MINISTRY OF FOREIGN AFFAIRS
OF DENMARK
*Invest in Denmark*

WEBINAR

# QUANTUM COMPUTING TO THE AID OF MANKIND

**September 09, 2021 11:30 AM CET**



**Gopal Karemore, PhD**
Principal Data Scientist
Novo Nordisk A/S

If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet.

(Niels Bohr)

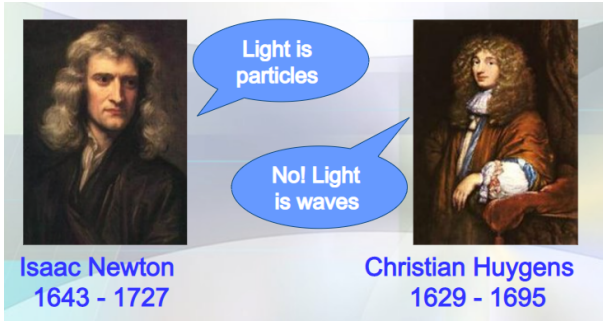
# Agenda

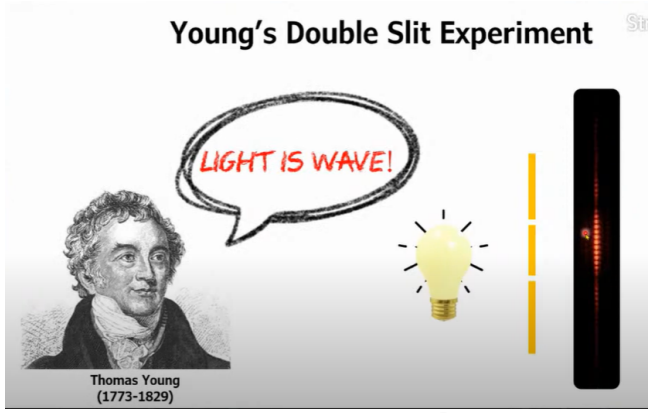
- Brief history of Quantum Computing (QC).
- What is Quantum Computing and its Status?
- What is Quantum Advantage?
- How will Quantum Transform Businesses?
- How will Quantum Impact Life Science and Pharma Market?
- Should your Industry Invest in Quantum Now?

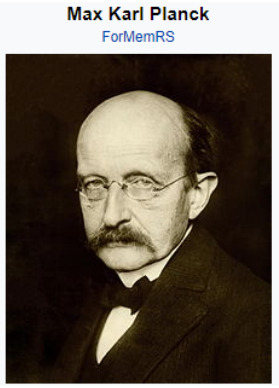


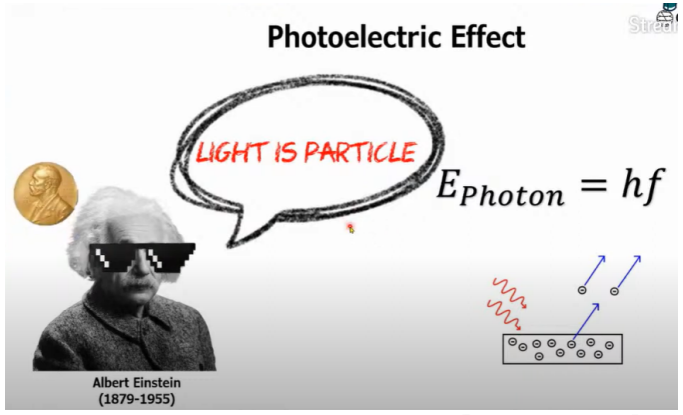
***Disclaimer:*** *The views expressed and ideas presented in this talk are those of the speakers and are not necessarily shared by the presenter's employers*

# Foundation of Quantum Computer : Quantum Mechanics




Picture Credit: Unknow



**Werner Heisenberg**

Heisenberg in 1933

| | |
|---|---|
| **Born** | Werner Karl Heisenberg<br>5 December 1901<br>Würzburg, Bavaria, German Empire |
| **Died** | 1 February 1976 (aged 74)<br>Munich, Bavaria, West Germany |

**Erwin Schrödinger**

| | |
|---|---|
| **Born** | Erwin Rudolf Josef Alexander Schrödinger<br>12 August 1887<br>Vienna, Austria-Hungary |
| **Died** | 4 January 1961 (aged 73)<br>Vienna, Austria |

**Niels Bohr**

Bohr in 1922

| | |
|---|---|
| **Born** | Niels Henrik David Bohr<br>7 October 1885<br>Copenhagen, Denmark |
| **Died** | 18 November 1962 (aged 77)<br>Copenhagen, Denmark |

**Max Born**

Born circa 1930–1940

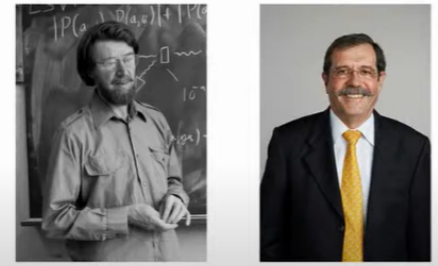
| | |
|---|---|
| **Born** | 11 December 1882<br>Breslau, German Empire |
| **Died** | 5 January 1970 (aged 87)<br>Göttingen, West Germany |

**EPR Paradox (1935)**

*Einstein* *Podolsky* *Rosen*

Local hidden variable
Quantum Mechanics is incomplete

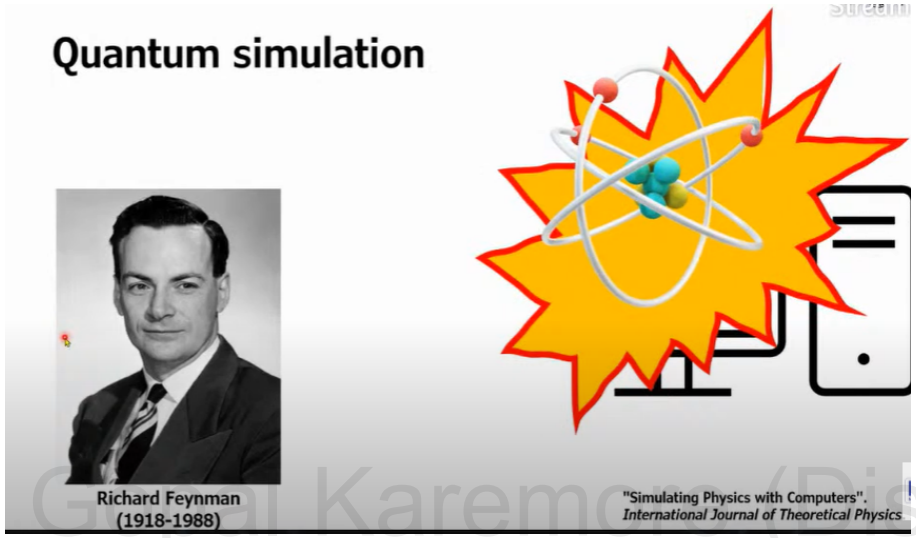
**Bell Test**



John Stewart Bell
(1928-1990)

Alain Aspect
(1947-Present)

# Dawn of Qauntum Computer




Proposed a concept of Quantum Computer

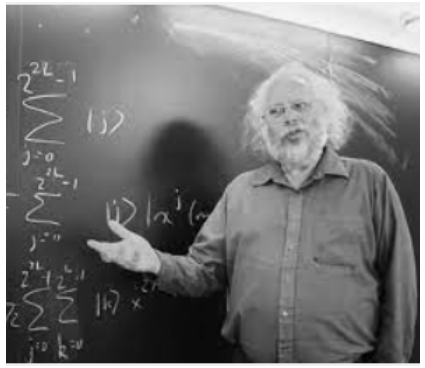
Paul A. Benioff in 2019

David Deutsch

Proposed a quantum mechanical model of the Turing machine



Iov Grover



Peter Williston Shor

Seth Lloyd

Michael Nielsen

Peter Wittek

Many more...

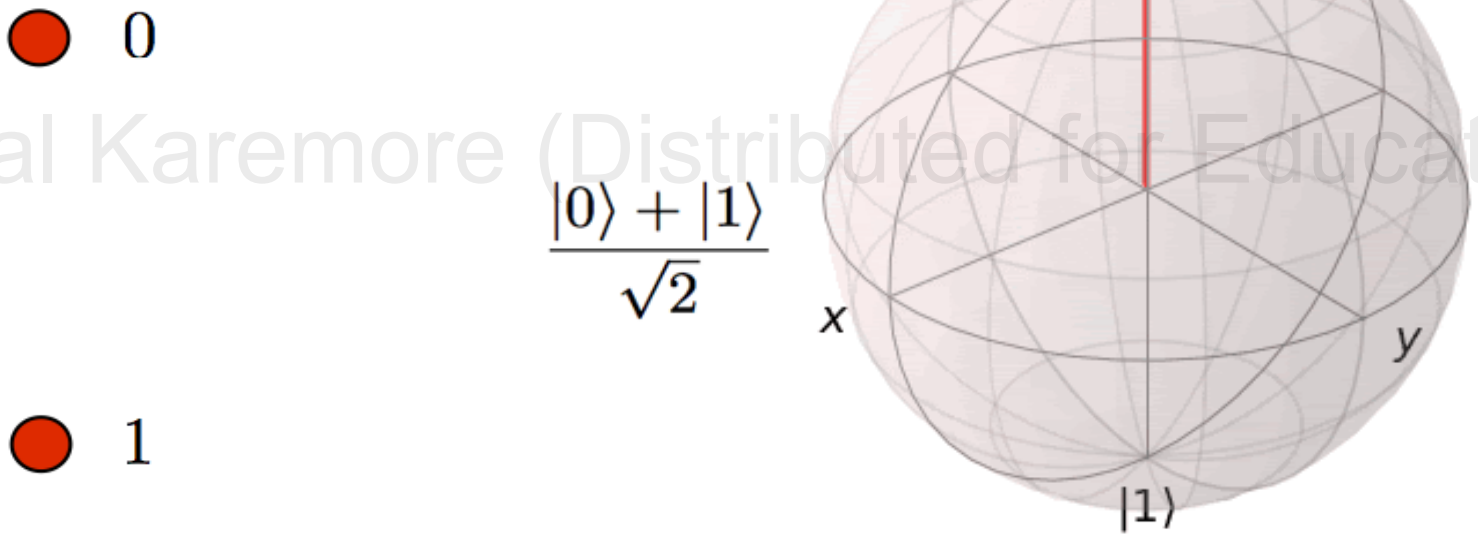
# What is Quantum Computer?

Quantum computer is a device to perform computation by exploiting the properties of quantum physics.



- Quantum Properties: superposition, entanglement, interference, and quantum tunnelling
- Basic of Quantum information is a Quantum Bit (Qubit)

# Qubit: Basis of Quantum Information



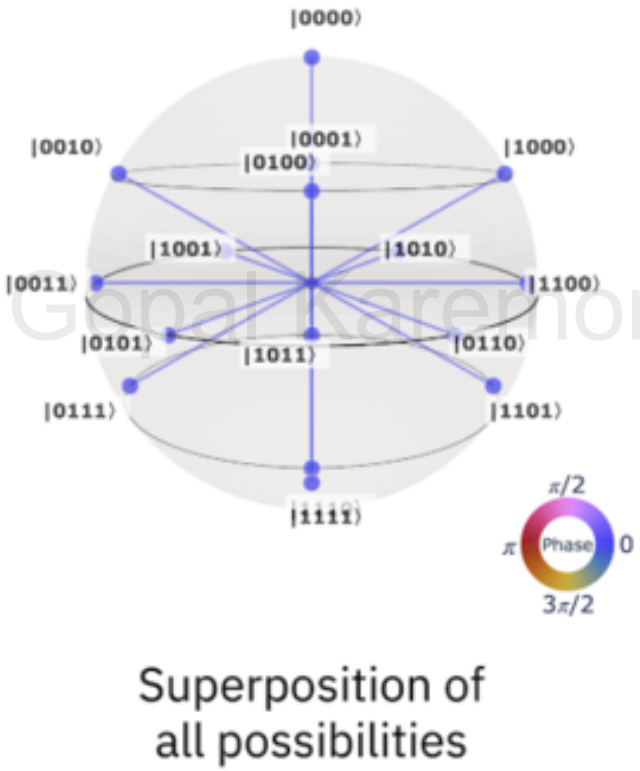

**Classical Bit**




**Qubit**

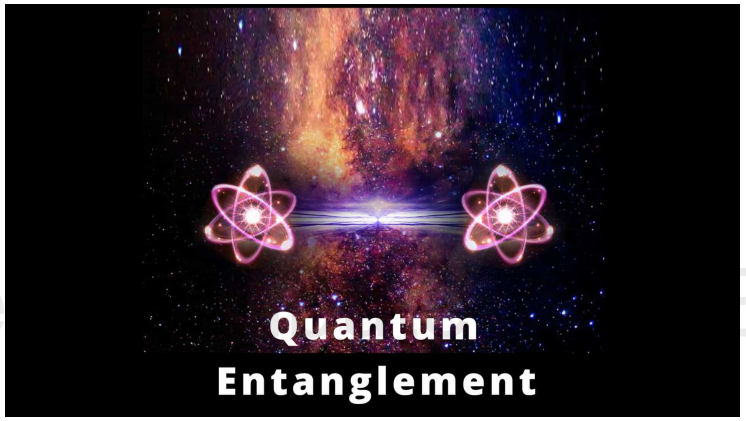
# Building Blocks of Quantum Computing

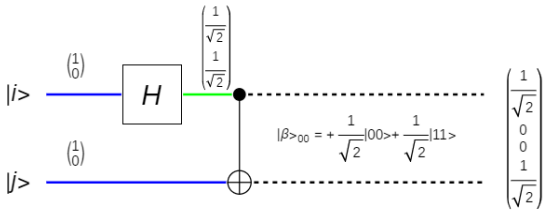
## Superposition




**Massive Parallelism**

## Entanglement




**Massive Correlation**

## Interference

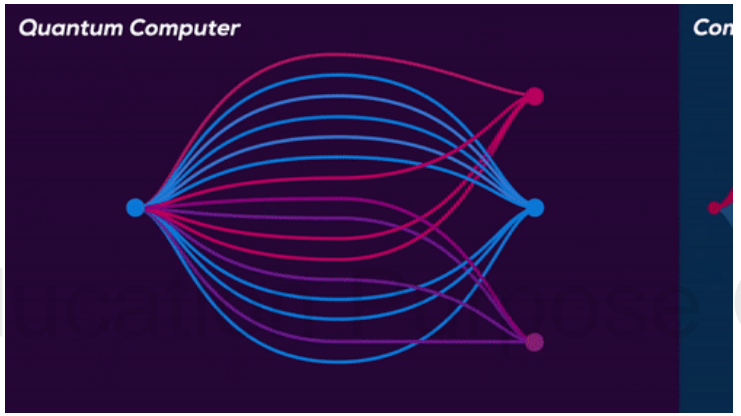



Image Credit: Mechomotive.com

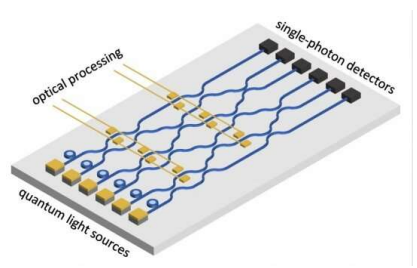
$$H(t)|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$

**Convergence of problem hamiltonian**

# How Qubit is implemented: Current Status of Quantum Computing Hardware


| Superconducting loops | Trapped ions | Silicon quantum dots | Diamond vacancies | Topological qubits |
|---|---|---|---|---|
| **Company support** | | | | |
| Google, IBM, Quantum Circuits | ionQ | Intel | Quantum Diamond Technologies | Microsoft, Bell Labs |
| **Pros** | | | | |
| Fast working. Build on existing semiconductor industry. | Very stable. Highest achieved gate fidelities. | Stable. Build on existing semiconductor industry. | Can operate at room temperature. | Greatly reduce errors. |
| **Cons** | | | | |
| Collapse easily and must be kept cold. | Slow operation. Many lasers are needed. | Only a few entangled. Must be kept cold. | Difficult to entangle. | Existence not yet confirmed. |

Image Credit: C. Bickle and Gabriel Popkin




**Photonics Based**

**DTU, KU, Xanadu**



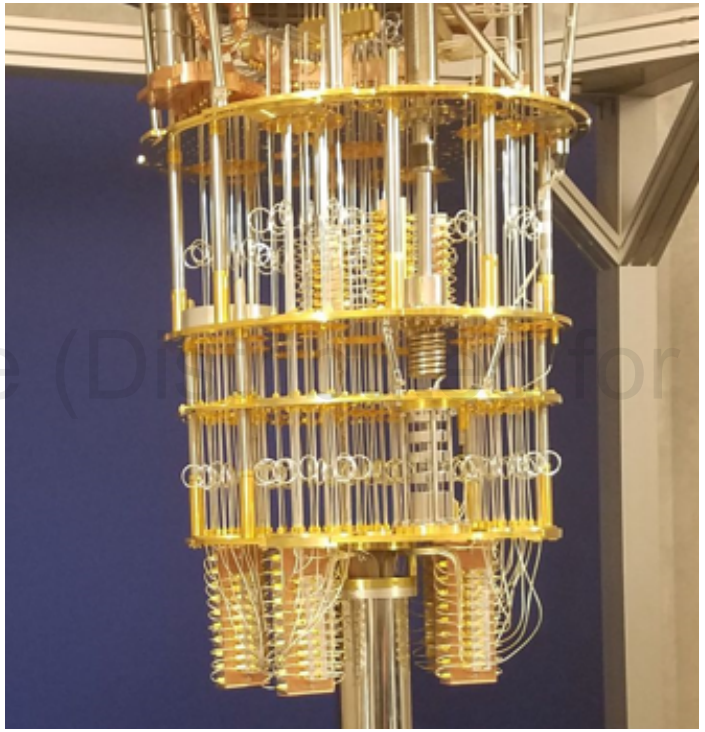
## Challenges

**Number of qubits:** How much quantum information can be stored?
**Coherence time:** How long will your quantum system stay "quantum"?
**Gate depth-gate fidelity:** How many quantum gates in an Algorithm?

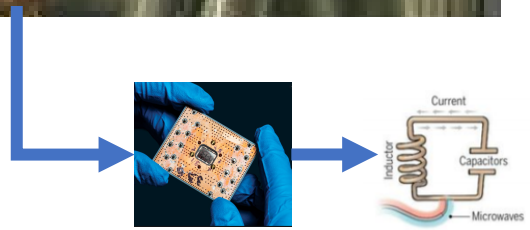
## Current Status

e.g. Google's Sycamore: 54 qubits, IBM 65, Dwave 5000
e.g. 1-10 Sec (Ion Trapped) to 1 Micro Sec (Superconducting)
e.g. Google's Sycamore 20 Gates

# A Typical Quantum Computer (Super conducting)



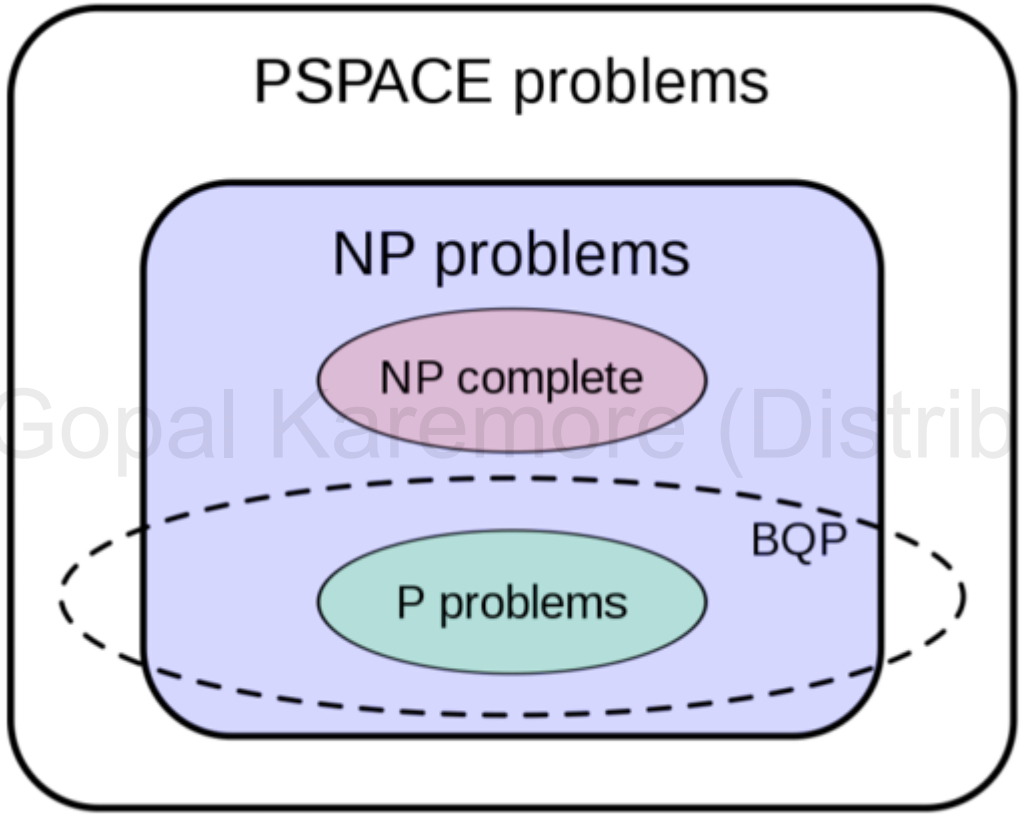




15 mK = -273.13 Degree Celcius
= colder than the coldest places in interstellar space

**Image Credit: IBM**

# Why Quantum?

## Complexity




## Speed

Quantum computing's potential for significant speedup over classical computers[1]

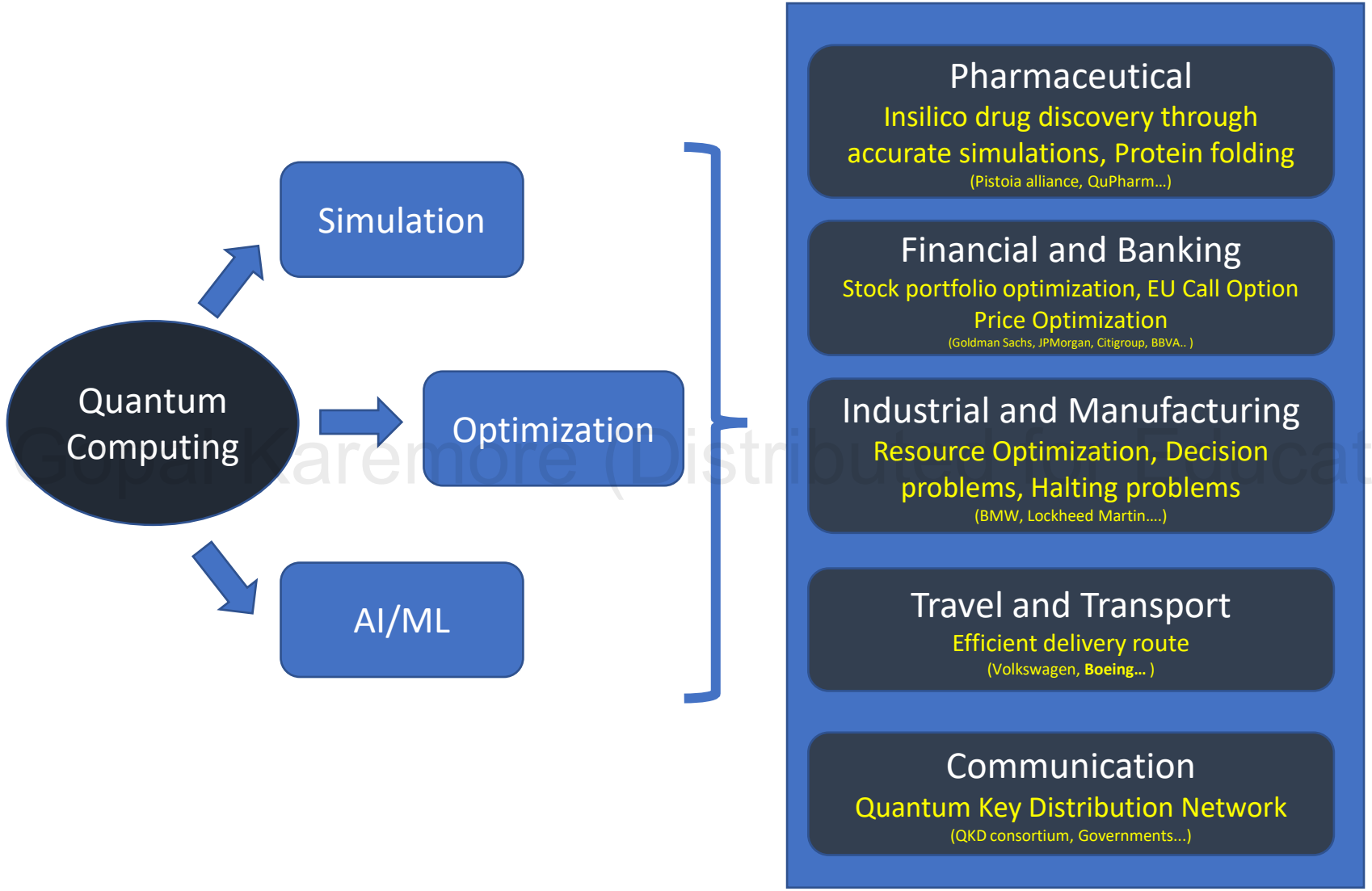
| Type of scaling | Time to solve problem | | | | |
|---|---|---|---|---|---|
| Classical algorithm with exponential runtime | 10 secs | 2 mins | 330 years | 3300 years | Age of the universe |
| Quantum algorithm with polynomial runtime | 1 min | 2 mins | 10 mins | 11 mins | ~24 mins |

Image Credit: IBM



| How to double the computation power | |
|---|---|
| **Classical** | Double the number of Transistors |
| **Quantum** | Add one more Qubit |

# How QC will Impact Industries?




## Quantum Algorithms

Variational Qauntum EigenSolver (VQE)

Qauntum Approximate Optimization Algorithm (QAOA)

Quadratic Unconstarinst Binary Optimization (QUBO)

Quantum Amplitude/Phase Estimation (QAE/QPA )

Variational Quantum Classifier (VQC)

Quantum Kernels (QK)

Grover's, Shor's, HHL etc.



**More Info:**

G. Karemore, **Immergence of QC in Finance** at Richmond's Finance Directors Forum Conference 2019, Zurich

G. Karemore, **Promises and challenges of Quantum Machine Learning in NISQ era** at Quantum.Tech conference 30th Sept. 2021 (Virtual – Free Registration)

# Quantum Computing in Pharmaceuticals

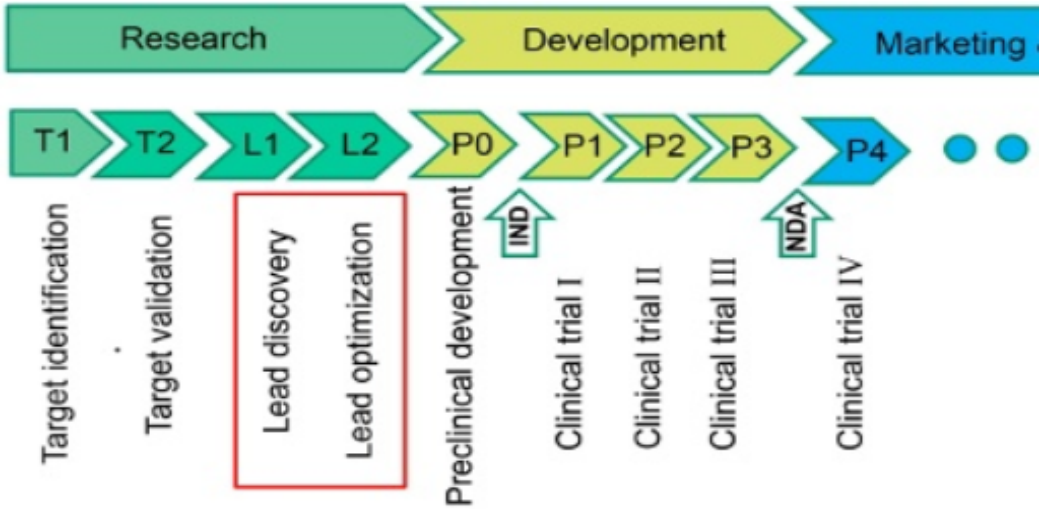



Image credit: RIKEN.JP

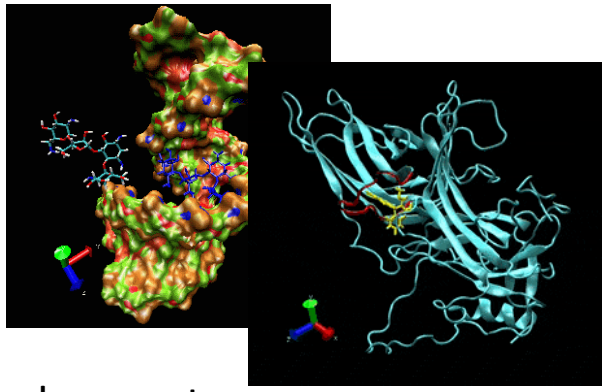


Clinical Development

Stability

Binding Affinity

Drug Delivery



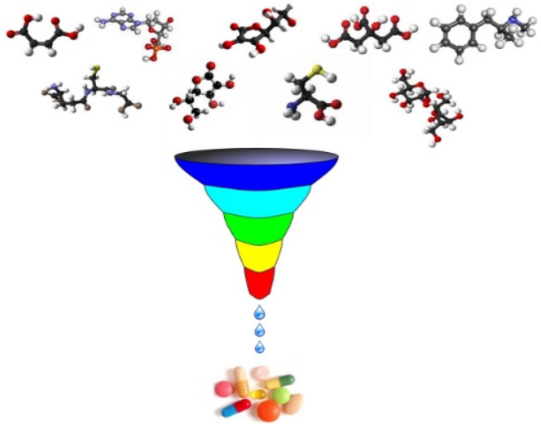
Immunogenicity

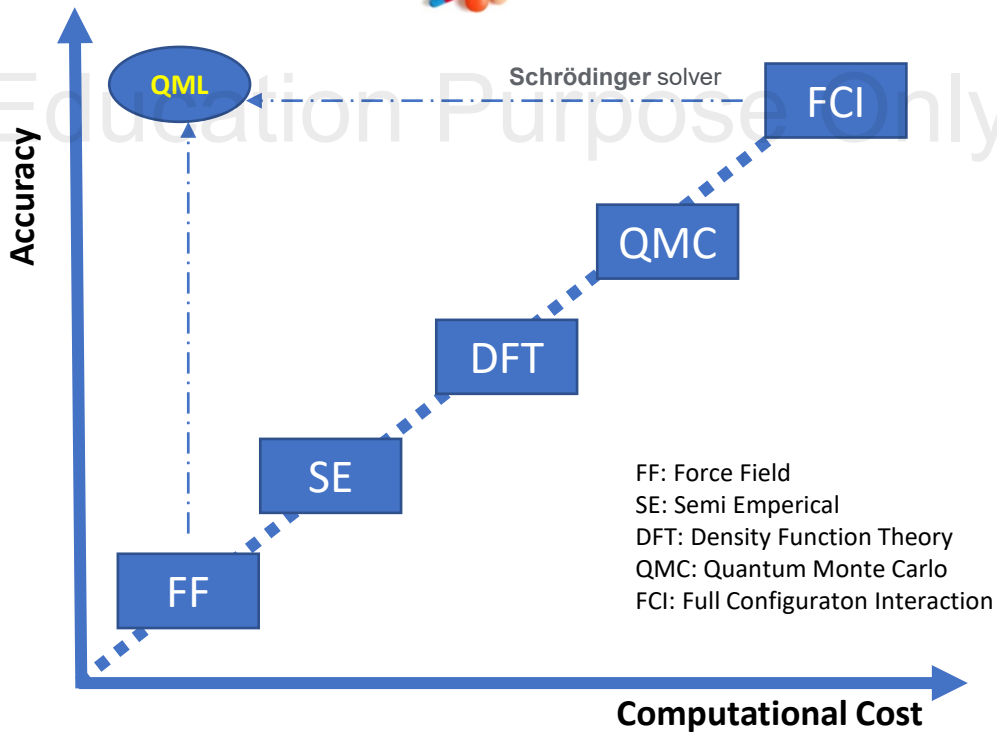
Formulation Development

PK/PD : ADMET-Tox

Synthesizability

Chemical Space: $10^{60}$

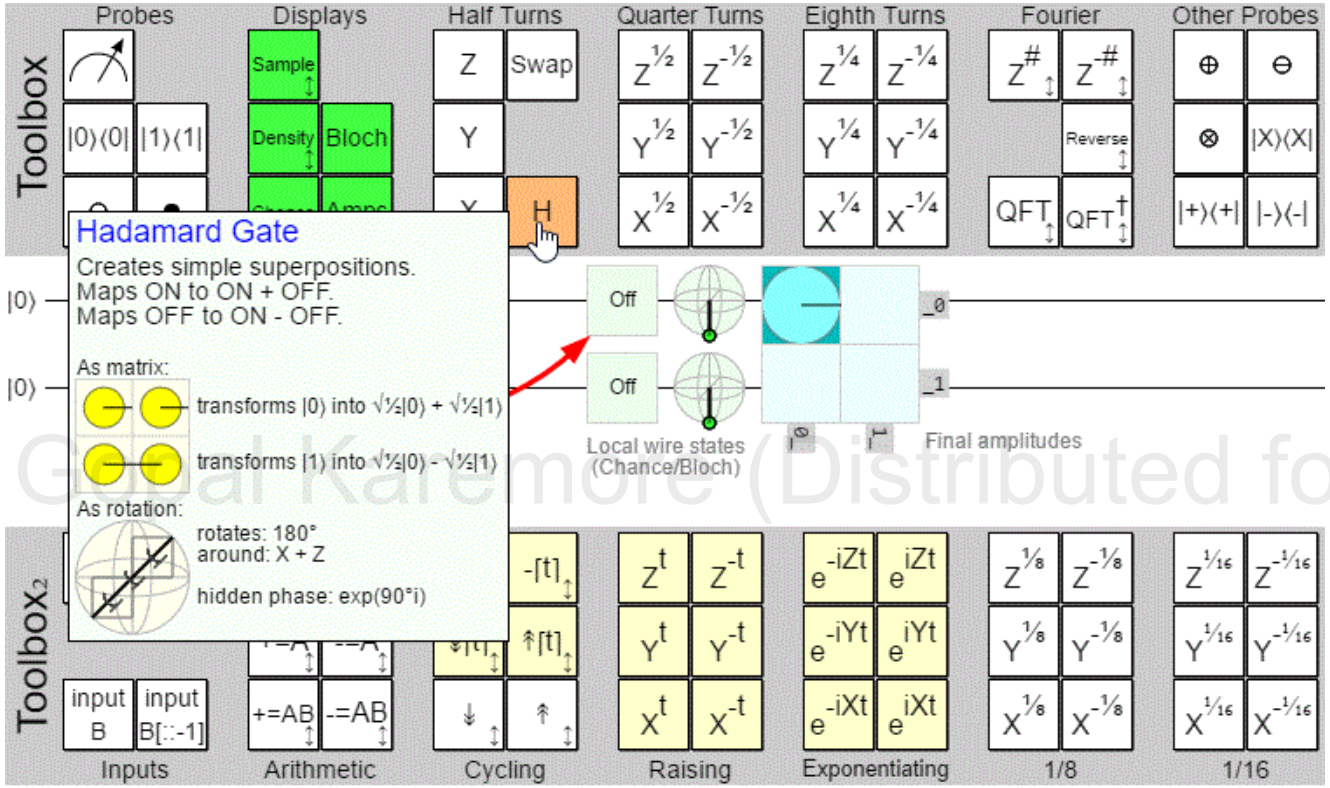





Ramakrishnan 2015, A. Lilienfeld 2018, K. Atz 2021

# A Quantum Circuit & Programming Quantum Computer

**Quantum Fourier Transform**




**Quantum Programming Language**

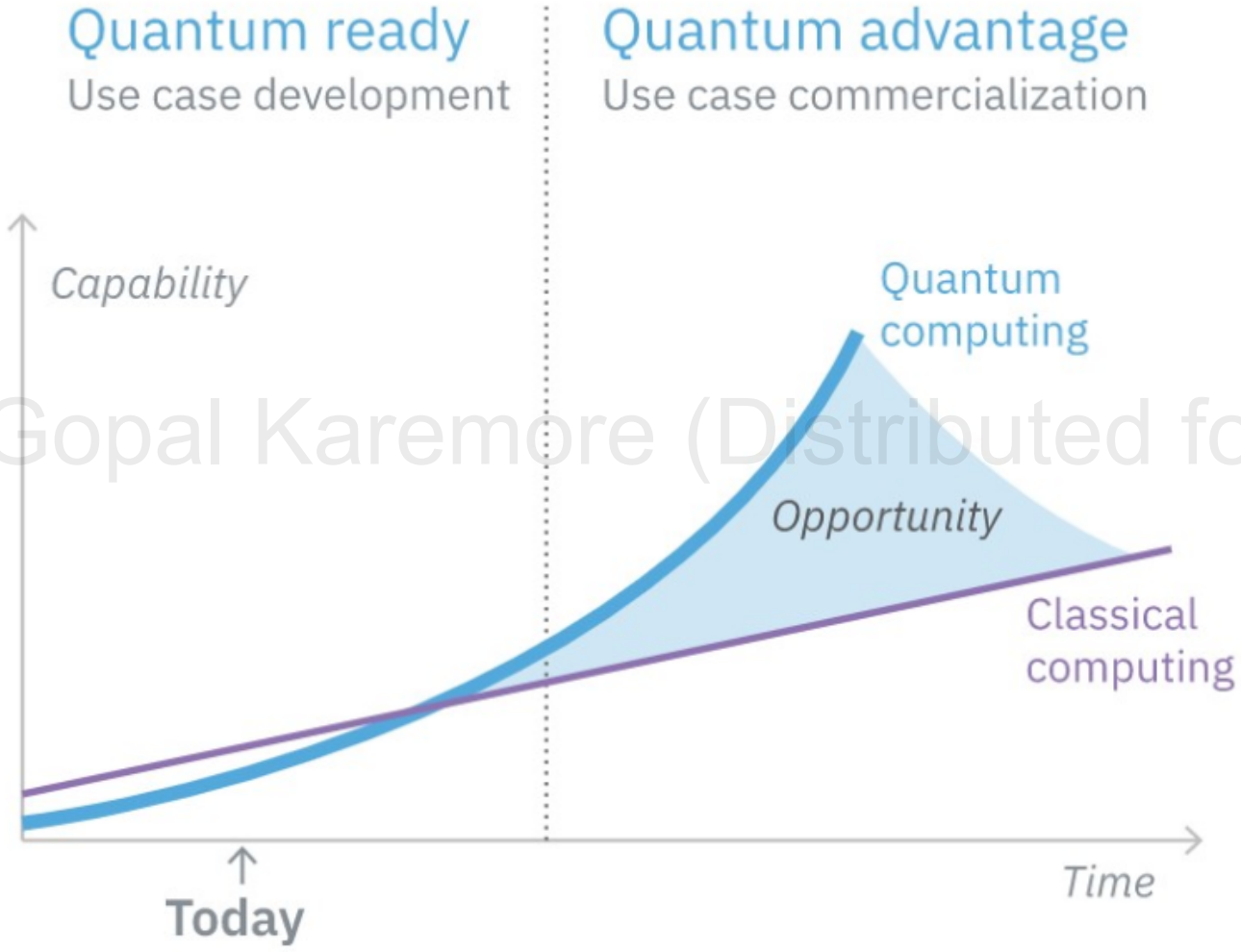
- OpenQASM
- Qiskit
- D-Wave Ocean
- Cirq
- Q#
- rigetti Forest™ SDK
- Orquestra
- PENNYLANE

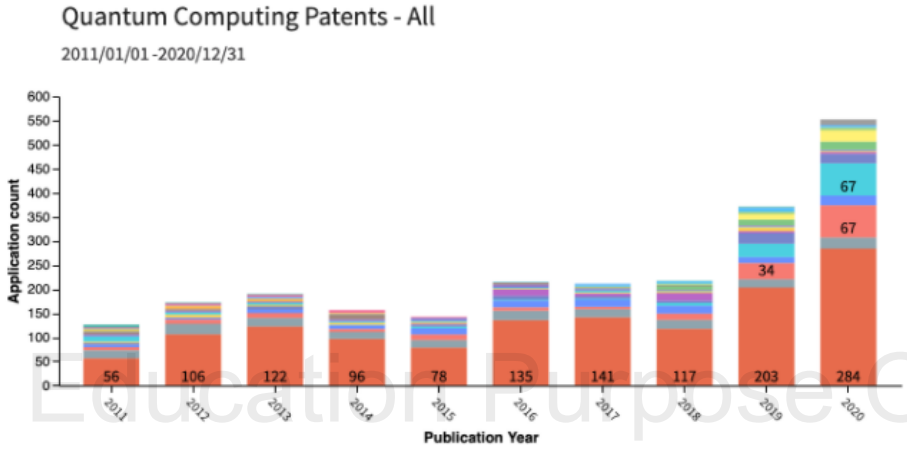
**Many more...**



https://algassert.com/quirk

# Why to invest now?




1. Other(1338)
2. D-WAVE SYSTEMS INC(184)
3. IBM(169)
4. NORTHROP GRUMMAN SYSTEMS CORP(110)
5. GOOGLE LLC(110)
6. MICROSOFT TECHNOLOGY LICENSING LLC(76)
7. SAMSUNG ELECTRONICS CO LTD(46)
8. RIGETTI & CO INC(38)
9. TOSHIBA KK(36)
10. NIPPON TELEGRAPH CORP(35)
11. NEC CORP(35)
12. INTEL CORP(34)
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14. NEWSOUTH INNOVATIONS PTY LTD(19)
15. 1QB INF TECH INC(18)
16. ROSE GEORDIE(17)
17. SONY CORP(16)
18. HYPRES INC(15)
19. QUCOR PTY LTD(14)
20. EQUAL1 LABS INC(12)

Image Credit: QED-C



Image Credit: IBM https://www.microcontrollertips.com/applications-algorithms-quantum-computing-faq/

# ‘Quantum for Life’ Center

novo nordisk fonden
Benefiting people and society

UNIVERSITY OF COPENHAGEN

- Mission: Demonstrate viability of quantum computing to the life sciences
- Payoff: Nucleus for Danish quantum life science community
- Unique Interdisciplinary Approach:



Professor Matthias Christandl
Center leader
**Quantum Software**

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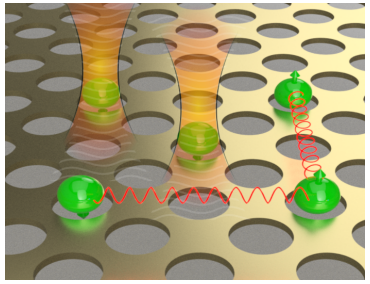
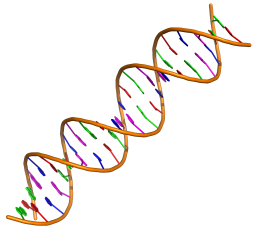
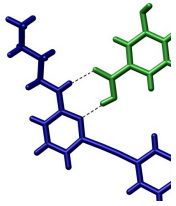
Professor Eugene Polzik
**Quantum Experiment**



Professor Anders Krogh
**Bioinformatics**



Professor Markus Reiher
ETH Zurich
**Quantum Chemistry**



# Thank you for your attention!

For any questions/comments : gopal.karemore@gmail.com

Connect me via **LinkedIn**:



Gopal Karemore