Quantum Machine Learning Algorithms and Applications

Presented by

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Outline

- Introduction
- Data for Quantum Machine Learning
- Quantum Computing Algorithms
- Quantum Machine Learning Algorithms
- Initiatives taken by Government of India to promote AI and Quantum Computing Algorithm in India
- Building of Quantum Machine Learning

Introduction

❑Computing Algorithms for Data Analysis

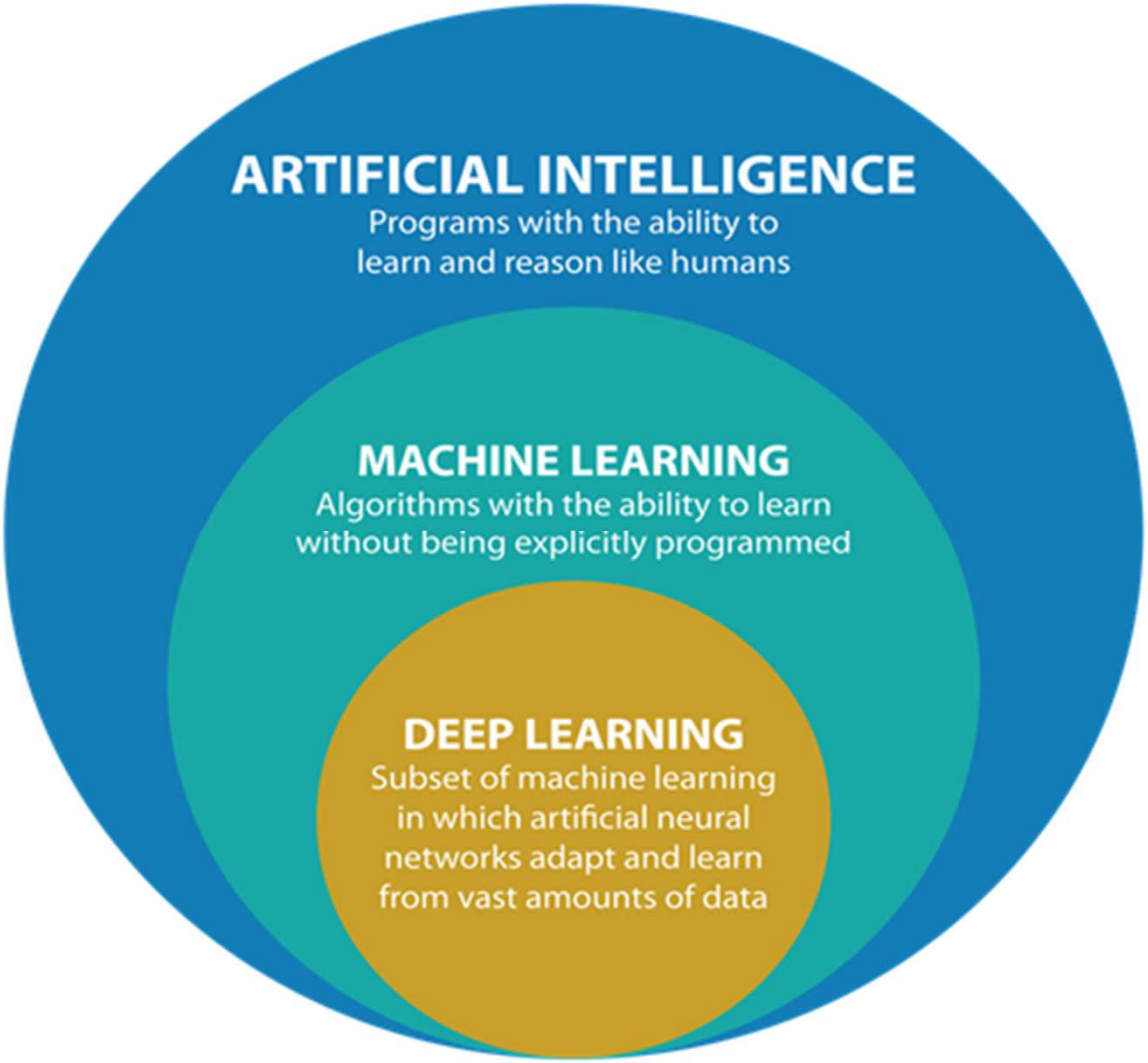
- Metaheuristic Optimization Algorithms-PSO, DPSO, DE, ACO, Cuckoo Search, etc.
- Artificial Intelligence (AI)-ML/DL
- Quantum Computing Algorithms- QML/QDL , etc.

Introduction

- **Prerequisite for Quantum Machine Learning (QML):**
- **Domain technical Knowledge:**
  - Linear Algebra
  - Probability and Statistics
  - Fundamental of Image Processing
  - Fundamental of Computer Vision
  - Strong foundation on Traditional Machine Learning algorithms
  - Quantum mechanics and physics
  - Other related subjects (i.e. Biomedical Signal Processing, Remote Sensing, 5G/B5G, IoT, Cyber Security, DSP, Mechanical, Electrical, Civil, Metallurgy and etc.)
- **Software and Hardware Skills:**
  - Python coding, Numpy, Scipy and Panda Library
  - OpenCV2
  - Scikit Library (https://scikit-learn.org/stable/)
  - Deep learning Library (Keras/TensorFlow/PyTorch)
  - Pennylane Library (https://pennylane.ai/)
  - Qiskit Library (https://pypi.org/project/qiskit/)
  - Raspberry Pi 5, NVIDIA Jetson Nano, & FPGA Board

Introduction

- Artificial Intelligence (AI)
- Machine Learning
- Deep learning



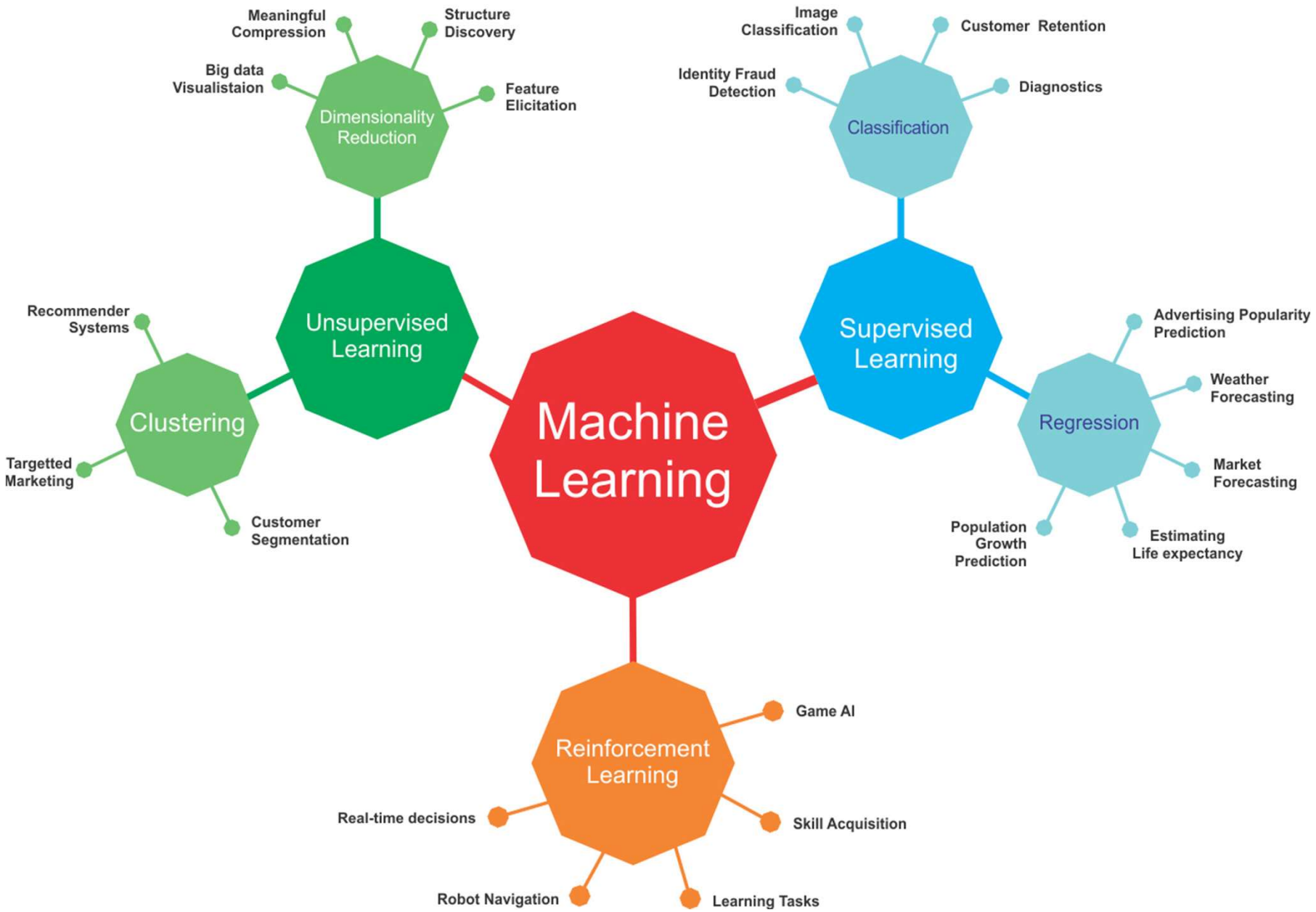
Source: https://datacatchup.com/artificial-intelligence-machine-learning-and-deep-learning/

Introduction

- Types of Neural Networks:

1) Artificial Neural Networks (ANNs)
2) Deep Neural Networks (DNNs)
3) Convolutional Neural Networks (CNNs)
4) Recurrent Neural Networks (RNNs)
5) Generative Adversarial Networks(GAN)
6) Graph Neural Networks (GNN)
7) Transformer Models-ViT, BERT, etc.
8) Liquid Neural Networks(LNN)
9) Kolmogorov-Arnold Network(KAN)

Introduction



Source: https://skilllx.com/list-of-machine-learning-algorithms/

Introduction

❑Supervised machine learning

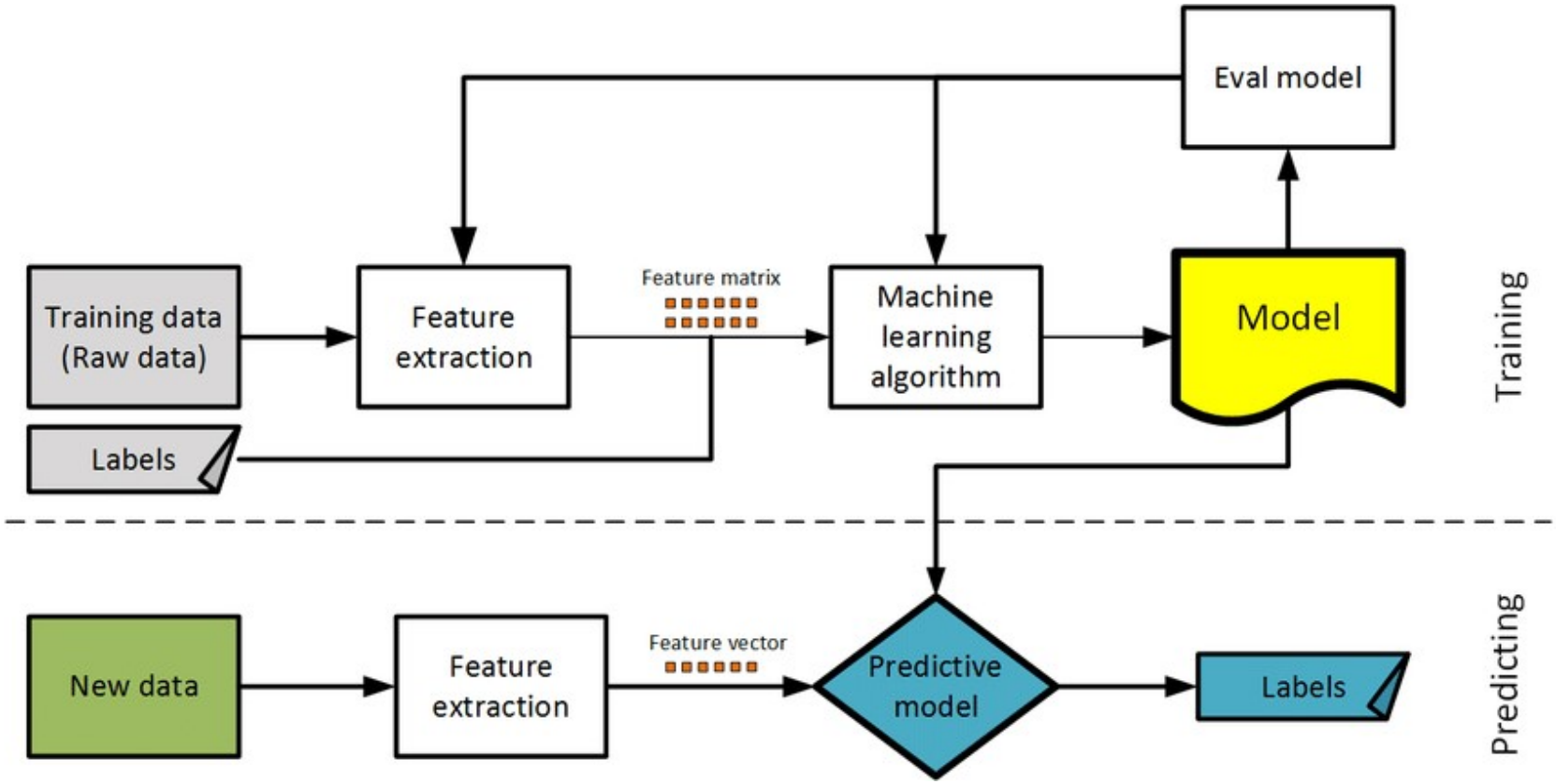


Figure 2. Workflow of supervised machine learning

Introduction

❑Traditional machine learning

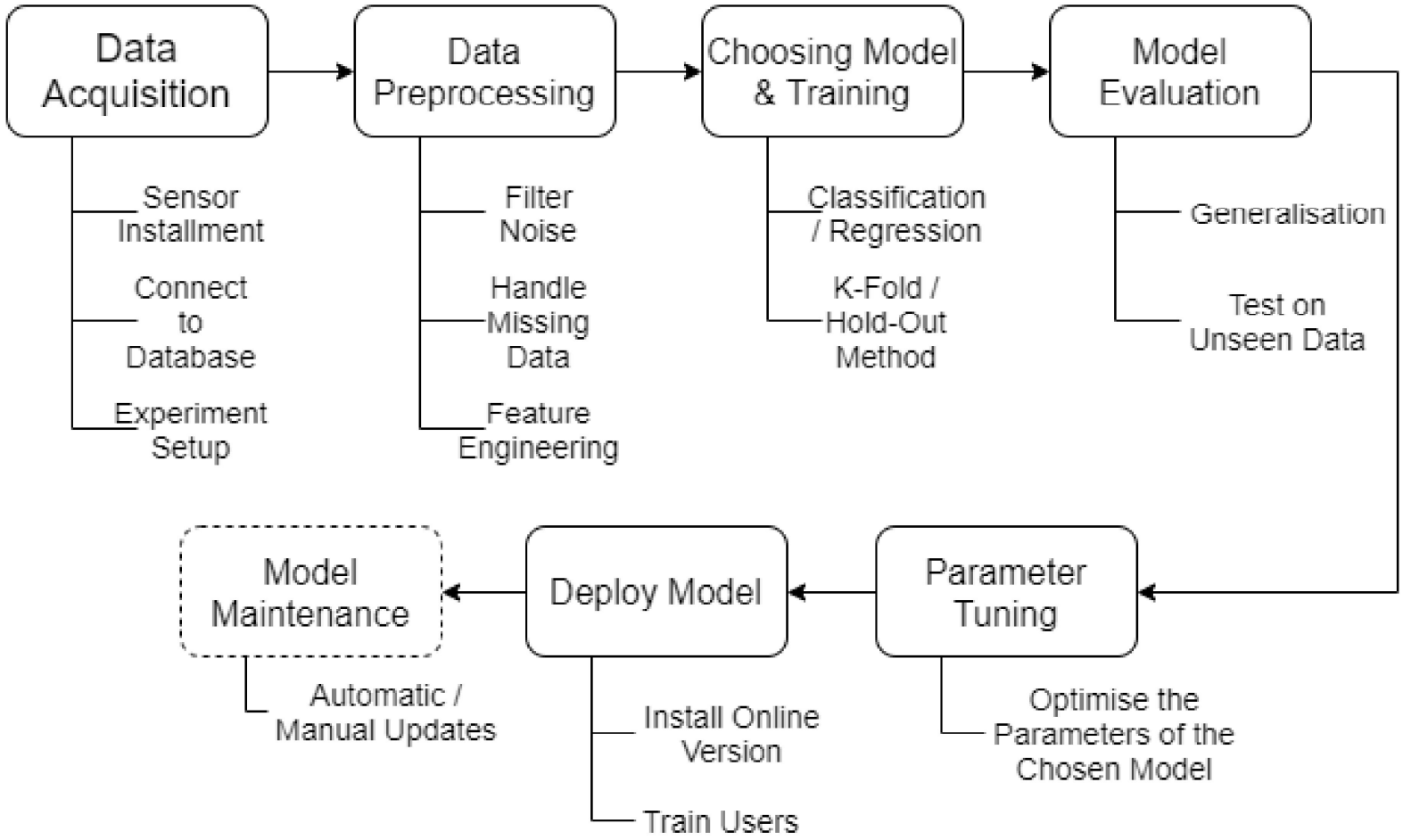
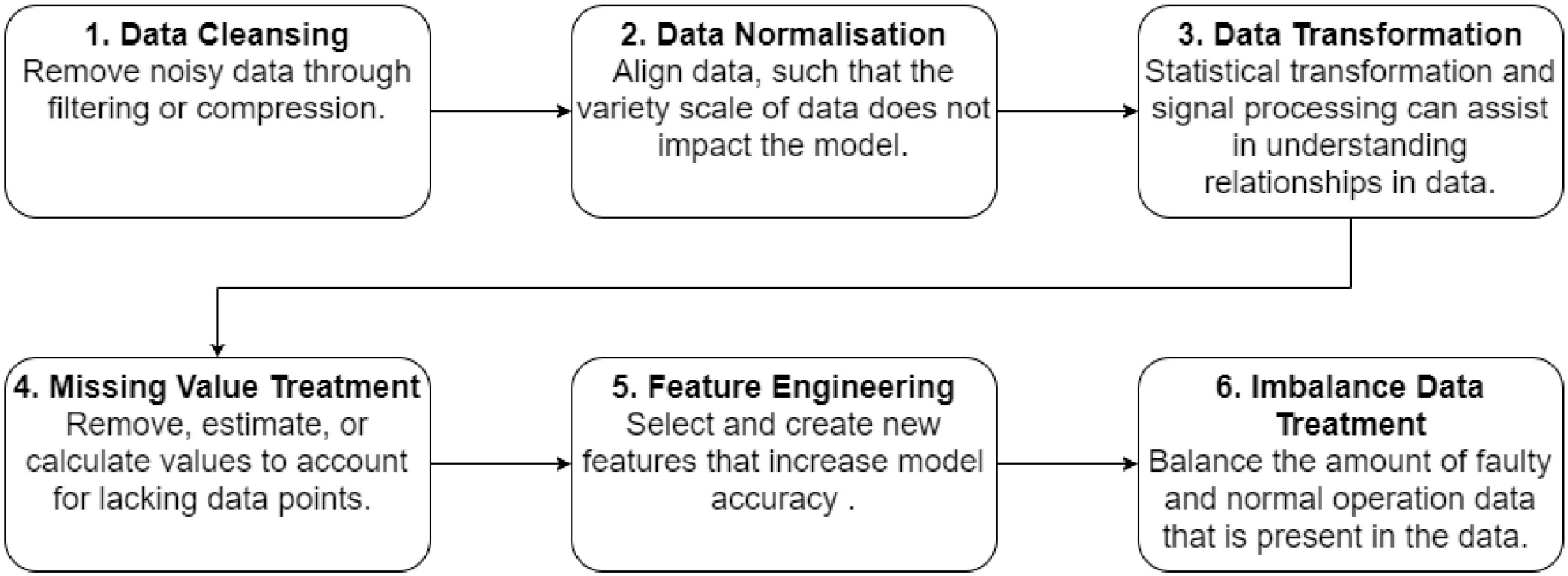


Figure 2. Workflow of machine learning

Fausing Olesen, J.; Shaker, H.R. Predictive Maintenance for Pump Systems and Thermal Power Plants: State-of-the-Art Review, Trends and Challenges. Sensors 2020, 20, 2425. https://doi.org/10.3390/s20082425

Introduction

❑ Data preprocessing in machine learning



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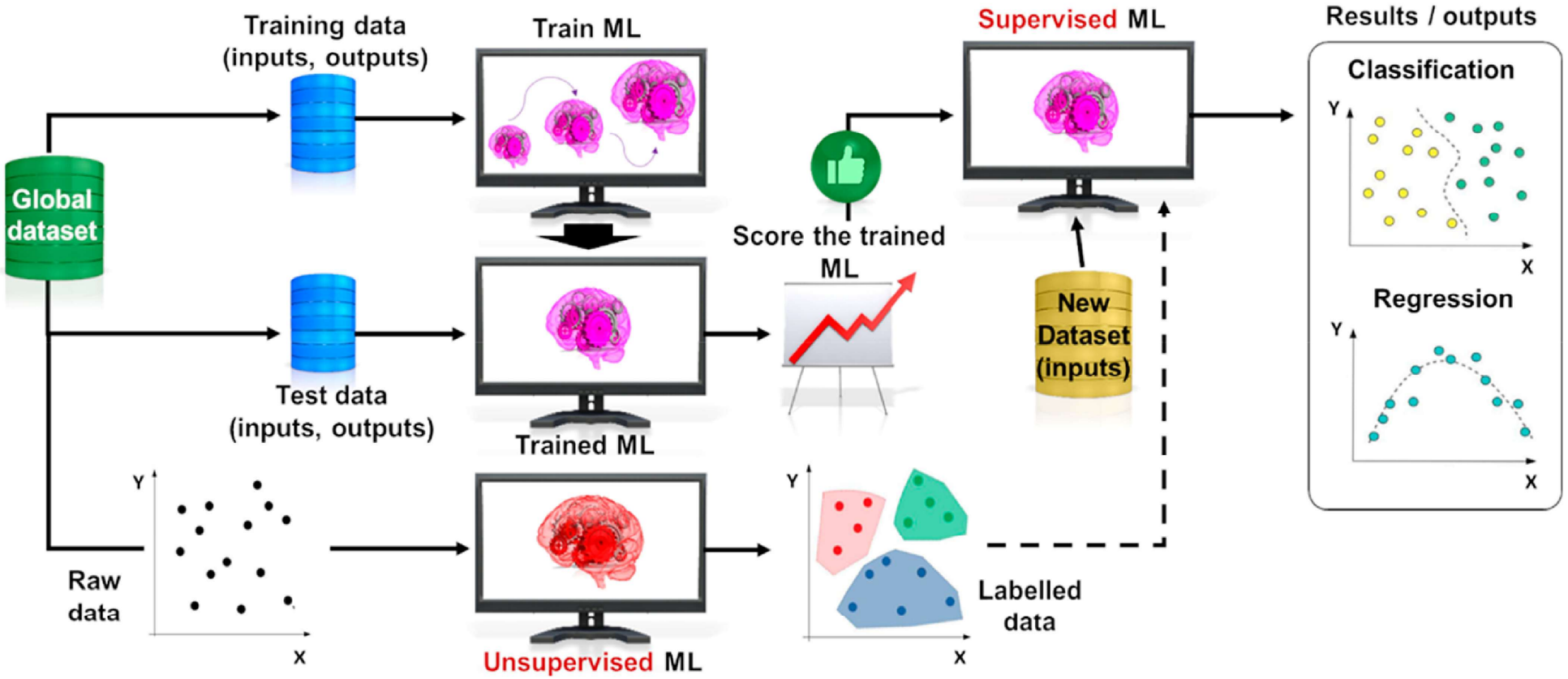
Introduction



Source: https://pubs.acs.org/doi/10.1021/acs.chemrev.1c00108

Introduction

- Traditional machine learning and deep learning

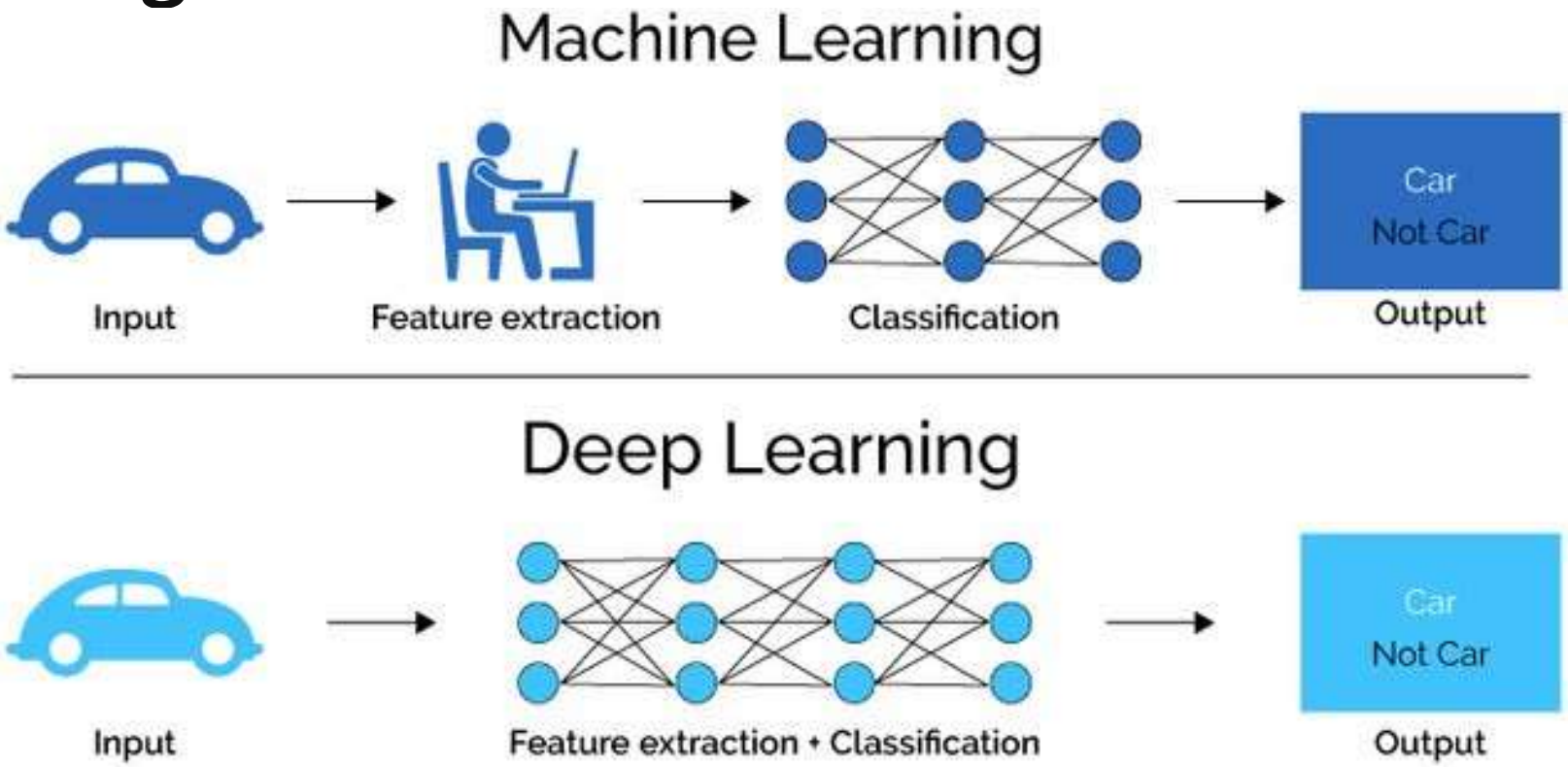


Figure. Difference between traditional machine learning and deep learning (Alex, 2017).

Fausing Olesen, J.; Shaker, H.R. Predictive Maintenance for Pump Systems and Thermal Power Plants: State-of-the-Art Review, Trends and Challenges. Sensors 2020, 20, 2425. https://doi.org/10.3390/s20082425

Introduction

❑Traditional machine learning Algorithms:

- MLP(ANN)
- SVM
- Decision Tree
- Random Forest
- XGBoost

❑Deep learning Algorithms:

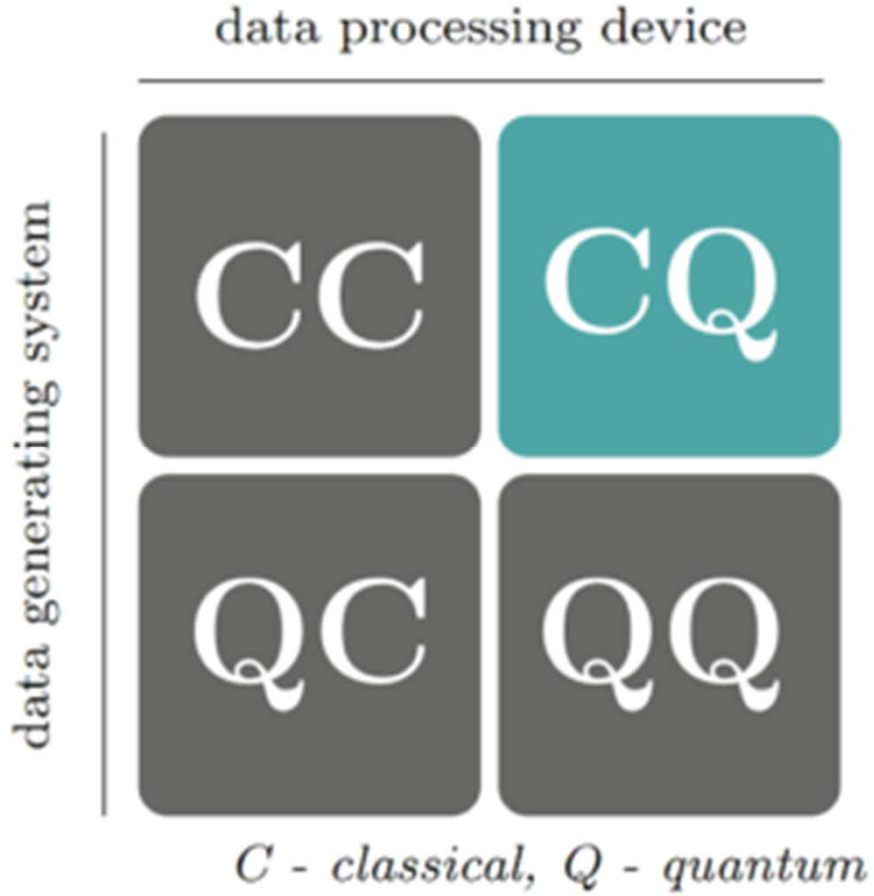
- DNN
- CNN
- RNN
- GNN
- LNN

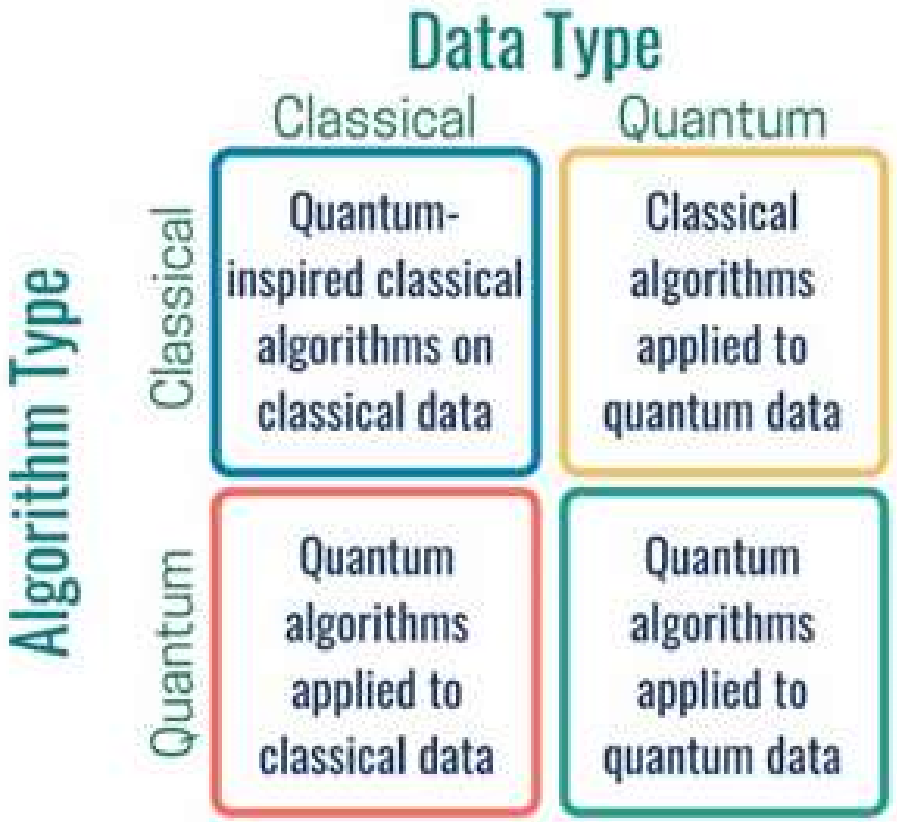
Data for Quantum Machine Learning

- **Sensor Data Types:**
- **Remote Sensing data**
  - Surveillance Camera
  - Drone(UAV) Images
  - Aerial Images
  - Multispectral Satellite Images
  - Hyperspectral Satellite Images
- **Temperature, Pressure and Humidity sensors, etc.**
- **Healthcare data**
  - Biological Signals
  - Radiology
  - Histopathology
  - Cytology
- **Other Sensors data**
  - IoT
  - Cybersecurity and etc.

Data for Quantum Machine Learning

❑Data Types





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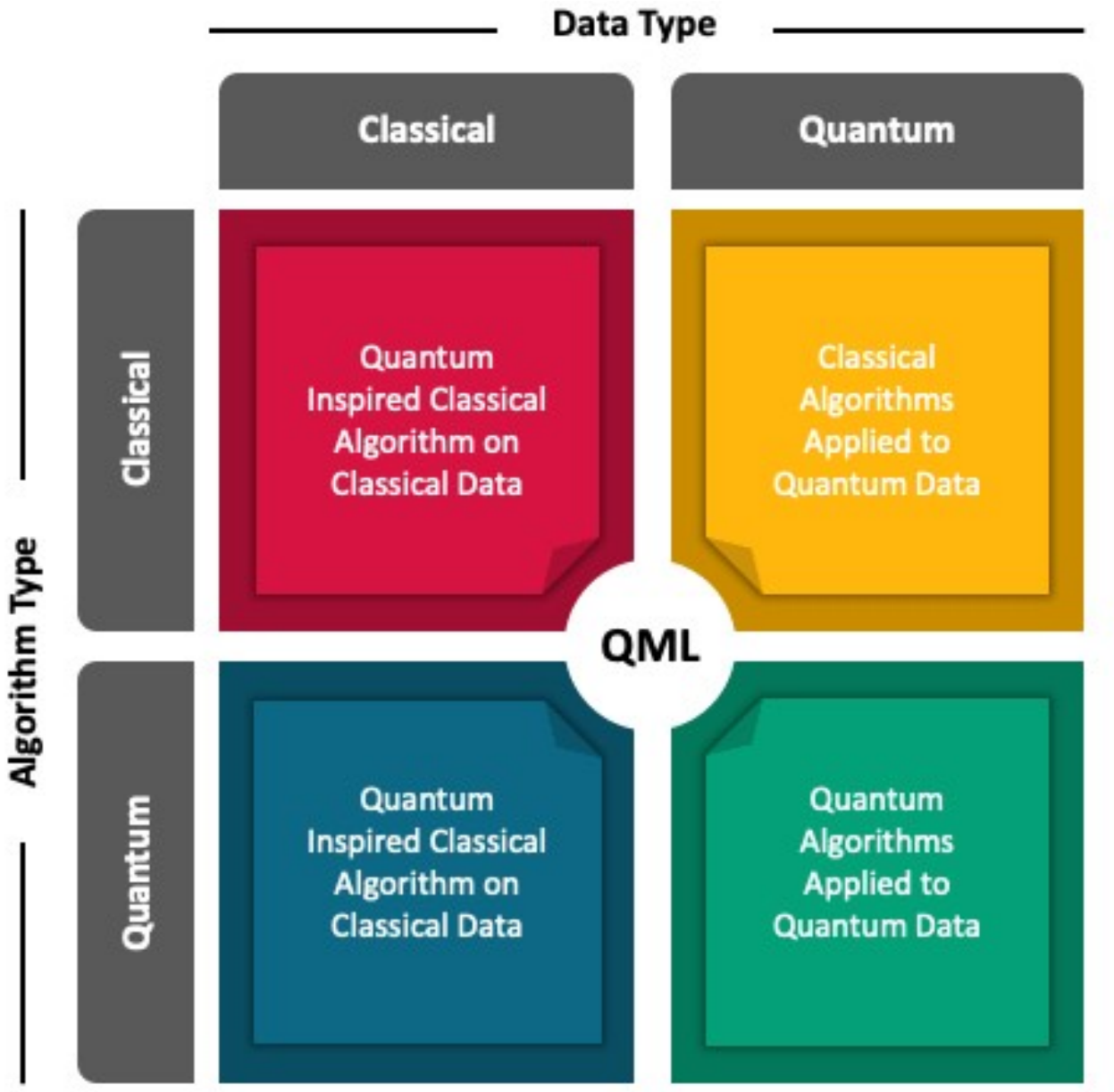
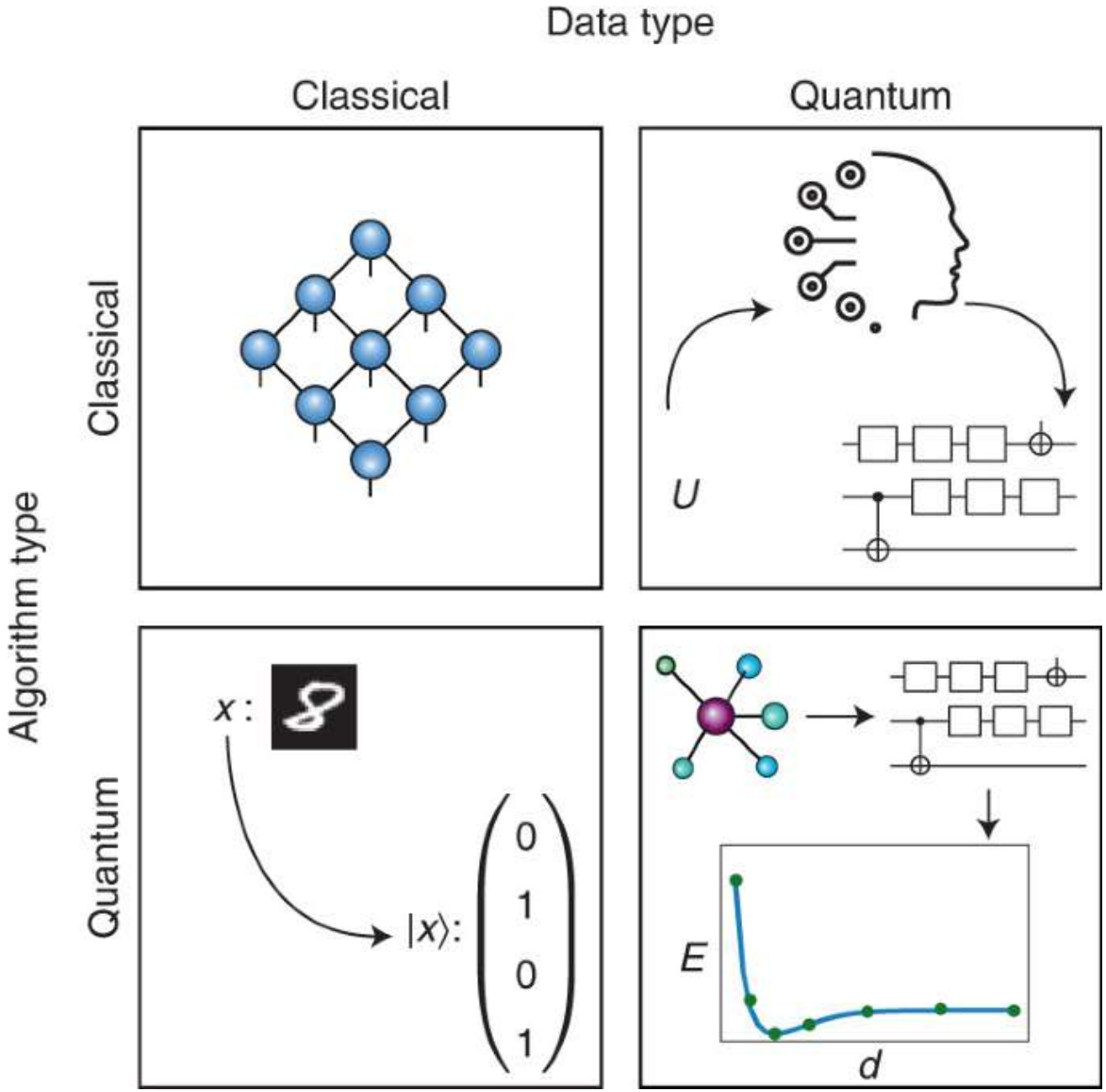
Data for Quantum Machine Learning



https://fastercapital.com/content/Quantum-Machine-Learning--Revolutionizing-AI-with-QIP.html

Data for Quantum Machine Learning



https://www.icvtank.com/newsinfo/828689.html

Quantum Machine Learning

❑Data Types

Classical Problems	Quantum Tools	Applications	Methods
BLAS → matrix inversion, inner products, eigenvalue decomposition, singular value decomposition	**QBLAS/HHL** → quantum phase estimation, post selective amplitude update, Hamiltonian simulation, density matrix exponentiation	Support vector machines, Gaussian processes, linear regression, discriminant analysis, recommendation systems, principal component analysis	*QSVM, QPCA, LSE Regression, Quantum Gaussian Processes*
Search → finding closest neighbors, Markov chains	**Grover Search** → amplitude amplification, quantum walks	k-nearest neighbor, page ranking, clustering, associative memory, perceptrons, active learning agents, natural language processing	*Quantum K-means clustering*
Sampling → sampling from the model distribution	**Quantum Sampling** → quantum annealing, quantum rejection sampling	Boltzmann machines, Bayesian nets, Bayesian inference	*Bayesian Inference, Quantum Boltzmann Machines*
Combinatorial Optimization → combinatorial optimization, QUBO problems	**Ground State Optimization** → adiabatic quantum computing, quantum annealing, quantum simulation	associative memory, boosting, debugging, variational Bayes inference, Bayesian networks, perceptron, EM algorithm, clustering	*Bayesian Inference, Perceptron*

https://qpiai.tech/blogdetails1

Quantum Computing Algorithms

❑List of Quantum Computing Algorithms:

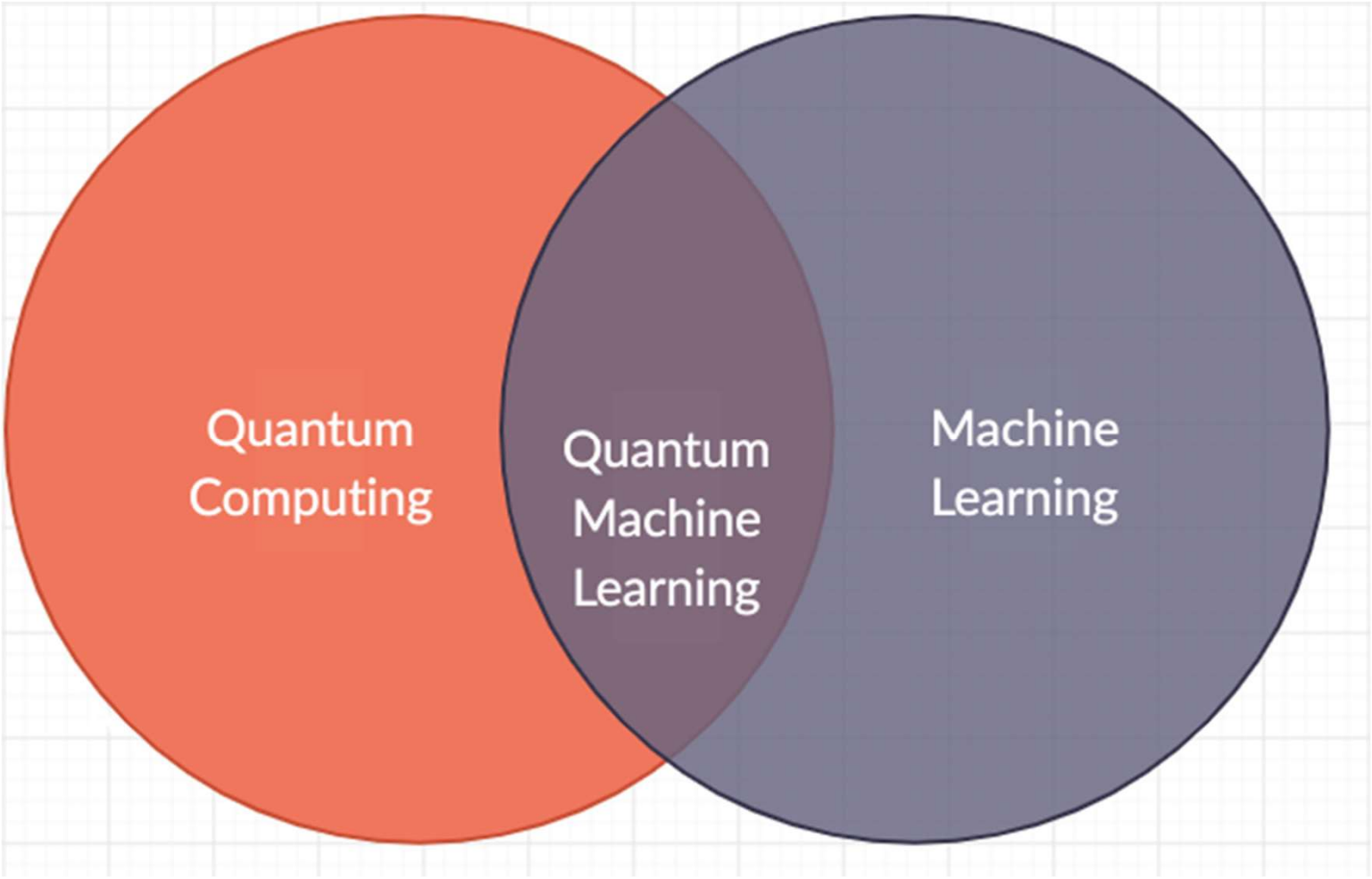
- Quantum Fourier Transform
- Variational-Quantum-Eigensolver
- Grovers Algorithm
- Shor's algorithm
- Hamiltonian Oracle Model
- Bernstein-Vazirani Algorithm
- Simon’s Algorithm
- Deutsch-Jozsa Algorithm
- Gradient Descent
- Phase Estimation
- Haar Tansform
- Quantum Ridgelet Transform
- Quantum NP Problem

Quantum Machine Learning

- What is Quantum Machine learning ?
- Why Quantum Machine learning is necessary ?
- What are types of Quantum Machine learning ?
- Where Quantum Machine learning will be used ?
- How Quantum Machine learning will be used ?

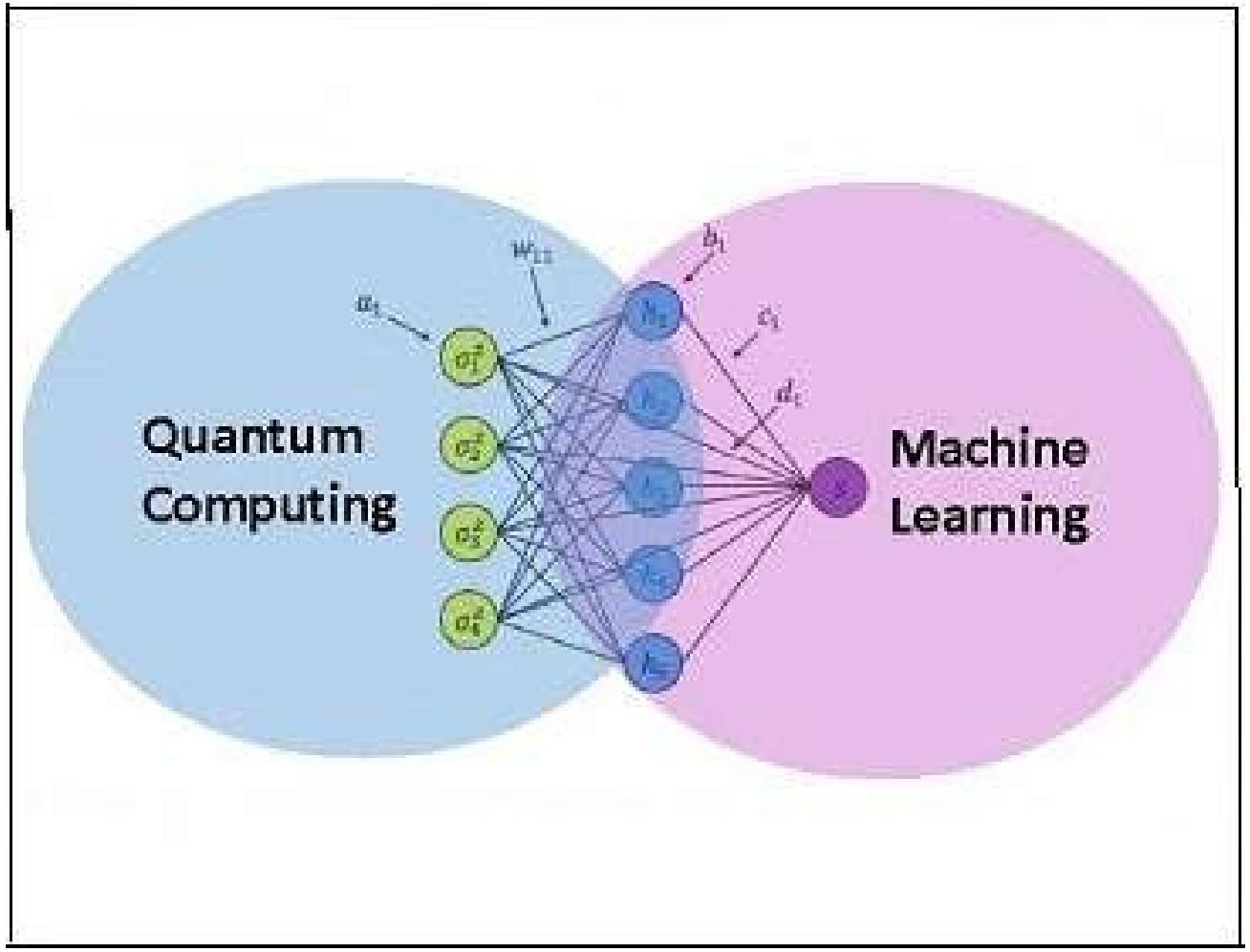
Quantum Machine Learning

❑ What is Quantum Machine learning ?



https://blog.paperspace.com/beginners-guide-to-quantum-machine-learning/

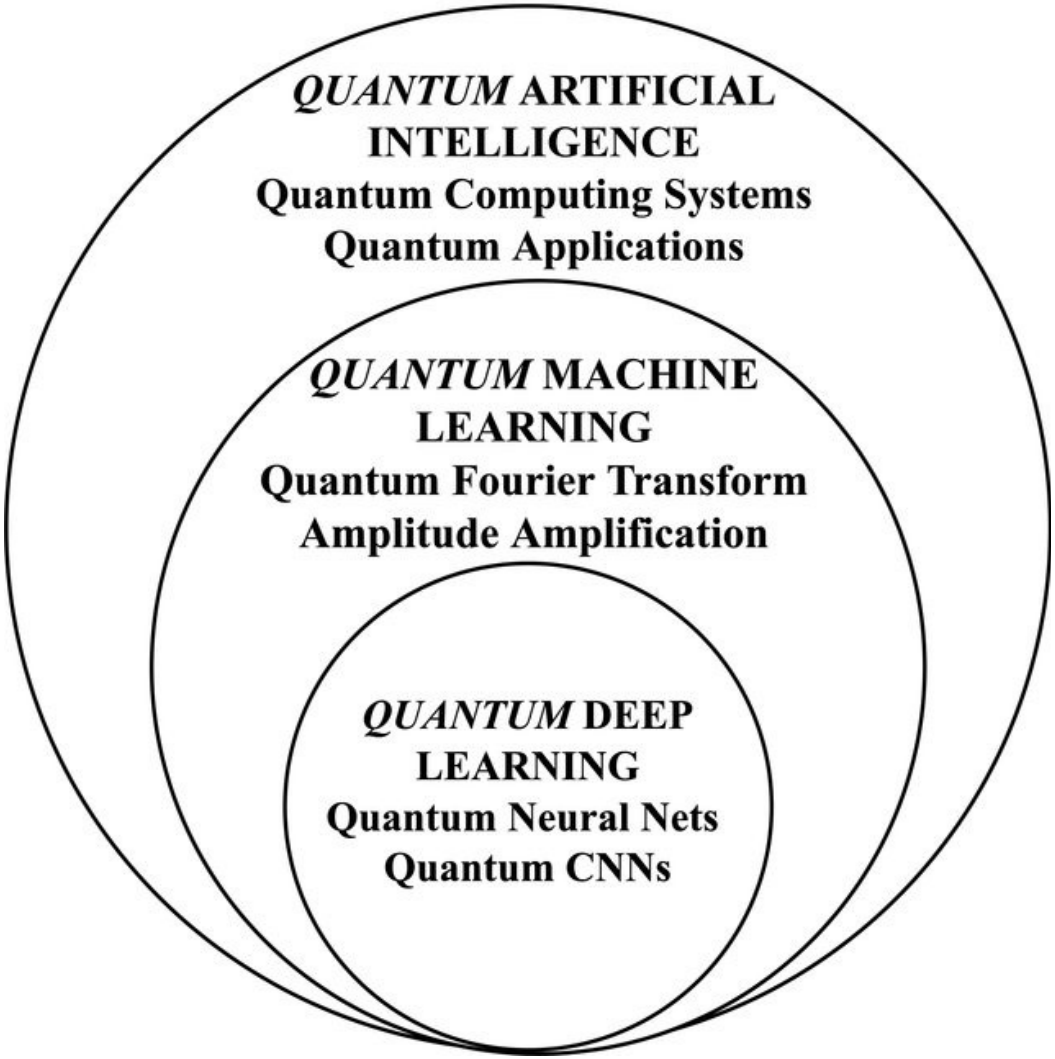
Quantum Machine Learning



https://www.chem.purdue.edu/kais/research/Quantum%20Machine%20Learning.html

Introduction

- Quantum Artificial Intelligence (AI)
- Quantum Machine Learning
- Quantum Deep learning



Source: https://www.mdpi.com/2306-5729/7/3/28

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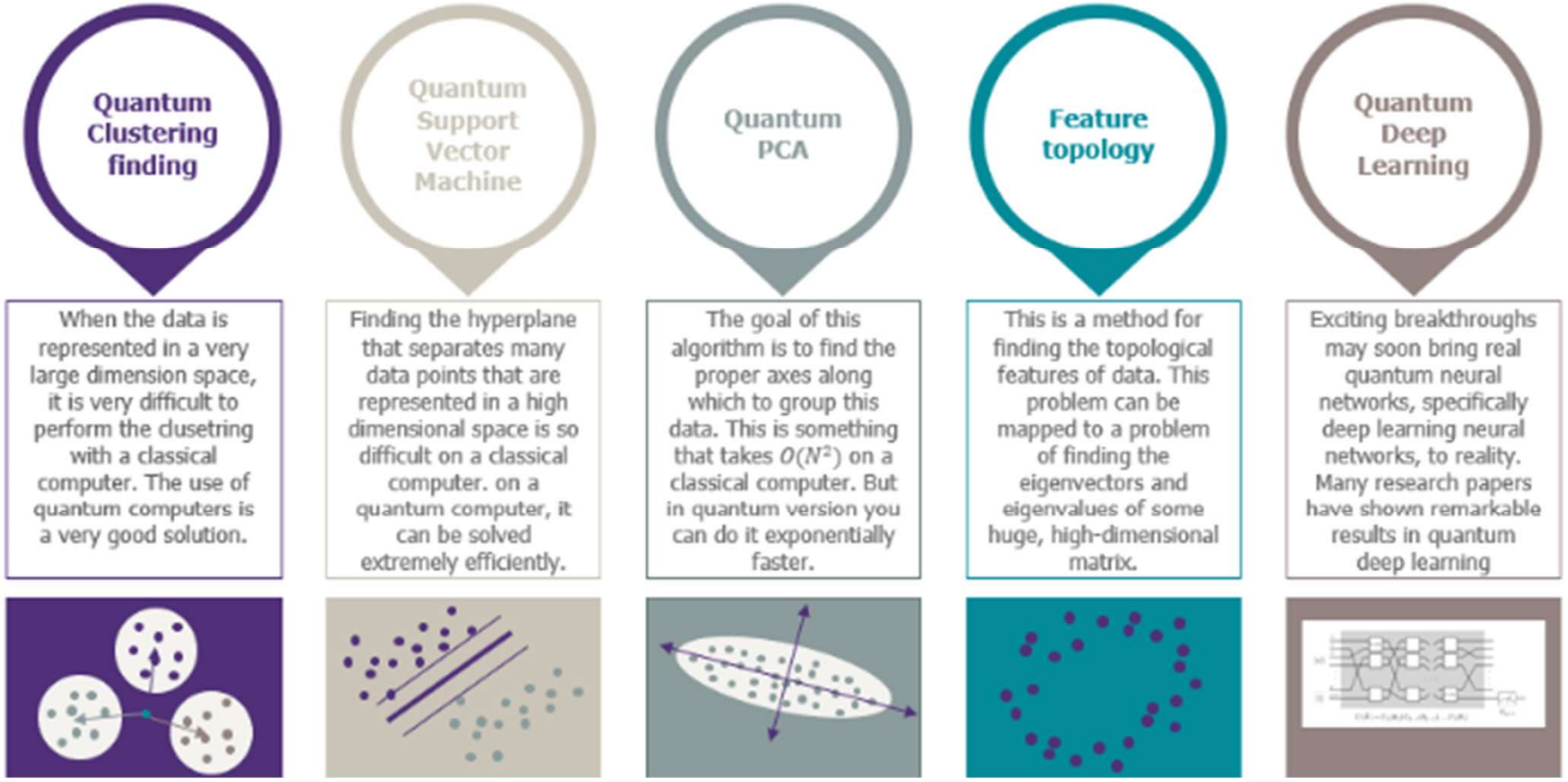
Quantum Machine Learning

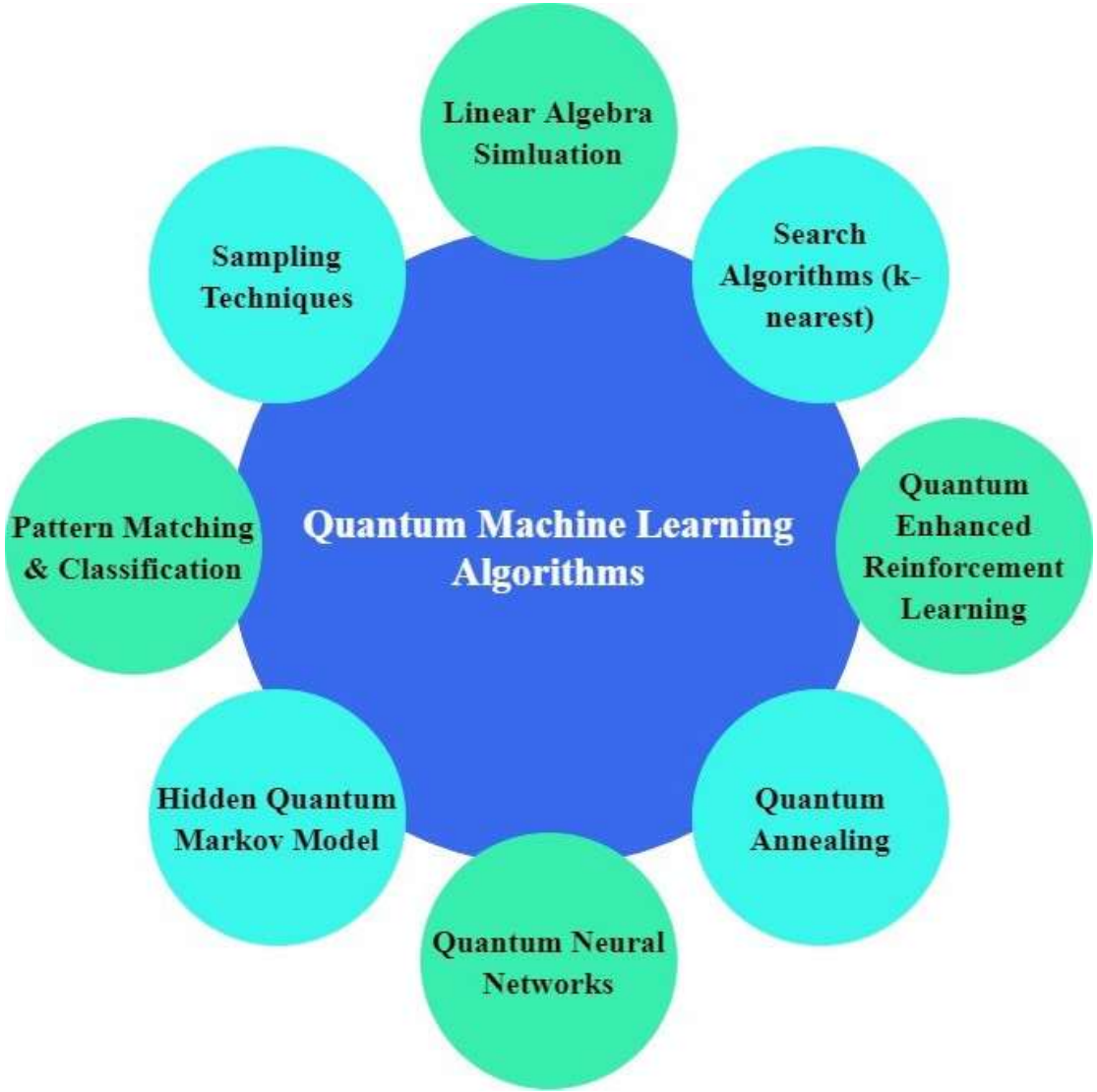
❑Road map:



https://fastercapital.com/content/Quantum-Machine-Learning--Revolutionizing-AI-with-QIP.html

Quantum Machine Learning

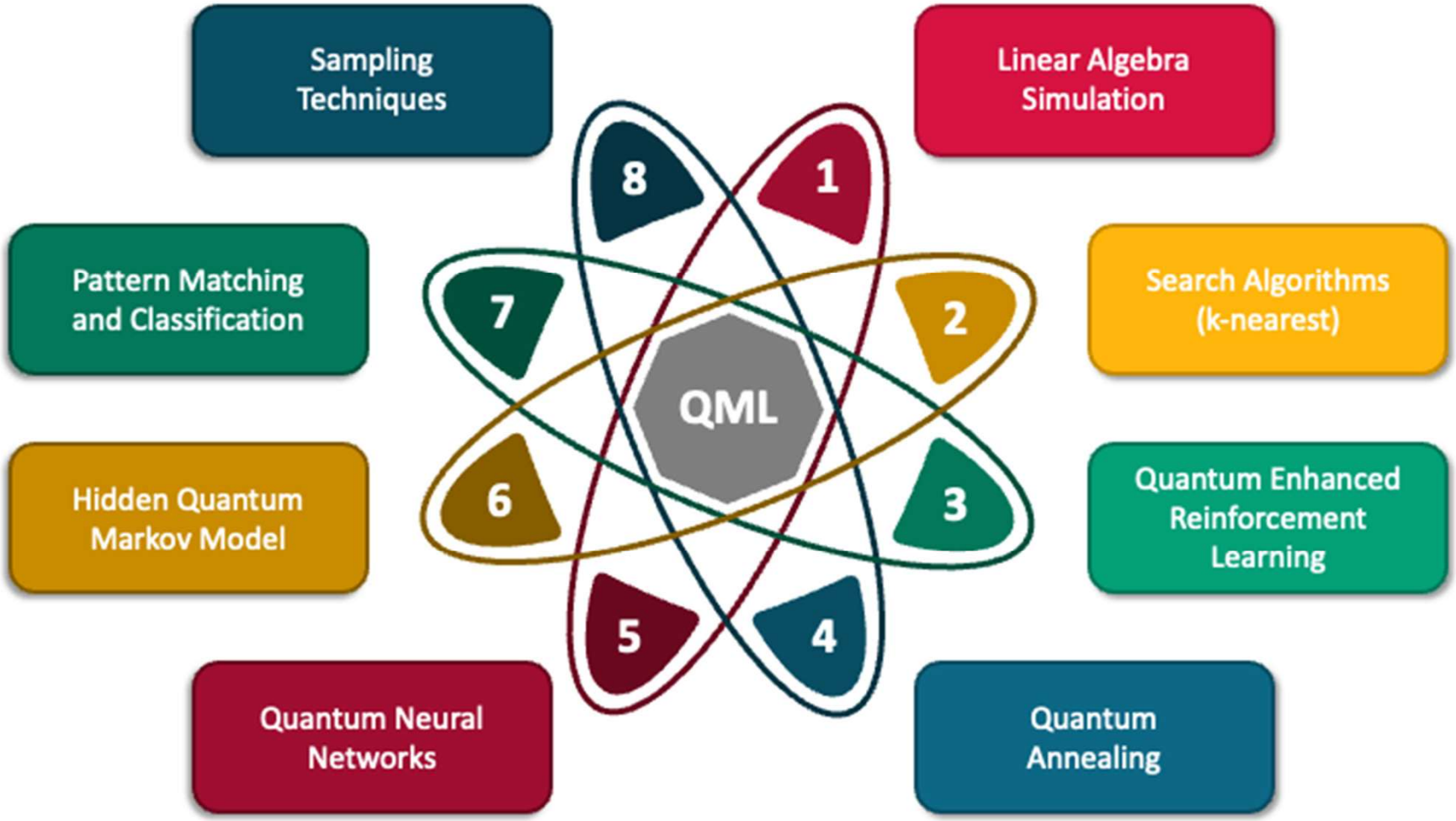
❑ **Road map:**



https://quantumstrategyinstitute.com/2022/02/28/quantum-machine-learning-a-roadmap-for-technologists/

Quantum Machine Learning

❑ Quantum Machine Learning algorithms:



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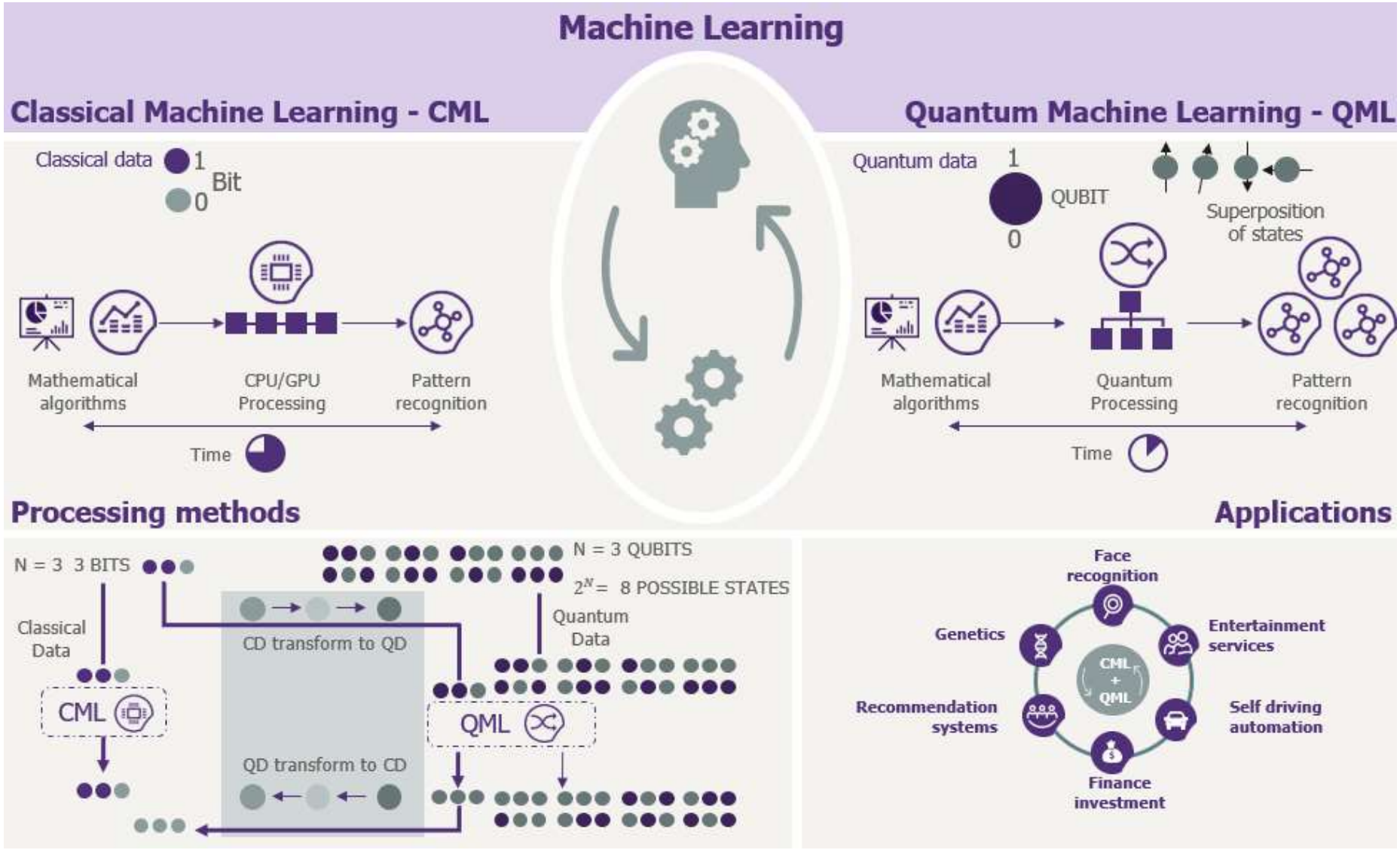
Quantum Machine Learning

❑ Classical ML and Quantum ML



https://www.chem.purdue.edu/kais/research/Quantum%20Machine%20Learning.html

Quantum Machine Learning

❑**List of Quantum Machine learning Algorithms for Science, Engineering and Technology Applications:**

- Quantum K-Nearest Neighbour
- Quantum K-Means
- Quantum Fuzzy C-Means
- **Quantum Support Vector Machine**
- Quantum Genetic Algorithm
- Quantum Hidden Morkov Models
- Quantum state classification with Bayesian methods
- Quantum Ant Colony Optimization
- Quantum Cellular Automata
- Quantum Classification using Principle Component Analysis
- Quantum Inspired Evolutionary Algorithm
- Quantum Approximate Optimization Algorithm
- Quantum Elephant Herding Optimization
- Quantum-behaved Particle Swarm Optimization
- Quantum Annealing Expectation-Maximization

Quantum Neural Networks

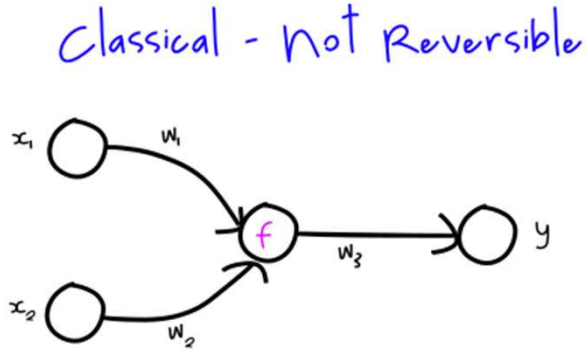
❑**List of Quantum Neural Networks for Science, Engineering and Technology Applications:**

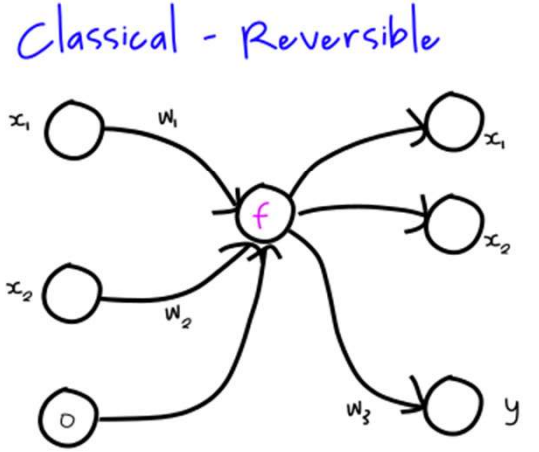
- **Quantum perceptron's**
- **Quantum Auto Encoder**
- Quantum Annealing
- Photonic Implementation of Quantum Neural Network
- **Quantum Feed Forward Neural Network**
- Quantum Boltzman Neural Network
- Quantum Neural Net Weight Storage
- Quantum Upside Down Neural Net
- Quantum Hamiltonian Neural Net
- Quantum ANN
- QPN
- SAL
- Quantum Hamiltonian Learning
- Compressed Quantum Hamiltonian Learning

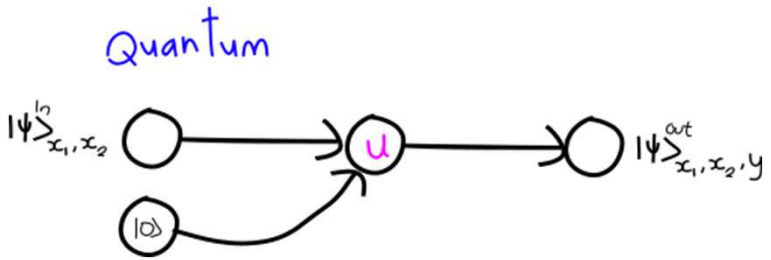
Quantum Neural Networks

❑Quantum Perceptron:

- Perceptron(layer) is the basic unit in Neural Network.
- The quantum version of perceptron must satisfy both linear and non linear problems.
-
- Quantum Concepts is combination of linear (calculus of superposition) and nonlinear (State approximation using probability)
- To make a perceptron in quantum world, Transformation (activation function) of non linearity to certain limit is needed, which is carrying by Phase estimation Algorithm.





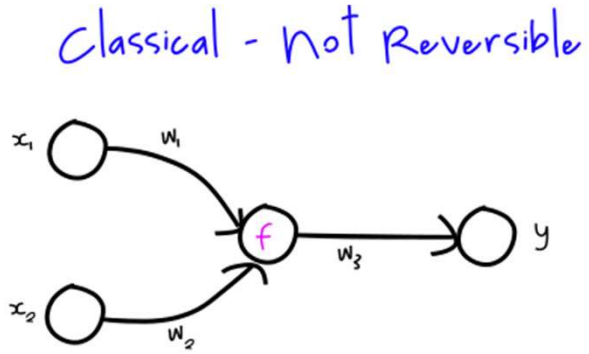


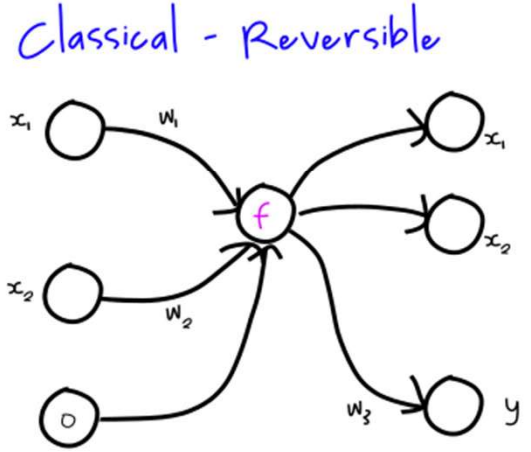
https://arxiv.org/pdf/quant-ph/0201144
https://axon.cs.byu.edu/papers/ricks.nips03.pdf
https://en.wikipedia.org/wiki/Quantum_phase_estimation_algorithm

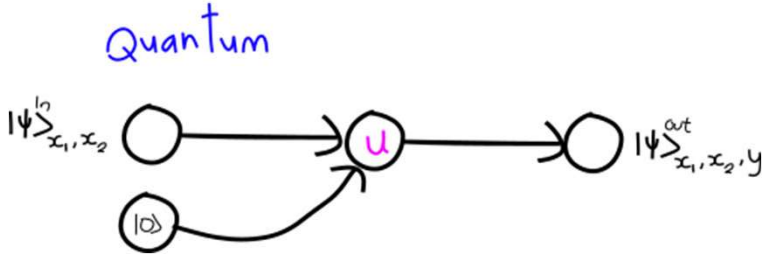
Quantum Neural Networks

❑Quantum Perceptron's:

- Normal Neural Network is doing parallel process whereas QNN is doing parallel of parallel processes.
- In theory combination of various activation functions is possible in QNN.
- Whereas in Normal NN more than one activation function reduce the performance and increase the complexity.







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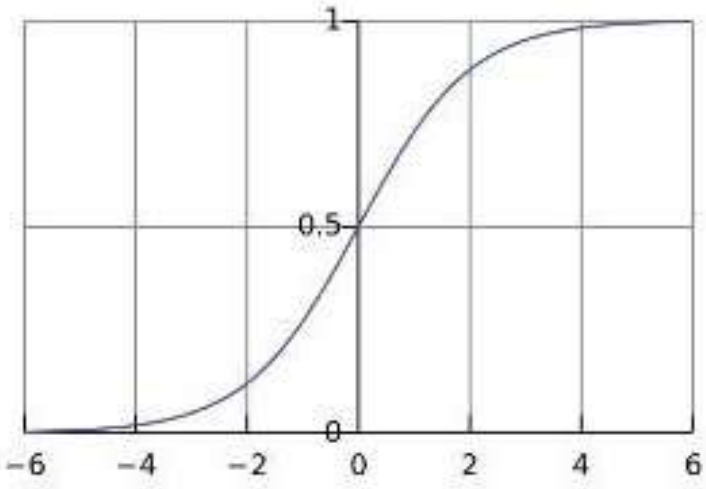
https://axon.cs.byu.edu/papers/ricks.nips03.pdf

Quantum Neural Networks

❑ **Quantum Perceptron's:**

Non Linear Activation

- Non-Linear activation functions is an important characteristic of neural networks.
- It is a source for non-linear properties of neural networks
- Sigmoid function is the most famous example
- One open issue of Quantum Neural Networks is how to incorporate non-linear functions in quantum systems which is linear



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Quantum Machine Learning

- Quantum Neural Networks·

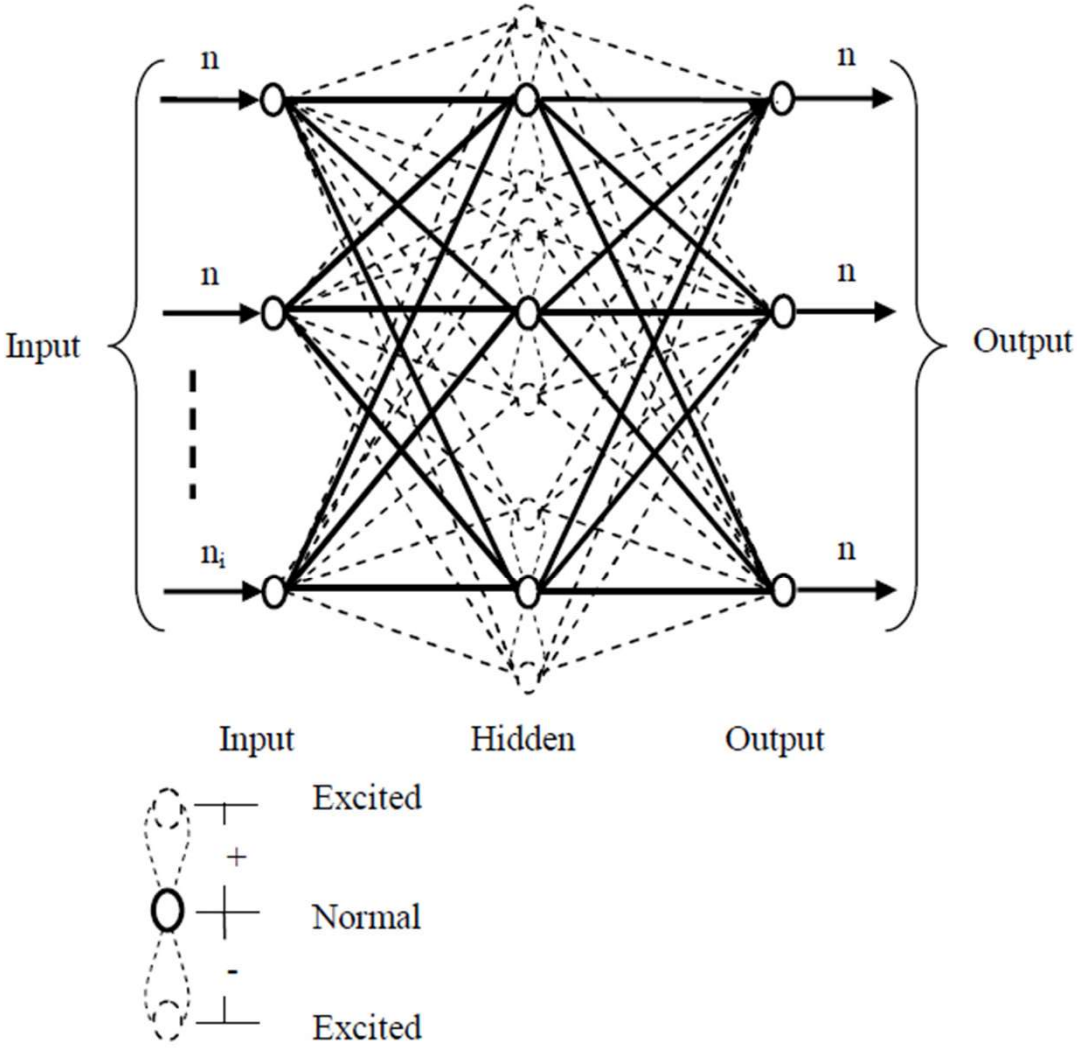
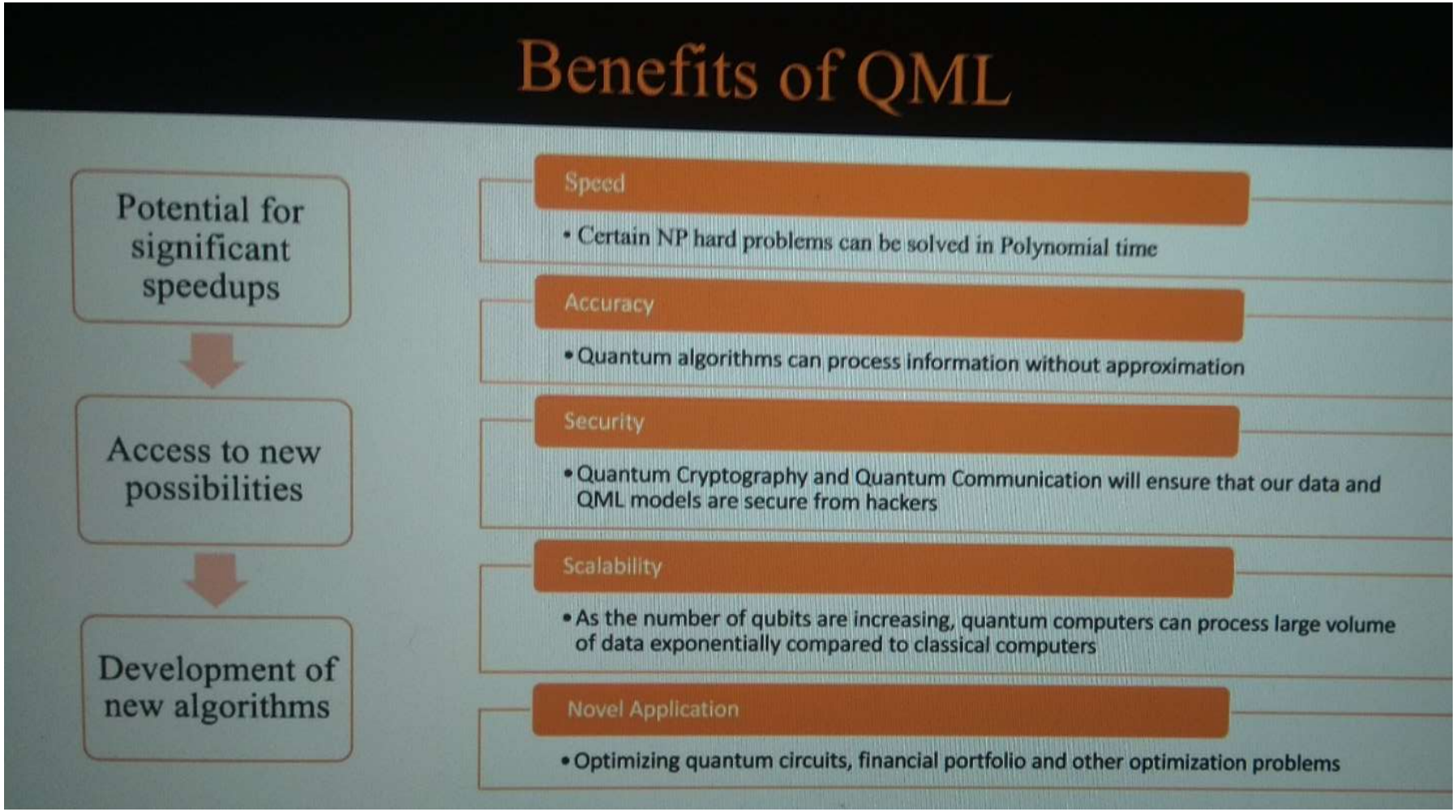


Fig.1 Architecture of Quantum Neural Network

https://arxiv.org/pdf/quant-ph/0201144
https://axon.cs.byu.edu/papers/ricks.nips03.pdf

Quantum Machine Learning

❑Why Quantum Machine learning is necessary ?



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Quantum Machine Learning

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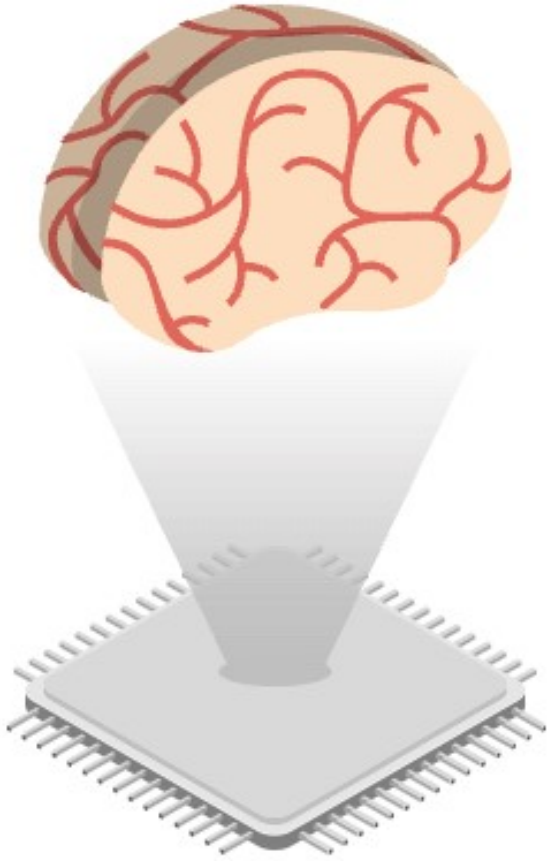

01 Quantum Machine Learning (QML) can Speedup the Training Time

02 Quantum Machine Learning (QML) can use quantum tunnelling to get the true objective instead of gradient descent

03 Quantum Machine Learning (QML) can Represent More Complex Network Topology

04 Quantum Machine Learning (QML) can Automatically Adjust the Hyperparameters

05 Quantum Machine Learning (QML) can perform complex matrix and tensor manipulation at a high speed

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Quantum Machine Learning

❑What are the types of Quantum Machine learning ?

❑Supervised learning:

- **Continuous-variable quantum neural networks**
- Bayesian Deep Learning on a Quantum Computer
- Quantum algorithms for feedforward neural networks
- **Quantum Convolutional Neural Networks**
- Sublinear quantum algorithms for training linear and kernel-based classifiers
- A Universal Training Algorithm for Quantum Deep Learning
- Classification with Quantum Neural Networks on Near Term Processors
- Barren plateaus in quantum neural network training landscapes
- Quantum classification of the MNIST dataset via Slow Feature Analysis
- A Derivative-free Method for Quantum Perceptron Training in Multi-layered Neural Networks

❑Unsupervised learning

- Quantum Enhanced Inference in Markov Logic Networks
- Unsupervised classification of quantum data

Quantum Machine Learning

❑ Reinforcement learning

- Quantum Algorithms for Solving Dynamic Programming Problems
- Quantum gradient estimation and its application to quantum reinforcement learning
- Reinforcement learning with neural networks for quantum feedback

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Applications of Quantum ML

❑Major Applications:

- **Signal Processing- Speaker recognition, Music and Speech separation and etc**
- **Image Processing- Image Classification, Pattern and Facial recognition and etc**
- **Healthcare-Medical diagnosis and cancer research.**
- **Wireless Communication- 5G Networks and Beyond**
- **Self driving vehicle trajectory prediction**
- **Robotics**
- **Remote Sensing**
- **Data Mining**
- **Cyber Security**
- **IoT Applications**
- **Finance,**
- **Email spam filtering,**
- **And etc.**

Applications of Quantum ML

❑Mechanical Engineering

- Steel defect detection or Steel surface defects.
- Bearing defect size assessment.
- Classifying Leather surface Defect.
- Tensile Test Application.
- Mechanical Parts Classifier using images of CAD models

Chemical Engineering:

- Predicting Molecular Properties: Can you measure the magnetic interactions between a pair of atoms?
- Chemical Texture properties

Civil Engineering, Water resources & Ocean engineering :

- Cracks on the surface of the construction.
- Remote Sensing Applications

Applications of Quantum ML

- **Electrical Engineering:**
- **Fault-Recognition-of-Induction-Motor-Based-on-CNN**
- **Bearing-fault-diagnosis-CNN**
- **Deep learning for Fault Diagnosis of Induction Motors in Manufacturing**
- **Solar power generation and sensor data for two power plants**
- **Smart Grids**

- **Material and Metallurgical engineering**
- **Corrosion Engineering**
- **Nonferrous metallurgy**
- **Sheet Metal Forming**

- **And many more……..**

Applications of Quantum ML

- **Artificial intelligence in the Pharma Industry:**
  - Johnson & Johnson,
  - Bristol-Myers Squibb,
  - Novo Nordisk,
  - AstraZeneca, Merck, etc.
- **Applications:**
  - Automated cell positioning,
  - Prime editing efficiency prediction,
  - **Treatment and prevention of respiratory diseases,**
  - Predictive modeling and control of cell culture,
  - Disinfection and Decontamination

- **And many more……..**

https://www.pharmaceutical-technology.com/data-insights/artificial-intelligence-in-pharma/?cf-view&cf-closed

Applications of Quantum ML

❑ Applications of AI in Energy Devices:

❑ Storage Energy Devices

- **Battery**
- **Super Capacitor**

❑ Energy Generation Devices

- **Solar Cell**
- **Photo electro chemical Cell**

Applications of Quantum ML

❑What are the applications of AI in energy devices ?

- Battery Research-Battery life prediction
- New Materials Design And Synthesis
- Solar Energy Prediction
- Short-term Solar Forecasting
- Solar PV Defect Detection
- Training, etc.

❑Machine Learning Algorithms for Solar Cell Efficiency Enhancement:

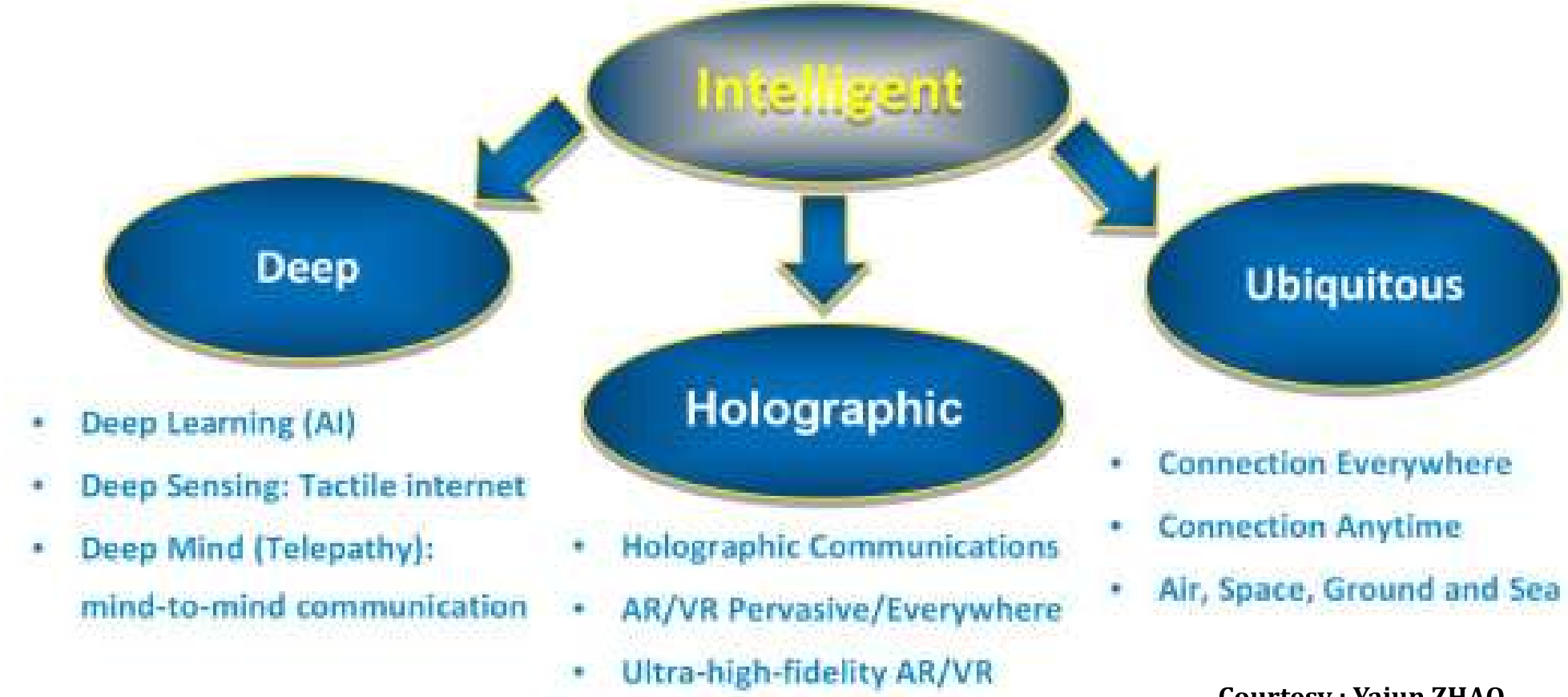
- Solar Cell Material Design And Development
- Solar Cell Performance Monitoring And Maintenance
- Overcoming Challenges In Solar Cell Manufacturing And Deployment

Applications of Quantum ML

- Major Applications of AI and ML in Wireless Communication
  - Modulation classification
  - Beamforming
  - Massive MIMO
  - Network Slicing
  - Chanel estimation
  - Chanel encoding and decoding
  - Security and Robustness
  - Wireless Networks-V2V, V2I, V2X
  - And Many more….
  - https://mlc.committees.comsoc.org/
  - https://mlc.committees.comsoc.org/papers-with-code/

Applications of Quantum ML

- **Application of AI in 6G Networks: Intelligent Connectivity**
  - **Deep Connectivity**
  - **Ubiquitous Connectivity**
  - **Holographic Connectivity**

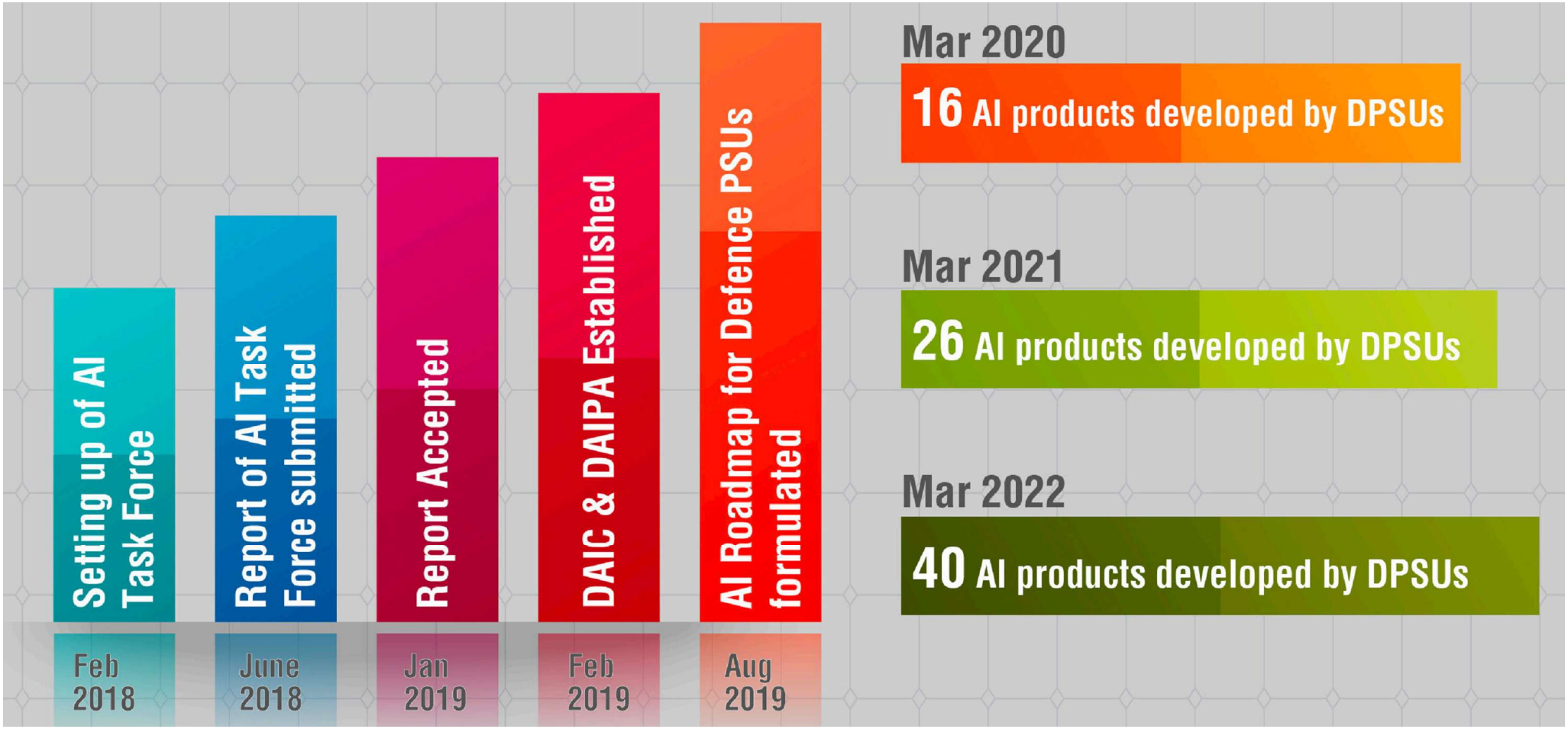


Courtesy : Yajun ZHAO

Applications of Quantum ML

https://fastercapital.com/content/Quantum-Machine-Learning--Revolutionizing-AI-with-QIP.html

Initiatives taken by Government of India to promote AI in India



- Ministry of Electronics and Information Technology(MeitY), Government of India Setup IndiaAI: https://indiaai.gov.in/

Source: https://www.ddpmod.gov.in/sites/default/files/ai.pdf

Initiatives taken by Government of India to promote Quantum Computing Algorithm in India

- The Union Cabinet, approved the National Quantum Mission (NQM) on 19th April 2023 at a total cost of **Rs.6003.65 crore** from **2023-24 to 2030-31.**
- The aim is to seed, nurture and scale up scientific and industrial R&D and create a vibrant & innovative ecosystem in Quantum Technology (QT).
- This will accelerate QT led economic growth, nurture the ecosystem in the country and make India one of the leading nations in the development of Quantum Technologies & Applications (QTA).
- **National Quantum Mission (NQM):**
- This mission Implementation includes setting up of four Thematic Hubs (T-Hubs) in top academic and National R&D institutes in the domains:
  1. Quantum Computing
  2. Quantum Communication
  3. Quantum Sensing & Metrology
  4. Quantum Materials & Devices

Source: https://dst.gov.in/national-quantum-mission-nqm

Building of Quantum ML

- How Quantum Machine learning will be used ?
  - Python coding, Numpy, and Panda Library
  - OpenCV2
  - Scikit Library (https://scikit-learn.org/stable/)
  - Deep learning Library (TensorFlow/PyTorch)
  - Pennylane Library (https://pennylane.ai/)
  - Qiskit Library (https://pypi.org/project/qiskit/)