

ChatGPT-5 for Technical Geeks: From Tutor to Research Companions

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On the AI road to AGI

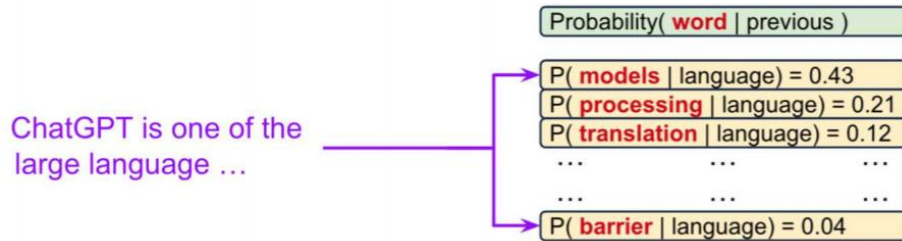
- Where does this all go?
- Sign indicates that we are going somewhere but where?
- how long?
- How do we even know when we have arrived?
- What is intelligence anyway?



An informal discussion on fascinating technology

- I'm not an AI expert nor do I develop AI tools
- Briefly, what is an LLM
- Why it is so powerful in the context of technical learning and research
- Is the LLM the only route to AGI? (speculation)
- Examples from my undergraduate class in electromagnetics
- Can the LLM based AI be creative and innovative in research?

What is a LLM



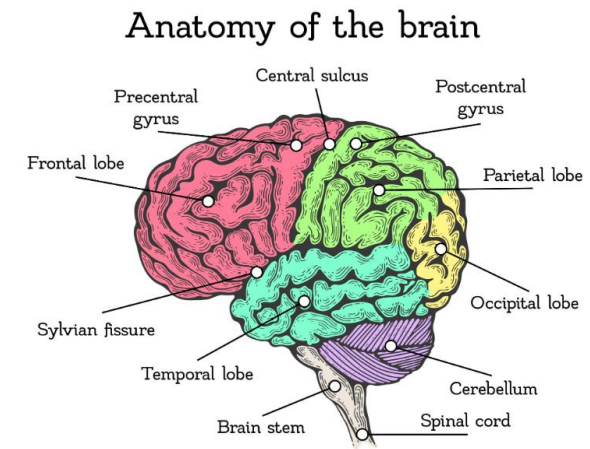
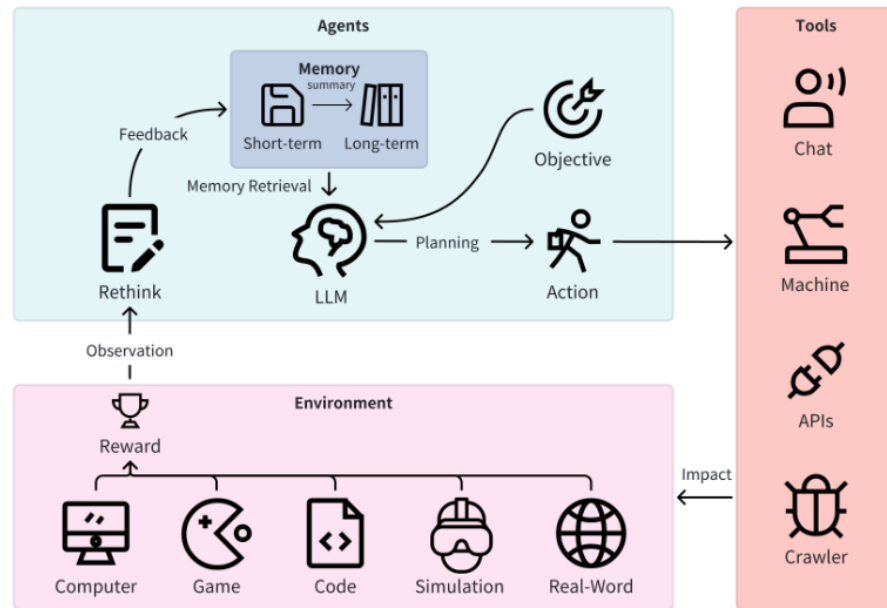
- Example with words but in general the LLM based on tokens, numbers representing words, image pixels, audio samples etc.
- hallucinations are innate property of LLM
- Breakthrough with Attention – context
- Words in sentence flag an ‘attention’ as to how important they are in the context of the overall sentence or paragraph.

“**The object** did not fit into **the box** as **it** was too_____”

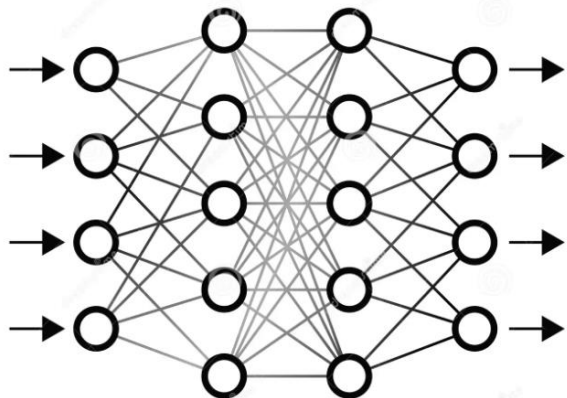
ambiguous sentence – what does **it** refer to

The emerging AI system

- LLM is the central NLP (natural language processor)
- Encapsulated in an agentic processing system
- Generates sequence of tasks for LLM, check, assembly of output
- Peripheral specialized tools – domain expertise
- May have multiple LLMs
- Not entirely dissimilar to biological brain

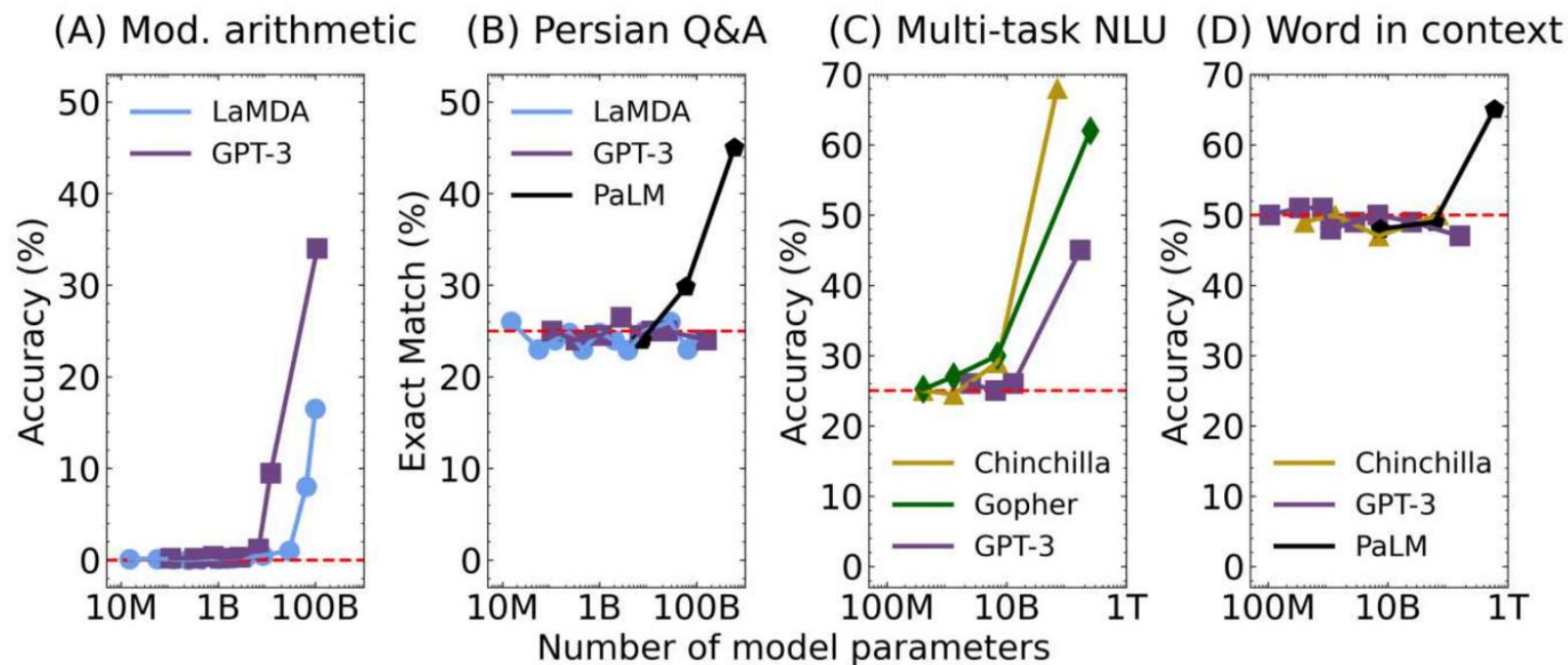


https://cdn.prod.website-files.com/6391b5b30283a58cafb3bb77/67a87d819e64b489ce4d74a3_agent-llm-modified.png



The mystery of emergent properties of scaling :

The emergent properties of large LLM transformers refer to **unexpected capabilities** that arise when these models are **scaled up** in terms of parameters (learned from data). These properties are not explicitly programmed or trained for—they "emerge" as a result of the model's complexity



"I found this book amazing!" —DANIEL KANEMAN

EVOLUTION, AI, AND THE
FIVE BREAKTHROUGHS
THAT MADE OUR BRAINS

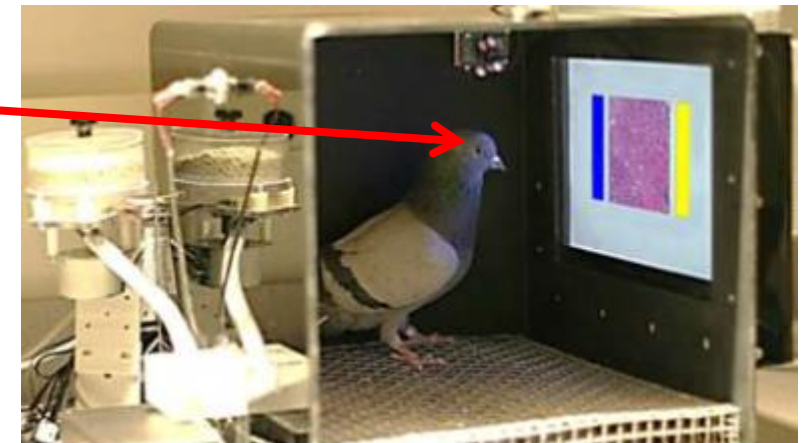
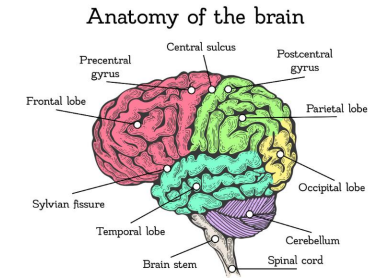
A BRIEF HISTORY OF INTELLIGENCE

MAX BENNETT

Emergent properties of the biological brain

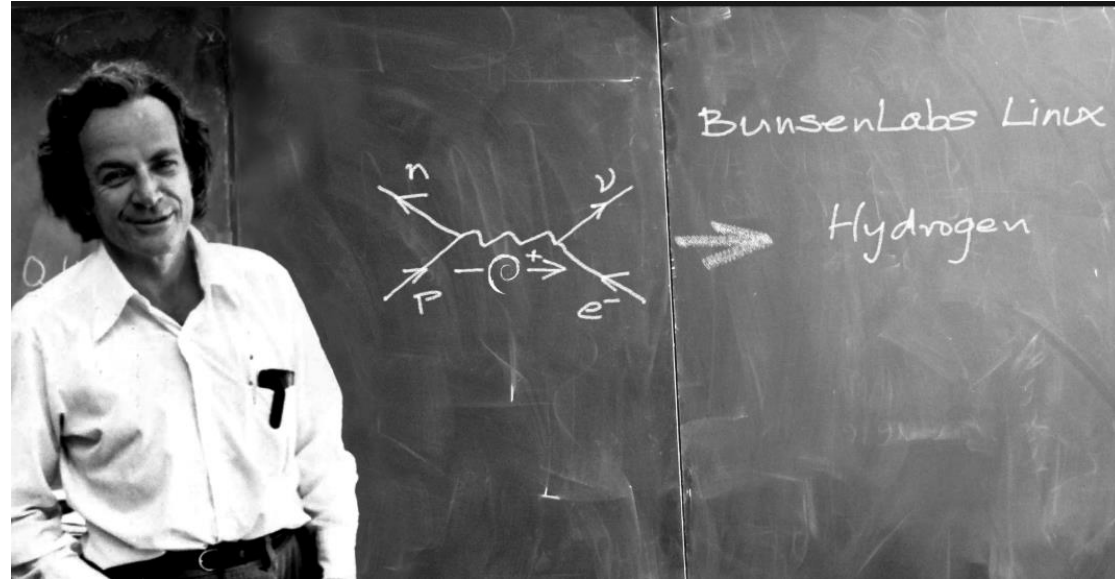
Fascinating question:

- Evolution grew the human brain to a large size – energy, weight, fragile, support systems
- Why did evolution focus on brain size and not algorithm complexity?
- Can we quantify emergent properties of the brain
- *loose parallels* to the LLM (+ agentic peripherals), large size but modest algorithm complexity
- humanlike learning and response of an LLM
- better understanding of how the human brain works, (learns, memory, cognitive functions) by LLM simulations?
- LLM exclusive path to AGI?
- Pigeon based LLM trained to discern malignant/benign tissue



"Anyone who claims to understand quantum theory is either lying or crazy."

Richard Feynman 1965 lecture series *The Character of Physical Law*



Perhaps the acclaimed 'Father of AI' Geoffroy Hinton would say:

"Anyone who claims to understand emergent properties of an LLM is either lying or crazy."



Dr. Hinton, Nobel laureate, University of Toronto, emeritus developed ways of training large neural networks thereby making them of practical use in the 2000's.

Scale Baby Scale!

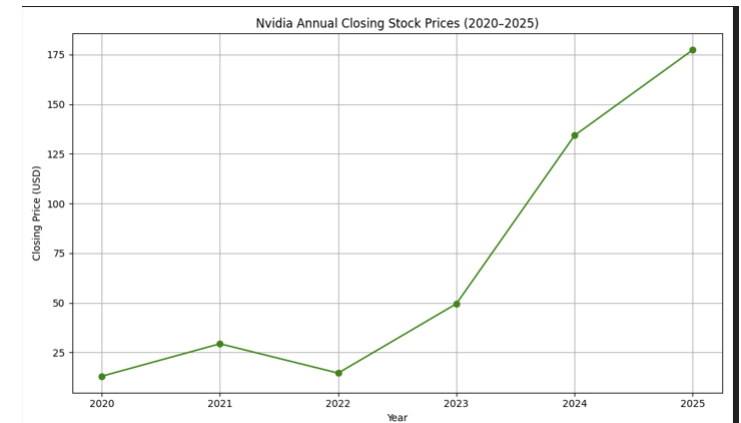
- Capitalize on emergent phenomenon - hundreds of billions to trillions of parameters.
- Costs giga-bucks of investment.
- Alphabet (Google) \$75B
Meta \$140B
Microsoft \$93 Billion (13 to openAI, 80 to data centers and agent development)

Amazon \$100B

Anthropic \$8.4B

Deepseek (CCP) ??

- LLM development creates a big-player oligopoly, small fries pushed out



Sad side Note: Missed that they are all dependent on Nvidia chips several years ago, Nvidia's monopoly, so not retired yet! (btw Nvidia just invested \$100B in OpenAI)

Big bad tech tycoon dictators and their evil giga data centers



[North America Data Centers - 4335 Facilities](#)

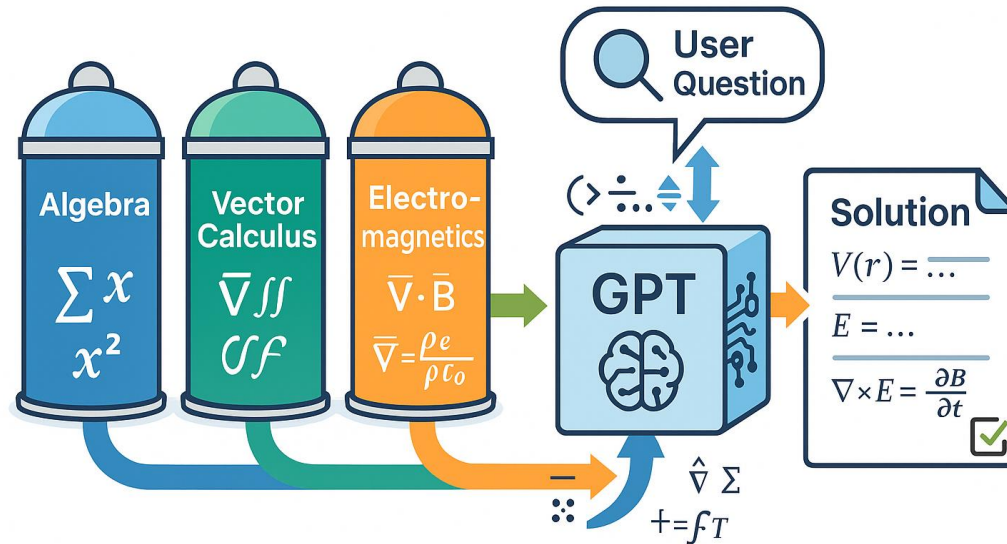
- Globally, data centers consumed around **415 TWh** in 2024 (**47 GW**)
- Water for cooling
- High cost feeds into oligopoly who ultimately controls AGI
- Geopolitical dystopia
- Inexorably headed for a crash – global demand and limited data center capacity, water and electric power scarcity

A more palatable scenario?

- Global electricity generation capacity is 30,853 terawatt-hours (TWh) annually
- Data centers consume 1.3% of world power, but will grow to maybe 5%? 10%?
- Creative recycled cooling water and higher efficiency processing
- AI should make worldwide electrical distribution and use more efficient – does that count as an offset?
- Agentic development is democratised over many s/m/l tech companies with the large players controlling the LLM
- parallel to Apple and it's many apps? Apple being a \$T company, net benefit to society
- Currently aggressive competition, hope the oligopoly does not turn into a monopoly (eg. Nvidia+OpenAI?)
- Trivia – human brain is about 20W, 25 billion brains same power as current data centers

What makes the LLM so useful in technical learning and research?

LLM is a 'next token selection' based on context and attention – that is it!

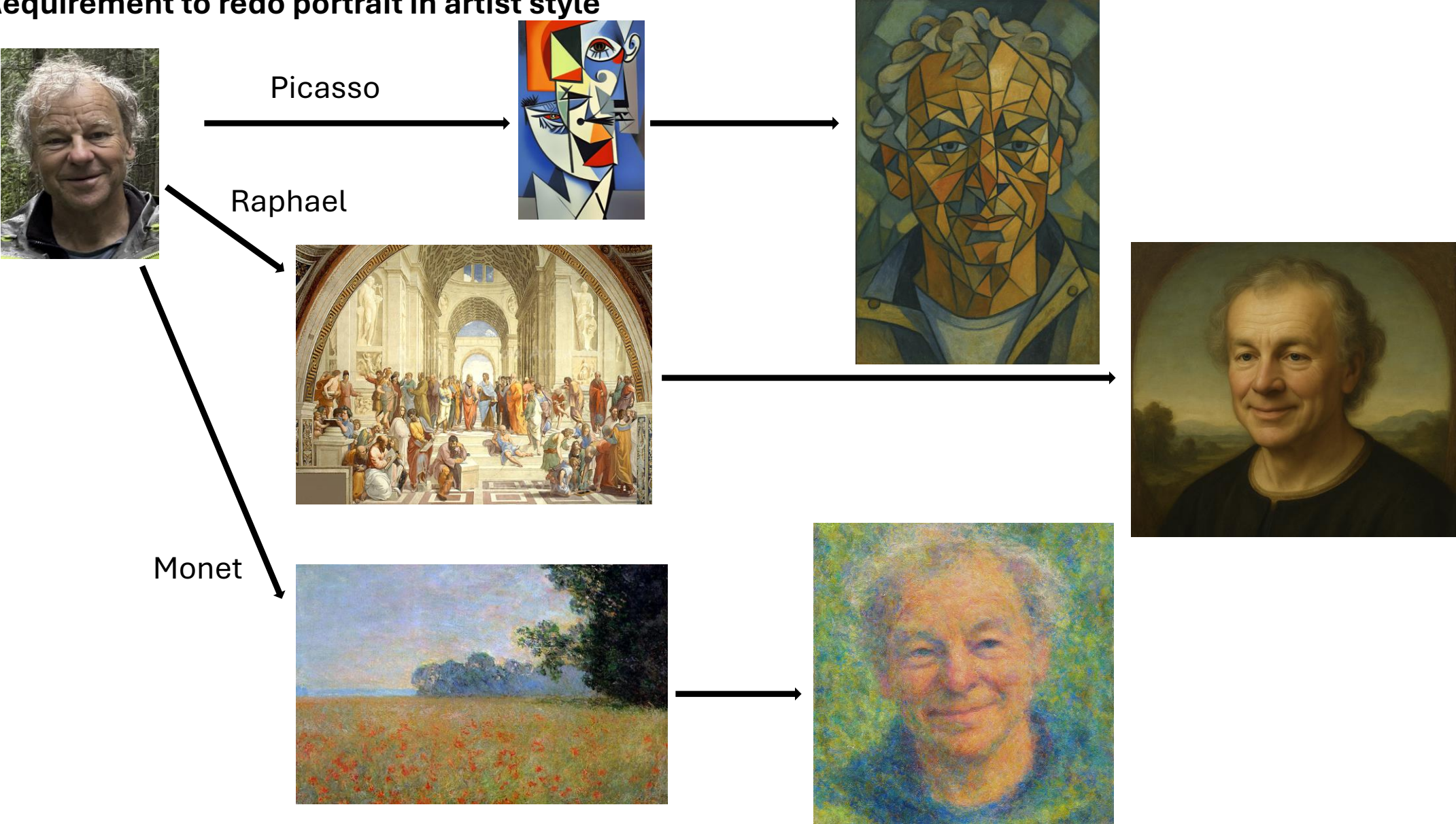


Deductive synthesis from multiple domains

openAI DALLE generated image

Deductive reasoning from multiple simultaneous silos of disparate knowledge is extremely useful.

Combining sources of data – portrait image with trained data of artists
Requirement to redo portrait in artist style



How can we use in engineering tech training?

- Much simpler than AGI as it is focussed to a specific subject and standardized ways of learning that subject.
- LLM already sufficient
- Aided by many published textbooks over the past 100 years.
- Experiment of applying to undergraduate class in electromagnetics and numerical problem analysis
- Have a personalized tutor for a specialized subject is reasonable in a couple of years time.
- Business opportunity for ailing textbook companies?
- Based on development of a specialized GPT with the LLM as the base.

Show the steps of a solution suitable for an undergraduate class tutorial in electromagnetics, of three simple problems. The first of the E field on the z axis with two point charges on the x axis. The next with the two point charges at arbitrary locations on the z=0 plane and the third problem with a segment of charge along the z axis and the E field evaluated on the x axis

Thought for 55s

Great choice of three “clean” setups. I’ll keep it tutorial-style: clear geometry, what to compute, the few identities you need, and the final expressions.

1) Two point charges on the x-axis; field on the z-axis

Geometry. Charges q_1 at $(+a, 0, 0)$ and q_2 at $(-a, 0, 0)$. Evaluate \mathbf{E} at $P = (0, 0, z)$.

Coulomb field of one charge.

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \frac{q \mathbf{r}}{\|\mathbf{r}\|^3}$$

↓

Vectors from charges to P :

Vectors from charges to P :

$$\mathbf{r}_1 = P - (a, 0, 0) = (-a, 0, z), \quad \mathbf{r}_2 = P - (-a, 0, 0) = (a, 0, z)$$

$$\|\mathbf{r}_1\| = \|\mathbf{r}_2\| = (a^2 + z^2)^{1/2}.$$

Fields and sum (superposition):

$$\mathbf{E}_1 = \frac{1}{4\pi\epsilon_0} \frac{q_1(-a\hat{\mathbf{i}} + z\hat{\mathbf{k}})}{(a^2 + z^2)^{3/2}}, \quad \mathbf{E}_2 = \frac{1}{4\pi\epsilon_0} \frac{q_2(+a\hat{\mathbf{i}} + z\hat{\mathbf{k}})}{(a^2 + z^2)^{3/2}}$$

$$\mathbf{E}(P) = \frac{1}{4\pi\epsilon_0} \frac{a(q_2 - q_1)\hat{\mathbf{i}} + z(q_1 + q_2)\hat{\mathbf{k}}}{(a^2 + z^2)^{3/2}}$$

Useful special cases.

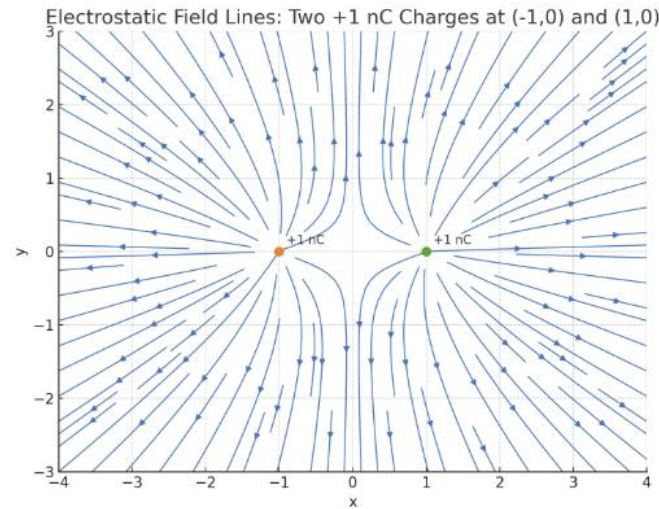
- If $q_1 = q_2 = q$: $E_x = 0$ by symmetry and

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{2qz}{(a^2 + z^2)^{3/2}} \hat{\mathbf{k}}.$$
 - If $q_1 = -q_2 = q$ (electric dipole): $E_z = 0$ and

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{2aq}{(a^2 + z^2)^{3/2}} \hat{\mathbf{i}}.$$
- ↓

Consider two charges of 1nC at x=-1 and x=1. Produce a Python script that plots the electrostatic field lines over a region of -4<x<4 and -3<y<3.

```
two_charges_fieldlines.py x
1 import numpy as np
2 import matplotlib.pyplot as plt
3
4 k = 8987551792.3 # Coulomb's constant (N·m²/C²)
5 q = 1e-09 # charge magnitude in Coulombs (1 nC)
6
7 charges = [(-1.0, 0.0, q), (1.0, 0.0, q)] # (x, y, charge)
8 nx, ny = 500, 400
9 x = np.linspace(-4.0, 4.0, nx)
10 y = np.linspace(-3.0, 3.0, ny)
11 X, Y = np.meshgrid(x, y)
12
13 Ex = np.zeros_like(X, dtype=float)
14 Ey = np.zeros_like(Y, dtype=float)
15 eps = 1e-3
16
17 for (x0, y0, qi) in charges:
18     Rx = X - x0
19     Ry = Y - y0
20     r2 = Rx**2 + Ry**2
21     r2[r2 < eps**2] = np.nan
22     r = np.sqrt(r2)
23     Er = k * qi / r2
24     Ex += Er * (Rx / r)
25     Ey += Er * (Ry / r)
26
```



1. Physics Behind the Code

Coulomb's Law

The electric field \vec{E} from a point charge q at a location (x_0, y_0) is given by:

$$\vec{E} = \frac{kq}{r^2} \hat{r}$$

where:

- $k \approx 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ (Coulomb's constant)
- r is the distance from the charge to the point of interest
- \hat{r} is the unit vector pointing from the charge to that point

Superposition Principle

Since the system is electrostatic, the total electric field is the **vector sum** of the fields from each charge. This is why the code loops over both charges and adds their E_x and E_y components.

2. Numerical Implementation

Grid Setup

```
python
x = np.linspace(-4, 4, nx)
y = np.linspace(-3, 3, ny)
X, Y = np.meshgrid(x, y)
```

- The plotting region $-4 < x < 4$, $-3 < y < 3$ is discretized into a rectangular grid.
- Each (X, Y) point is where we will compute the electric field vector.

Distance and Direction to Each Charge

```
python
Rx = X - x0
Ry = Y - y0
r2 = Rx**2 + Ry**2
r = np.sqrt(r2)
```

- R_x and R_y are the displacement components from the charge to each grid point.
- r^2 is used for the $1/r^2$ magnitude dependence in Coulomb's law.
- r is used for the unit vector $(R_x/r, R_y/r)$ ↓

Avoiding Division by Zero

All this from a clueless 'next token selection' program working with tokens that have nothing to do with electromagnetics nor python!

Example of a more challenging question

next do a step by step proof of Gauss' law starting with the total flux emanating from a point source on a spherical surface, then the generalization from there based on the beam solid angle

Thought for 32s

Awesome—here's a clean, tutorial-style proof that builds exactly the way you asked: (i) do the sphere around a point charge, then (ii) generalize using the "beam" (solid-angle) viewpoint, and (iii) conclude Gauss' law (integral and differential forms).

Step 1 — Flux of a point charge through a sphere

Setup. Point charge q at the origin. Field by Coulomb's law:

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{\mathbf{r}}.$$

On a sphere of radius R , $|\mathbf{E}| = \frac{1}{4\pi\epsilon_0} \frac{q}{R^2}$ is constant and $\mathbf{E} \parallel \hat{\mathbf{n}}$ (purely radial). So

$$\Phi_S = \iint_S \mathbf{E} \cdot d\mathbf{S} = \iint_S \left(\frac{1}{4\pi\epsilon_0} \frac{q}{R^2} \right) dS = \frac{1}{4\pi\epsilon_0} \frac{q}{R^2} (4\pi R^2) = \boxed{\frac{q}{\epsilon_0}}.$$

Step 2 — Flux element = "charge per solid angle" (beam picture)

For any small oriented surface patch dS at position \mathbf{r} ,

$$d\Phi = \mathbf{E} \cdot d\mathbf{S} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{\mathbf{r}} \cdot d\mathbf{S} = \frac{q}{4\pi\epsilon_0} \underbrace{\frac{\hat{\mathbf{r}} \cdot d\mathbf{S}}{r^2}}_{d\Omega}.$$

Here $d\Omega$ is the **solid angle** subtended by the patch as "seen" from the charge:

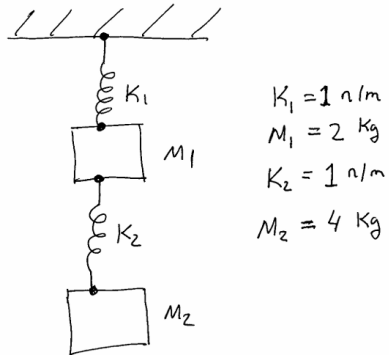
$$\boxed{d\Omega \equiv \frac{\hat{\mathbf{r}} \cdot d\mathbf{S}}{r^2}} \quad (\text{on a sphere: } d\Omega = \sin\theta \, d\theta \, d\phi).$$

Key interpretation: The field of a point charge sends out flux uniformly in direction; i.e., **flux per unit solid angle is constant** and equals $q/(4\pi\epsilon_0)$. So any "beam" of directions spanning solid angle Ω carries flux

$$\boxed{\Phi_{\text{beam}} = \frac{q}{4\pi\epsilon_0} \Omega}.$$

Engineering Pictionary

Can input sketches of mechanical diagrams and circuits
CV agent used in conjunction with LLM



Let $\mathbf{y} = [y_1 \ y_2]^T$. Then

$$\mathbf{M} \ddot{\mathbf{y}} + \mathbf{K} \mathbf{y} = 0, \quad \mathbf{M} = \begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}.$$

(Equivalently via Lagrange's equations with $T = \frac{1}{2} M_1 \dot{y}_1^2 + \frac{1}{2} M_2 \dot{y}_2^2$ and $V = \frac{1}{2} k_1 y_1^2 + \frac{1}{2} k_2 (y_2 - y_1)^2$.)

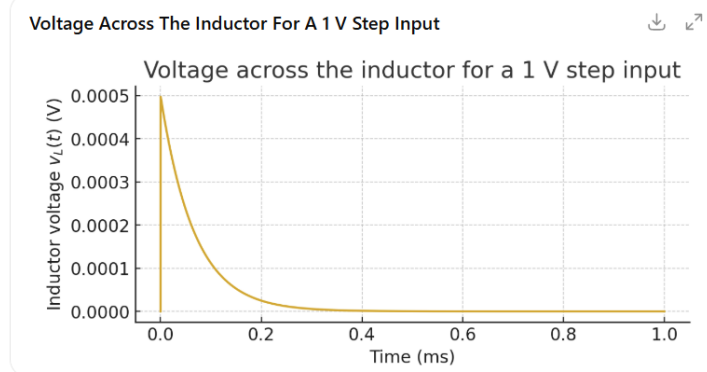
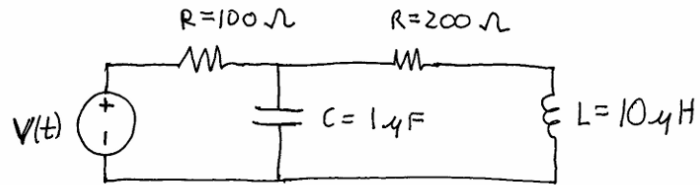
Optional check: natural frequencies.

Solve $\det(\mathbf{K} - \omega^2 \mathbf{M}) = 0$:

$$M_1 M_2 \omega^4 - [(k_1 + k_2) M_2 + M_1 k_2] \omega^2 + k_1 k_2 = 0.$$

(For the sketched numbers $k_1 = k_2 = 1$, $M_1 = 2$, $M_2 = 4$: $\omega \approx 0.331$ and 1.069 rad/s.)

Example of circuit diagram



Plotted! That's the inductor voltage $v_L(t)$ for a 1-V step at the input with $R_1 = 100\ \Omega$, $C = 1\ \mu\text{F}$, $R_2 = 200\ \Omega$, $L = 10\ \mu\text{H}$.

Model notes (what I simulated):

- Nodes: v_1 at the capacitor, $v_2 = v_L$ at the inductor.
- KCL/LTI equations (measured to ground):

$$C\dot{v}_1 = -\frac{v_1 - v_{\text{in}}}{R_1} - \frac{v_1 - v_2}{R_2},$$

$$v_2 = \frac{L}{R_2}(\dot{v}_1 - \dot{v}_2) \Rightarrow \dot{v}_2 = \dot{v}_1 - \frac{R_2}{L}v_2.$$

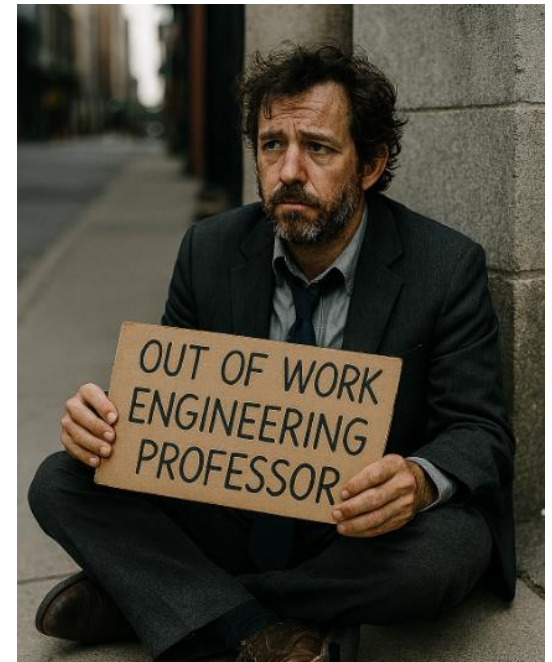
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Your personalized AI 24/7 tutor for electromagnetics around the corner?



openAI DALLÉ generated image

Where is the professor in this picture?



Limitations

LLM based entirely on context statistics – absolutely no understanding of the content

Will AGI eventually have ‘understanding’ whatever that means?

Lacks ‘coherence persistence’, cannot go over previous response and change some detail based on a conversational user query.

It starts over again just adding to the initial query and since the ‘next token algorithm’ is statistical it does unwanted changes.

This can lead to much frustration!

Much work to be done! ... but hey, look at how far AI has advanced in just a few years

Agentic AI is rapidly improving these deficiencies

Agentic LLM in research

- Can it be creative, inductive or innovative?
- Primarily deductive with a dash of randomness
- Are humans researchers also just deductive?
- Can there be creation out of nothing?

Hypothesis: For human or elusive AGI, creative genius does not come out of thin air. It all has roots in deduction from disparate fields spiced up with a touch of randomness.

Leonaird Euler 1850	fast fourier transform (FFT)	patterns in specialized math fields
Planck 1910	Blackbody radiation – birth of quantum mechanics	‘random’ desperation move of combining two disparate concepts
Einstein 1905	special relativity	inconsistency of Newton inertial frames and Maxwell
Shannon 1948	information theory	probability and Boltzmann entropy

Euler

Studied algebra, calculus, algorithms with application to mechanics and physics

For the FFT he saw a computational pattern (butterfly pattern)

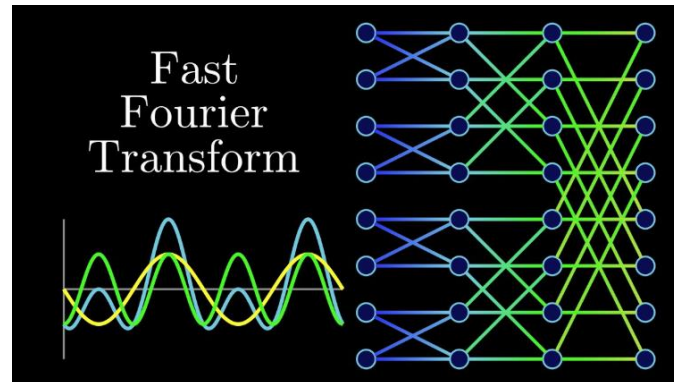
Computation went from N^2 to $N \log(N)$

Curiosity driven, as there was no computer to apply it to

A 'lucky **deduction**'?

Picked up by Tukey in 1960's, obscure paper

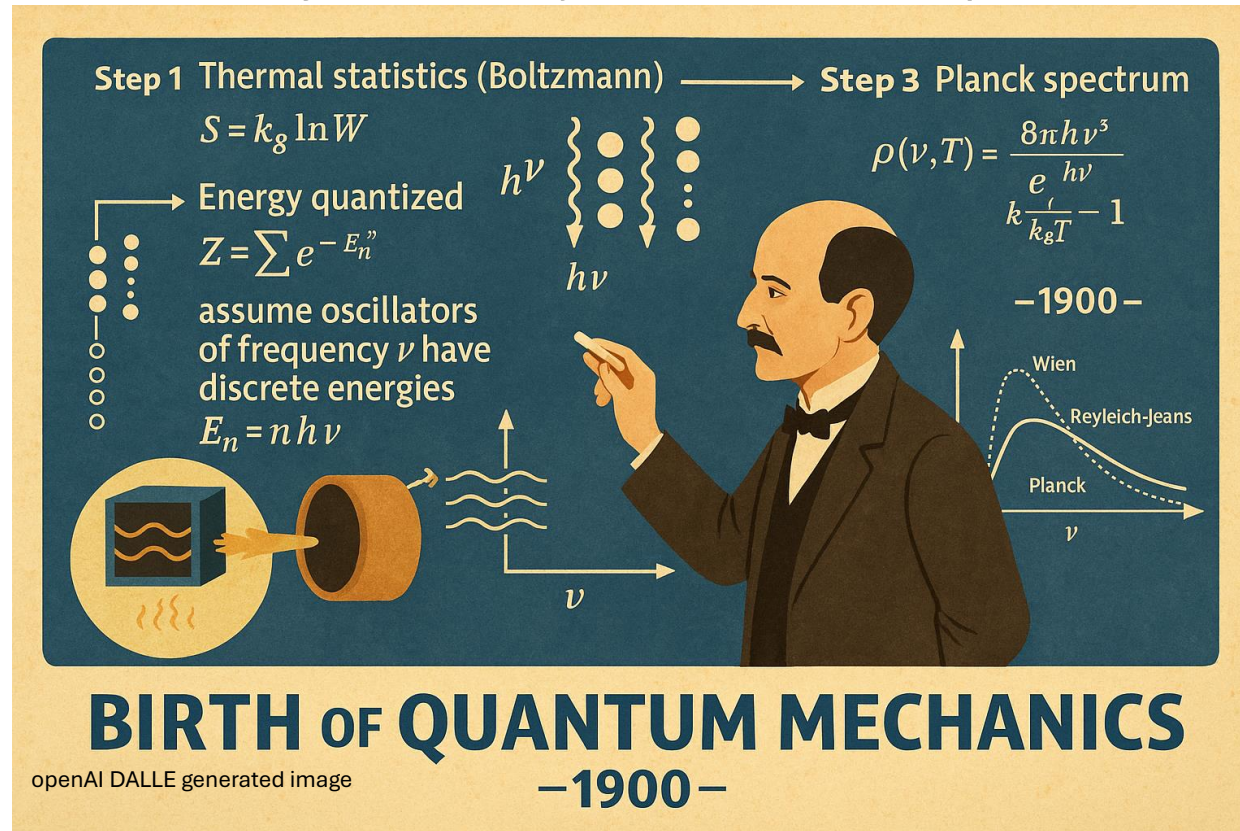
FFT cornerstone of DSP and generalized algorithms



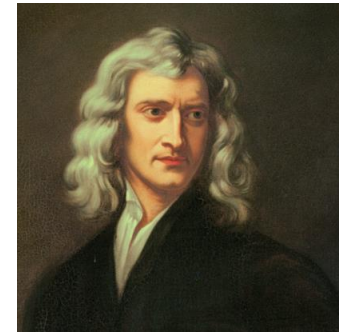
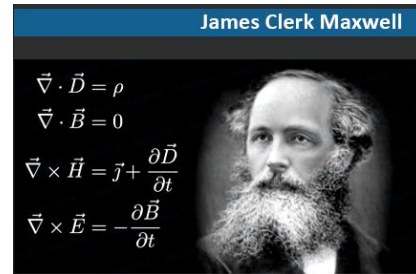
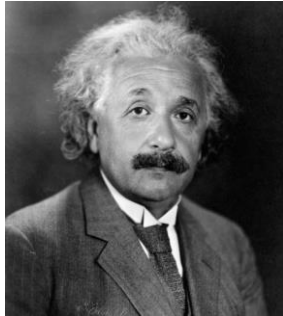
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Max Planck

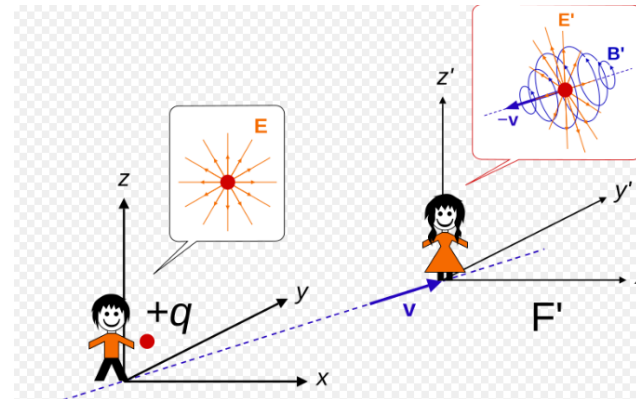
- Physics, discrete math, calculus, Boltzmann probability
- Blackbody radiator curve (wavelength vs temperature)
- Desperation move to quantize energy in calculation
- birth of quantum mechanics
- ***Desperate forced move*** to combine discrete math and continuous Boltzmann
- Did not understand why it worked – just did it out of desperation



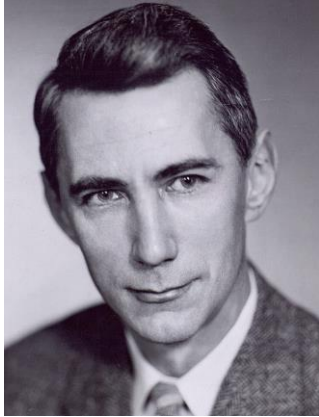
Einstein



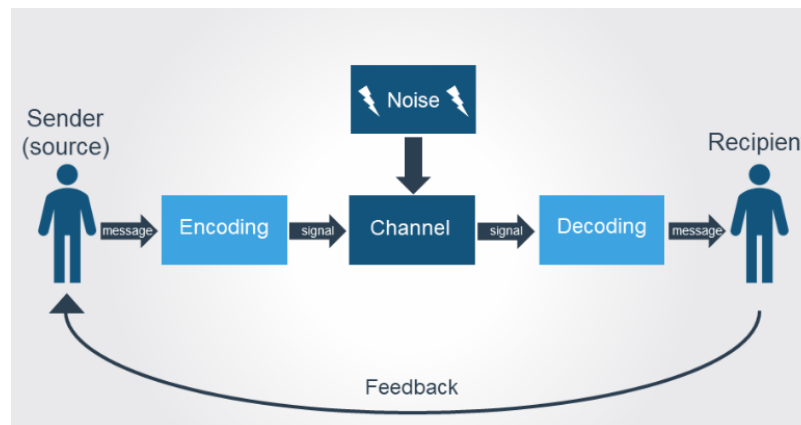
- Identified a **jarring inconsistency** – Newton universal time cannot be applied to electromagnetics.
- Electric and magnetic field are not referenced to an inertial frame
- Had the guts to state a preposterous solution to conundrum
- c is universal, time was not



Shannon



- Specialized in communications, probability and entropy
- **Saw the connection** between entropy and information
- Base of innovation that led to a clever formulism for how to quantify information
- Theoretical information theory led to practical coding theory
- Very clever deduction or creative genius?



Research innovation

Louis Pasteur, French chemist and microbiologist

In the fields of observation, chance favors only the well trained minds

A modern day version perhaps?

The emergent creative genius of an AGI favours a well trained LLM

Conclusion

Engineering education and research will dramatically change! (along with a whole bunch of other things)

These are exciting times of ‘move fast and break things!’

Hang on!!!