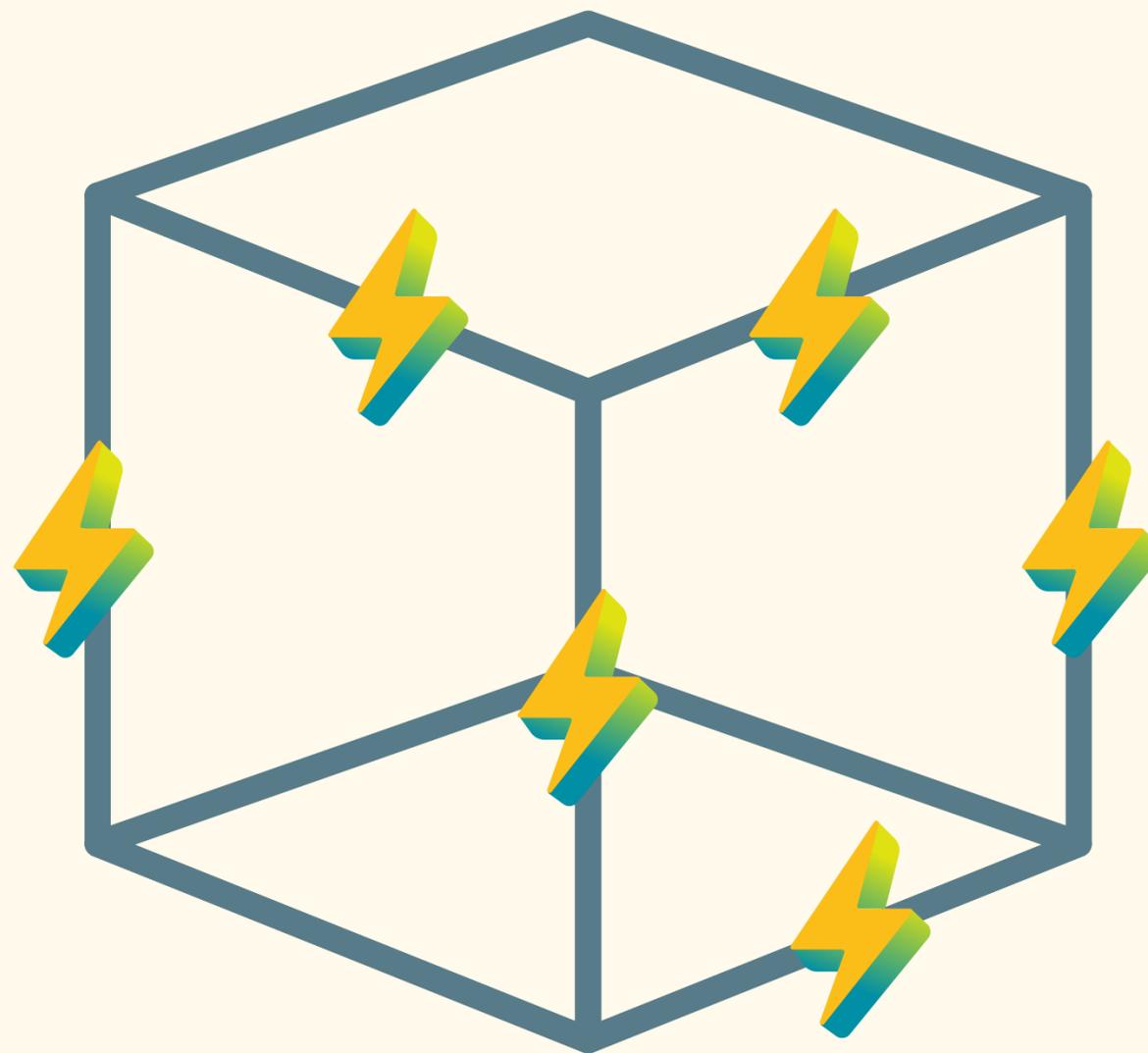
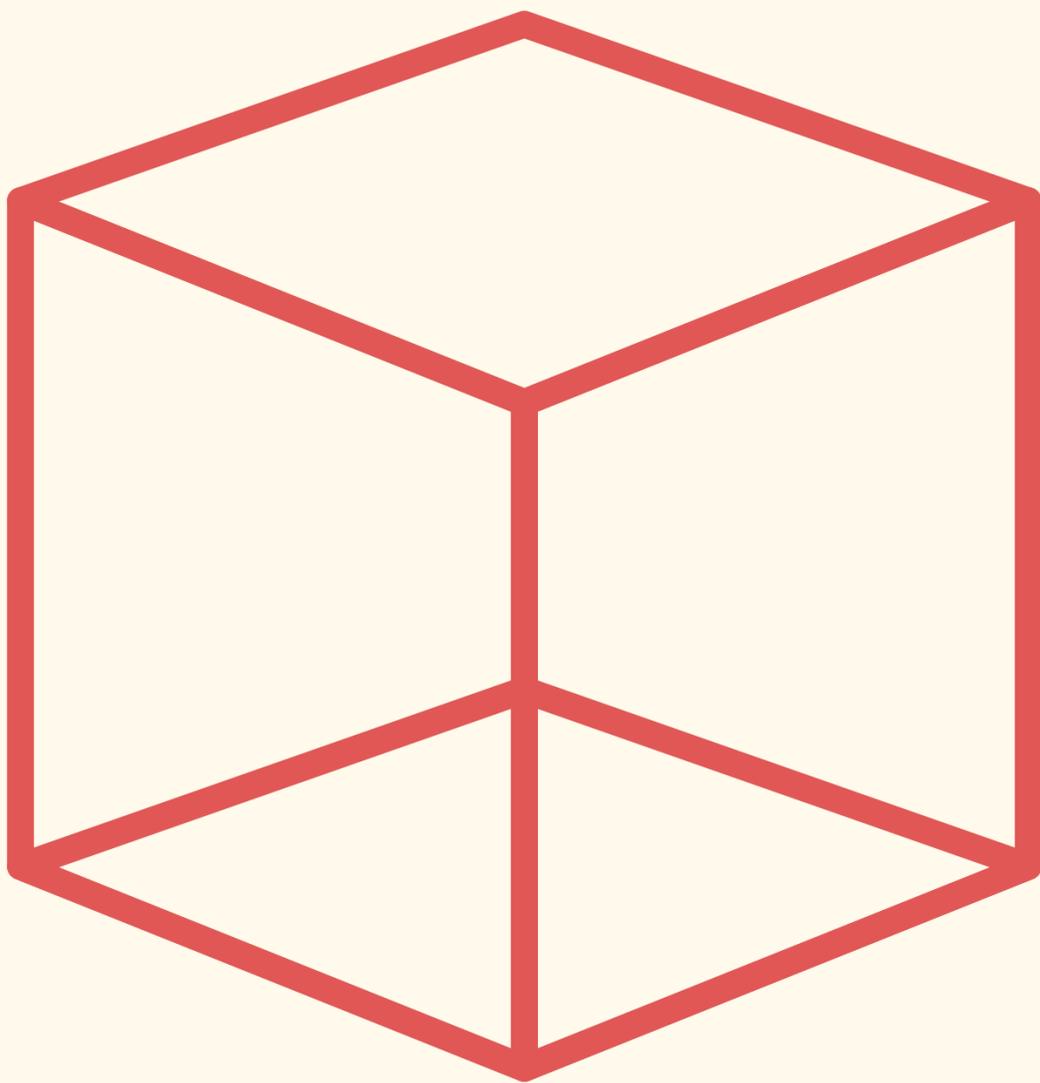
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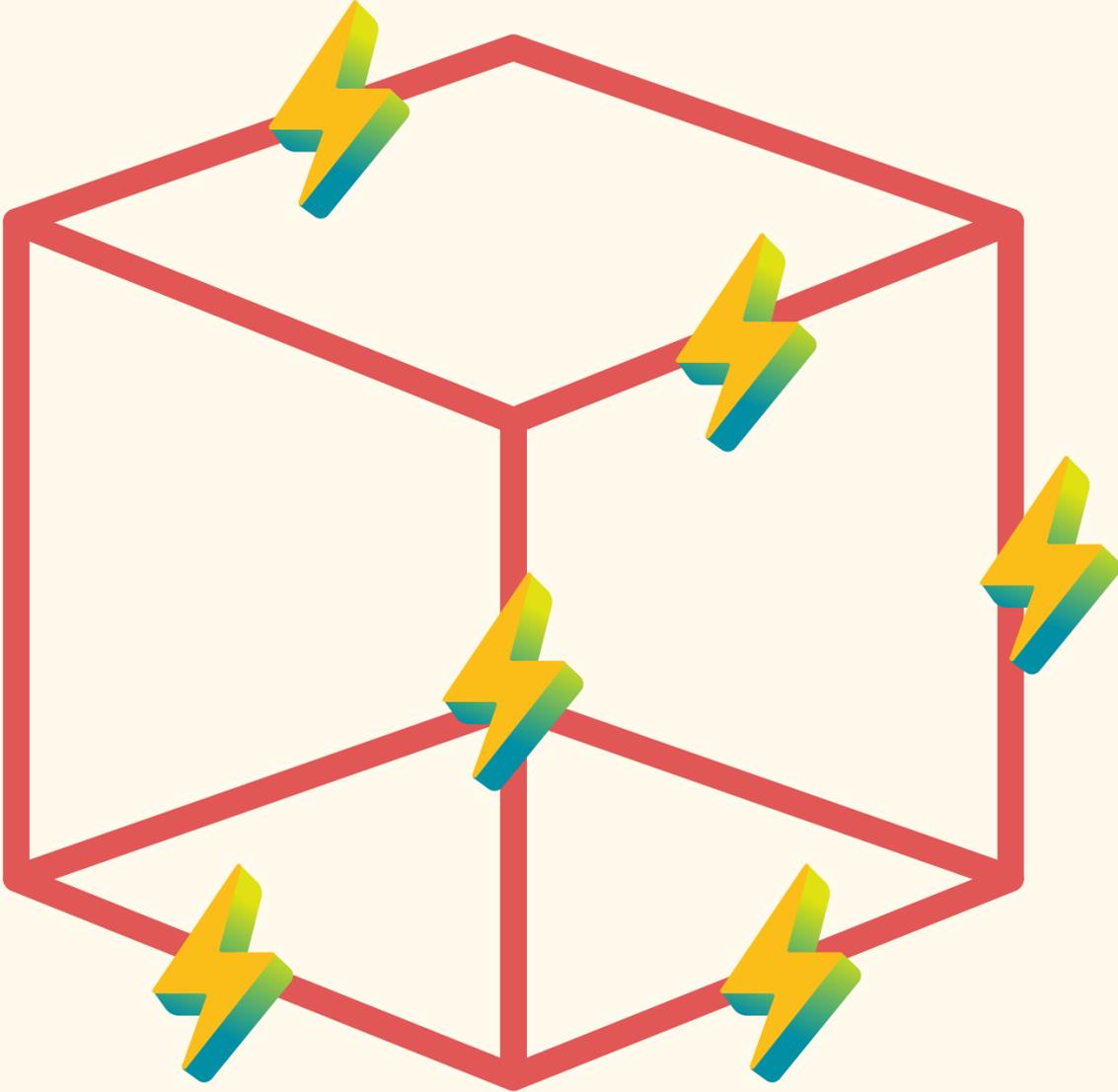


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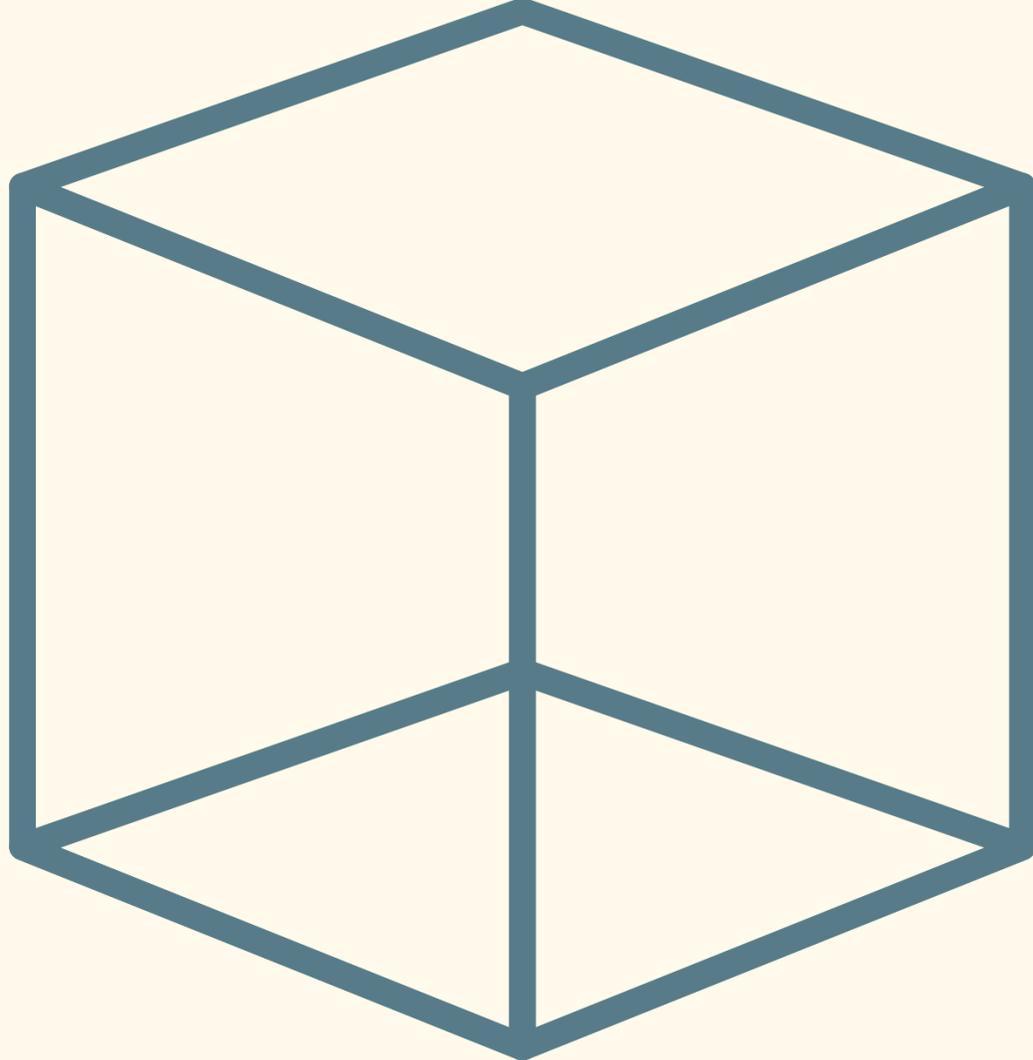


6

6



0



Distribution (A,B)	Microstates	Probability
(0,6)	12376	0.0261
(1,5)	52416	0.1105
(2,4)	106470	0.2246
(3,3)	132496	0.2795
(4,2)	106470	0.2246
(5,1)	52416	0.1105
(6,0)	12376	0.0261

$$\Omega = \binom{q + N - 1}{q} = \frac{(q + N - 1)!}{q!(N - 1)!}$$

$$\Omega_{\text{total}} = \Omega_A \times \Omega_B$$

Second law of thermodynamics:

**Entropy of an isolated system
always increase (to a maximum)**

Does this mean... our Earth would eventually mix together? 🤔

Energy becomes more spread out and less useful

- **Useful energy:** concentrated and ordered energy that can do work (low entropy)
- **Useless energy:** energy that is spread out and disordered that cannot easily do work (high entropy)
- Lowering entropy locally (like freezing water) requires increasing entropy by a greater amount elsewhere, so total entropy still increases.

If entropy always increases, how is the world even... functioning

SUNNNNNNNNN ☀️☀️☀️

Sun gives the earth low-entropy energy

Sun

low entropy

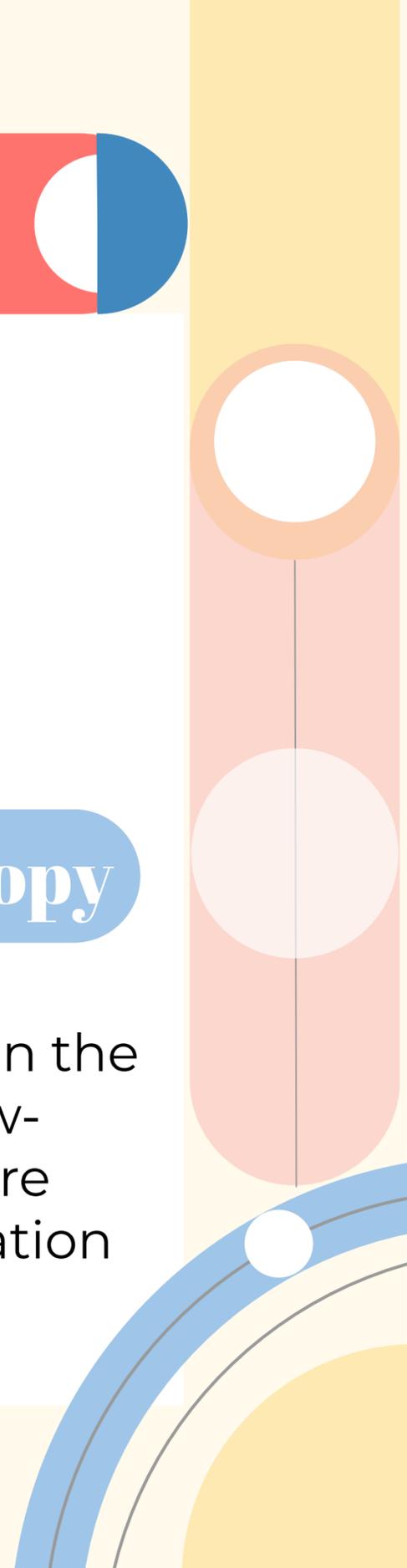
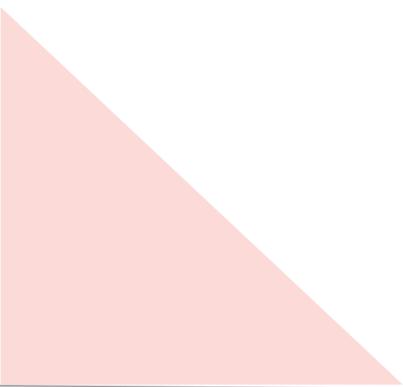
Earth radiates same amount of energy back into space

Earth

high entropy

this energy is in the form of high-temperature radiation (sunlight)

this energy is in the form of low-temperature infrared radiation





Arrow of time

- time moves in the direction in which entropy increases
- past → lower entropy
- future → higher entropy

arrow of time = arrow of entropy

Will we ever reach maximum entropy? And what happens when we do?

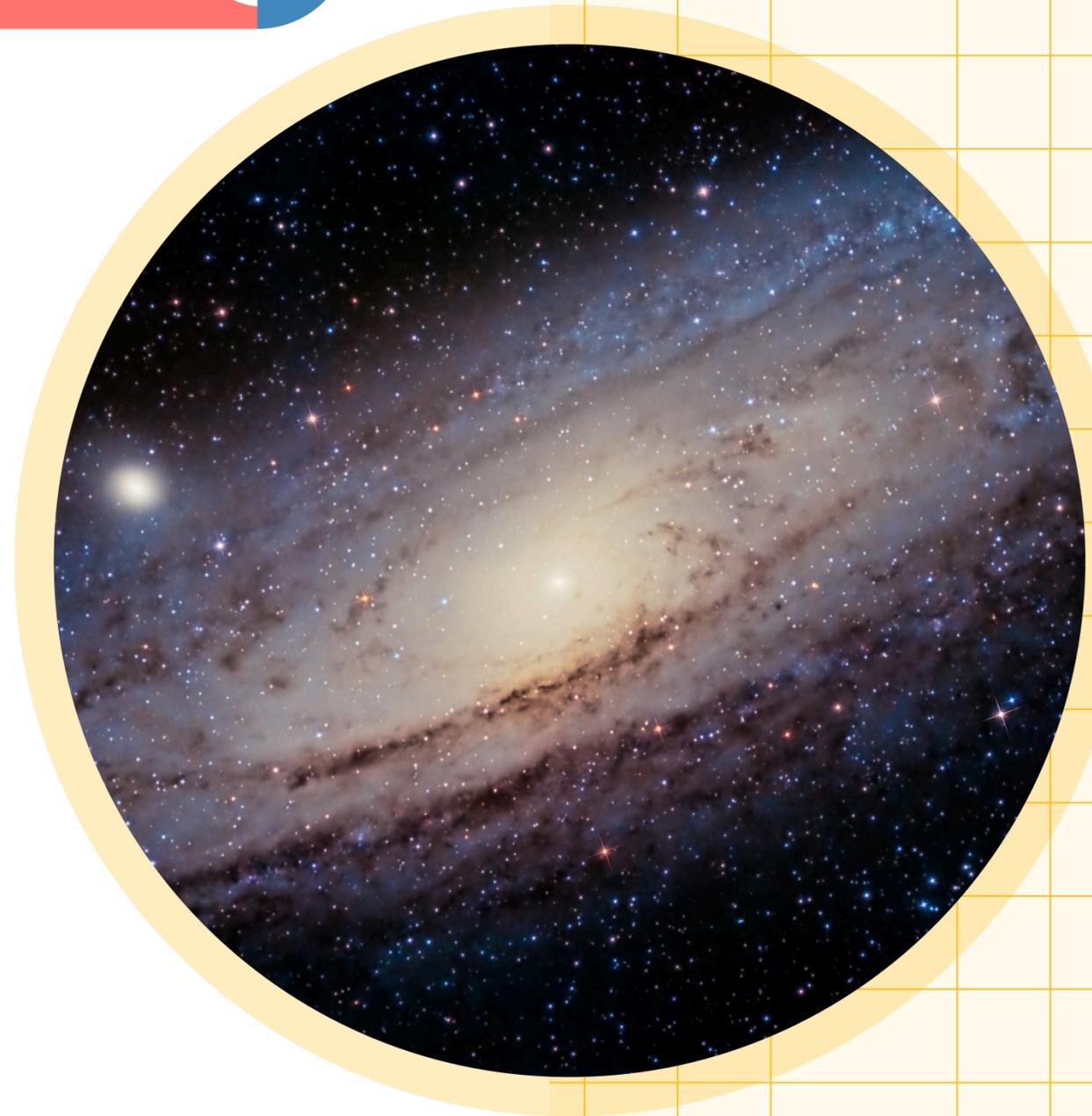
Heat death

Heat death - a possible fate of the universe

Energy spreads out so evenly, the universe reaches “thermal equilibrium”

Everything still exists, but nothing changes and nothing interesting can happen

Arrow of time disappears



04. Summary

The background features a light yellow grid. On the left, a blue vertical bar contains the text '04.' and 'Summary'. A red horizontal bar overlaps the bottom of the blue bar and the text 'Summary'. To the right, there are several overlapping geometric shapes: a large white circle, a yellow circle, a pink triangle, and a large yellow arc. A rainbow-like arc with pink, yellow, and red bands is on the far right. Small blue and pink circles are scattered throughout the design.

Back to the room we started with...

- Entropy is a measure of disorder
- Entropy measures no. of possible microstates, reflecting probability of macrostate
- Entropy always increases (stays the same only in idealised experiments)
- Arrow of entropy = arrow of time



Real life example of entropy

- Ice melting → water molecules become more disordered → increase in entropy.
- Gas expansion → molecules spread out → entropy increases.
- Biological systems → living organisms maintain low entropy internally, but overall entropy of the environment increases (e.g., metabolism).

Citations:

1. <https://pmc.ncbi.nlm.nih.gov/articles/PMC8534765/>
2. <https://towardsdatascience.com/a-brief-history-of-entropy-chapter-1-9a2f1bc0d6de/>
3. <https://www.britannica.com/science/entropy-physics>
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5. https://youtu.be/YM-uykVfq_E
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7. <https://youtu.be/DxL2HoqLbyA>
8. <https://www.physlink.com/education/askexperts/ae181.cfm>
9. <https://medium.com/science-spectrum/what-exactly-is-entropy-2a0e2fc067f8>
10. <https://theaveragescientist.co.uk/2024/04/26/the-power-of-time-entropy-and-human-experience/>
11. <https://www.labxchange.org/library/items/lb:LabXchange:ac117f1a:html:1>

Thanks!

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youremail@freepik.com
+91 620 421 838
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