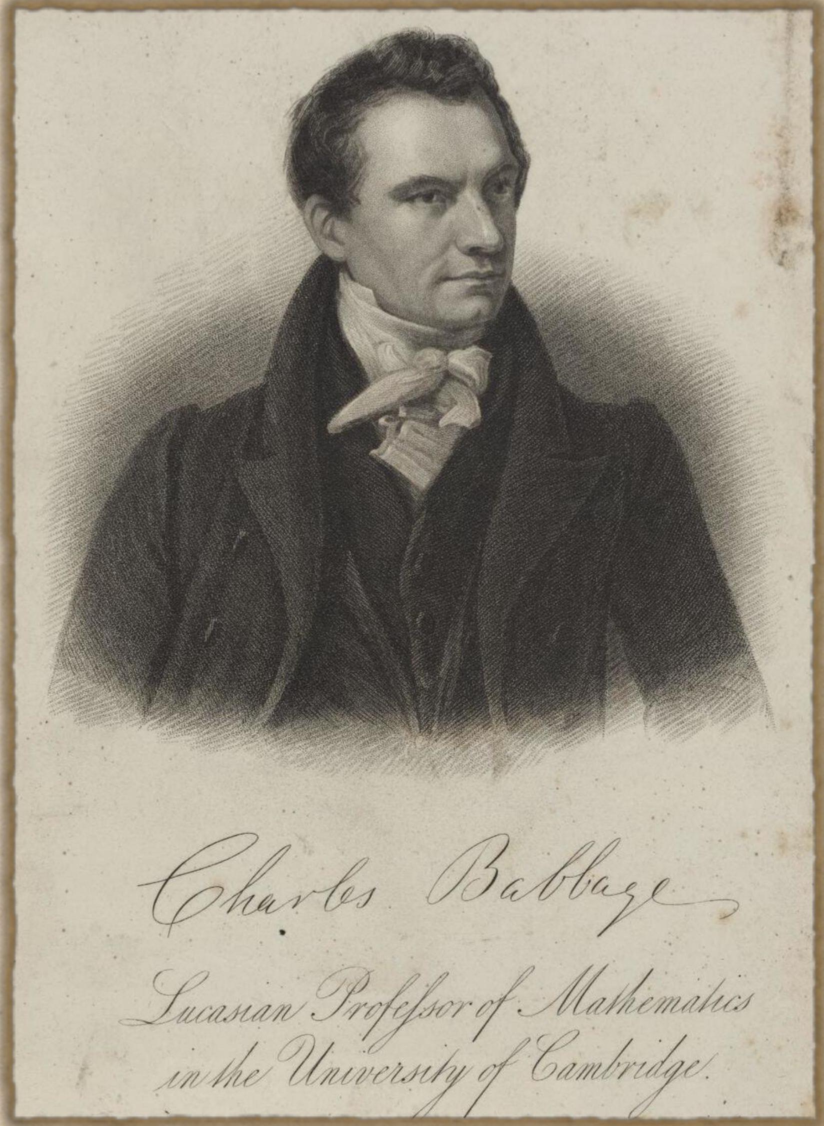
Charles Babbage

Father of the Computer

Charles Babbage: Polymath

Babbage had interests in Maths, Astronomy and Management Science.
He was a founder member of the Royal Astronomical Society and the British Association for the Advancement of Science.
He wrote “On the Economy of Machinery and Manufactures”



- Engraving of Babbage aged 42.

Babbage's Time Line

1791	Charles Babbage born in London
1812–14	Undergraduate at Peterhouse, Cambridge. Found maths old hat
1815	Lectured to Royal Institution (24 y.o.)
1816	Difference Equations. Made Fellow of the Royal Society (25 y.o.)
1820	Helped to found Royal Astronomical Society (29 y.o.)
1822	Invented Difference Engine (and printer) (31 y.o.)
1826	"Comparative View of Various Institutions for Life Assurance"
1827	Inherits equivalent of $10 million.
1828–39	Lucasian Professor at Cambridge. (37–48 y.o.) [Newton, Hawking]
1830	"Reflections on the Decline of Science"
1831	Helped found British Association for the Advancement of Science.
1832	"On the Economy of Machinery" (Babbage Principle) (41 y.o.)
1834–71	Plans for Analytical Engine; tinkered with until his death. (43-80 y.o.)
1847	Invented Difference Engine No. 2 (56 y.o.)
1871	Babbage died, age 80.

The Babbage Principle

Babbage observed that skilled workers often worked below their skill level. (Easy to notice when admin work stops you doing research.)

The Babbage Principle was that correct Division of Labour gave the easy jobs to unskilled workers, or even to machines.

Motivation for Difference Engine.

- In Babbage's day, sin(x), cos(x), etc., were found by looking them up in books of tables.
- Such books were full of errors.
- Babbage learnt that the French were generating navigational tables using a few skilled mathematicians and an army of people who merely had to add.
(An excellent use of the yet-to-be-invented Babbage Principle.)
- Even addition can be done incorrectly.
- Typesetting the results is error-prone.

Principle of Difference Engine

x	0	1	2	3	4	5	6	7	8	9
x^2	0	1	4	9	16	25	36	49	64	81
∂x^2		1	3	5	7	9	11	13	15	17
$\partial\partial x^2$			2	2	2	2	2	2	2	2

The differences between the squares are the odd numbers. The differences between the odd numbers are constant. Reverse the process and we can generate x^2.

Principle of Difference Engine

x	0	1	2	3	4	5	6	7	8	9
$\partial\partial\partial x^3$				6	6	6	6	6	6	6
$\partial\partial x^3$			6	12	18	24	30	36	42	48
∂x^3		1	7	19	37	61	91	127	169	217
x^3	0	1	8	27	64	125	216	343	512	729

With enough stages we can generate <u>any</u> power of x.

Principle of Difference Engine

x	0	1	2	3	4	5	6	7	8	9
$\partial\partial\partial(2x^2+x^3)$				6	6	6	6	6	6	6
$\partial\partial(2x^2+x^3)$			10	16	22	28	34	40	46	52
$\partial(2x^2+x^3)$		3	13	29	51	79	113	153	199	251
$2x^2+x^3$	0	3	16	45	96	175	288	441	640	891

With enough stages we can generate any polynomial in x.

Taylor Series (1715)

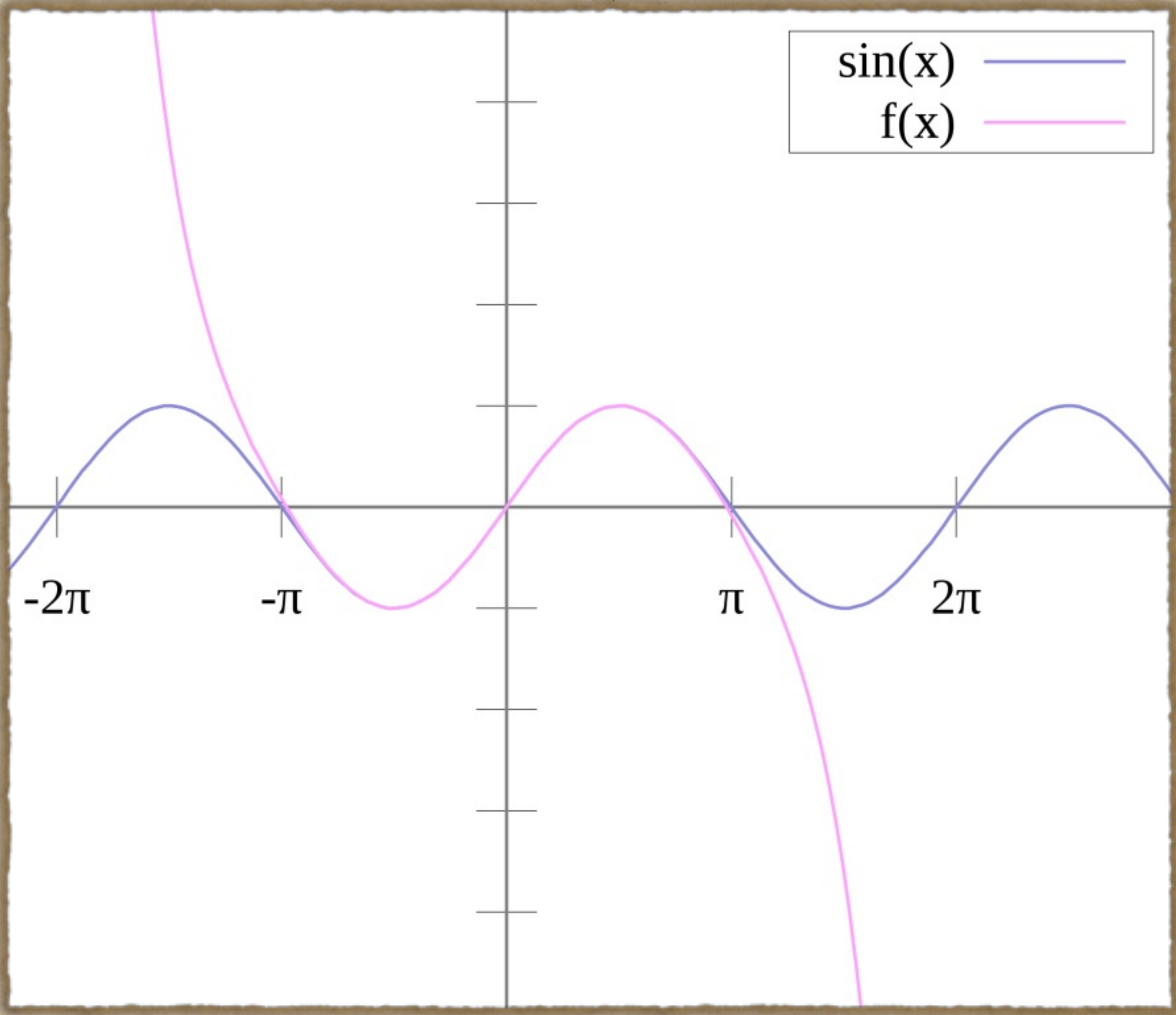
Any function can be approximated by a polynomial.

The blue line is the graph of sin(x).

The purple line is $f(x) = x/1! - x^3/3! + x^5/5! - x^7/7! + \ldots = x - x^3/6 + x^5/120 - x^7/5040 + \ldots$

For $x = \pi/2$, the value is $1.57079 - .64596 + .07969 - .00468 = 0.99984$. It should be 1.0.

The approximation is closest for small values of x, so that x^5, x^7, and so on are very small.



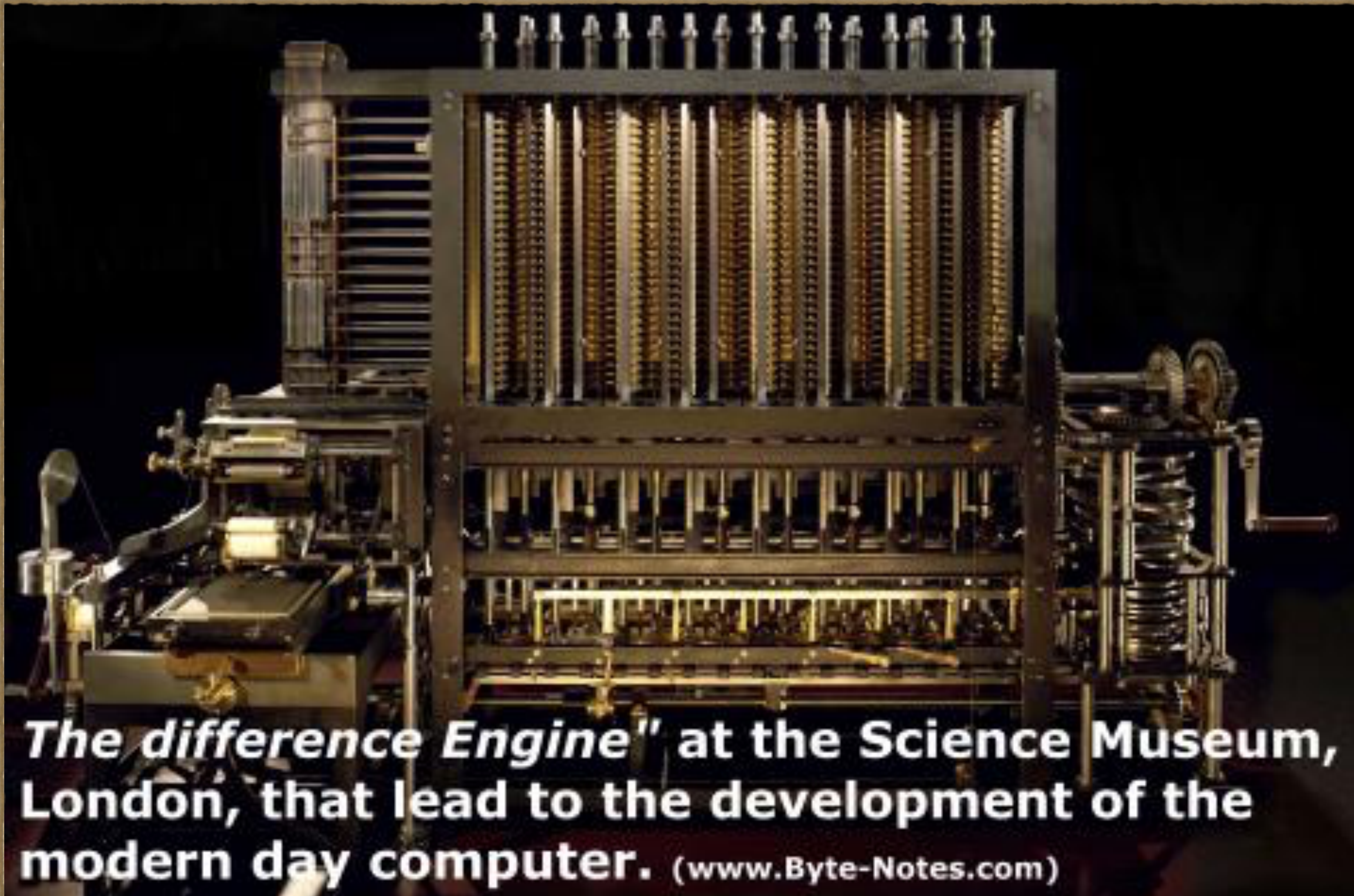
Taylor Series

The more terms the better,
but approximation is best for small values of x.

Degrees	0	10	20	30	40	50	60	70	80	90
Radians	0.0000	0.1745	0.3491	0.5236	0.6981	0.8727	1.0472	1.2217	1.3963	1.5708
sin(x)	0.0000	0.1736	0.3420	0.5000	0.6428	0.7660	0.8660	0.9397	0.9848	1.0000
$x-x^3/3!$	0.0000	0.1736	0.3420	0.4997	0.6414	0.7619	0.8558	0.9178	0.9426	0.9248
$+x^5/5!$	0.0000	0.1736	0.3420	0.5000	0.6428	0.7661	0.8663	0.9405	0.9868	1.0045
$-x^7/7!$	0.0000	0.1736	0.3420	0.5000	0.6428	0.7660	0.8660	0.9397	0.9848	0.9998
$1-(\pi/2-x)^2/2!$	-0.2337	0.0252	0.2537	0.4517	0.6192	0.7563	0.8629	0.9391	0.9848	1.0000
$+(\pi/2-x)^4/4!$	0.0200	0.1836	0.3465	0.5018	0.6434	0.7662	0.8661	0.9397	0.9848	1.0000
$-(\pi/2-x)^6/6!$	-0.0009	0.1733	0.3419	0.5000	0.6428	0.7660	0.8660	0.9397	0.9848	1.0000

The lower part of the table shows how we can keep x small.

We use the values of $90^\circ-x$. $\sin(x)=\cos(90-x)$. $\cos(x)=1-x^2/2!+x^4/4!-x^6/6!+\ldots$



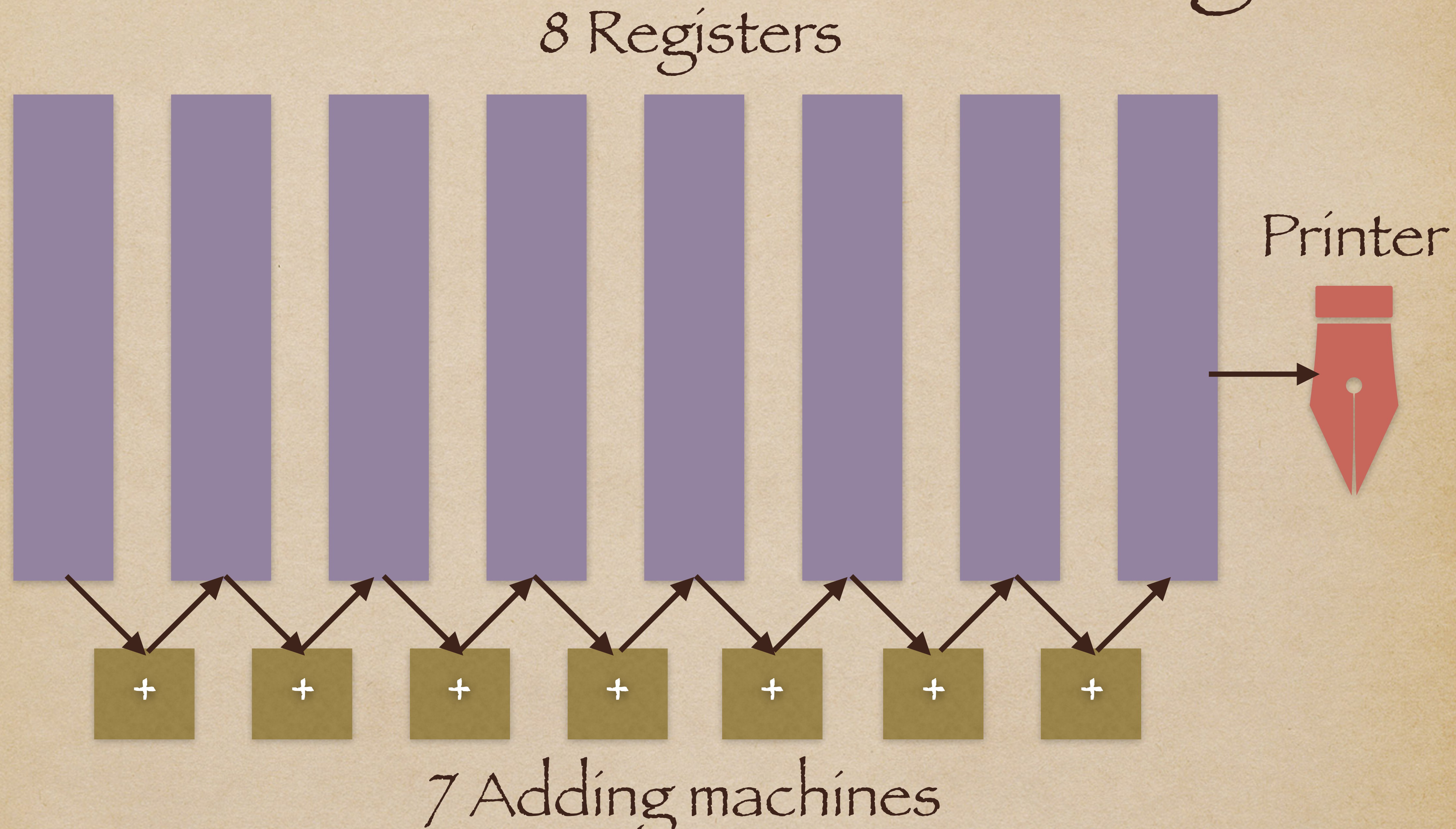
The difference Engine" at the Science Museum, London, that lead to the development of the modern day computer. (www.Byte-Notes.com)

The Arithmometer

Invented 1820 (2 yrs before Difference Engine),

Mass-produced 1851.

Structure of Difference Engine



This can generate any 7[th] order polynomial, given the right initial values in the registers.

Steam Age Time Line

1791	Charles Babbage born
1816	Babbage made FRS (age 25)
1820	'Arithmometer' (mechanical calculator) invented.
1821	Faraday demonstrates principle of electric motor
1822	Difference Engine (and its printer) invented (age 31)
1826	Photography invented
1828	Lucasian Professor at Cambridge (age 37)
1829	Stephenson's 'Rocket'
1832	'On the Economy of Machinery' (Babbage Principle)
1843	Typewriter invented
1834-71	Plans for Analytical Engine; tinkered with until his death.
1847	Difference Engine No. 2 invented
1991	Difference Engine No. 2 completed by British Science Museum
2000	Difference Engine Printer completed
2021?	Analytical Engine Completed. (Design was 'crowd-sourced'.)

Motivation for Analytical Engine

The design of the Difference Engine is <u>repetitive</u>.

Why not use <u>one</u> adder and store intermediate results?

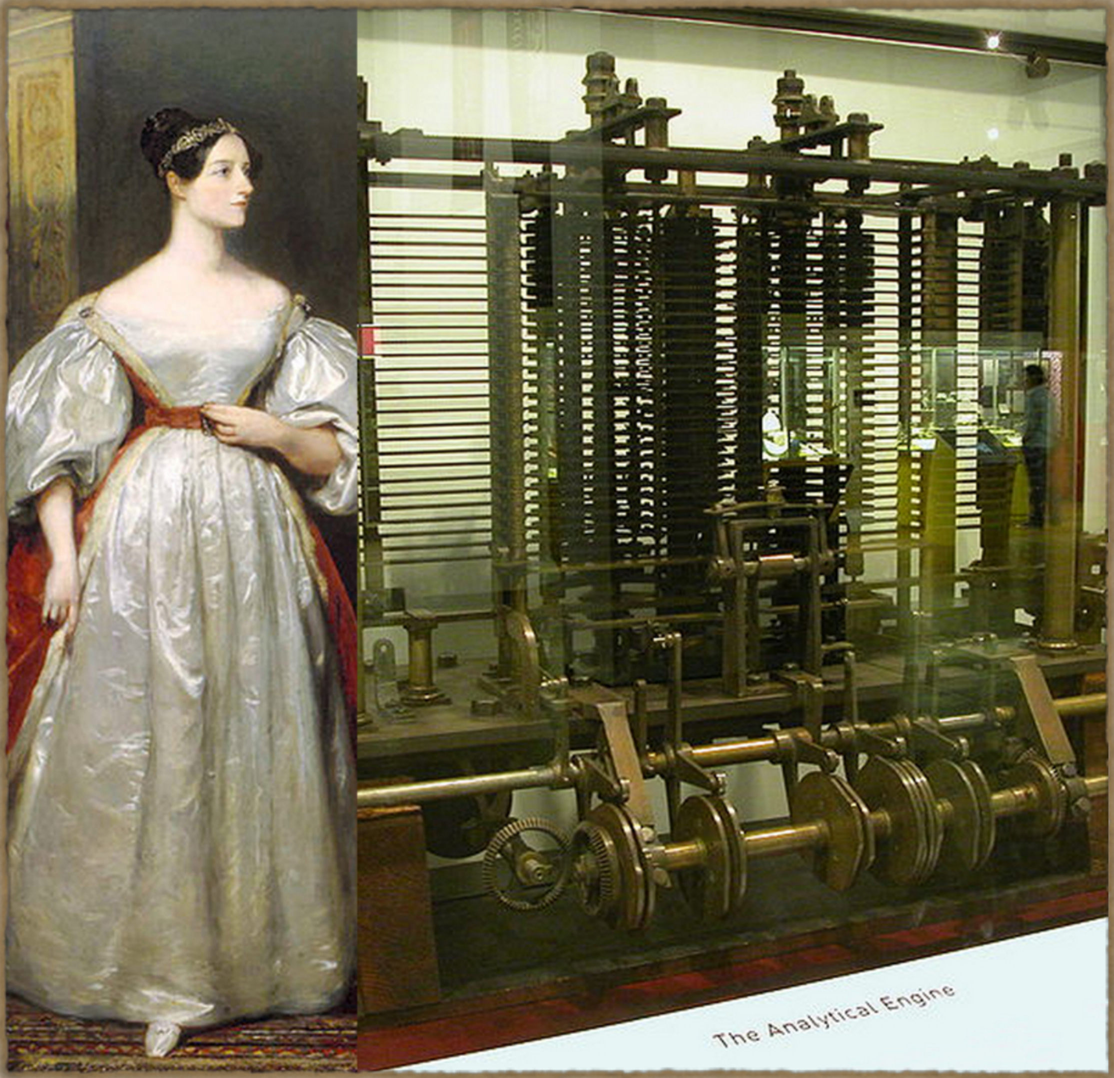
Now we need a <u>program</u> to tell it what to do.

But we can tell it what we like.

We can microprogram operations like multiplication.

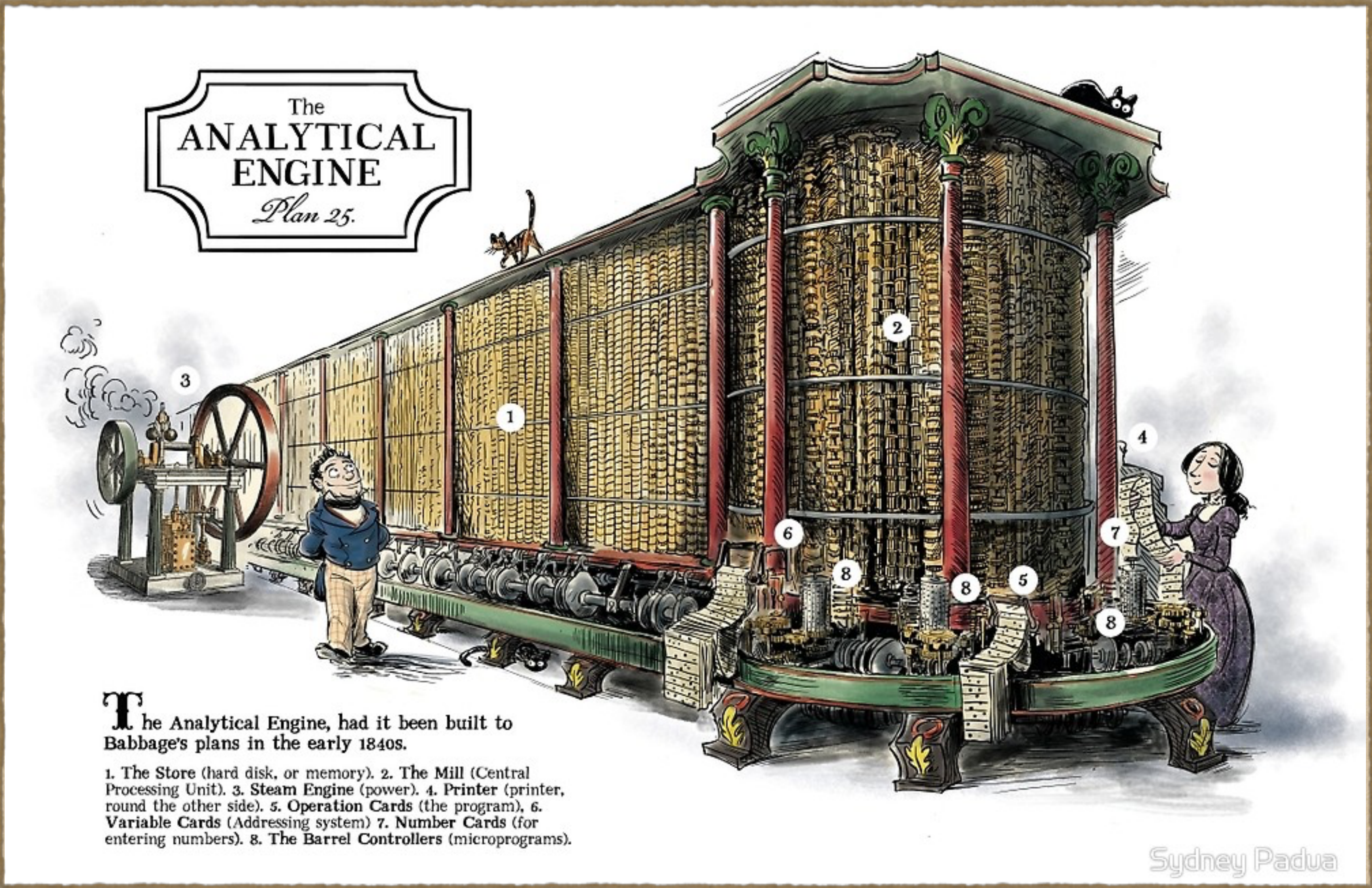
We now have all the ingredients of a modern computer!

Except binary. Except floating-point numbers.



Ada Lovelace & The Analytical Engine

Both are replicas. Not the whole machine!



Babbage's 25th plan for the Analytical Engine

1. The memory. 2. The CPU. 5. Program cards.
6. Addressing cards. 7. Data cards. 8. Microprogram.

Specification of Analytical Engine

- It had operation cards, 3-digit address cards, and 50-digit number cards.
- The 'Mill' had two 50-digit input registers, one with a 50-digit extension for double precision arithmetic, and one double-precision output register.
- It could divide a 100-digit dividend by a 50-digit divisor and store a 50-digit quotient and a 50-digit remainder.
- Why 50? It didn't support floating point, so numbers had to be scaled.
- It could also multiply, add, divide, find square roots and shift N places.
- A 'run lever' was set when, e.g., subtraction give a negative answer.
- It could skip N cards forward or back, depending on the state of the run-lever, enabling conditional loops and branches. (Turing complete.)

Work at the Science Museum

- Difference Engine No. 2 built to 19th century engineering tolerances. Completed in 1991.
- Computes 7th-order polynomials to 31 digit accuracy.
- Matching printer completed in 2000.
- Analytical Engine to be completed for 150th anniversary of Babbage's death in 2021.
- There was no final design by Babbage, so the design chosen was crowd-sourced.
- It is expected to weigh 15 tons and have a 7 Hz clock.
- A Triumph of Steam Punk!

Exit.

Halt.

Stop run.

Quit.