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2017 $\longrightarrow$ Now

One paper — *"Attention Is All You Need"* — launched ChatGPT, Claude, Gemini, and a $3 trillion industry.

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2017 → Now

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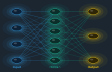
The secret? Every breakthrough in AI is built on math that already existed — most of it centuries old. Today we'll trace five mathematical ideas from ancient history to the AI running on your phone right now.



THE FIVE PILLARS

The Code of the Universe

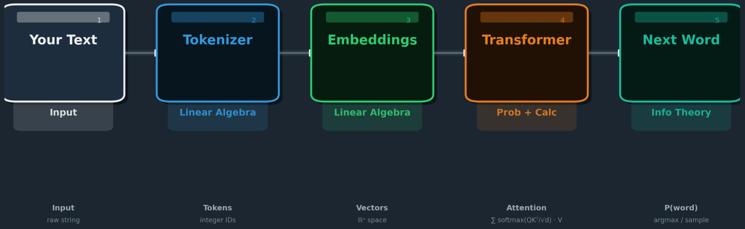
From Classical Mathematics to Large Language Models

The Five Mathematical Ideas Inside Every AI You Use

LLM Token Processing Pipeline

How an LLM Processes Text

Five mathematical stages from raw input to predicted next word



What Happens When You Ask ChatGPT a Question?

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4. The goal: minimize surprise (cross-entropy) — Information Theory
5. Optimizers like Adam make trillion-parameter training possible — Optimization

How LLMs Work — Visual Intro

Live Interactive Demo

3Blue1Brown — “Large Language Models explained briefly” (∼5 min)

`https://www.youtube.com/watch?v=LPZh9BOjkQs`

Transformer Explainer — Live GPT-2

Live Interactive Demo

Type text, see tokens $\rightarrow$ embeddings $\rightarrow$ attention $\rightarrow$ prediction

`https://poloclub.github.io/transformer-explainer/`

3D LLM Visualization

Live Interactive Demo

3D walkthrough of every matrix operation in a GPT model

`https://bbycroft.net/llm`

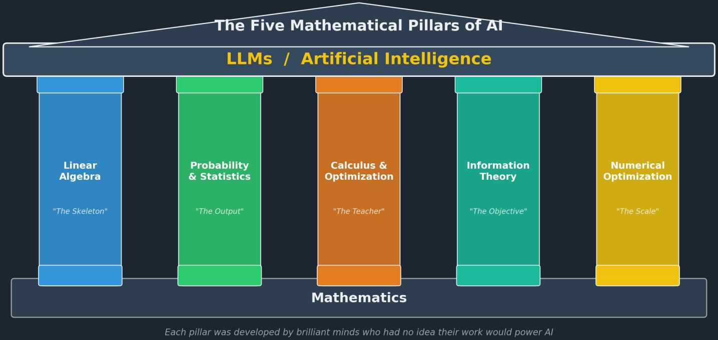
AnimatedLLM — Step by Step

Live Interactive Demo

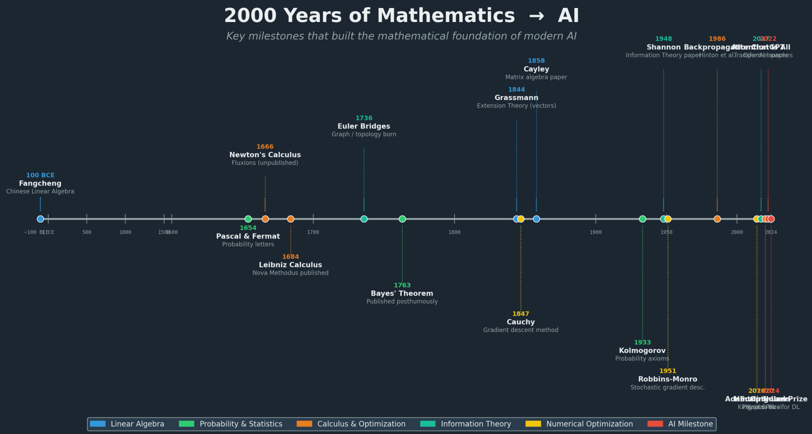
Step-by-step animation of text generation & training

`https://animatedllm.github.io/`

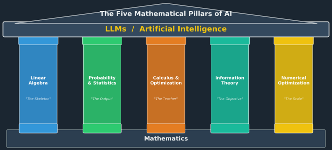
The Five Pillars of AI Mathematics



Mathematical Timeline: 100 BCE to 2024

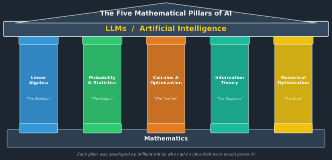


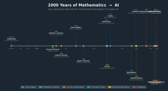
The Five Pillars



Each pillar was developed by brilliant minds who had no idea their work would power AI

The Five Pillars





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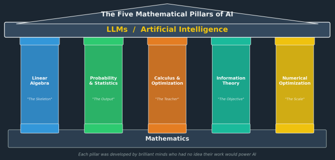

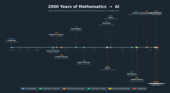

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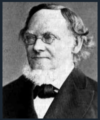
PILLAR 1

Linear Algebra

The Skeleton of AI

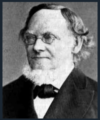
2000 Years of Linear Algebra



Hermann Grassmann

P1

2000 Years of Linear Algebra



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$\sim$**100 BCE** Chinese *Fangcheng* — solving systems with counting rods ORIGIN

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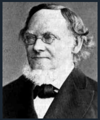

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1844 Grassmann publishes vector spaces — universally ignored

P1

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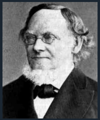

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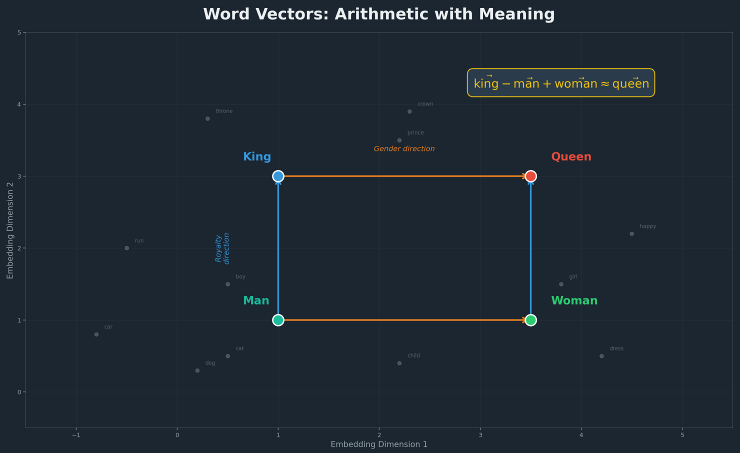
∼100 BCE Chinese *Fangcheng* — solving systems with counting rods ORIGIN

1844 Grassmann publishes vector spaces — universally ignored

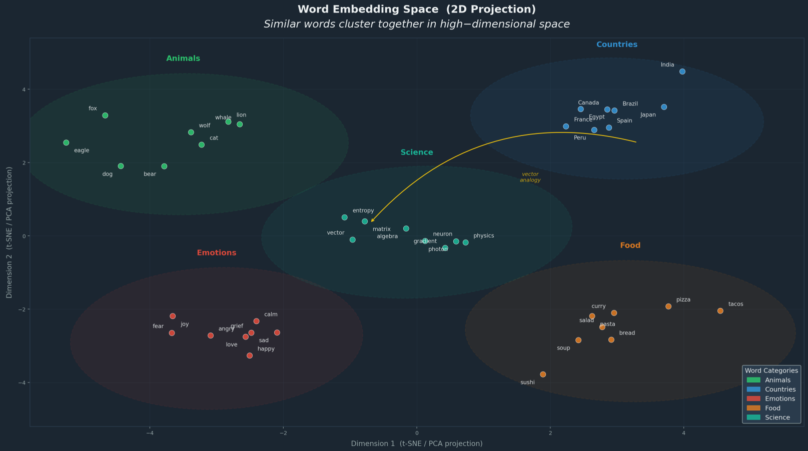
1858 Cayley invents matrix theory — while working as a lawyer

Arthur Cayley

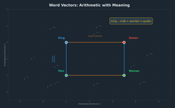
Word Vectors: King − Man + Woman = Queen



2D Word Embedding Space



P1 Words as Vectors AI Connection



$$\vec{\text{king}} - \vec{\text{man}} + \vec{\text{woman}} \approx \vec{\text{queen}}$$

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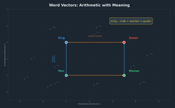

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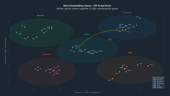

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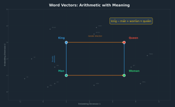

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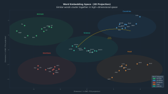
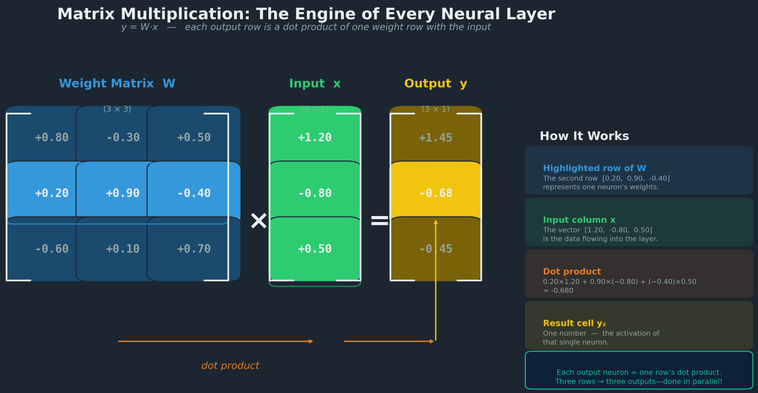


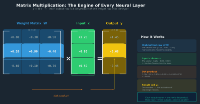
Mikolov et al., 2013 — Word2Vec: meaning encoded as geometry.

Matrix Multiplication: The Core Operation



The Engine: Matrix Multiplication

$$\text{output} = W \cdot \vec{x} + \vec{b}$$



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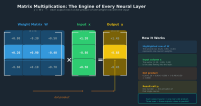

Every layer: multiply input vector by weight matrix

P1

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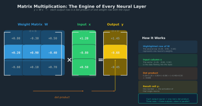


Every layer: multiply input vector by weight matrix

GPT-4: ∼1.8 trillion such multiplications per token

Attention Weight Heatmap

Attention: Which Words Look at Which?

Each word decides which other words are relevant ("Attention Is All You Need", 2017)

How to Read This

"The cat sat on the mat"

"cat" → The, sat

"cat" checks the article before it and the verb it performs

"sat" → cat, on

"sat" needs to know who is sitting and the location preposition

"mat" → on, the

"mat" ties back to "on" and the article "the" before it

Diagonal ≈ 0.18–0.25

Every word attends to itself with moderate weight

Bright cells = strong attention

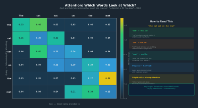
Yellow / green cells show the most important connections

Key insight: Transformers learn WHICH words to pay attention to — automatically!

P1 Attention = Three Matrix Multiplies BREAKTHROUGH

$$Q = XW_Q, \quad K = XW_K, \quad V = XW_V$$

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^T}{\sqrt{d_k}}\right)V$$



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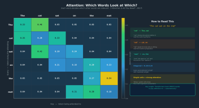


Three matrices. That's all attention is. Cayley's invention, applied to language.

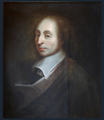
PILLAR 2

Probability & Statistics

The Language of Uncertainty

P2

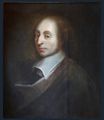
Born from Gambling



Blaise Pascal

Born from Gambling

1654 Pascal & Fermat exchange letters about a gambling problem ORIGIN



Blaise Pascal

Fermat

Bayes

Kolmogorov

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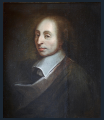

Blaise Pascal

Fermat

Bayes

Kolmogorov

P2 Born from Gambling

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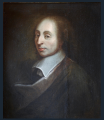
1763 Bayes' theorem published posthumously

1933 Kolmogorov writes the axioms — probability becomes rigorous



Blaise Pascal

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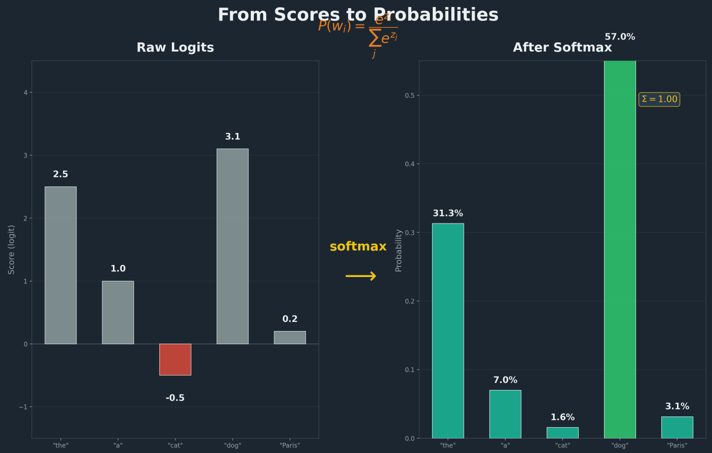
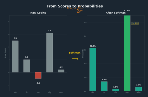
Softmax: From Logits to Probabilities

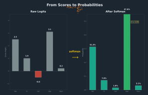


Turning Scores into Probabilities



$$P(w_i) = \frac{e^{z_i}}{\sum_j e^{z_j}}$$

Turning Scores into Probabilities



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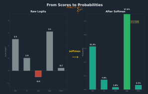
50,000+ words. One probability each. Kolmogorov's axioms in action.

Turning Scores into Probabilities



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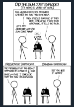
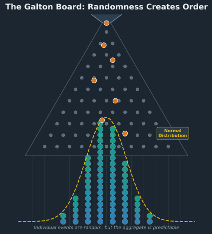


xkcd.com/1132 (CC BY-NC 2.5)

Randomness Creates Order

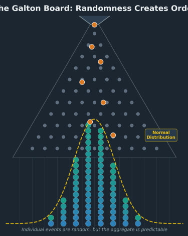


Wikimedia Commons (CC BY-SA 4.0)

Individual events are random.

But the aggregate forms a pattern.

Randomness Creates Order



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Individual events are random.

But the aggregate forms a pattern.

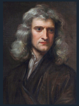
LLMs work the same way: each token is sampled randomly, but the sequence is coherent.

PILLAR 3

Calculus & Optimization

The Teacher

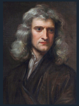
P3 The Calculus Wars ORIGIN



Newton (1666)

Leibniz (1684)

P3 **The Calculus Wars** ORIGIN



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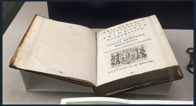
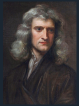


Principia Mathematica, 1713 ed.

The Calculus Wars

ORIGIN



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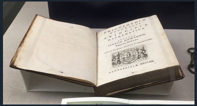
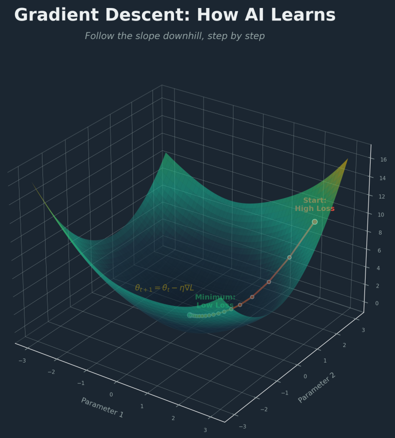


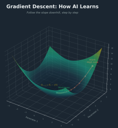
Principia Mathematica, 1713 ed.

Both invented calculus independently. We use Leibniz's notation: $\dfrac{dy}{dx}$

Gradient Descent on a Loss Surface

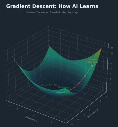


Gradient Descent: How AI Learns



Cauchy (1847)

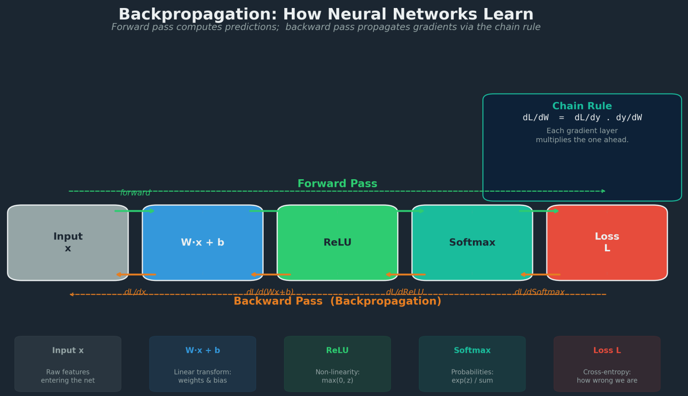
Gradient Descent: How AI Learns



Cauchy (1847)

Cauchy invented this in 1847 — for tracking planetary orbits.

Backpropagation: Forward and Backward Pass

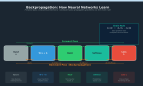


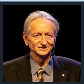
P3

Backpropagation = The Chain Rule

BREAKTHROUGH

$$\frac{\partial L}{\partial w} = \frac{\partial L}{\partial y} \cdot \frac{\partial y}{\partial w}$$





Hinton (Nobel 2024)

Backpropagation = The Chain Rule BREAKTHROUGH

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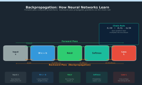

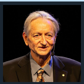

Hinton (Nobel 2024)

The chain rule: derivatives flow backward through every layer

P3 Backpropagation = The Chain Rule BREAKTHROUGH

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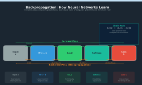

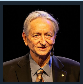

Hinton (Nobel 2024)

The chain rule: derivatives flow backward through every layer

1986: Rumelhart, Hinton & Williams publish in *Nature*

P3 Backpropagation = The Chain Rule BREAKTHROUGH

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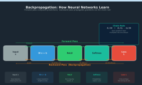

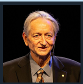

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2024: Hinton wins the Nobel Prize in Physics

PILLAR 4

Information Theory

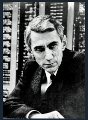
The Objective Function

P4

Shannon: Father of Information Theory

ORIGIN

> *"Information is the resolution of uncertainty."*
>
> — Claude Shannon



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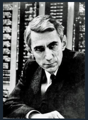

Claude Shannon

1948: "A Mathematical Theory of Communication" — invented the **bit**

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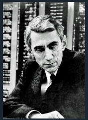
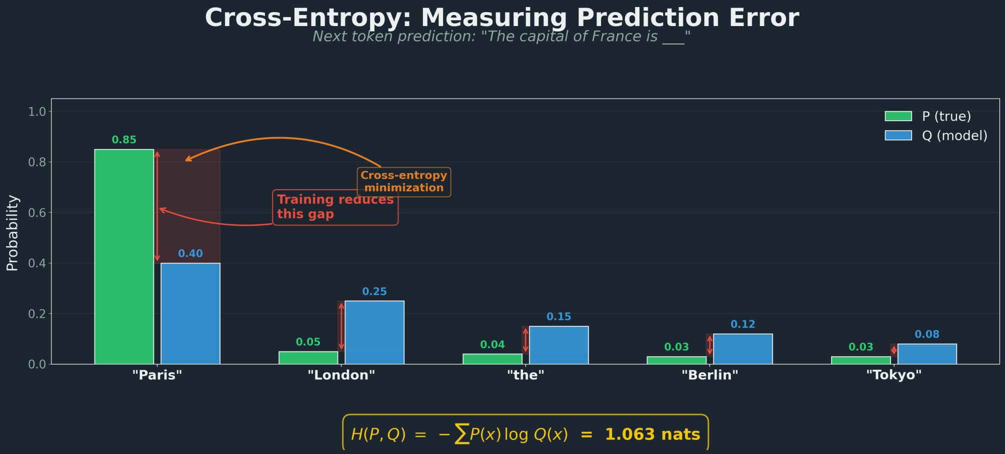


Claude Shannon

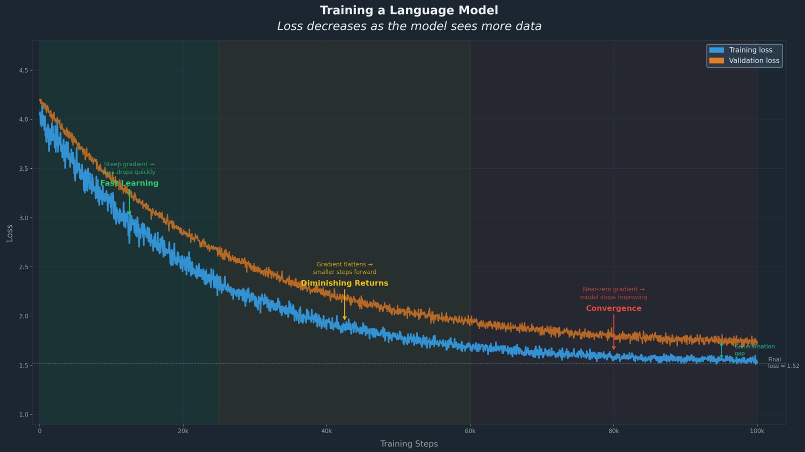
1948: "A Mathematical Theory of Communication" — invented the **bit**

Fun fact: Shannon juggled while riding a unicycle through Bell Labs

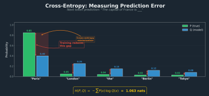
Cross-Entropy: Predicted vs True Distribution



Training Loss Curve Over Time

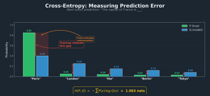


P4 Cross-Entropy: The LLM Loss Function AI CONNECTION



$$H(P,Q) = -\sum_x P(x) \log Q(x)$$

P4 Cross-Entropy: The LLM Loss Function AI CONNECTION



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Shannon's 1948 formula IS the training objective of every LLM.

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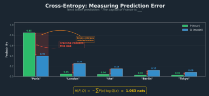

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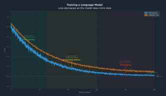
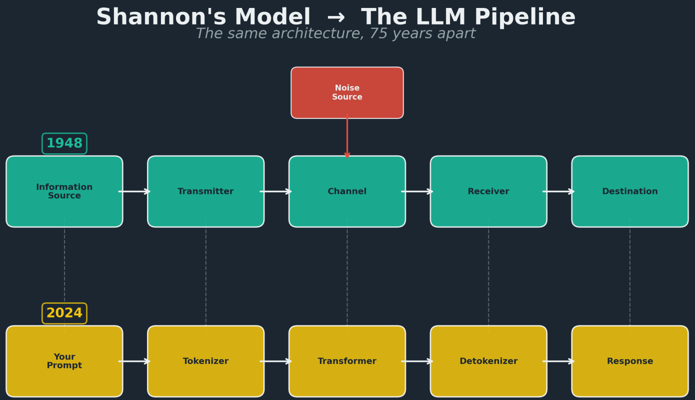


Training loss decreasing over time

Shannon's Communication Model as LLM Pipeline



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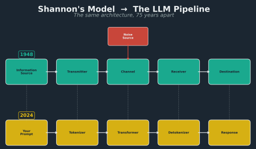

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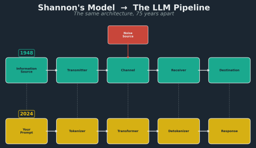


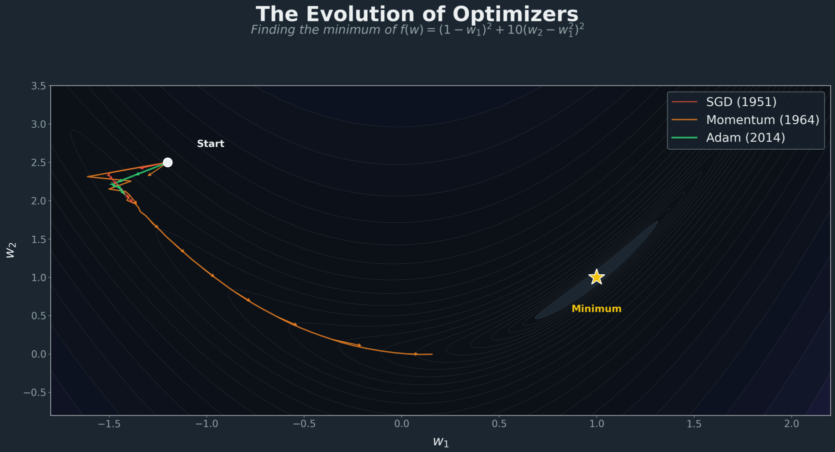
Shannon designed this for telephone lines. 75 years later, it describes exactly how ChatGPT works.

PILLAR 5

Numerical Optimization

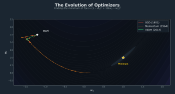
Training at Scale

SGD to Momentum to Adam

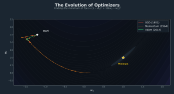


The Evolution of Optimizers

DISCOVERY



P5 The Evolution of Optimizers DISCOVERY

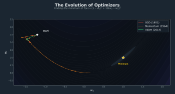


1951: Robbins & Monro invent SGD

P5

The Evolution of Optimizers

DISCOVERY



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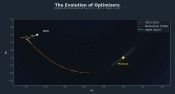

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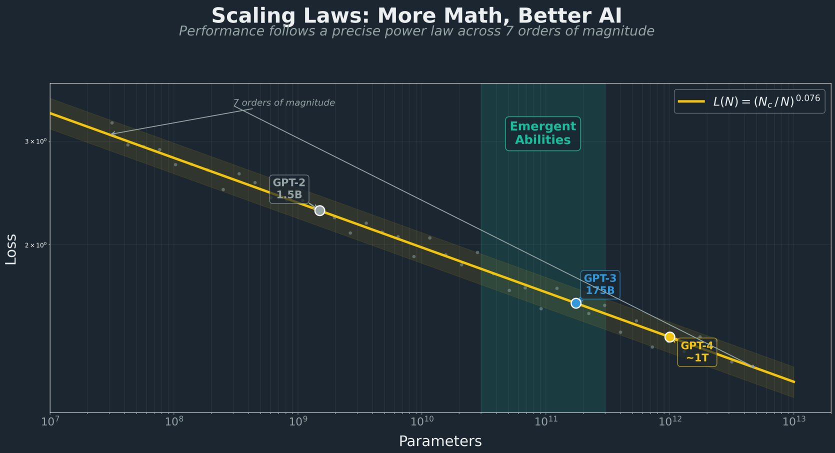
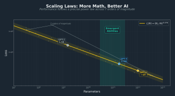
Neural Scaling Laws (Kaplan et al., 2020)



P5 More Math, Better AI AI CONNECTION



$$L(N) = \left(\frac{N_c}{N}\right)^{0.076}$$

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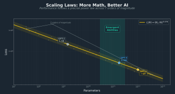

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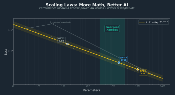
Kaplan et al., 2020 — why companies spend billions on bigger models.

P5

More Math, Better AI

AI Connection



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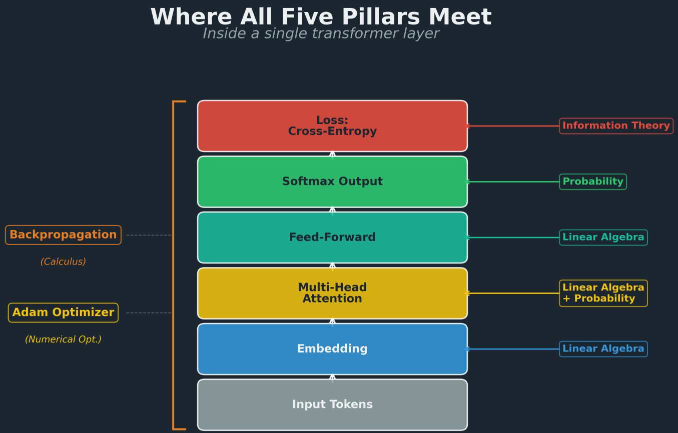
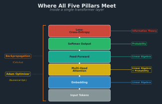
Kaplan et al., 2020 — why companies spend billions on bigger models.

xkcd.com/2048 (CC BY-NC 2.5)

All Five Pillars in One Forward-Backward Pass



Where All Five Pillars Meet



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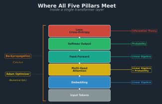
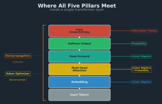


Linear Algebra	Probability	Calculus	Info Theory	Optimization
Skeleton	Language	Teacher	Objective	Scale

Where All Five Pillars Meet



Linear Algebra Skeleton	**Probability** Language	**Calculus** Teacher	**Info Theory** Objective	**Optimization** Scale

Five branches of pure mathematics, developed over 2000 years, all running simultaneously in a single forward-backward pass.

What LLMs Can Actually Do BREAKTHROUGH

> *"An AI won a Nobel Prize and a Math Olympiad gold medal. In back-to-back years."*

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35/42

IMO GOLD MEDAL 2025

Gemini Deep Think — only 67 of 630 humans earned gold

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Claude on standard benchmark

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Claude on standard benchmark

These are not predictions. These already happened.

The Numbers Are Stupid Big

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1.7T

Parameters in GPT-4

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$100M+

Training cost

25,000 GPUs for 90 days

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Training tokens

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Weekly ChatGPT users

1 in 10 humans on Earth (Oct 2025)

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Plot twist: DeepSeek R1 matched GPT-4 performance for $6 million. Open source.

Brilliant and Broken

> *“It solved an IMO problem but can’t count the letters in “strawberry.” Both true.”*

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Strawberry: Says there are 2 R's in "strawberry"

9.11 vs 9.9: Many LLMs claim 9.11 $>$ 9.9

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Why? LLMs are statistical pattern completers, not fact databases. There is no internal fact-checker.

The Race — Zero to Gold in 8 Years

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2017 **“Attention Is All You Need” paper** ORIGIN

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Jul 2025 AI scores IMO gold medal (35/42) AI CONNECTION

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   Free Copilot, free cloud credits, free everything
2. **Take the Kaggle Intro to ML course**
   Free, hands-on, takes one weekend
3. **Open Google Colab and run a notebook**
   Free GPU, no setup, works in your browser
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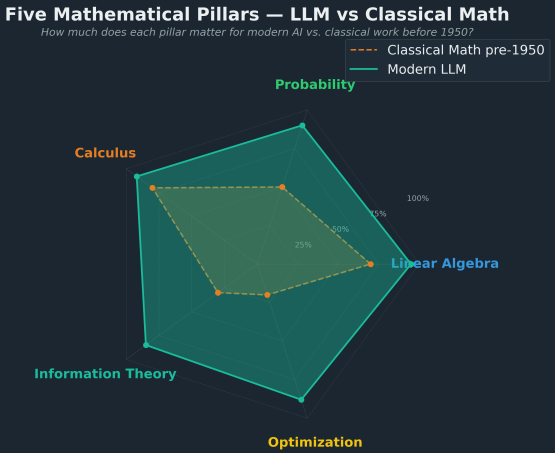
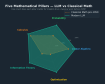
The tools are free. The courses are free. What are you doing this weekend?

Five Pillars: Convergence Radar



The Code Is Still Being Written



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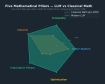

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- Research Mathematician
- Quantitative Analyst
- AI Safety Researcher

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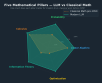

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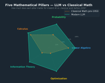

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