A Brief History of Early Mechanical Computation

15-110 supplemental slides, 11/25/24

Taking a step back...

- Most "History of Computing" lectures begin around the time of Babbage, Lovelace, and the Analytical Engine in the early 1800s

- If we broaden our perspective on computation, its history stretches *much* farther back

What is computing? What is a computer?

Let’s use a loose definition

- Loosely, something that generates an output given a particular set of inputs or initial configuration
- We’ll restrict ourselves to inputs and outputs that (mathematically) represent concepts or parts of problems
- Generally they solve (or allow us to solve) a set of problems faster
- A simple example: multiplication tables

Multiplication Square

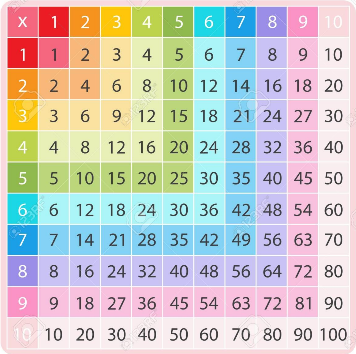
x	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	12	14	16	18	20
3	3	6	9	12	15	18	21	24	27	30
4	4	8	12	16	20	24	28	32	36	40
5	5	10	15	20	25	30	35	40	45	50
6	6	12	18	24	30	36	42	48	54	60
7	7	14	21	28	35	42	49	56	63	70
8	8	16	24	32	40	48	56	64	72	80
9	9	18	27	36	45	54	63	72	81	90
10	10	20	30	40	50	60	70	80	90	100

Function tables: How do they "work?"

It stores precomputed knowledge that we can systematically access to perform calculations faster.

To the right is an image of a rather intimidating logarithm table ---->

Multiplication Square



x	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	12	14	16	18	20
3	3	6	9	12	15	18	21	24	27	30
4	4	8	12	16	20	24	28	32	36	40
5	5	10	15	20	25	30	35	40	45	50
6	6	12	18	24	30	36	42	48	54	60
7	7	14	21	28	35	42	49	56	63	70
8	8	16	24	32	40	48	56	64	72	80
9	9	18	27	36	45	54	63	72	81	90
10	10	20	30	40	50	60	70	80	90	100

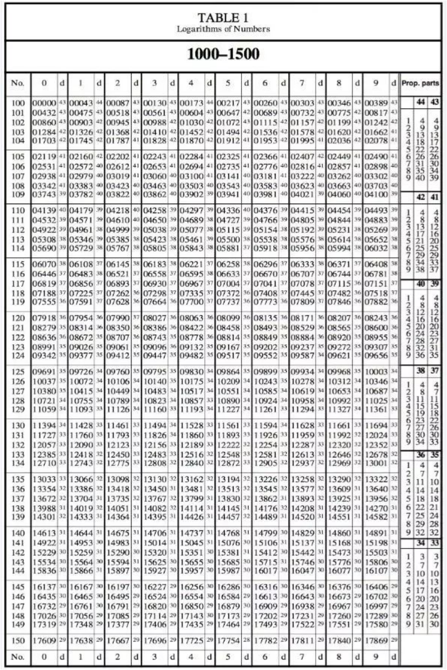


TABLE 1
Logarithms of Numbers

1000–1500

No.	0	d	1	d	2	d	3	d	4	d	5	d	6	d	7	d	8	d	9	d
100	00000	43	00043	44	00087	43	00130	43	00173	44	00217	43	00260	43	00303	43	00346	43	00389	43
101	00432	43	00475	43	00518	43	00561	43	00604	43	00647	42	00689	43	00732	43	00775	42	00817	43
102	00860	43	00903	42	00945	43	00988	42	01030	42	01072	43	01115	42	01157	42	01199	43	01242	42
103	01284	42	01326	42	01368	42	01410	42	01452	42	01494	42	01536	42	01578	42	01620	42	01662	41
104	01703	42	01745	42	01787	41	01828	42	01870	42	01912	41	01953	42	01995	41	02036	42	02078	41
105	02119	41	02160	42	02202	41	02243	41	02284	41	02325	41	02366	41	02407	42	02449	41	02490	41
106	02531	41	02572	40	02612	41	02653	41	02694	41	02735	41	02776	40	02816	41	02857	41	02898	40
107	02938	41	02979	40	03019	41	03060	40	03100	41	03141	40	03181	41	03222	40	03262	40	03302	40
108	03342	41	03383	40	03423	40	03463	40	03503	40	03543	40	03583	40	03623	40	03663	40	03703	40
109	03743	39	03782	40	03822	40	03862	40	03902	39	03941	40	03981	40	04021	39	04060	40	04100	39
110	04139	40	04179	39	04218	40	04258	39	04297	39	04336	40	04376	39	04415	39	04454	39	04493	39
111	04532	39	04571	39	04610	40	04650	39	04689	38	04727	39	04766	39	04805	39	04844	39	04883	39
112	04922	39	04961	38	04999	39	05038	39	05077	38	05115	39	05154	38	05192	39	05231	38	05269	39
113	05308	38	05346	39	05385	38	05423	38	05461	39	05500	38	05538	38	05576	38	05614	38	05652	38
114	05690	39	05729	38	05767	38	05805	38	05843	38	05881	37	05918	38	05956	38	05994	38	06032	38
115	06070	38	06108	37	06145	38	06183	38	06221	37	06258	38	06296	37	06333	38	06371	37	06408	38
116	06446	37	06483	38	06521	37	06558	37	06595	38	06633	37	06670	37	06707	37	06744	37	06781	38
117	06819	37	06856	37	06893	37	06930	37	06967	37	07004	37	07041	37	07078	37	07115	36	07151	37
118	07188	37	07225	37	07262	36	07298	37	07335	37	07372	36	07408	37	07445	37	07482	36	07518	37
119	07555	36	07591	37	07628	36	07664	36	07700	37	07737	36	07773	36	07809	37	07846	36	07882	36
120	07918	36	07954	36	07990	37	08027	36	08063	36	08099	36	08135	36	08171	36	08207	36	08243	36
121	08279	35	08314	36	08350	36	08386	36	08422	36	08458	35	08493	36	08529	36	08565	35	08600	36
122	08636	36	08672	35	08707	36	08743	35	08778	36	08814	35	08849	35	08884	36	08920	35	08955	36
123	08991	35	09026	35	09061	35	09096	36	09132	35	09167	35	09202	35	09237	35	09272	35	09307	35
124	09342	35	09377	35	09412	35	09447	35	09482	35	09517	35	09552	35	09587	34	09621	35	09656	35
125	09691	35	09726	34	09760	35	09795	35	09830	34	09864	35	09899	35	09934	34	09968	35	10003	34
126	10037	35	10072	34	10106	34	10140	35	10175	34	10209	34	10243	35	10278	34	10312	34	10346	34
127	10380	35	10415	34	10449	34	10483	34	10517	34	10551	34	10585	34	10619	34	10653	34	10687	34
128	10721	34	10755	34	10789	34	10823	34	10857	33	10890	34	10924	34	10958	34	10992	33	11025	34
129	11059	34	11093	33	11126	34	11160	33	11193	34	11227	34	11261	33	11294	33	11327	34	11361	33
130	11394	34	11428	33	11461	33	11494	34	11528	33	11561	33	11594	34	11628	33	11661	33	11694	33
131	11727	33	11760	33	11793	33	11826	34	11860	33	11893	33	11926	33	11959	33	11992	32	12024	33
132	12057	33	12090	33	12123	33	12156	33	12189	33	12222	32	12254	33	12287	33	12320	32	12352	33
133	12385	33	12418	32	12450	33	12483	33	12516	32	12548	33	12581	32	12613	33	12646	32	12678	32
134	12710	33	12743	32	12775	33	12808	32	12840	32	12872	33	12905	32	12937	32	12969	32	13001	32
135	13033	33	13066	32	13098	32	13130	32	13162	32	13194	32	13226	32	13258	32	13290	32	13322	32
136	13354	32	13386	32	13418	32	13450	31	13481	32	13513	32	13545	32	13577	32	13609	31	13640	32
137	13672	32	13704	31	13735	32	13767	32	13799	31	13830	32	13862	31	13893	32	13925	31	13956	32
138	13988	31	14019	32	14051	31	14082	32	14114	31	14145	31	14176	32	14208	31	14239	31	14270	31
139	14301	32	14333	31	14364	31	14395	31	14426	31	14457	32	14489	31	14520	31	14551	31	14582	31
140	14613	31	14644	31	14675	31	14706	31	14737	31	14768	31	14799	30	14829	31	14860	31	14891	31
141	14922	31	14953	30	14983	31	15014	31	15045	31	15076	30	15106	31	15137	31	15168	30	15198	31
142	15229	30	15259	31	15290	30	15320	31	15351	30	15381	31	15412	30	15442	31	15473	30	15503	31
143	15534	30	15564	30	15594	31	15625	30	15655	30	15685	30	15715	31	15746	30	15776	30	15806	30
144	15836	30	15866	31	15897	30	15927	30	15957	30	15987	30	16017	30	16047	30	16077	30	16107	30
145	16137	30	16167	30	16197	30	16227	29	16256	30	16286	30	16316	30	16346	30	16376	30	16406	29
146	16435	30	16465	30	16495	29	16524	30	16554	30	16584	29	16613	30	16643	30	16673	29	16702	30
147	16732	29	16761	30	16791	29	16820	30	16850	29	16879	30	16909	29	16938	29	16967	30	16997	29
148	17026	30	17056	29	17085	29	17114	29	17143	30	17173	29	17202	29	17231	29	17260	29	17289	30
149	17319	29	17348	29	17377	29	17406	29	17435	29	17464	29	17493	29	17522	29	17551	29	17580	29
150	17609	29	17638	29	17667	29	17696	29	17725	29	17754	28	17782	29	17811	29	17840	29	17869	29
No.	0	d	1	d	2	d	3	d	4	d	5	d	6	d	7	d	8	d	9	d

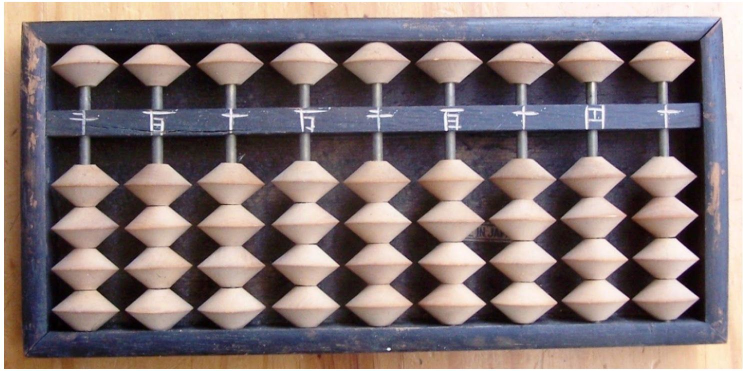
Prop. parts

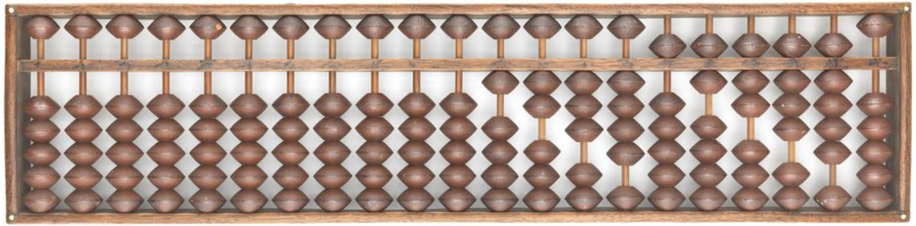
	44	43	42	41	40	39	38	37	36	35	34	33
1	4	4	4	4	4	4	4	4	4	4	3	3
2	9	9	8	8	8	8	8	7	7	7	7	7
3	13	13	13	12	12	12	11	11	11	10	10	10
4	18	17	17	16	16	16	15	15	14	14	14	13
5	22	22	21	20	20	20	19	18	18	18	17	16
6	26	26	25	25	24	23	23	22	22	21	20	20
7	31	30	29	29	28	27	27	26	25	24	24	23
8	35	34	34	33	32	31	30	30	29	28	27	26
9	40	39	38	37	36	35	34	33	32	32	31	30

Simple computers

The abacus: 2500BC to present

- Originally lines drawn in sand, pebbles
- Oldest known “computer,” excluding simple counting aids like tally sticks
- Procedural interaction allows user to perform four-function math on large numbers by storing an intermediate state
- Still in widespread use until recent decades
    - Japanese soroban was taught nationally and used in business until recently
- http://www.mathematik.uni-marburg.de/~thormae/lectures/ti1/code/abacus/soroban.html





Napier's Bones (1617)

Physical aid for multiplying large numbers

Represented with pen and paper *or* with inscribed rods: http://mathworld.wolfram.com/NapiersBones.html

John Napier also invented logarithms!

Slide rules: 1620 - 1950

Basic principle:

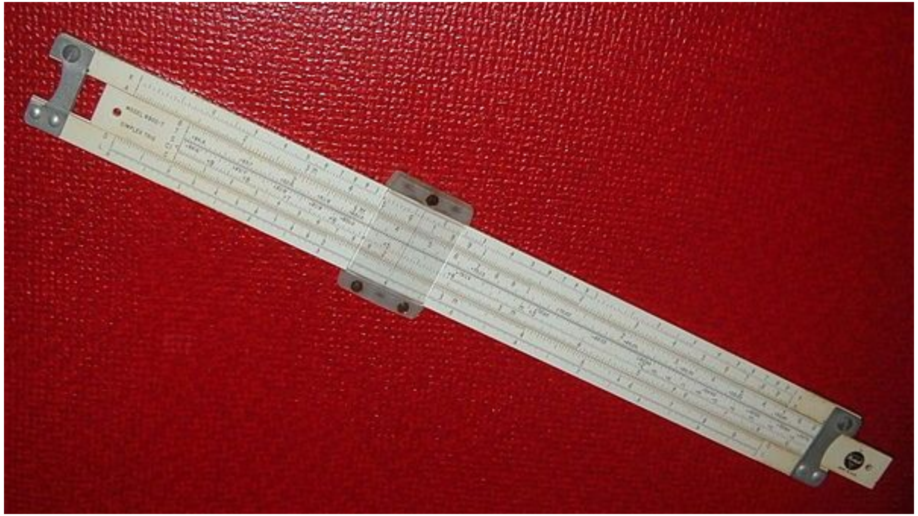
$$\log(xy) = \log(x) + \log(y)$$

$$\log(x/y) = \log(x) - \log(y)$$

Multiplication and division can be quickly performed using the sum of logarithms!

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

http://www.antiquark.com/sliderule/sim/virtual-slide-rule.html



Mechanical calculators (1623 - 1970)

Similar function to previous tools, but meant to be more convenient or automatic

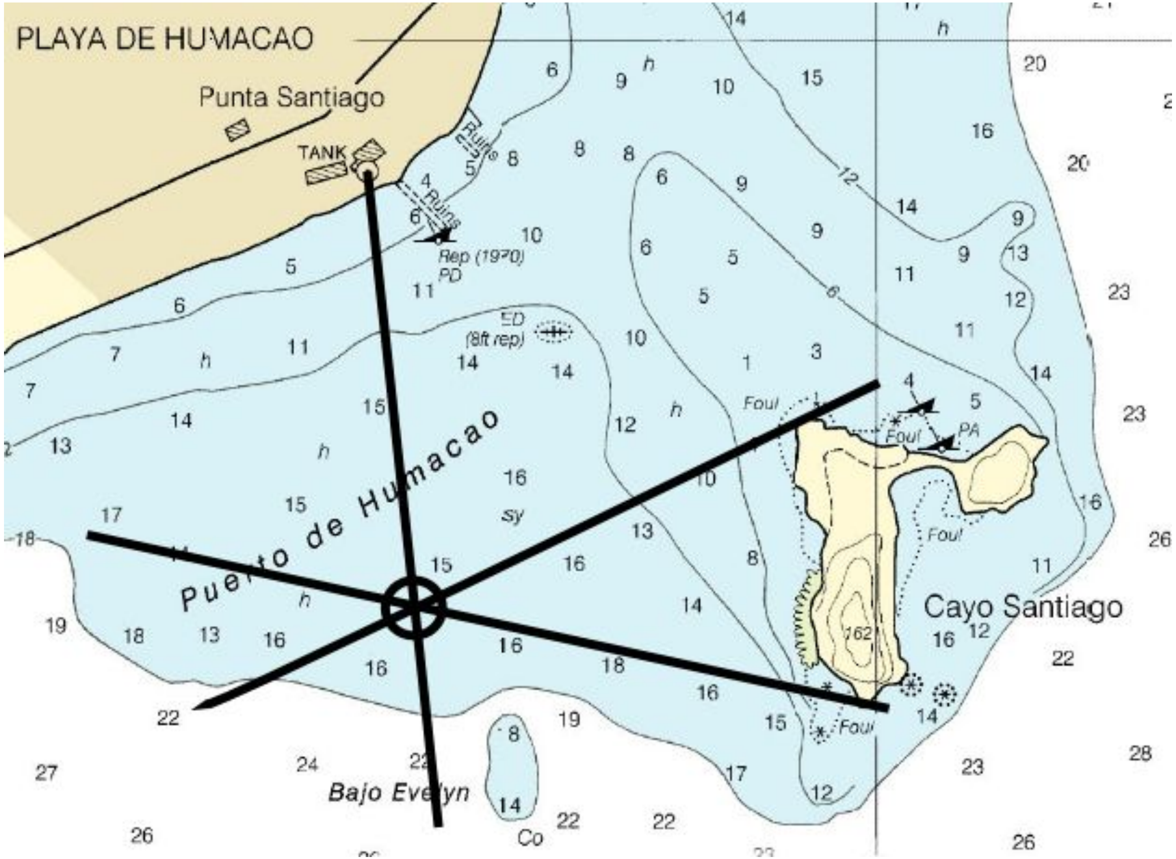
Antikythera mechanism

Mechanical complexity is *ancient*

- Antikythera mechanism: 2100 years old
- Accurately calculates celestial positions, eclipses, etc
- https://www.youtube.com/watch?v=UpLcnAIpVRA&feature=youtu.be&t=164

- Discuss: **Why might this have been built?**

Navigation!
A major incentive for innovation



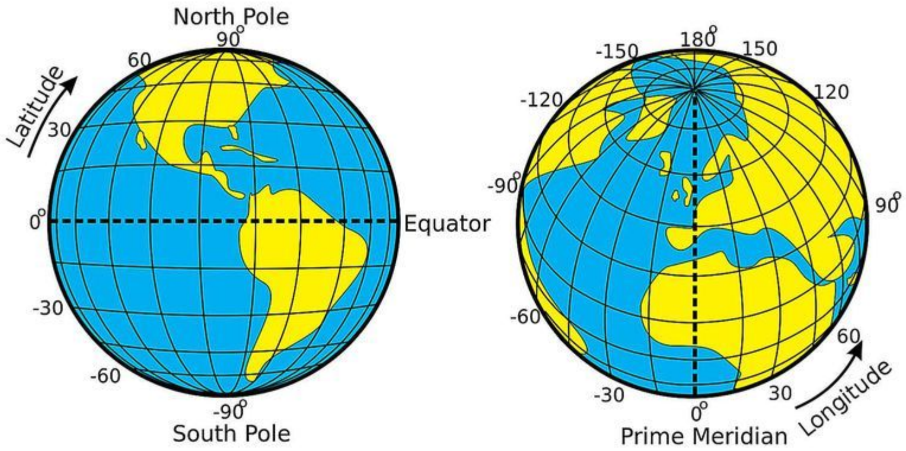
Positional navigation using landmarks

Sextants, astrolabes, etc for measuring angles

Time!
Can't navigate across an ocean without knowing the time.

Why is time important for navigational calculations?

- When we travel long distances, the sky changes
- Small errors are a big deal over large voyages



- So let's build a clock! Why is this hard?
    - Mechanical
    - No way to correct fast/slow if clock if you're alone in the ocean (don't know where)
    - Clock must be *extremely* accurate and precise, even through rough weather

Quick aside: How long have battery-powered watches been widespread?

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Before the 1980s, most watches were entirely mechanical.

The first “electric” watches from 1969 were absurdly expensive and still relied on mechanical regulation of time.

The first all-digital watch cost more than $2k when it first came out in 1970.

What functional parts do we need for a mechanical timekeeper?

1. A way to store energy (a spring)

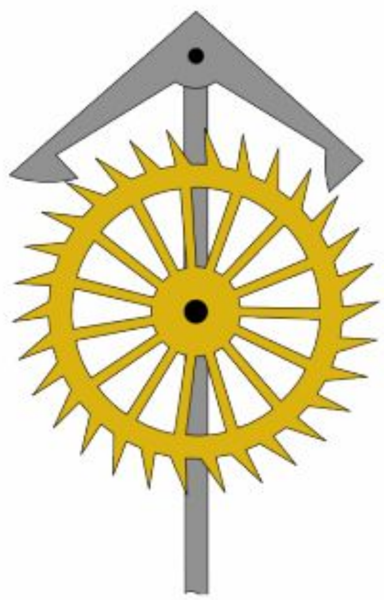
2. A way to convert between seconds, minutes, and hours (gears)

3. Most importantly: A way to move the hands at a very constant rate. **Ideate: How would you do that?**

The Escapement

- Why watches and clocks “tick”
- https://en.wikipedia.org/wiki/Escapement
- The escapement keeps the spring from rapidly unwinding
- A pendulum (or escape wheel, i.e. a rotary pendulum) allows the gears to advance a fixed amount at every oscillation
- The escapement also injects energy to keep the pendulum moving

Explanatory video:
https://youtu.be/rL0_vOw6eCc?t=370



Back to navigation

- Early timepieces were still inaccurate
- Isochronism: The ability to keep time at a constant rate over long periods of time
- 1714: British government offers the Longitude Prize, $4 million in 2019 currency for the first clock accurate enough for navigation
  - John Harrison wins the prize in 1761 after 31 years of dedicated work to improve the escapement
  - Chronometer escapement: https://www.youtube.com/watch?v=cQvopnjDI6E

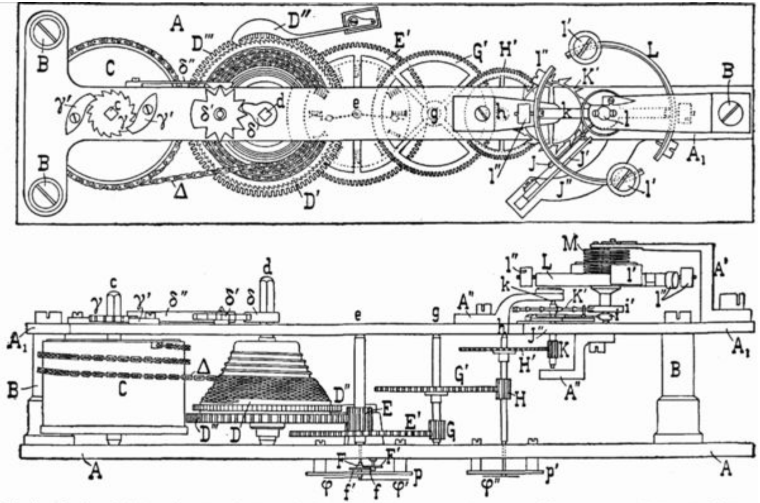


Fig. 1. *A* obere Platine. A_1 untere Platine. *A′* Brücke der Unruhe. *A″* Brücke der Hemmung. *B* Pfeiler der Platine. *C* Federhaus. *c* Federwelle. *γ* Sperrad für die Feder. *γ′* Sperrkegel. *D* Schnecke. *D′* Gegenſperrad. *D″* Sperrfeder für das Gegenſperrad. *D‴* Schneckenrad. *d* Schneckenwelle. *Δ* Kette. *δ* Zahn der Stellung. *δ′* Stellungsrad. *δ″* Stellungsfeder. *E* Trieb des Großbodenrads. *E′* Großbodenrad. *e* Achſe des Großbodenrads. *F* Minutenrohr. *F′* Wechſelrad. *f* Trieb des Wechſelrads. *f′* Stundenrad. *φ* Stundenzeiger. *φ′* Minutenzeiger. *φ″* Sekundenzeiger. *G* Trieb des Kleinbodenrads. *G′* Kleinbodenrad. *g* Achſe des Kleinbodenrads. *H* Trieb des Sekundenrads. *H′* Sekundenrad. *h* Achſe des Sekundenrads. *J* Hemmungsfeder. *J′* Anſchlagkloben für die Hemmungsfeder. *J″* Brücke der Hemmungsfeder. *i* Kleine Rolle. *i′* Große Rolle. *K* Trieb des Hemmungsrads. *K′* Hemmungsrad. *k* Steg der Unruhe. *L* Unruhe. *l* Achſe der Unruhe. *l′* Kompenſationsgewichte. *l″* Regulierſchrauben. *M* Spirale.

From watches to automata: Machines with programs

Other (more impressive) automata

Birdcage automata

Brittany Nicole Cox and Antiquarian Horology: https://www.youtube.com/watch?v=irdTng8MbIE

Late 1700s Creepy music robot: https://www.youtube.com/watch?v=nITEU4fsqCU

Late 1700s Writing robot: https://www.youtube.com/watch?v=C7oSFNKIlaM

And now we're back to Babbage