

HOW WILL THE AGE OF QUANTUM COMPUTING EFFECT INDUSTRY?

Franz G. Fuchs

SINTEF

Department of Mathematics and Cybernetics

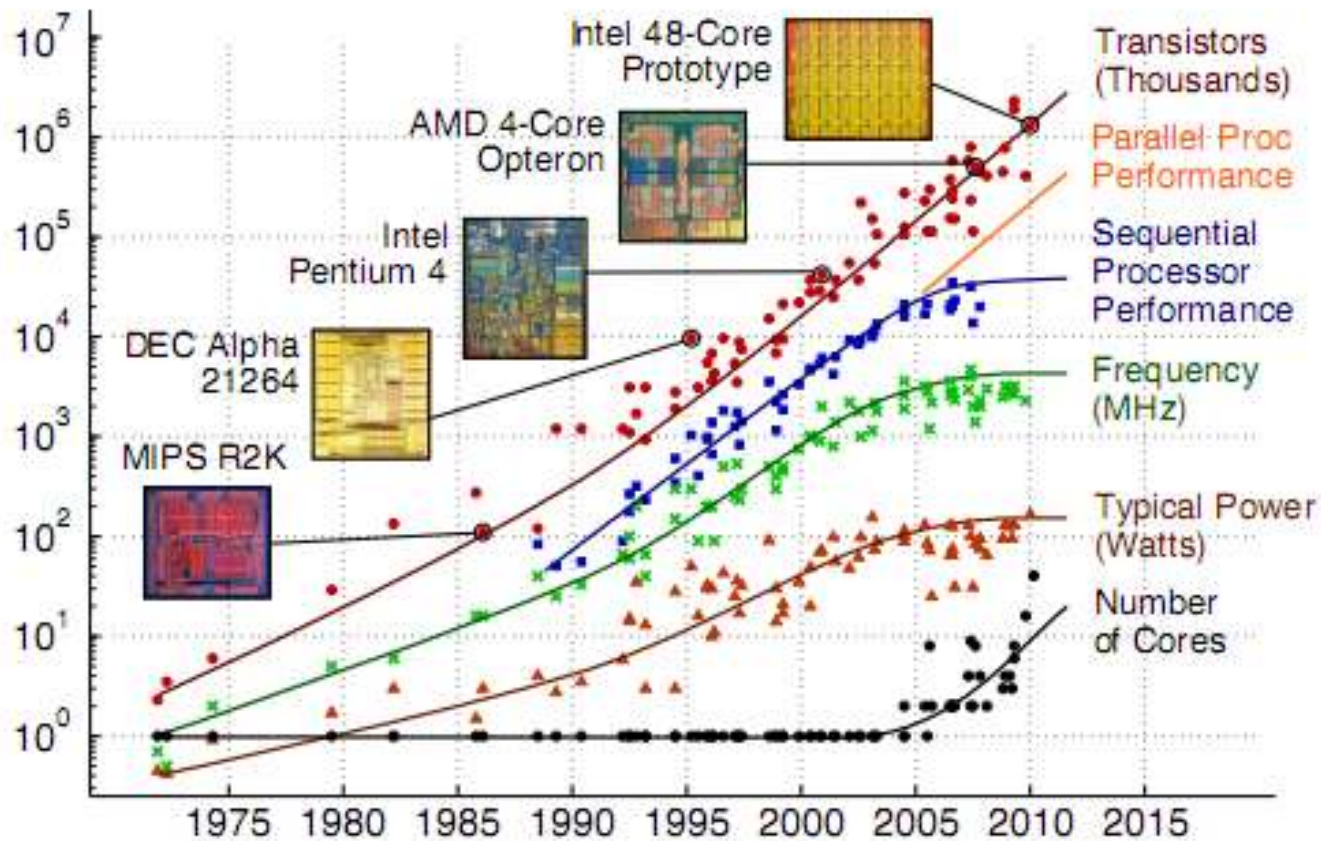




Miniaturization of Transistors

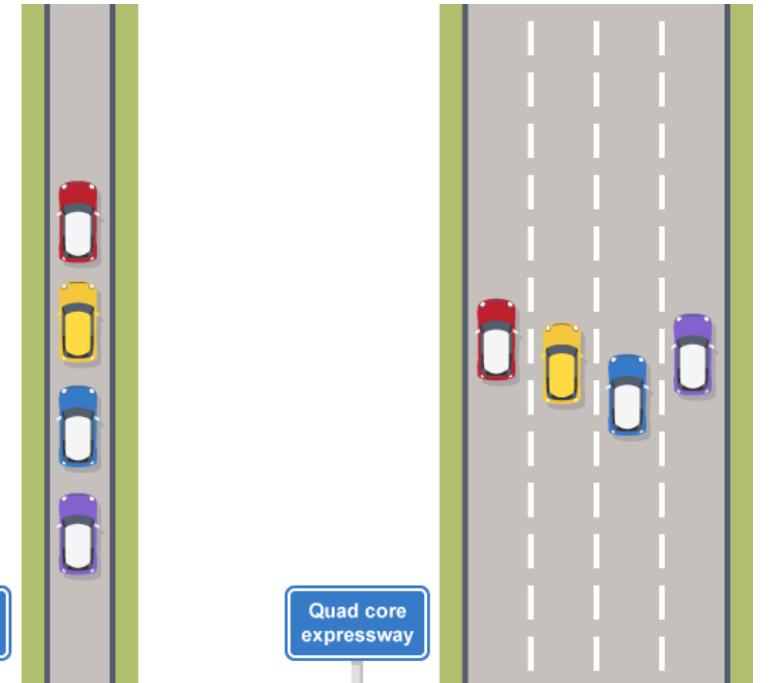


Moore's Law is Saturating



Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

Prepared by C. Batten - School of Electrical and Computer Engineering - Cornell University - 2005 - retrieved Dec 12 2012 - <http://www.csl.cornell.edu/courses/ece5950/handouts/ece5950-overview.pdf>



(Image credit – bbc.co.uk)

Supercomputers



Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	DOE/SC/Oak Ridge National Laboratory United States	Summit - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband IBM	2,414,592	148,600.0	200,794.9	10,096
2	DOE/NNSA/LLNL United States	Sierra - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband IBM / NVIDIA / Mellanox	1,572,480	94,640.0	125,712.0	7,438
3	National Supercomputing Center in Wuxi China	Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway NRCPC	10,649,600	93,014.6	125,435.9	15,371

Norwegian eInfrastructure Roadmap

Prepared by the eInfrastructure Scientific Opportunities Panel

Programme
eScience – Infrastructure, theory and applications (eVITA)



- Supercomputer has huge **energy costs** for processing and cooling systems
- Present-day **Petaflop systems** uses **MegaWatts**.
- An **exascale machine** would consume **600 MegaWatts**
- A **devoted electrical power plant** would be necessary to service it alone



Classical Computing Roadblocks

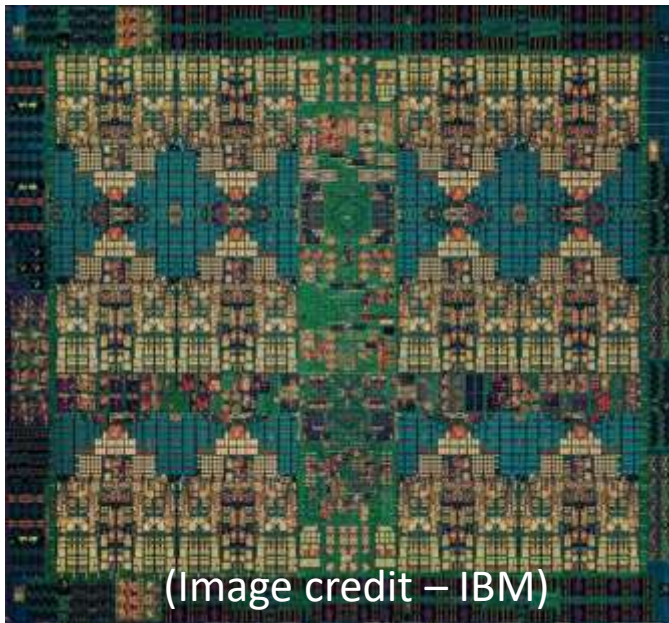
- Moore's law saturating
- Parallelization requirement
- Supercomputing is energy demanding
- Some problems can not be solved using classical machines on theoretical grounds

Potential solution: Quantum Computers

Potential Power of Classical vs Quantum Computer

Classical Computer:

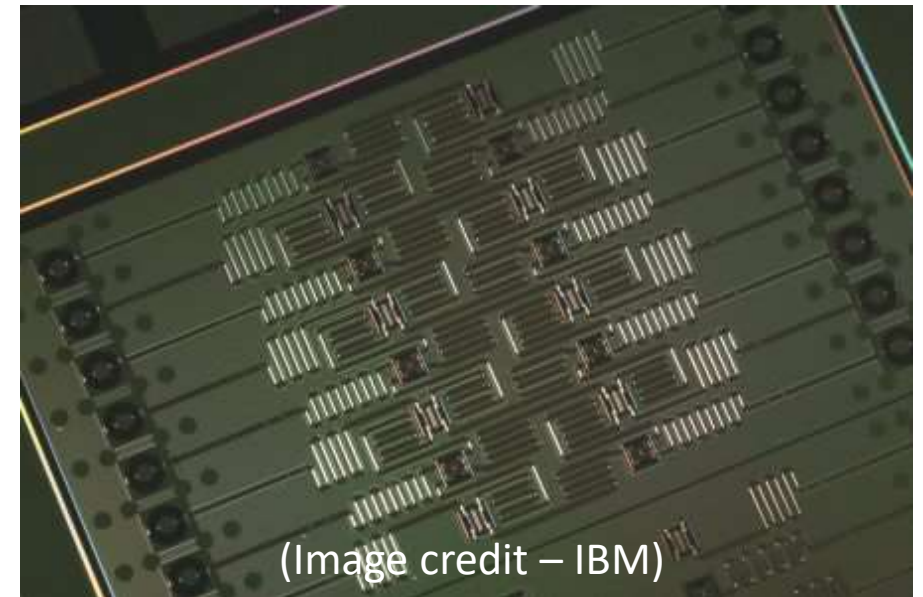
Power doubles by **doubling the number of transistors (bits)**



	bits	qubits
	4	2
	256	8
	1.048.576	20
	109.950.533.632	40
	Classical threshold	50
	> number of atoms on Earth	180
	> number of atoms in the universe	300

Quantum Computer:

Power doubles by **adding ONE more qubit**



Quantum Supremacy/Advantage

Quantum computer **outperforms** a classical computer:

Different **scaling** of the best "known" algorithms!

Example: Integer factorization (with n bits):

	Classical: number field sieve	Quantum: Shor's algorithm
Time for 512-bit number	x minutes	y minutes
Time for 1024-bit number	1.6 billion times x minutes	10 times y minutes

Short History of Quantum Computing

1982:
Feynman
proposes
quantum
computers

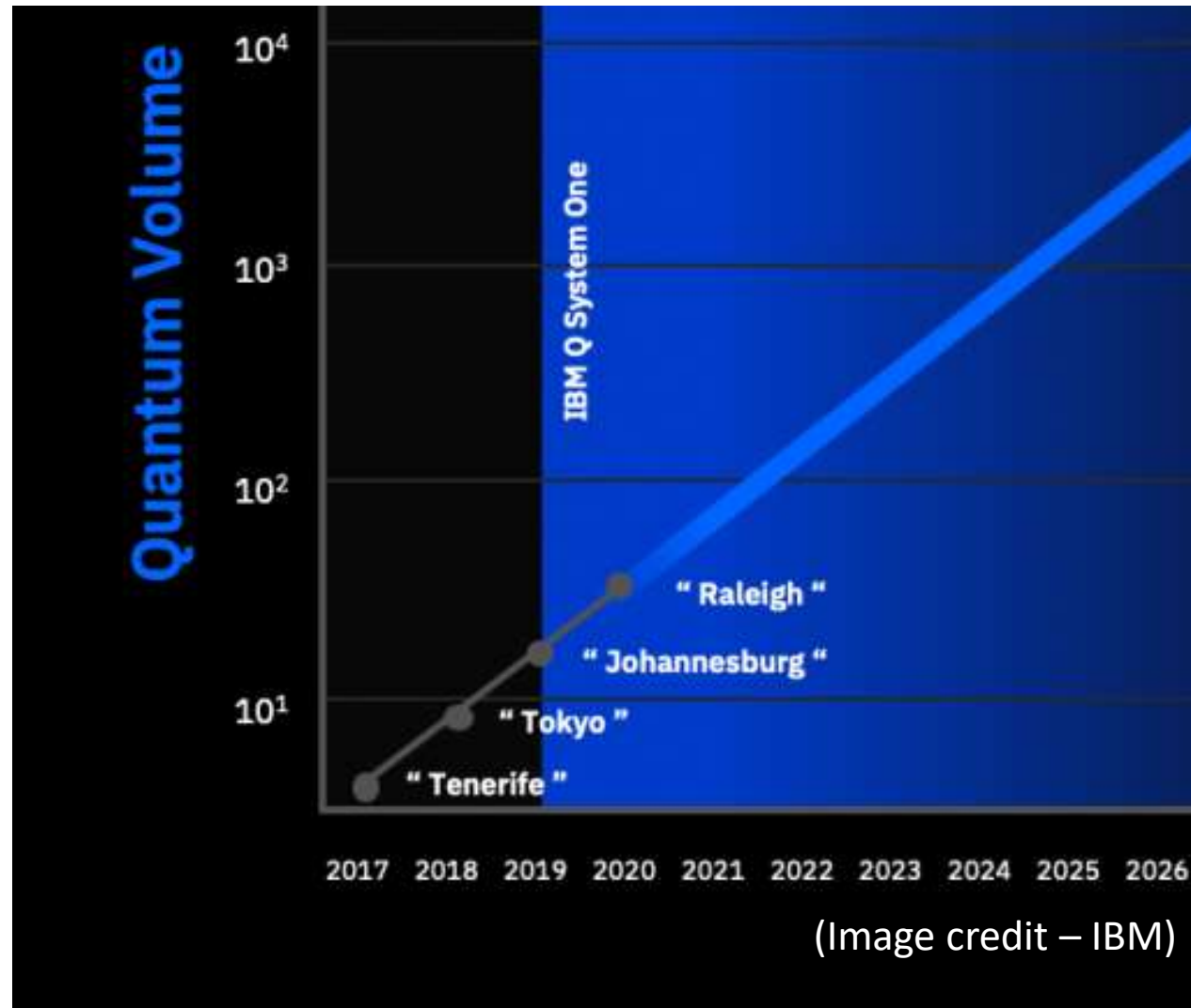
1994: Shor's
algorithm for
factoring with
exp. speed-up

1996: Grover's
algorithm for black-
box search with
quadratic speed-up

2009: Hanneke et
al. realize
first **programmable**
two-qubit
quantum processor

2016: IBM gives
public access to
their quantum
computers

Moore's law for quantum chips



Heavy Investment/Development

EU: Quantum Technologies Flagship **1 billion €**

US: National Quantum Initiative **1.2 billion \$**

UK: total investment ca. **1 billion £**

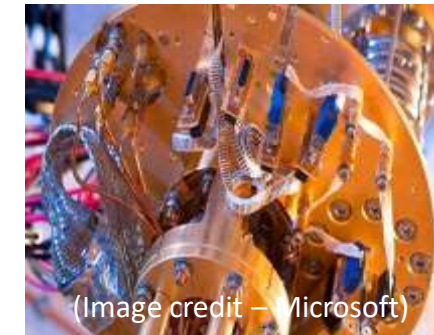
India **1.12 billion US\$**

China: National Laboratory for Quantum Information Sciences **10 billion US \$**

Australia: 15 years of Special Research Centre for Quantum Computer Technology

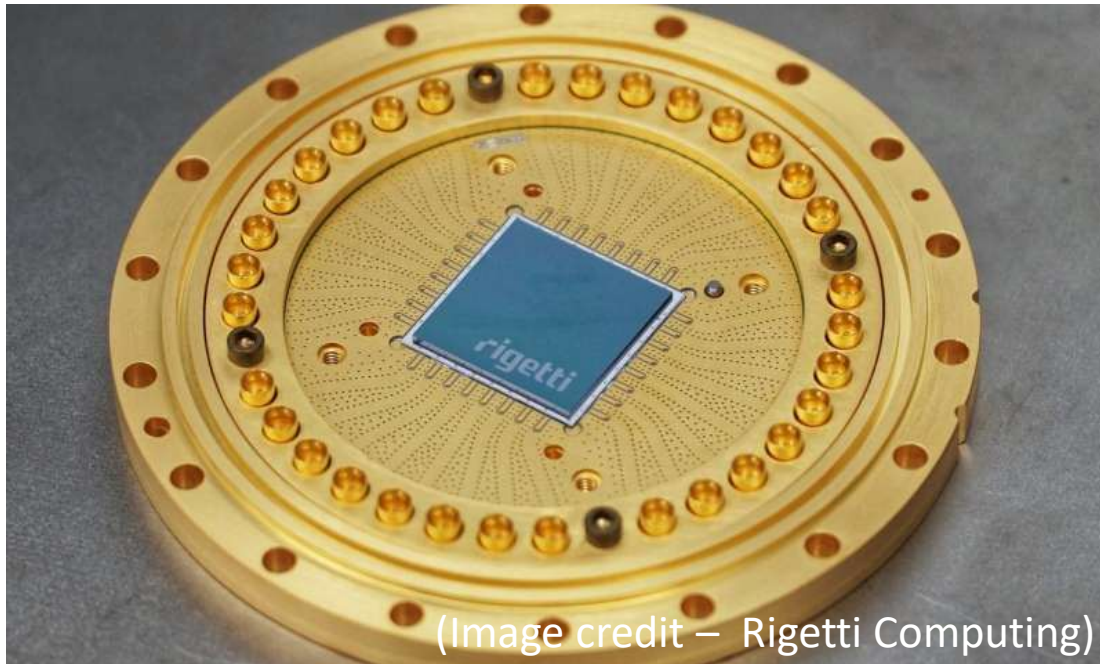
Universities in the **Middle East** and **Africa** have launched research groups

Companies such as IBM, Alibaba, Google, Microsoft, Intel, D-wave, Honeywell, Rigetti invest heavily

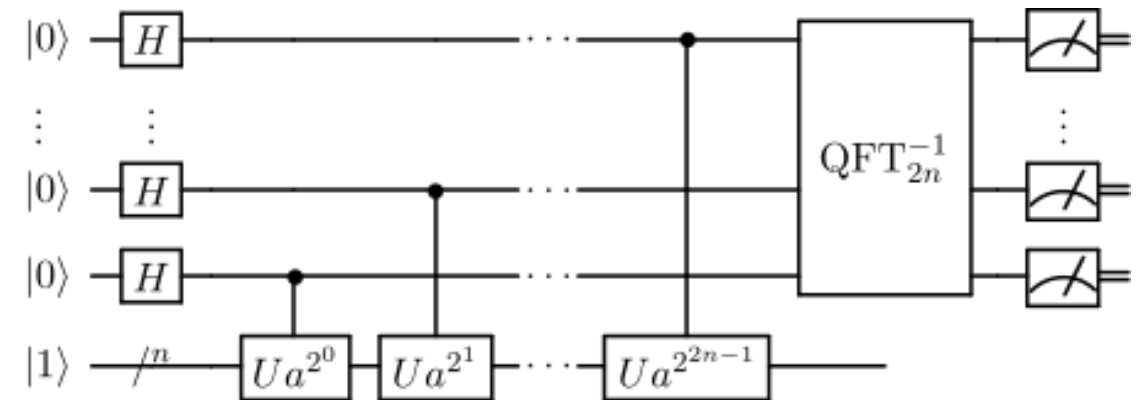


Two Challenges for quantum computing

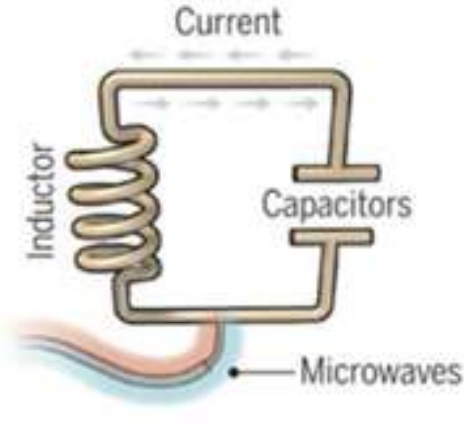
- Hardware



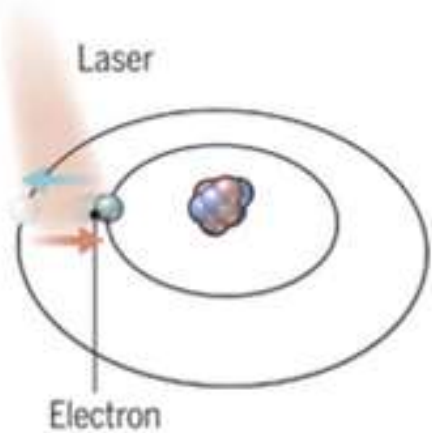
- Software/Algorithms



Common qubit technologies



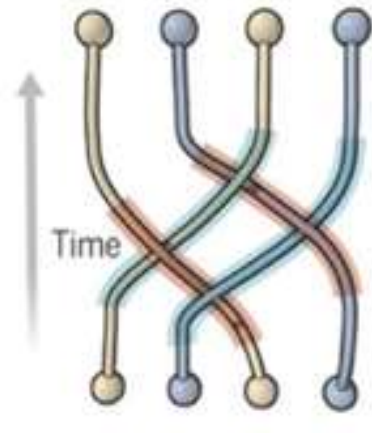
Superconducting loops



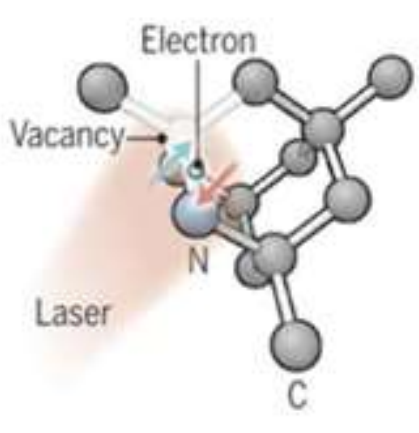
Trapped ions



Silicon quantum dots



Topological qubits



Diamond vacancies

Source: C. BICKLE

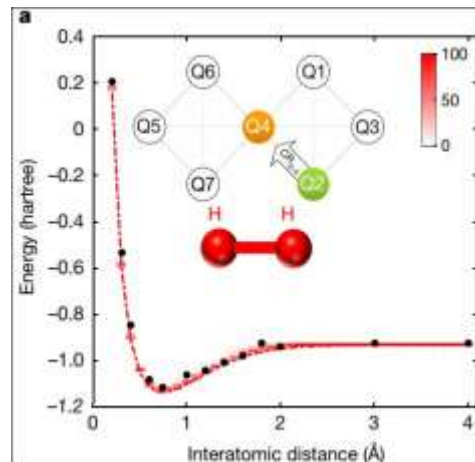
Predicted shortage of quantum experts

- Learn basic rules of quantum computing through a game
- Quantum Poker (Texas Hold' em)
 - Community cards = quantum register
 - Player's cards = quantum gates
 - Aim: increase chances of getting "1"



How will the age of quantum computing affect industry?

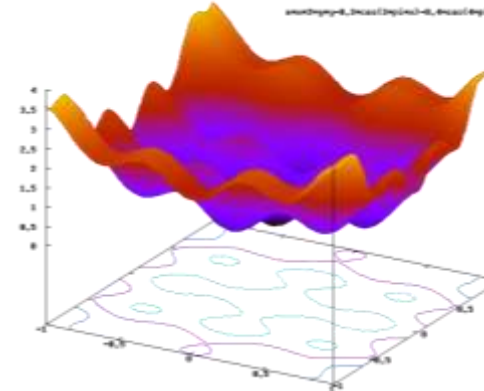
Quantum Chemistry



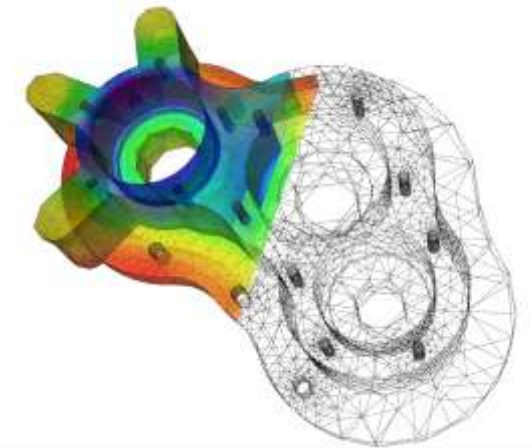
Artificial Intelligence



Optimization



Simulation



Sources: <https://commons.wikimedia.org/w/index.php?curid=10528672>
<https://commons.wikimedia.org/w/index.php?curid=258717>
doi.org/10.1038/nature23879

Advantages of Quantum Computing - What to do next

Advantages

- Speedup
- Memory efficiency
- Energy efficiency
- Some problems can simply not be solved on (any future) classical computer

CHALLENGES

- **Develop NISQ applications for quantum advantage**
- Quantum Computing Technology focus in Norway

Contact SINTEF if you are interested

- Workshops/Courses: Should my business use it and how?
- Projects

