DAIMLER

QuantumComputing @ Daimler

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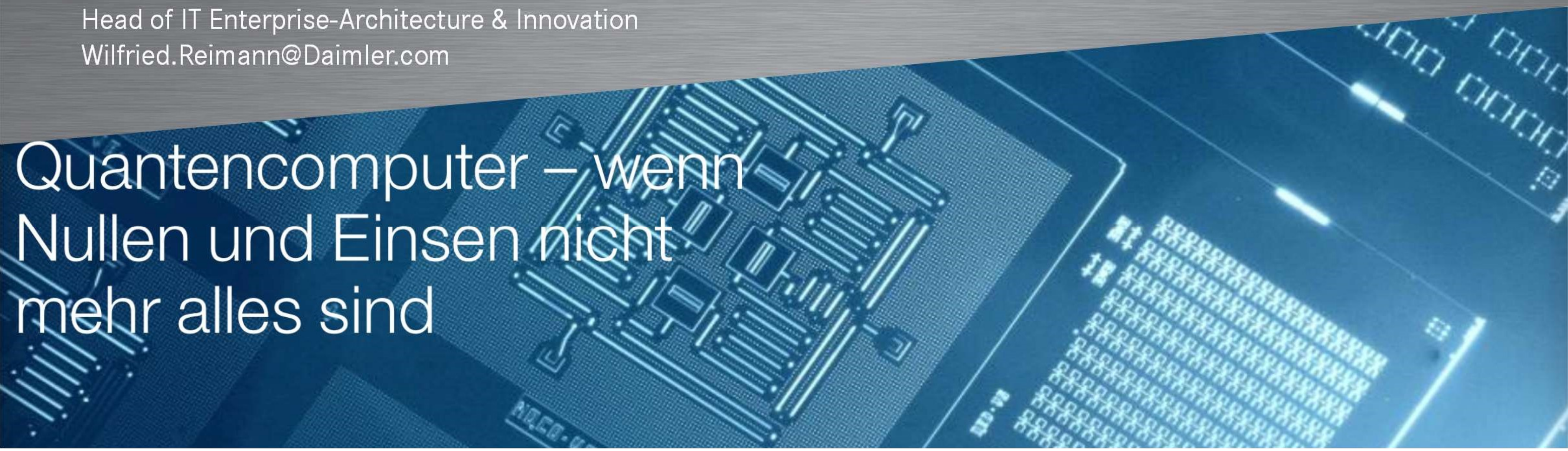


Daimler consists of five divisions

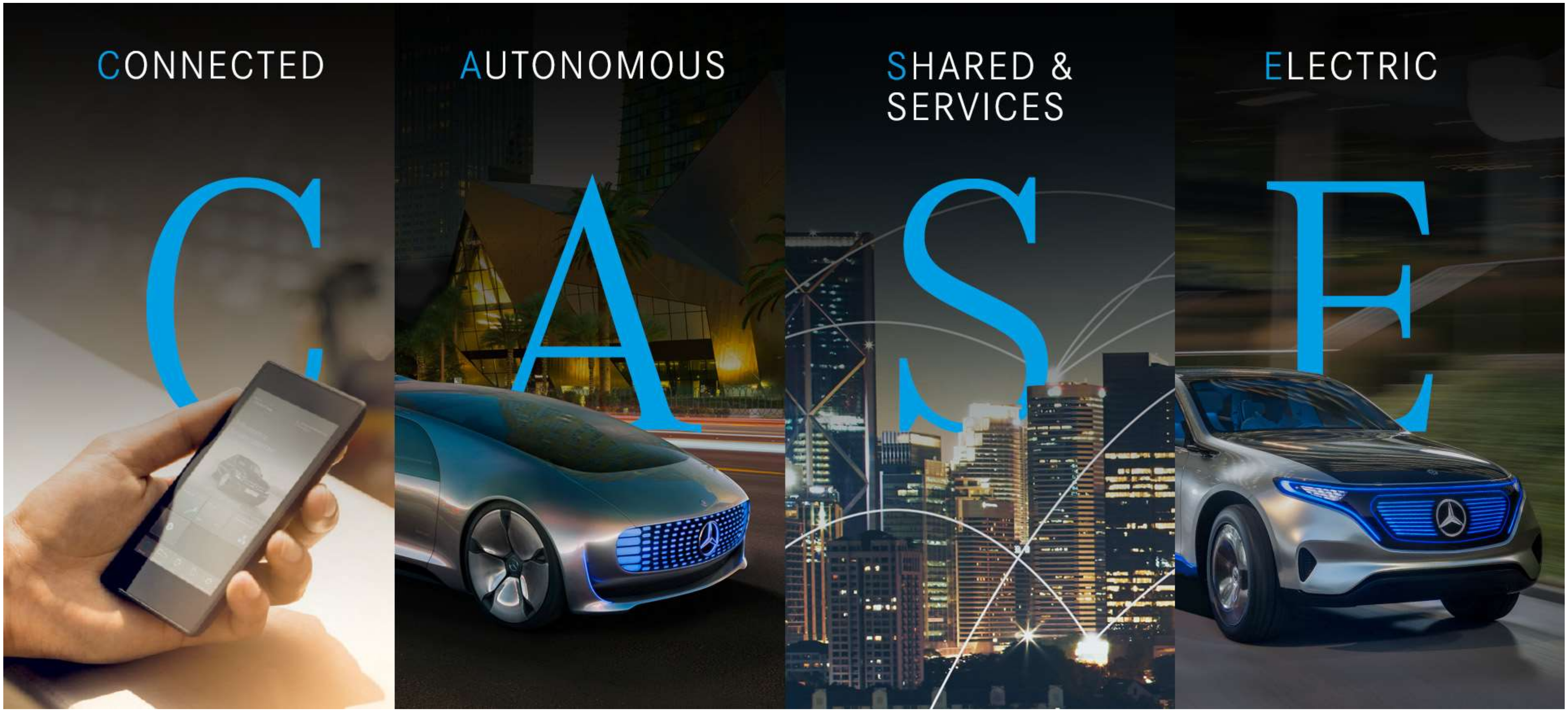




	Mercedes-Benz Cars	Mercedes-Benz Vans	Daimler Trucks	Daimler Buses	Daimler Financial Services
Umsatz	€ 94,7 Mrd.	€ 13,2 Mrd.	€ 35,7 Mrd.	€ 4,4 Mrd.	€ 23,8 Mrd.
Mitarbeiter	142.666	25.255	79.483	18.292	13.012

Note: 2017 revenue 164.330 Mio. €, employees 289.321

Daimler Strategy - CASE

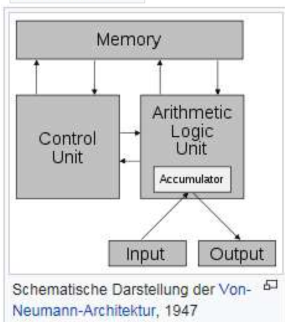


Agenda

1. **Why do we need Quantum Computing (QC)**
2. Introduction of QC
3. Daimler interest – Use Cases
4. Market players and research
5. Summary

“Von Neumann Computers” based on silicon have changed the world for more than 50 years, but since 2010 Moore’s law for doubling speed of a single processor isn’t valid for silicon based computers.

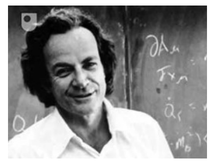
Introduction of a Computer
Von Neumann (1945)



Schematische Darstellung der Von-Neumann-Architektur, 1947

Transistor building first scientific computers

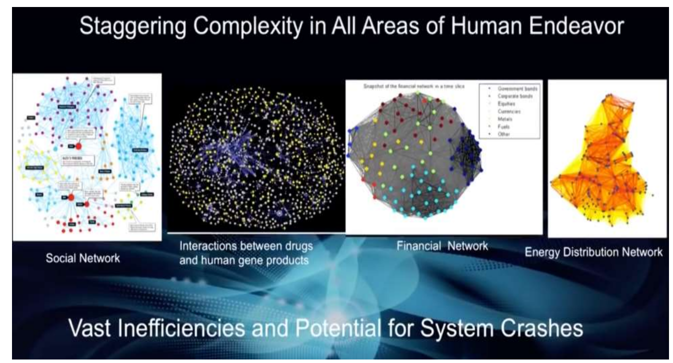
Integrated Circuits



Introduction of a Quantum Computer
Richard Feynman (1982)

Richard Feynman showed that a classical Turing machine would experience an exponential slowdown when simulating quantum phenomena, while his hypothetical universal quantum simulator would not.

Moore’s Law is over for speed of processors (max 6 Giga Hertz). The limitation is energy consumption!



1945 | 1960 | 1982 | 2010 | 2015 | 2050

Moore's law is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years

We need a different way to solve hard problems, which we can’t program classical and can’t run on silicon based computers. **Moore’s Law will be valid in future for Quantum Computers**

Which problems can we solve with QC?

Stuttgart 8:03 November 29th 2017

Daily traffic collapse in Stuttgart can possibly avoided by **optimizing route planning in backend** for millions of vehicles:

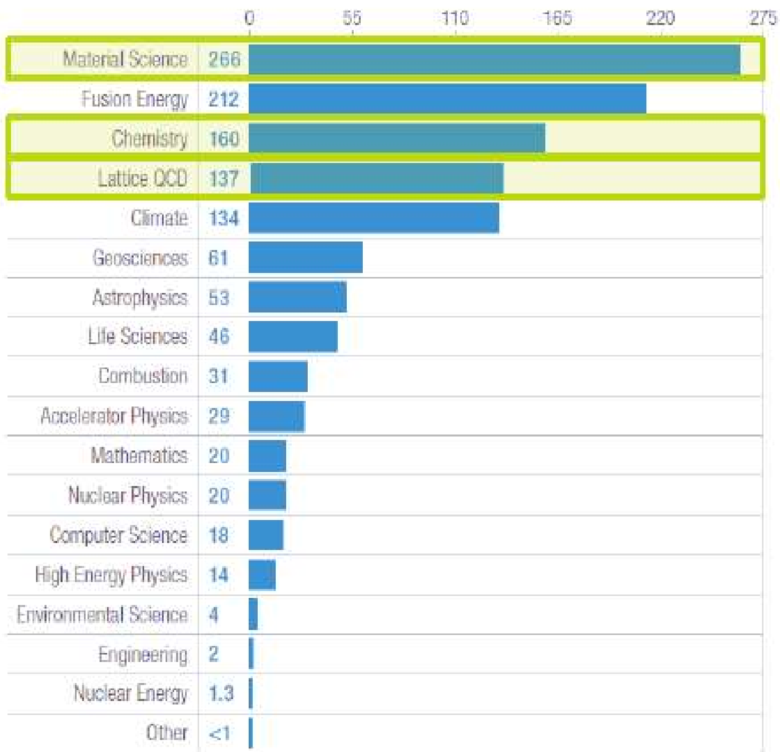
Predict traffic for the next 4 hours depending on most probable events:

Business Models:

- **Advise start time for drivers to office,** when to drive to office depending on (time arrival, shortest travel, dynamic)
- **Delivery of parcels** for hundreds of delivery services (VAN's)
- **Selling best route on demand** depending on price (fast, super fast)

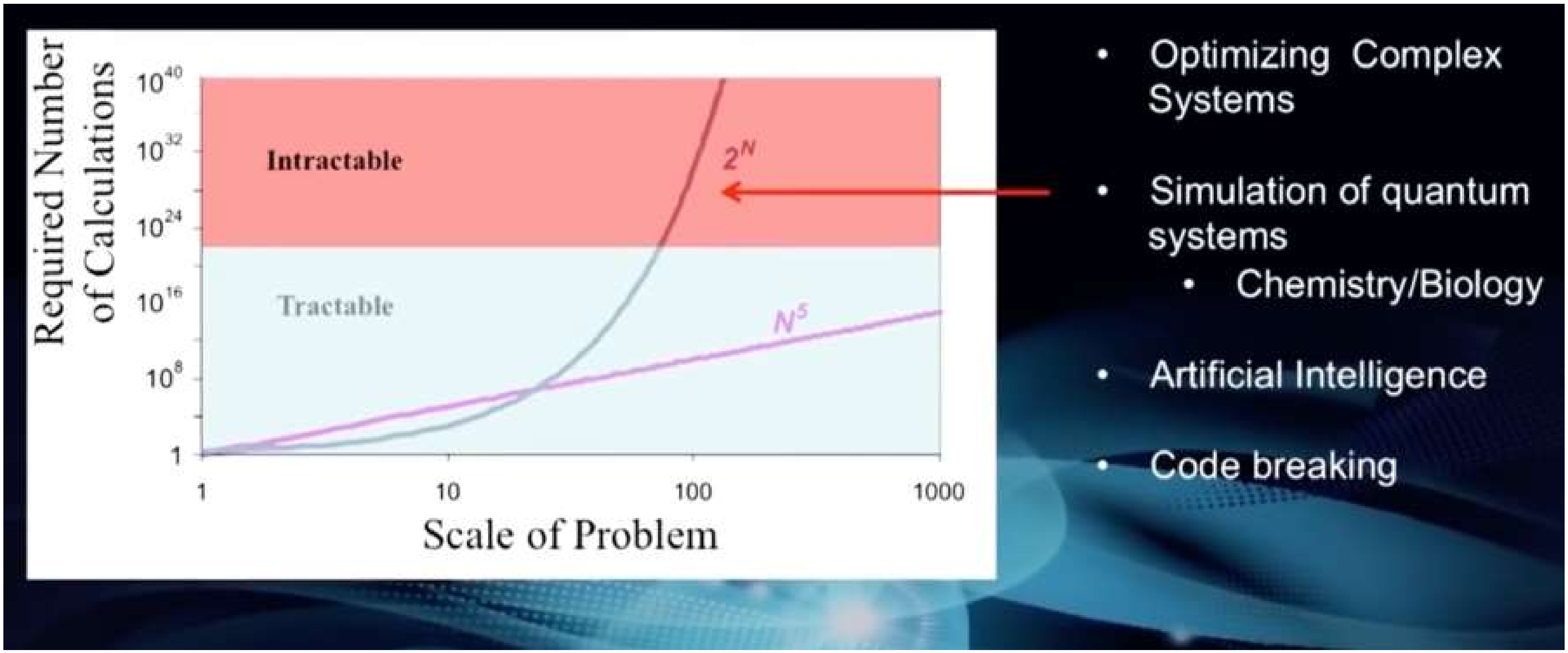
QC will improve simulation of physical systems

Hours (on Cray XE6)



- 50% of HPC time at NESRC (National Energy Research Scientific Computing Center) spent on quantum chemistry and materials science
- Solve for electronic structures of large systems (>50 spin orbitals)
- Represents problems we CAN solve classically

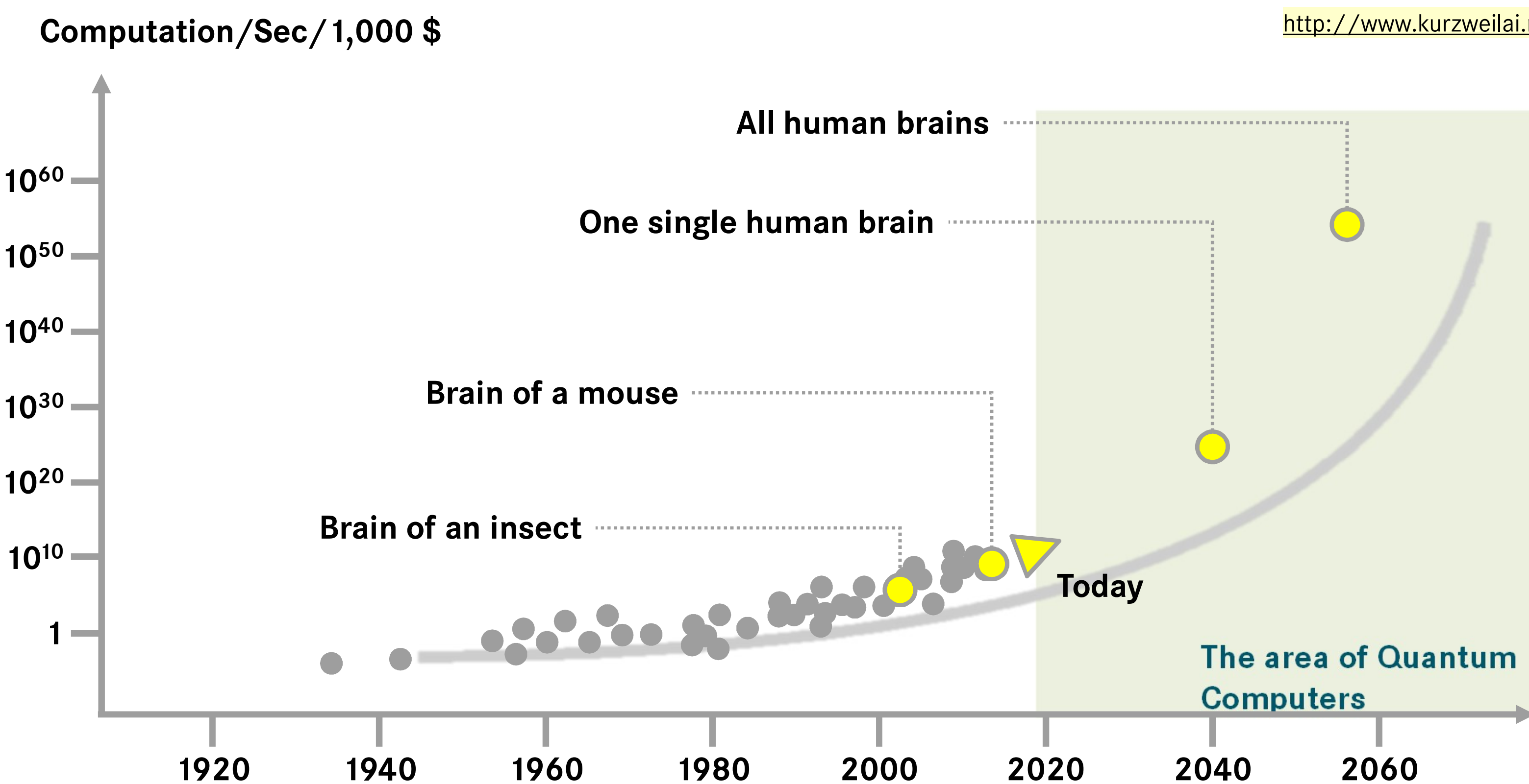
Important Problems will remain beyond the reach of any classical (silicon based) computers



Processing computing power and Artificial Intelligence

Increases exponentially over the last decades (Ray Kurzweil Head of Google research 2012)

http://www.kurzweilai.net/the-law-of-accelerating-returns



- Technological change is **exponential**
- **The "returns,"** such as chip speed and cost-effectiveness, also **increase exponentially**. This includes quantum computing as enabler
- Within a few decades, **machine intelligence will surpass human intelligence**,
- **Leading to The Singularity** – technological change so rapid and profound it represents a rupture in the fabric of human history.
- The implications include the **merger of biological and nonbiological intelligence**, immortal software-based humans, and ultra-high levels of intelligence

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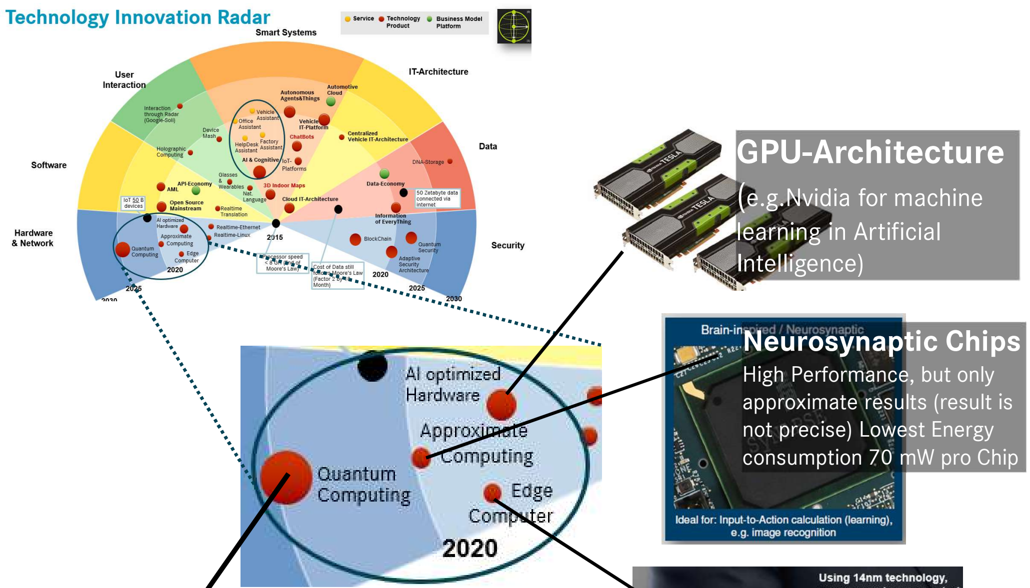
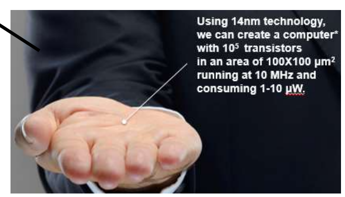
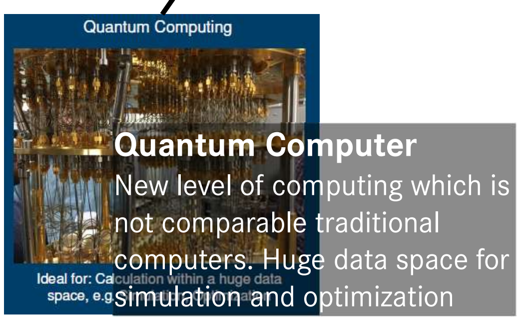
IT Innovation Radar – Hardware Technology





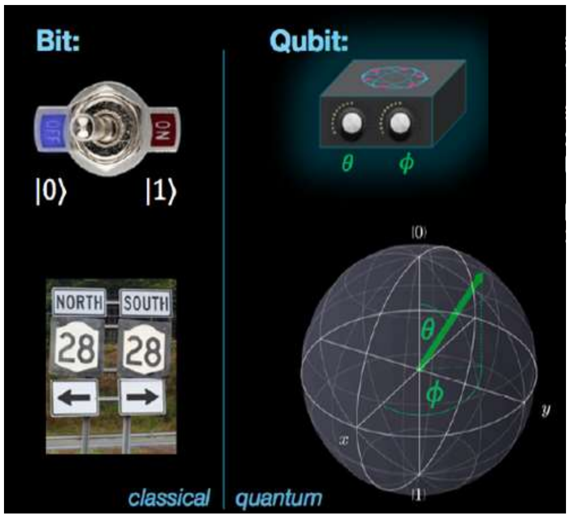


https://www.youtube.com/watch?v=yy6TV9Dntlw

Quantum Computing is on our IT-Technology radar beside other interesting hardware technologies, which are now available for innovative solutions. QC:

- **is expected to be available in 5-10 years** .
- **are incredibly powerful machines** which outperform classical computers by far.
- **can run new types of algorithms**
- **may one day lead to revolutionary breakthroughs**

Qubit store the information in a QC, but they are different to classical Bits



Source: IBM Quantum Computing

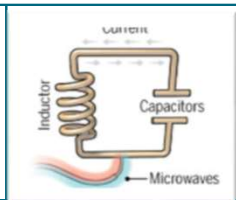
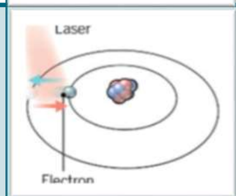
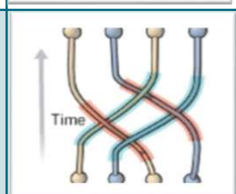
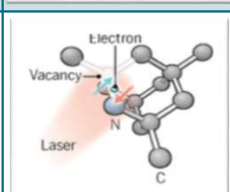
Quantum computers are based on qubits – Qubits outmuscle classical computer bits thanks to two uniquely quantum effects:

- **Superposition** allows a qubit to have a value of not just **0 or 1, but both states at the same time**, enabling simultaneous computation.

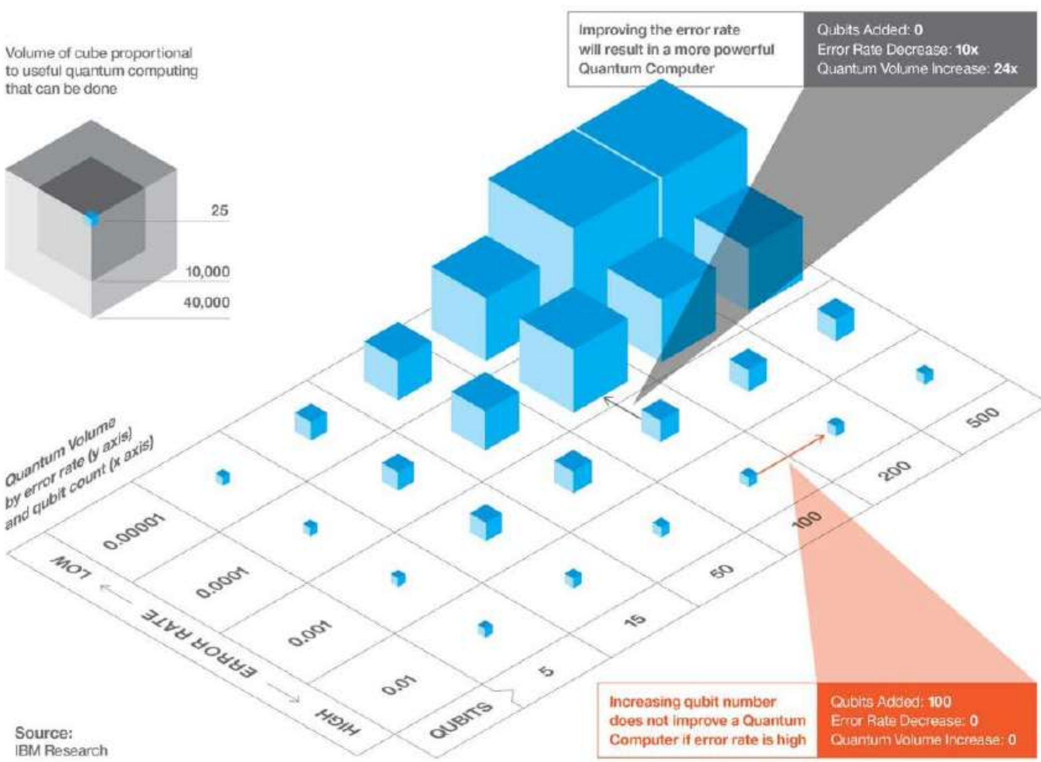
- **Entanglement** enables one qubit to **share its state with others** separated in space, creating a sort of super-superposition, whereby processing capability doubles with every qubit. An algorithm using, say, five entangled qubits can effectively do 25, or 32, computations at once, whereas a classical computer would have to do those 32 computations in succession. As few as 300 fully entangled qubits could, theoretically, sustain more parallel computations than there are atoms in the universe.

	Classical Computer	Quantum Computer
2 Bit/QuBit	1 number at one time with 2 bits	$2^2 = 4$ numbers at the same time (00,01,10,11)
n Bit/QuBit	1 number at one time with n bits	2^n numbers at the same time
n=100	Can store 1 number x with $0 \le x \le 2^{100}$	Can store 2^{100} numbers x with $0 \le x \le 2^{100}$ ($\ge 10^{18}$ Terabyte)

Physical implementation of a quantum computer

Superconducting loops		A resistance-free current oscillates back and force around a circuit loop. An injected microwave signal excites the current into super-position states	**Google** **IBM** **Quantum Circuits**	200-500 microseconds 99.4-99.98% fidelity 9 entangled
Trapped ions		Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in superposition states.	**ionQ**	>1mio microseconds 99.9% 14 entangled
Silicon quantum dots		These “artificial atoms” are made by adding an electron to a small piece of pure silicon. Microwaves control the electron’s quantum state.	**Intel**	3000 microseconds 0,0399,0% 2 entangled
Topological qubits		Quasiparticles can be seen in the behavior of electrons channeled through semiconductor structures. Their braided paths can encode quantum information.	**Microsoft** **Bell Labs**	
Diamond vacancies		A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light	**Quantum Diamond Technologies**	10 mio microseconds 99,2% 6

What makes QC powerful - number of qubits & error rate

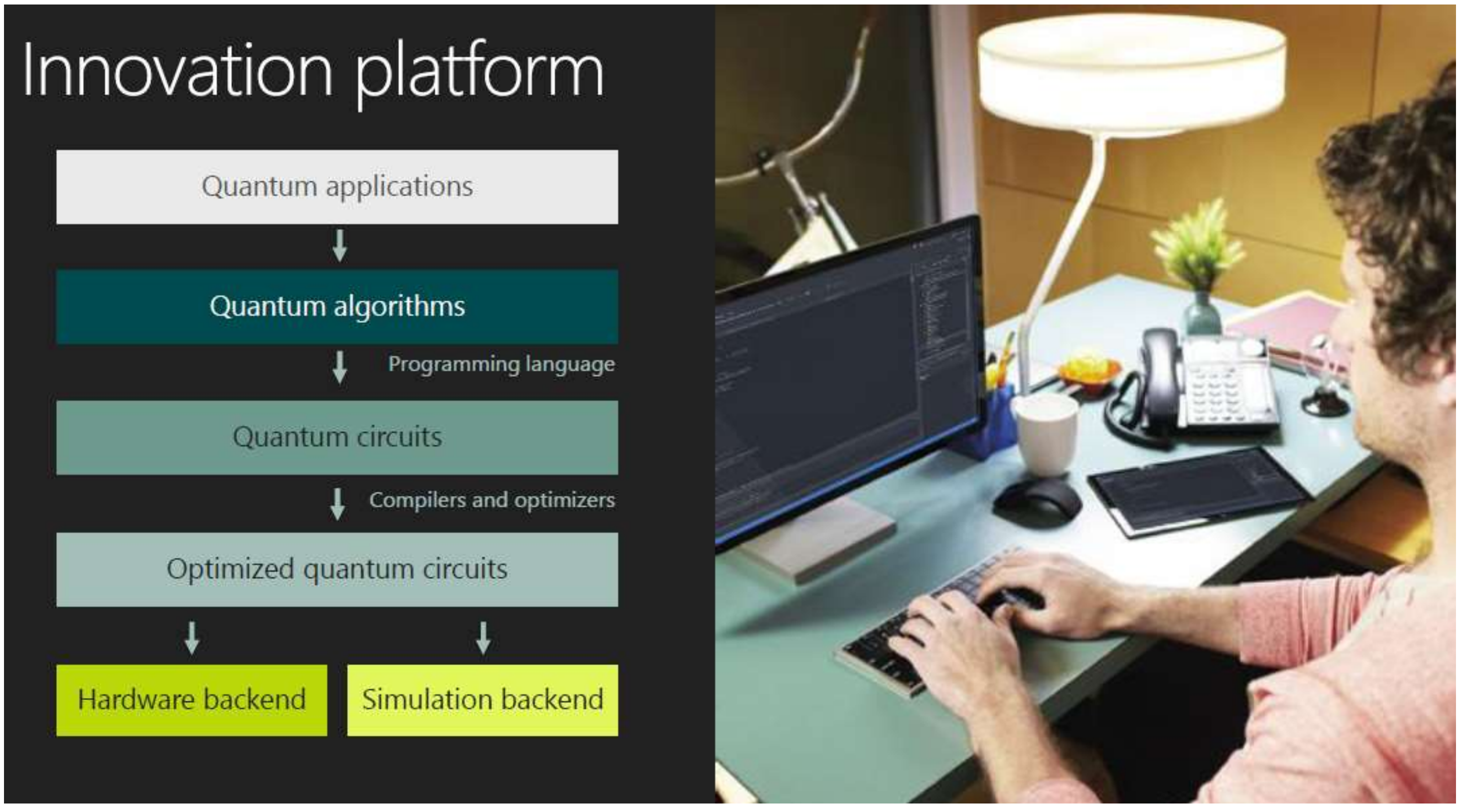


The computing environment of a quantum computer is not as stable as classical computers. The behavior is different:

- The QC operates on hardware gates
- If you read a qubit, you will change the value
- The QuBit isn't stable for a long time
- The state of QC exists for some 100 micro seconds
- The QC needs cold silent datacenter
- Power of a QC is depended on number of QuBits and correctness of computing (fidelity)

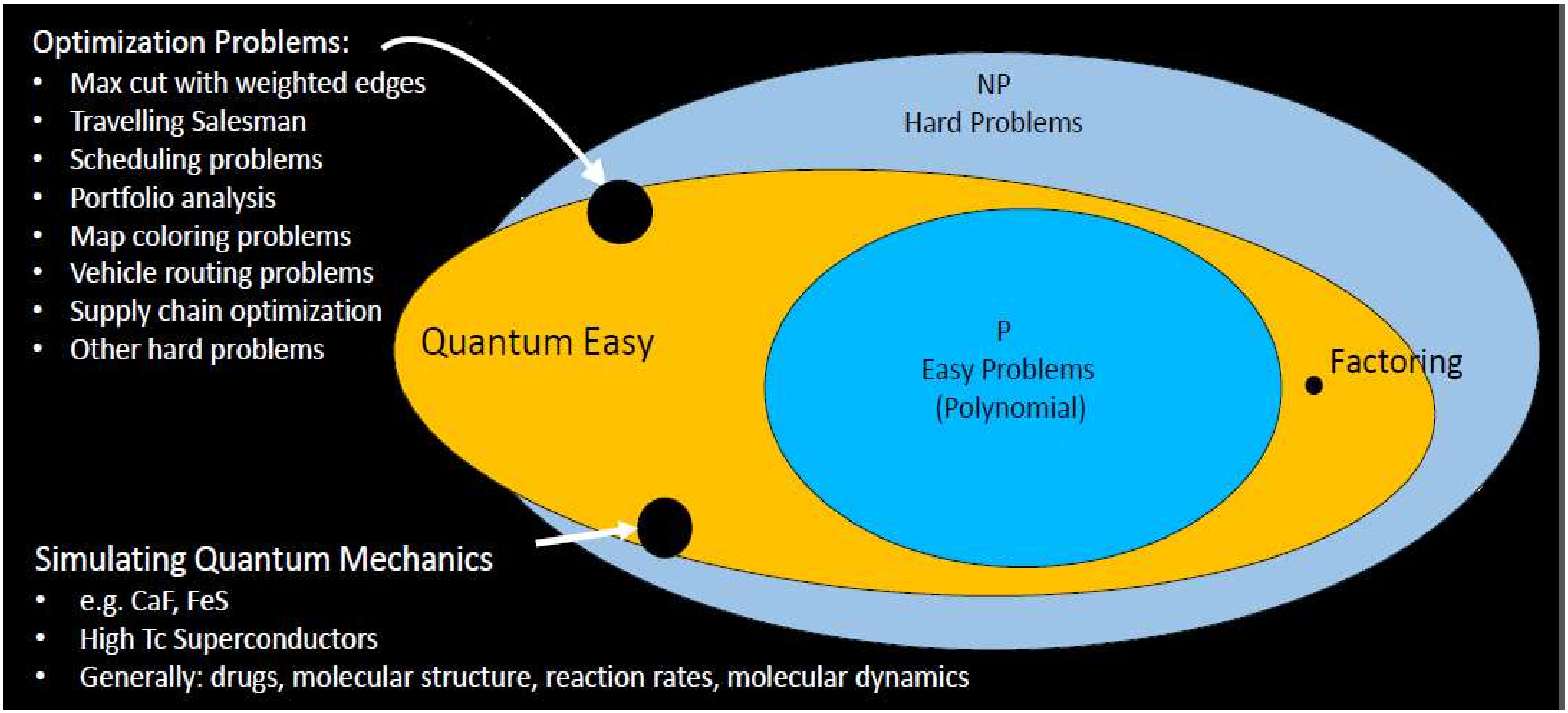
Source: IBM Quantum Computing

Tools and software for Quantum Applications Development are needed – IBM and Microsoft is leading this space



Source: Microsoft Quantum Computing

Quantum Computers are the only game-changer in IT



Source: IBM Quantum Computing

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Quantum Computer – Daimler possible use cases

Manufacturing and Supply Chain

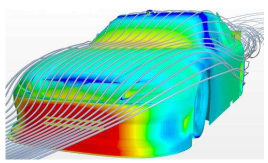
Optimization in production needs often solving NP hard problems.

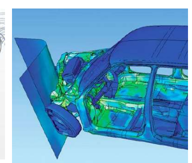
- Production Scheduling (N-Cube or sequence)
- Optimizing Logistics Transport
- Optimizing Robots Movement
- Analyzing BigData from IoT Sensors

Product Simulation

Simulation in digital engineering often uses FEM. This method needs solving large linear equations (e.g. A*x = b).

- Crash Simulation
- body stability
- Combustion process optimization in engine

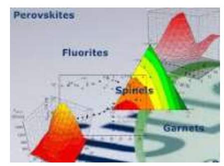


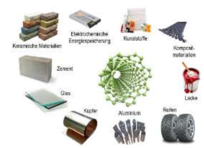


Material Science and Energy optimization

Finding new material and calculation the stability of molecular structure needs simulation molecular structures.

- Catalysts in batteries (replacing Cobalt)
- Lifetime of Batteries
- Combustion processes in the engine



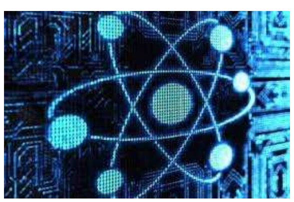


Testing (SW/HW)

Testing all possible branches of software code and finding possible program errors cannot be done by silicon computers. Quantum Computers give us the chance to do this in future

Security

QC can solve the factorization problem of large numbers. That means QC can crack the exiting security codes. ➔ Prepare Quantum Post Security (e.g. vehicle)



Mobility Solutions

Mobility solution often needs solving optimization of

- Traffic, Routplanning
- Transportation in Smart Cities

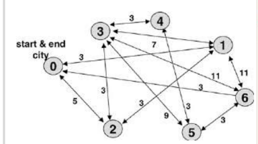
Artificial Intelligence

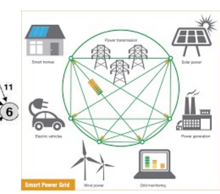
Analyzing pictures, videos, speech can be done with Deep Learning. QC will be key to reduce the time for deep learning. (100 years => 1 day computing effort)

New Business Models

Many new business models can be build by solving network optimization problems

- Timedependent Traveling Salesman
- Power Grid network





Traveling Salesman Problem can be solved with QC

what is the shortest route to visit each city once and return to the origin city?

NP-complete problem, important applications in finance and marketing
N nodes, distances as weights w_{ij}
(N-1)! possible routes
N^2 variables $x_{i,p}$, i ... nodes, p ... order in list

TSP - wikipedia

1. cost function

$$C(\mathbf{x}) = \underbrace{\sum_{i,j=1}^{N-1} w_{ij} \sum_{p=1}^{N-1} x_{i,p}x_{j,p+1}}_{\text{total distance}} + \underbrace{\sum_{j=1}^{N-1} w_{0j}x_{j,1} + \sum_{i=1}^{N-1} w_{i0}x_{i,N-1}}_{\text{return to original city}} + \underbrace{A\sum_{p=1}^{N-1}\left(1-\sum_{i=1}^{N-1}x_{i,p}\right)^2}_{\text{every city only once}} + \underbrace{A\sum_{i=1}^{N-1}\left(1-\sum_{p=1}^{N-1}x_{i,p}\right)^2}_{\text{each time one node}}$$

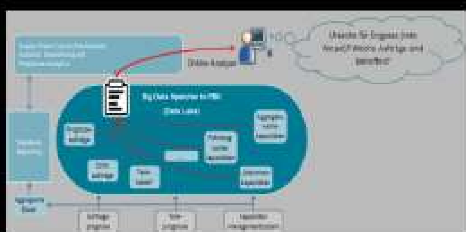
2. rewrite using Pauli matrices $(N-1)^2$ qubits necessary

3. solve Ising Hamiltonian

Supply Chain optimization based on big data is hard to solve for classical computers

Latest Supply Chain 4.0 focus topics Big Data

- **Program, Requirements, Capacities**



- **Freight volume forecast**

- **Tracking and Tracing**

- **Dynamic network optimization**

Automotive industry is relaying on cobalt for - electric drive – which is limited on earth

Wirtschafts Woche

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UNTERNEHMEN FINANZEN POLITIK ERFOLG LIFESTYLE TECHNOLOGIE

Thema Elektroautos

Lithium und Kobalt

15. November 2017

Bremsen Rohstoff-Engpässe das Elektroauto aus?

von Stefan Hajek

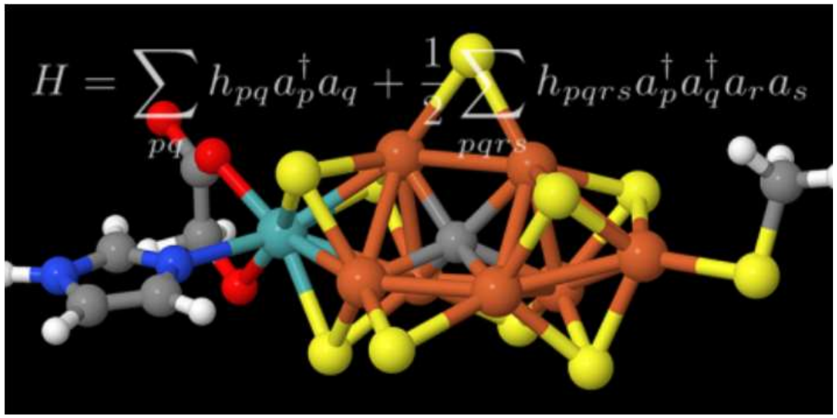
Egal ob Daimler, BMW, der Volkswagen-Konzern oder Elektro-Pionier Tesla: Die Autokonzerne wollen schon bald Millionen Elektroautos bauen. Doch sie ignorieren einen gefährlichen Engpass: Batterierohstoffe.

ANZEIGE

Source: Wirtschaftswoche: 15. November 2017

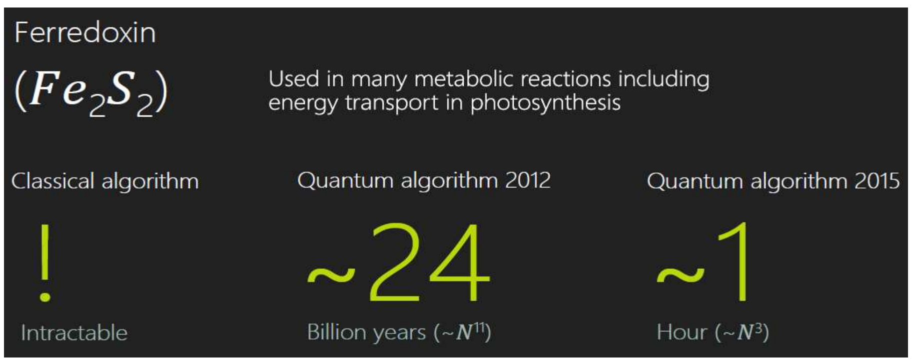
Cobalt is limited on earth and is needed as catalyst for today lithium-ion based batteries

QC can be a game changer in material science



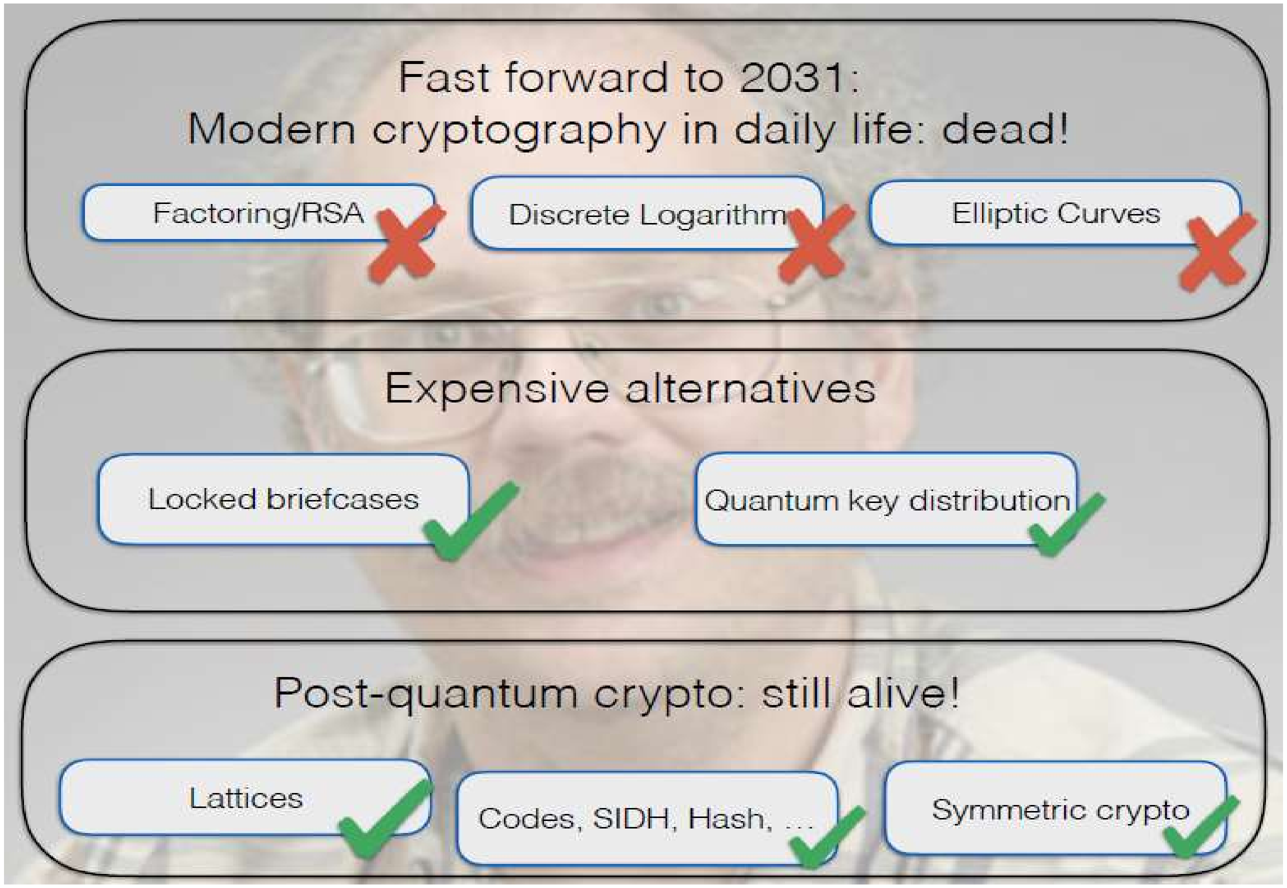
Researchers at ETH Zurich have now come up with a concrete example that demonstrates what quantum computers will be able to do in material science.

- Specialists expect nothing less than a technological revolution from quantum computers, which they hope will soon allow them to solve problems that are currently too complex for classical supercomputers.
- Areas of application include special problems in the fields of physics, quantum chemistry and materials research.



Source: Microsoft Quantum Computing

Implication of Shore’s Factorization - QC breaks existing security



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QC the big 5 Vendors

IBM (since 2001)

2017: 20 QuBits
2018: 50 QuBits?
full entangled

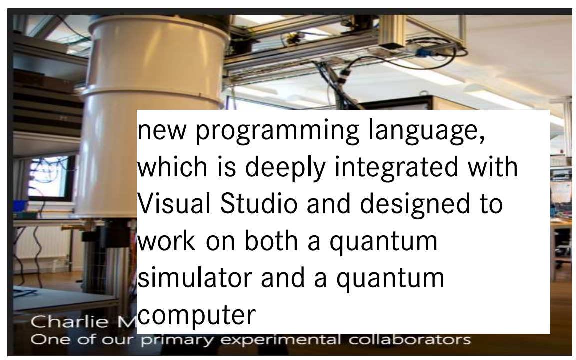
D-Wave (since 2001)

2017: 2000 QuBits
Only partly (4 Qubits) entangled (adiabatic)

Google (since 2011)

2017: 20 QuBits
2018: 50 QuBits?
full entangled

Microsoft (since 2008)

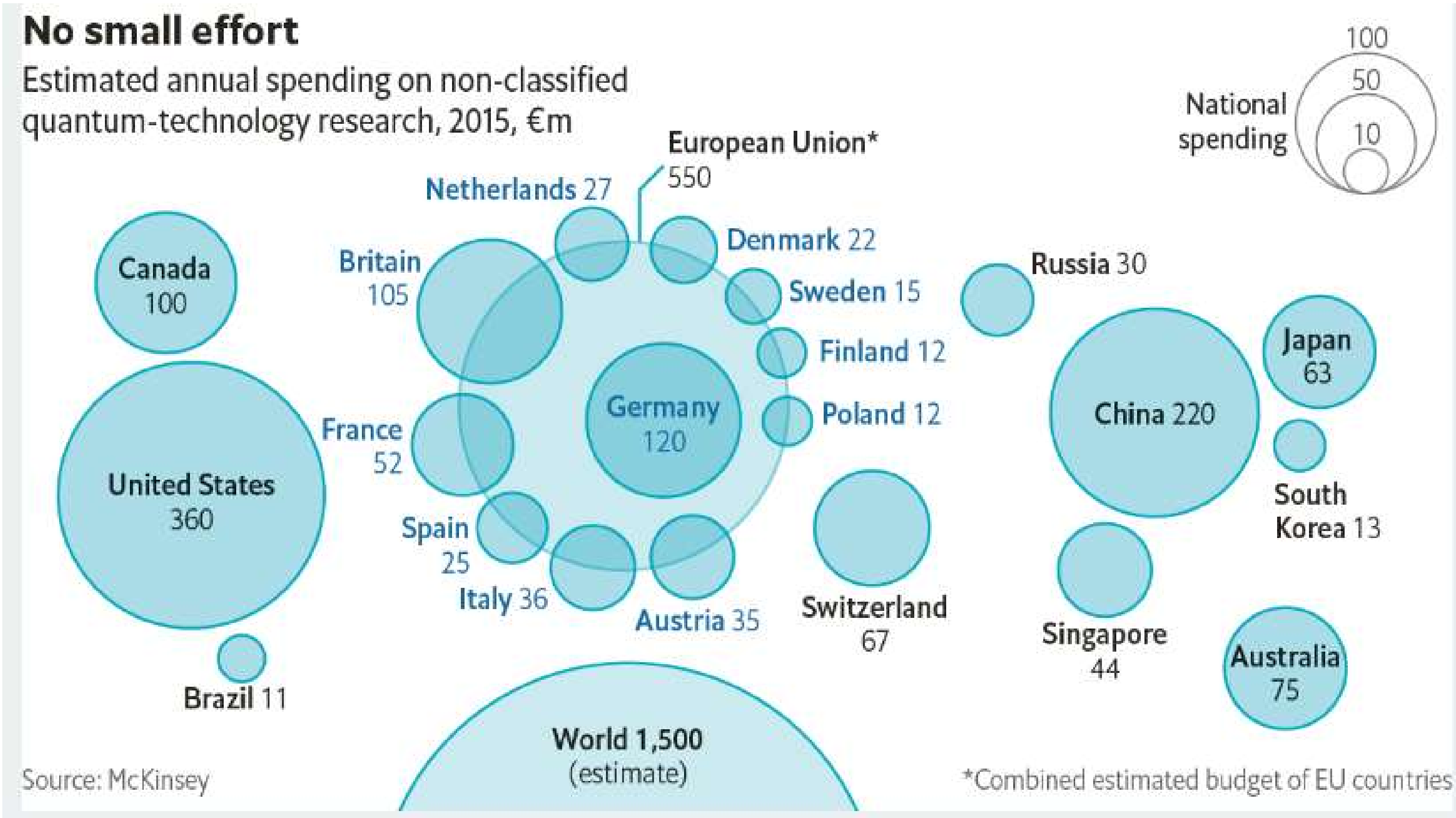


new programming language, which is deeply integrated with Visual Studio and designed to work on both a quantum simulator and a quantum computer

Intel (since 2017)

2017: 17 QuBits
Joint Venture QuTech
full entangled, silicon based

Quantum Computer research worldwide



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Quantum Computing – Summary -

- **QC are about to get real in the next 5 (-10) years**
- **In the next decade 1 Quantum Computer will beat out the performance of all existing silicon computer in the world**
  - 1000 Qbits can store (2^{1000} Bits = 10^{125} Bytes, PetaByte 10^{15} Bytes)
  - QC solves factorization of a 1000 digit number in minutes instead of 10^{150}sec (age of universe is 10^{17} sec)
- **QC will**
  - Break existing security (which includes bank accounts, bitcoin, secure vehicle..)
  - Change the way how material is developed (chemistry)
  - Solve many (hard NP-Complete problems) like traffic control for smart cities
  - Reduce deep learning problems to seconds instead of 100'rds of years
- **QC big players are**
  - US (IBM, Google, DWave, Microsoft, Intel) and the NSA, NASA have invested billions
  - China has announced to develop a QC the next 5 years (invest 15 billion $)
  - Europe plans 1 billion € research invest

Thank you

IT Innovations - Questions ?