INTRODUCING

TIME

A GRAPHIC GUIDE

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What is Time?

The great theologian and philosopher, **St Augustine** (AD 354-430), famously wrote of his puzzlemen in *The Confessions.*

After pointing out all the things he is able to say about time without knowing what it is – for instance that it takes *time* to say this – he admits that he really is in a "sorry state, for I do not even know wha I do not know!".

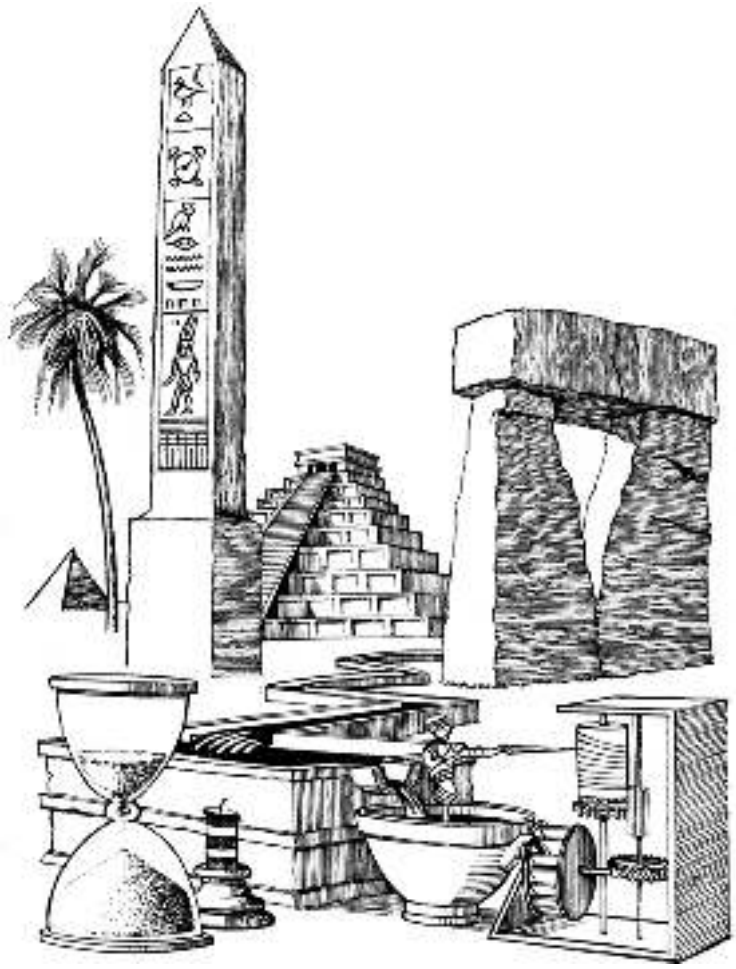
Augustine is not alone in his bewilderment. The question of what time is and related puzzles – such a whether the past and future are real, whether time travel is possible, and the explanation of the direction of time – are among the most intractable yet fascinating questions asked.

All Kinds of Clocks

In everyday life, we are probably most familiar with time from two sources: clocks, and our inner psychological experience of time.

Clocks are everywhere. There are grandfather clocks, watches, alarm clocks, even incense clocks that let you tell the time through scent.

There are also natural clocks.



But clocks existed well before the modern invention of portable artificial ones.

Over four thousand years ago, the Egyptians used obelisk shadow clocks, sundials, and water clocks which measured time by the flow of water passing through a stone vessel.

By 1800 BC, the ancient Babylonians had divided the day into hours, the hour into sixty minutes, and the minute into sixty seconds.

All the great civilizations of the past used the positions of the sun or stars to tell the time.

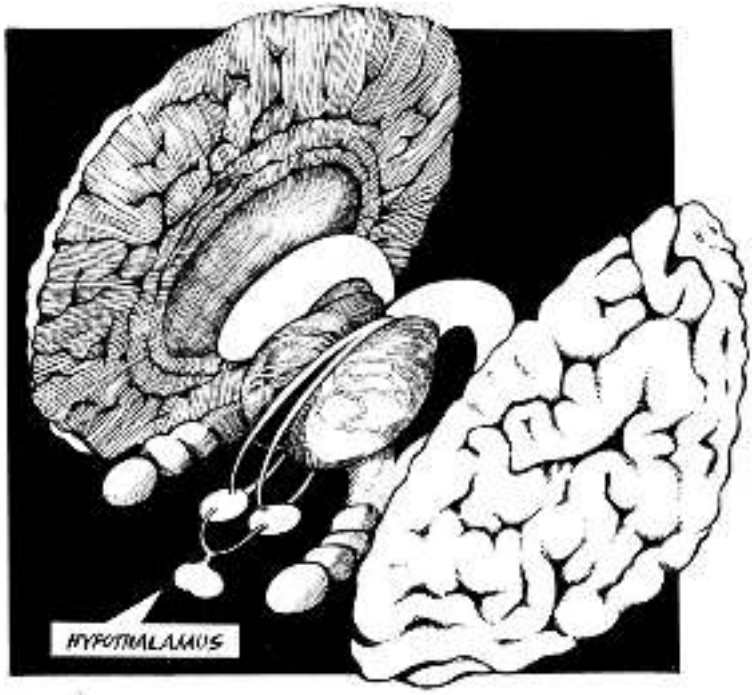
These clocks were very accurate.

Looking at the stars with the naked eye, an ancient astronomer could tell the time to within fifteen minutes. And anyone can tell roughly the time merely by looking up at the sun.

Biological Clocks

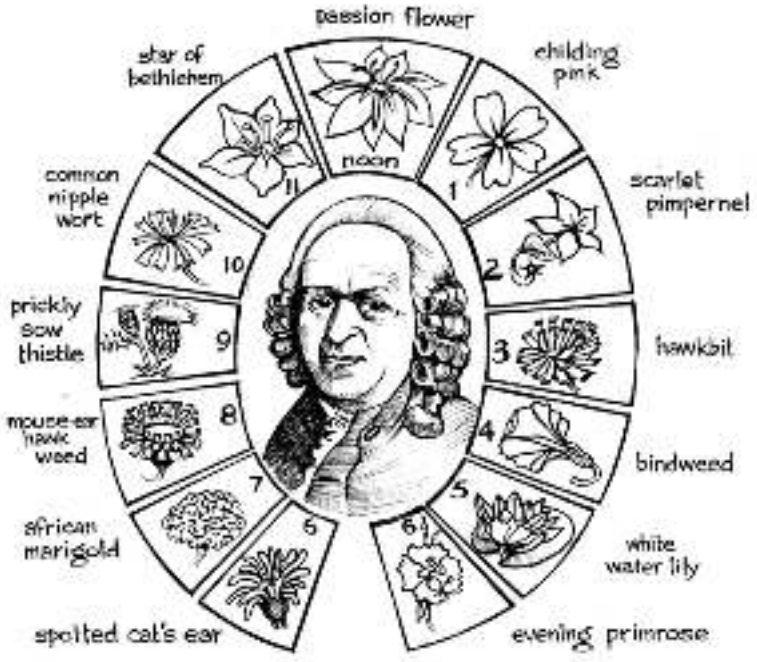
We also carry within us our own biological clocks. The human heart beats 70 times on average each minute. Our moods, alertness, and appetites follow regular patterns, depending on the time of day, th lunar cycle or the season.

Our biological clock seems to be intimately associated with a group of nerve cells in our brain's hypothalamus.



These cells are linked to the retina of our eyes and appear to regulate cycles of hormone secretion, ou skin temperature and cycles of rest and wakefulness. The hormone melatonin is thought to play a significant role in controlling our daily (circadian) rhythm.

Biological clocks are not special to us. Every creature in nature seems to have them. Some are so goo that they have been proposed for human use. The Swedish naturalist **Carl Linnaeus** (1707–78) thought we might use flowers as clocks.



Surprisingly, not every biological clock is based on the day, lunar cycle, season or year. The cicada is a remarkable chirping insect that remains underground for 17 years. Then 17 years after going underground, thousands of them emerge at the same time, climb the trees, mate and then die a few hours later, whereupon the 17-year cycle begins again.

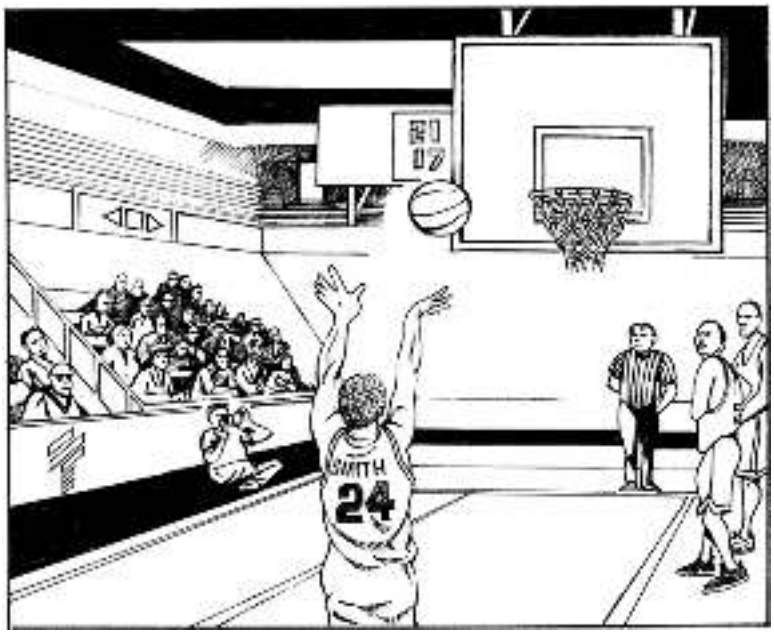
Whether natural or artificial, clocks have helped order the patterns of life for as long as human beings have been around. In modern society, they also can cause a lot of stress.

Psychological Time

We also *feel* time pass. In addition to the physical time measured by various clocks, there is also psychological time. We have memories of the past and anticipations of the future. And we experienc temporal durations of different sizes. We are personally, subjectively aware of time passing.

Everyone can guess roughly how much time has passed between two events.

Some people can do this surprisingly well, as if there were little inner clocks in our heads – related somehow to the biological clocks.



The interesting thing about these inner clocks is that they seem to speed up or slow down for a perso in ways that disagree with other people's inner clocks.

According to a watch, the trip on a super-fast roller coaster might take only 11 seconds.

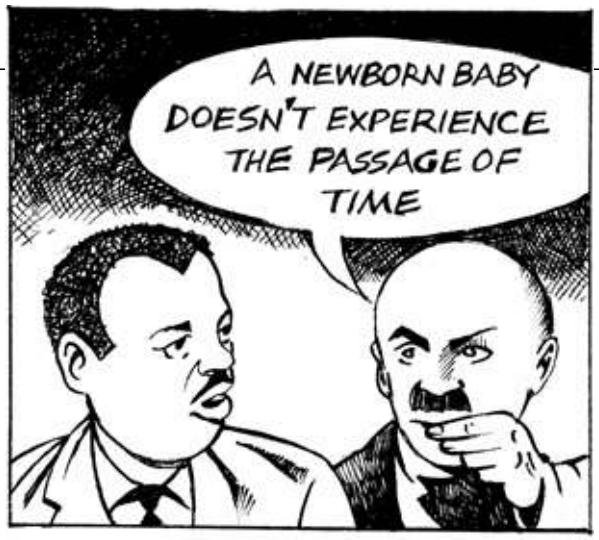
11 seconds might seem an eternity to the person on the ride, whereas it may seem like almost nothing to someone waiting. A game of basketball might seem to pass in no time to the child playing it, but forever for the parent watching his twentieth such game in a month!

To begin our investigation into time, it’s important to see that time is more than merely clocks or the subjective experience of time. Time isn’t simply the alarm clock on your nightstand or something solely in your mind. Once we establish this, curious and deep questions will be right around the corner.

Is Time Merely in the Head?

After calming from his initial panic, Augustine argues that time doesn't really exist outside the head.

The Persian philosopher **Avicenna** (980–1037) agreed with him.



And **Henri Bergson** (1859–1941), the French philosopher, argued for this position too.

Can this be right? Although people disagree about their feelings of how much time has passed, they also enjoy remarkable agreement about the temporal ordering of events.
For example, the father and son returning home from the basketball game might not have looked at a clock since they left for the game – and maybe it was overcast, so they have no sense of where the su is.

Suppose they guess what time it is before actually looking at a clock. Their guesses might disagree b as much as a couple of hours. They might even argue about who is right, but they typically won't argue much about the *ordering* of events that took place.
"We agree that the free throws by Smith in the second half occurred sometime after his free throw in the first half…"

"And Joey broke his finger when Smith stepped on it. "

Except in rare circumstances, everyone (who has the same information available) agrees – for the most part – on the *time order* of events. There is definitely something objective and independent of a particular person's feelings about the time ordering. The objectivity of the ordering of events in time proves that there is more to time than just our psychological sense of its passage. There is the fact tha events seem to be laid out in a unique and observer-independent succession in time.

Clocks and Time

Is this agreement merely agreement about what clocks will say? Maybe all there is to time *is* clocks. This is actually already a deep question. But, at least at first glance, it seems the answer is “no”, for we often talk about a clock being *wrong.* You might say my watch is ten minutes slow or even completely off. This may be your excuse for being late for an appointment. But is your watch an infallible guide to time? No, we know it will “lose” a few seconds per year, even if it’s pretty good.

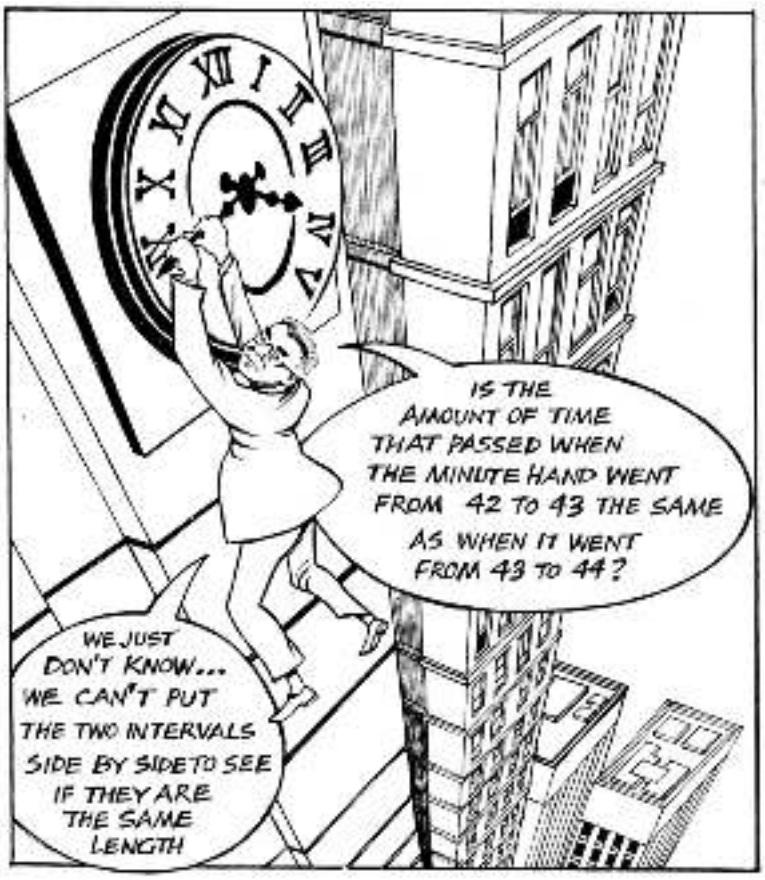
Between each “tick” of the clock, we want the same amount of time to pass. It should be no surprise that pendulums, which have regular periodic motion, can be used as clocks. But pendulums aren’t perfect. On a boat in high seas their motion will be disrupted, or in hot weather they may behave differently than in cold weather.

Consider a pendulum swinging back and forth twice. How do we know that the amount of time that passed on its first trip back and forth is the same as the amount of time that passed on its second trip? This question illustrates what the German philosopher **Hans Reichenbach** (1891–1953) called the “problem of the uniformity of time”.

Firstly, your personal estimations of time won't be precise enough for science. We need to know whether the first trip seemed *exactly* the same as the second trip. Secondly, your feeling as to the amount of time that passed is subjective. You might say the same amount of time went by, but your friend might not think so. Thirdly, and most importantly, you're measuring the time that passed with your thoughts, but these are – plausibly – physical processes, and so this merely pushes our question back a step. That is, we would then ask how you know how long your thoughts *last?*

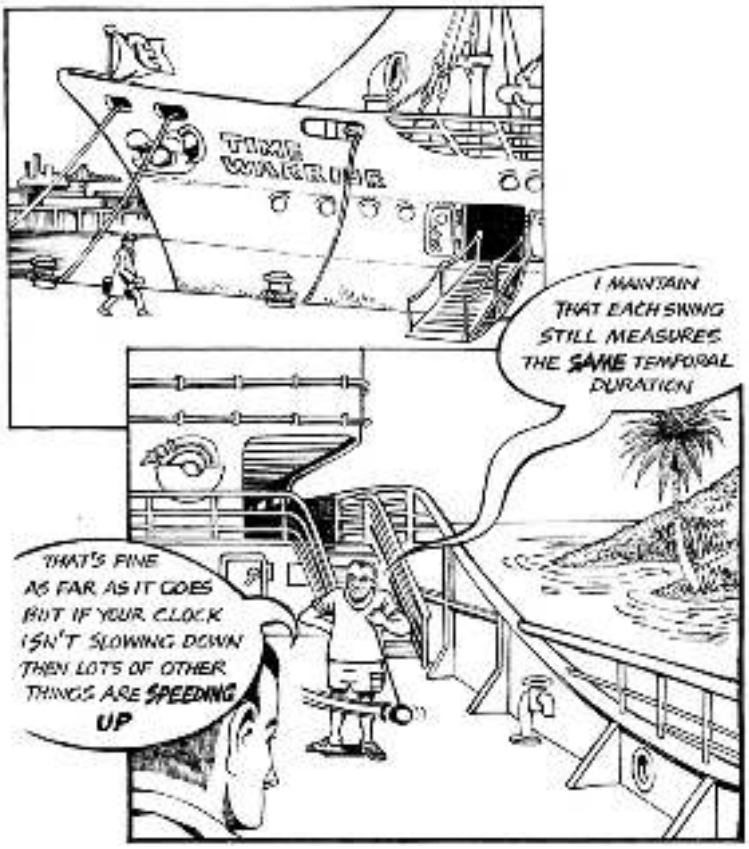
How Long is an Interval of Time?

We can't directly measure durations of time passing. *We never measure pure time.* Is this minute the same length of time as the next minute? In one sense the answer is of course yes: minutes are defined to be the same length of time. But we mean something deeper.



Back to the swings of the pendulum. Despite our inability to directly measure time-lapse, we still think a pendulum can be wrong. Why? Well, suppose some troublemaker wanted to treat his pendulu as an infallible guide to time. What would be wrong with this?

Imagine that he decided to take it to the equator by boat. Even discounting the rocking of the boat, w can expect at least two other factors to affect the pendulum: air at the equator is more humid and provides greater resistance to the pendulum, and the gravitational field that attracts the pendulum is slightly weaker at the equator. By our standards, the pendulum *slows down.*

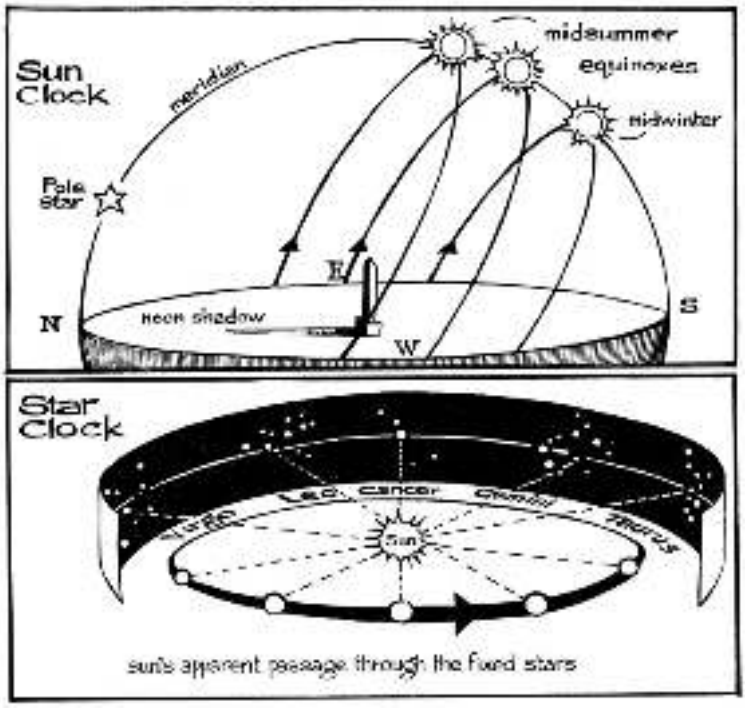


He is going to have to say his boat is moving faster than before, even though (let's assume) it has the same-strength wind on its sails, same-strength current, etc. He must explain why all the clocks in the world are magically starting to speed up; why the speed of the sun has altered. Since he can't provide an explanation for these changes, and yet we can, it seems we're right and he's wrong. Our hypothesis that time can be given by the motion of the stars, for example, is a scientifically better claim than his pendulum hypothesis.

The Most Reliable Clocks

Let's first pause to note that three clocks have proved to be very good. Historically the sun and the night sky have been most important.

The sun defines regular "ticks" of a clock, if we think of it as ticking each time it crosses the meridia The stars in the night sky define "ticks" through a chosen star's passing through due south. Both clocks are better than my wristwatch.



I can explain a discrepancy between the two by appealing to low batteries in my watch, whereas I cannot blame the discrepancy on the sun or stars slowing down or speeding up. Though these two clocks are amazingly accurate (the night sky being better than the sun), there are better still.

The Atomic Clock

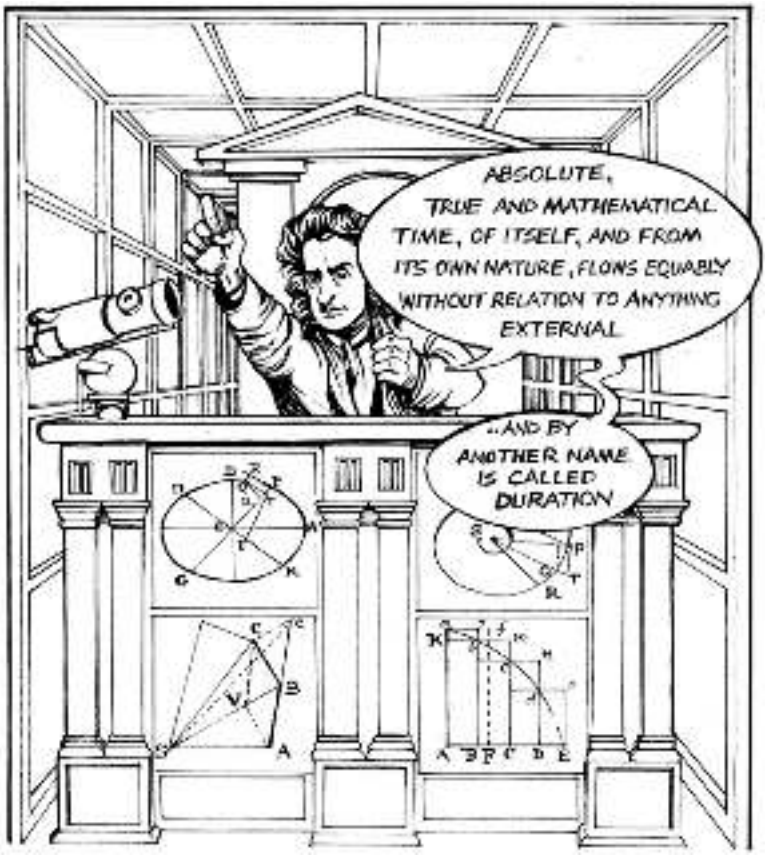
The development of particle physics in the 20th century, and in particular ideas by the American physicist **Isidor Rabi** (1898–1988), gave us the atomic clock in 1949. All atoms have a so-called natural resonance frequency, and this extremely regular oscillation can be used to define the “ticks” o a clock. Atomic clocks have proved more regular than solar or astronomical clocks. In 1999, the National Institute of Standards and Technology in Boulder, Colorado (US) started using an atomic clock known as the NIST F-1 to define the second.

A second is defined precisely to be 9,192,631,770 vibrations of the cesium atom! The NIST F-1 (with a similar clock in Paris) is the most accurate clock in the world today. With a pool of atomic clocks around the globe, it is used to help define Coordinated Universal Time, which in turn helps define the speed of light, the length of the standard metre, and so on. But even this incredibly accurate clock wi “lose” nearly a full second every 20 million years. Nothing is perfect!

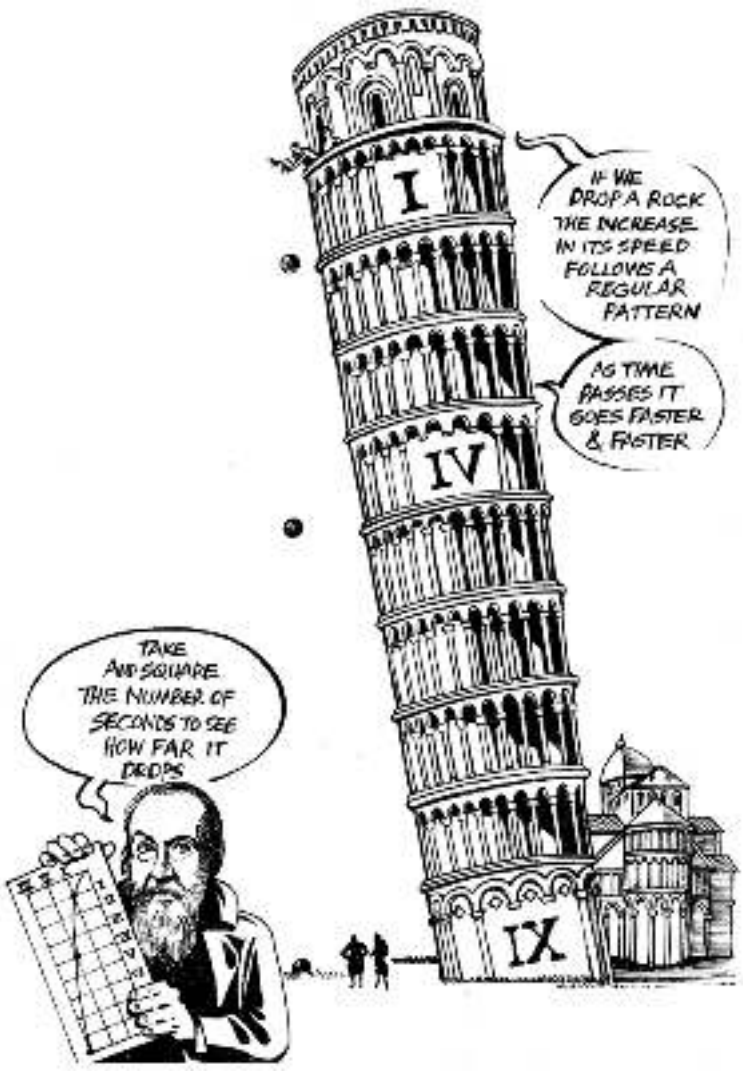
Absolute, True and Mathematical Time

If the NIST F-1 is the best physical clock that we know in the universe, how do scientists know it wil lose time, even only 1 second every 20 million years?

The answer is that the laws of physics tell them so. This is a deep point, made best by none other tha **Sir Isaac Newton** (1642–1727) – the father of classical mechanics and perhaps the greatest physicist of all time. Time, Newton says, should not be confused with its sensible measure. By "sensible measure", Newton means the actual clocks we happen to use.



Real time, according to Newton, does not depend on any particular clock, or even any particular material object in the universe. Time is independent of the contents of the universe.



It is this time that is used in the unchanging laws of physics. The laws of physics tell things *where* to be and *when to* be there. In telling them when to be where, Nature assumes a particular time measure

For example, classical physics says that the acceleration of a freely falling body is constant.