Measurement of Time

Peter Watson

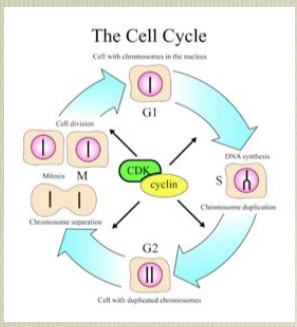
Town clock in Mantua

When did time start to matter?

Work, eat, play, mate

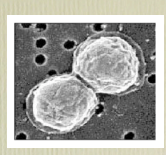
- Sleep, play, mate

- Many biological processes require a coordinated sequence of events These events are repeated with a well defined period



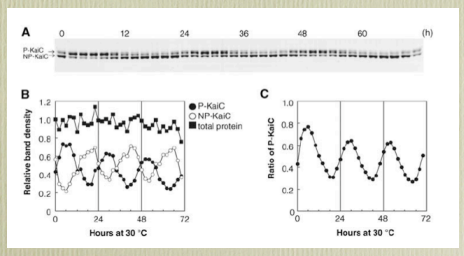
Text

Biological Clocks



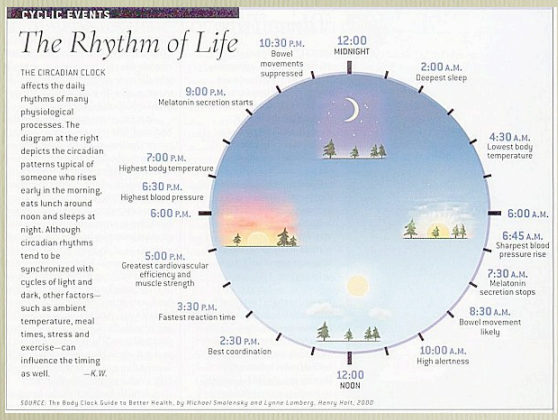
Circadian rhythms are controlled by biochemical networks

- Even bacteria need to keep time: e.g CyanoBacteria
- Eldon Emberley, SFU, finds 3 proteins give an oscillatory system with 24 hour period



Text

Humans



Text

- Natural cycle ~ 24 hours 11 minutes (average) but wide variations.
- Gets reset ("phase-locked") by light
- Mostly in hypothalamus: suprachiasmatic nucleus, but requires most of endocrine system to work
- Universal in mammals: mechanism can vary, and disappear in arctic animals

- As to moral courage, I have very rarely met with the two o'clock in the morning kind. I mean unprepared courage, that which is necessary on an unexpected occasion. (Napoleon)

Text

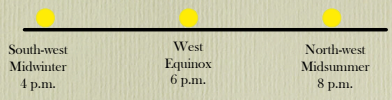
The first human time-keeper (or the earliest we know about)

- Midsummer day: when the sun rises/sets in most northerly position.

Measured at Stonehenge: important to define seasons and hence time to plant crops
Probably 2300 BC ± 100 years

Text

Sunset

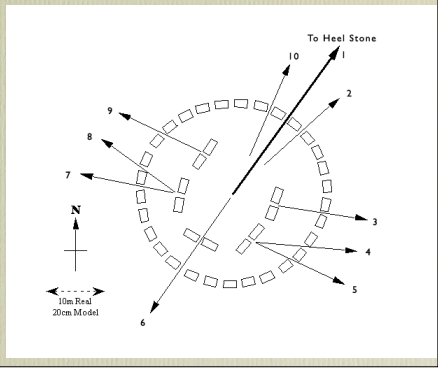


- Note that position varies more as you move away from the equator

Text

- Alignments let you measure summer solstice

1. Midsummer sunrise
2. Winter moonrise low point
3. Midwinter Sunrise
4. Southern moonrise (minimum)
5. Southern moonrise (maximum)
6. Midwinter sunset
7. Northern moonset (minimum)
8. Northern moonset (maximum)
9. Winter moonrise high point



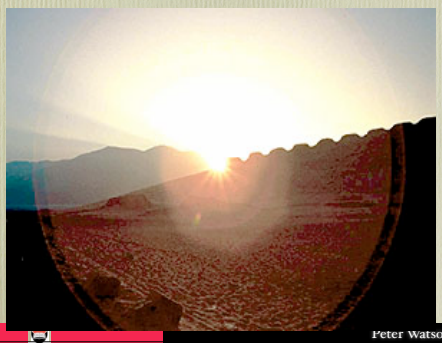
http://www.fas.harvard.edu/~scidemos/AstronomyAstrophysics/Stonehenge/Stonehenge.html

Chankillo

- Much later
- Row of 13 towers on a ridge in a desert in Peru

Peter Watson

- From observation sites the towers line up with sunrise and sunset
- Can tell date to within 2-3 days. (Ivan Ghezzi and Clive Ruggles)



Peter Watson

For everything there is a season
And a time for every purpose under heaven:
A time to be born, and a time to die;
A time to plant, and a time to reap;
A time to kill, and a time to heal;
A time to break down, and a time to build up;
A time to weep, and a time to laugh;
A time to mourn, and a time to dance;
A time to throw away stones, and a time to gather stones together;
A time to embrace, and a time to refrain from embracing;
A time to seek, and a time to lose;
A time to keep, and a time to throw away;
A time to tear, and a time to sew;
A time to keep silence, and a time to speak;
A time to love, and a time to hate,
A time for war, and a time for peace.
Ecclesiastes 3:1-8

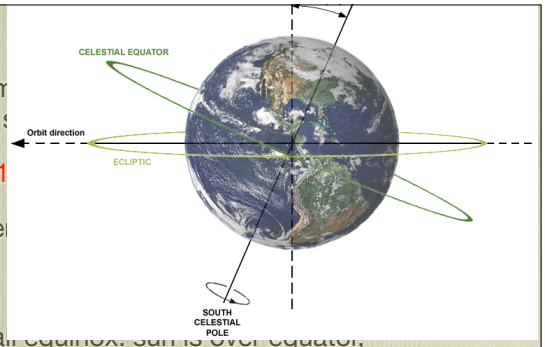
Text

Need some definitions (roughly as the Babylonians might have used them)

- Year: interval between (e.g) most northerly sunrises. ~365 1/4 days
- (lunar) Month: interval between (e.g.) full moons ~ 29 1/2 days
- Solar day: interval between times when the sun is due south = 24 hours (defn)
- Sidereal day: interval between (e.g.) Sirius being due south = solar day - 4 minutes

Peter Watson

- Midsumm
  day, sun
- 20th or 21
- Midwinte
- 21st/22nd
- Spring/fa
  night & day are equal (roughly)
- 20th/21st March 22nd/23rd Sept



But note

- Year is not a whole # ofdays
- Year is not a whole # of lunar months
- However 19 years = 235 lunar months (+ 2 hours): Metonic cycle
- Most societies fudge 12 months = 1 year by adding in extra days.

Babylonian

- 12 lunar months + extra short month


MS 4151
List of month names for the Lagash (Larsa?) calendar, including the extra 13th month.
Babylonia, 2000-1600 BC

e.g Chinese

- Months are alternately 29 & 30 days
- Gives year of 354 1/3 days
- Add in intercalary month every second or third year to re-align year and month
- Sun also passes through 12 zodiacal constellations in year (Aries, Pisces, Aquarius ...) or roughly 1/month

1. The months are lunar months. This means the first day of each month beginning at *midnight* is the day of the astronomical dark moon.
2. Each year has 12 regular months, which are numbered in sequence (1 to 12) and have alternative names. Every second or third year has an intercalary month which may come after any regular month. It has the same number as the preceding regular month, but is designated intercalary.
3. Every other jiéqì of the Chinese solar year is equivalent to an entry of the sun into a sign of the tropical zodiac (a principal term or cusp).
4. The sun always passes the winter solstice (enters Capricorn) during month 11.
5. If there are 12 months between two successive occurrences of month 11, not counting either month 11, at least one of these 12 months must be a month during which the sun remains within the same zodiac sign throughout (no principal term or cusp occurs within it). If only one such month occurs, it is designated intercalary, but if two such months occur, only the first is designated intercalary. Note that for calendars before true motions of the sun were used for naming (i.e., before 1645), or in years where there is no double-cusp month in that year or the previous or following years (i.e., usually), the following rule suffices: a month with no principal term (or cusp) in it is designated intercalary.

Are you confused?

e.g Hebrew calendar

- Lunar months
- Intercalary month added 7 times in 19 years
- gives 6939.550 days
- vs 6939.750 days

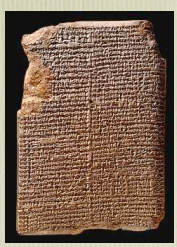
e.g Roman calendar

- Romulus: 10 months of 30 or 31 days + 61 days of winter
- Numa: 12 months of 28-31 days, totalling 355, so add 22 or 23 days to Feb. every 2nd year
- Julius Ceasar: essentially modern calendar with leap years adding one day to Feb every 4 years

Babylon: Mul Apin tablet

http://www.mesopotamia.co.uk/astronomer/explore/exp_set.html

On the 1st of Nisannu the Hired Man becomes visible.
- On the 20th of Nisannu the Crook becomes visible.
- On the 1st of Ayyaru the Stars become visible.
- On the 20th of Ayyaru the Jaw of the Bull becomes visible.
- On the 10th of Simanu the True Shepherd of Anu and the Great Twins become visible.
- On the 5th of Du'uzu the Little Twins and the Crab become visible.
- On the 15th of Du'uzu the Arrow, the Snake, and the Lion become visble; 4 minas is a daytime watch, 2 minas is a nighttime watch.
- On the 5th of Abu the Bow and the King become visible.
- On the 1st of Ululu [. . . .]
- On the 10th of Ululu the star of Eridu and the Raven become visible.
- On the 15th of Ululu Shu-pa, Enlil, becomes visible.
- On the 25th of Ululu the Furrow becomes visible



Text

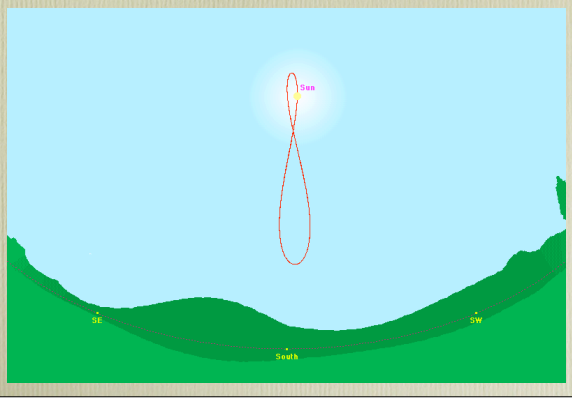
Sundials

- Good to few minutes but
- ...Position of the noon sun in the sky varies throughout the year:

- It moves against the fixed stars because
- the earth orbits the sun
- the earths axis is tilted

Text

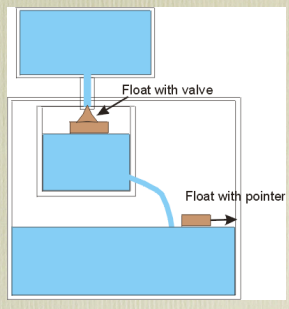
- it also moves in the sky at a given time of day: (i.e. the time of noon varies by about 8 minutes) because the earth moves at varying speeds in its orbit,
- so we actually need a **better** clock than the sun to measure this



Text

Water-clock (probably first non-astro clock)

- www.mlahanas.de/ Greeks/Clocks.htm
- Water in a container drains out through small hole: problem is that the flow is non-uniform.
- Hence keep container full with valve so as to have constant pressure
- clepsydra (= "water thief")



Text

E

Tablet with a list of eclipses between 518 BC and 465 BC, mentioning the death of king Xerxes.

British Museum, London

Why do these matter?

CALPURNIA: When beggars die, there are no comets seen;

The heavens themselves blaze forth the death of princes. *Julius Caesar*

(Chinese astronomers Hi and Ho executed for failing to predict eclipse in 2134 BC).

Text

GLOUCESTER These late eclipses in the sun and moon portend no good to us: though the wisdom of nature can reason it thus and thus, yet nature finds itself scourged by the sequent effects.....

.....

EDMUND I am thinking, brother, of a prediction I read this other day, what should follow these eclipses.

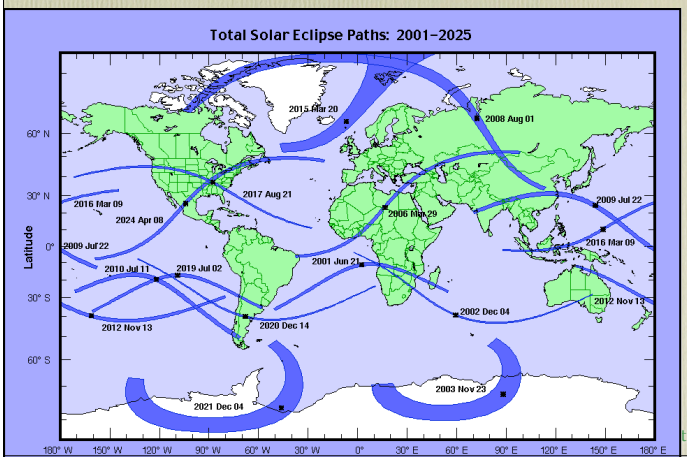
EDGAR Do you busy yourself about that?

EDMUND I promise you, the effects he writes of succeed unhappily; as of unnaturalness between the child and the parent; death, dearth, dissolutions of ancient amities; divisions in state, menaces and maledictions against king and nobles; needless diffidences, banishment of friends, dissipation of cohorts, nuptial breaches, and I know not what.

EDGAR How long have you been a sectary astronomical?

Text

Eclipse preediction



Saros cycle

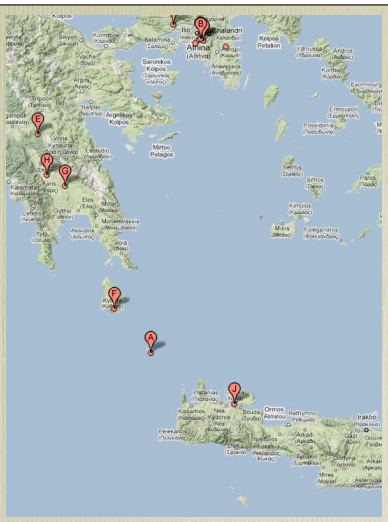
- Eclipses repeat after 18 years and 11.3 days.
- The .3 days shifts the eclipse about 110º degrees west.
- Also some saros sequences start at the south and drift North, others at the North and drift South.
- This means that the cycle is very complex: can only see it after many years.
- Why is it so complicated? Need to combine
  I.Earths rotation
  II.Moons orbit (not quite circular)
  III.Earth's orbit (ditto)
  IV.and the plane of the moons orbit precesses

Text

Eclipse of 1999 seen from Mir

Text

Antikythera



- Wreck full of sculptures

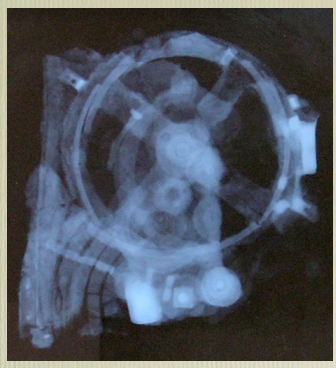
Peter Watson

Antikythera Mechanism

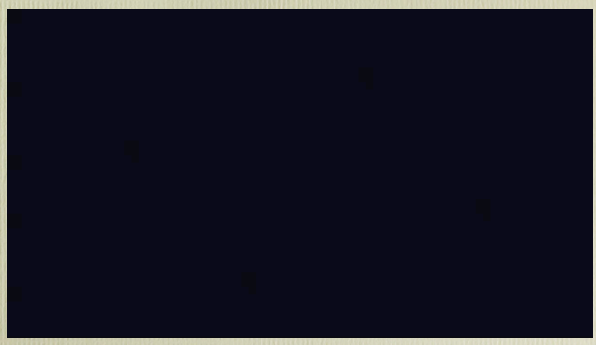
- Found in 1901
- probably late second century BC.
- National Archaeological Museum in Athens: wikipedia

Peter Watson

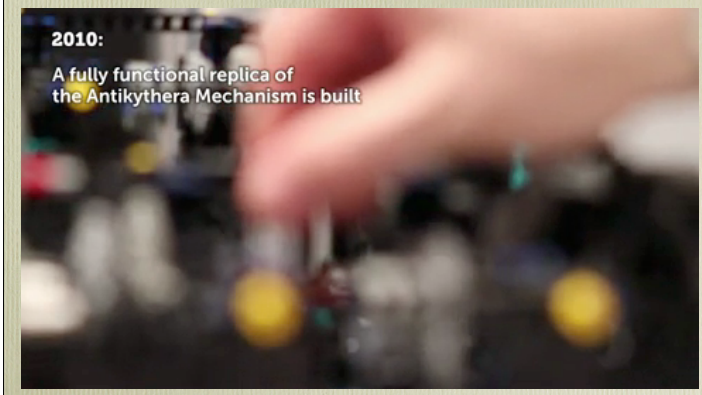
- X-rays show very complex structure
- Many (at least 30) gears: one has 47 teeth !!!!



This may be how it works

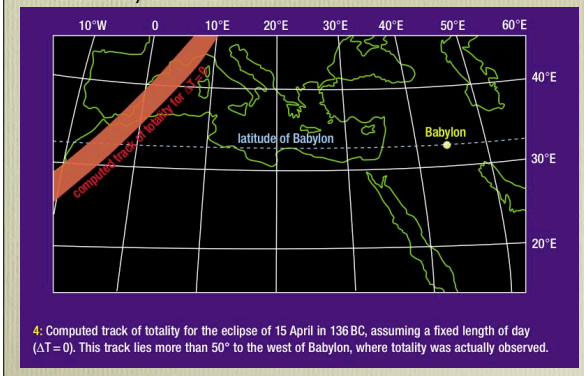


- Shows Metonic sequence (235 lunar months = 19 solar years + 2 hours)
- Shows Saros eclipse cycle (223 lunar months)
- But not programmable
- No driving mechanism



Observed total Eclipse 15 April 136 BC.

- and they would even have seen it from the moon !
- But they shouldn't have!



4: Computed track of totality for the eclipse of 15 April in 136 BC, assuming a fixed length of day ($\Delta T = 0$). This track lies more than 50° to the west of Babylon, where totality was actually observed.

- Earth's rotation has slowed down, by 1/100 sec/century, because of tidal effects! i.e. earth isn't a very good time-keeper

Text

Pendulum Clock

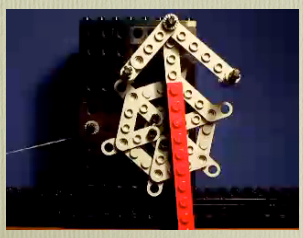
- Invented by Huyghens (1656)
- Look at the Foucault pendulum in the entrance to Herzberg building: Watch the animation.
- Period:

$$P = 2\pi\sqrt{\frac{L}{g}}$$

Need three Ingredients

Pendulum

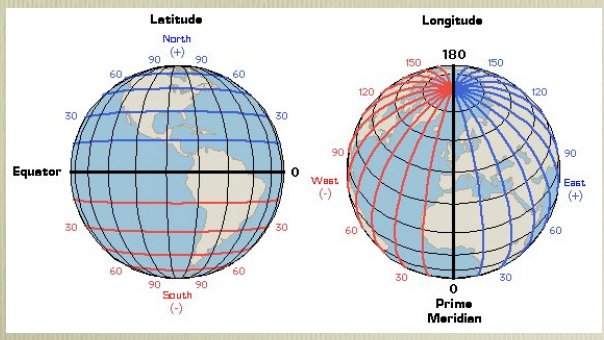
Power supply: usually gravity)



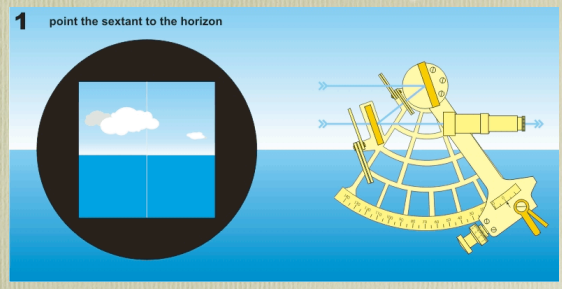
Escapement: must transfer energy to pendulum to keep it swinging

Chronometer

At sea, need to determine latitude and longitude: see Longitude (Dava Sobel)



Latitude is "easy"



- Need to be able to measure south (compass)
- and postion of sun (or star) wrt horizon
- astrolabe or sextant

Longitude problem: error on longitude typically 100 km (!) in 18th century.

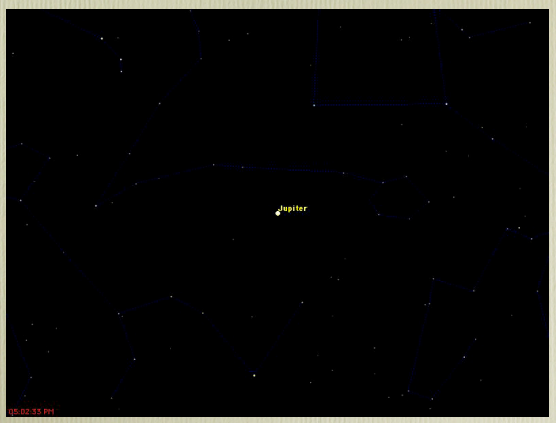
Admiralty offered £20,000 ($10,000,000 today) to solve problem

If we know when the sun is a certain point in sky, can get longitude

(e.g. if it's due south at 2 pm, we are 2/24*360 = 30° W of Greenwich)

So by measuring time accurately, can get position (first link between time and space!)

- Could use Moons of Jupiter: act as astronomical timekeeper



Chronometer

Longitude problem: error on longitude typically 100 km (!) in 18th century. Admiralty offered £20,000 ($10,000,000 today) to solve problem

- Need to determine time to better than 1 s/day

He made five chronometers

- .....

Note that this depends on mechanical escapement mechanism

Photo Suat mEan FreeDigitalPhotos.net

A doctor's watch c 1815

Any sufficiently advanced technology is indistinguishable from magic (Arthur Clarke)

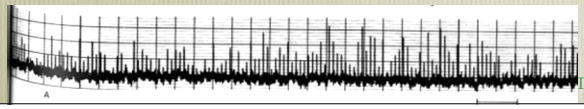
My watch (c 2009)

What's the difference?

- **Power Source:** Coiled spring
- Mercury Battery
- **Time:** escapement mechanism
- Quartz crystal
- **Displays:** second hand + date wheel
- LCD
- **Setting:** listen to the church clock!
- Reset once a day by transmitter in Colorado Springs

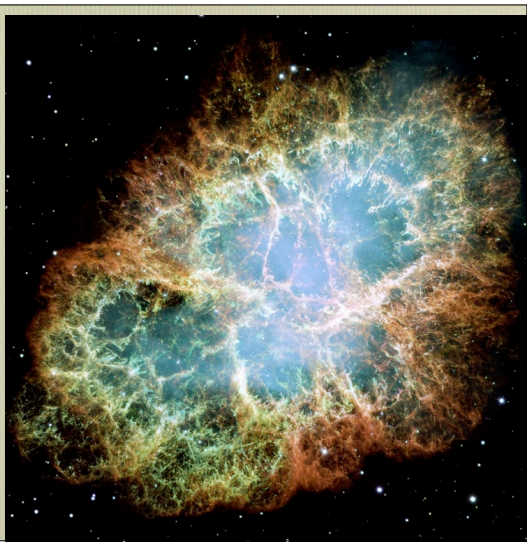
Pulsars (1968)

- neither earth's orbit or rotation are sufficiently stable now: best astronomical timekeeper are pulsars, accidentally observed as pulsars (Jocelyn Bell etc)
- Very regular radio pulses,period of 4 s to 2 ms
- Note that height of pulse is very irregular



Text

Best known is Crab. Known to be remnant from supernova in 1054 (seen by Chinese) Pulsar at centre has period of ~0.03s



And you can even listen to them

- This is Vela
- And this is PSR 0329+54

Text

Frequency and Period

Note for what follows:

•for repeated motions (e.g. Oscillators), Time and frequency are closely linked

•Frequency = 1/Period

•So something that vibrates with a period of 0.5 s has a frequency of 2 Hertz (2 Hz)

$$F = \frac{1}{P}$$

Text

Units

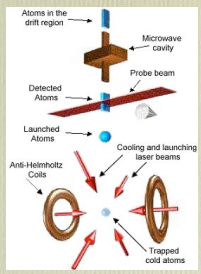
Unit	Abbreviation	Defined by
1 metre	1 m	1/40,000,000 th of circumference of the earth
1 second	1 s	1/84,600 th of mean solar day
1 kilogram	1 kg	Mass of lump of platinum in Paris

- But..... This leads to more problems: circumference of earth differs at various places,....rotation speed of earth varies...
- Need **reproducible unit**, so any lab can measure it
- Define time via the oscillations of a caesium atom
- 1 s = 9,192,631,770 f
- Distance used to be via wavelength of red line from Kr^{86} light (1 m = 1,650,763.73 l)
- but now speed of light (c) is much better measured, so
- 1 m = distance travelled by light in 1/299,792,458 s

Text

Atomic Clocks

- Best is now at NRC: Caesium fountain clock better to 1 part in 10^{12} i.e. would lose or gain ~ hour over lifetime of universe: so accurate that the only comparison is one Cs clock to another!
- Works because atoms are isolated from each other, so don' influence each other
- Target is 1 part in 10^{15}: one minute in lifetime of universe

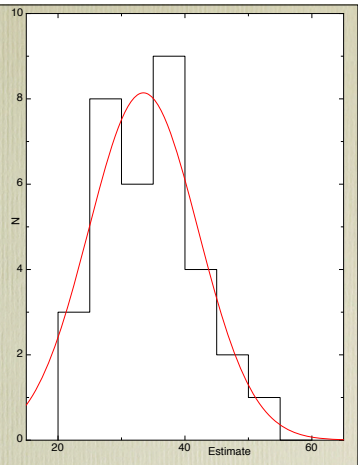


Text

Subdivisions of time: Direct perception

- Roughly 1/10s = 100 ms, but depends very much on the stimulus
- Roughly: error in timing depends on length of interval
- Lets try it: close your eyes
- estimate when 30s has passed
- open them and write down the value showing

- Results:
- Average = 33.5 s
- Spread (standard deviation) = 8.6



Perception of Time

- We are not very good …
- e.g Shakespear, As You Like It

ROSALIND I pray you, what is't o'clock?

ORLANDO You should ask me what time o' day: there's no clock in the forest.

ROSALIND Then there is no true lover in the forest; else sighing every minute and groaning every hour would detect the lazy foot of Time as well as a clock.

ORLANDO And why not the swift foot of Time? had not that been as proper?

ROSALIND By no means, sir: Time travels in divers paces with divers persons. I'll tell you who Time ambles withal, who Time trots withal, who Time gallops withal and who he stands still withal.

Text

ORLANDO I prithee, who doth he trot withal?

ROSALIND Marry, he trots hard with a young maid between the contract of her marriage and the day it is solemnized: if the interim be but a se'nnight,Time's pace is so hard that it seems the length of seven year.

ORLANDO Who ambles Time withal?

ROSALIND With a priest that lacks Latin and a rich man that hath not the gout, for the one sleeps easily because he cannot study, and the other lives merrily because he feels no pain, the one lacking the burden of lean and wasteful learning, the other knowing no burden of heavy tedious penury; these Time ambles withal.

ORLANDO Who doth he gallop withal?

ROSALIND With a thief to the gallows, for though he go as softly as foot can fall, he thinks himself too soon there.

ORLANDO Who stays it still withal?

ROSALIND With lawyers in the vacation, for they sleep between term and term and then they perceive not how Time moves.

Subdivisions of time: Direct perception

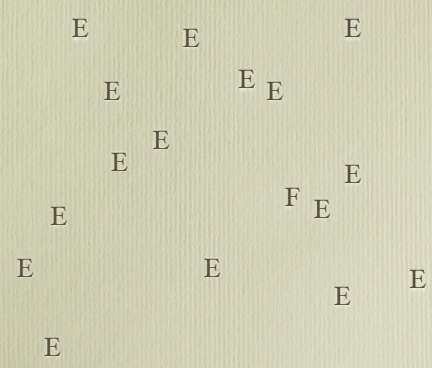
- Roughly 1/10s = 100 ms, but depends very much on the stimulus
- E.g. Some slides stolen from Marcus Watson

Text

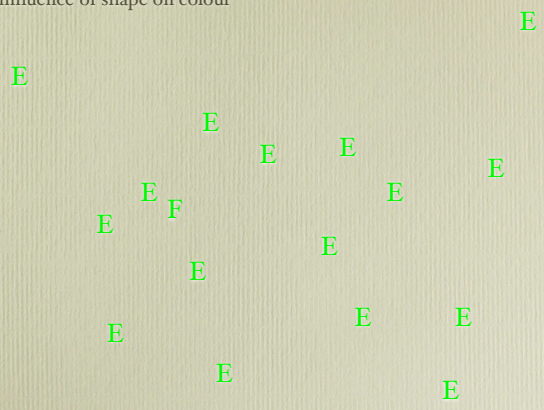
The influence of shape on colour

Find the “F”

The influence of shape on colour



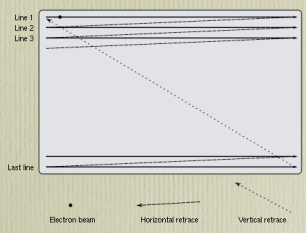
The influence of shape on colour



The influence of shape on colour

Limits:

- Eyes can't respond in much less than 1/20 s (= 50ms)
- Which is why we can watch TV
-

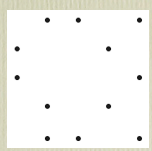


Text

Picture as seen

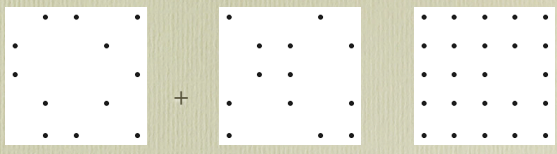
- But shoot it too fast

Brain will actually superimpose pictures if time is very short

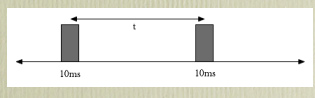


Text

Analyzing



If the gap t < 100 ms, see one image and can pick out missing spot
If the gap t > 100 ms, see two images, cannot pick out missing spot



Text

Indirect perception via sounds

- We can hear notes in octaves: each octave is a doubling of frequency
- C Db D Eb E F Gb G Ab A Bb B

C	8.2	16.4	32.7	65.4	130.8	261.6	523.3	1046.5	2093.0	4186.0	8372.0	
Db	8.7	17.3	34.6	69.3	138.6	277.2	554.4	1108.7	2217.5	4434.9	8869.8	
D	9.2	18.4	36.7	73.4	146.8	293.7	587.3	1174.7	2349.3	4698.6	9397.3	
Eb	9.7	19.4	38.9	77.8	155.6	311.1	622.3	1244.5	2489.0	4978.0	9956.1	
E	10.3	20.6	41.2	82.4	164.8	329.6	659.3	1318.5	2637.0	5274.0	10548.1	
F	10.9	21.8	43.7	87.3	174.6	349.2	698.5	1396.9	2793.8	5587.7	11175.3	
Gb	11.6	23.1	46.2	92.5	185.0	370.0	740.0	1480.0	2960.0	5919.9	11839.8	
G	12.2	24.5	49.0	98.0	196.0	392.0	784.0	1568.0	3136.0	6271.9	12543.9	
Ab	13.0	26.0	51.9	103.8	207.7	415.3	830.6	1661.2	3322.4	6644.9	13289.8	
A	13.8	27.5	55.0	110.0	220.0	440.0	880.0	1760.0	3520.0	7040.0	14080.0	
Bb	14.6	29.1	58.3	116.5	233.1	466.2	932.3	1864.7	3729.3	7458.6	14917.2	
B	15.4	30.9	61.7	123.5	246.9	493.9	987.8	1975.5	3951.1	7902.1	15804.3	

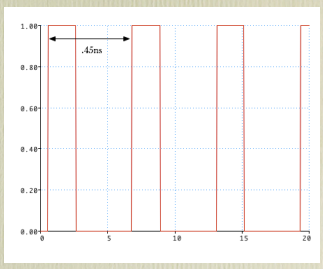
Text

- Roughly 20 Hz to 20 kHz
- O.K. 10 kHz for us!
- I.e. 50 ms down to 0.05 ms=50μs
- (why have we bothered to evolve this?)

Text

Electronics Directly

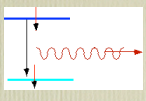
- Clock circuit in computer
- 2.8 GHz in this Mac:
- i.e. ~.35 nanoseconds (ns)



Text

Atomic transitions

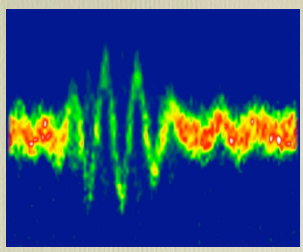
- E.g the laser pointer
- Atom makes transition from one level to another, emitting photon
- Typical time ~ 1 picosecond (ps)=10^{-12} s = 1/trillionth second=0.0000000000001s



Text

Pulsed lasers

- Paul Corkum at NRC/ Ottawa U developed techniques for cutting laser beams in few atto-second lengths:
- 1 attosecond (as)=10^{-18} s =0.000000000000000001s
- Allows still pictures of atoms



Text

Particle Physics

- Reactions occur roughly at speed of light over the size of a proton
- Typical time ~ 10^{-24} s = 1/trillion-trillionth second =0.000000000000000000000001s
- 1 yoctosecond, except no-one ever calls it that

Text

Planck time

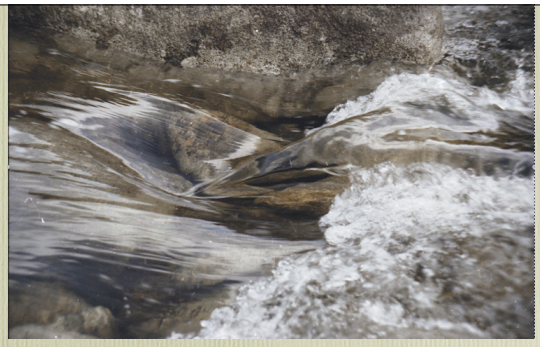
- *If* we believe in superstring theory, they oscillate with a period
- $$t_p = \left(\frac{G\hbar}{c^5}\right)^{1/2} = 5.4 \times 10^{-44}\, s$$
- 0. 00000 00000 00000 00000 00000 00000 00000 00000 00000 00005s
- Shortest time scale that makes any sense in physics

Text

But wait a moment

- Can we really go on subdividing time?
- Is it really continuous or a succession of moments?
- Like a water-wave?

Text

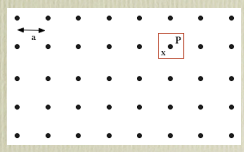


- Magnify by 1000: OK
- Magnify by 1000000: OK
- Magnify by 1000000000: start seeing molecules

Text

Is time continuous?

- Is space?
- Suppose space is discrete at some scale a: say 1 attometre (1/1000 size of a proton)
- Then sizes smaller than this have no meaning

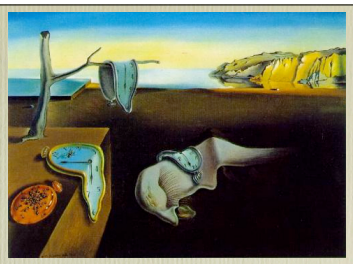


Text

- How Dali changed "the Persistence of Memory

into

- "The Disintegration of the Persistence of Memory"



Is time continuous?

- Hence time scales shorter then $a/c \sim 10^{-27}$ s have no meaning
- Which is roughly the kind of limit we have now
- If space or time is quantized in some way, the reality is probably much more complicated

Text

Is time continuous?

- Hence time scales shorter then a/c ~ 10^{-27} s have no meaning
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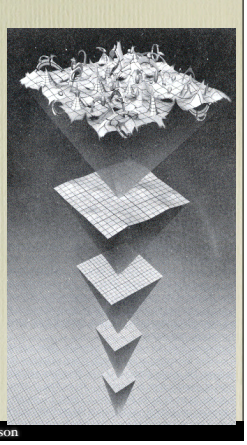

How about large time intervals?

- Much less interesting
- Human lifetime ~ 2×10^9s = 2 Gigasecond = 2Gs ~88 years
- Lifetime of the universe ~ 5×10^{17}s = 0.5 exasecond = .5 Es ~14 billion years
- SO we can measure time to fantastic accuracy: can we even understand why there is a past and a future?