Just a Second

Time and motion	Motion defines time
What is a second?	How is it defined?
What can happen in one second?	A lot, so it matters
Earth's rotation is slowing down	Why?
What are the consequences?	Are seconds getting longer?
What is a leap second?	Why are they needed?

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Time and Motion

How do humans think about time?

Ultimately, we always measure **time** by the **motion** of … something.

For millennia the passage of time has been measured by the motion of astronomical objects such as the Sun moving across the sky during the day …

… or the changing phases of the Moon at night.

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What Is a Second?

Surely that's trivial – the Earth spins on its axis once a day, where

1 day = 24 hours 1 hour = 60 minutes 1 minute = 60 seconds

$$\text{So one second} = \frac{1}{24 \times 60 \times 60}$$

$$= \frac{1}{86400} \text{ of one day.}$$

Simples!

So that's the end of the talk …? No. Let's look at how the Earth moves.

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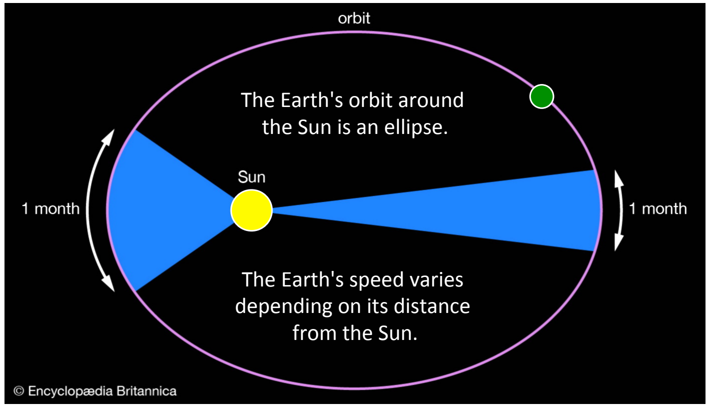
Earth Orbits the Sun



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Earth Orbits the Sun

Photographing the Sun at a the same time of day throughout the year produces an **analemma**.

The North–South variation is a result of the 23° tilt of the Earth's axis. In the Northern hemisphere, the Sun appears higher in the sky in Summer and lower in the Winter.

The East–West variation is a result of the Earth's speed varying in its elliptical orbit around the Sun.

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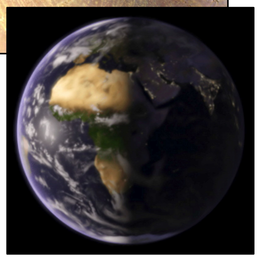
Earth Spins On Its Axis

An analemma shows us that sundials do not accurately indicate the passage of time because of the Earth's orbit, **not** because of variations in the rate at which the Earth spins on its axis.



To measure the variations in the length of a day (meaning the rotation period of the Earth, not the time between sunrise and sunset) we need a clock much more accurate than a sundial.

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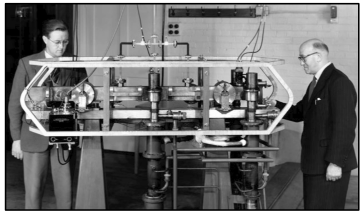
What Is a Second?

Since 1968 the second has had the precise definition of

9,192,631,770

oscillations of a caesium atom (or, more accurately, the microwave radiation corresponding to the transition between two energy levels of the isotope caesium-133).

This is called the **caesium standard**.



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Atomic Clocks

An atomic clock uses this caesium radiation to determine the passage of time to a precision of better than 1 ns per day.

That's equivalent to 1 s in 30 million years.

NASA are developing a Deep Space Atomic Clock (DSAC) that is about the size of a toaster.

It will be used in space probes to improve navigation accuracy.

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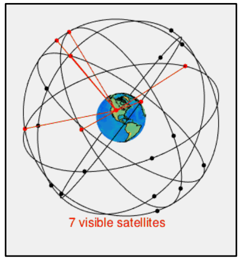
Time Matters

The GPS system relies on calculating the distances between you and a handful of satellites. Each satellite has an atomic clock on board.



If a clock is wrong by one ***milli*** second, the distance would be wrong by 300 km.

If a clock is wrong by one ***micro*** second, the distance would be wrong by 300 m.

Accuracy matters.

GPS clocks are re-synchronised every few hours to eliminate drift.

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What Can Happen In One Second?

The fastest supercomputer can do

200,000,000,000,000,000

calculations per second.

Even with this speed, running a simulation of the evolution of the Universe can take days, weeks or months of number crunching.

That's a lot of calculations.

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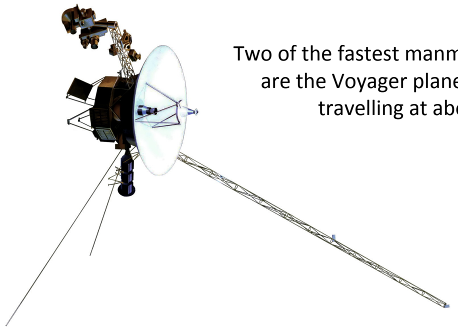
What Can Happen In One Second?

Light travels 186,000 miles or 300,000 km in one second.



Two of the fastest manmade objects are the Voyager planetary probes travelling at about 16 km/s.

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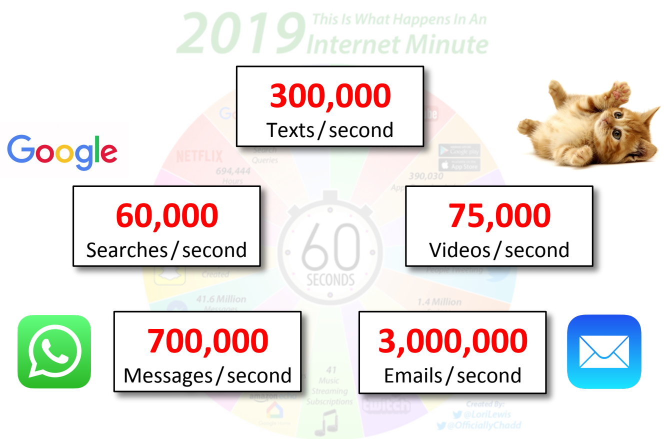
An Internet Second



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The Earth Is Slowing Down

Atomic clocks tell us that the Earth is slowing down.

Back in 1968 when 'atomic time' was instigated the Earth made one turn (relative to the Sun) in 24 h 00 m 00 s = 86400 s.

So a day *was* exactly 24 h.

More than fifty years later a day is now 86400.001 s.

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Theia Impact

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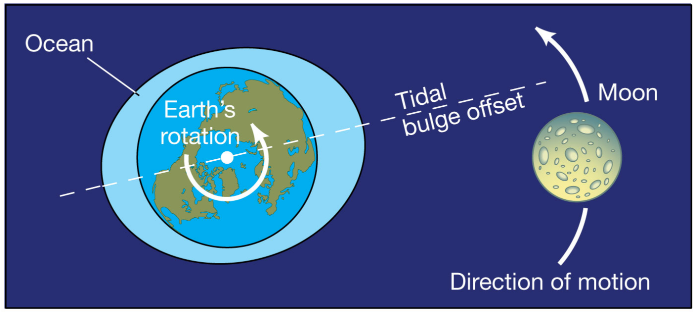
The Moon's a Drag

For the past 4.5 billion years, tidal forces have slowed the Earth's rotation



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So What?

So a day is not an exact number of seconds. So what?

It's just like the problem we have with a year not being an exact number of days.

1 year = **365.2422** days

If not addressed, the calendar would drift very slowly relative to the seasons. Inserting an extra day every fourth year would make the calendar year = 365.25 days. Almost right.

Skipping a leap day in a century year that is not divisible by 400 makes the calendar year = **365.2425** days. That's pretty close.

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So What?

If we want our 24-hour clocks to stay synchronised with the rotation of the Earth (so that the Sun is in the sky when our clocks say it is daytime) then we need to add **leap seconds** every once in a while.

(Actually, we don't **NEED** to. Alternatively, we could keep clocks synchronised with the rotation of the Earth by letting seconds get longer as the Earth slows down.

However, scientists would be **furious**!

Atomic clocks would have to be set to run at slower and slower rates. Having the definition of the second change every few minutes would be totally impracticable.)

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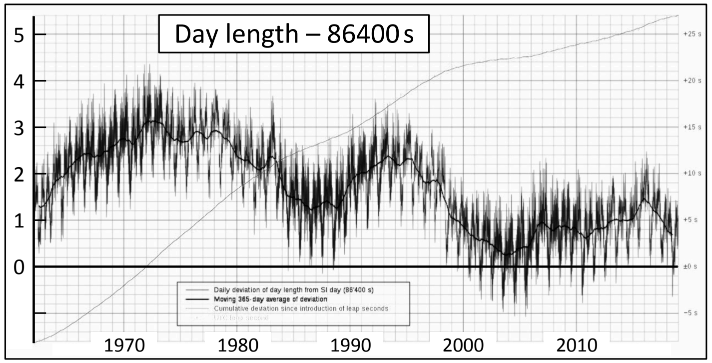
Length of a Day

milliseconds



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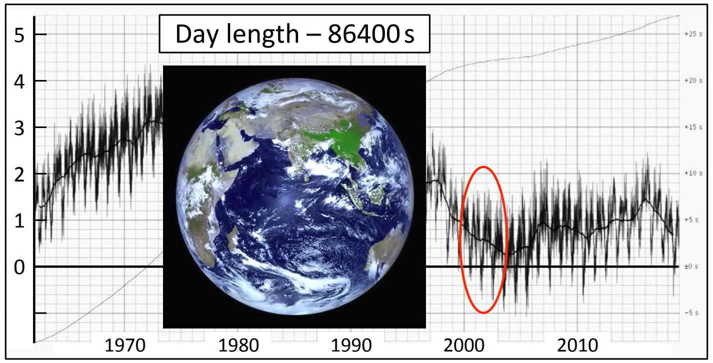
Length of a Day

milliseconds



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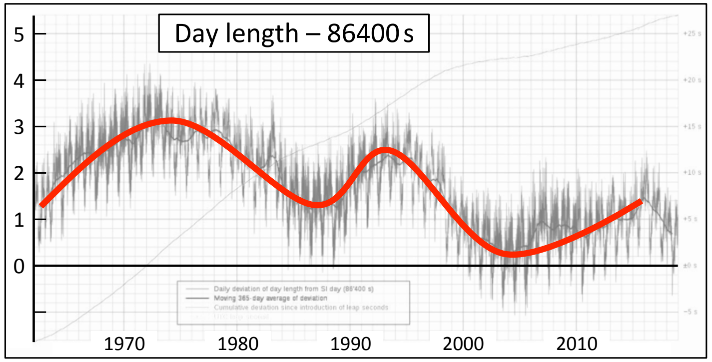
Just a Second

Length of a Day



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Leap Seconds

Leap **days** are inserted into the Gregorian calendar as an extra day – 29 February.

What about leap **seconds**?

That is decided by the …

International Earth Rotation Service

How often should a leap second be added?

When should leap seconds be inserted into a day?

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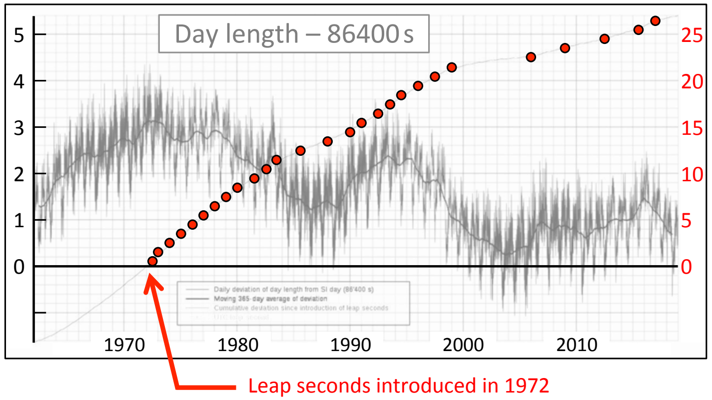
Length of a Day



Leap seconds introduced in 1972

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Leap Seconds

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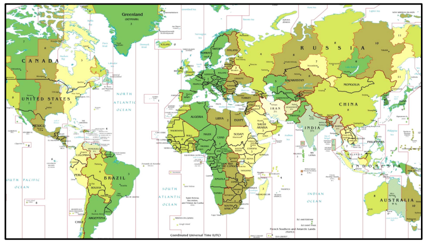
Leap Seconds

When should leap seconds be inserted into a day? Local midnight? But midnight where? Every time zone has its own midnight.



If leap seconds are not inserted at the same **instant**, clocks around the world will be out of synch by up to 1 second. In the world of global electronic finance, that lack of synchronisation matters.

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Leap Second Smearing

Some people *really* don't like leap seconds.

Some computer systems *really* don't like leap seconds.

Some companies *really* don't like leap seconds.

For instance, Google use leap second **smearing** to avoid the minute before midnight having 61 seconds. They add the leap second, a few microseconds at a time, continuously throughout the day.

They do this by running their clocks 0.001% slow for a day.

Imagine doing that with a leap day …

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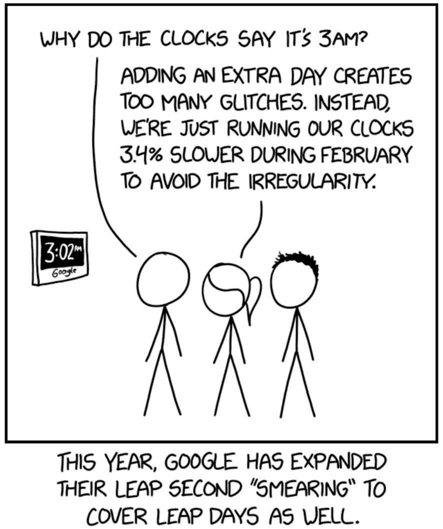
Leap Seconds



Leap day smearing is a joke, but the problem of what to do about leap seconds is serious.

The International Telecommunication Union (ITU) is a UN agency that has considered whether or not time signals should continue to have leap seconds inserted.

In 2015 they decided … not to decide until 2023.

xkcd.com

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