

IS TIME BROKEN?

In March of 1949, the British astronomer Fred Hoyle appeared on a BBC Radio Show, talking about various theories of the universe. Hoyle was a firm believer in the steady state model of the universe, meaning the universe had no beginning or end. It always was and always will be. But a new model had been gaining in popularity for a couple of decades, one where the universe did have a beginning.

That started from an infinitesimal point and expanded outward from there and continues to expand to this day. And when talking to the interviewer about this idea, he kind of flippantly referred to it as “that big bang idea,” and the name stuck. Yes, ironically, the Big Bang was named by somebody who didn't believe in the Big Bang. And one of the reasons that Hoyle and many other people at the time didn't take this idea seriously was because one of the people who was behind this big bang idea was an astronomer and mathematician named George Lament.

Astronomers knew the universe was expanding as far back as 1912, when Vestal Slifer first measured the Doppler shift of a spiral galaxy and suggested it was moving away from us. Later, scientists like Alexander Friedman and Edwin Hubbell refined this idea, and they found further evidence that the universe was expanding. But it wasn't until 1931 that George Lament became the first person to look at that and say, if the universe is expanding, then that means that it used to be smaller than it is today, And, if you go back far enough to the very beginning, that means that it would have shrunk down to an infinitely small point. Which means the universe had a beginning.

Now, all of this sounds reasonable enough. The problem is that Lemaître was a Belgian Roman Catholic priest. And this whole idea that the universe had a beginning, that it began with an explosion of matter and energy out of completely nothing, sounds suspiciously biblical.

“Let there be light,” and all that over time, as our telescopes have become more and more powerful, we've been able to see further and further back in time, to the earliest galaxies. And Lemaître has been proven more and more right.

But actually, the general acceptance of the Big Bang Theory is shockingly new. It wasn't really until the 1980s that it was truly embraced by scientists.

But still, the Big Bang is messy, and a lot of theories have been put forth to explain it. There are still people who think that maybe there is a steady state explanation for the universe. One of those explanations is called the Causal Set theory of the universe, and it's pretty solid mathematically. And it could explain a lot of other vexing questions about reality.

As a jumping off point to look further into this topic, this big cosmological mystery of topics all start with the whole divide between quantum mechanics and general relativity.

Quantum mechanics basically describes fundamental forces; the behavior of particles like atoms, electrons, and everything in the molecular and sub-molecular realms. Whereas general relativity underlies our understanding of spacetime and gravity. It treats gravity as a curvature in spacetime, created by mass. But general relativity in quantum mechanics operates with very different rules,

and physicists have been trying to bring these two theories together for decades.

Different Theories

There are four fundamental forces of the universe, and those are gravity, electromagnetism, the weak nuclear force, and the strong nuclear force. And gravity is only one of these forces that is not carried by a particle. So, scientists have been searching for a theory of quantum gravity to solve this problem, especially around Singularities like black holes, because that's where general relativity pretty much breaks down. So, to figure out quantum gravity is to figure out nothing less than the beginning of the universe.

And over the years, physicists have attempted this in a few ways. One of which is string theory, which is the idea that reality consists of infinitesimal vibrating strings that are smaller than Atoms, electrons, quarks, and anything you can imagine. And, according to string theory, when the strings vibrate, twist, and fold, they produce effects in several dimensions, and then we interpret that as everything from particle physics to gravity. Many have quantum loop gravity.

This is a theory that's concerned with the quantum properties of spacetime. In other words, in this theory, spacetime is quantized, or built out of discrete chunks. Imagine zooming into spacetime according to quantum loop gravity; it wouldn't be a smooth motion. It would stutter from one spacetime pixel to another. Time wouldn't move continuously; it would work in quick little ticks of a discrete clock. And this new theory expands on this idea, and it's called causal set theory.

Causal Set Theory

In this theory, kind of like quantum Loop gravity, spacetime consists of discrete elements, but these are called events that are related to each other through causal relationships, meaning basically, one event causes the next to happen, and then the next, and the next, and so, if you can imagine a collection of dots on a piece of paper and then each dot represents an event in spacetime, the lines that connect them represent the causal relationships between those two dots. And if that event causes another event, then another line will form, and so on, and this sort of lattice work of connections between the events is known as a causal structure.

Now, if you're talking about the tiniest discrete chunks of spacetime, you have to measure them in the tiniest measurements that we know of. And that's plank length and plank time. So, with causal set theory, plank length and plank time represent the smallest possible distances and times between spacetime events. In causal set theory, spacetime is granular.

But what does that mean? What that means is that singularities can't happen because the chunks of spacetime can't get infinitely close together if there are no singularities. That means there was no big bang; the universe has always existed, and time has no beginning. Steady state is another important thing to remember.

We have no proof; we haven't found evidence of these tiniest causal units, which are called causets. It's kind of like string theory. We've never found the strings, but the math checks out the same with causal set theory. It's a mathematical construct, and there are two similarities about the math and causal set theory. 0

So, causal set theory, at its core, is based on a mathematical concept called partial order relation. This is used to describe a set of events that have a cause-and-effect relationship with each other.

Causal set theory builds on top of a partial order relation by defining a set of axioms, which are rules for how it all works. They define the essential properties of the causal structure. So, one of these axioms has a requirement that the partial order relation be cyclic. This means there can't be any loops between the causal relationships, between events. Another axiom requires that the partial order relation has to be locally finite, which ensures that the causal structure is not too dense or sparse.

There's way more to it, but it's math-based on partial order relation, and the elements of the causal set itself are explained in detail in a paper by Professor Emeritus at Syracuse University, Rafael Sorkin. He describes Kassettes as point events that carry information saying, quote, "for some pairs X, Y of elements have the information that X comes before Y , or that X comes after Y ."

Physically, you should think of this ordering as a microscopic counterpoint of the macroscopic relation of before and after in time. For some events, they take place after certain other events. He goes on to explain that the word causal comes in because we say that an event is later than another event if the latter could exert a causal influence on the former. Another way of describing it was made by Professor Samadhi Surya, saying, "Causal set theory is deeply rooted in the Lorenzian character of spacetime, where a primary role is played by the causal structure, particularly the assumption of a fundamental discreteness in CST does not violate local Lorentzian variants in the continuum approximation."

What all that means is that causal set theory works with Lorentzian geometry. This is what uses light cones to describe the geometry of light traveling through spacetime. You could say light cones are to Lorentz geometry what a circle is to Euclidean geometry.

This means that Kazettes can be mapped onto Lorentzian light cones, and what's cool about that is that using this mapping, we can study the implications of spacetime's discreteness and how particles behave at high energies, and the properties of black holes.

Why Causal Set Theory is Popular with Physicists

So, there's a reason why this whole approach is popular to some physicists. So, there was a paper written on CST called 'If Time Had No Beginning', and in it, the authors talk about how, to explain physics before the Big Bang, we turn to quantum gravity, which we still haven't quite cracked, but they argue that using a causal set approach fixes that "it doesn't have to explain the Singularity", because there is no Singularity. This of course, raises the Question," How can there be passage of time, if there's no beginning to it?"

Physicists suggest that time can be explained in CST through the process of spacetime growth, or as the paper's co-author Bruno Binto, told life science in a quote, "A huge part of the causal set philosophy is that the passage of time is something physical that it should not be attributed to some emergent sort of Illusion or to something that happens inside our brains that makes us think that the time passes."

This passing is in itself a manifestation of the physical theory. So, in a causal set theory, a causal set will grow one atom at a time and get bigger and bigger. Okay, but what about all those observations that point to there having been a Big Bang in a universal expansion?

Well physicist's explanation is to say that from time to time in this infinite expanse of spacetime, random fluctuations and energy could sort of merge into an explosion of energy and matter, kind of like a rogue wave in the ocean.

Meaning, if you could see for Infinity in this vast expanse, over Infinite Space and Time, you would just see universes bubbling up in this Endless Ocean of quantum spacetime foam, but because of the speed of light, none of them would be able to reach any others and none of us would ever know that any of these other universes were there kind of like a steady state version of the multiverse now.

All of this sounds bonkers; every theory about the beginning of the universe sounds bonkers, like this isn't the first theory that tries to explain the idea of quantum spacetime foam bubbling up universes. The Big Bang explained is a breakaway piece of quantum membrane that breaks off and smacks into another quantum membrane, hitting another universe in the face.

The most accepted theory so far was created by a Roman Catholic priest, but there are no experiments in the works to prove this just yet, so, for anybody who wants to dive further into the origins of time, what does that mean to you to be in a universe with no beginning or end? Does it make you feel a part of something infinite?

There are two fundamental constants of nature related to spacetime's discreteness. They're called Planck length and Planck time. Planck length is the smallest length scale with any physical meaning. Planck time is the smallest unit of time that we can meaningfully measure.

Loop quantum gravity is a theory that's concerned with the quantum properties of spacetime. The idea is that spacetime is a network of nodes and links in which quantum properties are assigned. In essence, spacetime is built up of discrete chunks.

With causal set theory, spacetime is not a smooth, continuous fabric, as defined by general relativity. It consists of discrete, indivisible building blocks called events that are causally related to each other to help form a causal structure.

Just to start, we're going to be speaking a lot in broad terms here because with this subject we can quickly get in the weeds.

Okay, so there's a divide between quantum mechanics and general relativity. You all know this, but let's just get this out of the way.

Quantum mechanics basically describes fundamental forces, the behavior of particles like atoms, electrons, and almost everything in molecular and submolecular realms.

Whereas general relativity describes how gravity affects the fabric of spacetime.

This theory underlies our understanding of space, time, and gravity. It treats gravity as a curvature in spacetime.

When an object bends spacetime's fabric, it makes a gravitational "well" at the location where anything with mass resides.

But general relativity doesn't appear to fit into quantum mechanics, even though three fundamental forces of nature do because they're mediated by particles.

By the way, those three fundamental forces of nature are electromagnetism, the weak nuclear force, and the strong nuclear force.

General relativity does imply that galaxies should be racing apart, but the reasons why are up for debate.

General relativity passes all the tests thrown at it and successfully explains gravitational interaction at a macro level.

But things get whacky when scientists try to calculate space's curvature around an electron or other quantum objects.

Quantum fluctuations of spacetime also happen at distances super close to the center of black holes.

When trying to outline the gravitational field of a black hole using general relativity, the spacetime curvature diverges at the center.

This signals a breakdown of the theory. It also means we need a new theory that includes both general relativity and quantum mechanics.

This is where the theory of quantum gravity comes in. Scientists have tackled it in a variety of ways.

But maybe we don't have the right theory yet.

Or maybe we do.

There are a couple of theories for quantum gravity.

One of them is string theory, which is the idea that reality consists of infinitesimal vibrating strings that are smaller than atoms, electrons, or quarks.

According to the theory, when the strings vibrate, twist, and fold, they produce effects in several tiny dimensions.

And then we interpret that as everything from particle physics to gravity.

It's been proposed often as a possible "theory of everything" that brings together quantum mechanics and general relativity.

Then you have loop quantum gravity, a theory that's concerned with the quantum properties of spacetime.

The idea is that spacetime is a network of nodes and links in which quantum properties are assigned.

In essence, spacetime is built up of discrete chunks.

Imagine zooming in to spacetime. As you do so, you'd see that time doesn't move into the future continuously but in quick little ticks of a discrete clock.

And when you move, it wouldn't be in a smooth motion. It would be stuttering steps from one spacetime pixel to another.

A new theory has been recently put forward that takes a unique approach. And it may have massive implications.

It's called causal set theory, and it's a framework that describes spacetime's structure.

In this theory, spacetime consists of discrete elements called "events" that are related to each other through causal relationships.

Imagine a collection of dots on a piece of paper. Each dot represents an event in spacetime. The lines that connect them represent the causal relationships between them.

If event one causes event two, a line will connect one to two on the paper.

One of the main ideas of this theory is that the universe is fundamentally discrete instead of continuous.

In other words, spacetime is not a smooth, continuous fabric, as defined by general relativity.

It consists of discrete, indivisible building blocks called events that are causally related to each other to help form a causal structure.

There are two fundamental constants of nature related to spacetime's discreteness. They're called Planck length and Planck time.

Planck length is the smallest length scale with any physical meaning. Planck time is the smallest unit of time that we can meaningfully measure.

With causal set theory, Planck length and time are believed to represent the smallest possible distances and times between spacetime events.

This means that spacetime is granular.

Traditionally, spacetime was thought of as smooth. Massive objects interact with it, causing it to bend. This is what we perceive as gravity.

But causal set theory suggests the opposite. Singularities can't happen because the chunks of spacetime can't get infinitely close together.

If there are no singularities, this means there is no Big Bang. The universe has always existed, and time has no beginning.

Causal set theory at its core is based on partial order relation. That's a mathematical concept used to describe a set of events that have a cause-and-effect relationship with each other.

The theory's math builds on top of the partial order relation by defining a set of axioms that capture the essential properties of the universe's causal structure.

These axioms include a requirement that the partial order relation must be acyclic. That means there can't be any loops in the causal relationships between events.

Another axiom requirement is that the partial order relation has to satisfy certain conditions of local finiteness, which ensures the causal structure is not too dense or sparse.

Okay, let me back up and define a causal set.

According to Rafael Sorkin, a Professor Emeritus at Syracuse University, a causal set, or causet, is a discrete set of elements.

These elements are the basic building blocks of spacetime, which is often described mathematically speaking as relationships among point-events carrying information.

But for elements of a causet, the only relational info is what mathematicians call a partial (or quasi-) order.

In *Einstein Online*, Sorkin writes:

“... for some pairs x, y of elements (not for all!) we have the information that x comes before y , or, in other cases, that x comes after y . Physically, you should think of this ordering as a microscopic counterpart of the macroscopic relation of before and after in time: For some events, we know that they take place after certain other events.”

He goes on to explain that the word causal comes in because we say an event is later than another event if the latter could exert a causal influence on the former.

In his paper, *Causal Sets Dynamics: Review & Outlook*, physics professor at the University of Athens in Greece Petro Wallden writes that:

“a causal set mathematically is a set C with the following features:

(i) A partial order relation $<$ which is (a) irreflexive ($x \not< x$) and (b) transitive ($x < y < z \Rightarrow$

$x < z$)

(ii) The partial order corresponds to the causal relation between elements of C , so if $x < y$ it

means that x is in the past of y .

(iii) Locally finite: $[x, y] \equiv |\{y \text{ such that } x < y < z\}| < \infty \forall x, z \in C$.
And $|A|$ indicates

cardinality of the set A . It is this condition that imposes the discreteness of spacetime,

since it requires that between every pair of elements of the causal set, to be only a finite

number of other elements.”

In *Living Reviews in Relativity*, physics professor [Sumati Surya](#) at the Raman Research Institute in India, writes:

“[Casual set theory] is deeply rooted in the Lorentzian character of spacetime, where a primary role is played by the causal structure poset. Importantly, the assumption of a fundamental discreteness in CST does not violate local Lorentz invariance in the continuum approximation.”

Lorentzian geometry is a mathematical framework that describes spacetime’s geometry in the context of special and general relativity.

This makes causal set theory compatible with it because the causal event relationships can be mapped onto the light cones of Lorentzian spacetimes.

By the way, [light cones](#) are basically a flash of light moving through spacetime.

They play the same role in Lorentz geometry that a circle plays in Euclidean geometry.

Using this mapping, we can study the implications of spacetime's discreteness for physical phenomena, like how particles behave at high energies or the properties of black holes.

The authors of the paper titled "If time has no beginning" state that we have to turn to quantum gravity to understand physics before the Big Bang.

But they argue that using a causal set approach allows us to go beyond that singularity and consider the idea that time has no beginning.

The authors say this raises the question of, can there be a passage of time if there is no beginning to it?

They suggest that time's passing is captured by a process of spacetime growth using the causal set approach.

As co-author Bruno Bento told *Live Science* in 2021:

"A huge part of the causal set philosophy is that the passage of time is something physical, that it should not be attributed to some emergent sort of illusion or to something that happens inside our brains that makes us think time passes; this passing is, in itself, a manifestation of the physical theory. So, in causal set theory, a causal set will grow one 'atom' at a time and get bigger and bigger."

With causal set theory, the problem of the Big Bang singularity goes away because singularities don't exist in causal sets.

That's because it's impossible to compress down to infinitely tiny points. They can't get any smaller than the size of a spacetime atom.

The paper explores if a beginning has to exist in a causal set approach.

In classical causal set formulation and dynamics, causets grow from nothing into the universe we know today.

But in the author's work, the Big Bang wouldn't exist, because the causal set would be infinite to the past.

In other words, there's always something before.

Their explanation for the observations in our universe that point to a Big Bang is to say that basically from time to time in this infinite expanse of spacetime, random fluctuations in energy could merge into an explosion of energy and matter like a rogue wave in the ocean.

Meaning, if you could see for infinity in all directions over infinite time, you would see universes bubbling up in this endless ocean of quantum spacetime foam.

But because of the speed of light, none of them would be able to see each other and never know they're there.

The authors have only shown that the math behind this idea works. It still needs to be proven experimentally.

As Bento told *Live Science*:

“One can still ask whether this [causal set approach] can be interpreted in a ‘reasonable’ way, or what such dynamics physically means in a broader sense, but we showed that a framework is indeed possible. So at least mathematically, this can be done.”

This makes me think of the famous movie line:

“Your scientists were so preoccupied with whether they could, they didn’t stop to think if they should.”

If time has no beginning, does that mean it doesn’t exist? If it doesn’t exist, does that mean it can’t be measured?

If it can’t be measured, what else can’t be measured?

Or to paraphrase Walt Whitman, we contain multitudes. As beings made from star stuff, we’re infinite, no beginning, middle, or end.