

# Entropy, time and demons

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## Two questions:

- What is entropy?
- Where is it coming from?



## Two demons:

- Can Maxwell's demon destroy entropy?
- Can Laplace's demon see into the past and future?



# Entropy in the news!

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[K-Pop rock group DAY6 on their 'brotherhood' and why The ...](#)

[Metro](#) - 3 Nov 2019

"**Entropy**" is a scientific concept, and we use it as a metaphor, referring to when someone falls in love and how his or her life has changed in ...



[Social \*\*entropy\*\* paralyzes investment](#)

[Globes](#) - 7 minutes ago

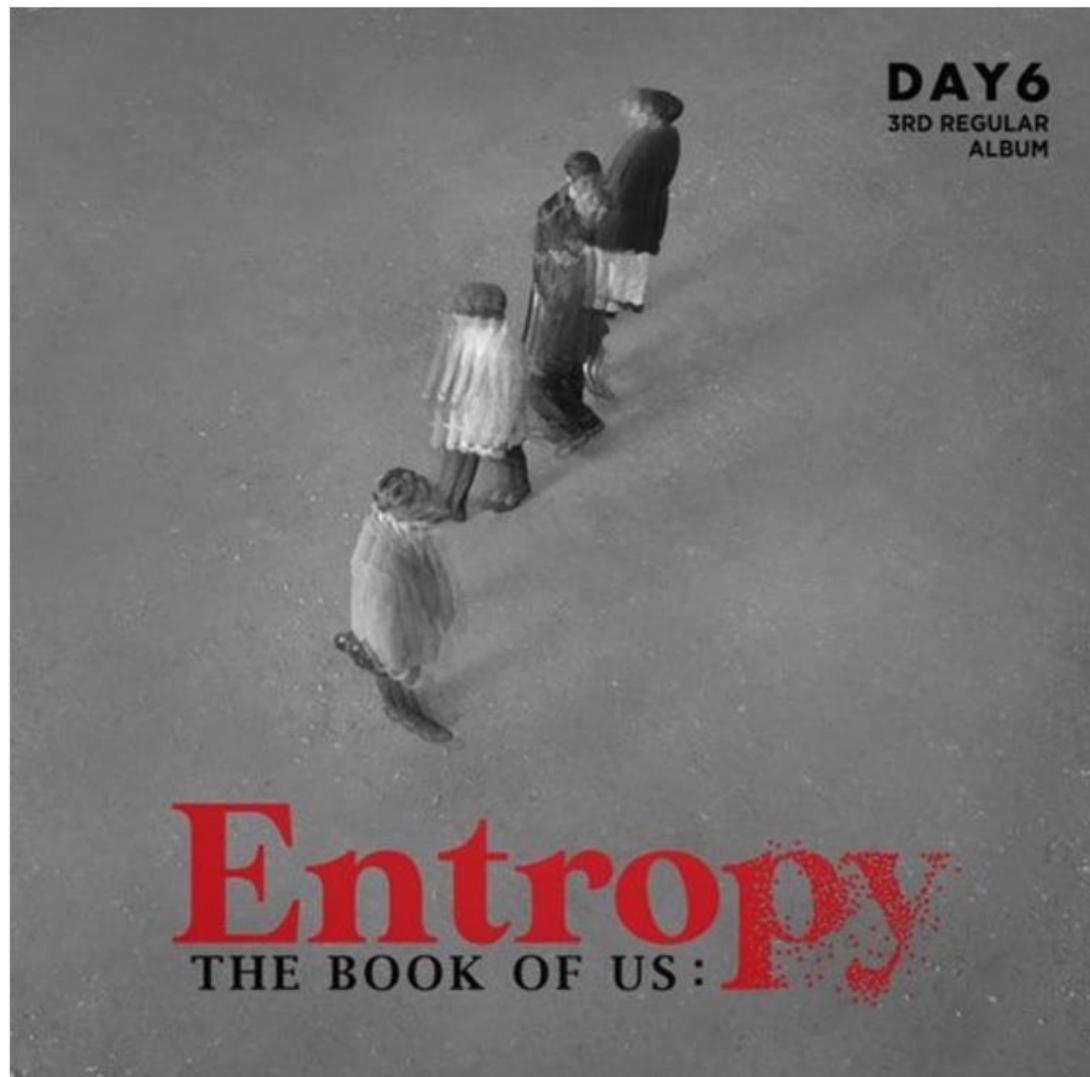
In physics, **entropy** is the tendency of all matter to disintegrate into its constituent particles, so that a counterforce is required to hold the universe ...



[Behind the scenes look at Voyager's \*\*Entropy\*\* video](#)

[Louder](#) - 18 Oct 2019

Last week Aussie proggers Voyager released the music video for their new track **Entropy** that features Leprous' Einar Solberg on vocals.



## Sweet chaos

The world that I've been living in

Because of you, it's been

Reversed and overturned

Right is left

Left is right



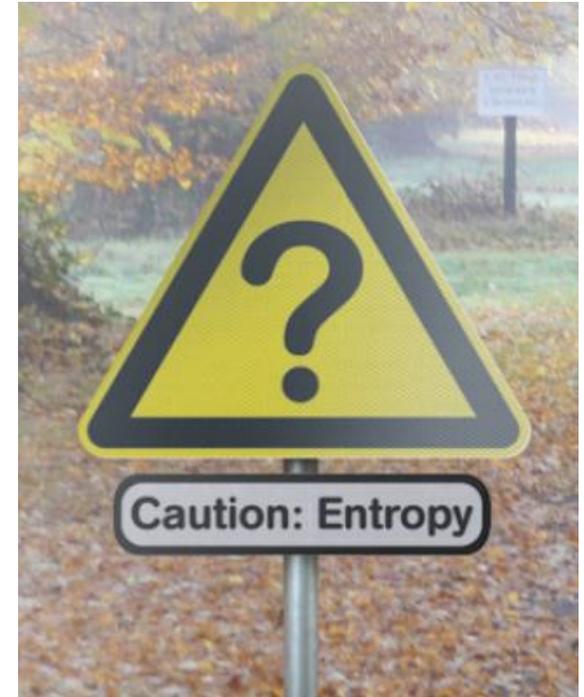
[Verse 2: Danny Estrin]

So you say that everything's right as rain

As you see it is all entropy!

# What is entropy?

- A measure of disorder?  
Of decline and decay?
- The arrow of time?



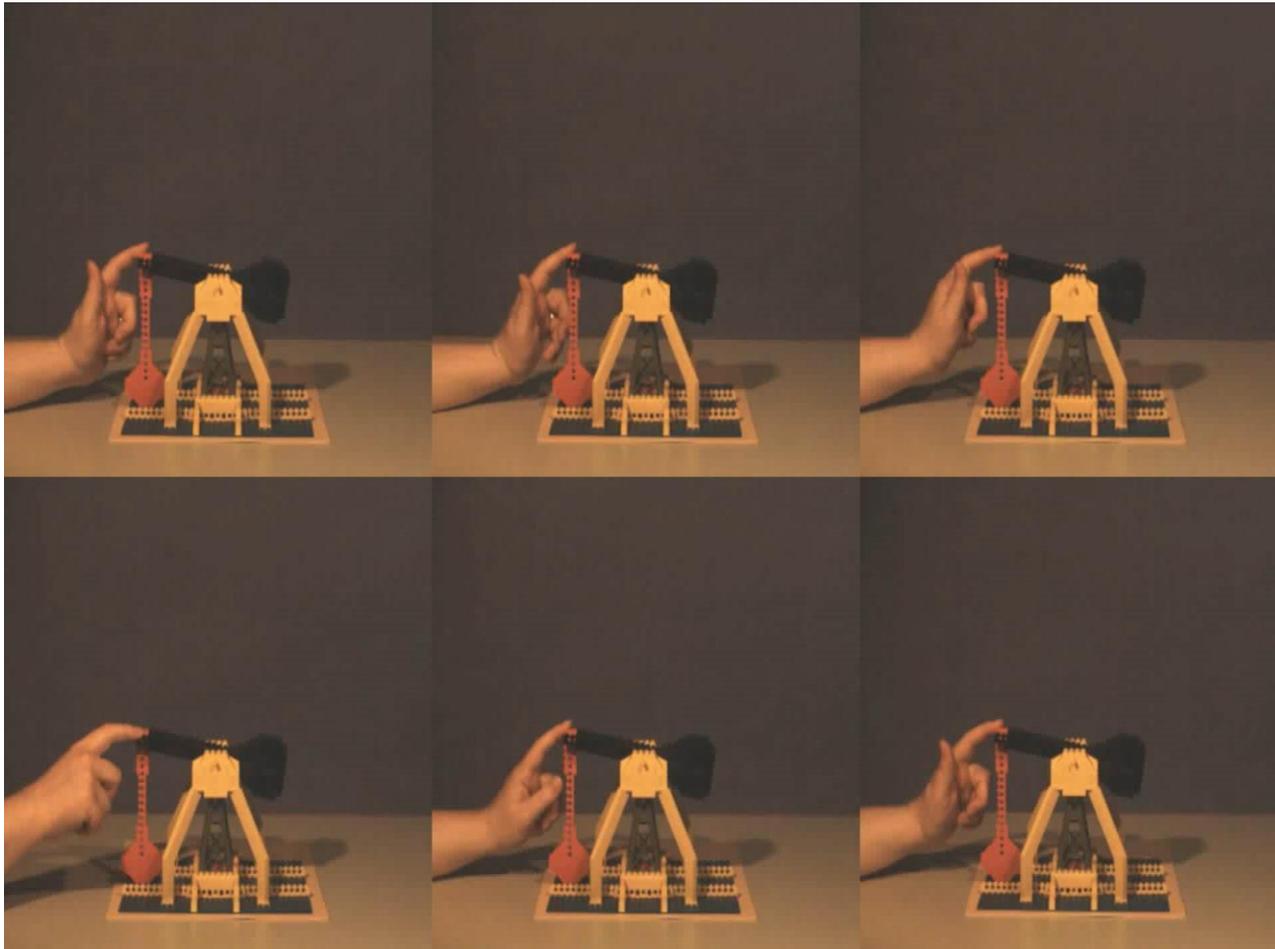
# The second law of thermodynamics

(Rudolf Clausius 1865)

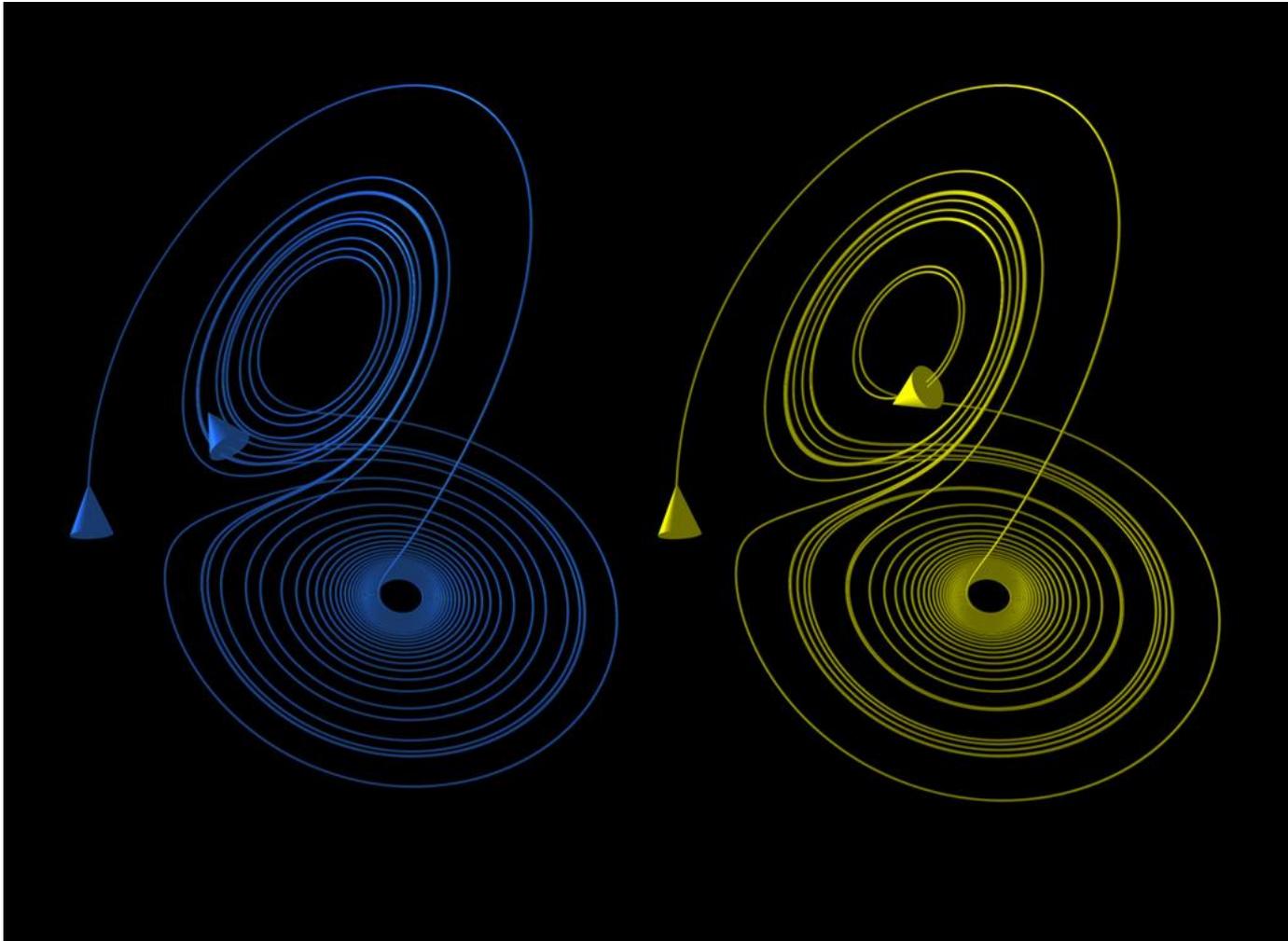
- As an isolated system evolves its entropy increases towards a maximum



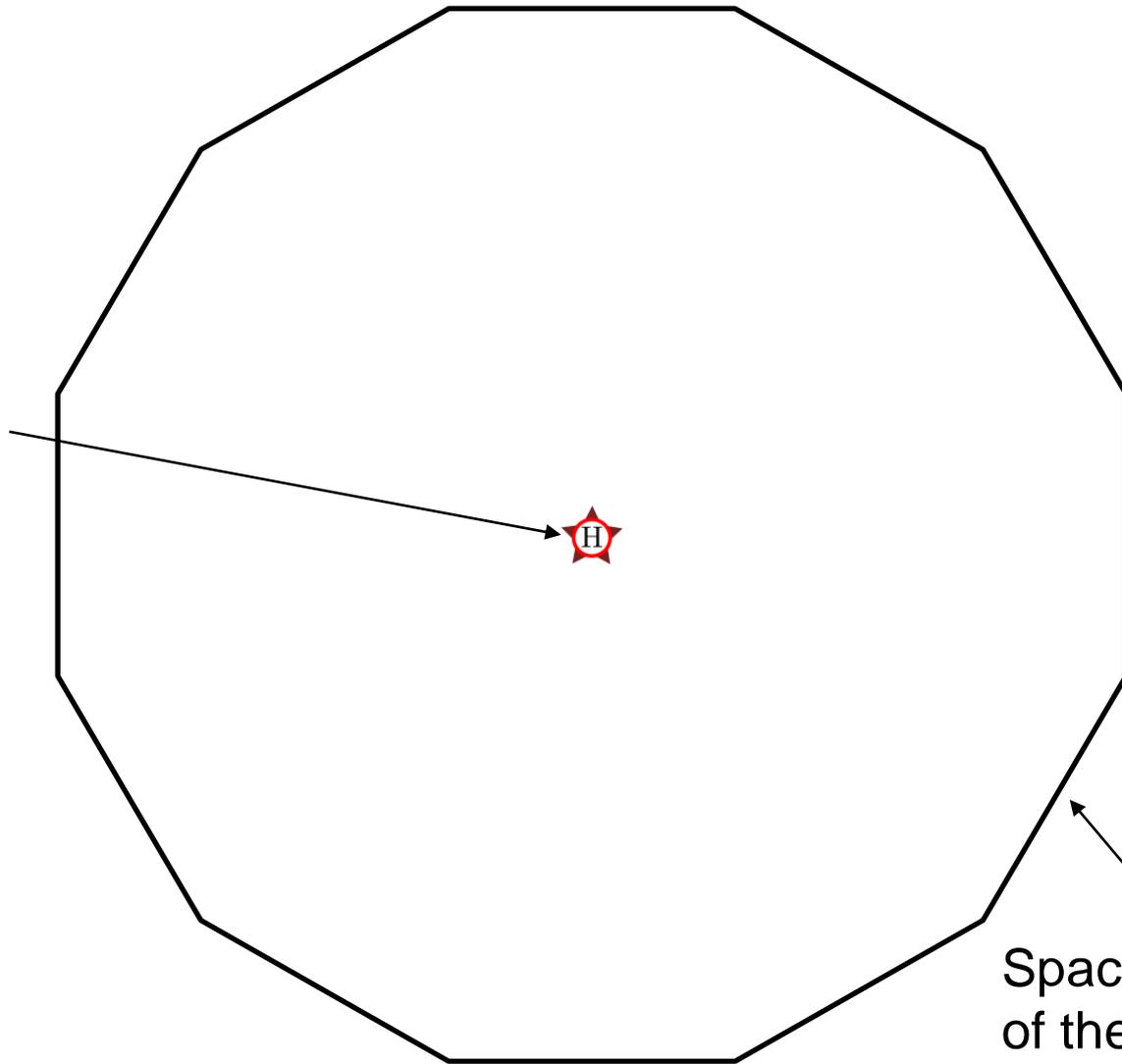
# Chaotic dynamics



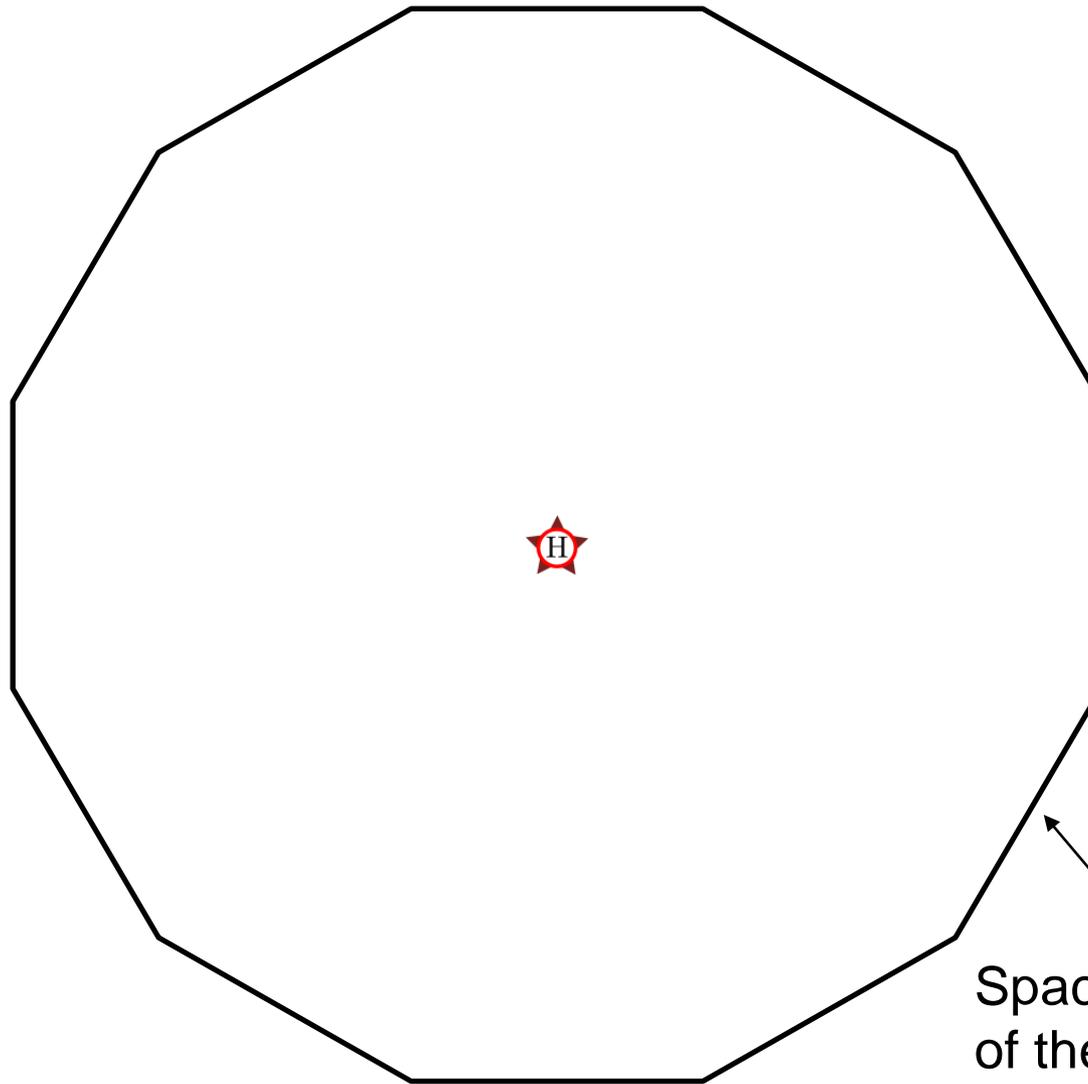
# Chaotic dynamics



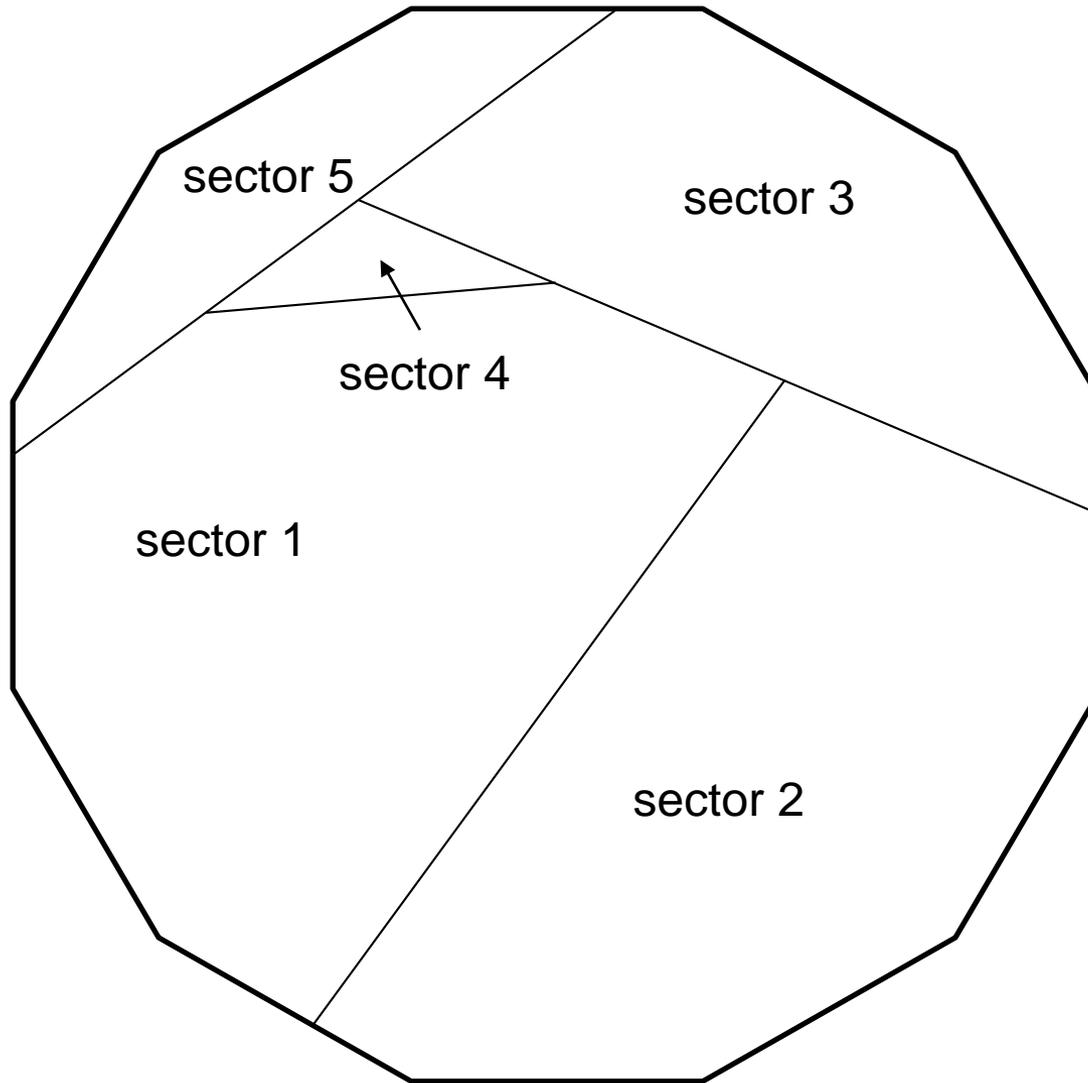
Current  
microscopic  
state of the  
universe



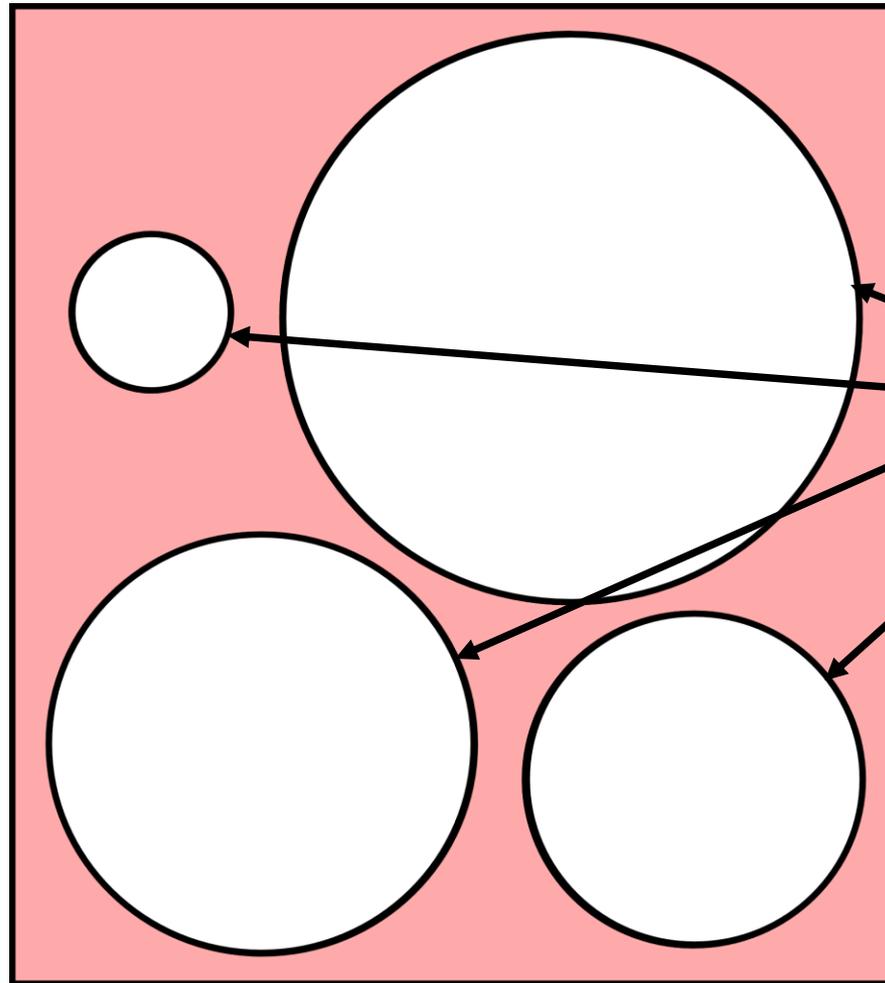
Space of coordinates  
of the  $10^{86}$  particles in  
the universe



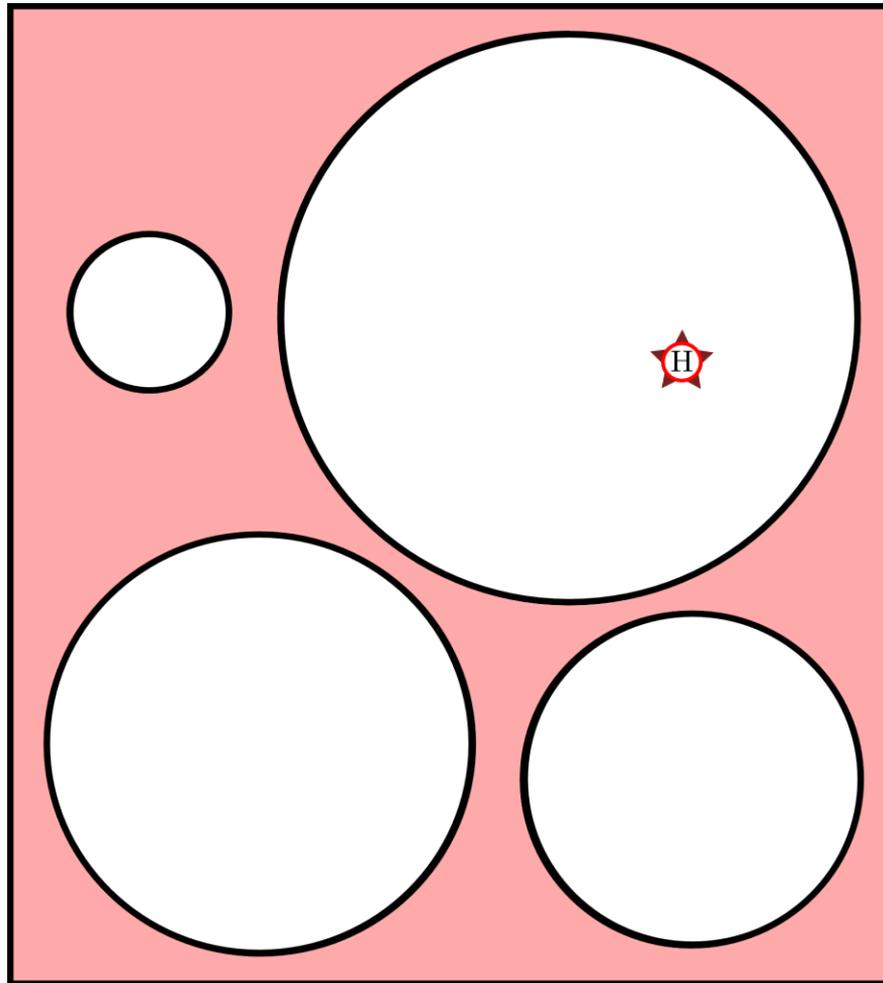
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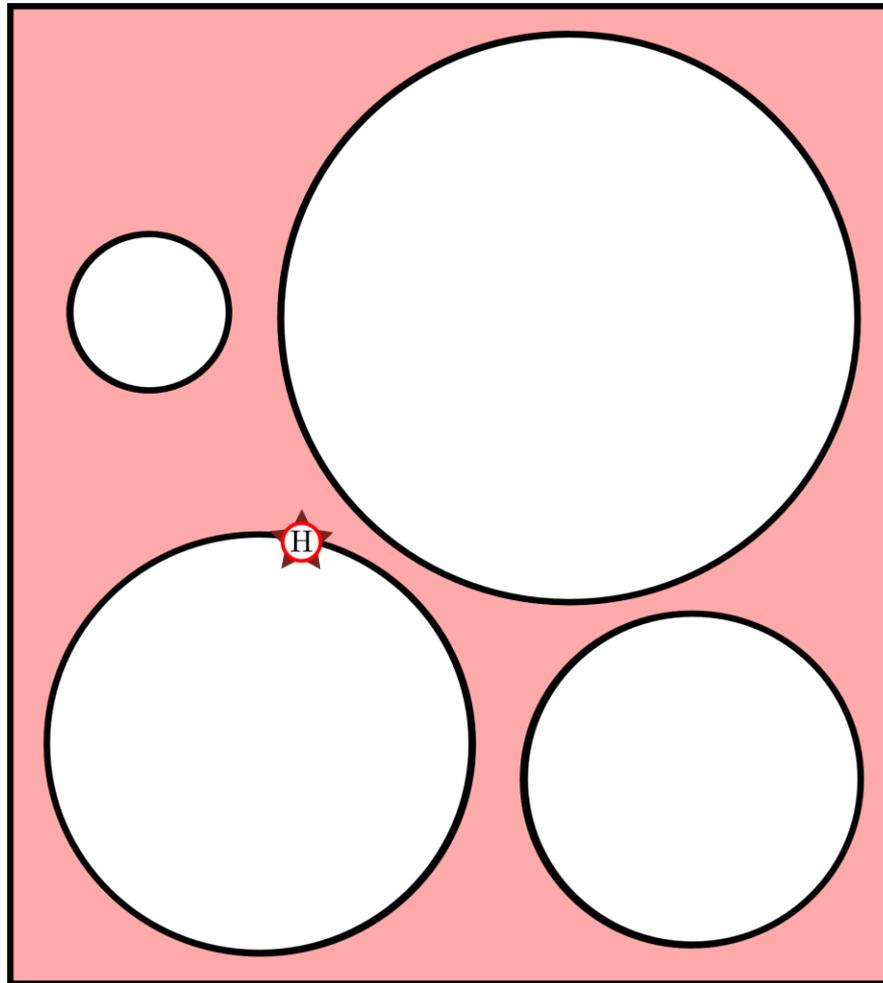


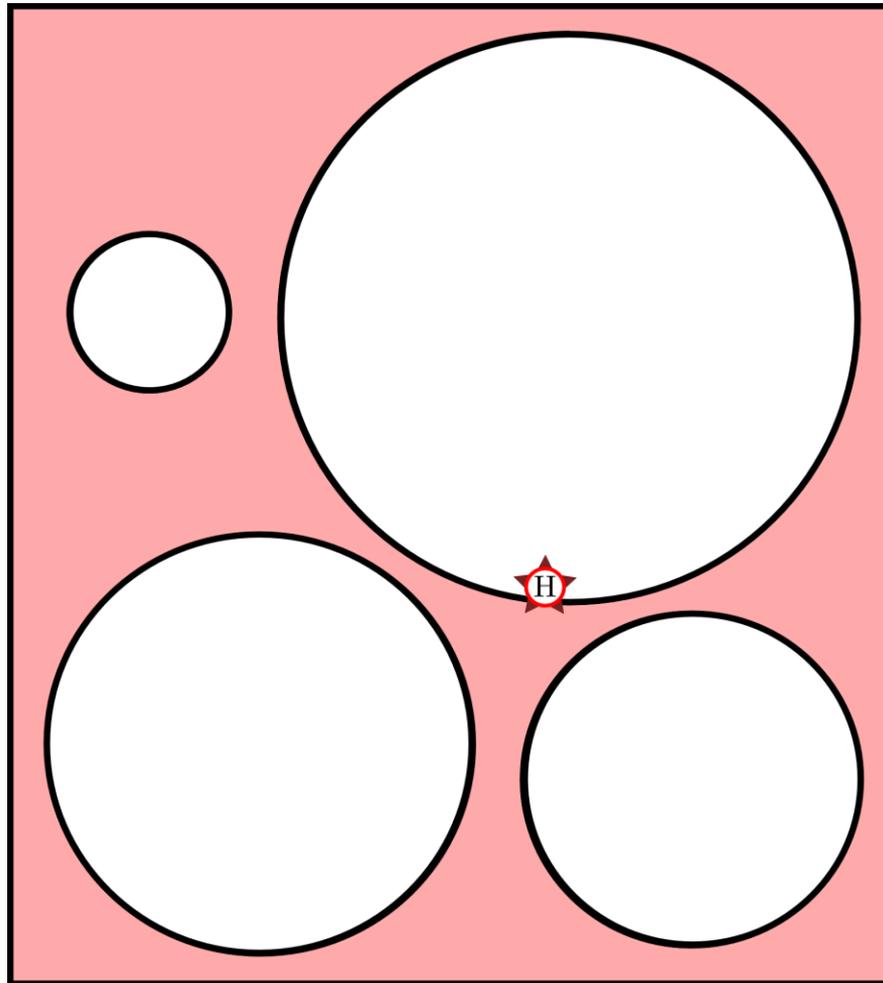
Our limited perception of the state of the universe

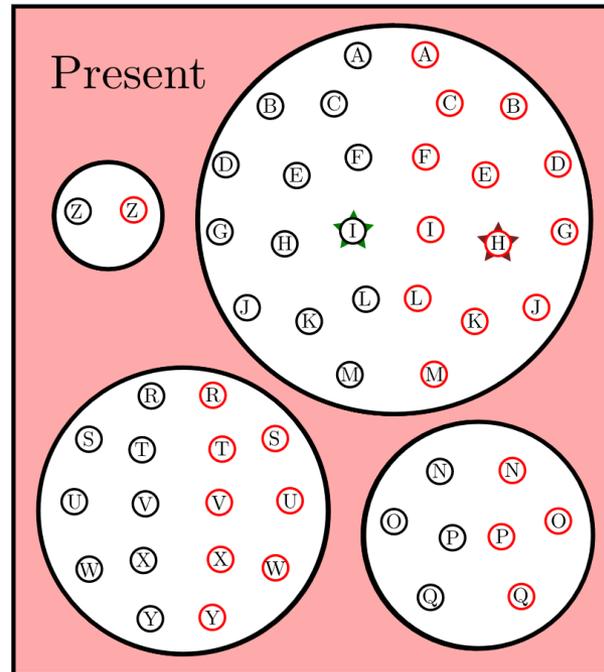


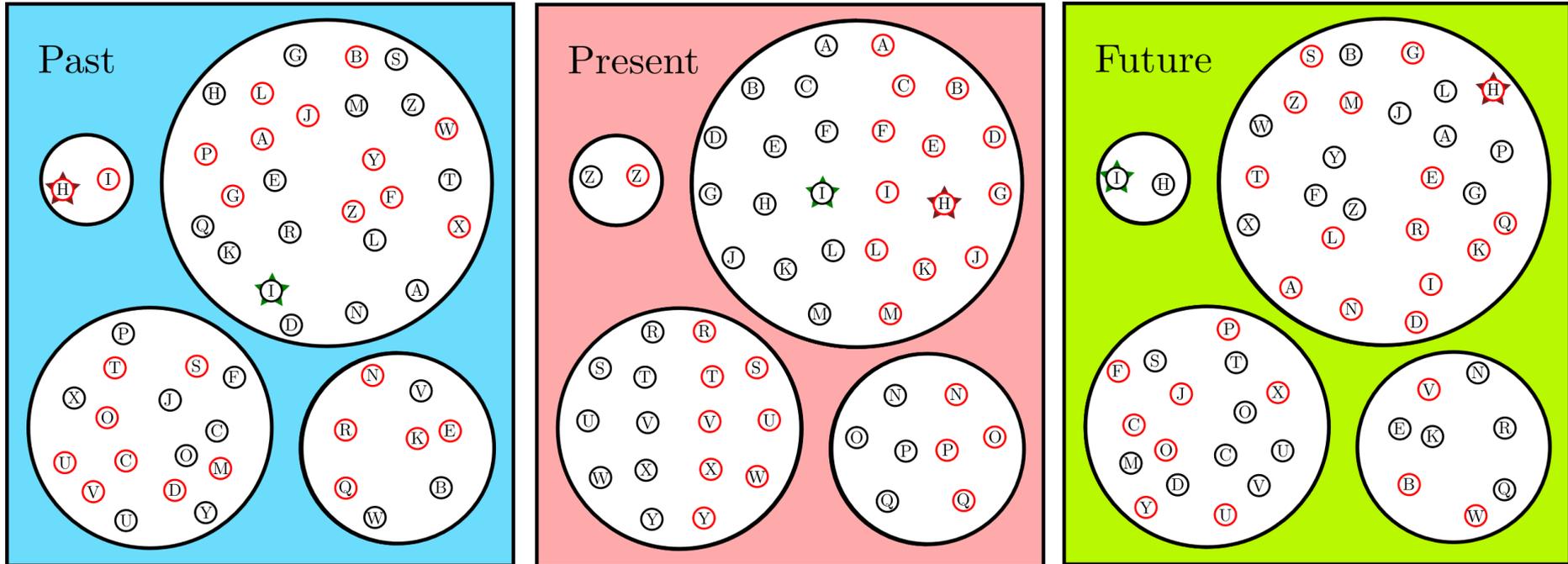
The  
coarseness  
of our  
perception





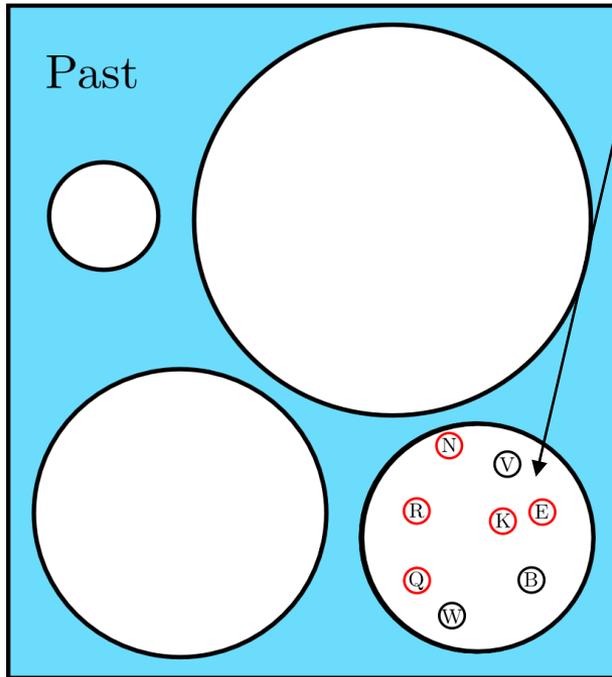




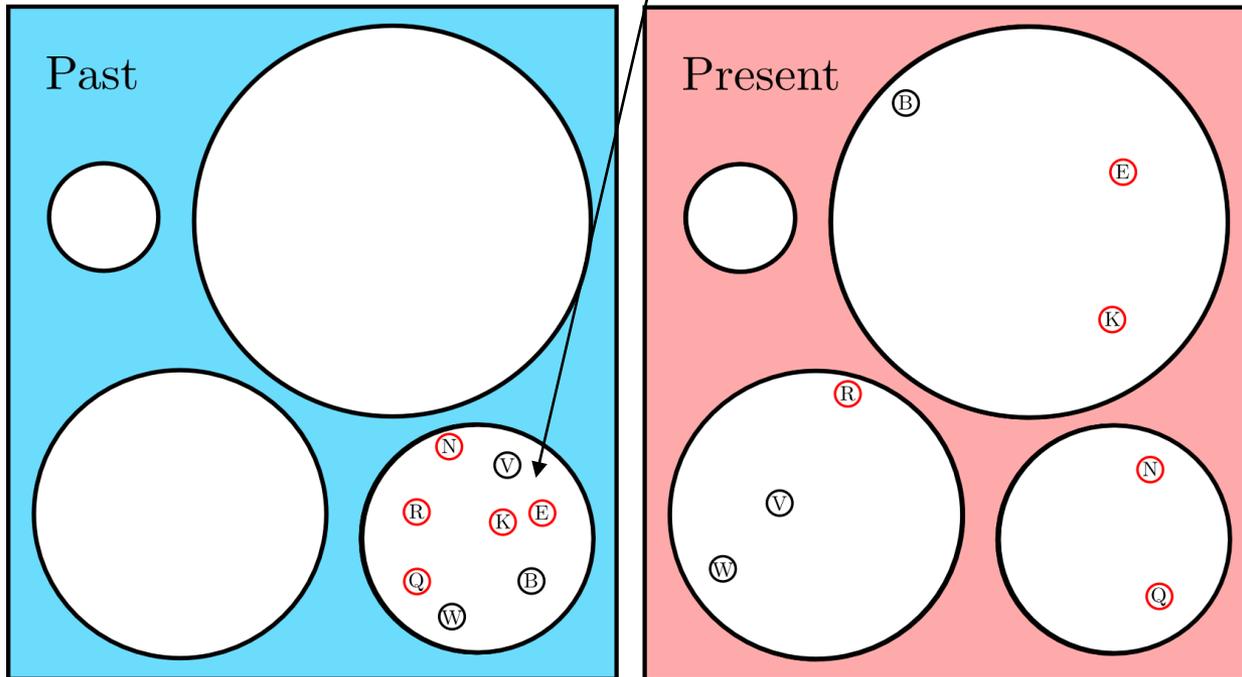


The universe might have followed any number of trajectories

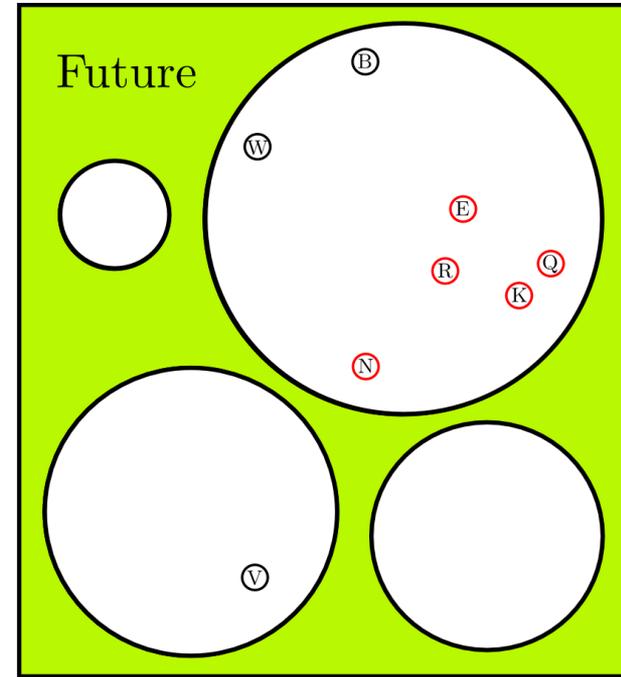
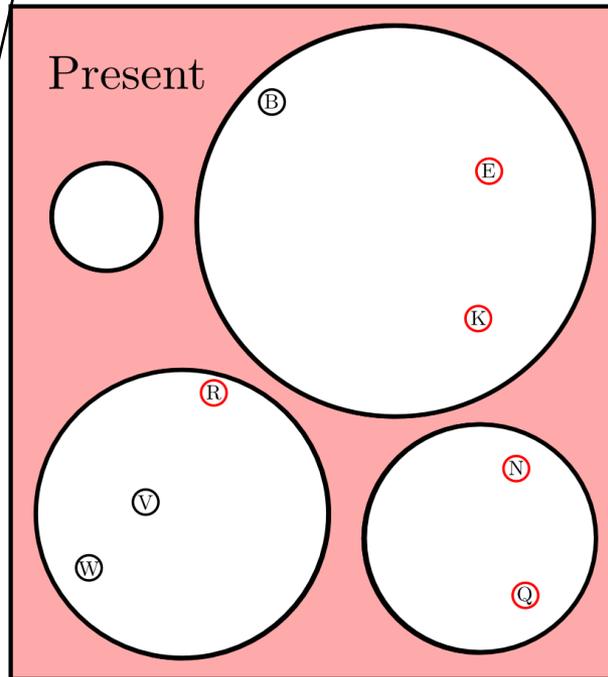
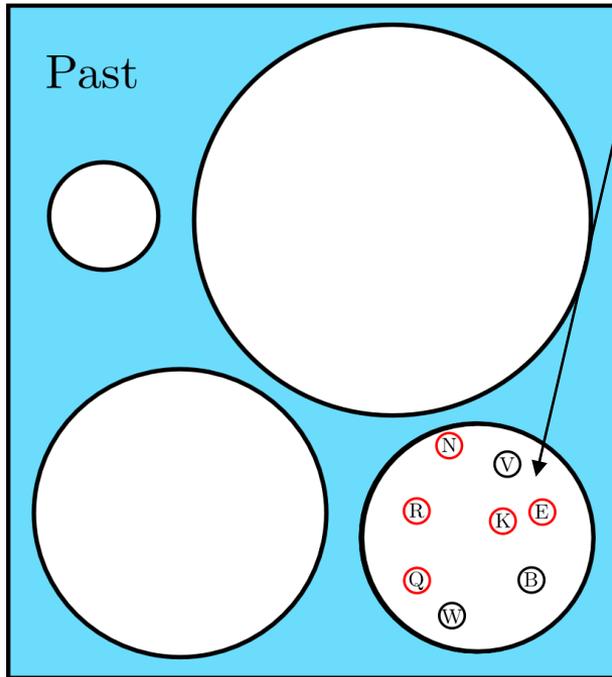
Given that the universe initially adopts one of the microscopic configurations in here....

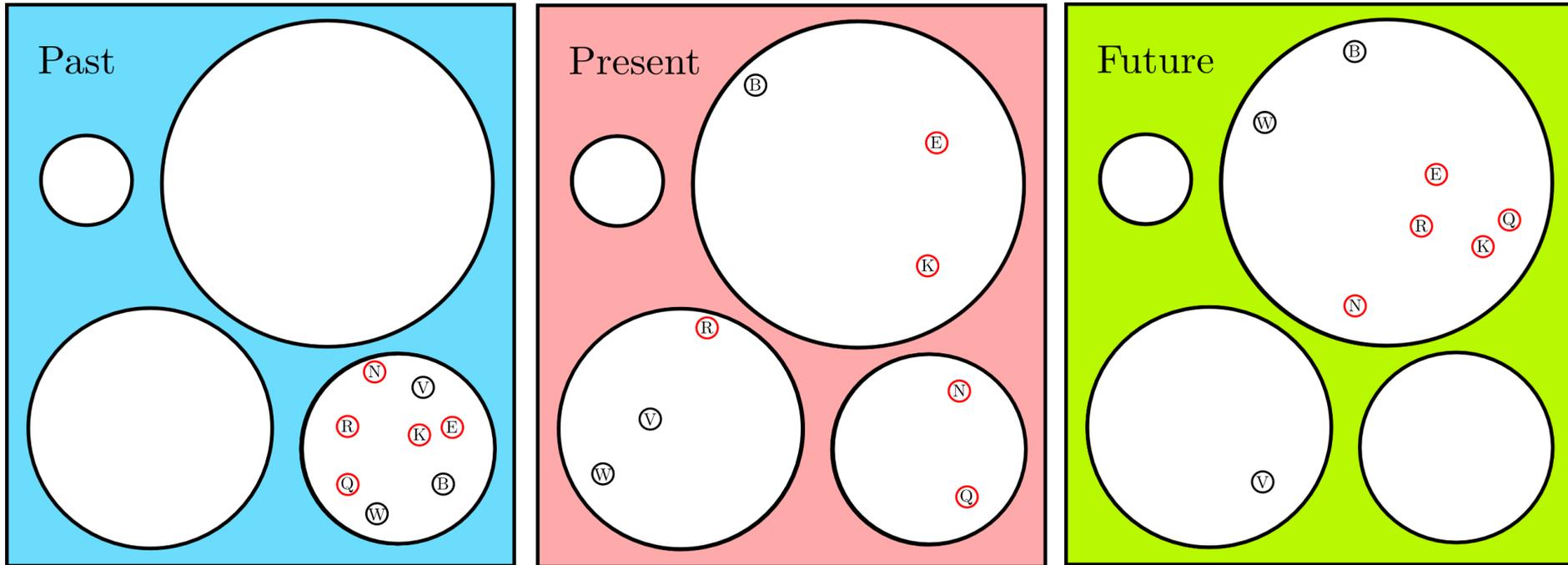


Given that the universe initially adopts one of the microscopic configurations in here.... then,



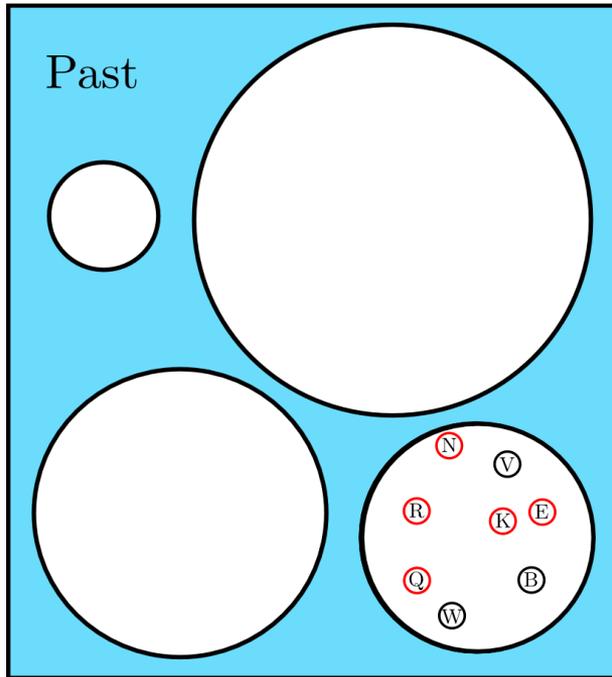
Given that the universe initially adopts one of the microscopic configurations in here.... then, and...



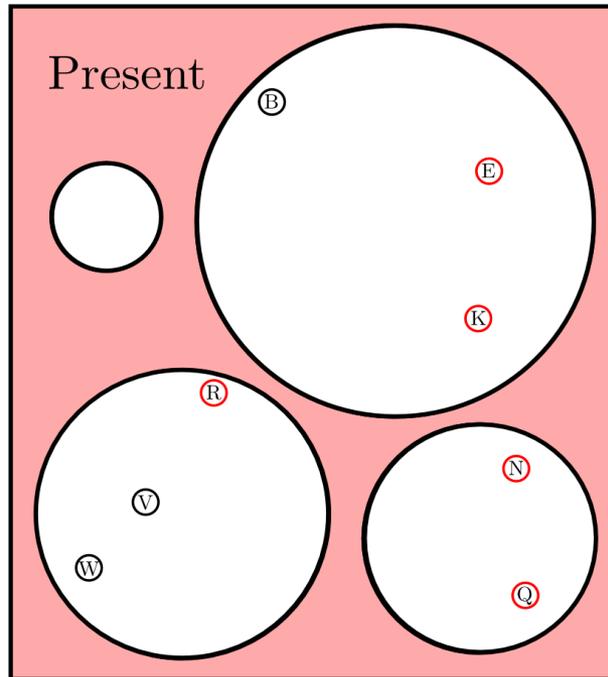


small

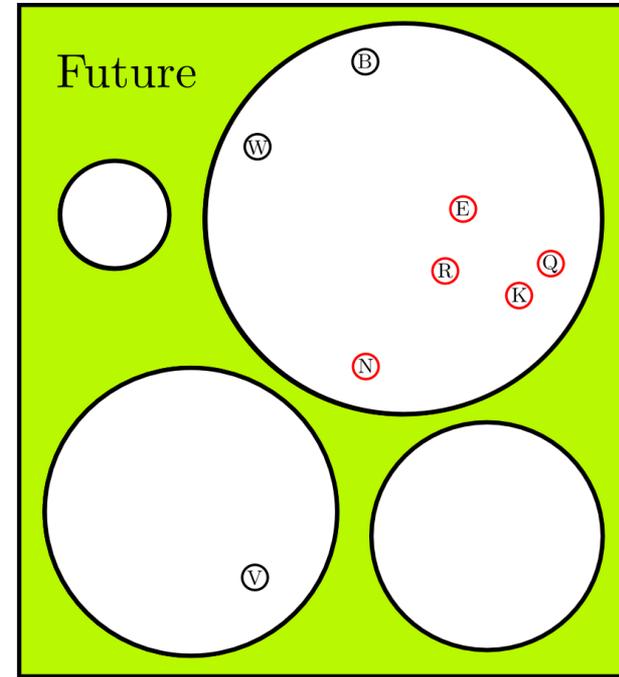
What is the likely size of the currently visited sector?



small

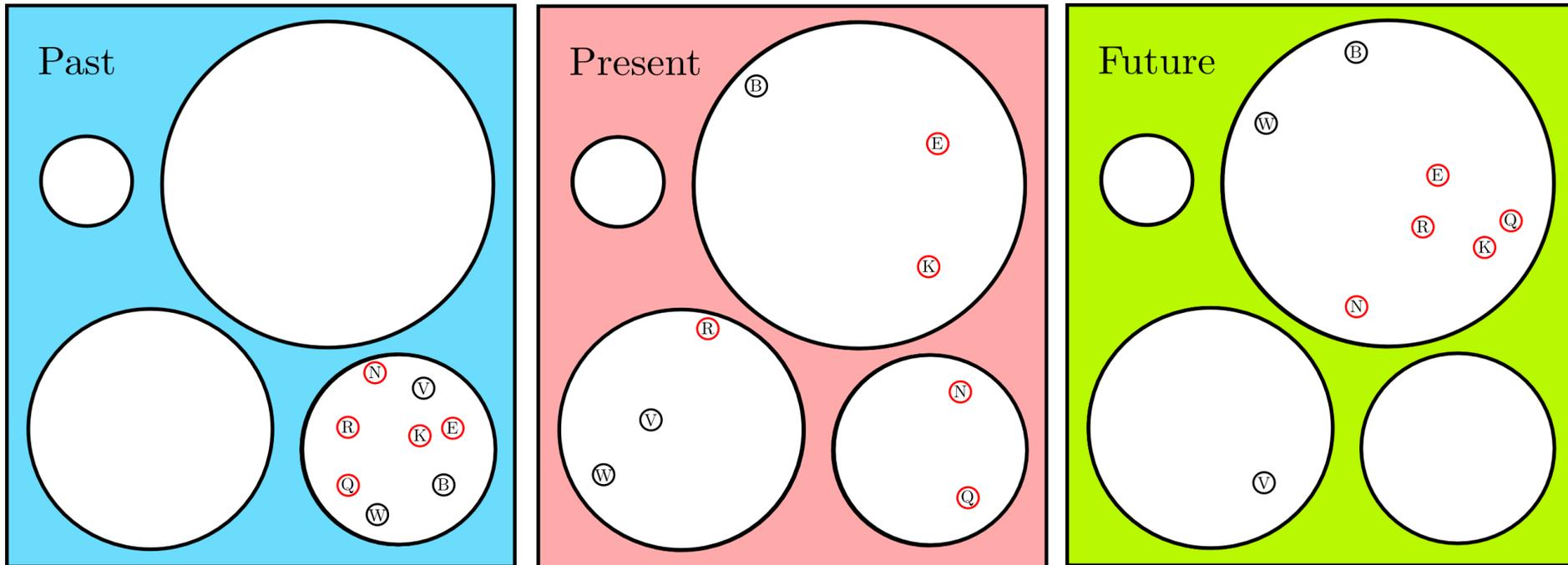


medium



What is the likely size of the currently visited sector?

Entropy is the *likely* size of the perceptible macroscopic sector that contains the imperceptible microscopic configuration!



small

medium

large

What is the likely size of the currently visited sector?

# Entropy is a measure of our microscopic uncertainty

- It increases with time in a chaotic world!



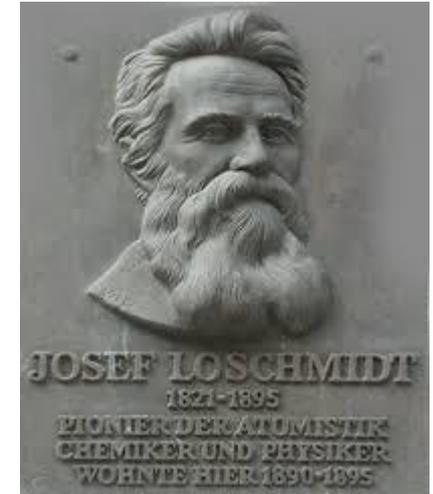
- It depends on how deeply we perceive detail



- This is the second law of thermodynamics

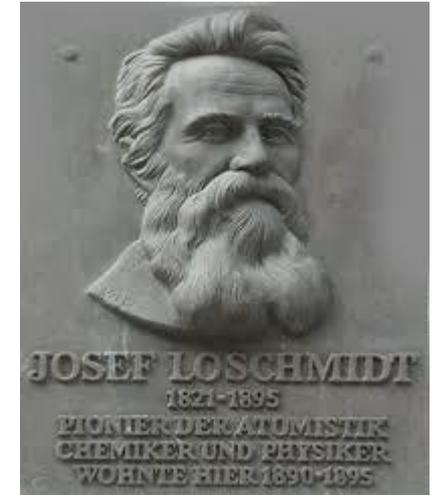


# Loschmidt's paradox

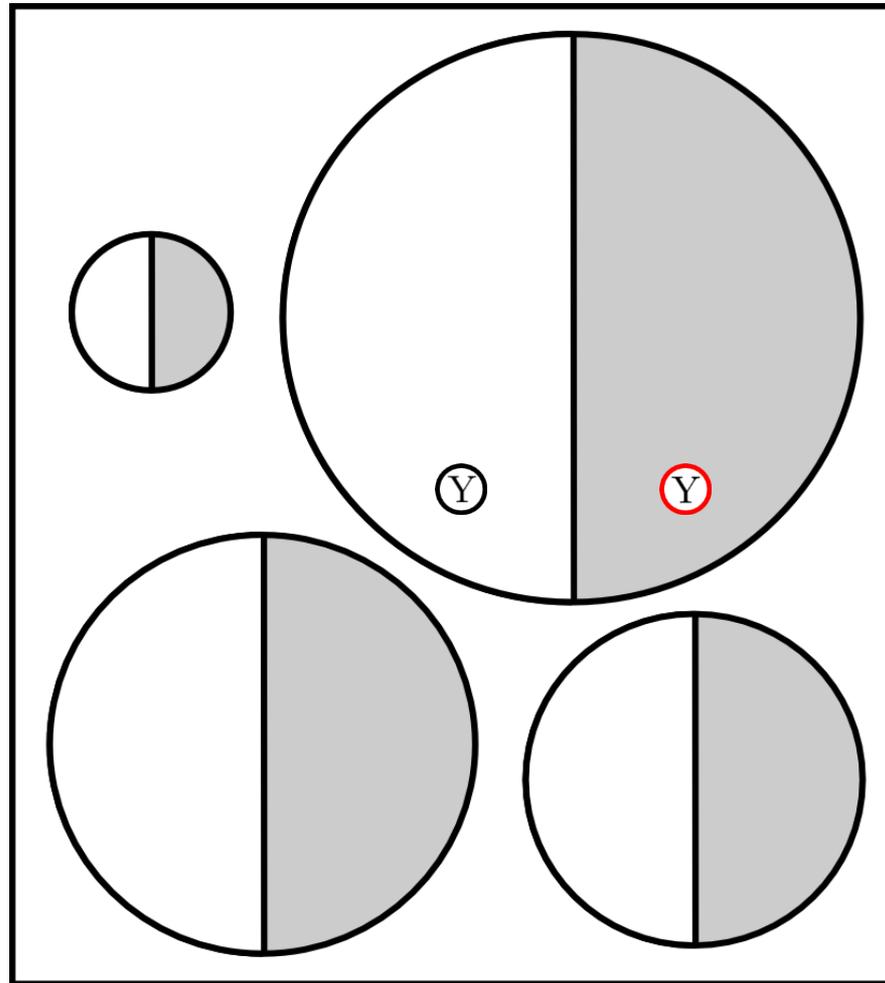


- Microscopic physics has no arrow of time.
  - time reversal symmetry

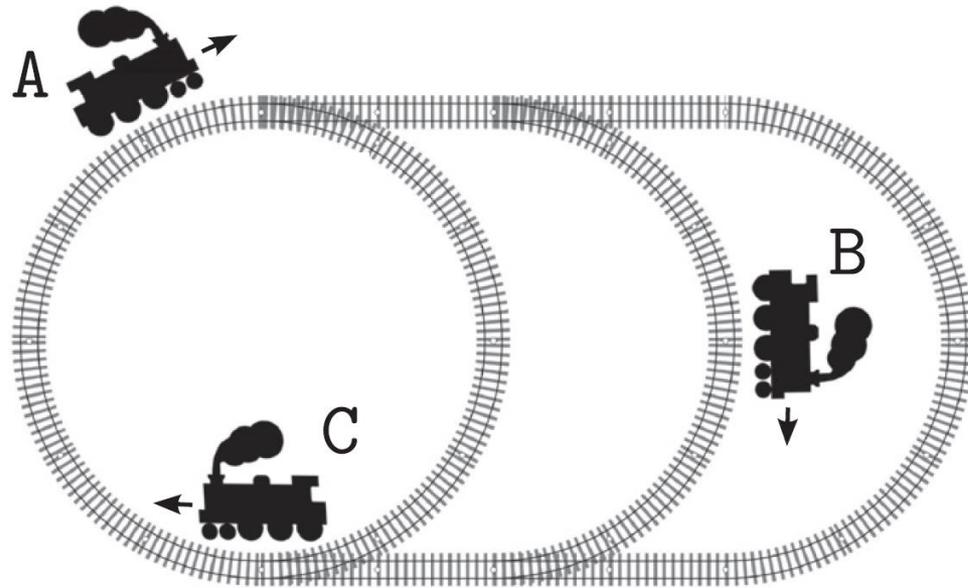
# Loschmidt's paradox



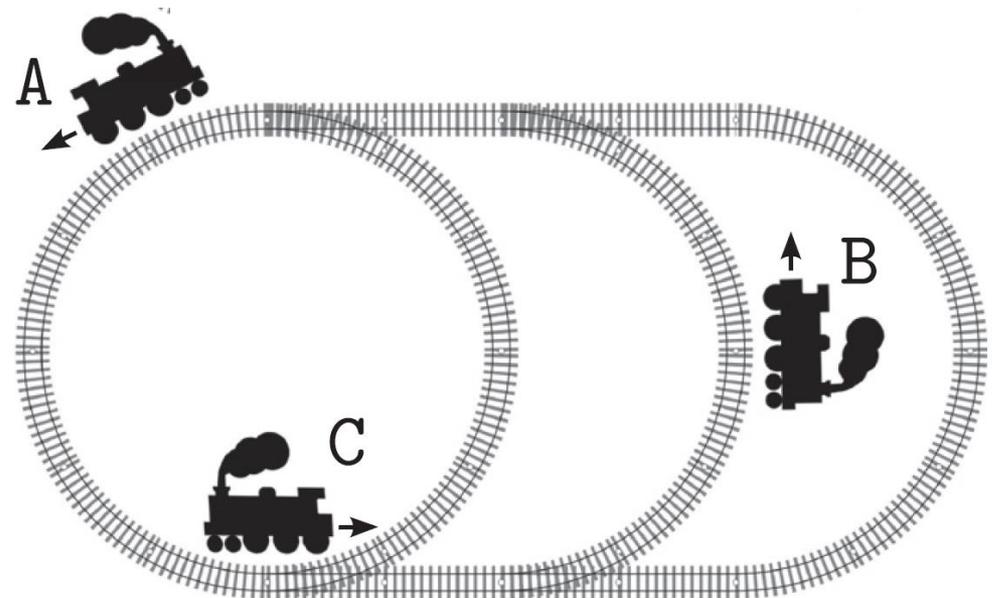
- Microscopic physics has no arrow of time.
  - time reversal symmetry
- How can there be an arrow of time in the second law of thermodynamics?



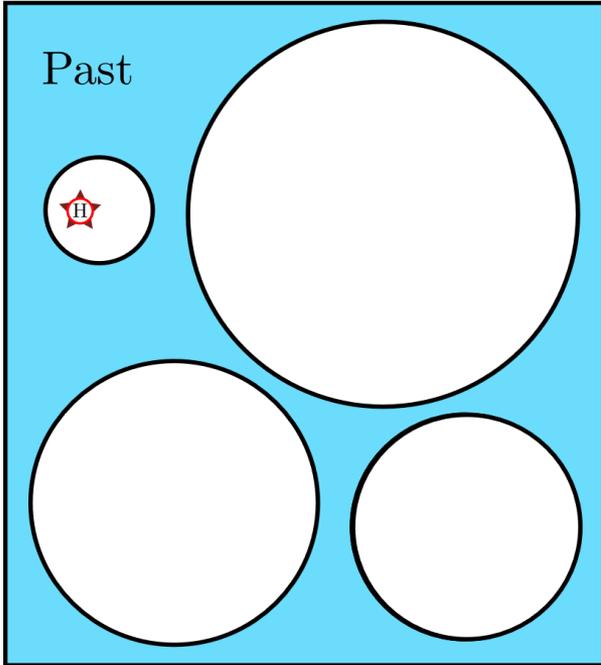
Velocity reversed  
pairs of  
configurations



A pair of velocity reversed configurations!

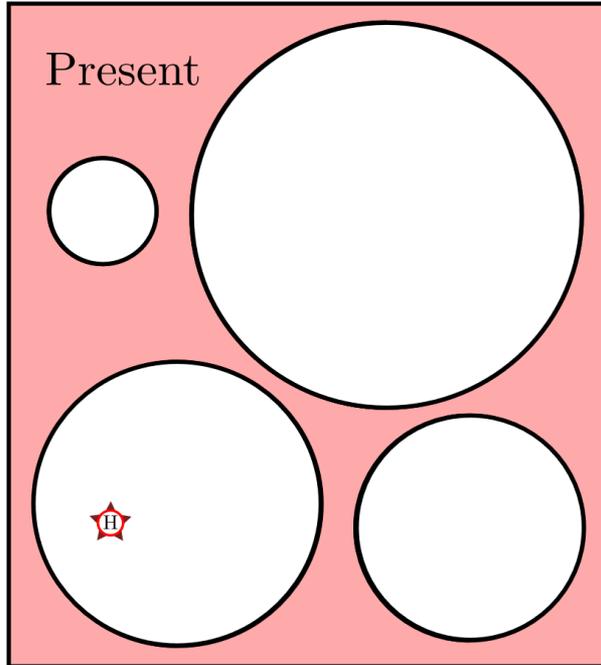


Past



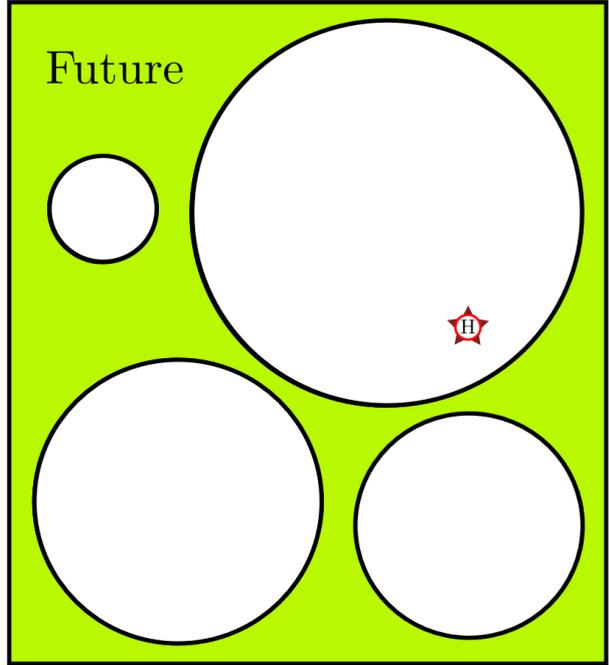
A blue rectangular panel with the word "Past" in the top left. It contains four white circles: a large one in the top right, a small one in the middle left containing a red star with a white 'H', and two medium-sized ones in the bottom left and bottom right.

Present



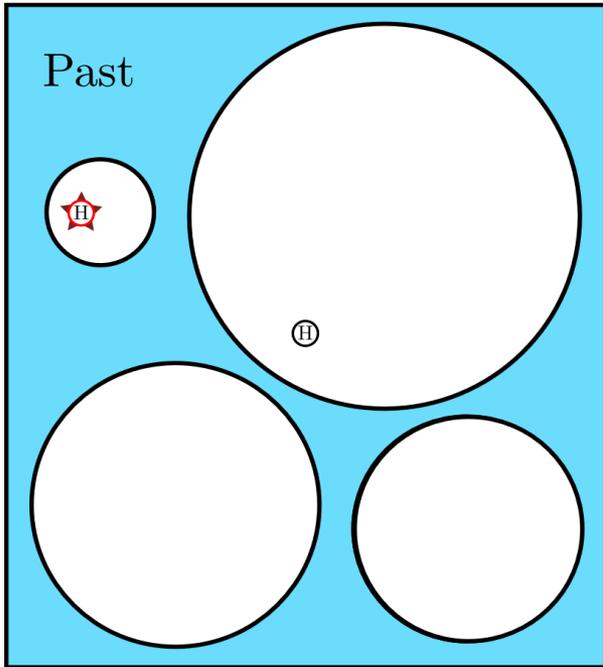
A pink rectangular panel with the word "Present" in the top left. It contains four white circles: a large one in the top right, a small one in the middle left, a medium one in the bottom left containing a red star with a white 'H', and another medium one in the bottom right.

Future

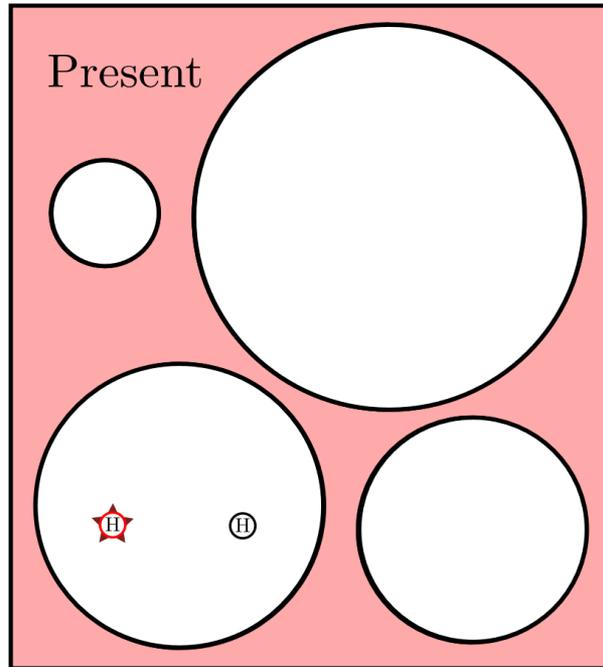


A green rectangular panel with the word "Future" in the top left. It contains four white circles: a large one in the top right containing a red star with a white 'H', a small one in the middle left, and two medium-sized ones in the bottom left and bottom right.

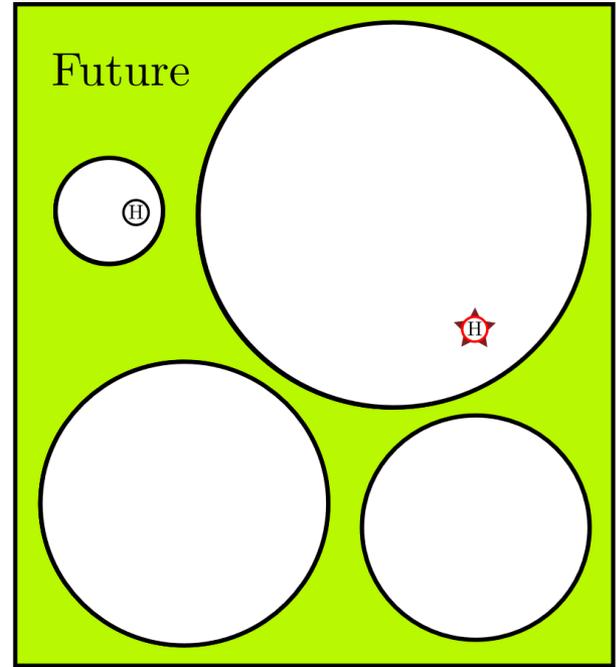
Past

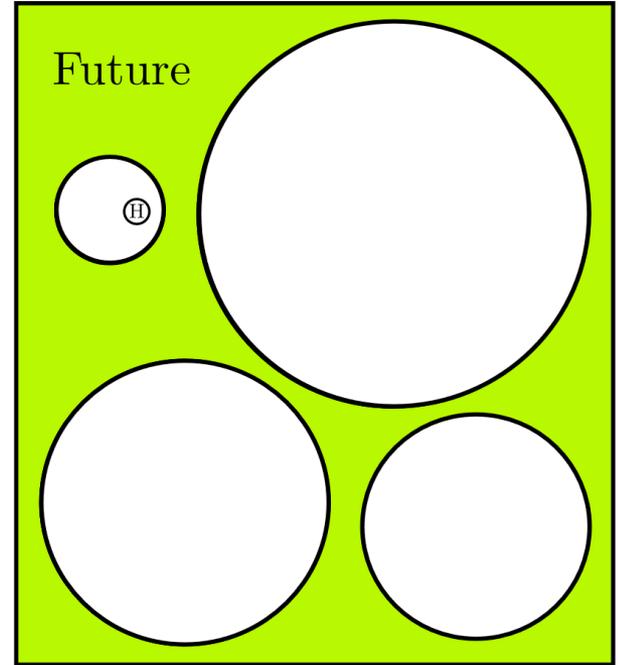
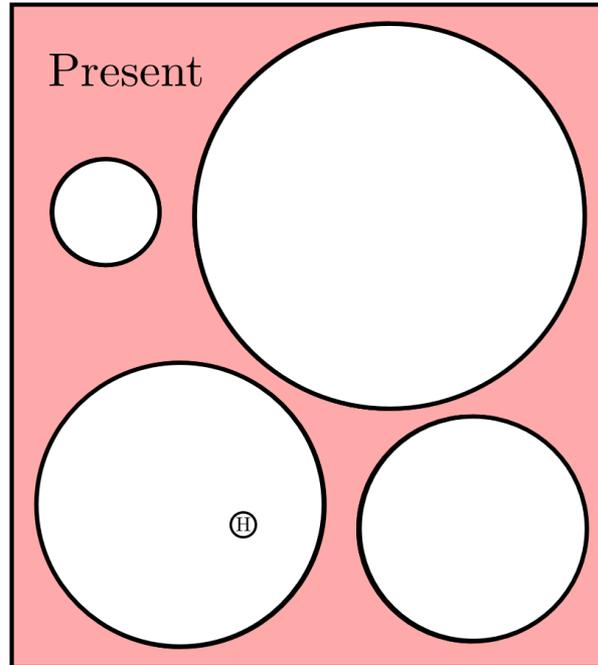
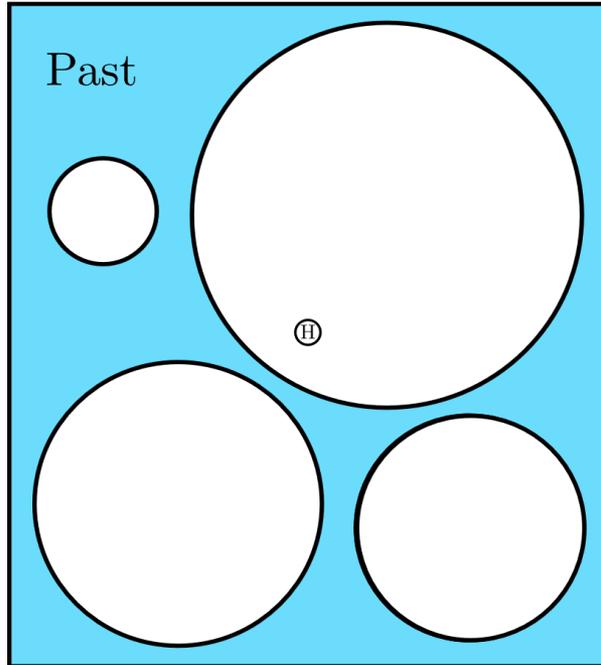
A blue rectangular panel with the word "Past" in the top left. It contains four white circles: a large one at the top right, a medium one at the bottom left, and two smaller ones at the bottom right. A red star with a white 'H' is inside the top-left small circle, and a white 'H' in a circle is inside the top-right large circle.

Present

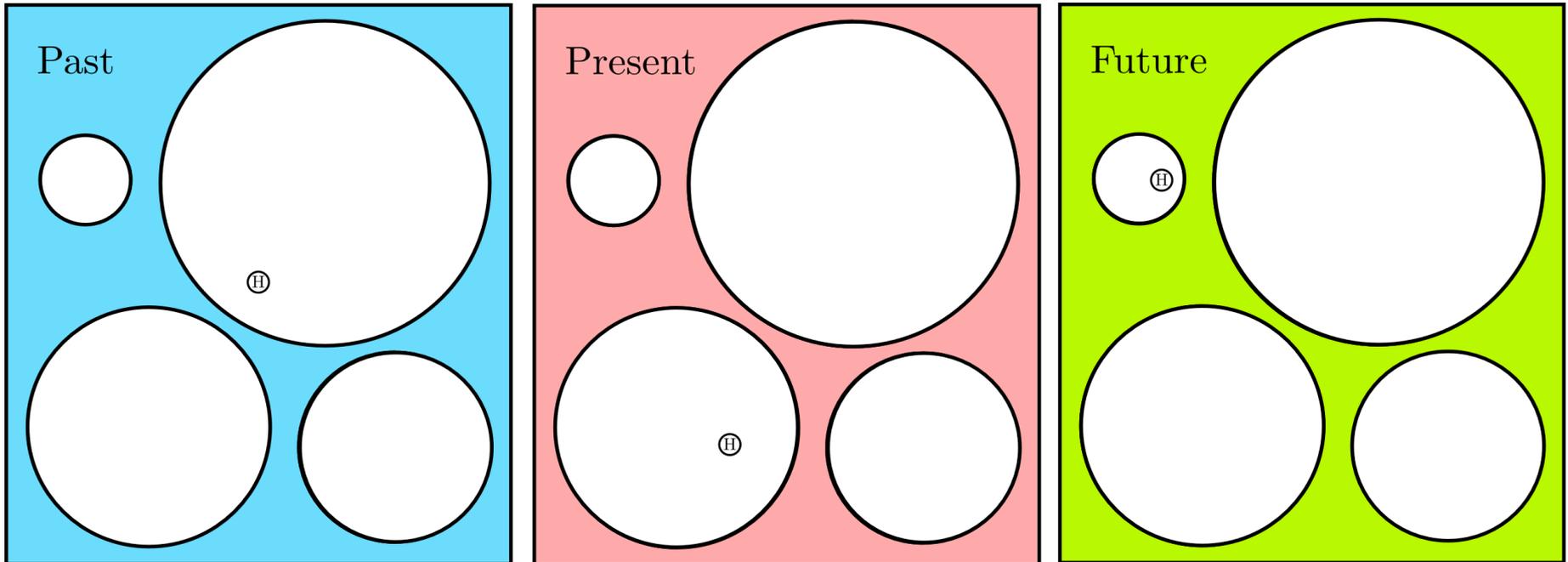
A pink rectangular panel with the word "Present" in the top left. It contains four white circles: a large one at the top right, a medium one at the bottom left, and two smaller ones at the bottom right. A red star with a white 'H' is inside the bottom-left medium circle, and a white 'H' in a circle is inside the bottom-right small circle.

Future

A green rectangular panel with the word "Future" in the top left. It contains four white circles: a large one at the top right, a medium one at the bottom left, and two smaller ones at the bottom right. A red star with a white 'H' is inside the top-right large circle, and a white 'H' in a circle is inside the top-left small circle.

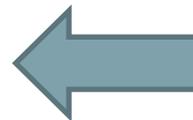


# A Loschmidt trajectory universe



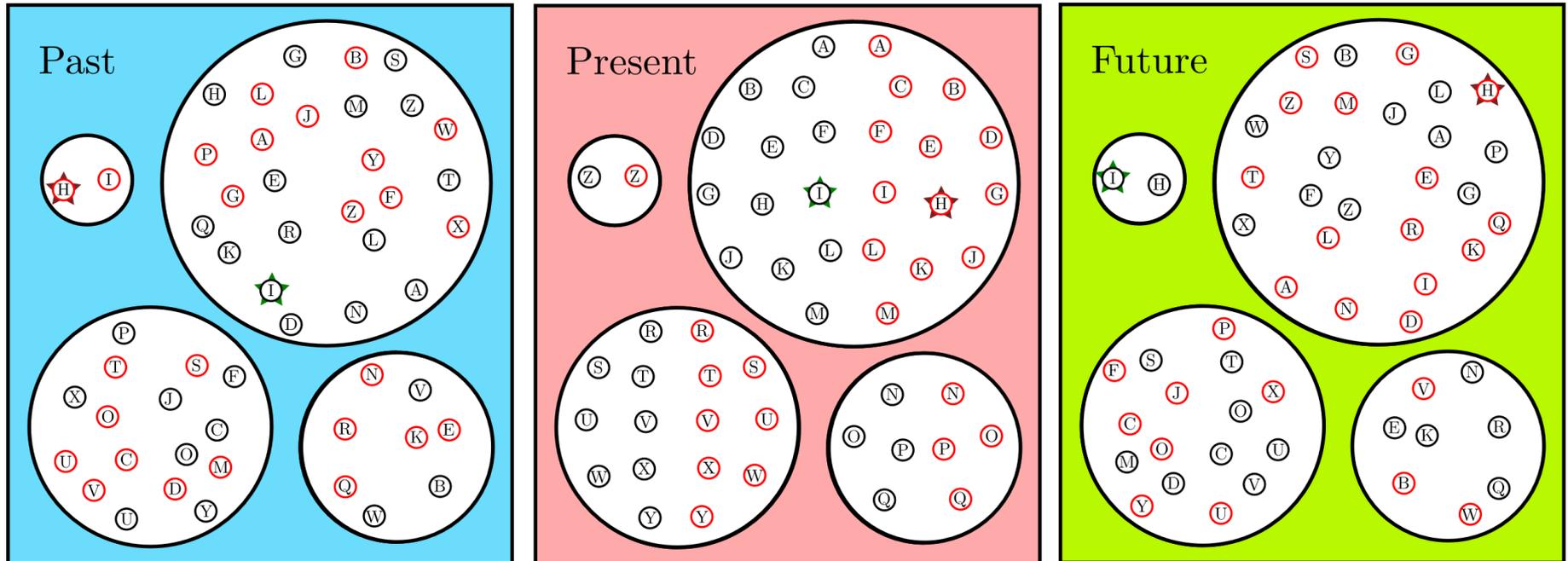
High entropy past

Low entropy future

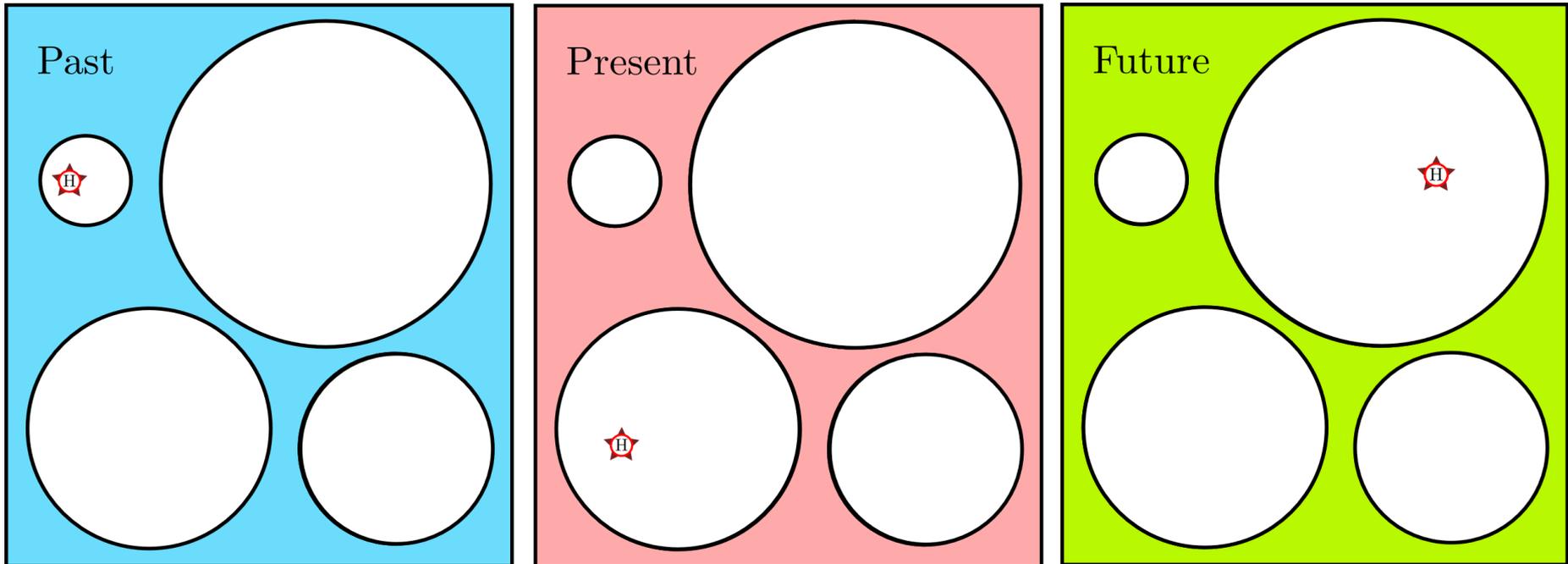


Perceived flow of time

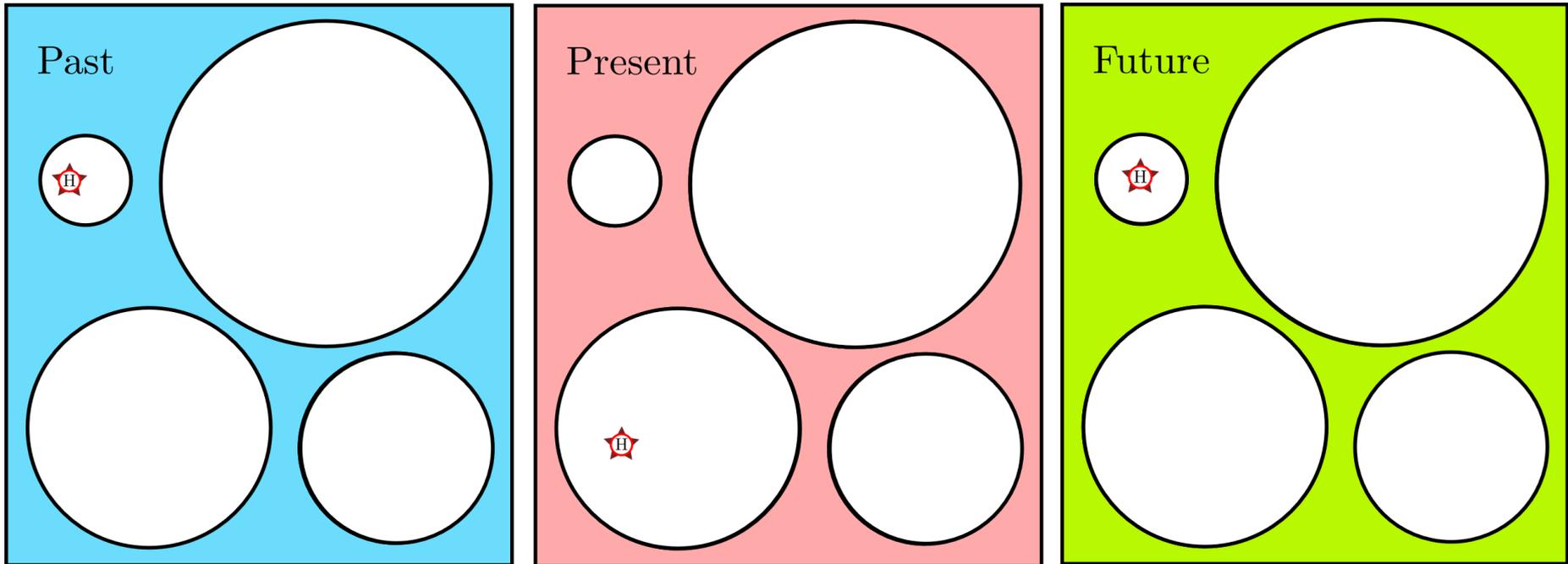
# Most trajectories of the world are boring



Time may pass, but nothing perceptible happens.  
 Examples: red A, black G.



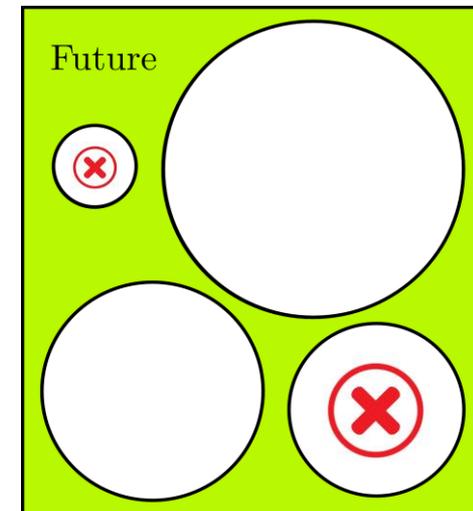
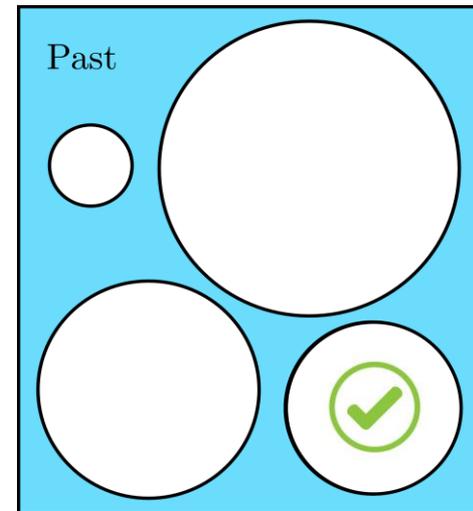
A history of increasing entropy is exceptional!  
But it is a fact.

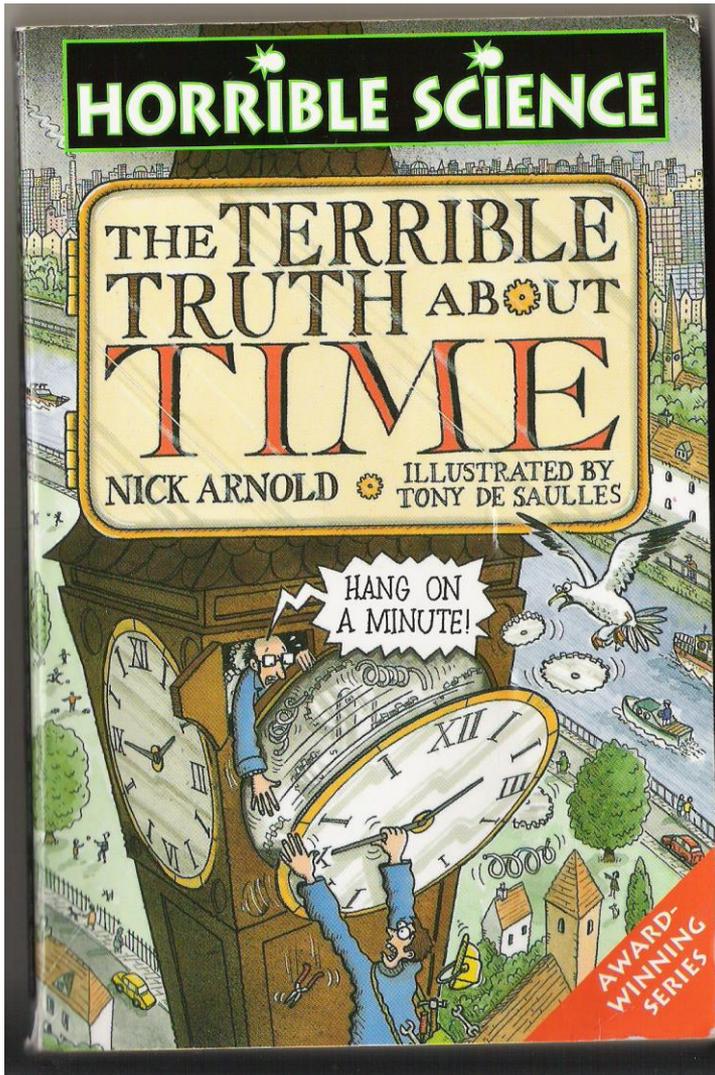


Low-high-low entropy history is **extremely** unlikely

# Statistical resolution of Loschmidt's paradox

- Given that the configuration was in a small sector in the past
  - and thus is following an exceptional trajectory
- it is very unlikely to end up in a small sector in the future
  - this would make it doubly exceptional

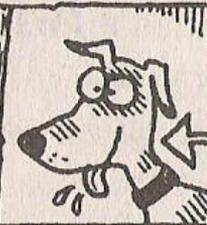




*Bet you never knew!*

*1 Boltzmann's theory suggests that it's possible for an ice cream left in a warm room to actually stop melting and start to freeze again ... but it's not very likely. Mind you, if someone sits on your ice cream it's even less likely to re-freeze.*

TEN MILLION  
BILLION TO ONE  
CHANCE THAT  
ICE CREAM WILL  
RE-FREEZE



BUT VERY  
LIKELY  
THAT IT'LL  
BE EATEN

**SPLAT!**



ER,  
MAYBE  
NOT!

# Ludwig Boltzmann: hero of physics

- 'Big, bearded and miserable'  
(The Terrible Truth about Time)





The growth of entropy: nothing to worry about

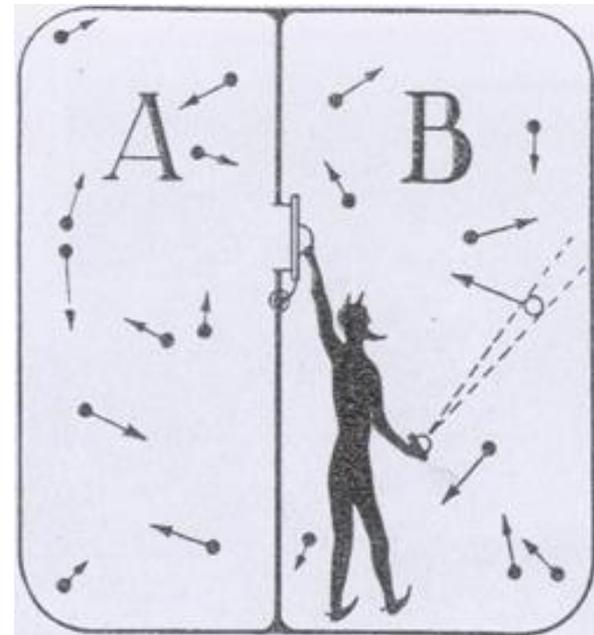
# Might we be able to destroy entropy?

- Enter Maxwell's demon!



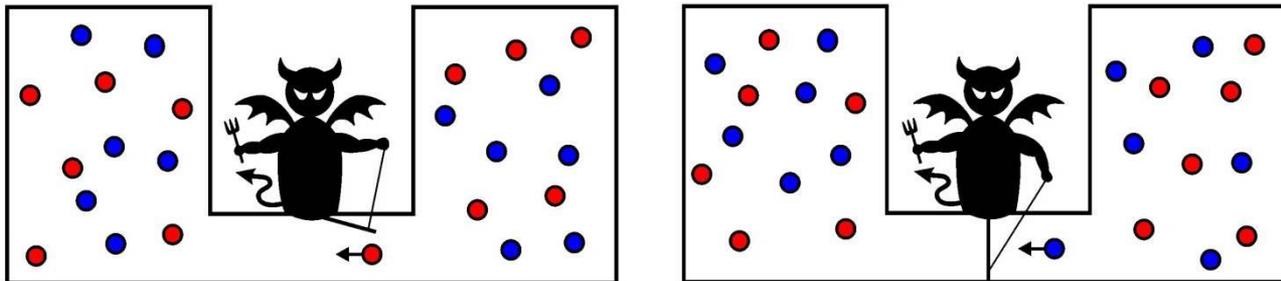
## James Clerk Maxwell 1867

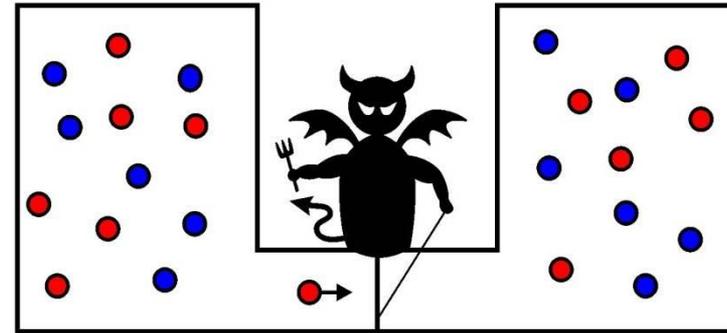
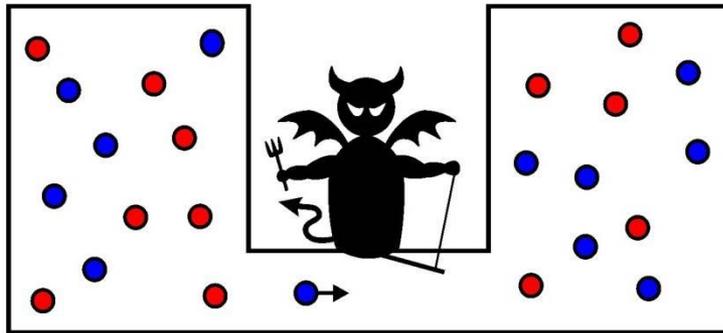
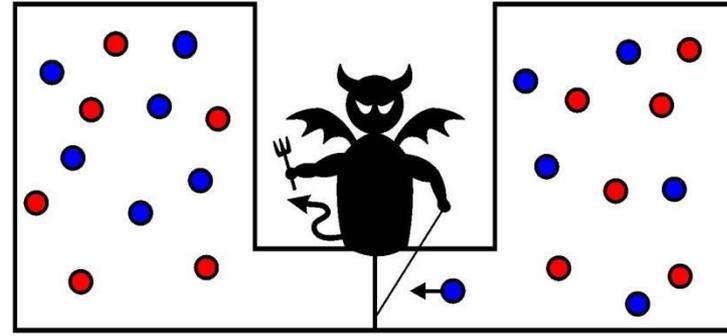
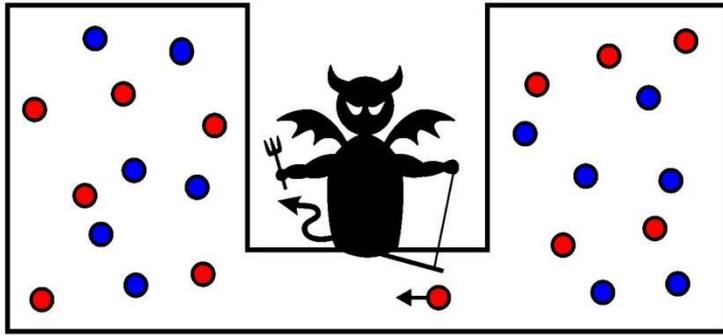
- ...the second law is continually being violated....  
in any sufficiently small group of molecules ...
- ...consider a very observant and nimble fingered fellow...

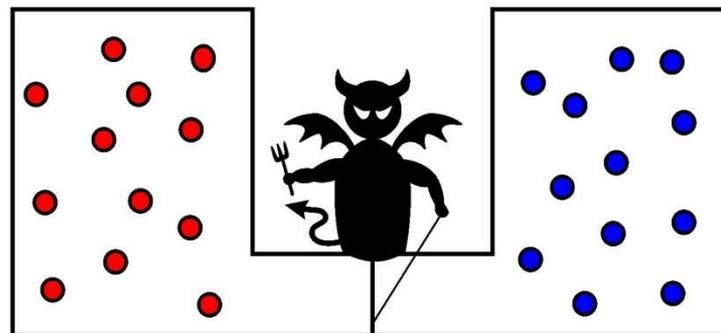
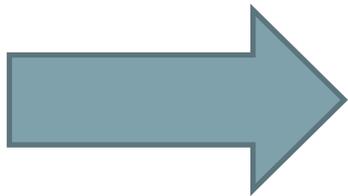
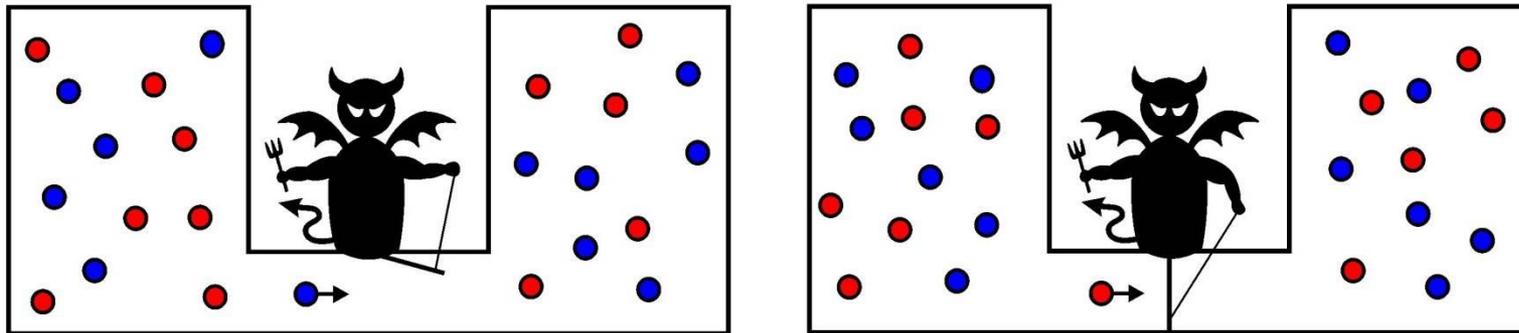
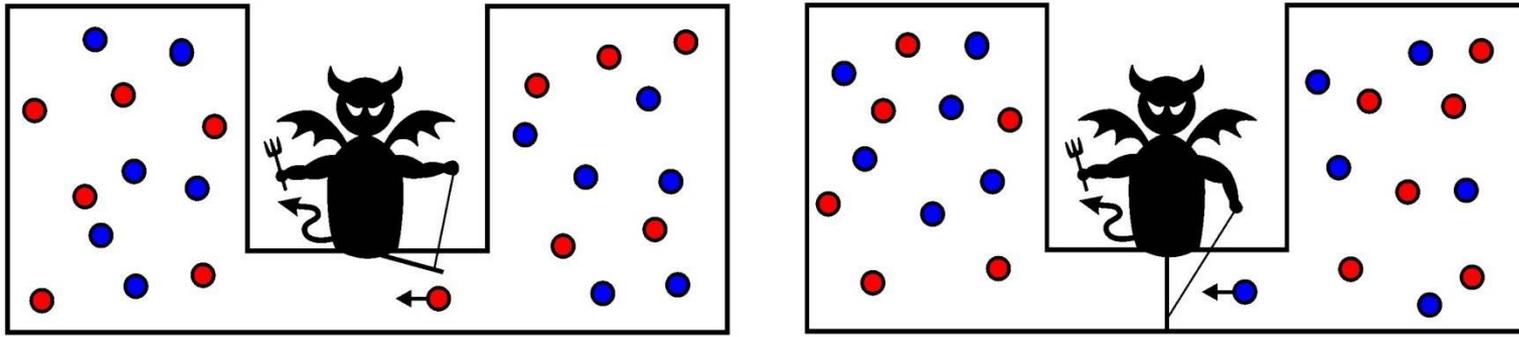


# Maxwell's demon

- If demon sees either:
  - a fast atom approaching from the right
  - a slow atom approaching from the left
- then he opens trapdoor and lets it through







Reduction in entropy since it is a measure of **uncertainty**



<http://abstrusegoose.com/319>

Maxwell's Demon  
only the least scariest  
demon... EVAH





<http://abstrusegoose.com/319>

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only the least scariest  
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<http://abstrusegoose.com/319>

Maxwell's Demon  
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Maxwell's Demon  
only the least scariest  
demon... EVAH

## Breaking the second law



- Can we build a demon?
  - Maxwell: ‘if we are clever enough’
- Or are they impossible?
- What is the nature of *measurement*?
  - does it generate entropy?
- Or is the issue the *forgetting* of a measurement?
- Suspicion is that we can’t destroy entropy
  - **because the world is chaotic!**

# Now for a VERY SCARY demon!

FULL CAST AND CREW | TRIVIA | USER REVIEWS | IMDbPro | MORE ▾ | SHARE

**+ The Laplace's Demon (2017)** ★ 6.6 /10  
173 ☆ Rate This

Il demone di Laplace (*original title*)  
1h 45min | Horror, Mystery, Sci-Fi | 22 February 2019 (USA)



**THE LAPLACE'S  
DEMON**



1:00 | Trailer 4 VIDEOS | 13 IMAGES

A team of researchers have developed a system to calculate seemingly random events. A mysterious professor invites them to his remote house on a rock in the middle of the ocean. All they have to do is survive the night.

# Reviews!

## CRITIC REVIEWS FOR *THE LAPLACE'S DEMON*

All Critics (2) | Fresh (2)



If *The Laplace's Demon* is something like a slasher (or a locked-room mystery), whittling down its characters one by one, then their adversary is not some masked, heavy-breathing killer but rather destiny itself

Aug 26, 2018 | [Full Review...](#)



**Anton Bitel**

SciFiNow



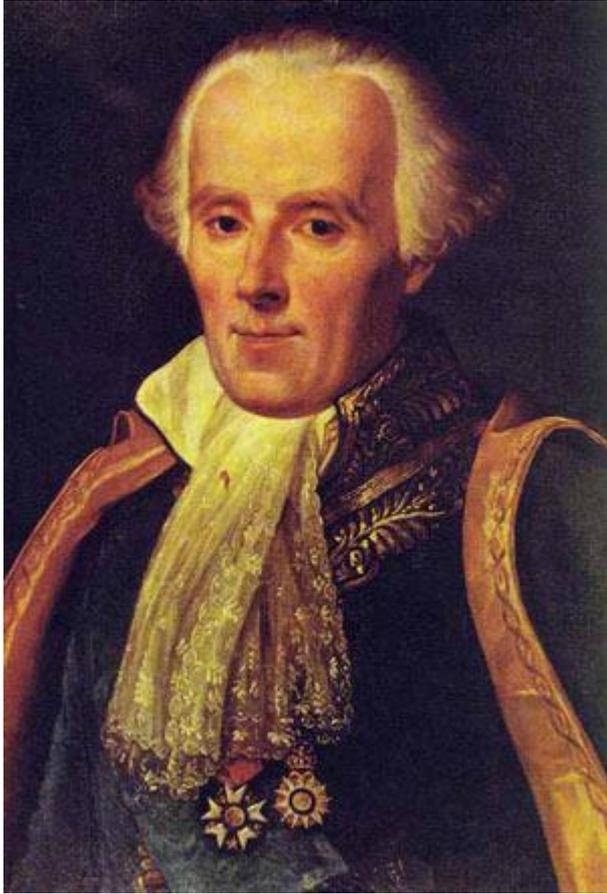
It's a testament to the importance of viewing art in context, of understanding where movies come from, of exercising more intellectual rigour than blindly watching whatever an algorithm predicts we want to watch next.

Mar 28, 2018 | [Full Review...](#)

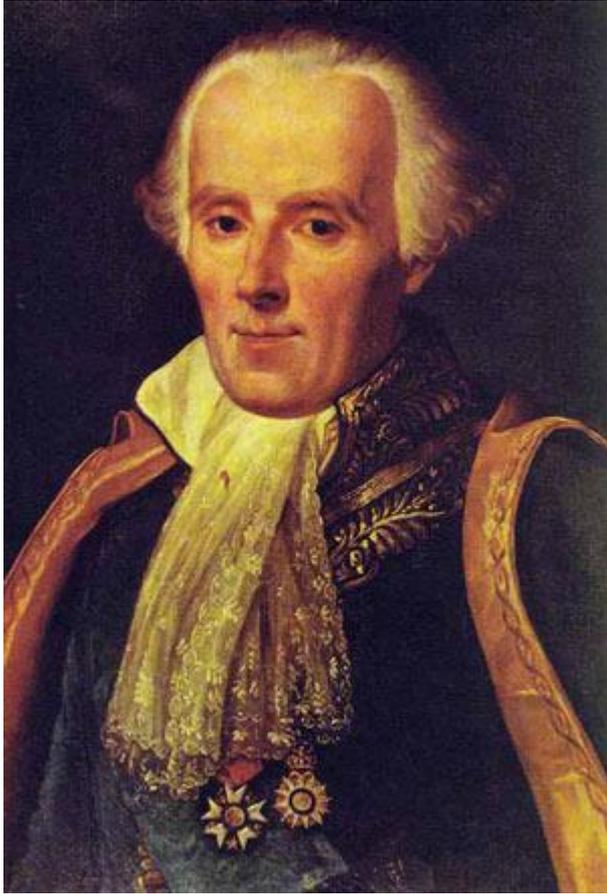


**Andrew Todd**

Birth.Movies.Death.

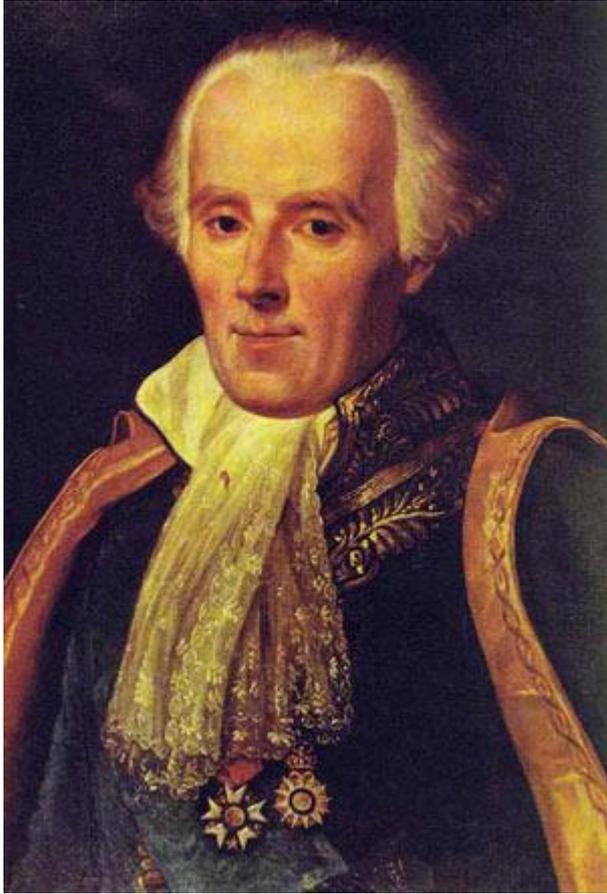


— *Pierre Simon Laplace*



We may regard the present state of the universe as the effect of its past and the cause of its future.

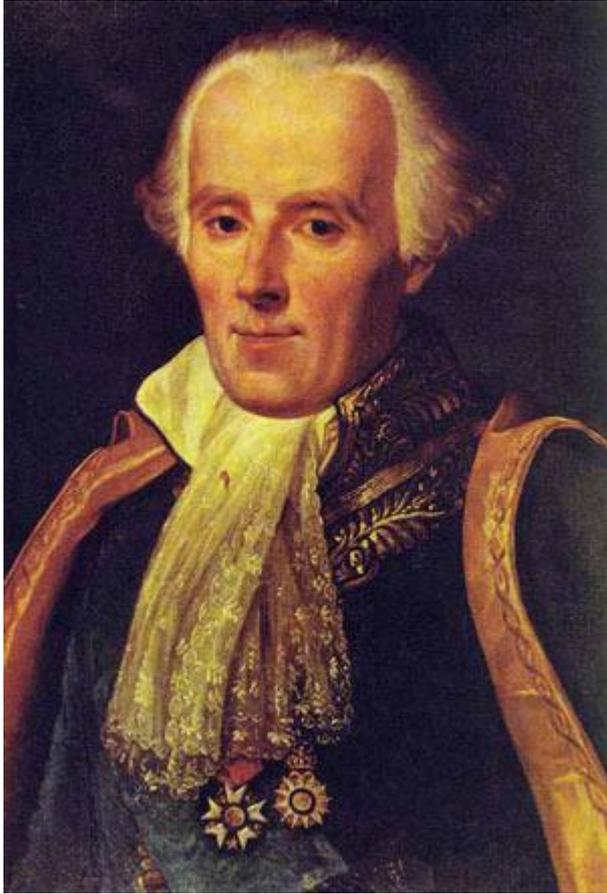
— *Pierre Simon Laplace, A Philosophical Essay on Probabilities, 1814*



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An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed,

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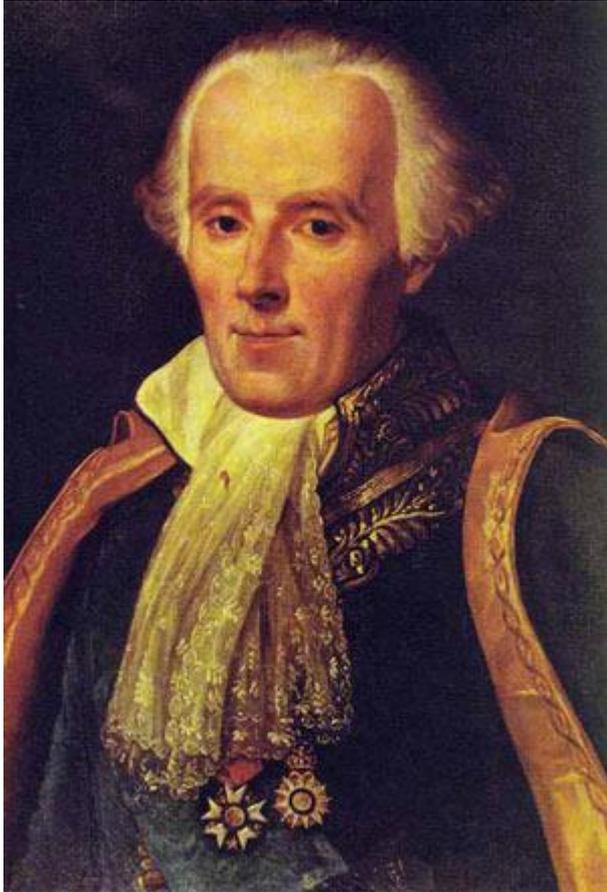


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if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom;

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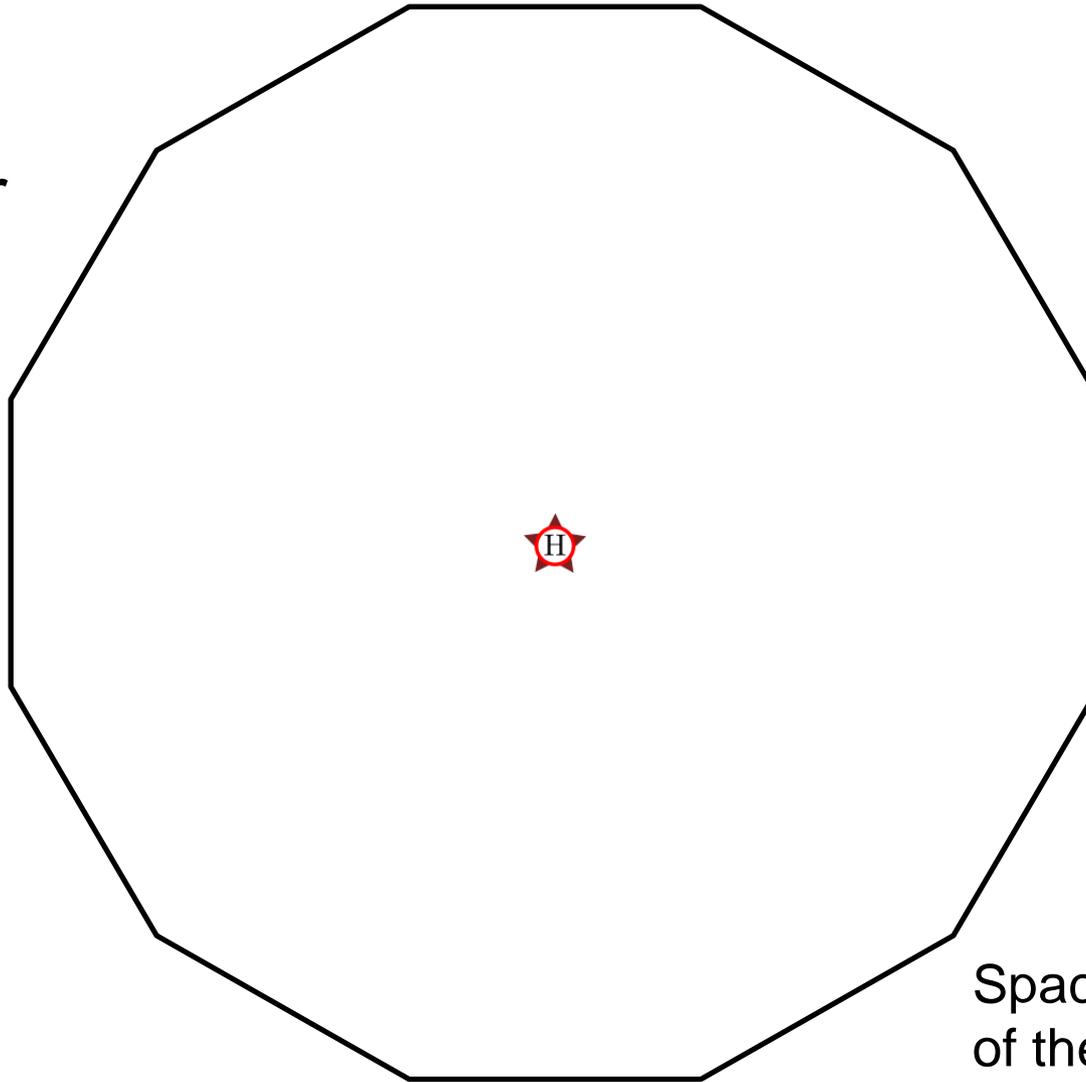
for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

— *Pierre Simon Laplace, A Philosophical Essay on Probabilities, 1814*

# Laplace's demon

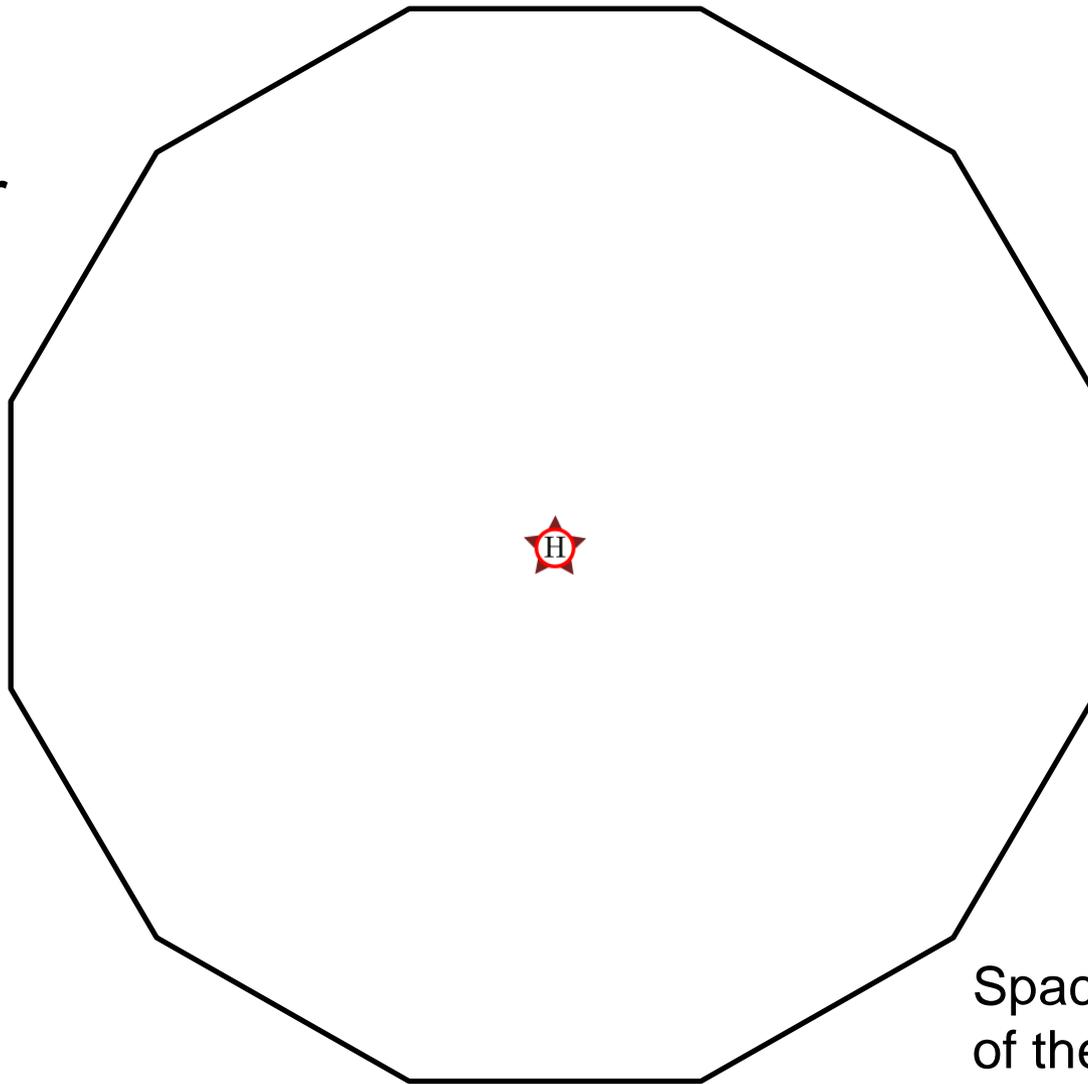


Future  
behaviour



Space of coordinates  
of the  $10^{86}$  particles in  
the universe

Past  
behaviour



Space of coordinates  
of the  $10^{86}$  particles in  
the universe

# Laplace's demon has no concept of the growth of entropy



- The future is clear, and the past also
- How would the demon perceive the flow of time?
- Is our perception of the flow of time an illusion?
  - like entropy itself

## Things to take away!

- The second law of thermodynamics is not scary
  - things are not ‘falling apart’
- The world evolves chaotically and wonderfully
  - we just cannot perceive all of its intricacies and our uncertainty is entropy
- The world has a low entropy past
  - it is exceptional!
- Maxwell’s demon tries and (probably) fails to tame the chaos
- Laplace’s demon suggests that the future is fixed
- **Thanks for listening!**