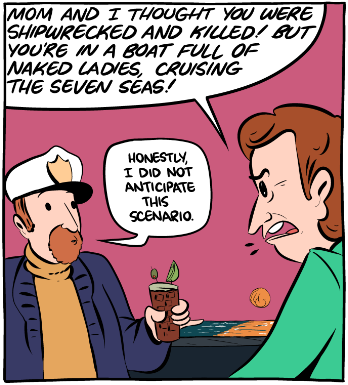
# Is Time Travel Possible?




This is the main risk of traveling back in time
to stop a parent's death.

Danny Calegari

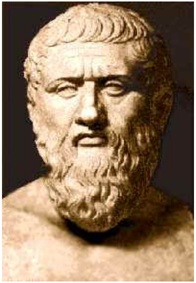
# 1. Is space travel possible?

Short answer: yes!

Long answer: depends where you want to go . . .

# But is motion even possible at all?

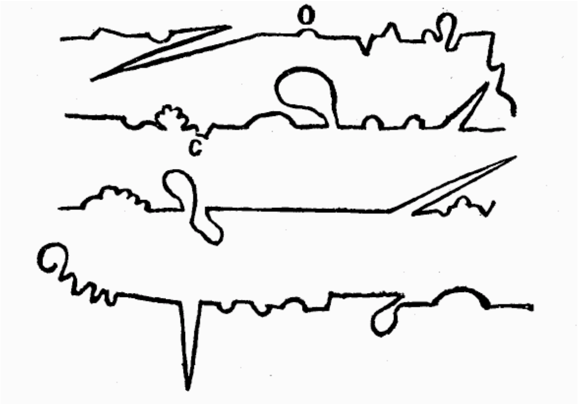
Zeno's paradox (∼450 BC?): To cross a room, first you must go halfway. Then you must go half of the remaining half. Then half of the quarter that remains. Then half of the eighth that remains. Then half of the remaining sixteenth. Then . . .



To go anywhere at all, there are infinitely many places you need to go first. So motion is impossible!

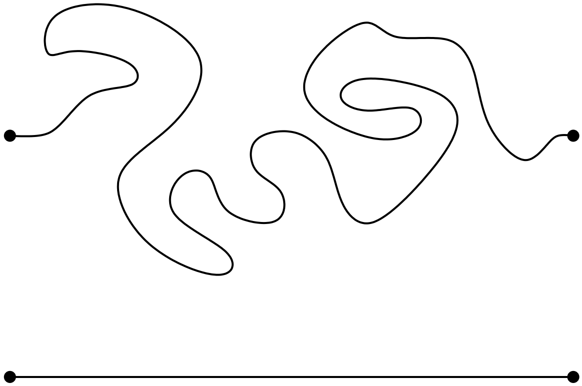
Most people find this argument unconvincing, but it's not easy to say exactly why. Let's set it aside for the moment.

# Getting from here to there



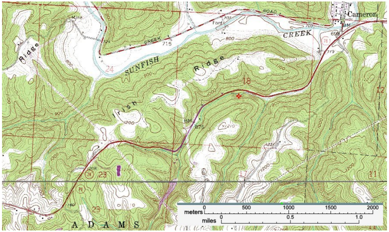

There's lots of ways to travel between two points.

# The shortest distance between two points is a straight line



The “amount of space” between two points depends on how you go between them.

# ...but when space itself is curved, what's a straight line?



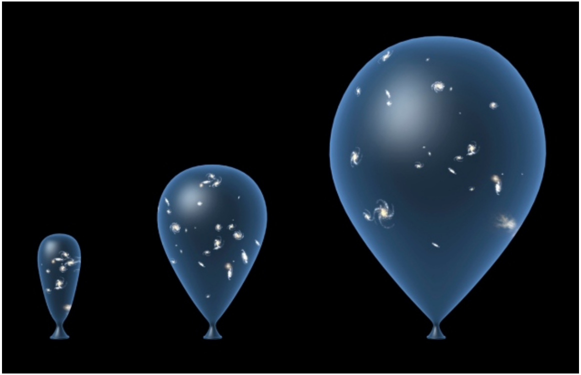

The shortest path can sometimes look pretty curved ...

. . . and if you travel far enough in curved space, a straight line can even close up!

# Space travel takes time!

You have to hurry to get to some places.

# The universe is expanding



. . . and the speed of expansion is accelerating!

# Zeno redux

The universe doubles in size every 10 billion years or so.

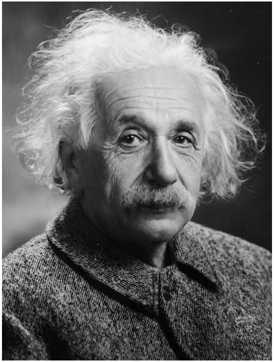
Suppose you want to visit the planet Tatooine, which is in a galaxy far, far away (10 billion light years away to be precise).

If you travel slower than the speed of light (186,282 miles per second), by the time you have traveled for 10 billion years, the distance has doubled.

So you have only gotten (at most) half way . . .

. . . and there's another 10 billion light years to go.

Einstein (1905): Nothing can travel faster than the speed of light.



So space travel is possible, but you can't go *everywhere*.

Everything sufficiently far away is outside the cosmic horizon, and is inaccessible to us forever.[1]

[1] but maybe there's a hole in this argument?

# 2. Is time travel possible?

Short answer: yes!

Long answer: depends where you want to go …and when.

# Events

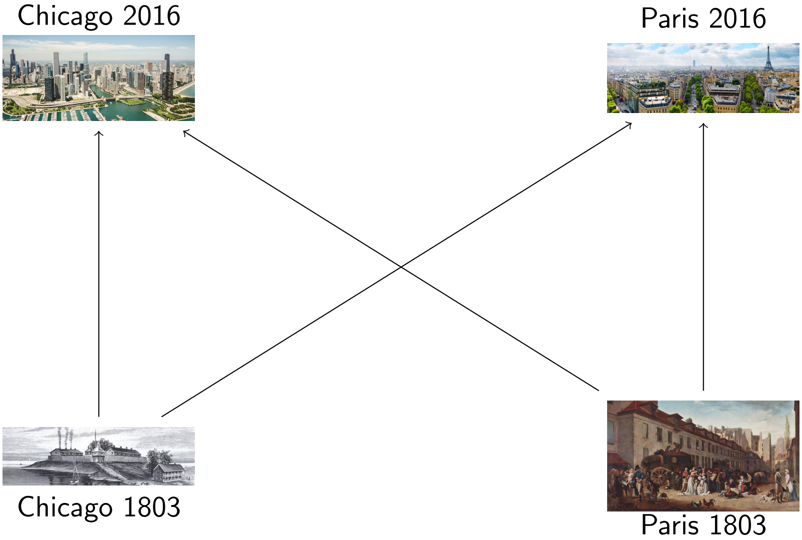
An event is a place and a time.


Example: 57th street books, Thursday evening 6:30pm.

Example: 5 feet north of the top floor of the Sears tower, Friday morning 8am.

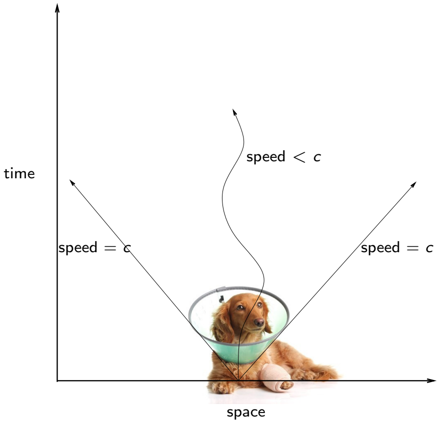
Example: Woodlawn Memorial Park, 6 feet underground, Friday afternoon 4pm.

"Time travel" is about travelling between events.




Our “time machine” should be able to take us from Chicago 1803 to Chicago 2016 (or Paris 2016).

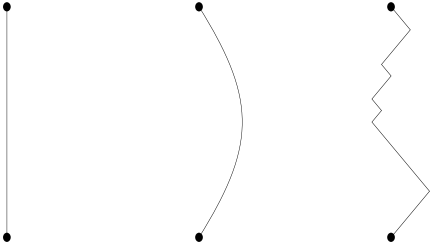
# Space-Time diagram




We plot all the events in a graph, with space "horizontal" and time "vertical".

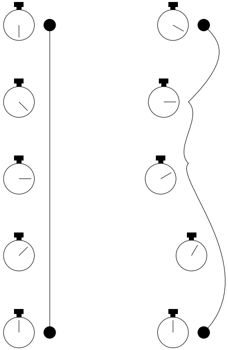
Motion at the speed of light is a straight line at 45 degrees. Any "allowable" motion is confined to the light cone.

There's still lots of ways to get from "now" to "then" ...



... but watch out for the speed limit!

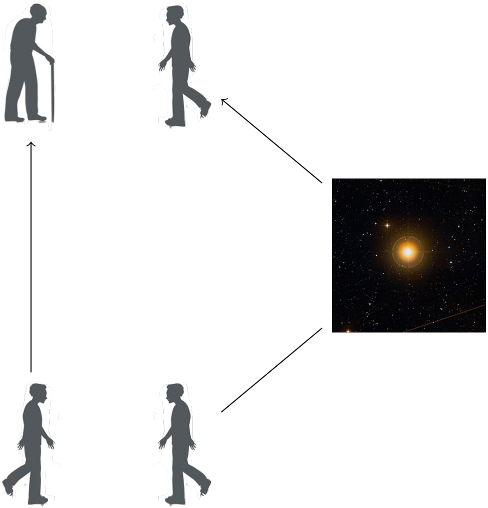
# The **longest** time between two events is a straight line



The amount of time that passes between two events depends on how you go between them.

The more "roundabout" your path, the shorter time it takes!

# The twin "paradox"



Two twins in Chicago 2016.

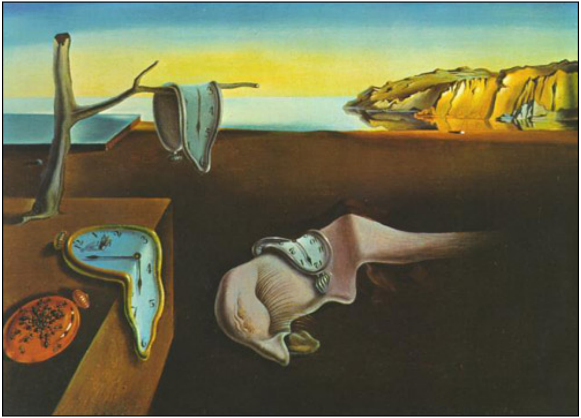
One stays put. The other takes a spaceship to Delta Eridani and back, traveling at 99.9% of the speed of light.

He returns to Chicago in 2075 but only 2.6 years have elapsed from his point of view.

# So you can travel into the future — as **fast** as you like!

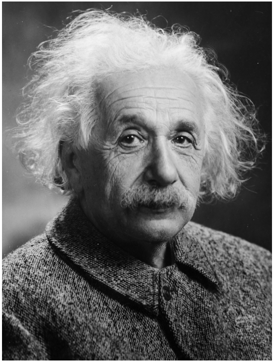
Just get in a rocket and accelerate until you are traveling almost at the speed of light.

# But space and time can be curved — by gravity!



# The **equivalence principle**

Einstein (1907): There is a complete physical equivalence between the effect of gravity and the effect of acceleration.



So instead of getting in a rocket and accelerating, you can just go and stand next to something very heavy.

# The effect of gravity is to **shrink space** and **expand time**.

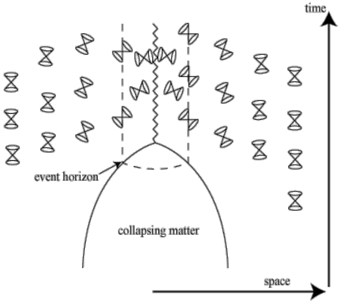
Time goes slower closer to the earth's surface than high up. This effect is real, and measurable: GPS satellites need to have their clocks "corrected" to account for it, and stay synchronized with clocks on the ground!

# Black holes

The “straight lines” in curved spacetime can get so curved, that they close up, and nothing — not even light — can escape. In 1967 John Wheeler came up with the term black hole to describe such objects.

The heavier an object, the more it curves space and time. The light cone is "tilted" in the direction of the heavy object by gravity.

When a star burns all its fuel, there is nothing to stop it from collapsing inwards from its own gravity. If the star has enough mass, when it becomes sufficiently dense, it forms a black hole.



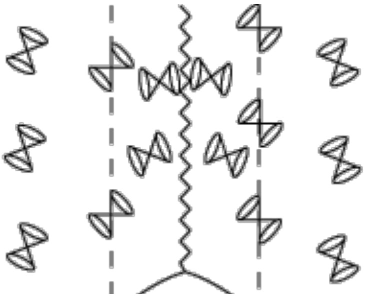

When something falls into a black hole, it can never escape again.

# Out of time

Inside the black hole is a single point called a singularity, where the laws of physics (as we understand them) break down.

From the outside, a black hole is finite in space. But from the inside, it is finite in time.

An object that falls in a black hole will come to a bad end: time will literally run out!



# . . . except . . .

That's the picture for a "stationary" black hole.

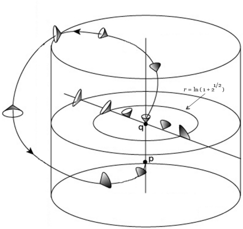
But stars (and most other things in the universe) are all rotating, at least a bit.

When a heavy object rotates, its gravity drags space and time with it (this is called frame dragging). The light cones are tilted in the direction of motion.

# Closed timelike curves

How much can the frame dragging effect distort space and time? Is it enough to allow time travel to the past?

Gödel (1949): Yes! If the universe were uniformly filled with spinning dust particles, and if the particles were spinning fast enough, there would be closed timelike curves through every point, and time travel to the past would be possible.



# Rotating black holes

It turns out that the entire universe is not uniformly filled with spinning dust (just as well!)

But when a rotating star, or something more massive, collapses to a black hole, the black hole keeps rotating.

Kerr (1963): A rotating black hole has a ring singularity (like a hula hoop).

It is (mathematically?) possible to enter the black hole and pass through the middle of the ring without encountering the singularity.

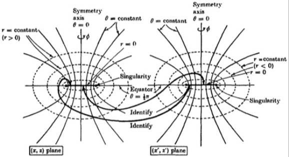



FIGURE 27. The maximal extension of the Kerr solution for $a^2 > m^2$ is obtained by identifying the top of the disc $x^2+y^2 < a^2$, $z = 0$ in the $(x, y, z)$ plane with the bottom of the corresponding disc in the $(x', y', z')$ plane, and vice versa. The figure shows the sections $y = 0$, $y' = 0$ of these planes. On circling twice round the singularity at $x^2+y^2 = a^2$, $z = 0$ one passes from the $(x, y, z)$ plane to the $(x', y', z')$ plane (where $r$ is negative) and back to the $(x, y, z)$ plane (where $r$ is positive).

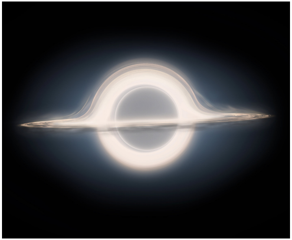
# Wormholes

No one knows what you'll find if you pass through the ring singularity in a rotating black hole. But the equations of general relativity seem to say that you would come out in an "anti-gravity" universe (or another part of our own universe) in which the black hole is "white", and there are closed timelike curves.

Physicists have speculated that such rotating black holes could be used as wormholes which would allow unrestricted travel in space and time.

The more massive the rotating black hole, and the faster it spins, the "wider" the ring, and the more comfortable your trip through would be. Fortunately, most galaxies seem to contain supermassive black holes at their center. Our own galaxy has such a black hole, weighing about 4 million times as much as the sun (this is still probably too small for a pleasant trip).

Andromeda (the closest galaxy to the Milky Way) has a black hole weighing about 100 million times as much as the sun (this is roughly the size of the black hole Gargantua in the movie "Interstellar").



THE END

. . . until next time?