What is Time?

A label on points in the universe, just like space.

Time helps us locate things.
We measure time using **clocks**: repetitive, predictable motions.
Biological rhythms -- our pulse, breathing, nervous system -- are (somewhat) reliable clocks. They allow us to feel the passage of time.
A profound difference between time and space: 

*time has a direction*, space does not.
The **arrow of time** points from the past to the future.

Things change, in consistent ways, throughout the universe.
Just as organisms change and evolve, so do stars, and so does the universe.
1 second: hot, smooth plasma.
380,000 years: ripples in a smooth background
$10^{10}$ years: stars and galaxies.
$10^{15}$ years: black holes and rocks.
$10^{100}$ years: empty space (forever).
There is no arrow of time in the fundamental laws of nature.

Interactions between simple objects (atoms, billiard balls) are perfectly reversible.

The arrow of time only emerges when there are many moving parts.
What really happens as time passes?
The world gets messier -- more disorderly.

We can clean things up, but that takes effort; it doesn’t happen by itself.
Disorder in the universe increases with time.

[Charles Mallory]
The Second Law of Thermodynamics: entropy increases with time (in closed systems).

Disorder is measured by Entropy. Messier, less-organized things have higher entropy.
Growth of entropy is responsible for all the aspects of the arrow of time.

Without the arrow of time, the universe would be in thermal equilibrium -- everything static, nothing ever changing.

Life and death
Biological evolution
Memory
Cause and effect
The “flow” of time

[Roger Penrose]
Ludwig Boltzmann, 1870’s:

Entropy counts the number of ways we can re-arrange a system without changing its basic appearance.

low entropy: delicately ordered

high entropy: all mixed up

[Martin Röll, Wikimedia]
Boltzmann’s idea explains why entropy tends to go up: there are more ways to be high-entropy than to be low-entropy.

But why did the entropy start out so low?

A question about the early universe!
This includes ideas like causality and even free will.

We can reconstruct the past from the present only by appealing to a low-entropy boundary condition.
The origin of the arrow of time is cosmological.

Entropy was low near the Big Bang. Our initial conditions were finely-tuned, “unnatural.” Nobody knows why.
Why was the early universe so “unnatural”?

Could the whole universe just be a random fluctuation?
Boltzmann, 1895: maybe there is a **multiverse** mostly in high-entropy equilibrium, and our galaxy is just a random fluctuation.

The **anthropic principle**: in a big universe, we will only observe those parts that are hospitable to the existence of intelligent life.
Boltzmann wasn’t the first to suggest this scenario.

“For surely the atoms did not hold council, assigning order to each, flexing their keen minds with questions of place and motion and who goes where.

But shuffled and jumbled in many ways, in the course of endless time they are buffeted, driven along, chancing upon all motions, combinations.

At last they fall into such an arrangement as would create this universe…”

-- Lucretius, *De Rerum Natura*, c. 50 BC.
In 1931, Sir Arthur Eddington explained why we cannot be just a random fluctuation.

Fluctuations are rare, and large fluctuations are very rare.

This scenario predicts that we should be the minimum possible fluctuations -- “Boltzmann Brains.”
I don't know if you exist

But I do! I do not agree with your article and I do not believe that "MOMBO - JOMBO" if you do... well! It's disturbing thought. But I know how to deal with it! I will not let the Wallc. Disipar under my nose. But if you do, I can't say I'm sorry!

Sincerely
A ten year old who knows a little more than SOME PEPEO!

George. Wing

Ps. some people have a list in the men prime.
Perhaps the answer is to be found before the Big Bang.

General relativity predicts its own downfall at the moment of the Big Bang. Needs to be replaced by something better.

There could be spacetime before the Big Bang, and many possibilities are currently being pursued.
A high-entropy universe would look like empty space.

That’s where our universe is headed.

But in the presence of vacuum energy, even empty space has a nonzero temperature.

Fields will constantly be gently fluctuating, even though space is “empty.”
Einstein says that space and time are dynamical; they will have their own fluctuations.

We can even imagine forming a new bubble of spacetime -- a baby universe.

Baby universes start out small, with low entropy; then they expand and cool, creating an arrow of time.

Just like the Big Bang.
Baby universes cost zero energy to produce.

A bubble could form in this room and we’d never know.

The universe is like an eternal bubble-making machine. It will never turn off.

Each new bubble increases the entropy of the larger multiverse. That’s the difference between this scenario and Boltzmann’s; entropy grows forever, rather than jiggling near a maximum.
This can happen in both directions in time.

Evolving empty space to the past, we would also see baby-universes created; their arrow of time would be reversed with respect to ours. The multiverse can be perfectly time-symmetric; we just don’t see all of it.
The multiverse business is obviously speculative.

What’s important is:

You remember the past and not the future because the early universe had a very low entropy.

Understanding why is a profound challenge for modern cosmology.