Origins of Data, Computing Lines, Curves, and Numbers

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Outline

- Measuring the Solar System
  - Stonehenge / Sun Dial
- Continuous physical analog computing
  - Ankithera / Planet Mobile / Slide Rule / Pilot E6B
- Digital physical devices
  - Pen / Clocks / Adders / Multipliers
- CRC Standard Mathematical Tables
  - More complex mathematical functions without calculator
- Iteration
  - "Human Computers" / Babbage Difference Engine
- Electromechanical Computers
  - Bombe / Pinball Machine
- Electronic Computers – Tubes
  - Colossus

Computing and Mathematics

- This is not a math class and there is no math pre-requisite
- In my C class I talk about how everything changed in 1978 (roughly)
- Before 1978
  - Much of computing was computations – numbers were the focus
  - No Internet
  - Computers were large – filled a room
- After 1978
  - Much of computing is information
  - Internet - people communicating to other people through text
  - Computers kept getting smaller and faster
- The arc of computers and computing starts with numbers

Our eyes "see" objects in a straight line from our eye to the object. But in nature, any moving object is moving along a curve. Predicting the path of a moving object requires a lot of measuring, analysis, and mathematics. Our brains understand (or have been programmed to understand) curved motion implicitly. Predicting the path of a moving object in three dimensions is necessary for us to survive (or play sports)

Astronomy – Star Gazing

- Amateur scientists from the beginning of human consciousness have gazed at the Sun, Moon, Planets, and Stars and tried to gain insight

December → March → June

December ← September ← June

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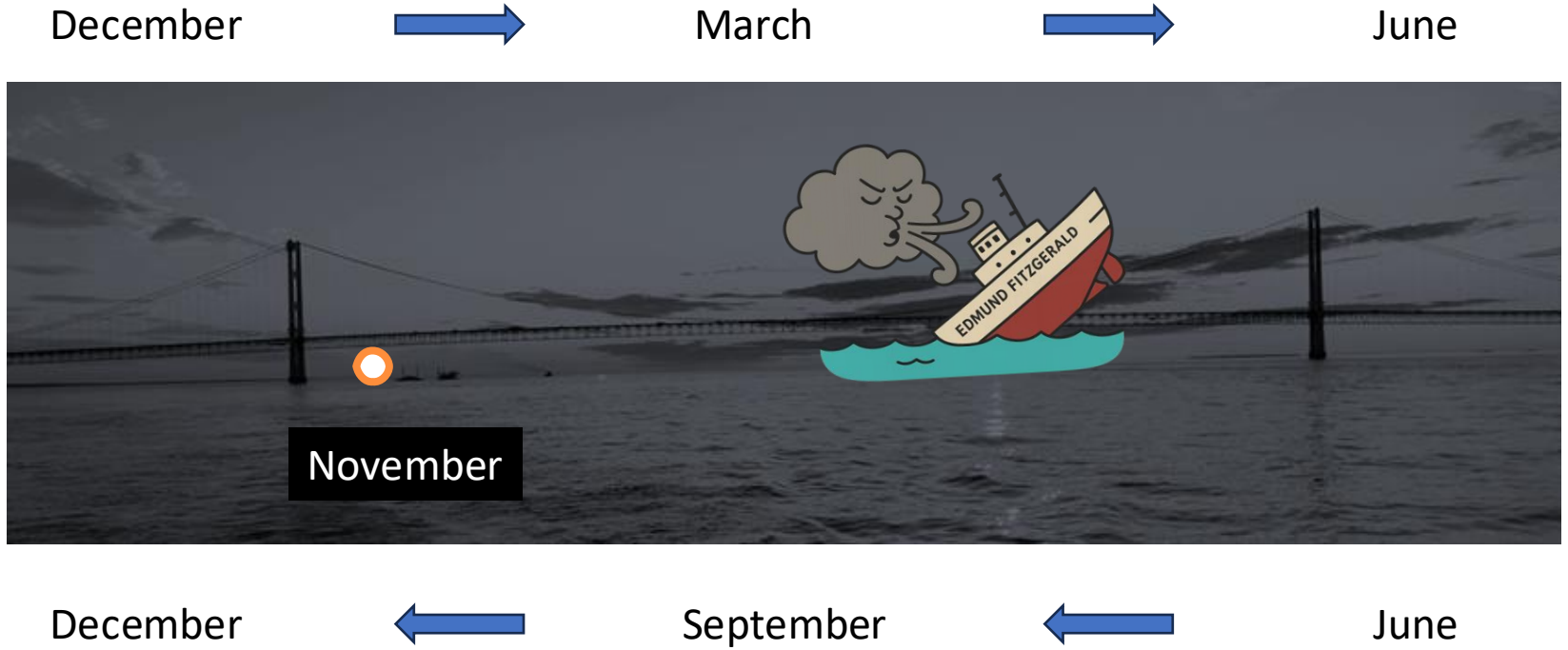


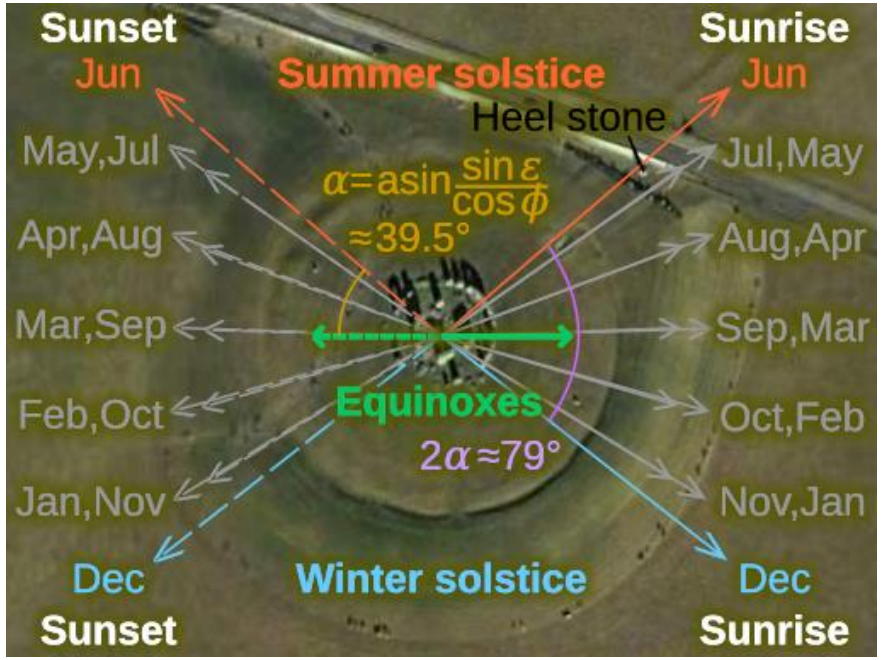
Stonehenge – 4500 Years Ago (YA)

- AI: Ancient artifacts to measure the Sun around the world
  - Göbekli Tepe, Turkey Lunar / Solar Calendar (?) – 12000YA
  - Egypt Sun dials invented 3500 years ago (YA)
  - China sun dials over 3000 YA
  - Mexico The Descent of Kukulkán – 1200 YA
  - Temple of Petra 1000 YA
  - India Sun Temple, Konark – 750 YA
- Modern Henges
  - Manhattan Henge 2020-01
  - Chicago henge 2022-03
  - Dr. Chuck's commute henge 2024-09

Photos from Wikipedia.

Stonehenge: Sunrise and sunset tracking

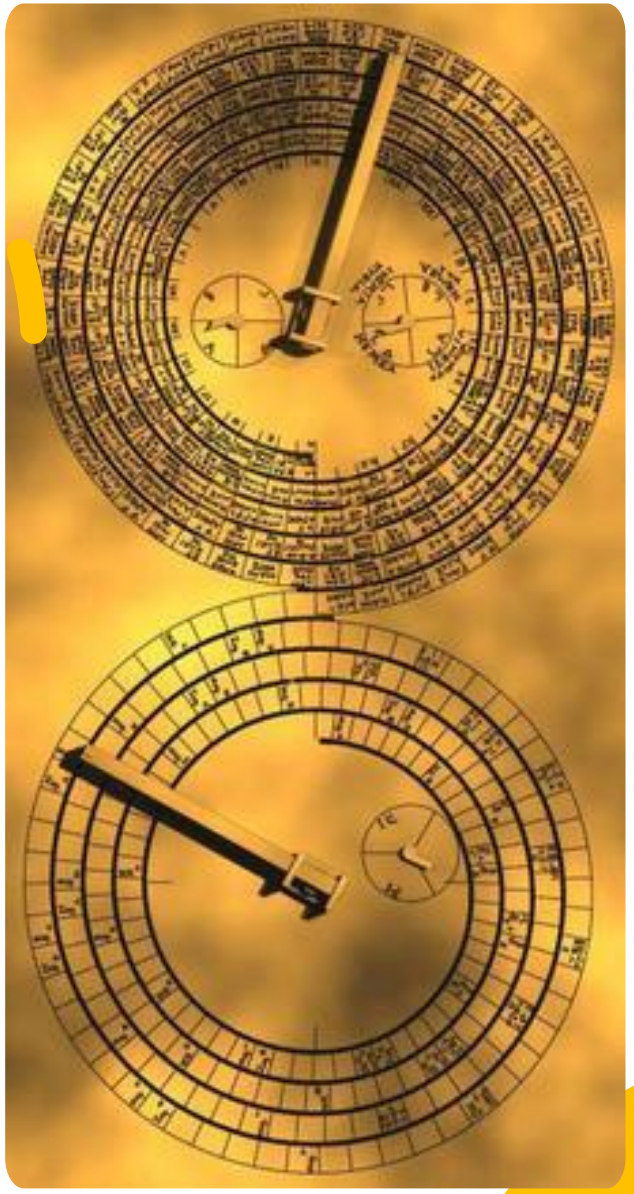
- Stonehenge had several versions and was built iteratively from 5100 YA to 3600 YA (Years ago)
- By the time the latest structure was built, the earlier structures measured the angle of sunrise and sunset throughout the year
- You can think of it as a sun tracking data table calibrated over 2500 years



Continuous / Analog Computing

Physical Devices - Printed Scales

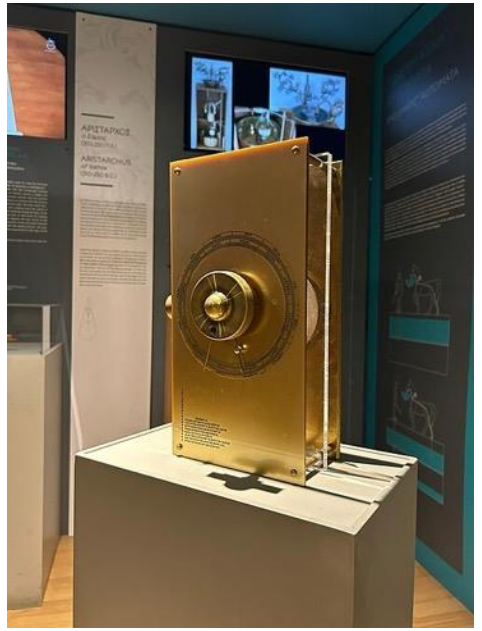
- "Continuous" means that these devices have knobs, gears or sliders that use physical movement to accurately approximate a computation
- A key to these devices is intricate and accurate printed scale
- Data is input into the devices by moving an indicator to a point on a scale and then moving something else and reading an answer from an indicator and scale.



Wikipedia

Antikythera mechanism – 2100 YA

- Oldest known continuous analogue computer
- Uses gears to model the known solar system
  - Sun, Moon, Earth, Mercury, Venus, Mars, Jupiter, Saturn
  - Models more complex Sun-Moon-Earth 19, 76 and 223 year cycles
- *Indiana Jones and The Dial of Destiny*
- You can buy one on Amazon
- AI: Antikythera like mechanisms in cultures around the world



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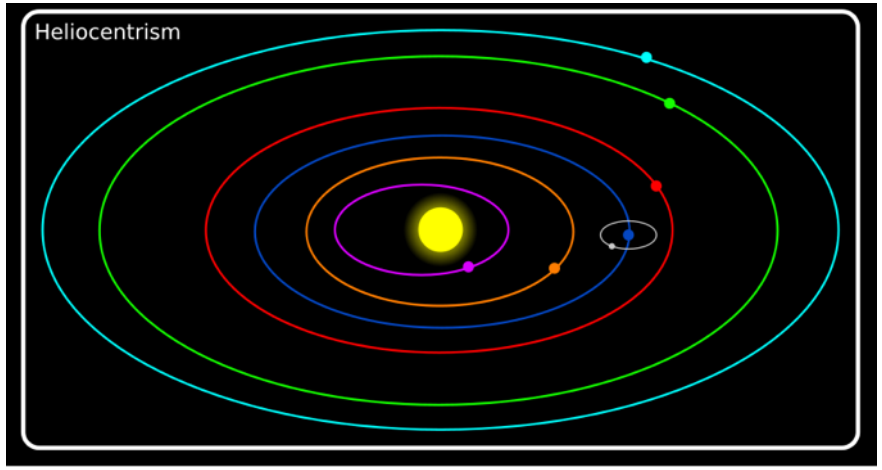
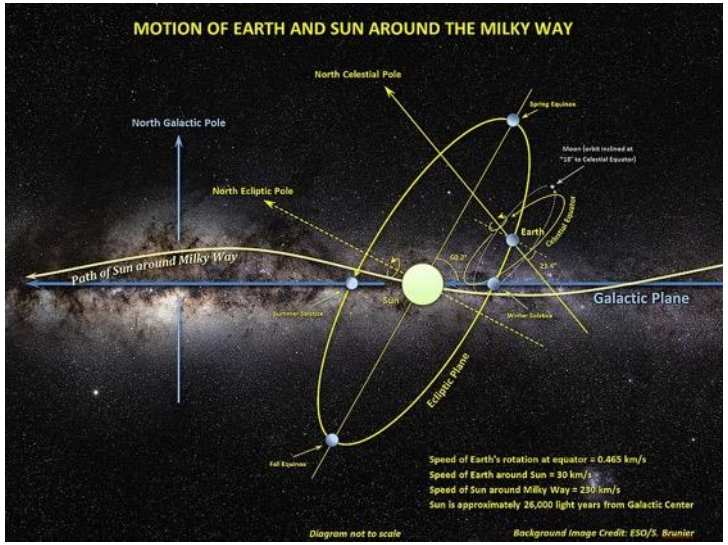
Reflections on Solar System Models

- We have been taught a simple model of the solar system called "heliocentrism" conceived by Nicolaus Copernicus in 1543
- But the planets orbits are at different angles and the sun is also moving
- As the Sun moves through the Milky Way, Earth and the other planets follow along — so our orbits trace helical paths through space.
- AI: Actual motion of earth through the milky way galaxy
- AI: Nicolaus Copernicus gets in trouble

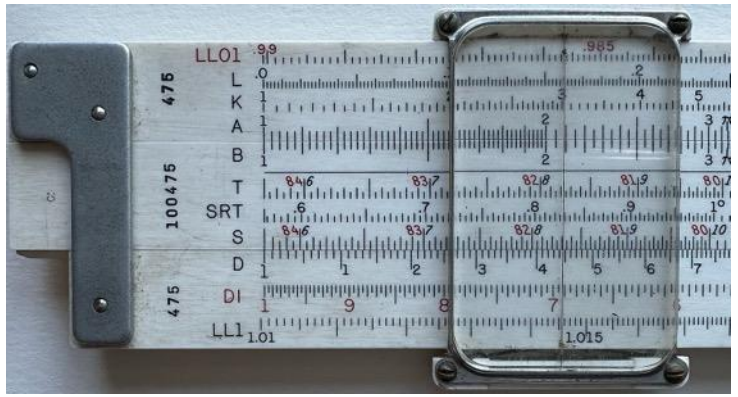




Modern Continuous Analog Computing Devices

- Slide Rule – Multiplication using addition and logarithms
- E6B wind calculator for airplane pilots that uses a circular calculator to do trigonometry and Pythagorean theorem computations

- Ignore the math details ☺



https://commons.wikimedia.org/wiki/File:Slide_rule_scales_front.jpg

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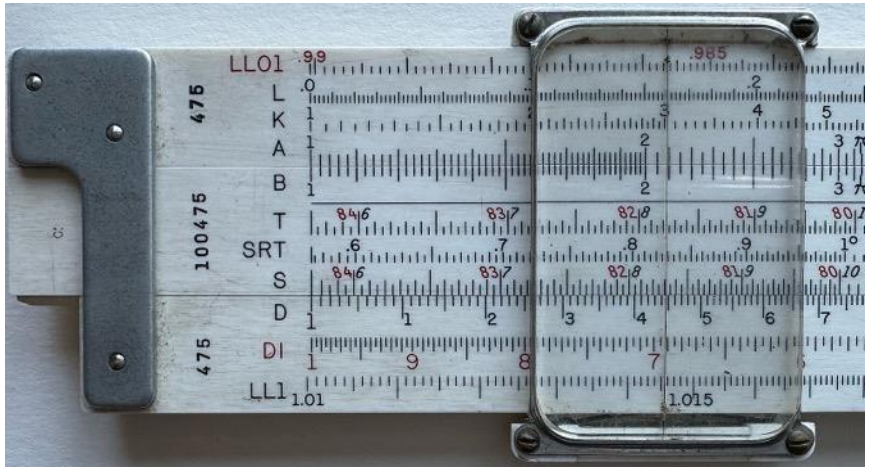
Slide Rule



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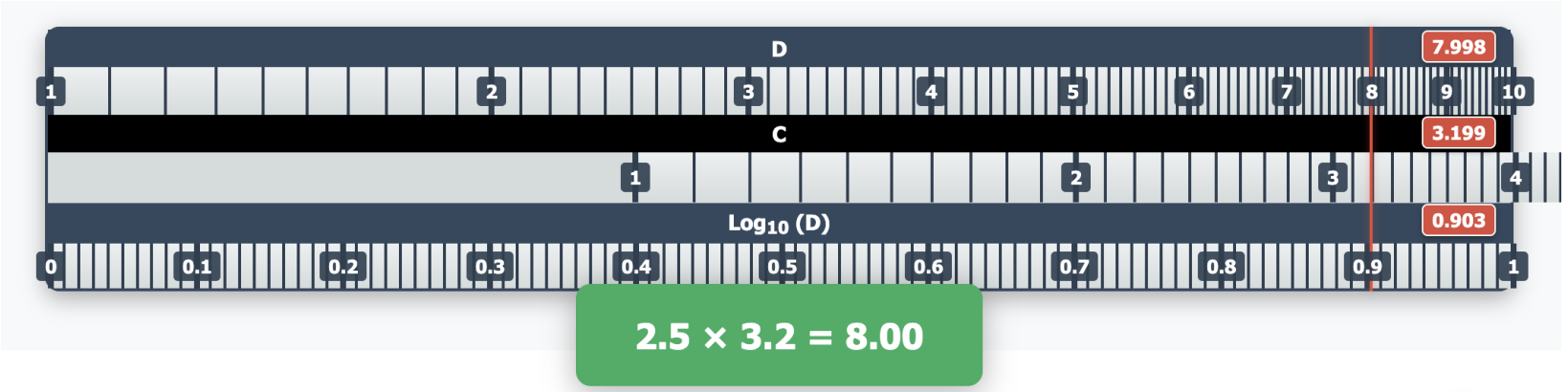
Screen shot from Hidden Figures movie



Computing Wind Correction for Airplanes (drift angle)

- Our airplane goes 100 knots air speed and we want to go west (270 degrees)
- The wind is out of the northwest (300 degrees) at 15 knots
- If we fly straight west, the wind will both slow us down and push us south
- Where should we point the plane to actually have a ground track that is west and what is our effective ground speed?

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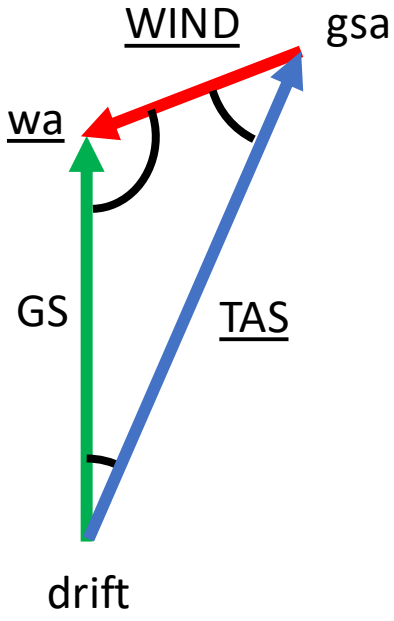
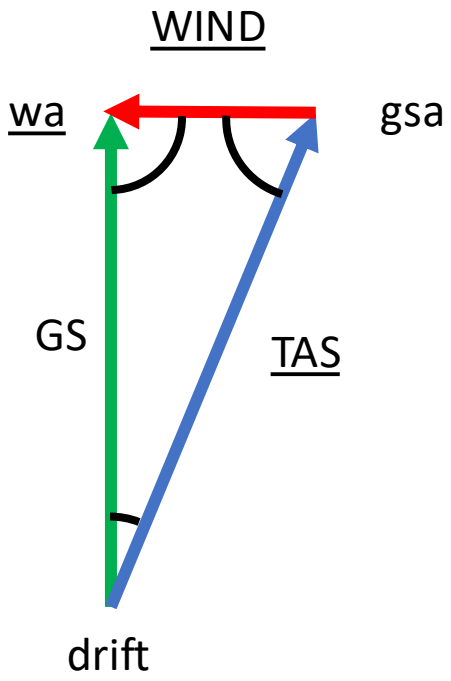
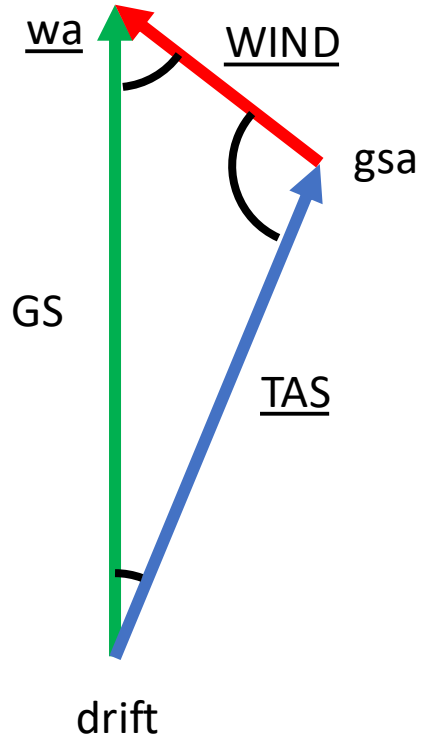






Use Law of Sines!

$$\frac{TAS}{\sin wa} = \frac{Wind}{\sin drift} = \frac{GS}{\sin gsa}$$

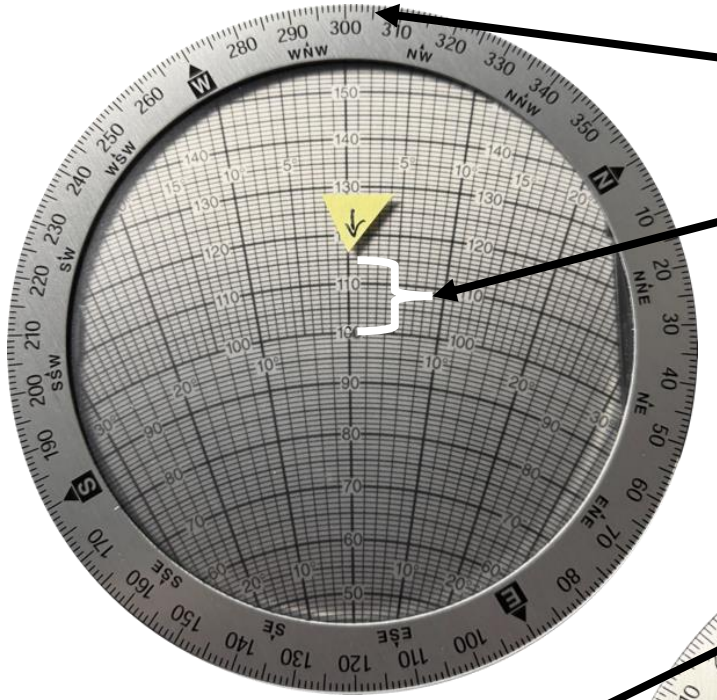
```
# Python:
drift = math.degrees(math.asin(math.sin(math.radians(wa)) / tas * wind))
gsa = 180 - ((wa % 180) + drift)
gs = math.fabs((wind * math.sin(math.radians(gsa))) / math.sin(math.radians(drift)))
```

To *actually* go west…

- Our airplane goes 100 knots and we want to go west (270 degrees)
- The wind is out of the northwest (300 degrees) at 15 knots
- We will fly a heading of 274.3 degrees and expect a ground speed (west) of 87 knots

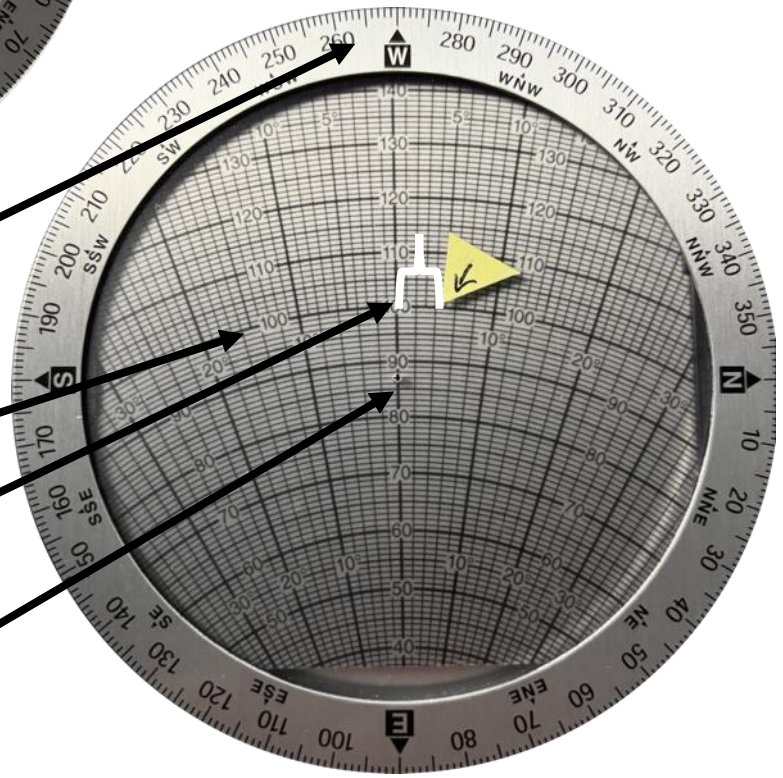
Pilots and Trigonometry?

- We have an analog computer called the E6B that does the entire calculation by rotating and sliding and reading numbers directly from the device
- This is an analogue equivalent to the law of sines computation



Wind Direction
300 degrees

Wind Speed
15 knots



Desired course 270 degrees

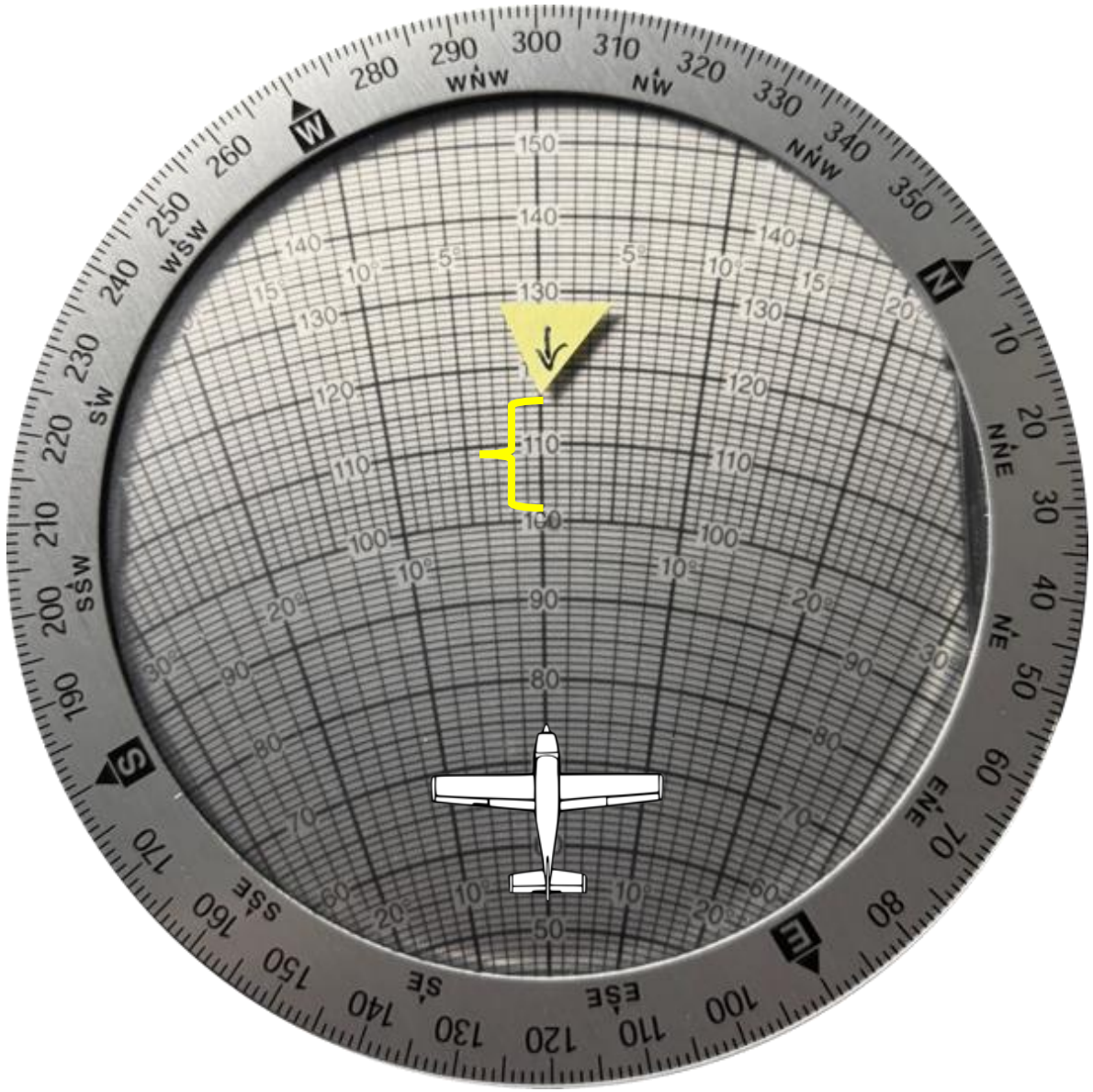
Air speed 100 Knots

Drift angle 4 degrees

Ground speed 87 knots

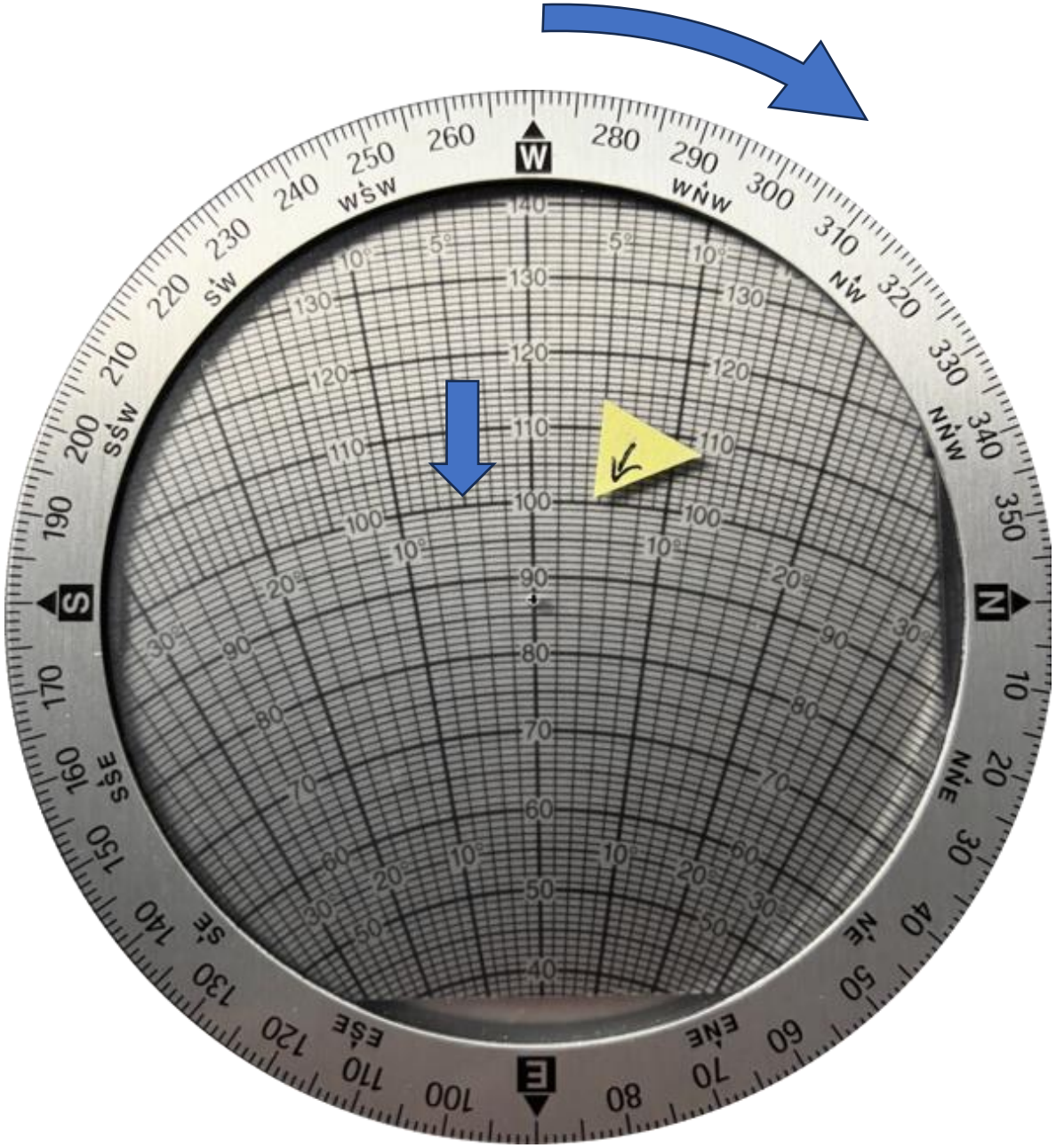
Put the wind in the E6B

1. Rotate the dial to the wind direction (300 degrees)
2. Move the speed slider to 100 knots
3. Add 15 knots and make a mark at 115 knots.



Apply the wind to the plane

1. Rotate to desired course of 270 degrees
2. Move the mark to the true air speed of the plane (100 knots)

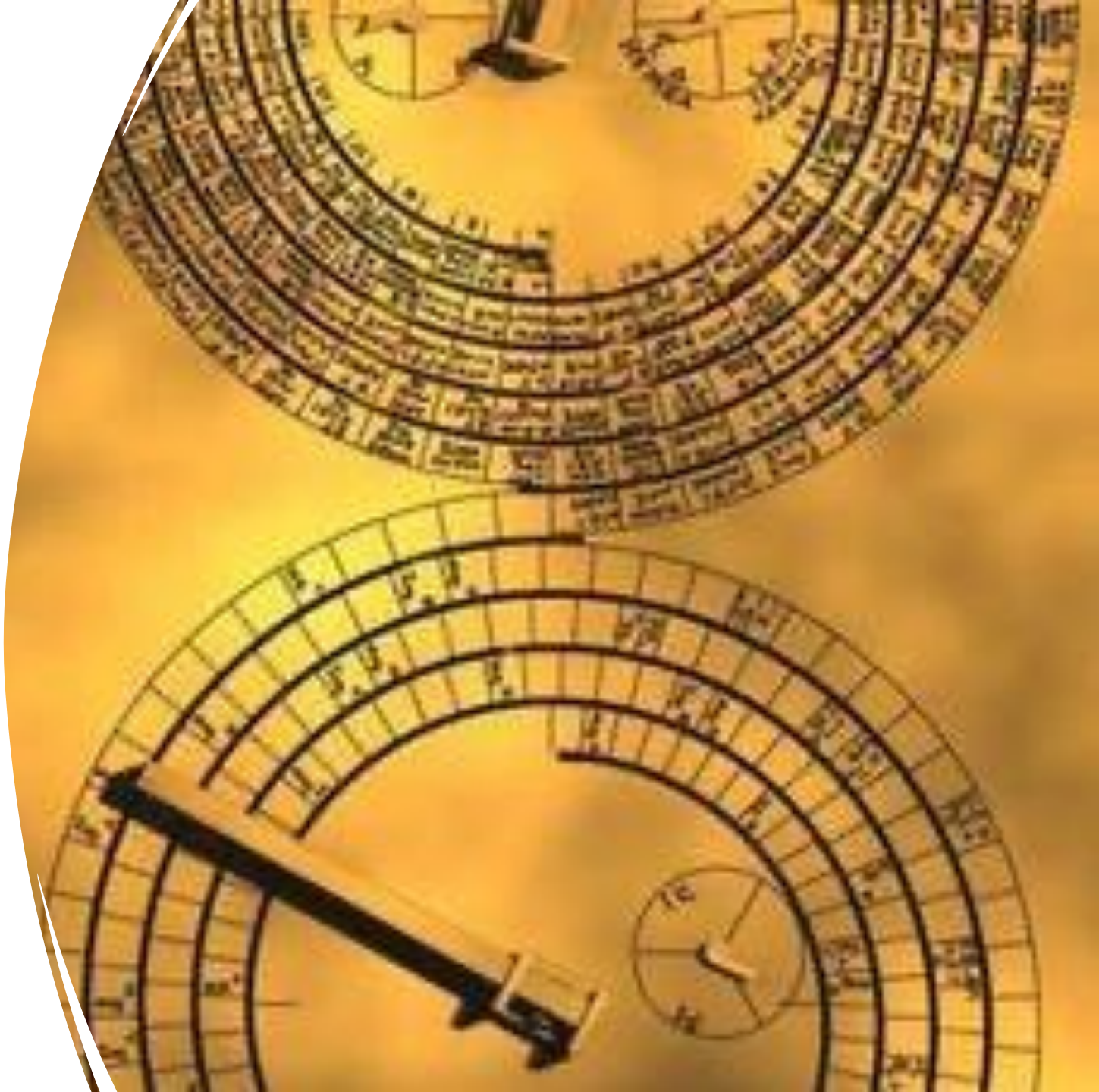


Read the result of the calculation

1. Since the wind is mostly coming form the front, the ground speed will be about 87 knots
2. To compensate for the drift we need a "crab angle" of 4 degrees so we fly a heading of 274 degrees

The point is not to teach flying

- A physical (analog) device can do "graphical calculations"
- Sliding or rotating scales
- Gears
- Other things can compute
  - Water
  - Pulleys



Wikipedia

Physical Digital Devices

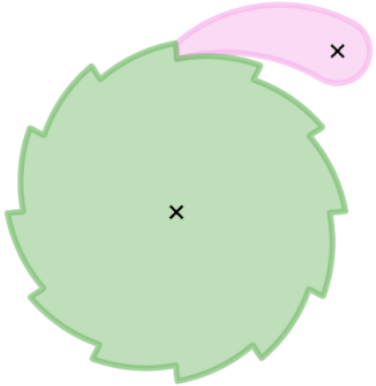
Physical devices that are digital

- Physically built to have two stable states
  - On (1) or Off (0)
- Require sufficient physical input to switch states – you often hear a click
- If the input is not enough to change state they usually fall back to the previous stable state
- Capturing the new state is often called "latching" – it sounds a bit like clicking

https://en.wikipedia.org/wiki/Retractable_pen

Clocks as Counters

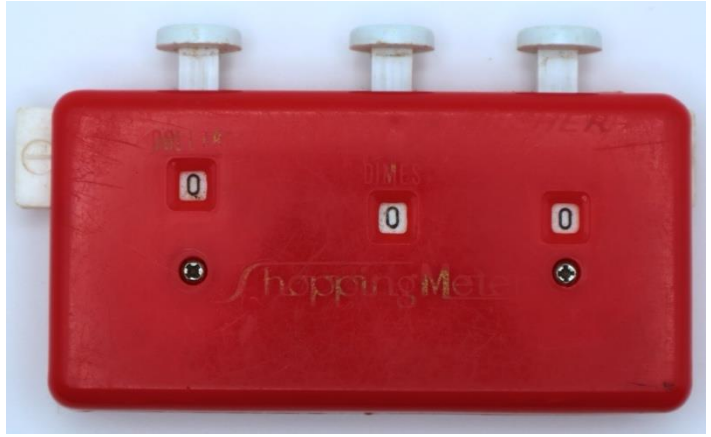
- Early clocks used a pendulum and a series of ratchets and gears that acted as counters for seconds, minutes, and hours
- At particular times / counts they would run "programs" to make sounds to mark the passage of time



https://en.wikipedia.org/wiki/Ratchet_(device)
https://en.wikipedia.org/wiki/Cuckoo_clock

Counters with Carry Propagation

- Numbers with multiple columns can be added if there is a carry mechanism that advances the next column when the current column overflows
- Note that carrying into a column can cause overflow into the next column – so we call this "ripple carry" as it has the potential to ripple through several columns.

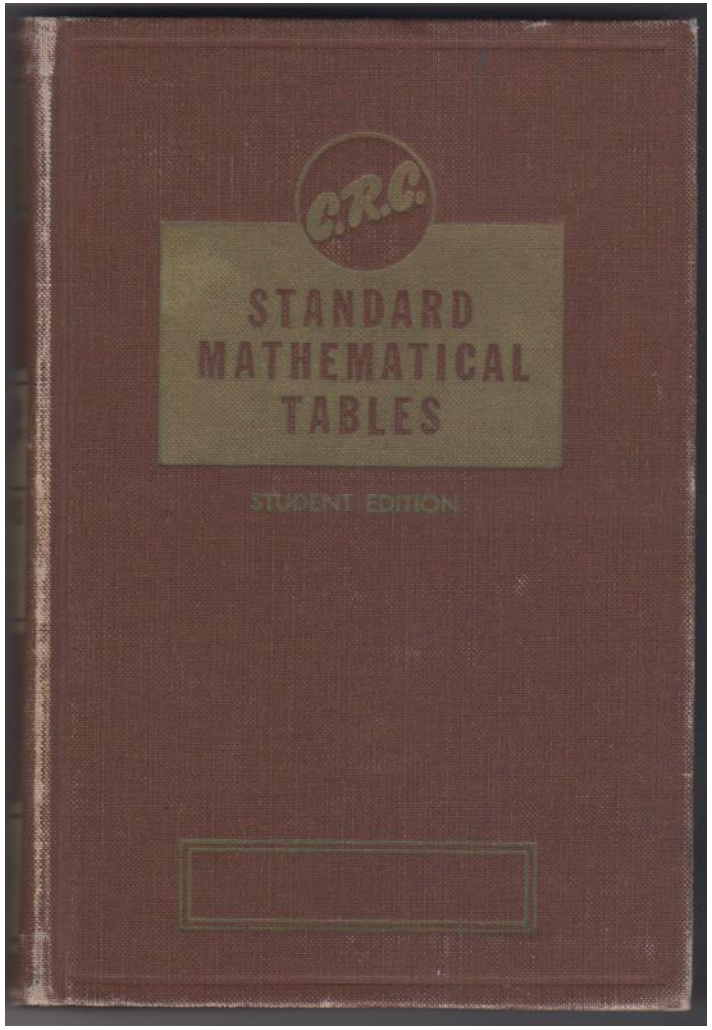


Iteration

- With larger numbers and addition with carry as something that can work, the move is to "iterate"
- Multiplication is repeated addition. If you have a way to count down from a number, you can add a motor or crank to automate multiplication.

https://en.wikipedia.org/wiki/Mechanical_computer

More Complex Math



FOUR-PLACE LOGARITHMS

FOUR-PLACE

N	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	*4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	*3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	5	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	5	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

* Interpolation in this section of the table is inaccurate.

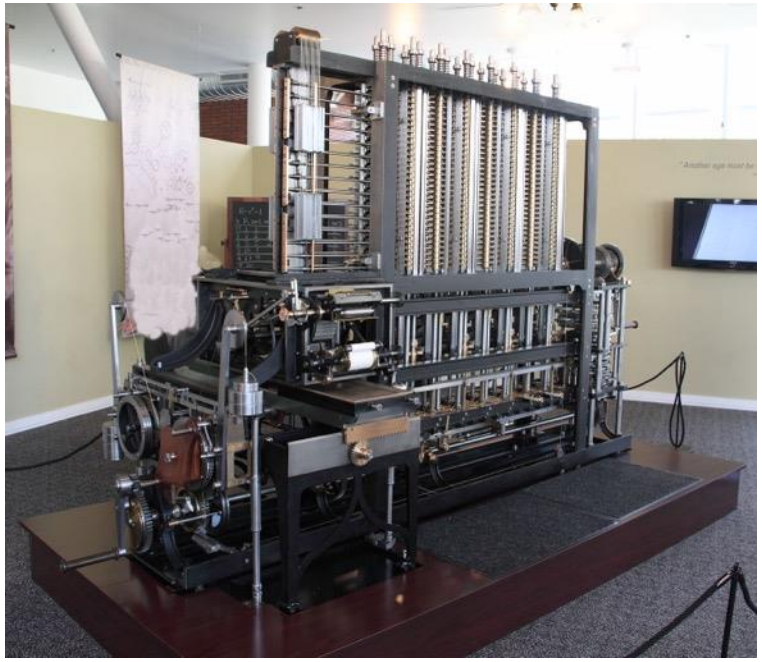
18

Before Scientific Calculators

- For more complex math like trigonometry and logarithms we often used books with tables of numbers.

Babbage Difference Engine

- In the 1820's Charles Babbage designed a mechanical calculator to compute up to seventh order polynomials
- It could produce tables of advanced functions using polynomial approximation
- Babbage built a small prototype in the 1800's but a full scale system was not built until 1991 – and it worked!



https://en.wikipedia.org/wiki/Difference_engine

Human Computers

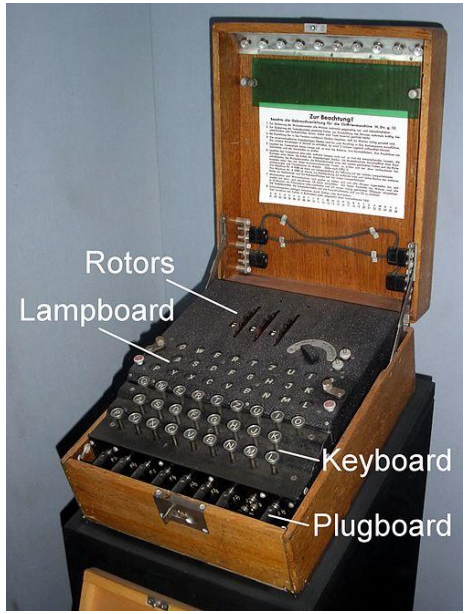
- Until the advent of Scientific Calculators (sin, log, etc.) we depended on tables for complex functions
- Often these tables were produced using "Computers" – people that used add/multiply machines to run long calculations to produce the tables
- The movie "Hidden Figures" (2016) explores the shift from human to electronic computers

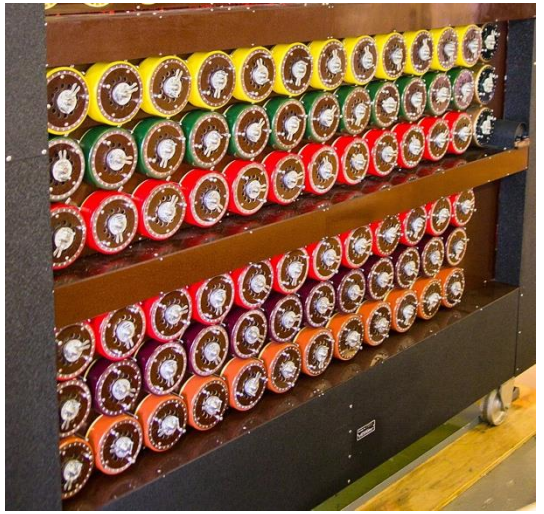
https://en.wikipedia.org/wiki/Computer_(occupation)
https://en.wikipedia.org/wiki/Hidden_Figures

Iteration / Loops

Bombe – Electromechanical Iteration

- During World War II, the Germans used a device called "Enigma" to encrypt messages and send them using morse code and radios
- The Bombe was a British device that tried repeatedly to guess the Enigma settings for the day (like a "password")





https://en.wikipedia.org/wiki/Bombe

Pinball Machine – Electromechanical

- A Pinball machine uses switches, relays, and physical storage to keep track of a game score, award specials, count the number of balls, take money, start and stop games
- It requires careful attention to the timing of signals and devices
- It is very much like a simple Bombe in terms of the technology used

Electronic Computers

Colossus – Moving toward pure electronic

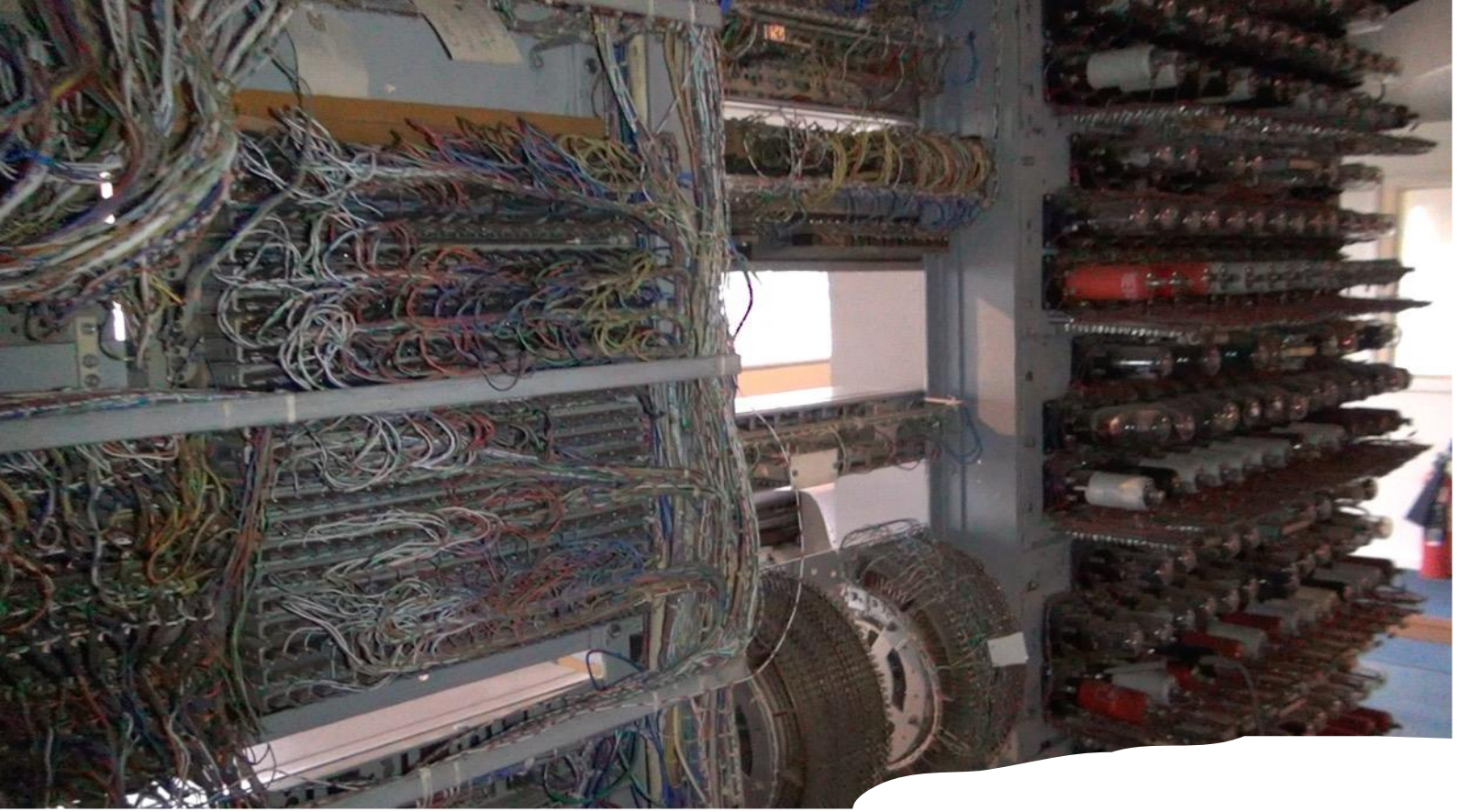
- Up to this point, when there is a numeric value, we are changing like the "current time" or the "total points" we must physically change the value.
  - "Latch", "Click", etc..
  - This takes time, power, and generates friction / heat / wear
- The speed of computation is physically limited so as not to damage the machine

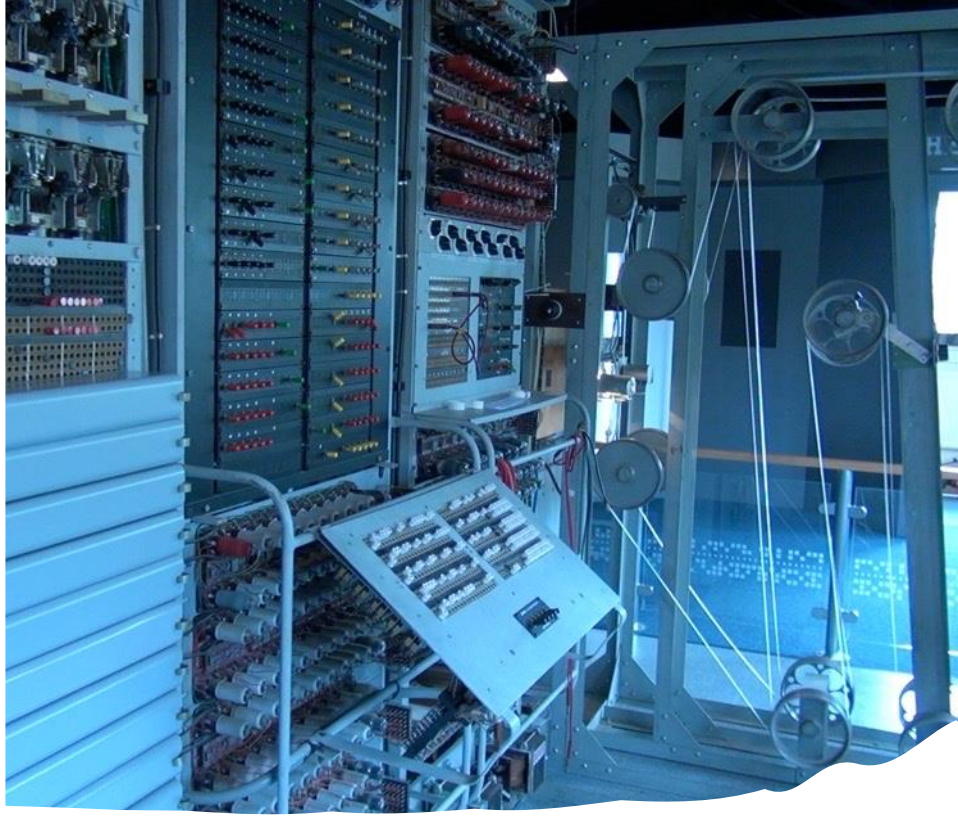
ChatGPT: A Babbage Difference Engine overheating and starting to fall apart because it is running too fast.

Electronic Switching using Tubes

- An electronic "tube" or "valve" takes an input signal and power connection and produces a "louder" / "amplified" version of the signal
- Tubes are analog and continuous but with a little more electronics they can be "digital" and latch in and maintain a "zero" or "one" value
- Tubes take power and generate heat, but have no moving parts so they can switch faster than physical "latches"

https://en.wikipedia.org/wiki/Vacuum_tube





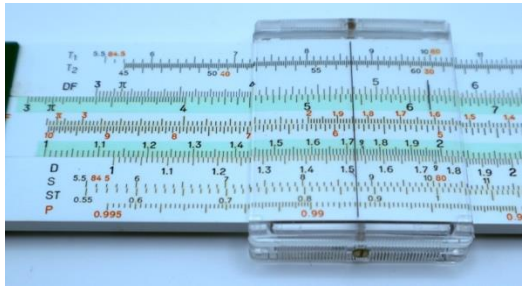
Colossus

By using tubes, Colossus could do addition and other computations much faster than the Bombe.

Power consumption and heat dissipation are still a challenge.

Hidden Figures - Programming

- A subplot within the Hidden Figures (2016) movie is the transition from doing complex calculations manually to writing programs using FORTRAN on an IBM 7090
- There was a natural parallel between following instructions precisely and precisely defining the instructions that a computer would follow
- Being a human computer was a natural training ground for the emerging programming field



```
      SUM = 0
      DO 10 I = 1, 10
      SUM = SUM + I
10    CONTINUE
```

Summary

- Humans have built endless physical devices over time to help us better understand things like
  - Astronomy
  - The passage of time
  - Navigation through moving mediums (airplane / boat)
  - Accounting / money
  - Curved motion under the effect of gravity (space craft)
- The IBM 7090 in Hidden Figures was built using transistors – solid state electronics that greatly reduced heat and power consumption and increased speed (40,000 multiplications per second)

Acknowledgements / Contributions

Initial Development: Charles Severance, University of Michigan School of Information

Insert new Contributors and Translators here including names and dates

Continue new Contributors and Translators here