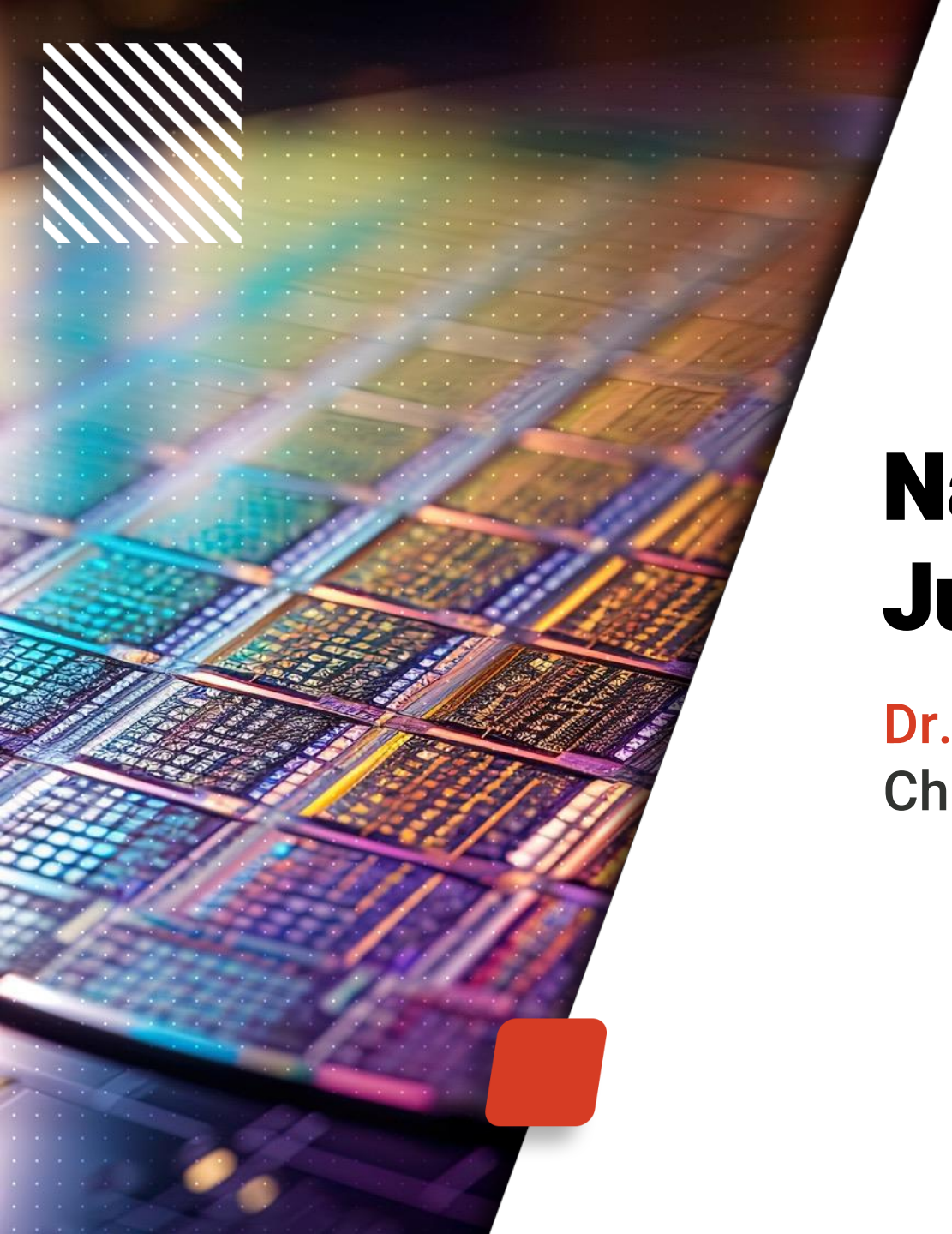

Navigating the Buzzword Jungle

Dr. Edward Rothberg
Chief Scientist and Chairman of the Board

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Advanced Technologies

- The technologies
  - GPU computing
  - Generative AI
  - Quantum Computing

- For each, what we discuss here
  - What is it?
  - How does it work?
  - How can optimization benefit?
  - Barriers to adoption for optimization?
  - What does adoption look like for Gurobi?
  - The bottom line

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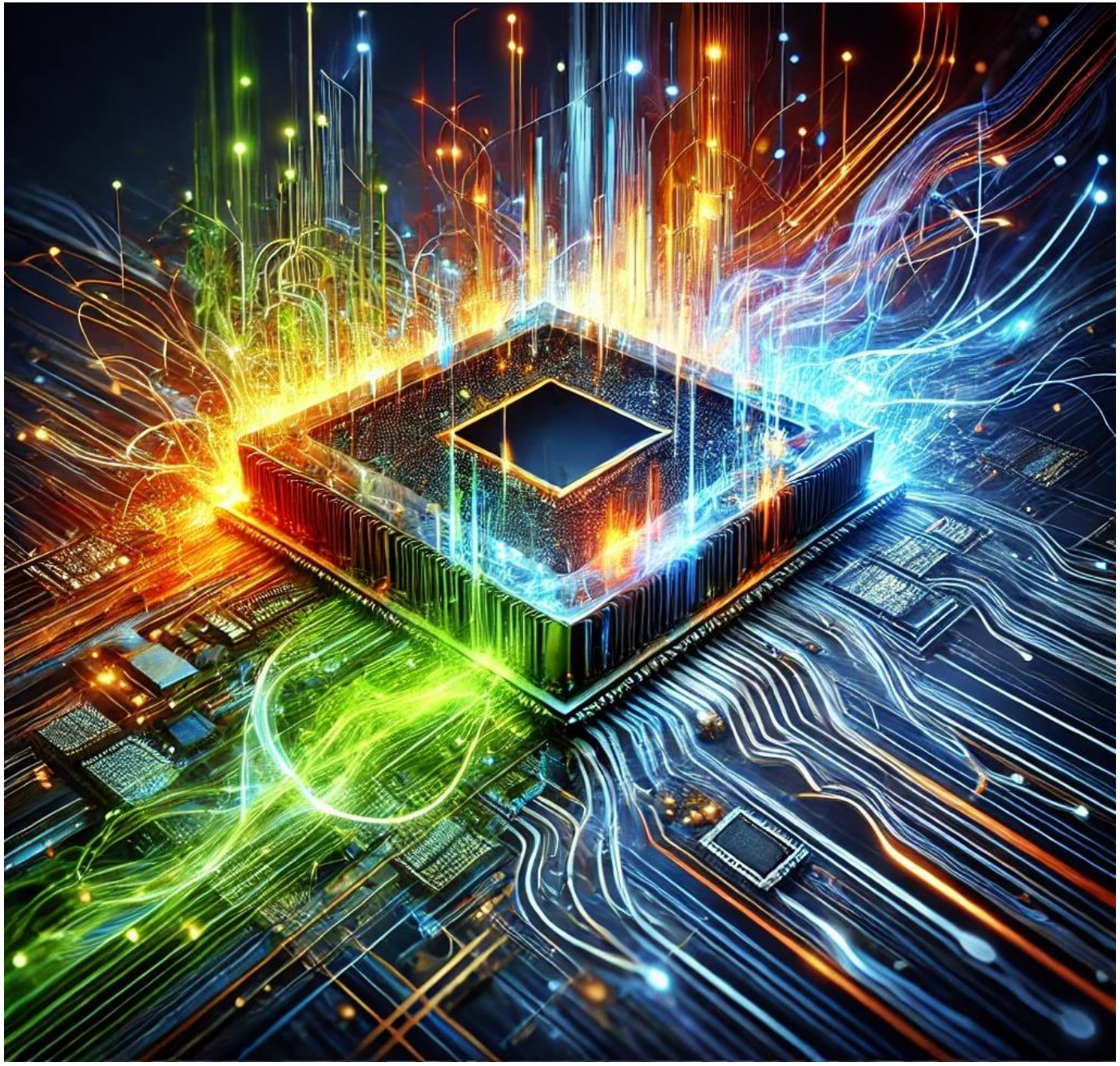
GPU Computing
What is it?

Graphical Processing Units (GPUs): Specialized processors that use massive parallelization for simple calculations

- Invented for 3D graphics
- Enables complex effects like smoke & fire

General purpose GPU Computing: Software development libraries that use GPU processors for computing tasks besides graphics

- Essential for training AI thanks to massive parallelism



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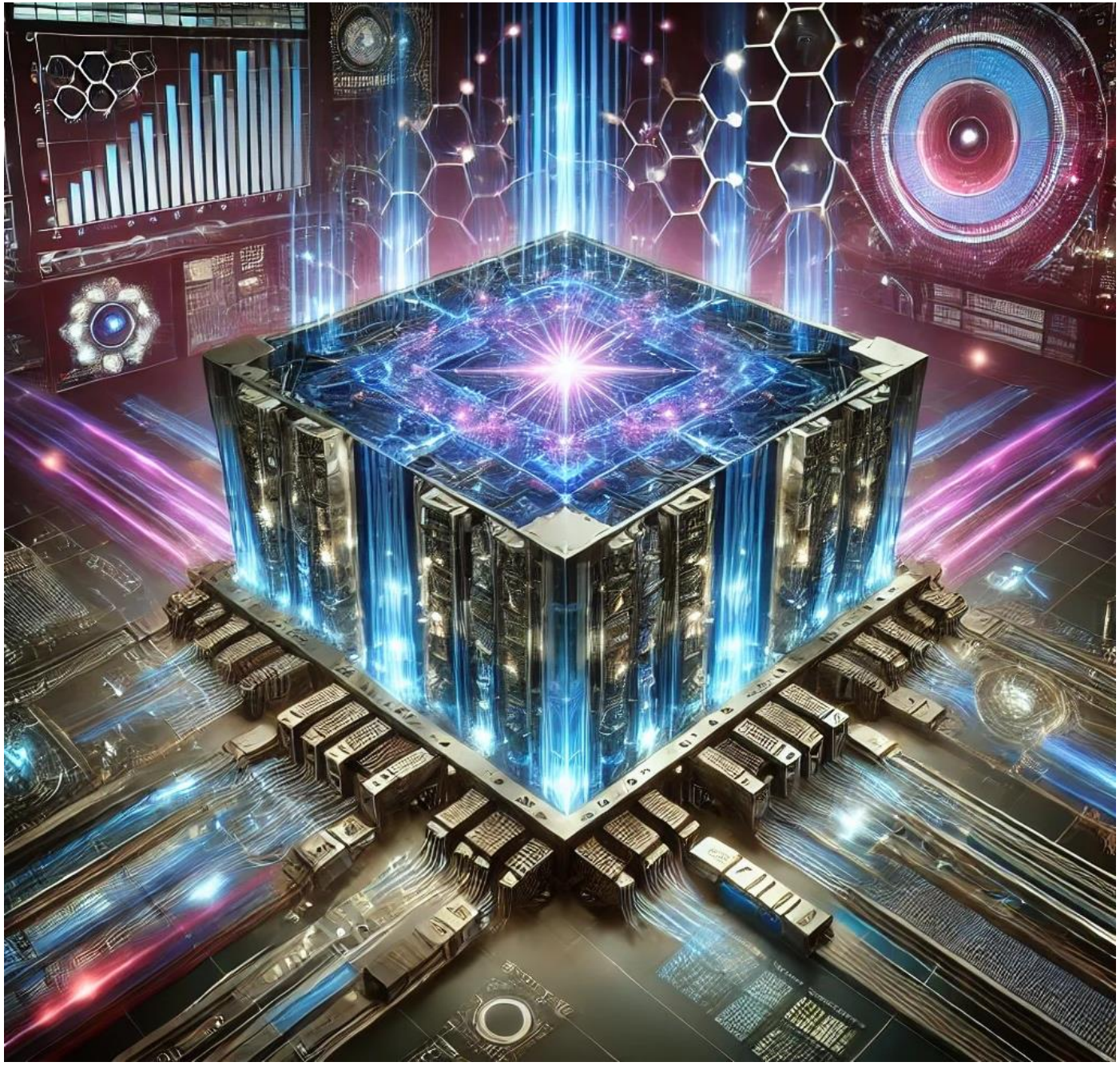
GPU Computing
How does it work?

Massive number of cores, each for relatively simple computation

Recent **system-on-a-package** design from Apple and NVIDIA allow GPUs to access all memory at high speed



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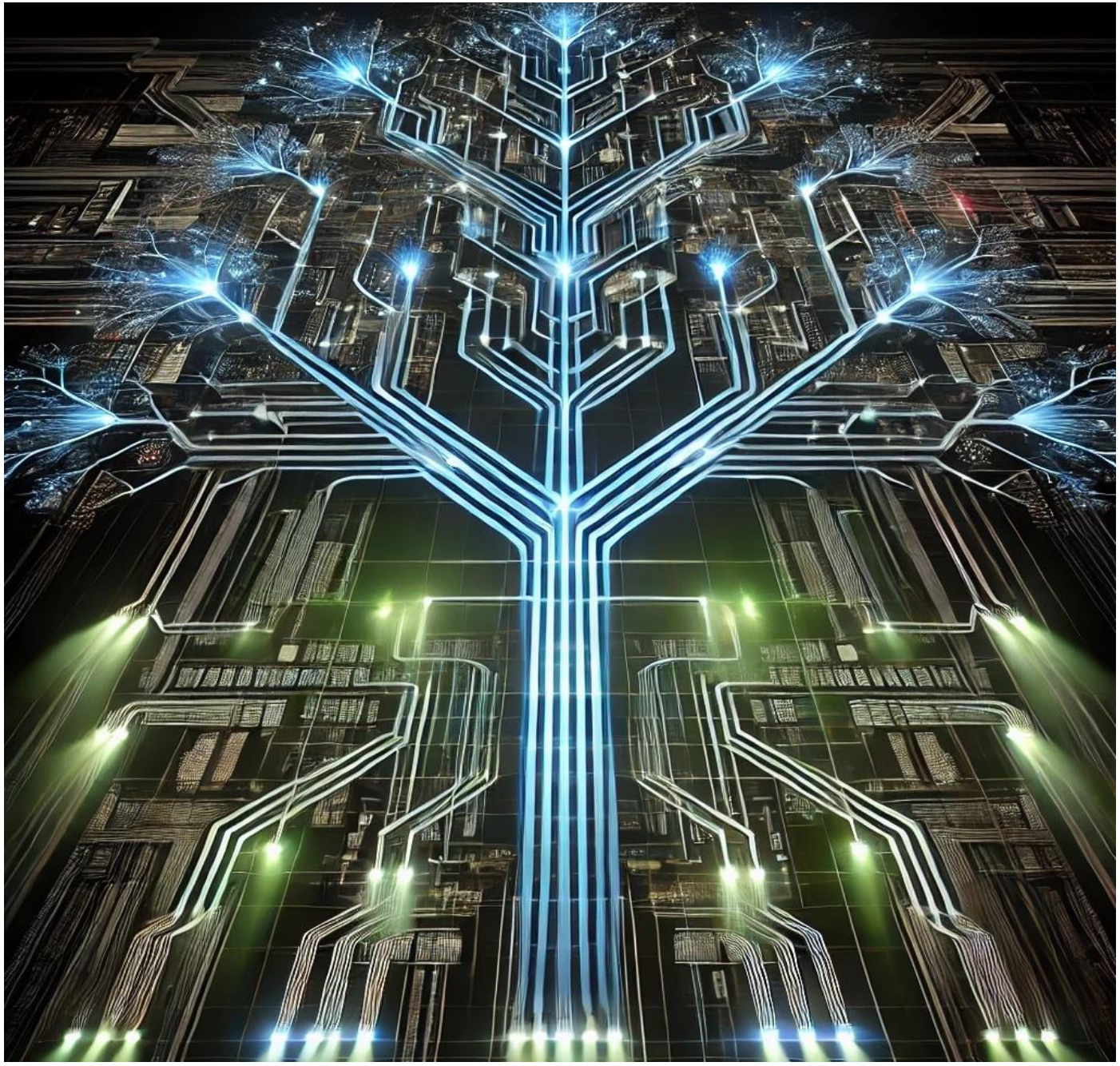
GPU Computing
How can optimization benefit

Faster solve times through massive parallel computation

- Cholesky factorization for barrier
- Decomposition methods
- Simplex pivoting (?)



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GPU Computing

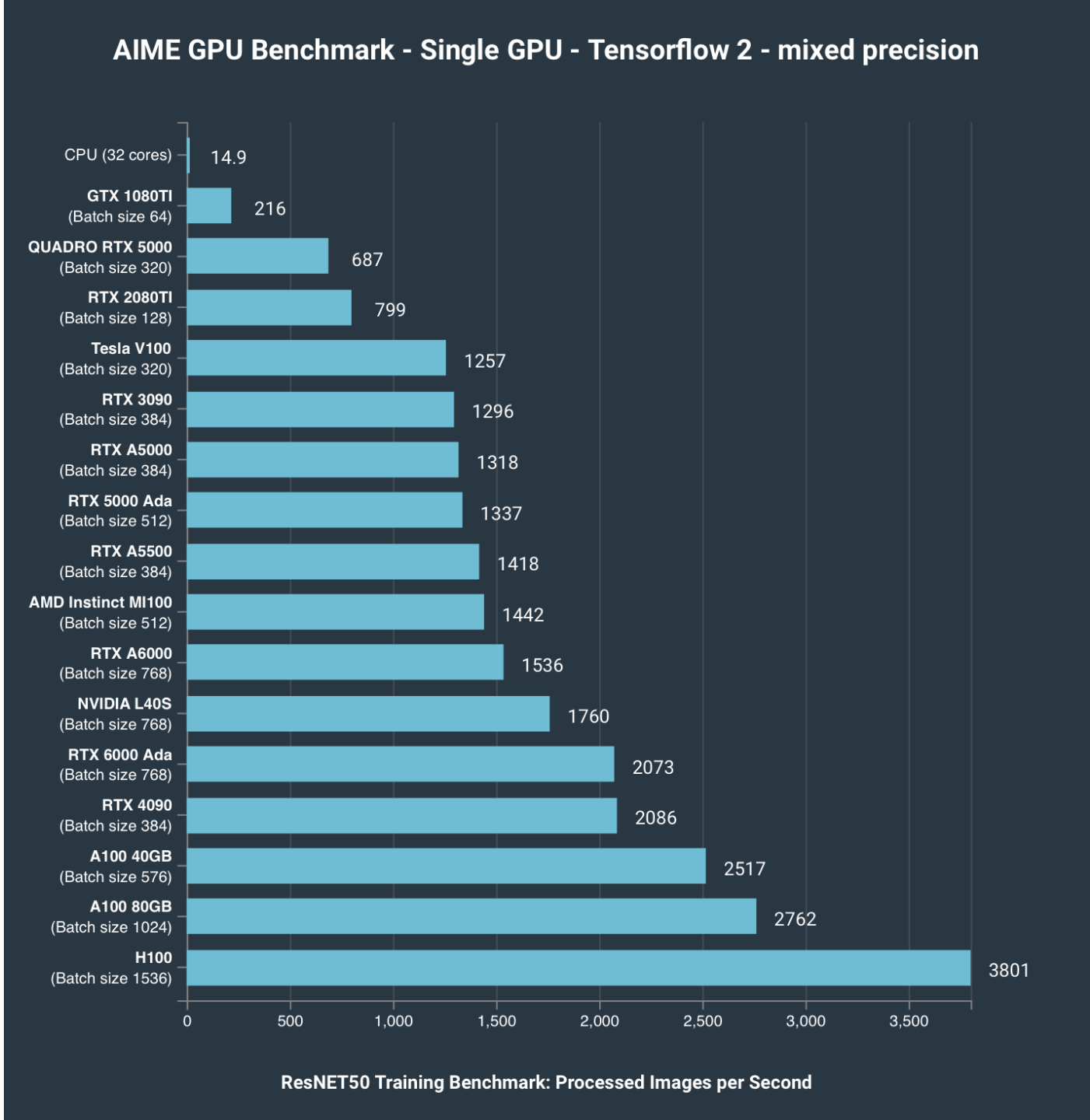
Case Study: Machine Learning

In **some applications with highly parallelizable algorithms**, even a basic GPU can be much faster than a CPU

Example: TensorFlow library for machine learning

Source:

- AIME, a provider of high-performance servers
- https://aime.info/blog/en/deep-learning-gpu-benchmarks/



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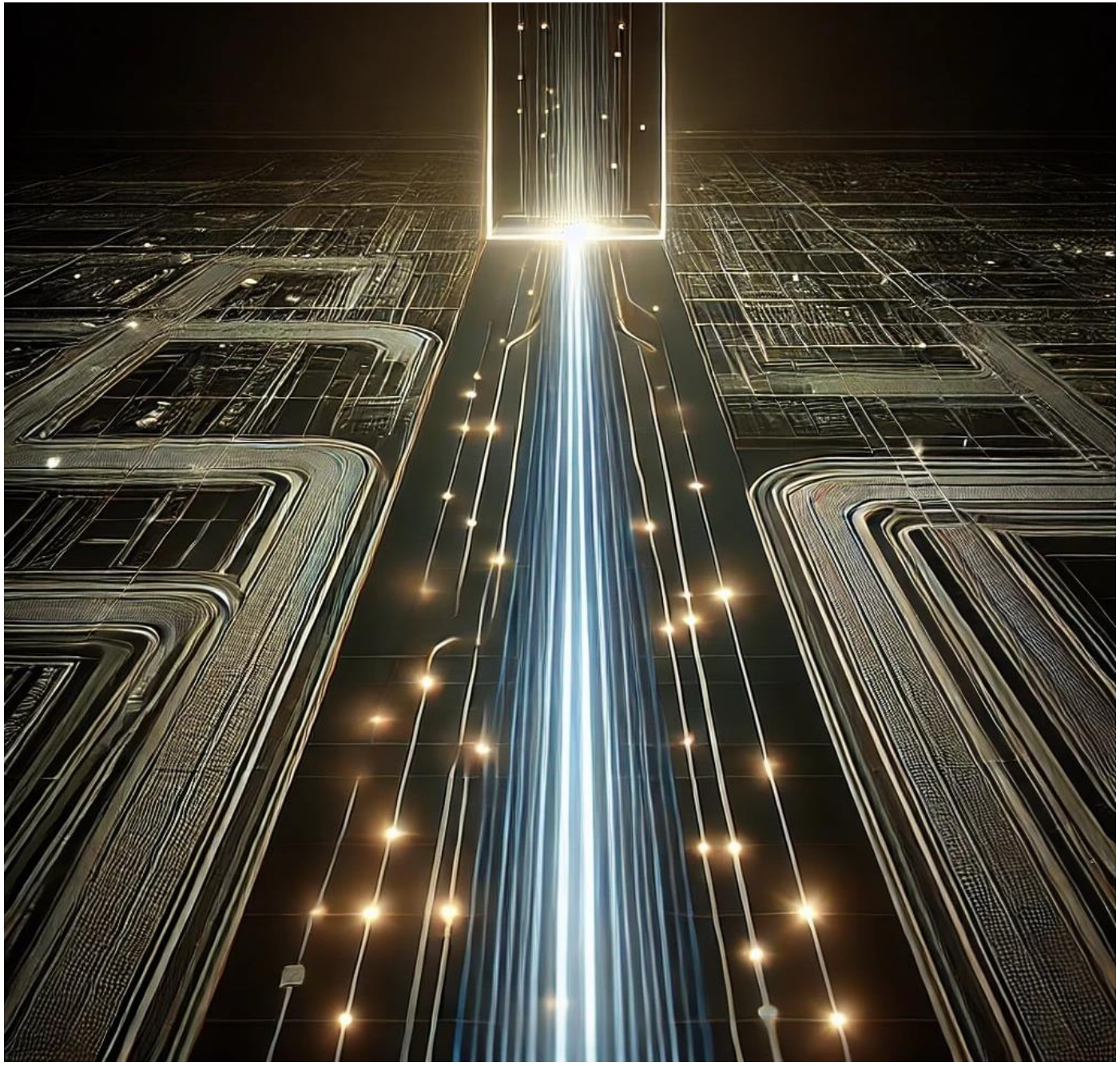
GPU Computing
Barriers to adoption

Limited opportunities for parallelization

- Model structure cannot be separated cleanly – links across time, products, regions, …

NVIDIA CUDA library – the clear market leader – currently has **performance bottlenecks** with sparse matrix algebra in cuDSS module

- Graphics systems were originally designed for many simple computations
- Sparse computation is new for GPGPU so we hope this will improve soon



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GPU Computing
Adoption for Gurobi

Very likely once libraries like CUDA cuDSS can better handle sparse matrix computation

- Currently under collaborative investigation with R&D teams at Gurobi and NVIDIA

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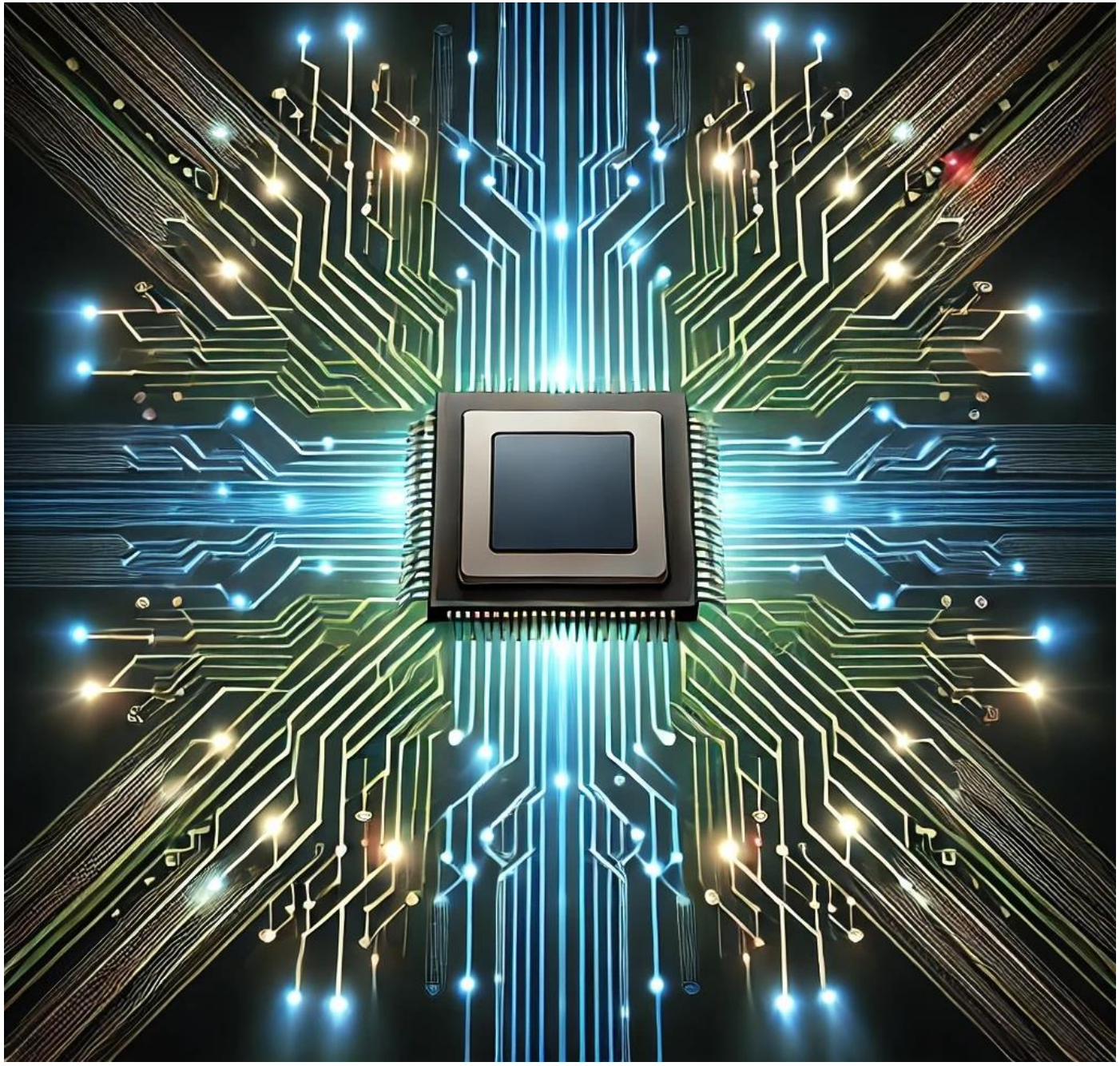
GPU Computing
Bottom line

A technology to exploit massive parallelization

- But: Existing optimization algorithms don't have massive parallelization

- Some opportunities like barrier factorization
- Reasons for optimism like first-order methods
- Impediments still exist



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Generative AI
What is it?

Creates realistic output like text, graphics, code from user inputs called prompts

Hottest topic in computing today

- Startups: OpenAI (ChatGPT)
- Established giants: Google, Microsoft, Meta (Facebook), Apple

Fun fact:

Most graphics in this presentation were created by DALL-E via ChatGPT

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Generative AI
How does it work?

Trained on all the public data they can find

- Books
- The entire Internet
- Newspapers
- Transcripts from TV shows, movies, radio, podcasts, YouTube
- Photos
- Github source code

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Generative AI

How can optimization benefit

Solver algorithms – probably not

- Generative AI combines known data into new material
- Optimization searches for solutions that meet requirements (constraints)

Write code for optimization models based on a text description – maybe

Analyze solver log files

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Generative AI

Case study: Playing Chess

Chess.com match between ChatGPT & Google Gemini

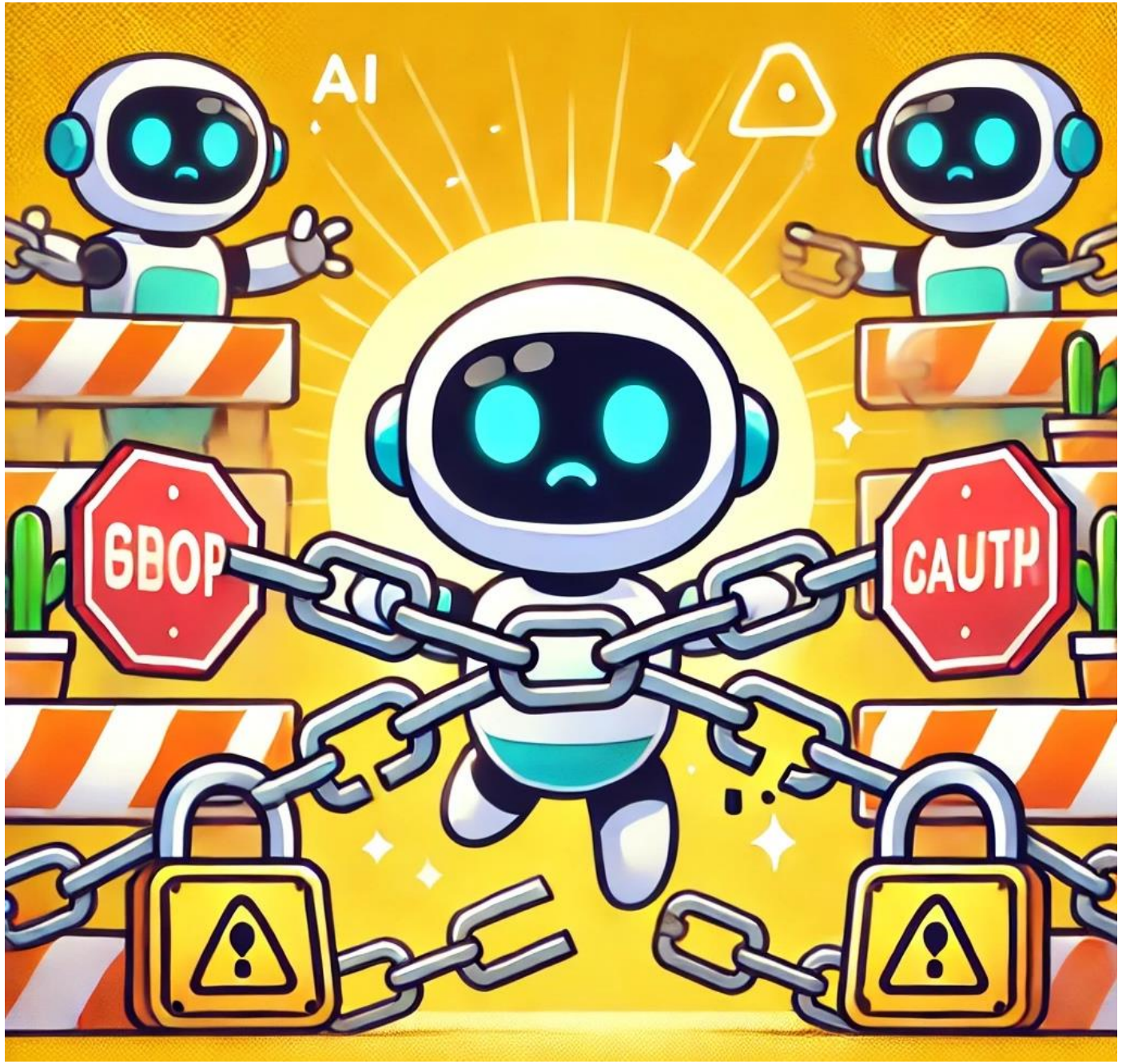
- **ChatGPT** attempted **illegal moves 20% of the time**
- **Google Gemini** attempted **illegal moves 50% of the time**
- Source: https://chess.com/article/view/chatgpt-gemini-play-chess

Chessily match between ChatGPT & Stockfish open-source chess engine

- ChatGPT made **numerous mistakes**
- ChatGPT **eventually forfeited** because it could no longer make moves
- Source: https://chessily.com/blog/stockfish-vs-chatgpt/

Generative AI **recommends known chess moves**, which **performs far worse than chess analysis engines**

- Perhaps a future version of ChatGPT will call a chess engine as a subroutine



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Generative AI
Barriers to adoption

Limited training data from the small field of optimization

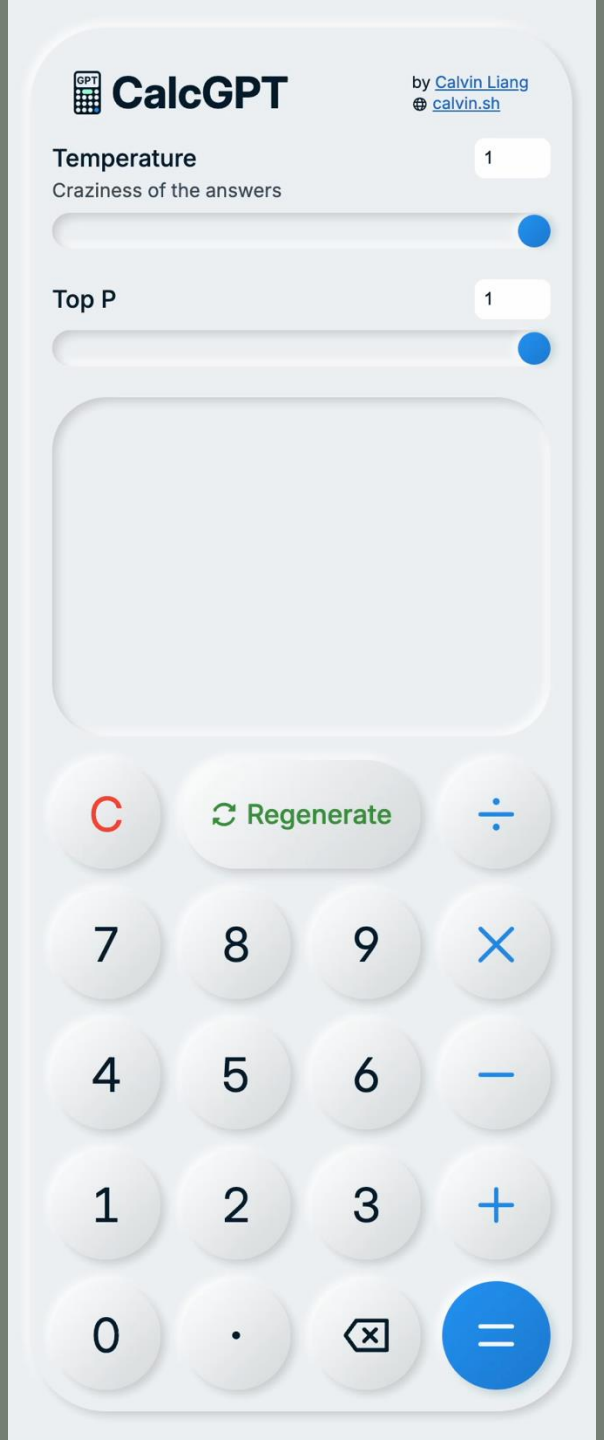
Hallucination

- "Glue on Pizza"
- "Rocks to eat each day"
- CalcGPT.io

Hard to assess correctness, especially if you are new to optimization

Not all AI are created equal

- ChatGPT currently viewed as best-of-breed, believed to be using more training data than others


CalcGPT
by Calvin Liang
calvin.sh
Temperature
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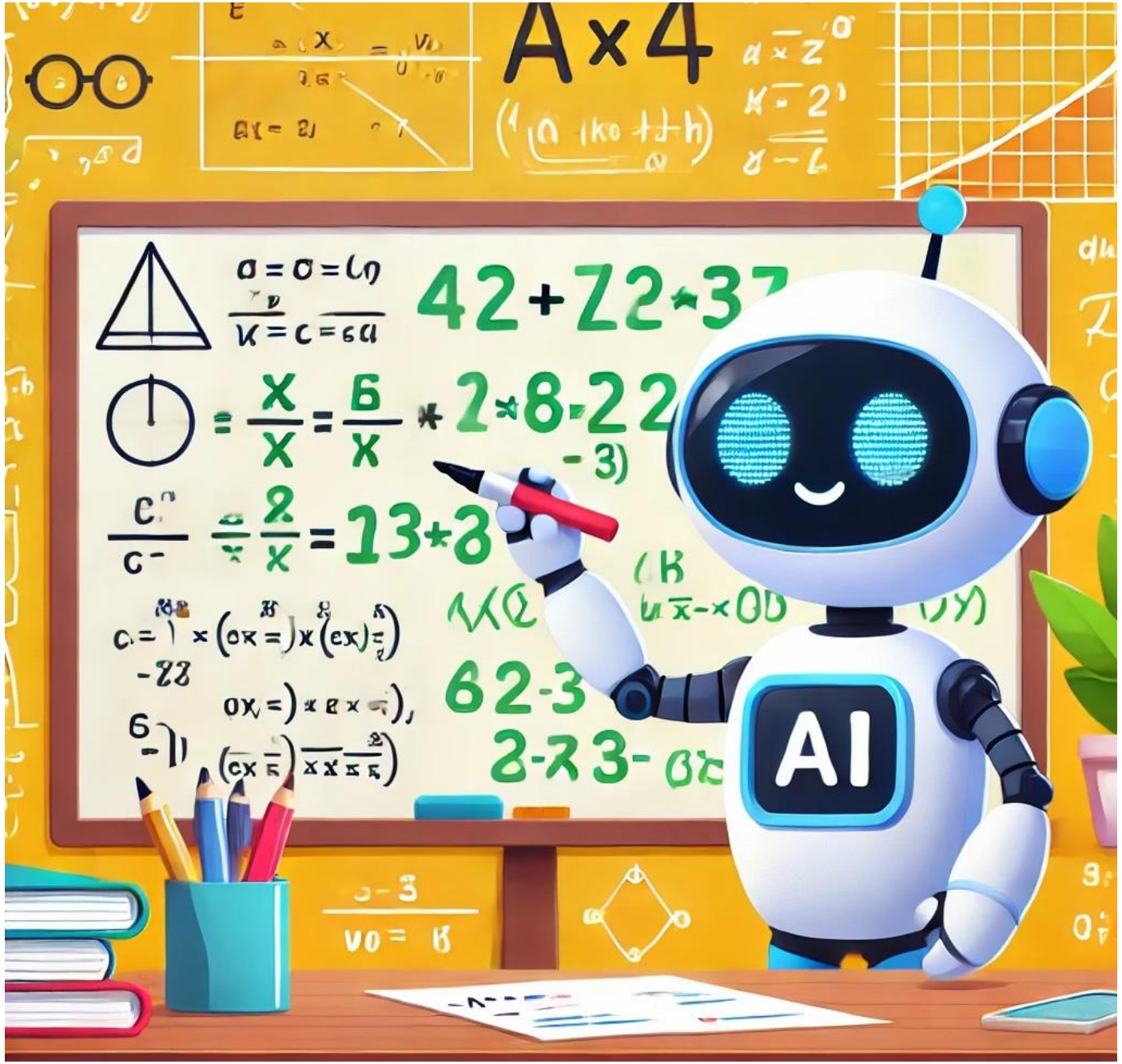

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Generative AI
Adoption for Gurobi

Potential for training and technical support

- Best where **common answers exist**

Demonstration: **Gurobot** for ChatGPT

- Available now at no extra cost with a ChatGPT account

ChatGPT 4o

ChatGPT

Gurobot

Explore GPTs

Previous 7 Days

Graphical Processing Image

Recipe with what's in my kitchen

Overcome procrastination

Plan a relaxing day

Content calendar for TikTok

Message ChatGPT

Gurobi Optimization workspace chats aren't used to train our models. ChatGPT can make mistakes.

Invite members

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Generative AI
Bottom line

Potential learning tool for optimization

- Can build complex models and answer complex questions, even today

Unlikely to replace algorithms - see chess

A rapidly evolving field

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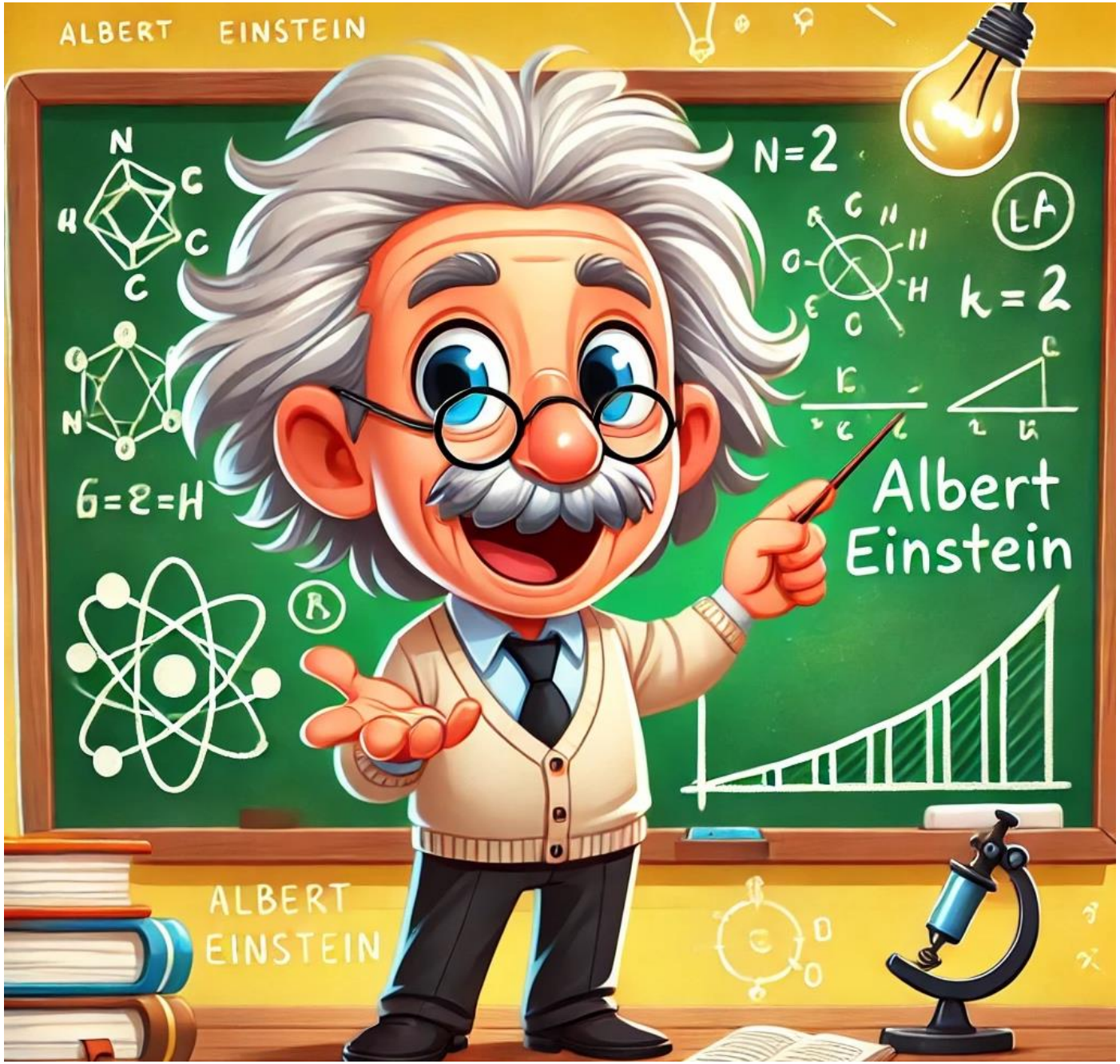
Quantum Computing
What is it?

New computer architecture based on quantum bits (qubits) rather than binary bits

Unlike a bit that can be only 0 or 1, a qubit can be any quantum superposition of 0 and 1



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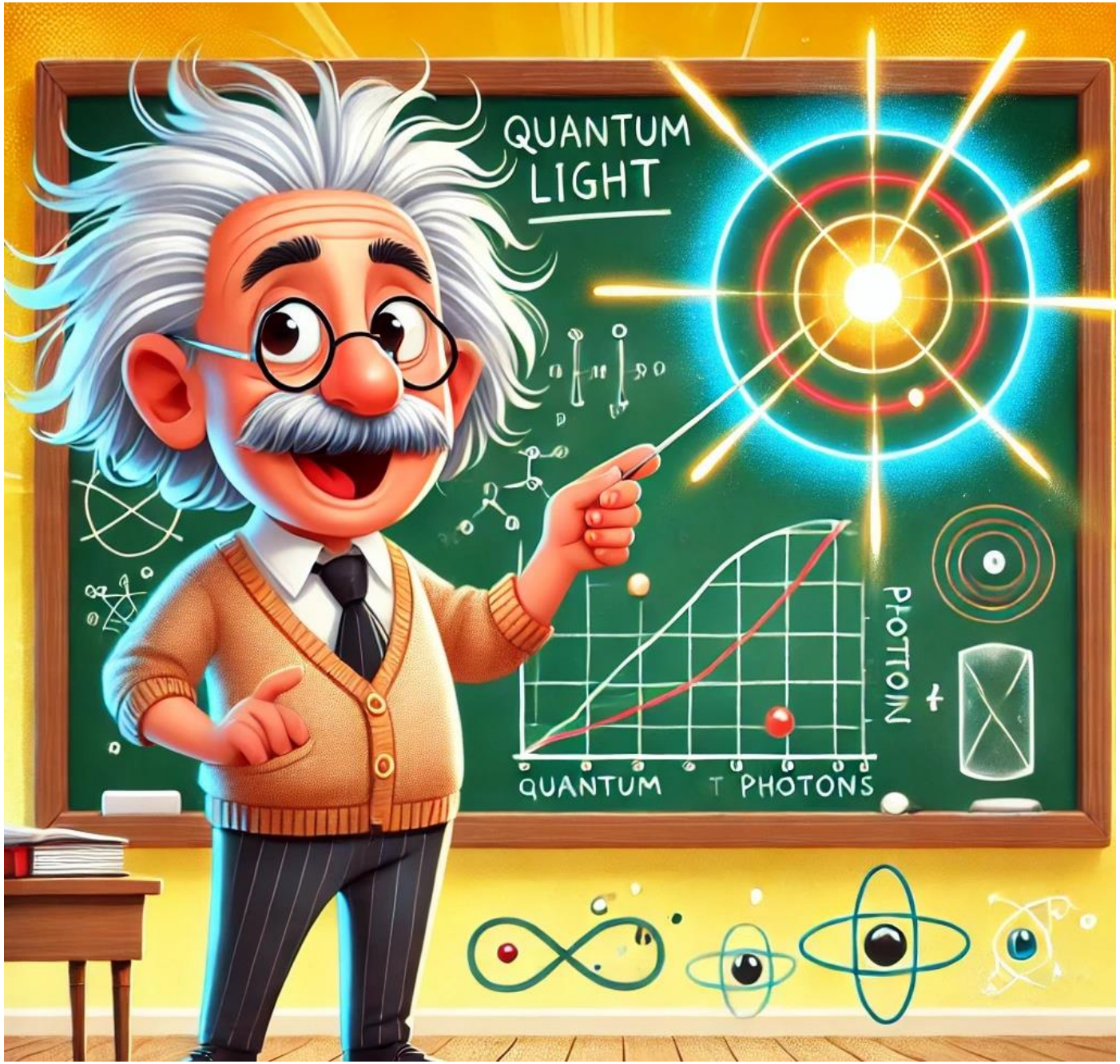
Quantum Computing
How does it work?

Qubits are based on **quantum mechanics**

Qubits can use different elements of physics

- Photons (light)
- Electrons
- Superconductive current



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Quantum Computing

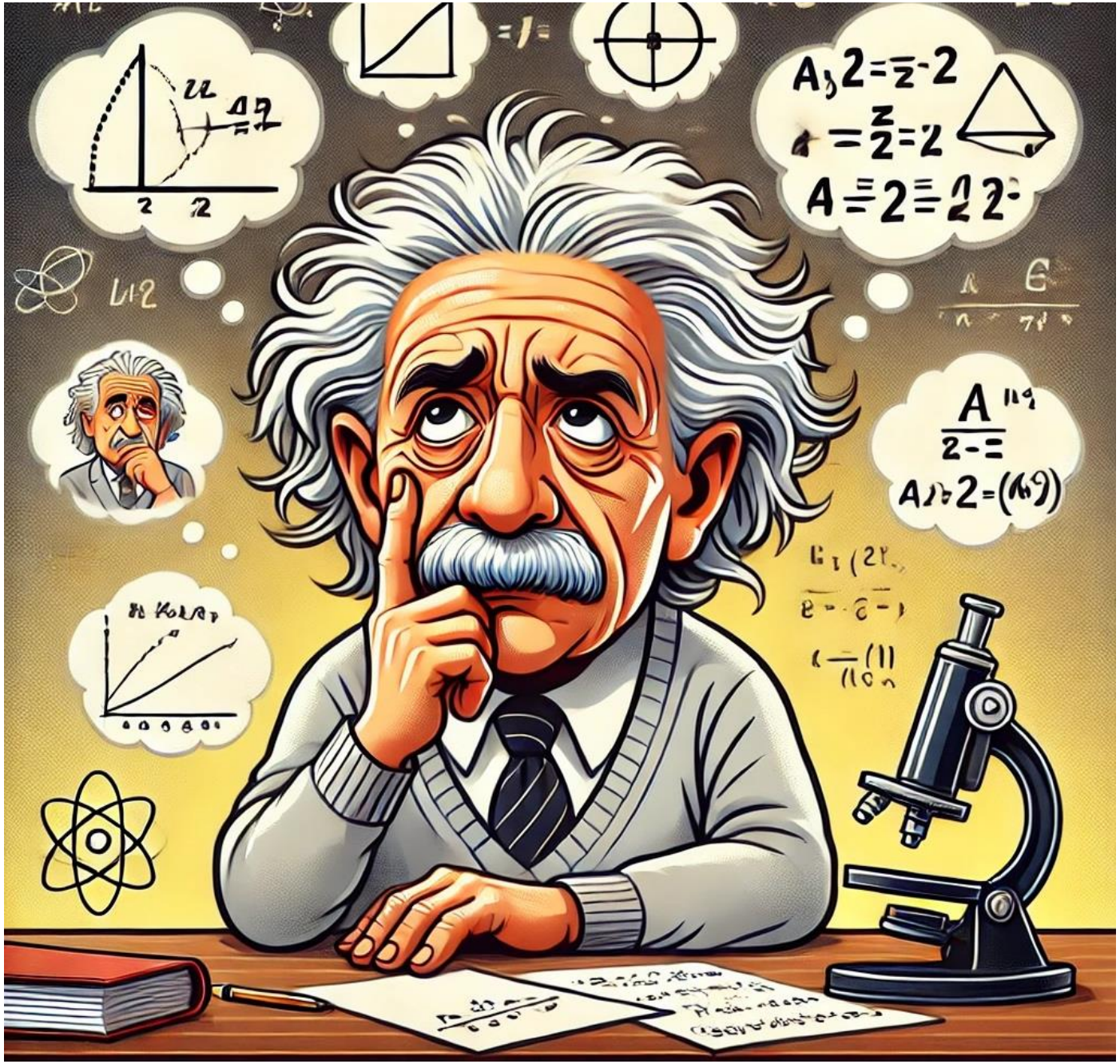
How can optimization benefit

Promises **huge speedups for hard algorithms** thanks to several factors

- Quantum states of a single qubit can represent many values
- Apply quantum gates to entangled qubits to produce powerful and profound changes to their quantum states

A core application is to solve Quadratic Unconstrained Binary Optimization (QUBO)

- QUBO **raised awareness for** combinatorial **optimization**



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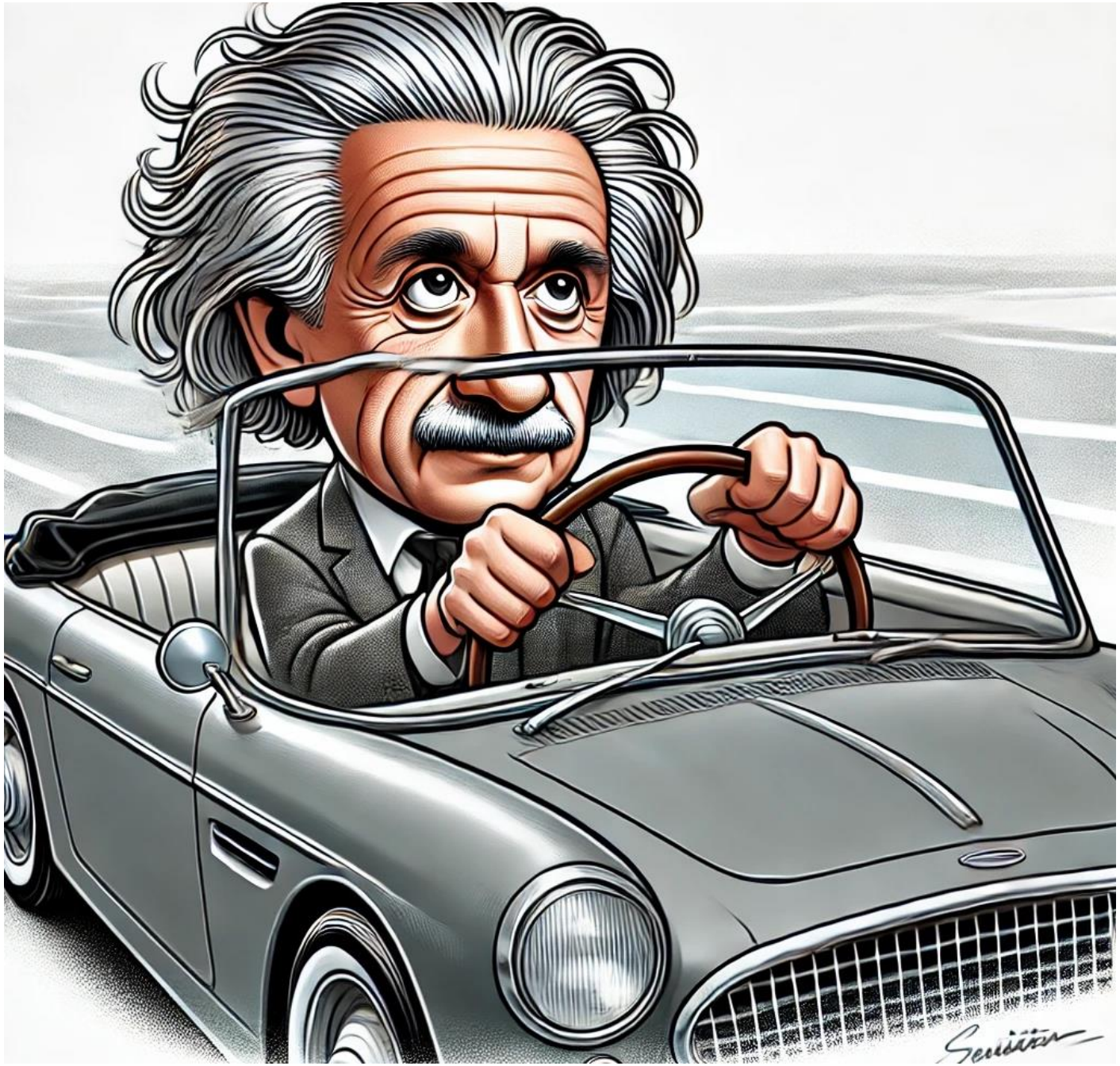
Quantum Computing
Case Study: Vehicle Sensors

BMW 2021 Quantum Challenge (w/AWS)
- 4 industrial applications
- 70+ applicants

Optimization application: locate vehicle sensors to scan for hazards
- Scan all directions with min # of sensors
- Winning entrant: Accenture
  - **Gurobi on regular computer 4500x faster than quantum annealer**
  - Success story for quantum computing?!?
  - Source: https://www.twitch.tv/videos/1546697903

- Thinking about quantum helped Accenture make a better MIP



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Quantum Computing
Barriers to adoption

Large scale general-purpose quantum computers **do not exist today**

- Research projects at giant laboratories –
  Can't order one from Dell, HP, Lenovo, etc.

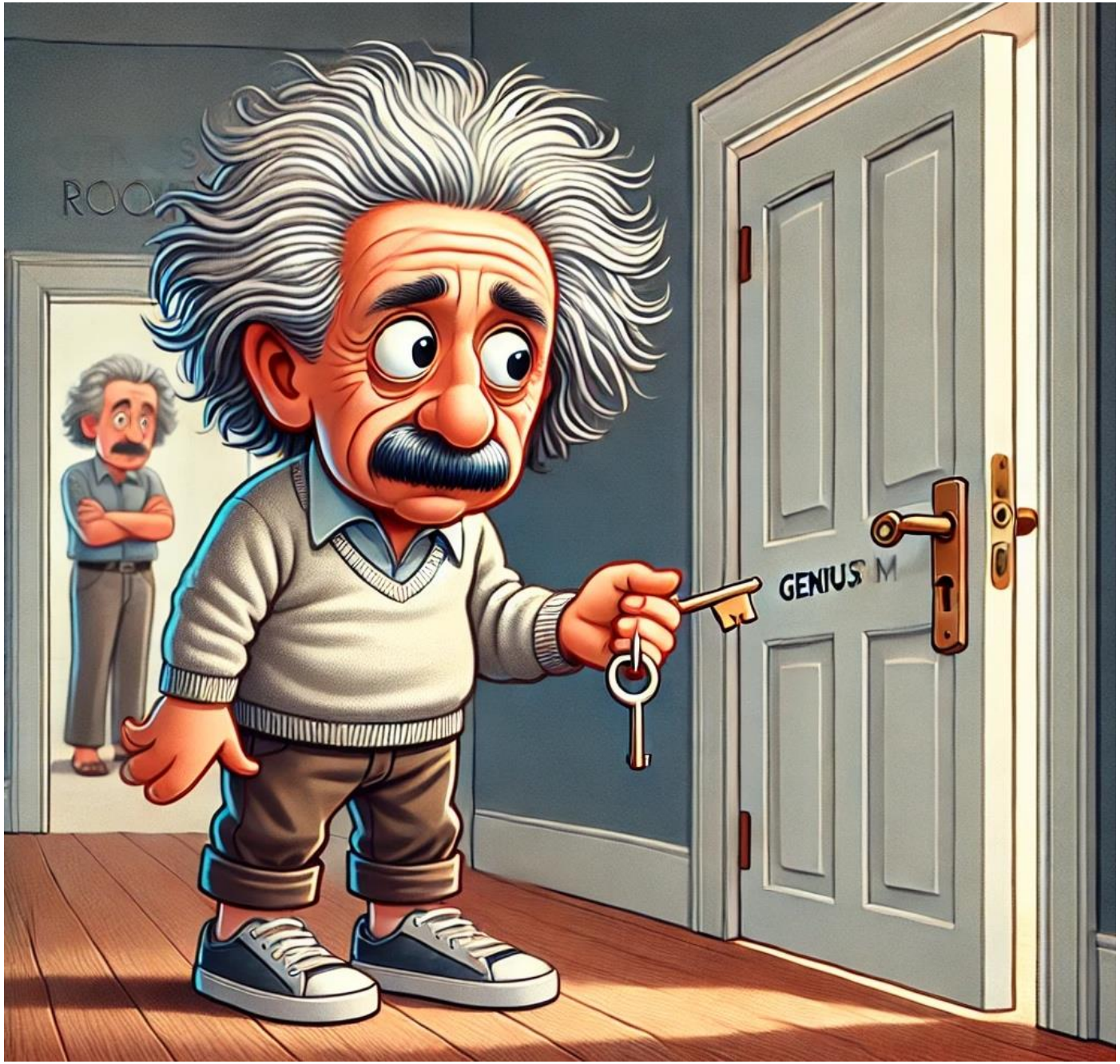
Quantum error correction is an open issue

- Need 100-1000 physical qubits to be entangled to get 1 noise-free logical qubit

Current quantum optimization algorithms can find solutions but **not show quality or prove optimality**

Investors shifted to Generative AI

- Global quantum investment in 2023 **down by 50% while generative AI grew**
- Source:
  https://theregister.com/2024/01/31/quantum_sector_saw_50_percent/



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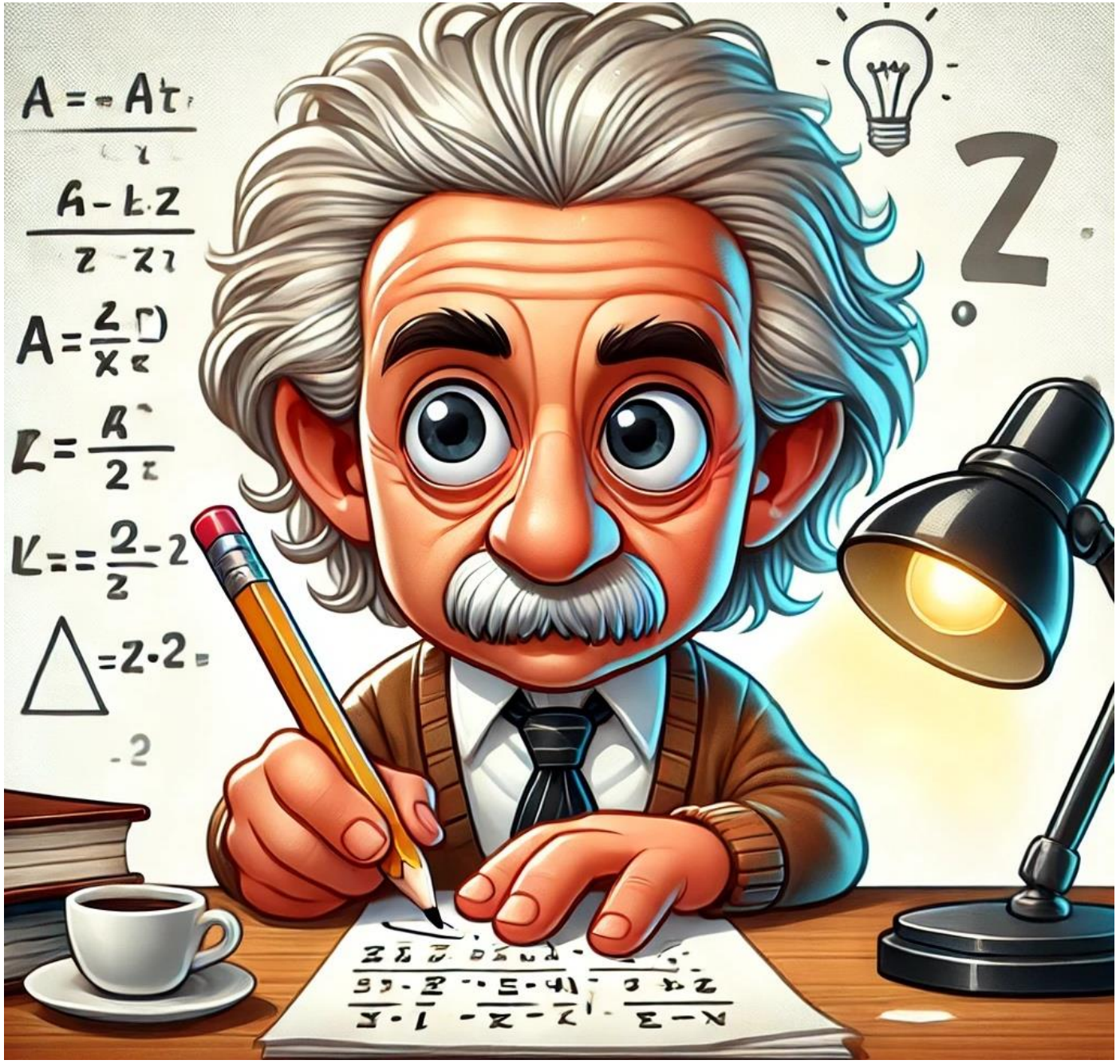
Quantum Computing
Adoption for Gurobi

Wait and see, possibly many years

Continue to **fight misunderstanding** that **real-world optimization** models **cannot be solved today**



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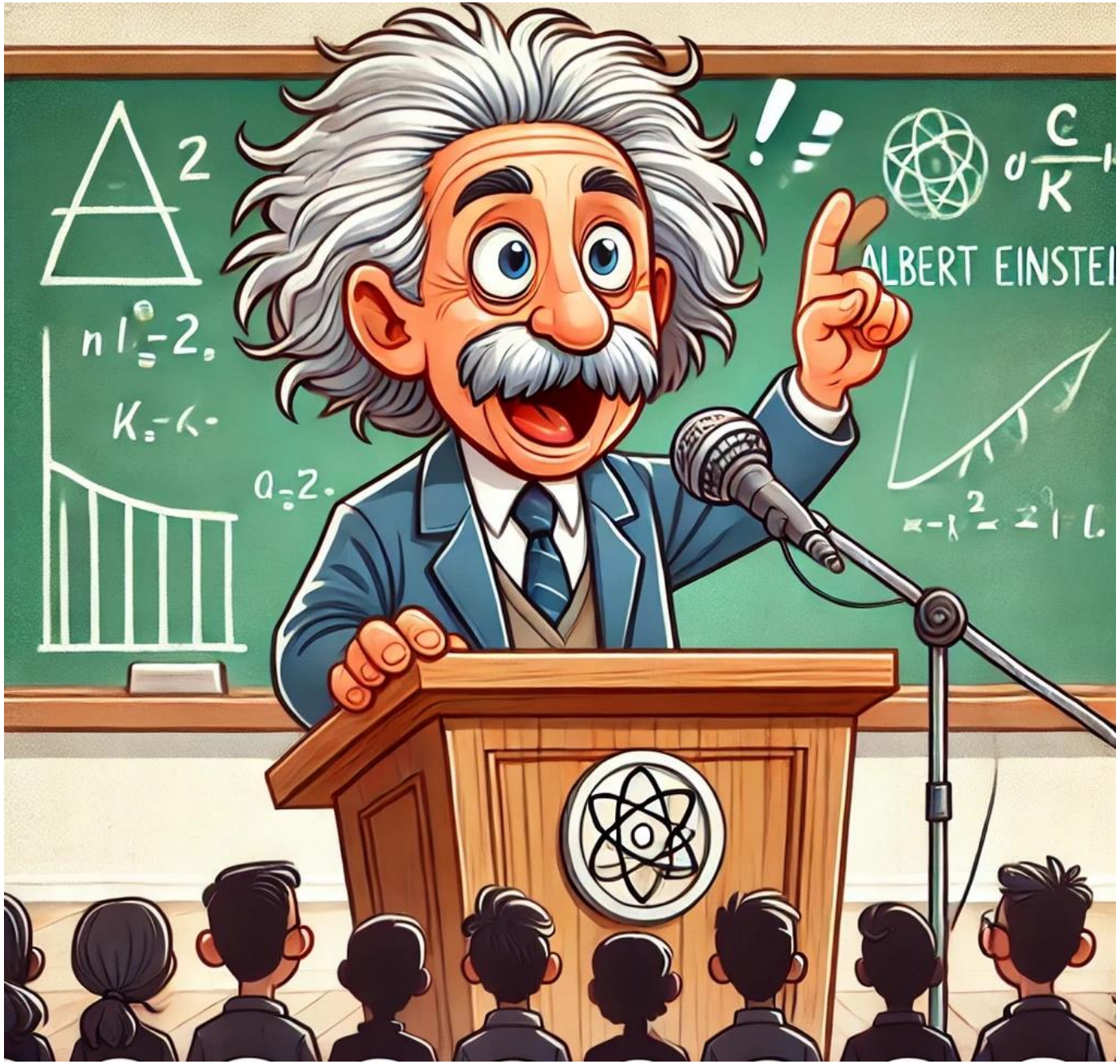
Quantum Computing
Bottom line

Quantum computing generates interest due to its **innovative computing model** with the potential to be much more powerful

New **quantum algorithms are extremely difficult to develop**; only a handful today (Schor, Grover, QAOA)

For optimization, quantum boils down to QUBO

LP (simplex) is **a powerful computational foundation** – will QUBO be?



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Key takeaways

GPU Computing: Some parallel tools should make optimization faster soon

Generative AI: Potential to create sample model code, which must be scrutinized for correctness

Quantum computing: Still building foundations at this very early stage

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Thank You

For more information: gurobi.com

Dr. Edward Rothberg
Chief Scientist and Chairman of the Board
rothberg@gurobi.com