Slide 1

Just a Second

What is a second, what can happen in one second, and why do we need leap seconds?

Dr Steve Barrett   SSS 7 Dec 2023

Slide 2 — 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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Slide 3 — 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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Slide 4 — 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

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

$= \dfrac{1}{86400}$ 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

The Earth's orbit around the Sun is an ellipse.

The Earth's speed varies depending on its distance from the Sun.

orbit

Sun

1 month

1 month

© Encyclopædia Britannica

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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.

June

December

Giuseppe Petricca

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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.

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.

7 visible satellites

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.

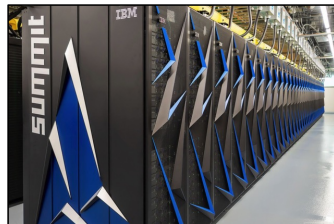GPS clocks are re-synchronised every few hours to eliminate drift.
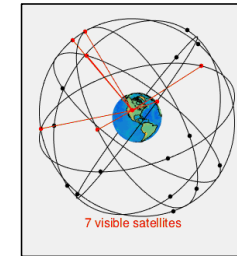
What Can Happen In One Second?

The fastest supercomputer can do
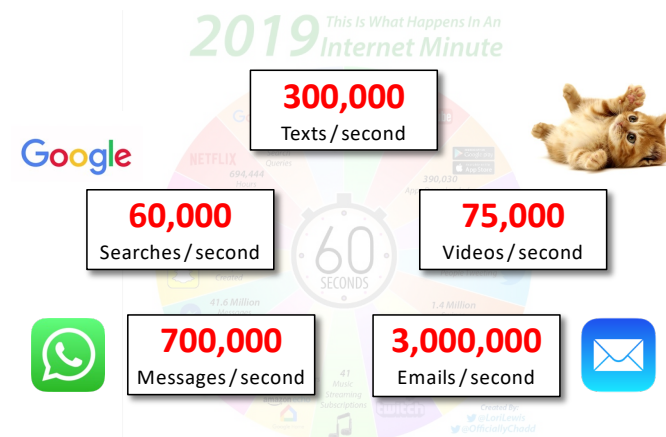
200,000,000,000,000,000

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.

An Internet Second

2019 *This Is What Happens In An Internet Minute*

Google

300,000 Texts / second

60,000 Searches / second

75,000 Videos / second

700,000 Messages / second

3,000,000 Emails / second

The Earth Is Slowing Down

Atomic clocks tell us that the Earth has been slowing down.

In 1956 the Earth made one rotation (relative to the Sun) in 24h 00m 00s = 86400 s.

So a day *was* exactly 24 h.

Two decades later a day was 86400.003 s.
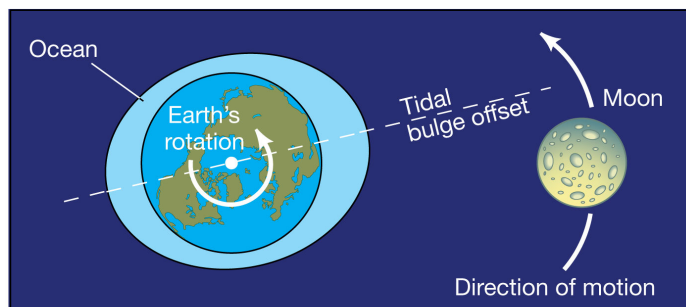
13

Theia Impact

4.5 billion years ago

When the Earth recovered from the shock of the impact of Theia its rotation period was about 5h.

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The Moon's a Drag

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

Ocean

Earth's rotation

Tidal bulge offset

Moon

Direction of motion

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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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Just a Second

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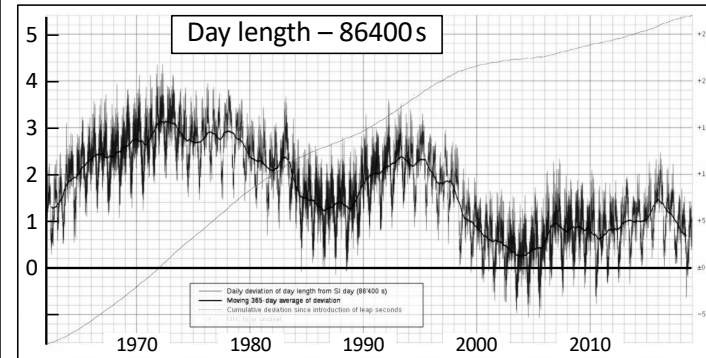
(Actually, we don't **NEED** to. Alternatively, we could keep clocks synchronised with the rotation of the Earth by letting seconds get longer as the Earth slows down.

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.)
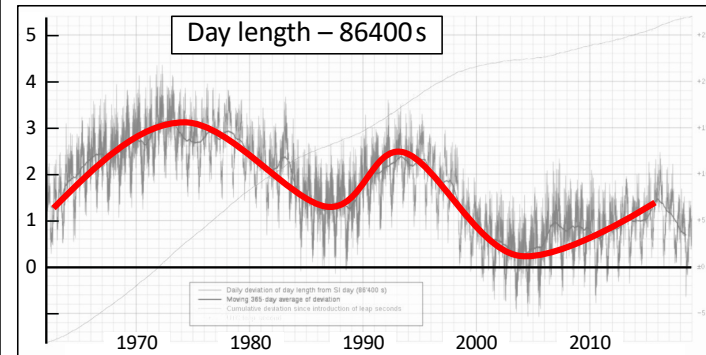
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Length of a Day

milliseconds

Day length – 86400 s

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18

Length of a Day

milliseconds

Day length – 86400 s

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19

Length of a Day

milliseconds

Day length – 86400 s

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Just a Second

Slide 21 — Lemma / Leap Seconds
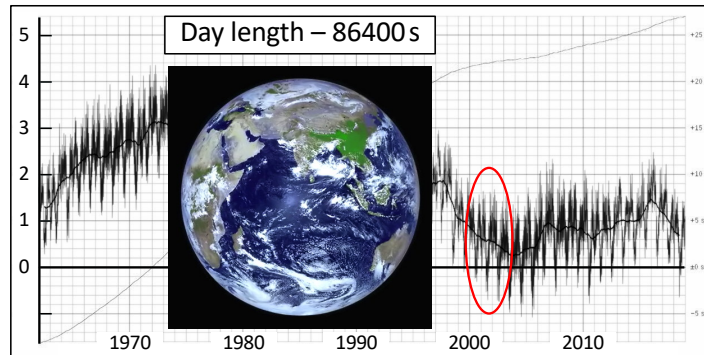
Leap Seconds

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

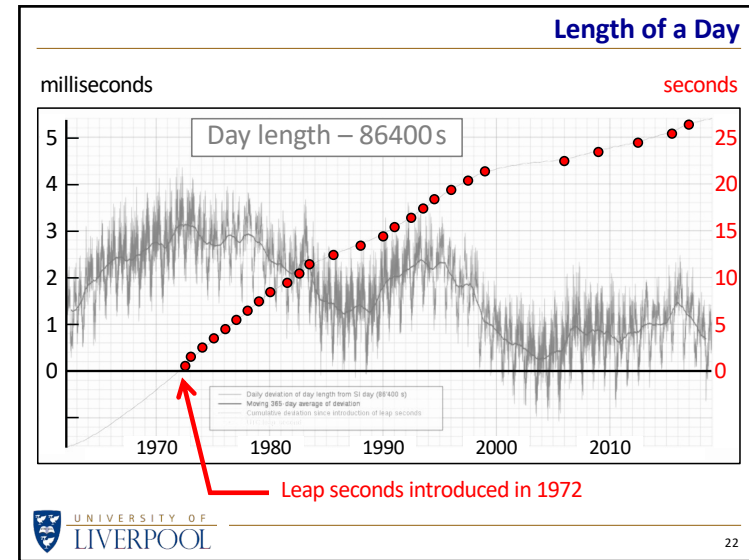What about leap **seconds**?

That is decided by the …

International Earth Rotation Service

How often should a leap second be added?
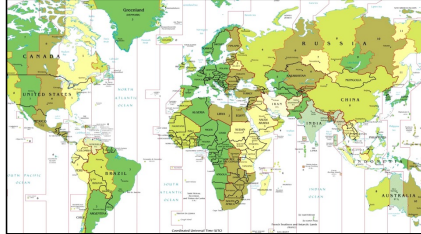
When should leap seconds be inserted into a day?

February
1
2 3 4 5 6 7 8
9 10 11 12 13 14 15
16 17 18 19 20 21 22
23 24 25 26 27 28 29

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Slide 22 — Length of a Day

Length of a Day

milliseconds   seconds

Day length – 86400 s

Daily deviation of day length from SI day (86'400 s)
Moving 365-day average of deviation
Cumulative deviation since introduction of leap seconds

1970   1980   1990   2000   2010

Leap seconds introduced in 1972

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Slide 23 — Leap Seconds

Leap Seconds

23:59:60

23:59:60

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Slide 24 — Leap Seconds

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

WHY DO THE CLOCKS SAY IT'S 3AM?

ADDING AN EXTRA DAY CREATES TOO MANY GLITCHES. INSTEAD, WE'RE JUST RUNNING OUR CLOCKS 3.4% SLOWER DURING FEBRUARY TO AVOID THE IRREGULARITY.

3:02

THIS YEAR, GOOGLE HAS EXPANDED THEIR LEAP SECOND "SMEARING" TO COVER LEAP DAYS AS WELL.

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

The International Tele-communication 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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Latest News

Finally … a decision.

World votes to stop pausing clocks

No more leap seconds after 2035.

For how long should the clocks be allowed to drift?

For a century? … or until the drift adds up to minute? … or an hour?

The ITU might yet veto the decision so … keep an eye on the time.

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Just a Second

www.liverpool.ac.uk/~sdb/Talks

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