QC ARCHITECTURE:
WHEN LIFE GIVES YOU LEMONS…

Igor L. Markov

University of Michigan

LEMONS → LEMONADE

Traditional digital systems

- Huge numbers of fast gates and wires of exceptional quality
- A deep memory hierarchy (cheap ECC)
- Data are routinely copied, e.g., cached
- An illusion of digital determinism
  - CMOS xtors pull up to 1 or pull down to 0
  - Analog delays masked by FFs & clocking
  - Design guard-bands for crosstalk, etc
  - Careful yield management
- High-perf I/O, large amounts of data
- Verification, test, full-system simulation
- Programming, power-density, security

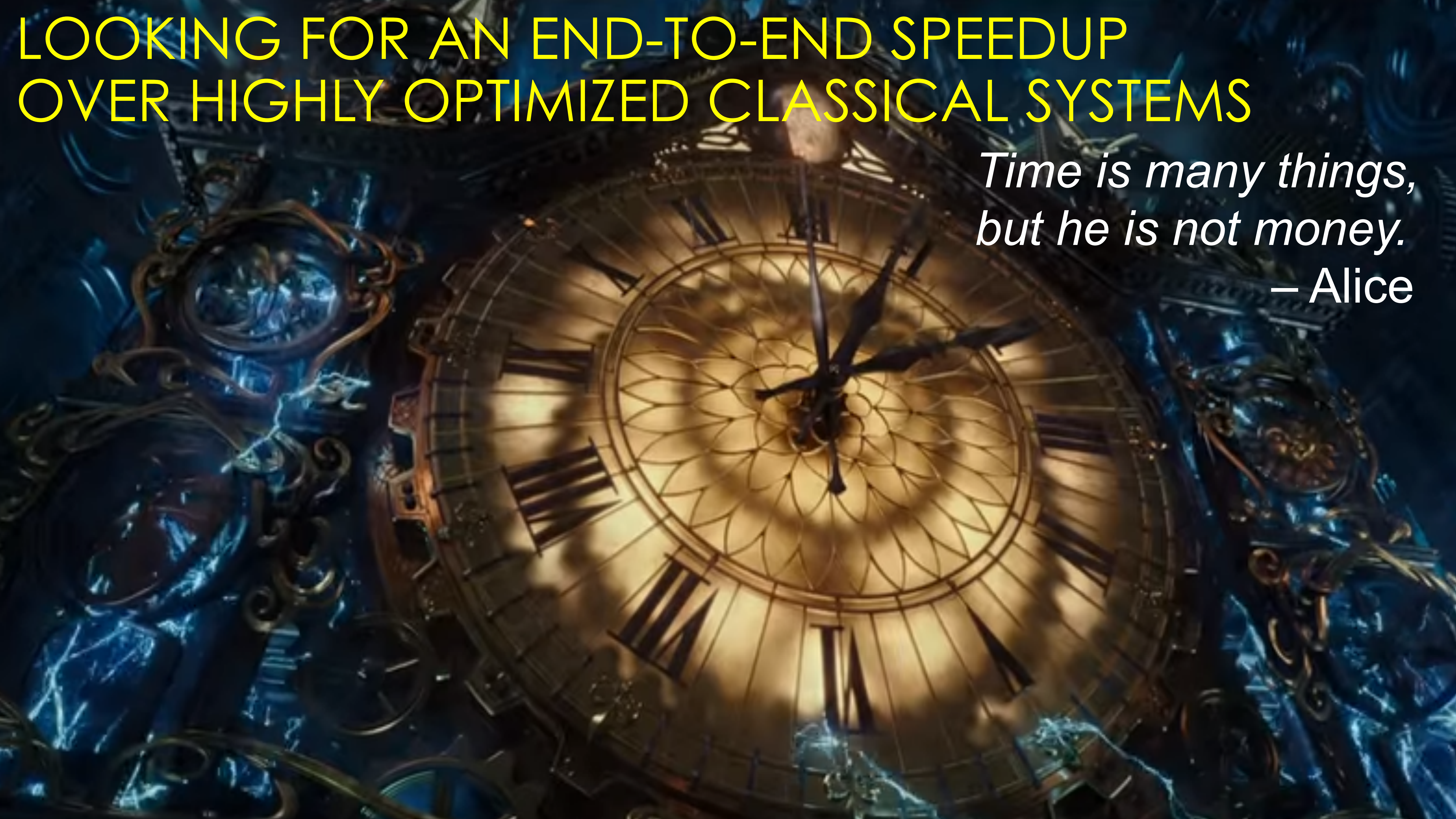
Qubit systems

- Very few, flaky gates; so-so interconnect
- No memory modules to speak of
- Quantum no-cloning theorem
- Non-deterministic errors in gates, I/O
  - No error masking by gates
  - Nonstationary error distributions
  - Tricky correlations
  - QECC is too expensive for near-term QC
- Slow I/O, sometimes pathologically so
- Extreme cooling
- Cannot be fully simulated on existing sys
- Promise to solve some comp tasks quickly

QUANTUM COMPUTATION: THE FINEPRINT

- No new decision powers
- No NP-complete problems in poly time
- No asymptotic speed-up for sorting
  - Hence, no *universal* speed-up
- No speedup from single-q gates expected
- Main promise is in accelerators
  (with some programmability)
  - Surprisingly few good applications
  - Surprisingly difficult to build hardware

LOOKING FOR AN END-TO-END SPEEDUP OVER HIGHLY OPTIMIZED CLASSICAL SYSTEMS



Time is many things,
but he is not money.
– Alice

CRITERIA FOR SUCCESS: "QUANTUM SUPREMACY" STYLE

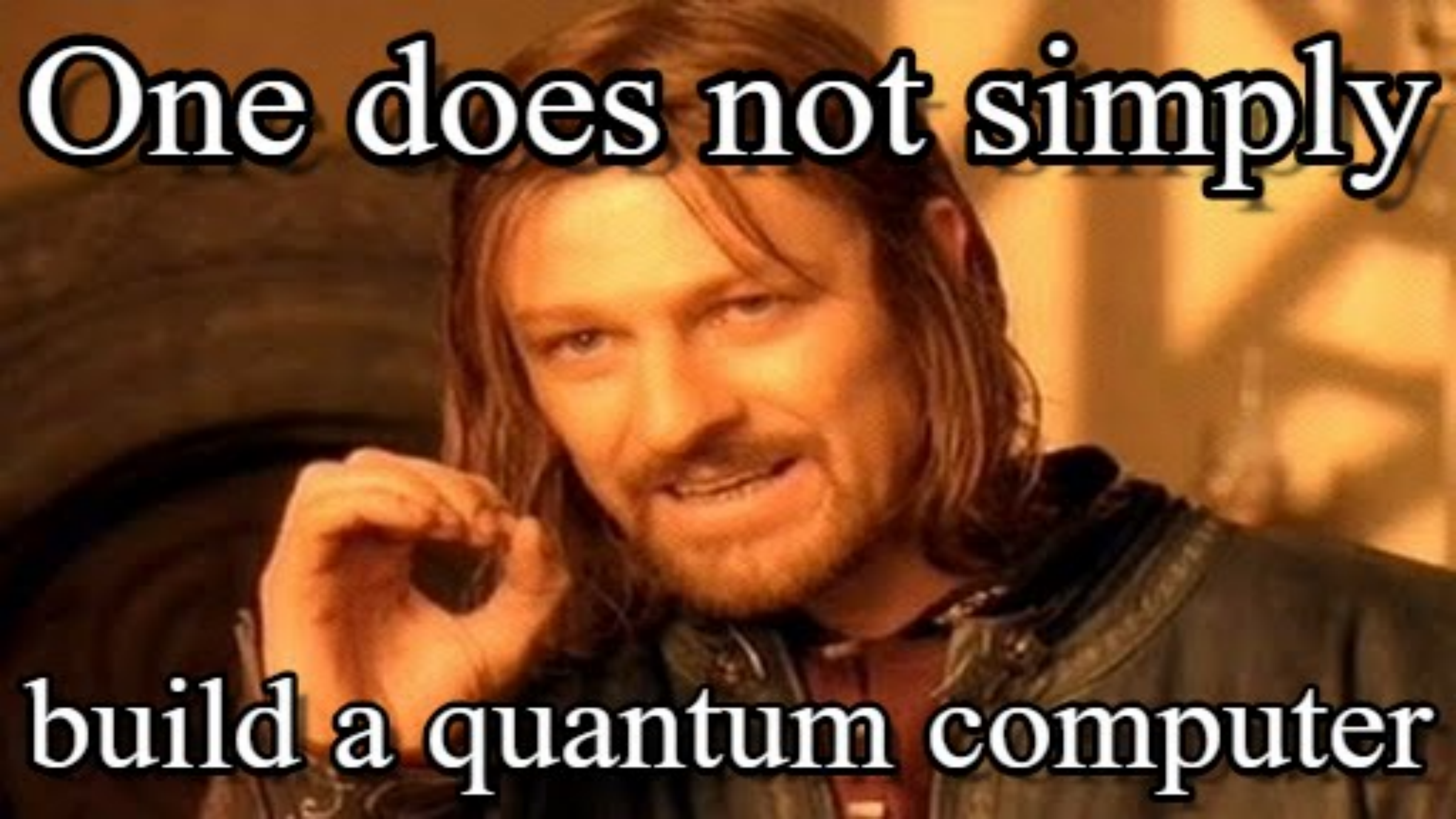
- A concrete application
  - No vagueness ("variants of this problem find uses in…")
  - Useful or made-up?
- Problem instances clearly described + benchmarks
  - OK to revise later, OK to post-select on easiness for QC
- Best classical methods identified, improved if needed
  - Don't repeat the D-Wave QUBO fiasco
- **Compelling speedup over best classical methods**
  - CPUs? GPUs? FPGAs? Supercomputers?
  - ASICs? Dilution refrigerators?
- Objectives and constraints other than time
  - Power dissipation, cost, form factor

QUANTUM ARCHITECTURE TRADEOFFS

KEY DESIGN ISSUES

- Quantum speedup: exp? sqrt?
- Data and I/O
- Quantum resources needed:
  - Qubits, gates, circuit depth
- Qubits:Superconductors? Ions?
- Hard-to-simulate gates
  - Locality
- Quantum overheads, such as
  - Slow quantum gates, arith circuits
  - QECC and classical control

- Environment: cooling, etc
- Error rates and distros
- Validation, BIST/feedback
- Classical control HW
- Room for optimization?
- Software toolchain?
  - Compilers
  - Circuit optimizers
  - Simulators & validation
  - SW control


One does not simply
build a quantum computer

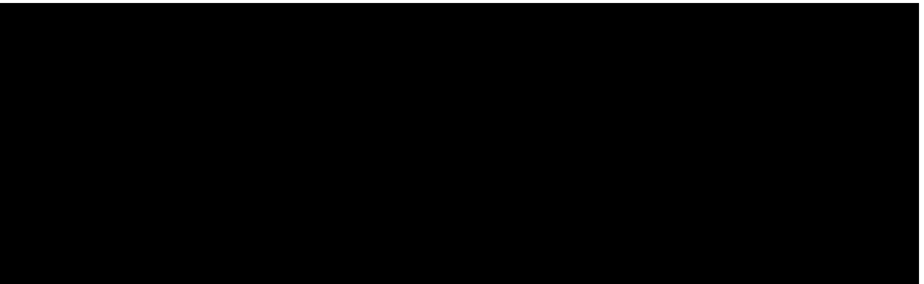
Intelligent Machines

IBM Raises the Bar with a 50-Qubit Quantum Computer

Researchers have built the most sophisticated quantum computer yet, signaling progress toward a powerful new way of processing information.

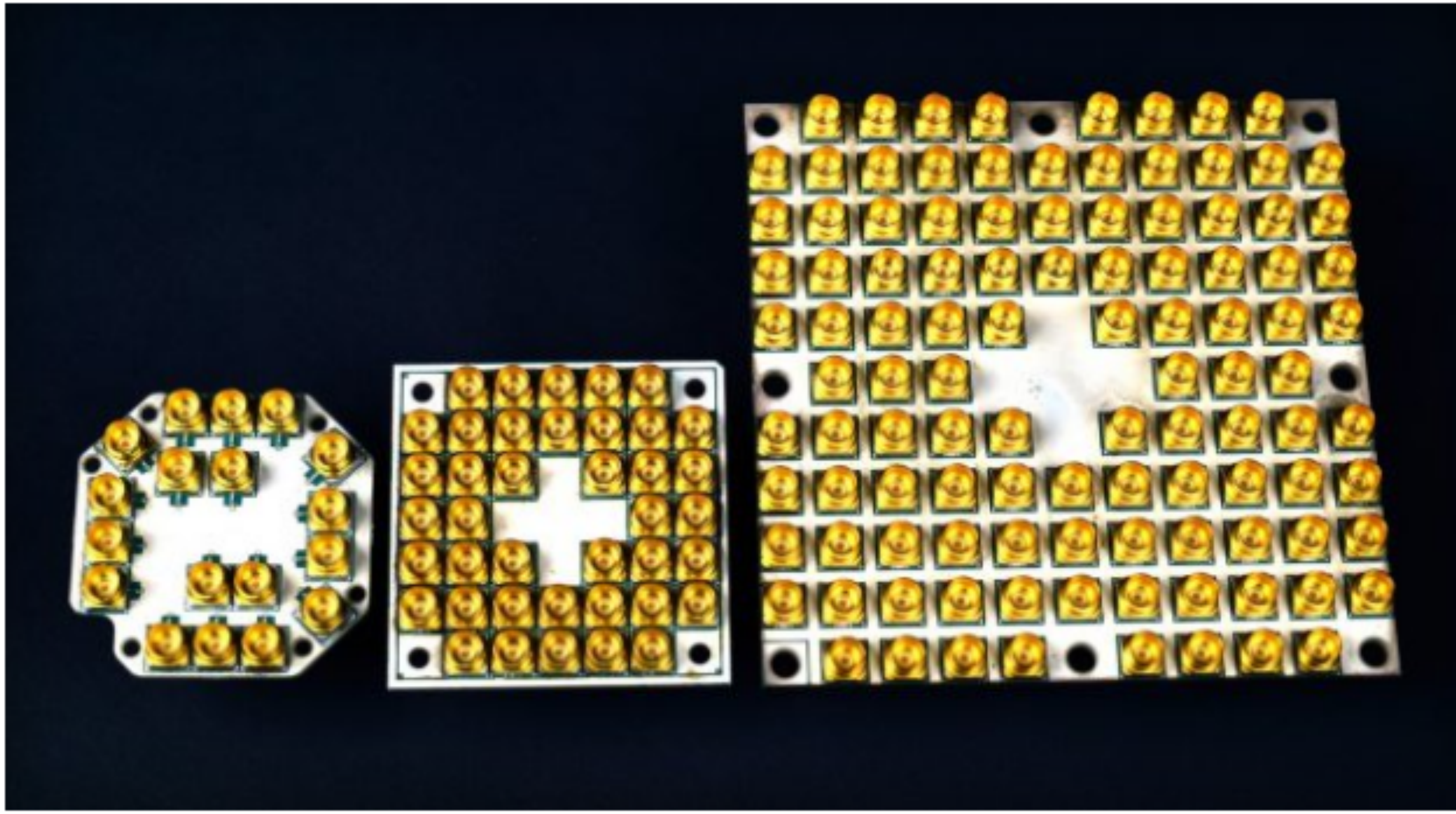
by Will Knight November 10, 2017

IBM's 50-qubit machine.



Intel Unveils 'Breakthrough' Quantum Computer

By Joel Hruska on January 9, 2018 at 4:15 pm | 172 Comments



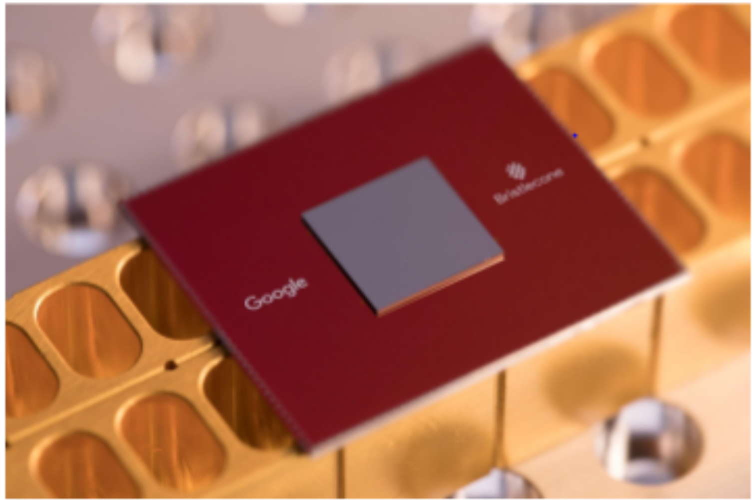
Google Research Blog

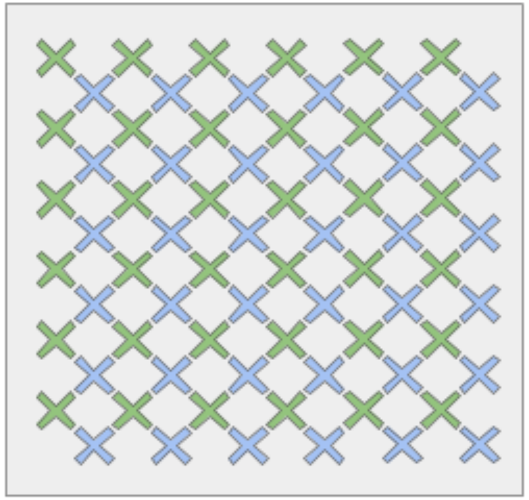
The latest news from Research at Google

A Preview of Bristlecone, Google's New Quantum Processor

Monday, March 05, 2018

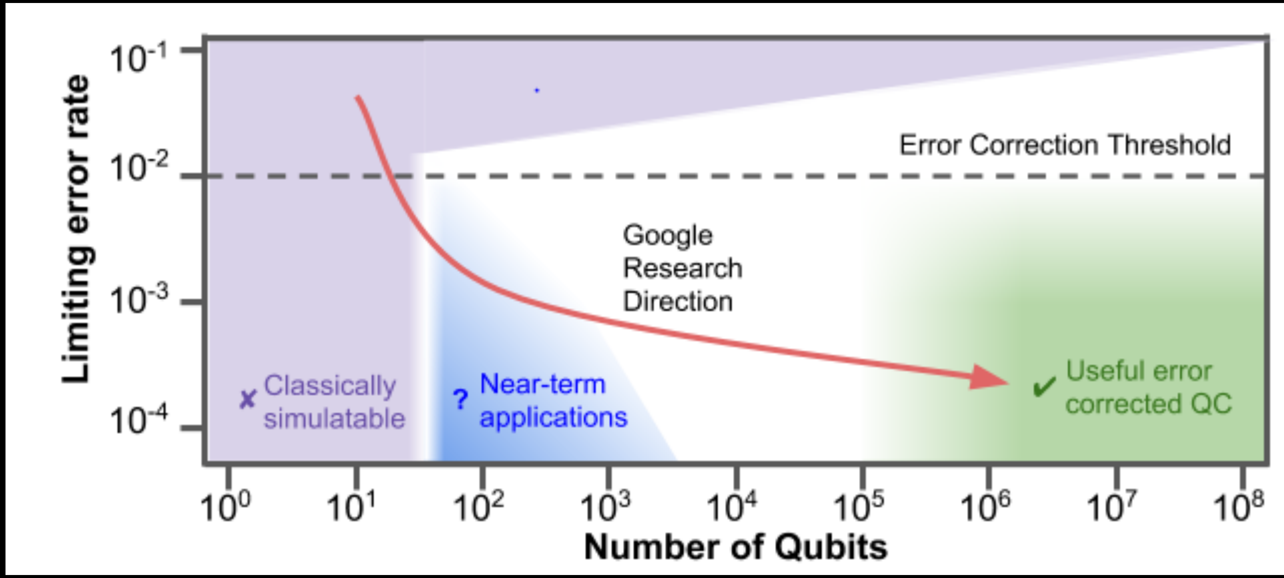
Posted by Julian Kelly, Research Scientist, Quantum AI Lab

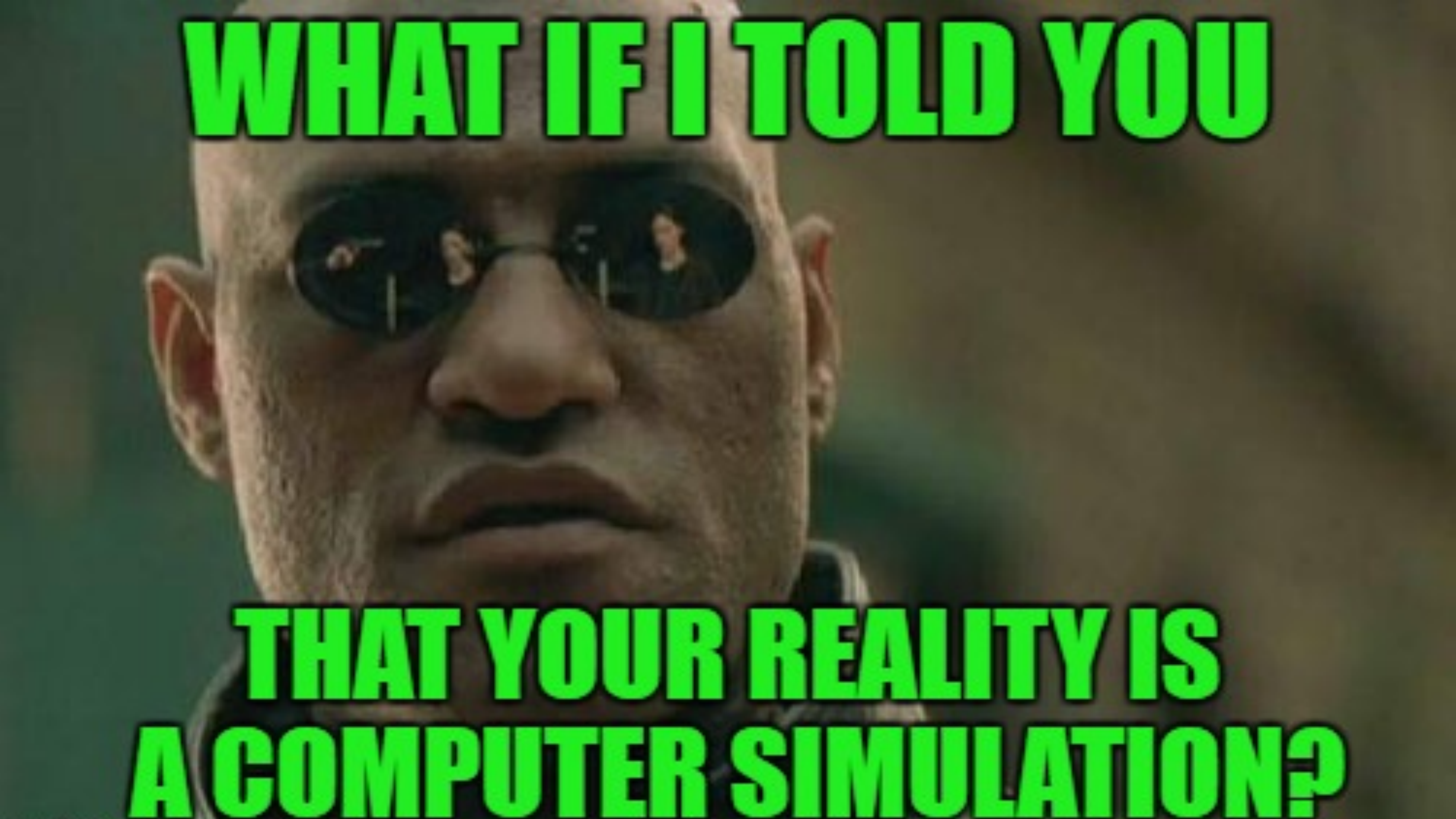




Bristlecone is Google's newest quantum processor (left). On the right is a cartoon of the device: each "X" represents a qubit, with nearest neighbor connectivity.

- 72 qubits, runs Google QS circuits
- Although no one has achieved this goal yet, we calculate quantum supremacy can be comfortably demonstrated with **49** qubits, a circuit depth exceeding **40**, and a two-qubit error below **0.5%**
  - $(1 - 0.005)^{420} \sim 0.12$
  - Also, measurement and qubit-init errors
  - Folklore: circuit fidelity target **0.005**



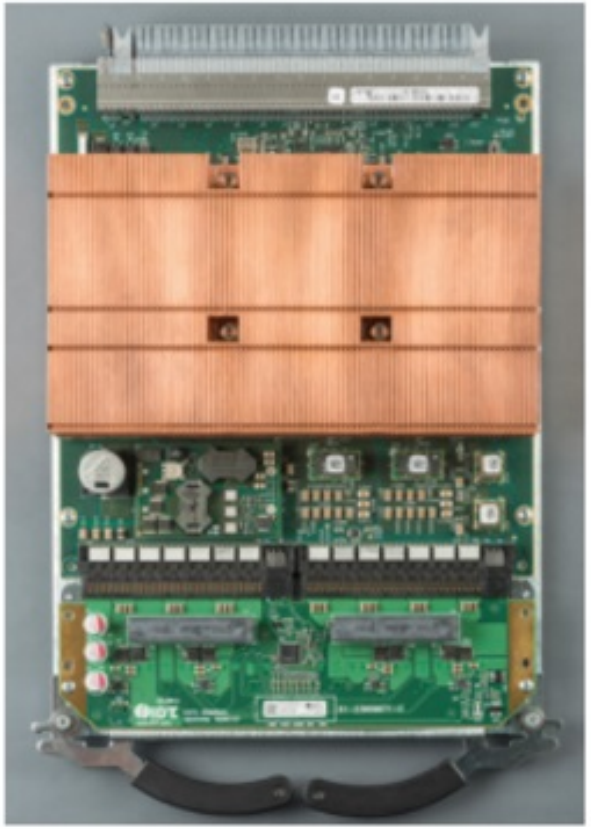

WHAT IF I TOLD YOU
THAT YOUR REALITY IS
A COMPUTER SIMULATION?

HISTORICAL EXAMPLES

Anton

Anton is a special purpose supercomputer for biomolecular simulation designed and constructed by D. E. Shaw Research (DESRES).

"Like its predecessor, Anton 2 performs the entire molecular dynamics computation within custom ASICS that are tightly interconnected by a specialized high-performance network. Each ASIC devotes a quarter of its die area to specialized hardware pipelines for calculation interactions between pairs of atoms, and also contains 66 general purpose programmable processor cores that deliver data to these pipelines and perform the remaining computations required by the simulation."



Both systems are operational

- Anton 1 and 2 used in many scientific studies / papers
- Commercial success unclear

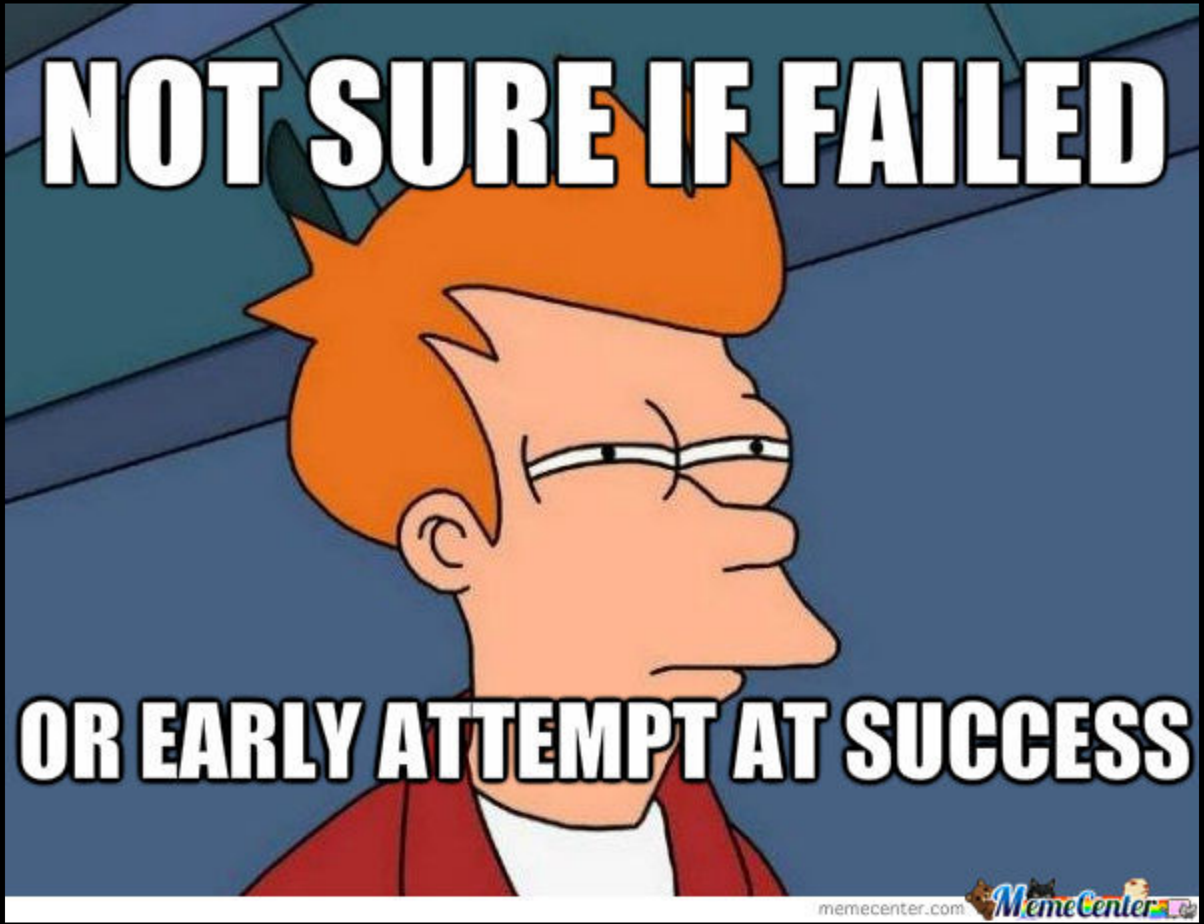
Iridium

Replica of a first-generation Iridium satellite

Manufacturer	Motorola (original constellation), Thales Alenia Space (NEXT

The Rise and Fall and Rise of Iridium

Iridium's constellation of 66 comsats was a technological triumph but a business disaster-until an executive and a computer geek found salvation in the Pentagon.


NOT SURE IF FAILED
OR EARLY ATTEMPT AT SUCCESS
memecenter.com MemeCenter

QUESTIONS?


Neilson
skim milk 0.1%
VITAMINS A & D ADDED
fresh
skim milk
0.1% M.F.
Foodland
LOW IN CHOLESTEROL
2 L
Neilson
1% partly skimmed milk
VITAMINS A & D ADDED
fresh
1% M.F. partly skimmed
milk
Foodland
LOW IN FAT
2 L
Neilson
2% partly skimmed milk
VITAMINS A & D ADDED
fresh
2% M.F. partly skimmed
milk
Foodland
2 L
Neilson
homogenized 3.25% milk
VITAMIN D ADDED
fresh
3.25% M.F.
homogenized
milk
Foodland
2 L