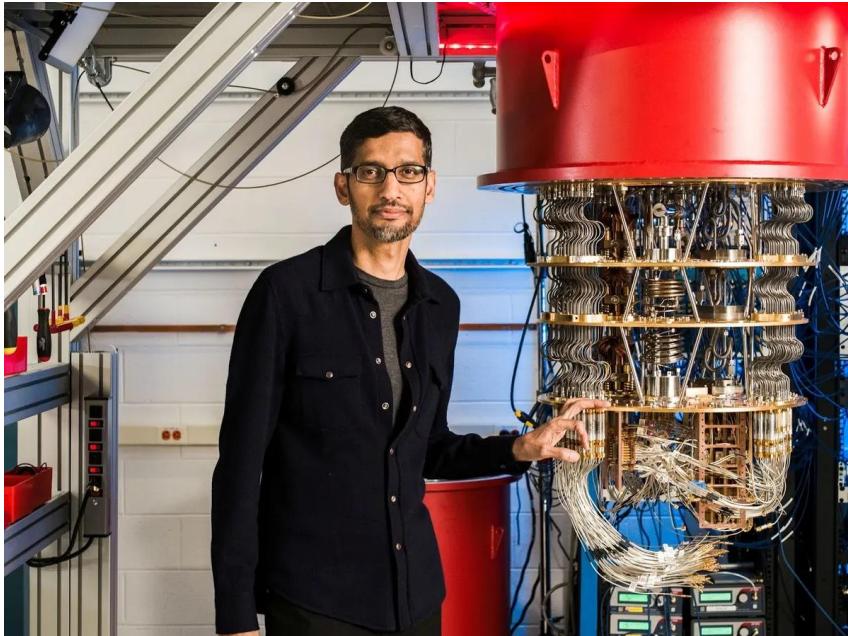


# Quantum Computing: myth and reality

ZOLTÁN ZIMBORÁS

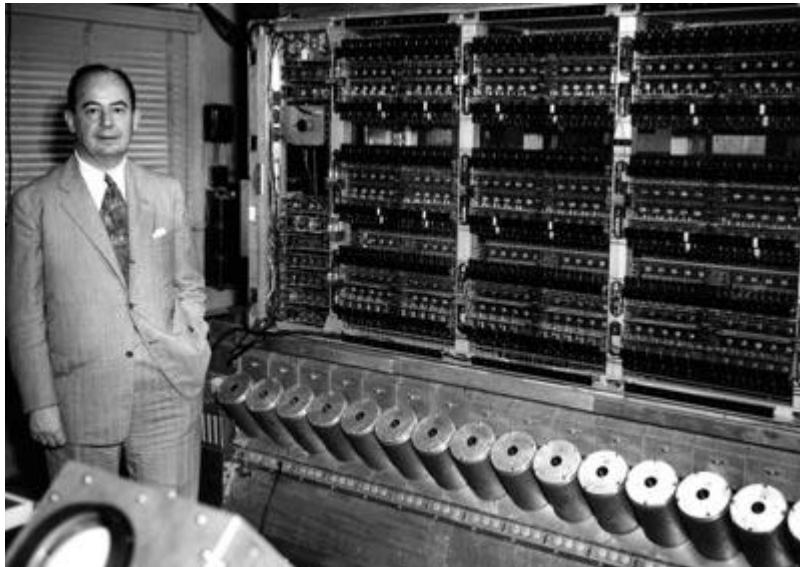
WIGNER RCP | NOVEMBER 15, 2022

# Computational Supremacy of Sycamore



- 2019: Sundar Pichai (Google) announces that they reached Quantum Computational Supremacy (or Quantum Supremacy for short) for a specific task:
  - Sycamore can solve a task in 200s
  - the best supercomputer in the world can solve it in 10000 years.

# The computational supremacy of ENIAC



- 1948: John von Neumann announces the supremacy of ENIAC compared to the Mathematical Tables “computers” of Mathematical Tables for a Gauss elimination task:
  - For ENIAC it took 9 hours,
  - for the MT employees 21 days.

# Logarithm Tables, French Revolution, Hairdressers



TABLE V.					
Nomb.	Logarithmes.	Nomb.	Logarithmes.	Nomb.	Logarithmes.
1163	.6655 9114 2818 0 14	1212	.0911 1196 3165 0 35	1323	.1155 0 8144 8-560 9-13
1163	.6655 5623 6303 7 74	1213	.0911 0 8515 3 155 1 59	1325	.1155 2 8122 8-560 6 53
1165	.6659 8866 4353 0 35	1217	.0953 2 8515 6 107	1327	.1157 12 8122 6 135 5 110
1167	.6661 8866 4353 0 37	1219	.0953 1 0 8506 4 105	1329	.1157 12 8122 6 135 5 110
1171	.6655 8866 4353 0 37	1220	.0953 1 0 8506 4 105	1331	.1157 12 8122 6 135 5 110
1172	.6655 8866 4353 0 37	1221	.0953 1 0 8506 4 105	1333	.1157 12 8122 6 135 5 110
1173	.6659 8866 4353 0 37	1222	.0953 1 0 8506 4 105	1334	.1157 12 8122 6 135 5 110
1175	.6659 8866 4353 0 37	1223	.0953 1 0 8506 4 105	1335	.1157 12 8122 6 135 5 110
1176	.6659 8866 4353 0 37	1224	.0953 1 0 8506 4 105	1336	.1157 12 8122 6 135 5 110
1177	.6659 8866 4353 0 37	1225	.0953 1 0 8506 4 105	1337	.1157 12 8122 6 135 5 110
1178	.6659 8866 4353 0 37	1226	.0953 1 0 8506 4 105	1338	.1157 12 8122 6 135 5 110
1179	.6659 8866 4353 0 37	1227	.0953 1 0 8506 4 105	1339	.1157 12 8122 6 135 5 110
1180	.6659 8866 4353 0 37	1228	.0953 1 0 8506 4 105	1340	.1157 12 8122 6 135 5 110
1181	.6659 8866 4353 0 37	1229	.0953 1 0 8506 4 105	1341	.1157 12 8122 6 135 5 110
1182	.6659 8866 4353 0 37	1230	.0953 1 0 8506 4 105	1342	.1157 12 8122 6 135 5 110
1183	.6659 8866 4353 0 37	1231	.0953 1 0 8506 4 105	1343	.1157 12 8122 6 135 5 110
1184	.6659 8866 4353 0 37	1232	.0953 1 0 8506 4 105	1344	.1157 12 8122 6 135 5 110
1185	.6659 8866 4353 0 37	1233	.0953 1 0 8506 4 105	1345	.1157 12 8122 6 135 5 110
1186	.6659 8866 4353 0 37	1234	.0953 1 0 8506 4 105	1346	.1157 12 8122 6 135 5 110
1187	.6659 8866 4353 0 37	1235	.0953 1 0 8506 4 105	1347	.1157 12 8122 6 135 5 110
1188	.6659 8866 4353 0 37	1236	.0953 1 0 8506 4 105	1348	.1157 12 8122 6 135 5 110
1189	.6659 8866 4353 0 37	1237	.0953 1 0 8506 4 105	1349	.1157 12 8122 6 135 5 110
1190	.6659 8866 4353 0 37	1238	.0953 1 0 8506 4 105	1350	.1157 12 8122 6 135 5 110
1191	.6659 8866 4353 0 37	1239	.0953 1 0 8506 4 105	1351	.1157 12 8122 6 135 5 110
1192	.6659 8866 4353 0 37	1240	.0953 1 0 8506 4 105	1352	.1157 12 8122 6 135 5 110
1193	.6659 8866 4353 0 37	1241	.0953 1 0 8506 4 105	1353	.1157 12 8122 6 135 5 110
1194	.6659 8866 4353 0 37	1242	.0953 1 0 8506 4 105	1354	.1157 12 8122 6 135 5 110
1195	.6659 8866 4353 0 37	1243	.0953 1 0 8506 4 105	1355	.1157 12 8122 6 135 5 110
1196	.6659 8866 4353 0 37	1244	.0953 1 0 8506 4 105	1356	.1157 12 8122 6 135 5 110
1197	.6659 8866 4353 0 37	1245	.0953 1 0 8506 4 105	1357	.1157 12 8122 6 135 5 110
1198	.6659 8866 4353 0 37	1246	.0953 1 0 8506 4 105	1358	.1157 12 8122 6 135 5 110
1199	.6659 8866 4353 0 37	1247	.0953 1 0 8506 4 105	1359	.1157 12 8122 6 135 5 110
1200	.6659 8866 4353 0 37	1248	.0953 1 0 8506 4 105	1360	.1157 12 8122 6 135 5 110
1201	.6659 8866 4353 0 37	1249	.0953 1 0 8506 4 105	1361	.1157 12 8122 6 135 5 110
1202	.6659 8866 4353 0 37	1250	.0953 1 0 8506 4 105	1362	.1157 12 8122 6 135 5 110
1203	.6659 8866 4353 0 37	1251	.0953 1 0 8506 4 105	1363	.1157 12 8122 6 135 5 110
1204	.6659 8866 4353 0 37	1252	.0953 1 0 8506 4 105	1364	.1157 12 8122 6 135 5 110
1205	.6659 8866 4353 0 37	1253	.0953 1 0 8506 4 105	1365	.1157 12 8122 6 135 5 110
1206	.6659 8866 4353 0 37	1254	.0953 1 0 8506 4 105	1366	.1157 12 8122 6 135 5 110
1207	.6659 8866 4353 0 37	1255	.0953 1 0 8506 4 105	1367	.1157 12 8122 6 135 5 110
1208	.6659 8866 4353 0 37	1256	.0953 1 0 8506 4 105	1368	.1157 12 8122 6 135 5 110
1209	.6659 8866 4353 0 37	1257	.0953 1 0 8506 4 105	1369	.1157 12 8122 6 135 5 110
1210	.6659 8866 4353 0 37	1258	.0953 1 0 8506 4 105	1370	.1157 12 8122 6 135 5 110
1211	.6659 8866 4353 0 37	1259	.0953 1 0 8506 4 105	1371	.1157 12 8122 6 135 5 110
1212	.6659 8866 4353 0 37	1260	.0953 1 0 8506 4 105	1372	.1157 12 8122 6 135 5 110
1213	.6659 8866 4353 0 37	1261	.0953 1 0 8506 4 105	1373	.1157 12 8122 6 135 5 110
1214	.6659 8866 4353 0 37	1262	.0953 1 0 8506 4 105	1374	.1157 12 8122 6 135 5 110
1215	.6659 8866 4353 0 37	1263	.0953 1 0 8506 4 105	1375	.1157 12 8122 6 135 5 110
1216	.6659 8866 4353 0 37	1264	.0953 1 0 8506 4 105	1376	.1157 12 8122 6 135 5 110
1217	.6659 8866 4353 0 37	1265	.0953 1 0 8506 4 105	1377	.1157 12 8122 6 135 5 110
1218	.6659 8866 4353 0 37	1266	.0953 1 0 8506 4 105	1378	.1157 12 8122 6 135 5 110
1219	.6659 8866 4353 0 37	1267	.0953 1 0 8506 4 105	1379	.1157 12 8122 6 135 5 110
1220	.6659 8866 4353 0 37	1268	.0953 1 0 8506 4 105	1380	.1157 12 8122 6 135 5 110
1221	.6659 8866 4353 0 37	1269	.0953 1 0 8506 4 105	1381	.1157 12 8122 6 135 5 110
1222	.6659 8866 4353 0 37	1270	.0953 1 0 8506 4 105	1382	.1157 12 8122 6 135 5 110
1223	.6659 8866 4353 0 37	1271	.0953 1 0 8506 4 105	1383	.1157 12 8122 6 135 5 110
1224	.6659 8866 4353 0 37	1272	.0953 1 0 8506 4 105	1384	.1157 12 8122 6 135 5 110
1225	.6659 8866 4353 0 37	1273	.0953 1 0 8506 4 105	1385	.1157 12 8122 6 135 5 110
1226	.6659 8866 4353 0 37	1274	.0953 1 0 8506 4 105	1386	.1157 12 8122 6 135 5 110
1227	.6659 8866 4353 0 37	1275	.0953 1 0 8506 4 105	1387	.1157 12 8122 6 135 5 110
1228	.6659 8866 4353 0 37	1276	.0953 1 0 8506 4 105	1388	.1157 12 8122 6 135 5 110
1229	.6659 8866 4353 0 37	1277	.0953 1 0 8506 4 105	1389	.1157 12 8122 6 135 5 110
1230	.6659 8866 4353 0 37	1278	.0953 1 0 8506 4 105	1390	.1157 12 8122 6 135 5 110
1231	.6659 8866 4353 0 37	1279	.0953 1 0 8506 4 105	1391	.1157 12 8122 6 135 5 110
1232	.6659 8866 4353 0 37	1280	.0953 1 0 8506 4 105	1392	.1157 12 8122 6 135 5 110
1233	.6659 8866 4353 0 37	1281	.0953 1 0 8506 4 105	1393	.1157 12 8122 6 135 5 110
1234	.6659 8866 4353 0 37	1282	.0953 1 0 8506 4 105	1394	.1157 12 8122 6 135 5 110
1235	.6659 8866 4353 0 37	1283	.0953 1 0 8506 4 105	1395	.1157 12 8122 6 135 5 110
1236	.6659 8866 4353 0 37	1284	.0953 1 0 8506 4 105	1396	.1157 12 8122 6 135 5 110
1237	.6659 8866 4353 0 37	1285	.0953 1 0 8506 4 105	1397	.1157 12 8122 6 135 5 110
1238	.6659 8866 4353 0 37	1286	.0953 1 0 8506 4 105	1398	.1157 12 8122 6 135 5 110
1239	.6659 8866 4353 0 37	1287	.0953 1 0 8506 4 105	1399	.1157 12 8122 6 135 5 110
1240	.6659 8866 4353 0 37	1288	.0953 1 0 8506 4 105	1400	.1157 12 8122 6 135 5 110
1241	.6659 8866 4353 0 37	1289	.0953 1 0 8506 4 105	1401	.1157 12 8122 6 135 5 110



- 1791: money from the National Assembly
- Three (1793-1801):
  - 6 planning mathematician (Legendre, Carnot)
  - 8 processing mathematician
  - 80 computers (many of the hairdressers)

Gaspard de Prony

# Babbage elbóbiskolása és hirtelen ötlete

“... I was sitting in the rooms of the Analytical Society, at Cambridge, my head leaning forward on the table in a kind of dreamy mood, with a table of logarithms lying open before me. Another member, coming into the room, and seeing me half asleep, called out, "Well, Babbage, what are you dreaming about?" to which I replied "I am thinking that all these tables" (pointing to the logarithms) "might be calculated by machinery...."



Charles Babbage

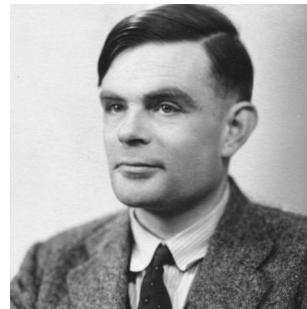
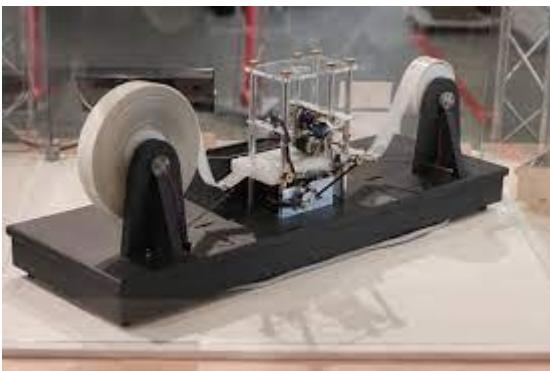
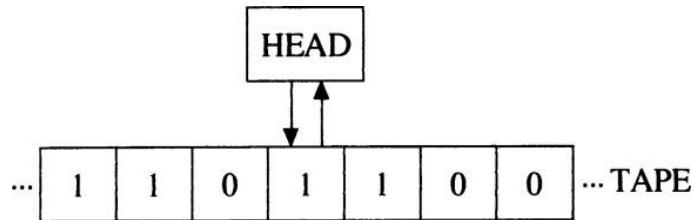
# Babbage's engines



Charles Babbage

- Difference Engine
  - devoted to the specific task of evaluation polinom functions
- Analytical Engine
  - universally programmable with punchcards (!)

# The concept of a Universal Computer



Alan Turing

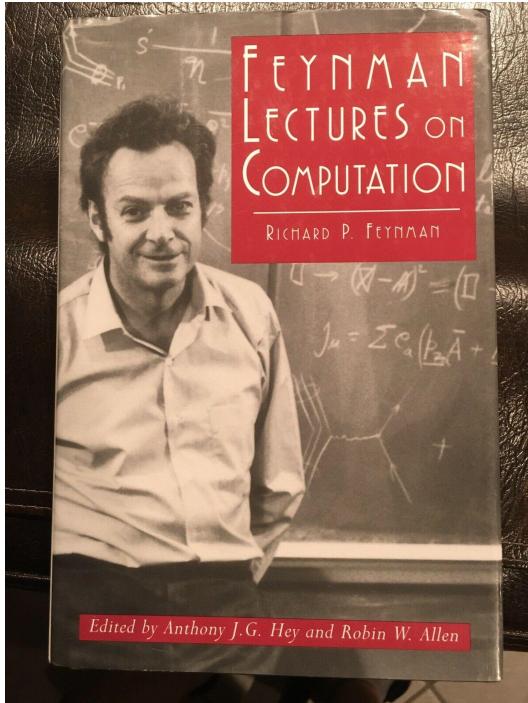
- Turing machine:  
the theoretical concept of a universal  
computer

# Church–Turing thesis

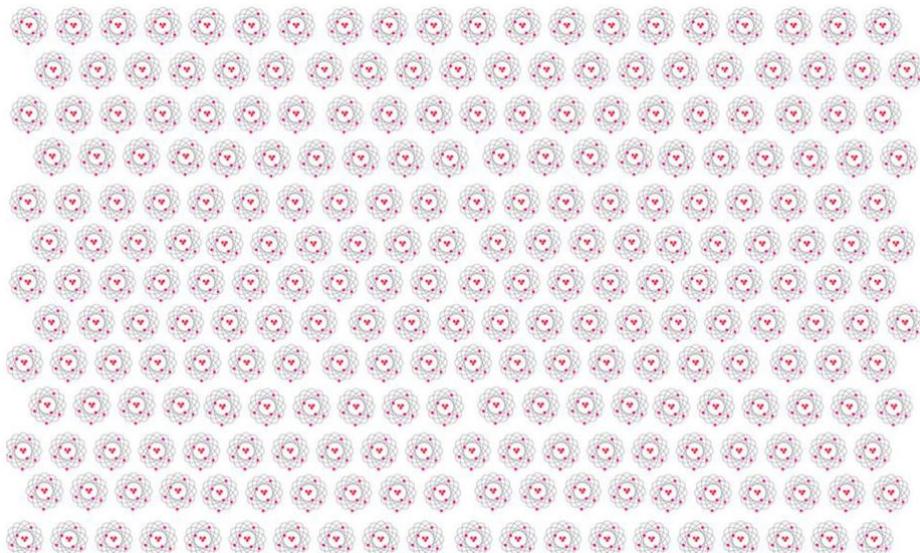


- Church–Turing thesis
- Strong Church–Turing thesis

# Computers and Physicists



# The problem of Feynman



- To fully describe the state of a systems consisting of 300 two-state quantum levels, we would need more bits than the number of atoms in the Universe.

# Feynman's way out



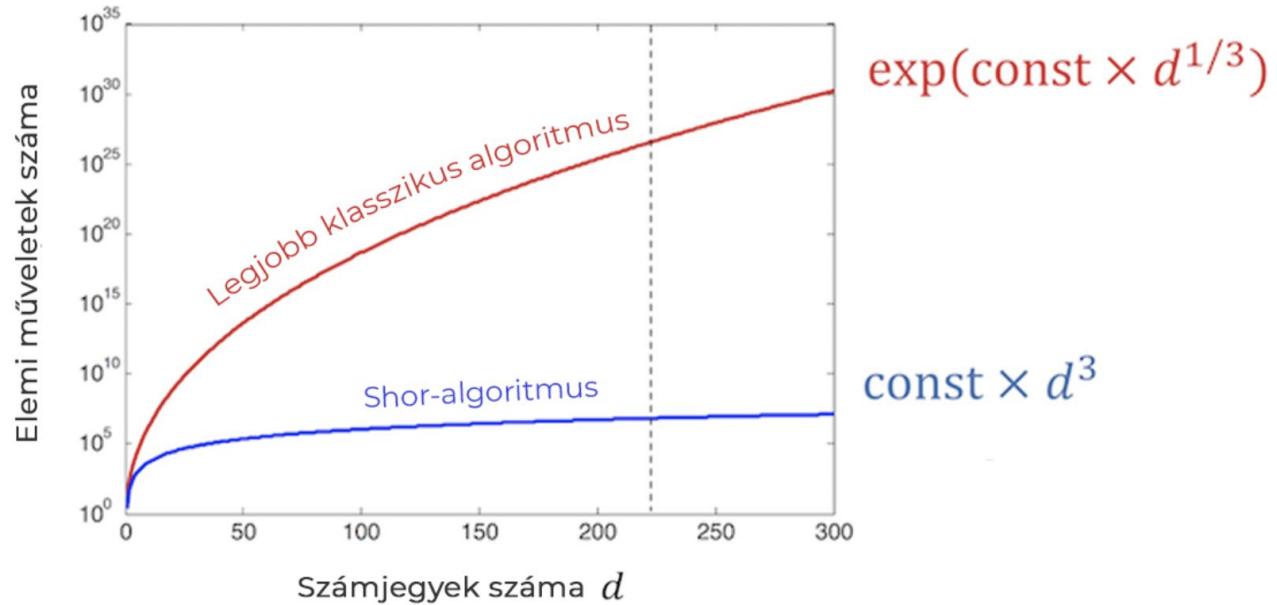
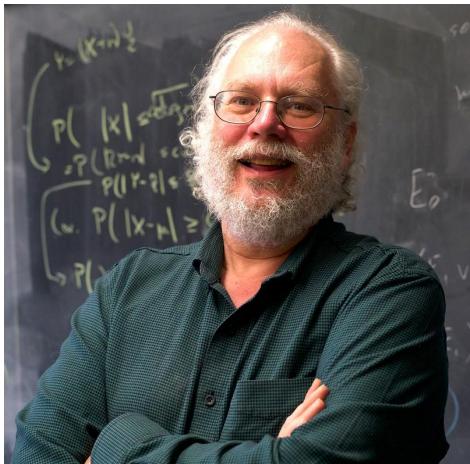
- Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy.  
(Feynman, Simulating Physics with Computers)

# Feynman's deep idea

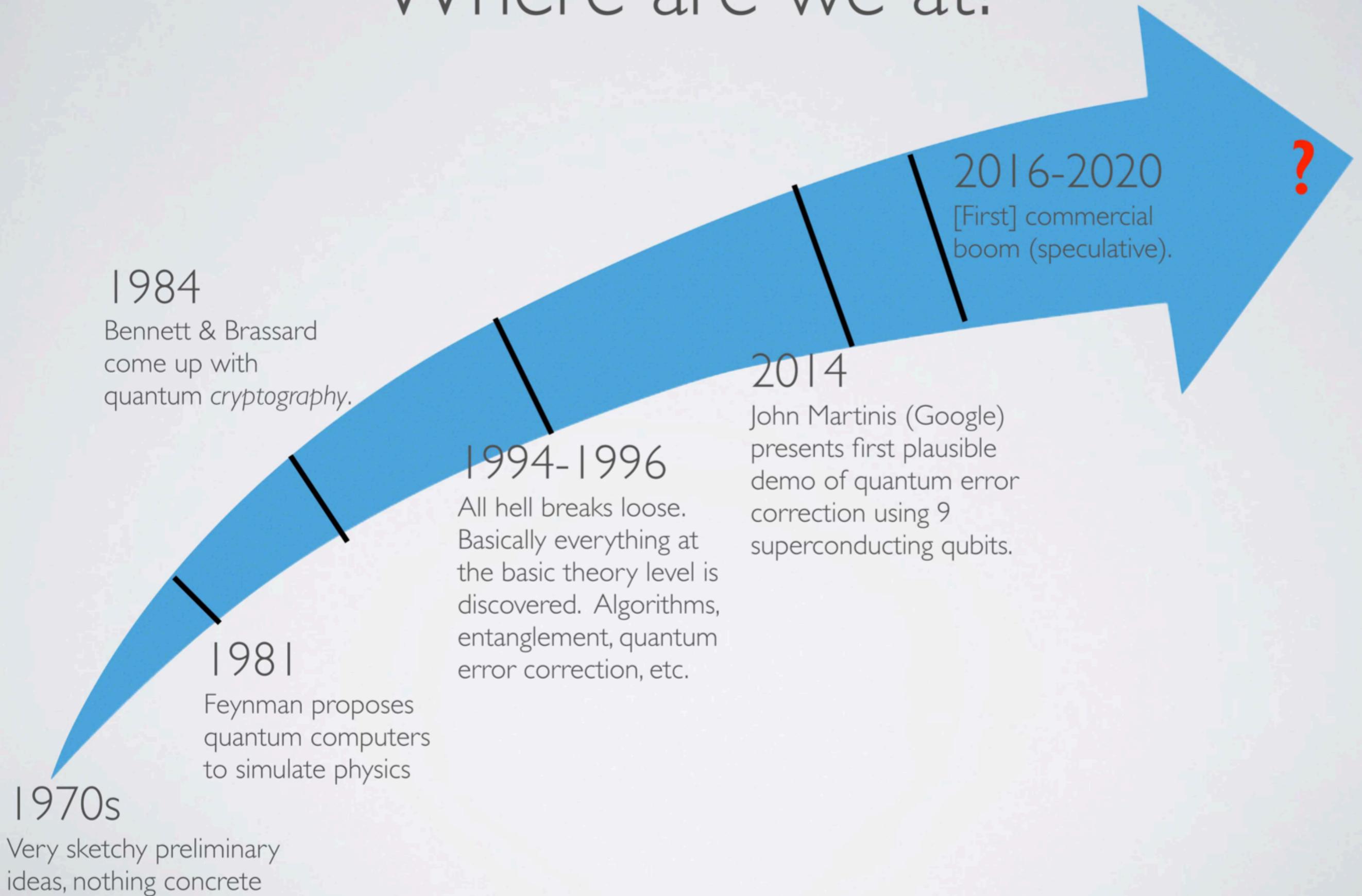


- "Hogyan szimulálhatjuk a effektíven a kvantummechanikát? (...) Ez talán megtehető egy új típusú géppel, a kvantumszámítógéppel. Ez már nem egy Turing-gép."  
(Feynman, Simulating Physics with Computers)

# Surprise: Shor's algorithm for factorization



# Where are we at?



# The myth

- In the history of mankind, this is the first time we will have the possibility of solving important problems with a completely new method of calculation.
- Various Quantum Algorithms promise us an exponential advantage.

## ...and the reality

The probability of  
transistor switch error

$$p \sim 10^{-27}$$

The probability of  
single qubit error

$$p \sim 10^{-4}$$



23 orders of  
magnitude difference

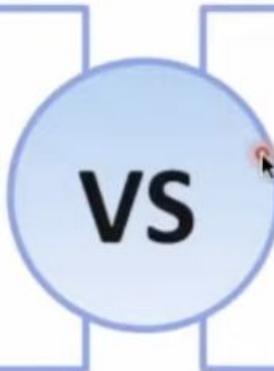
## ...and the reality

The probability of  
transistor switch error

$$p \sim 10^{-27}$$

The probability of  
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$$p \sim 10^{-4}$$



23 orders of  
magnitude difference



quantum error correction

1000 physical qubit



1 logical qubit

# Quantum Computer Platforms

**Quantum Computing: Progress and Prospects**  
(2018 Consensus Study Report of National Academies of Sciences-Engineering-Medicine)

<b>5 ESSENTIAL HARDWARE COMPONENTS OF A QUANTUM COMPUTER.....</b>	<b>5-1</b>
5.1 Hardware Structure of a Quantum Computer .....	5-1
5.1.1 Quantum Data Plane.....	5-2
5.1.2 Control and Measurement Plane .....	5-2
5.1.3 Control Processor Plane and Host Processor.....	5-3
5.1.4 Qubit Technologies.....	5-4
5.2 Trapped Ion Qubits.....	5-4
5.2.1 Current Trapped Ion Quantum “Computers” .....	5-5
5.2.2 Challenges and Opportunities for Creating a Scalable Ion Trap Quantum Computer.....	5-5
5.3 Superconducting Qubits.....	5-7
5.3.1 Current Superconducting Quantum “Computers” .....	5-7
5.3.2 Challenges and Opportunities for Creating a Scalable Quantum Computer .....	5-8
5.4 Other Technologies .....	5-10
5.5 Future Outlook .....	5-11

# When will be able to run traditional Quantum Algorithms?

How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits

Craig Gidney<sup>1,\*</sup> and Martin Ekerå<sup>2</sup>

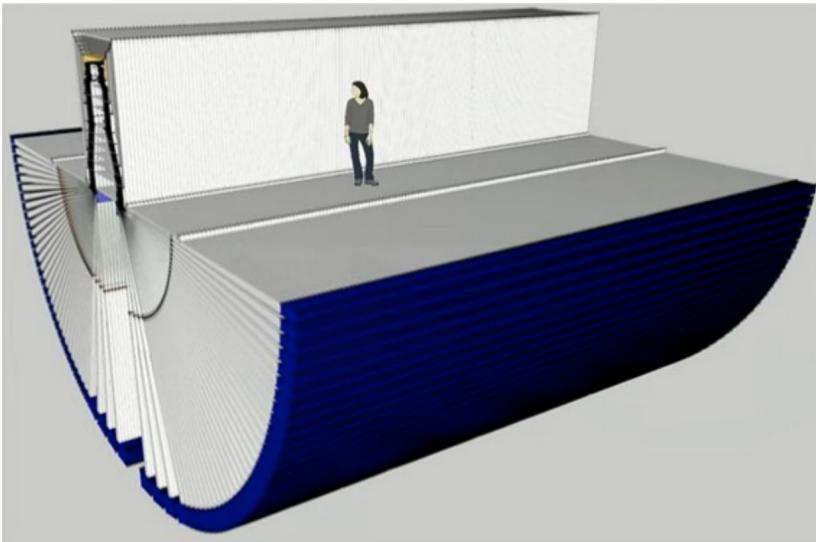
<sup>1</sup>*Google Inc., Santa Barbara, California 93117, USA*

<sup>2</sup>*KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden  
Swedish NCSA, Swedish Armed Forces, SE-107 85 Stockholm, Sweden*

(Dated: May 24, 2019)

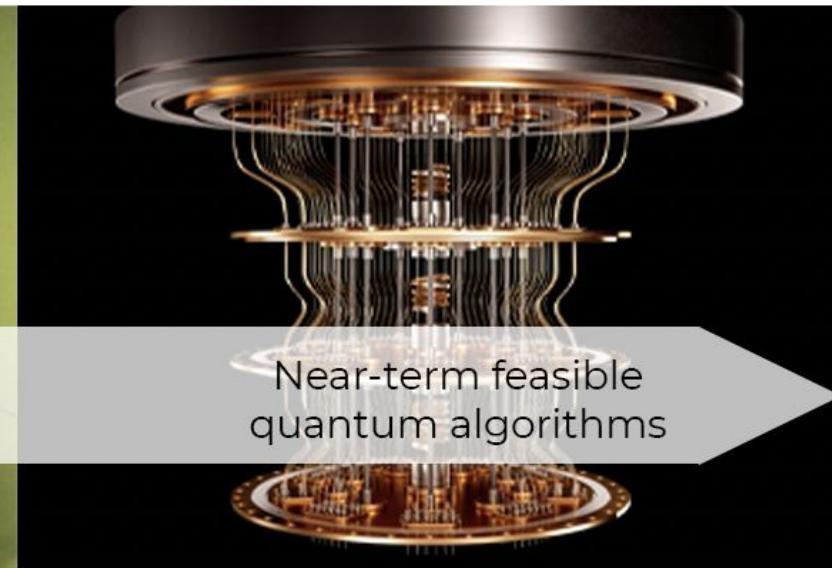
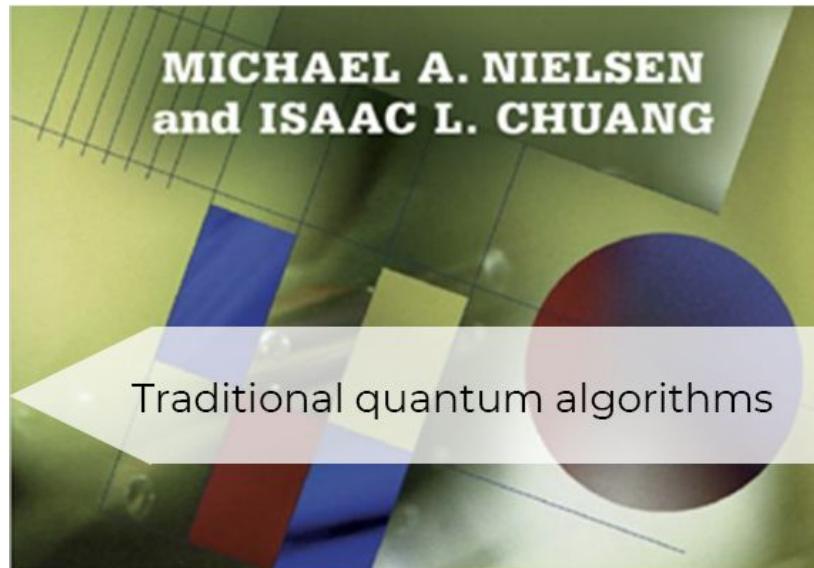
Historical cost estimate at $n = 2048$	Physical assumptions				Approach		Estimated costs		
	Physical gate error rate	Cycle time (microseconds)	Reaction time (microseconds)	Physical connectivity	Distillation strategy	Execution strategy	Physical qubits (millions)	Expected runtime (days)	Expected volume (megaqubitdays)
Fowler et al. 2012 [9]	0.1%	1	0.1	planar	1200 T	single threaded	1000	1.1	1100
O'Gorman et al. 2017 [18]	0.1%	10	1	arbitrary	block CCZ	single threaded	230	3.7	850
Gheorghiu et al. 2019 [19] (ours) 2019 (1 factory)	0.1%	0.2	0.1	planar	1100 T	single threaded	170	1	170
(ours) 2019 (1 thread)	0.1%	1	10	planar	1 CCZ	serial distillation	16	6	90
(ours) 2019 (parallel)	0.1%	1	10	planar	14 CCZ	single threaded	19	0.36	6.6
	<b>0.1%</b>	<b>1</b>	<b>10</b>	<b>planar</b>	<b>28 CCZ</b>	<b>double threaded</b>	<b>20</b>	<b>0.31</b>	<b>5.9</b>

# Google's vision



- 1 million physical qubits
- Fault tolerant quantum computing with 1000 qubits
- Dates: 2029? 2035? Even later?

# Quantum algorithms for the near term



# Quantum Supremacy experiment: the hype

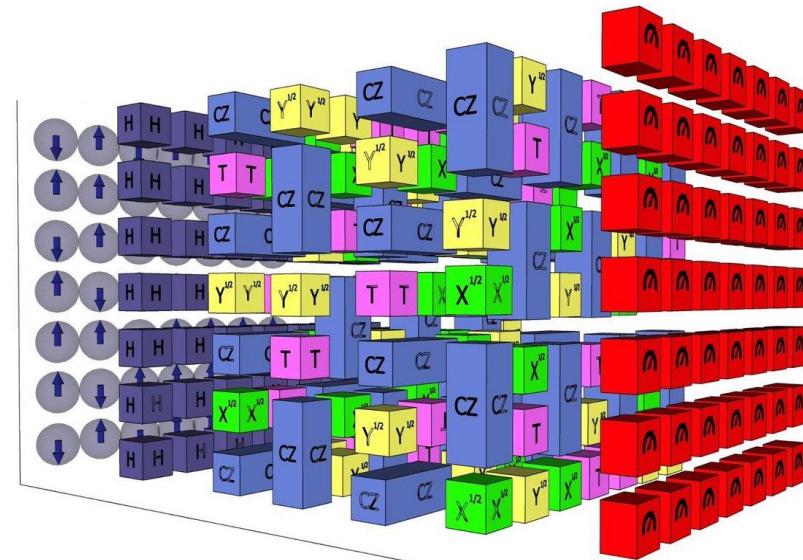
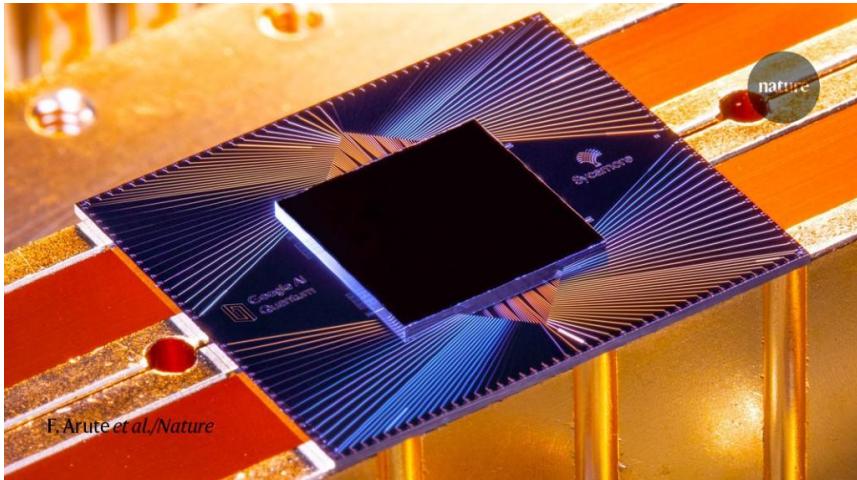


It's official! ⚡ The US has achieved quantum supremacy!

In a collaboration between the Trump Admin, [@Google](#) and UC Santa Barbara, quantum computer Sycamore has completed a calculation in 3 min 20 sec that would take about 10,000 years for a classical comp.



# Quantum Supremacy experiment: the reality



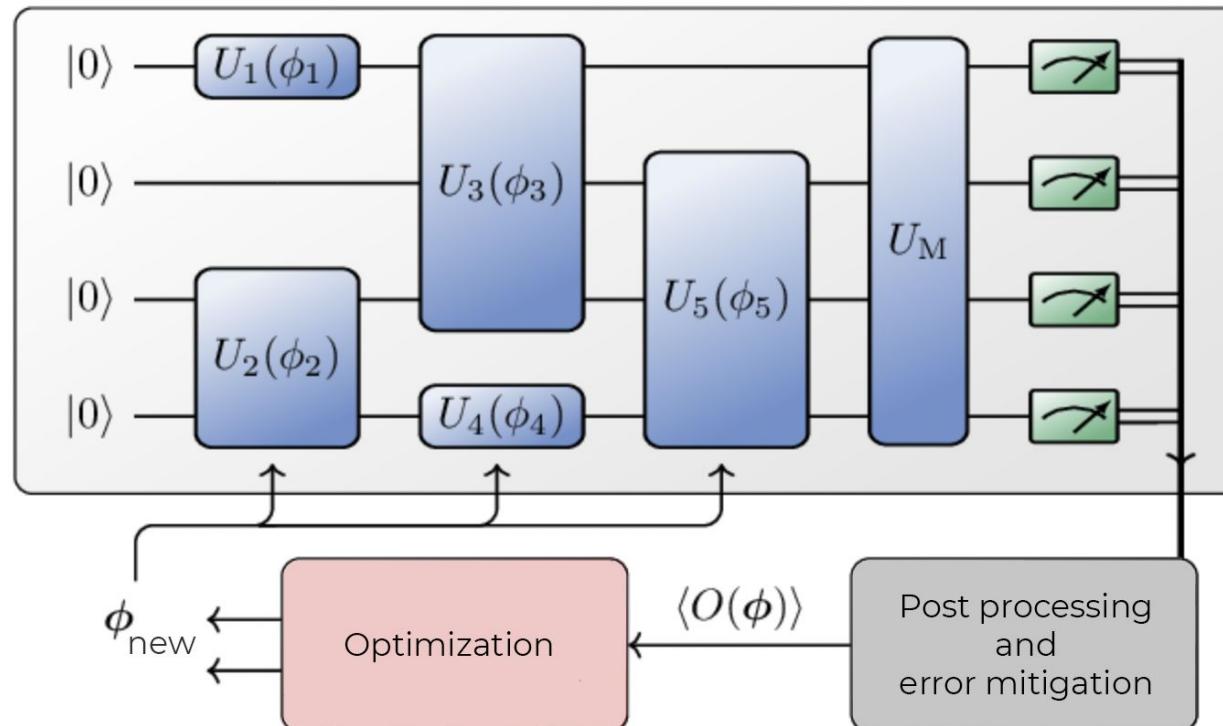
Over 20 layers of gates on 53 qubits

# Quantum Supremacy experiment: the reality

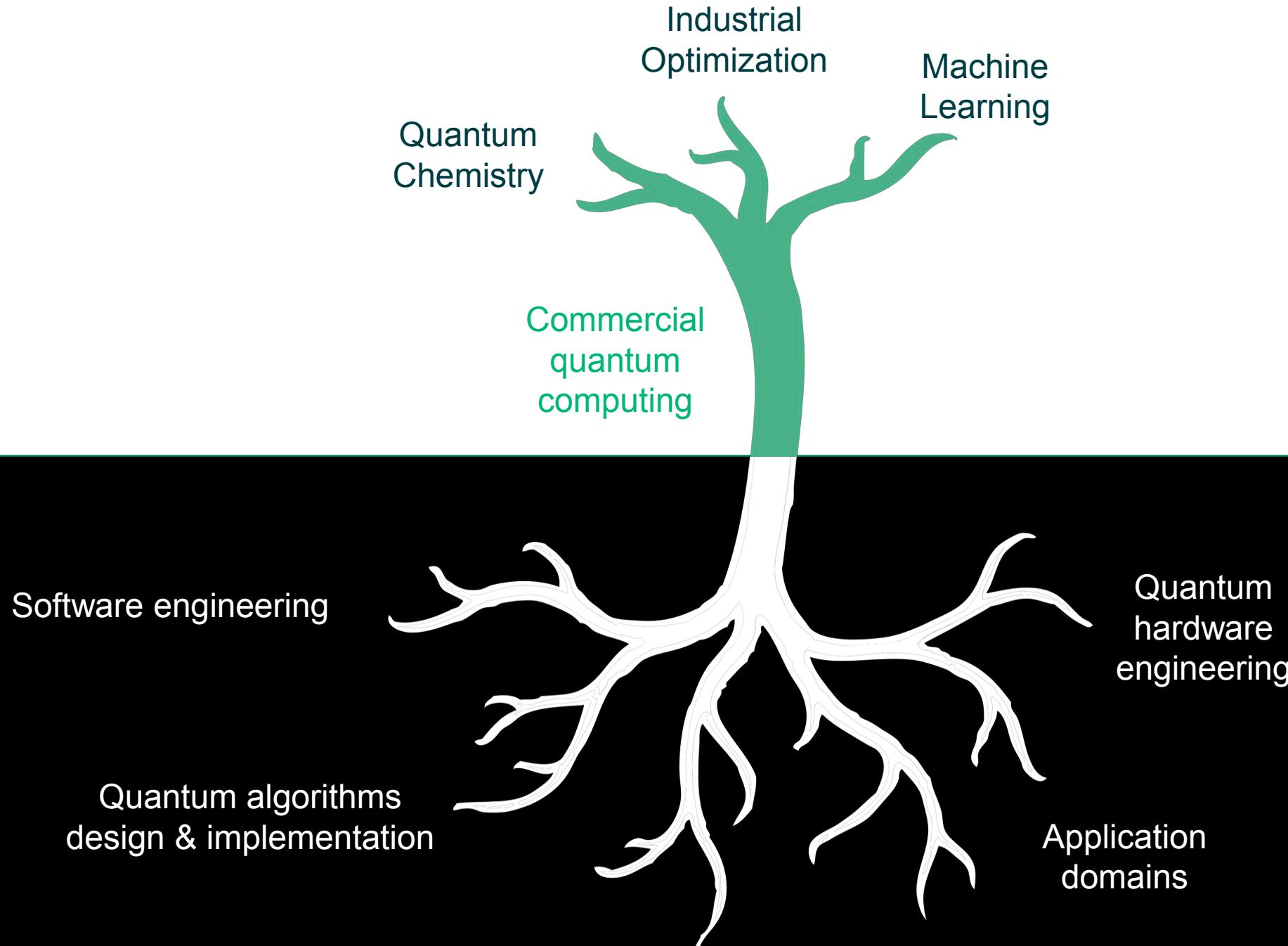
## Valóság

- No precisely verified Quantum Supremacy. (Also classical methods caught up.)
- We are close to Quantum Supremacy.
- There is no Quantum Advantage. Active research is going on in this field.

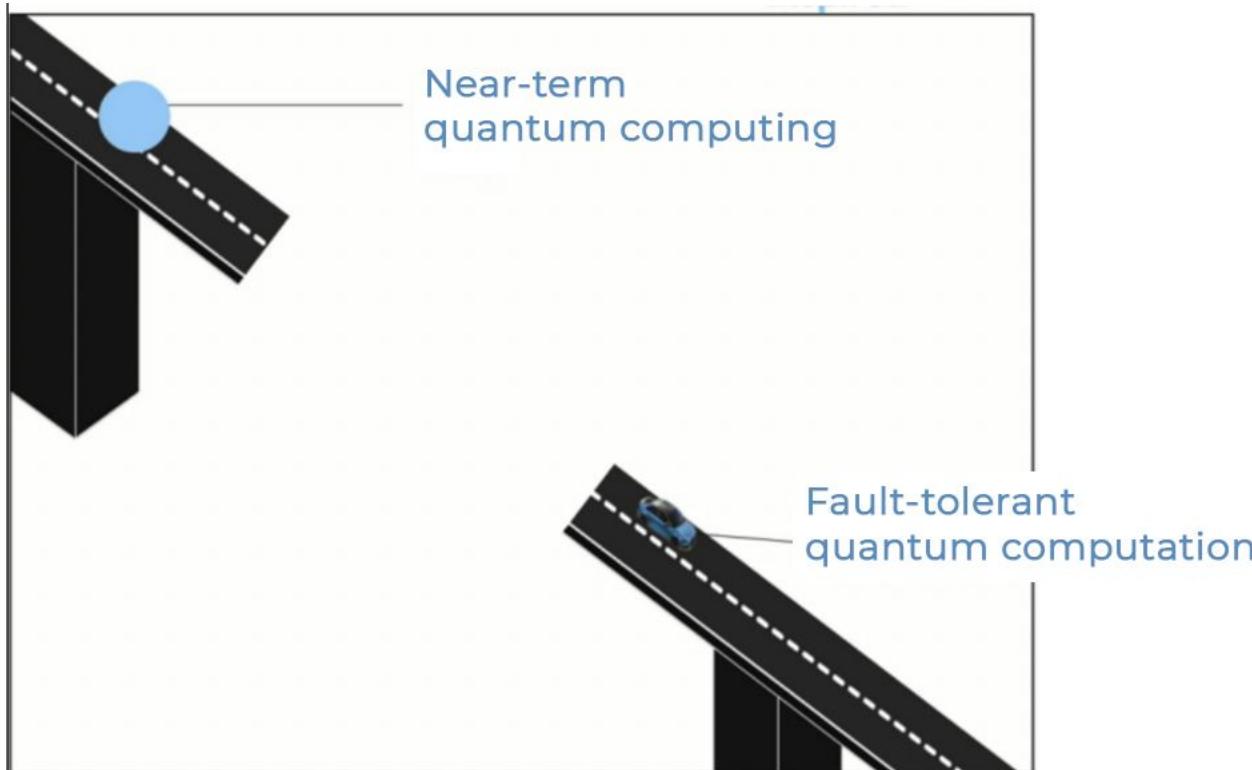
# Variational Quantum Computing



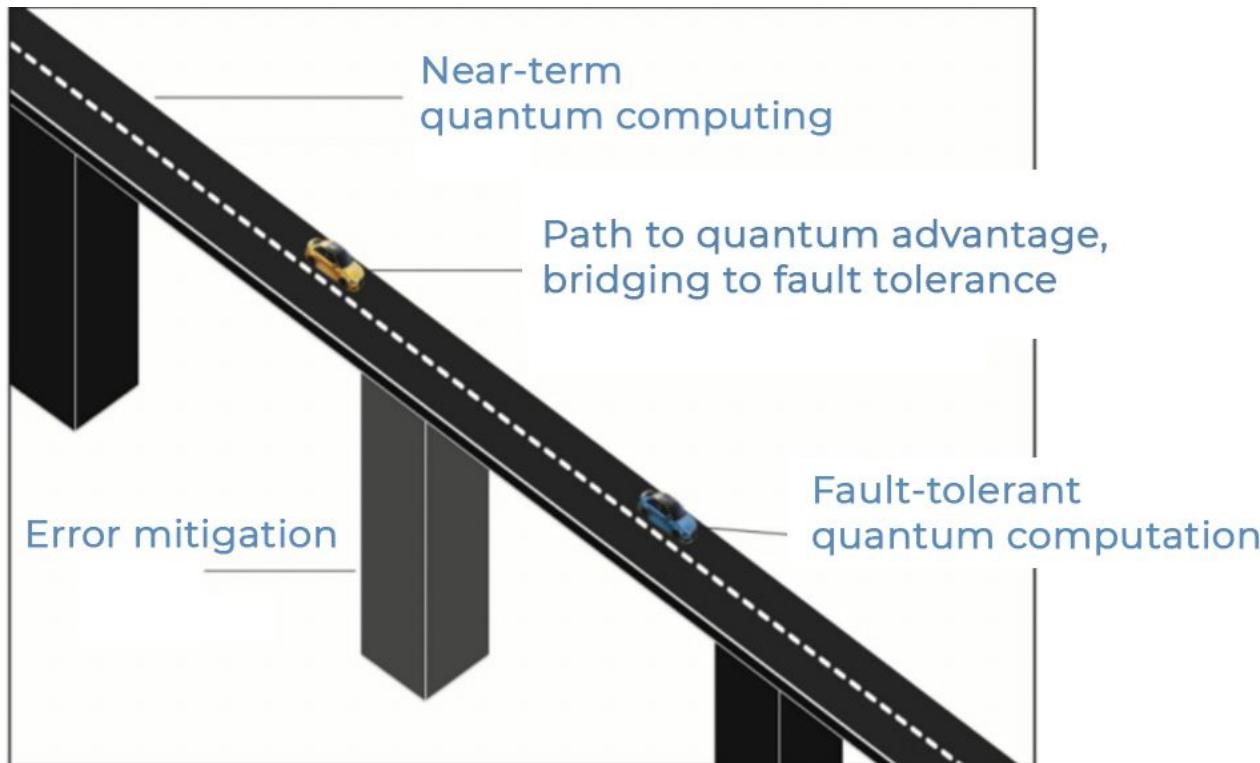
# The promise of near-term Quantum Computing



# A schematic picture of current



# The picture that I like



# Az előadás

## Myth

## Reality

- In the history of mankind, this is the first time we will have the possibility of solving important problems with a completely new method of calculation.
  - Various QUantum Algorithms promise us an exponential advantage.
- We haven't reached yet a Quantum Advantage (i.e, useful Quantum Supremacy).
  - Fault-tolerant quantum computation is to be expected earliest in the middle of next decade
  - In near- to mid-term future quantum devices will serve mostly as coprocessors.

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  - In near- to mid-term future quantum devices will serve mostly as coprocessors.
  - But the myth yields a strong motivation.