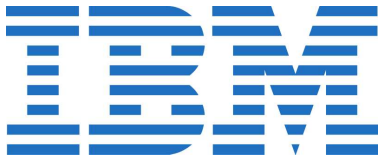
Quantum Data Center (QDC)


with Connor Hann, Liang Jiang

ArXiv: 2207.14336

Junyu Liu 2022 @ MIT and the University of Notre Dame

Quantum Data Center from DALLE2

Worldline of Junyu Liu

1995
Born

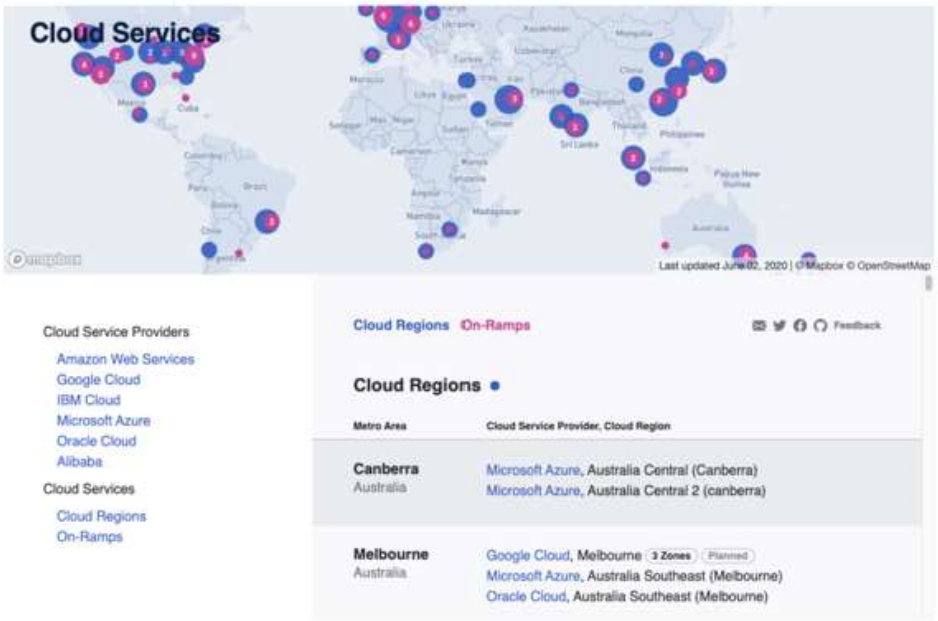
2012-2016
Univ. of Sci & Tech of China
Bachelor of Science

2016-2021
California Institute of Technology
Ph.D in Physics

2021-now
Chicago-IBM
Postdoc Scholar

A Quantum Version of Data Centers

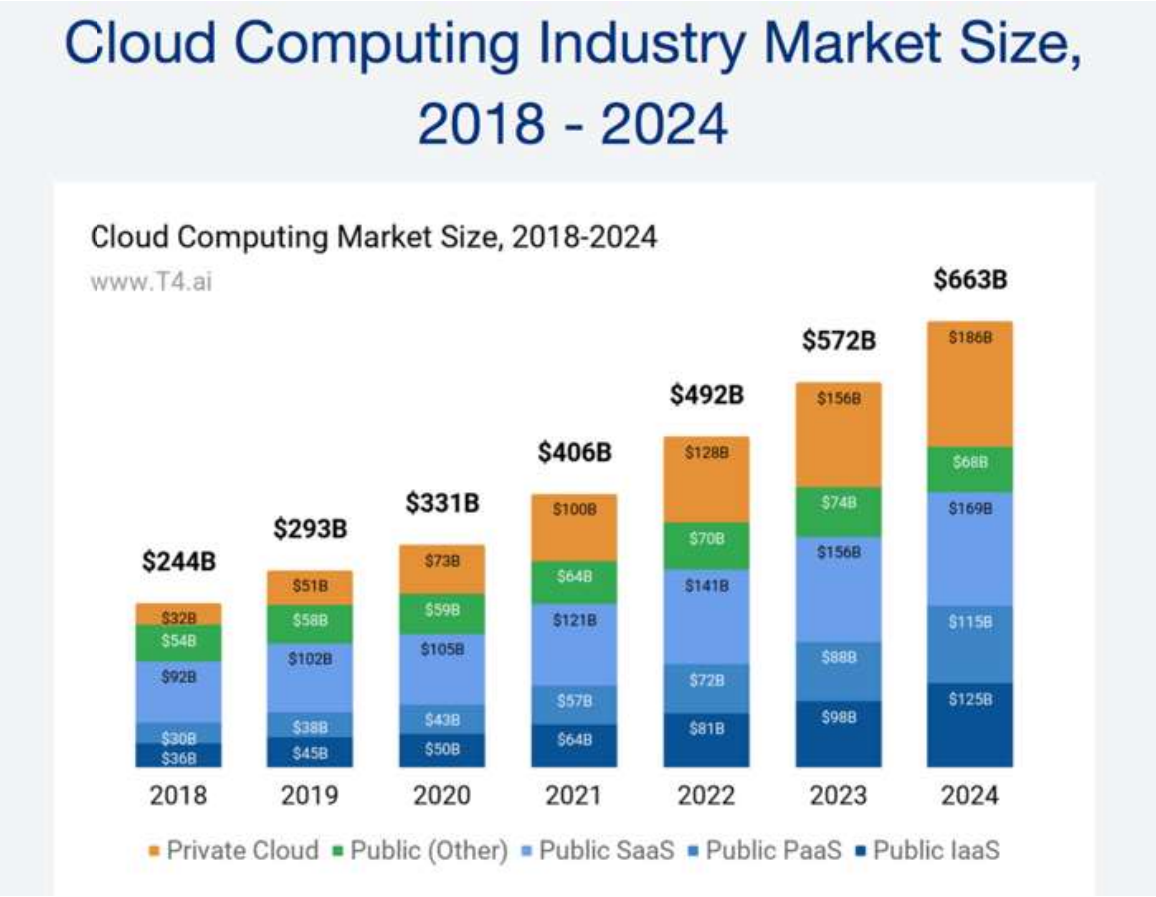
Data centers are widely used
in the modern science, technology
and business



Main players: AWS, Google, IBM,
Microsoft, Oracle, Alibaba

nearly 8,000 data centers globally

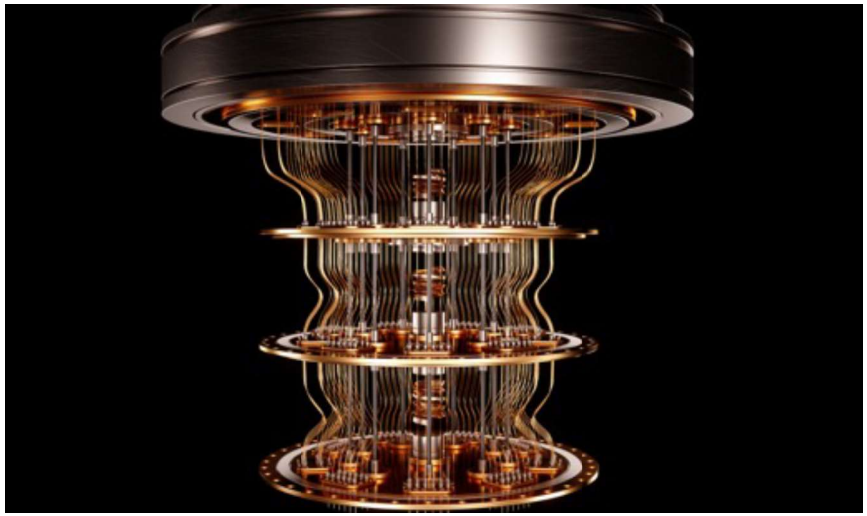
A Quantum Version of Data Centers



Market size:
O(10^{11})-O(10^{12})

A Quantum Version of Data Centers

In the quantum era, we naturally should have a quantum version of data centers

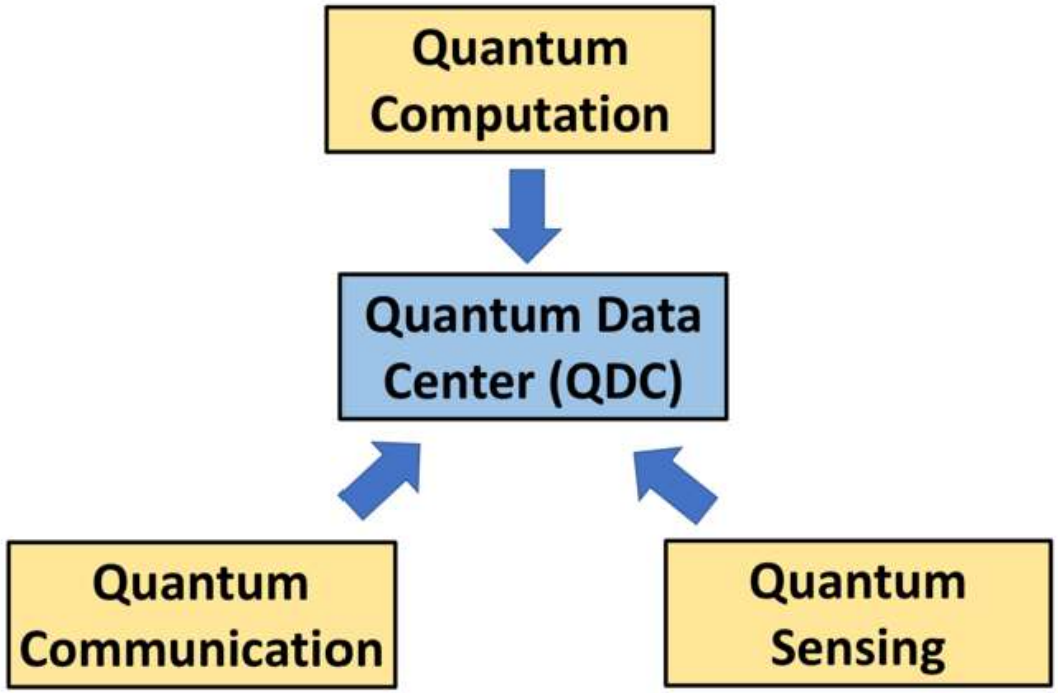


A Quantum Version of Data Centers

Basic constructions: QRAM + Quantum Internet

A Quantum Version of Data Centers

Would benefit quantum computing,
and will be impactful to science, technology, and business.



Outline:

1). Basic Introduction

2). QDC for quantum computing

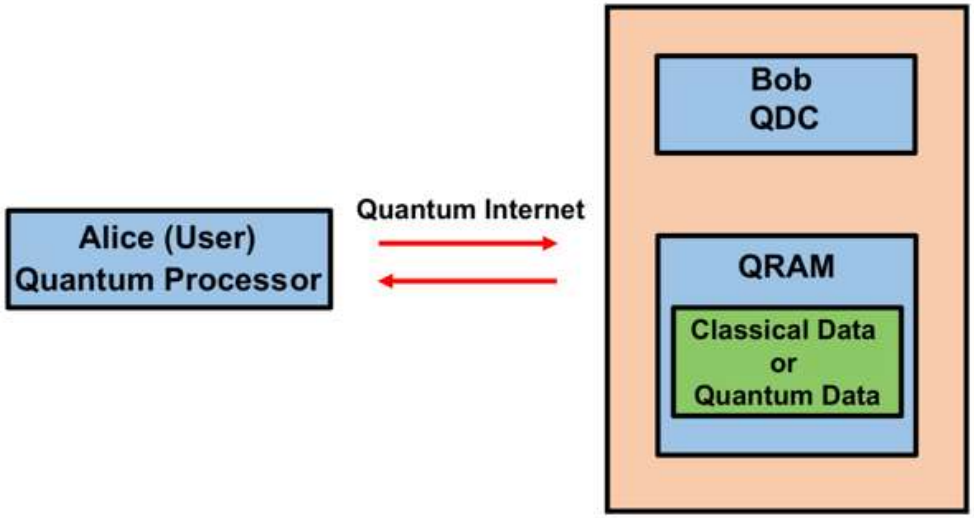
3). QDC for quantum communication

4). QDC for quantum sensing

5). Final comments

Basic Introduction

Basic Introduction



The minimal definition of QDC contains the quantum internet and QRAM.
The data stored in QRAM can be either classical or quantum.

Basic Introduction

Quantum Random Access Memory: QRAM
(Giovannetti, Lloyd, Maccone 07)

$$\sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |0\rangle^{Q_2} \rightarrow \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |x_i\rangle^{Q_2}$$

QRAM is a unitary that could implement the above operation.
Addresses and data are presented by quantum states.
One could allow superpositions of addresses.

Basic Introduction

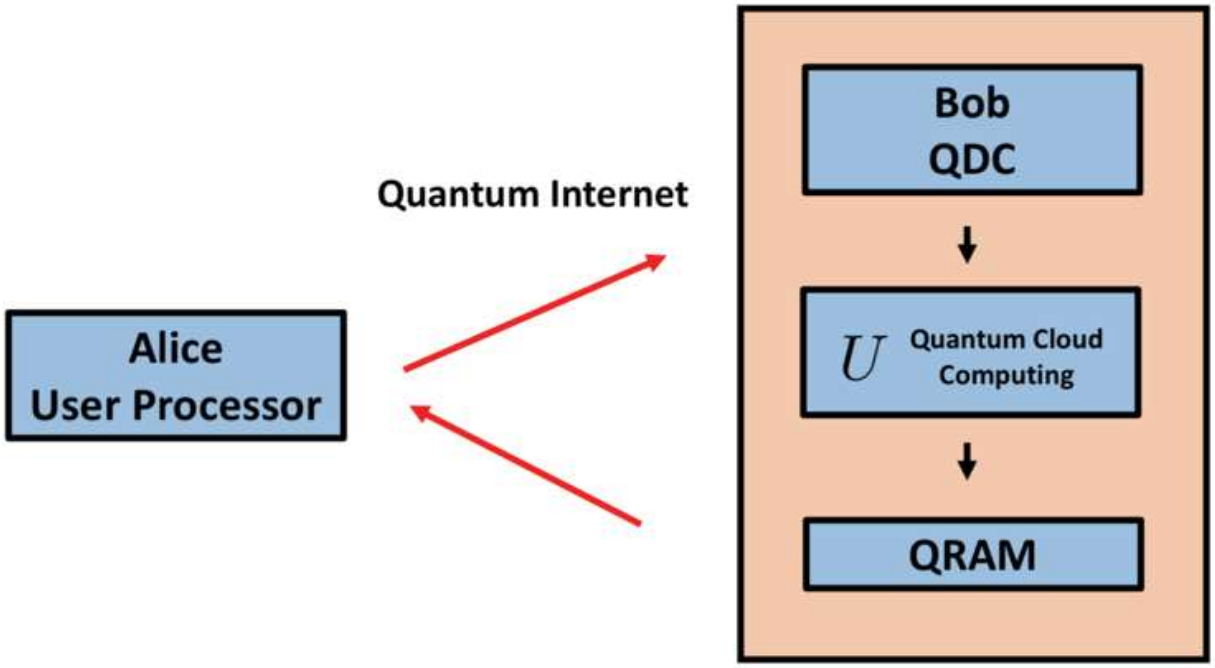
QRAM for quantum data

$$\sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |0\rangle^{Q_2} \left[\bigotimes_{j=1}^{N} |\psi_j\rangle^{D_j} \right] \rightarrow \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |\psi_i\rangle^{Q_2} \left[\bigotimes_{j=1}^{N} \left| \bar{\psi}_j^{(i)} \right\rangle^{D_j} \right]$$

$$\text{where } \left| \bar{\psi}_j^{(i)} \right\rangle = |0\rangle \text{ for } i = j \text{ and } \left| \bar{\psi}_j^{(i)} \right\rangle = |\psi_j\rangle \text{ otherwise.}$$

QDC could allow both classical and quantum data.
QRAM could also be modified as QROM, or other extensions.

Basic Introduction



QDC allowing quantum cloud computation

QDC could also allow cloud computing.
A natural extension of existing data centers.

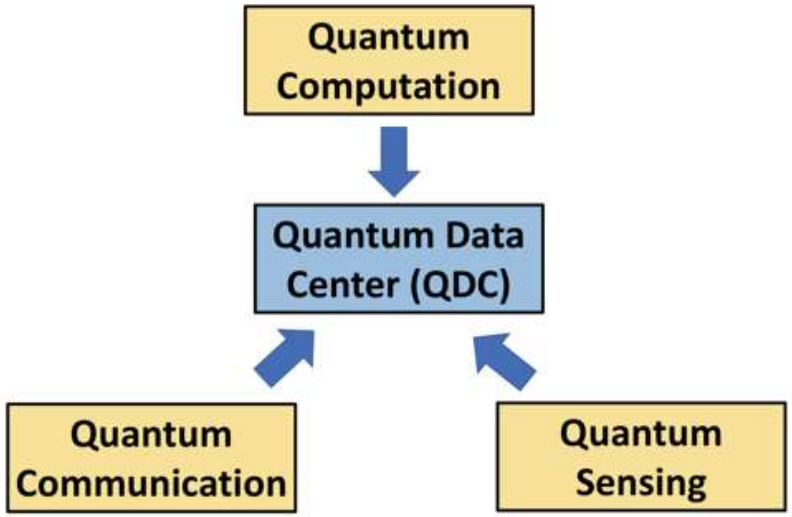
Basic Introduction

Example of QDC applications:

1). Computing:
QDC as oracles;
QDC as T-gate libraries.

2). Communication:
Quantum Private Query;
Blind Quantum Computing;
Multi-party private quantum communication.

3). Sensing:
QDC for distributed sensing.

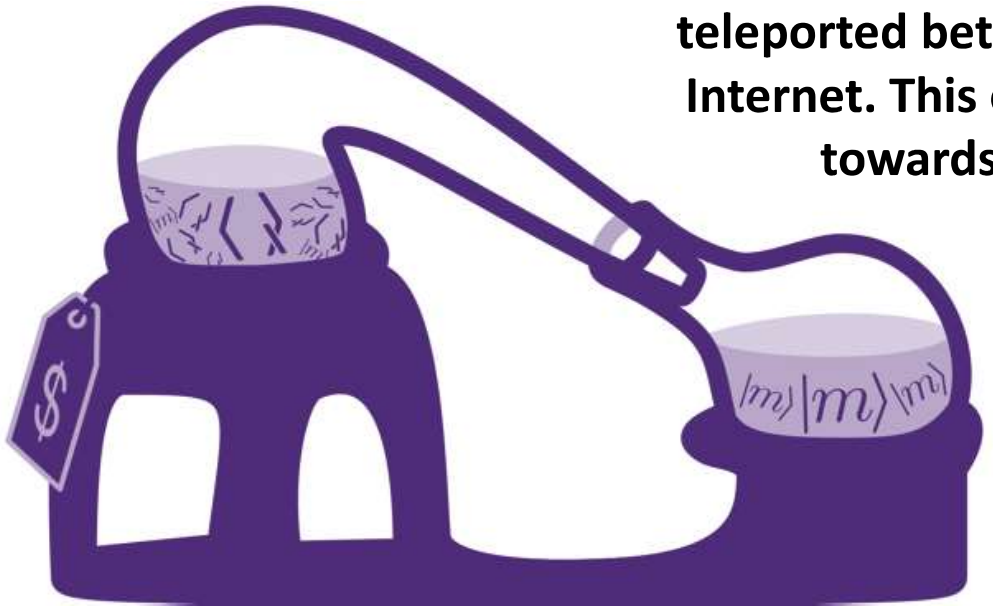


QDC for quantum computing

QDC for quantum computing

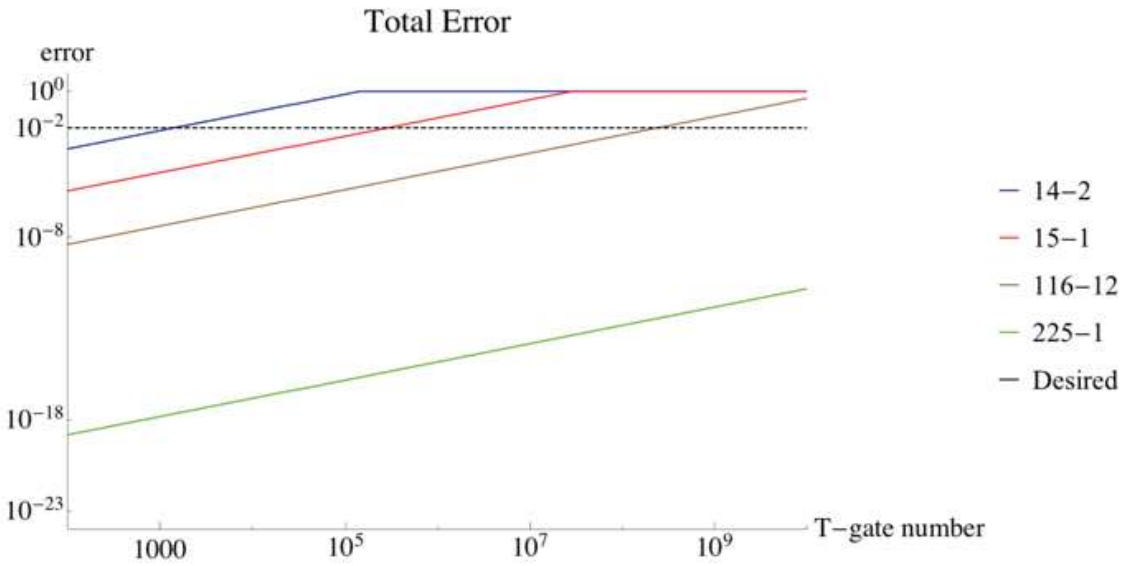
T-gate is expensive in quantum computing and magic state distillation algorithm is hard.

We could assume a localized database that could serve as a source for T-gates. Those gates could be teleported between QDC and users by the quantum Internet. This could serve as an application of QDC towards efficient quantum computing.



QDC for quantum computing

Setup: 100 qubit algorithm.
10^8 T-gates.
10^{-3} physical error rate of the user devices.
<1% total computational error.

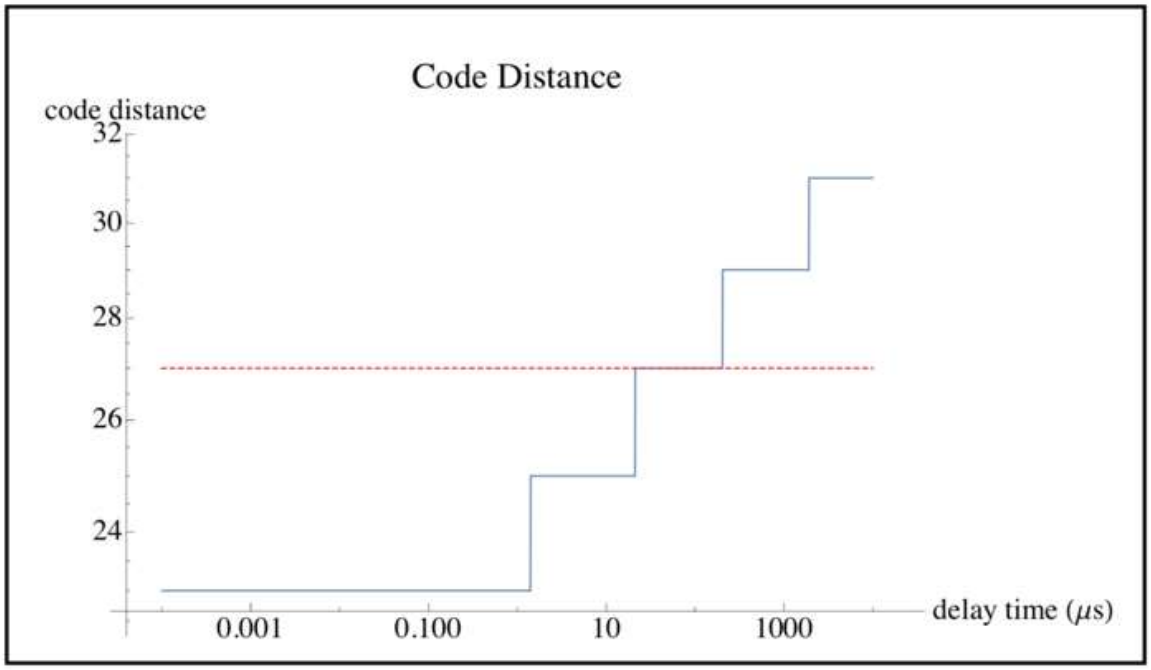


Choosing proper surface codes.

Based on Litinski, 19.

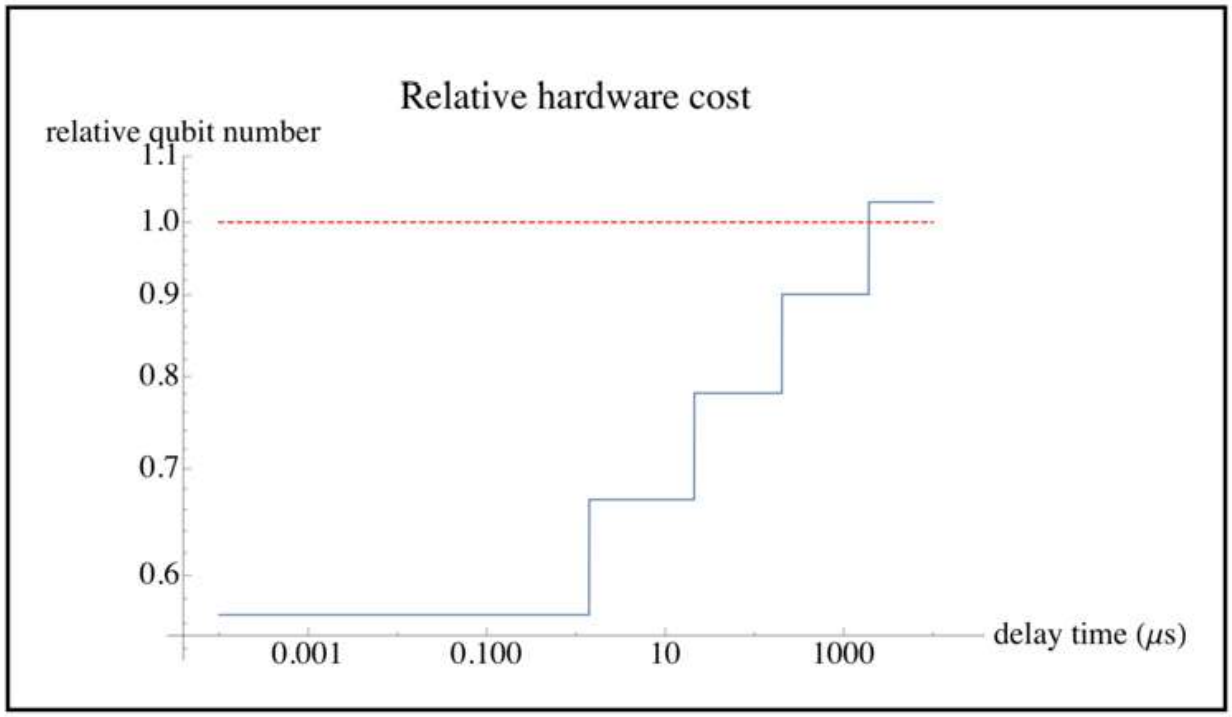
QDC for quantum computing

The advantage from QDCs is from the quantum communication delays during iterativelly call T-gates from QDCs.



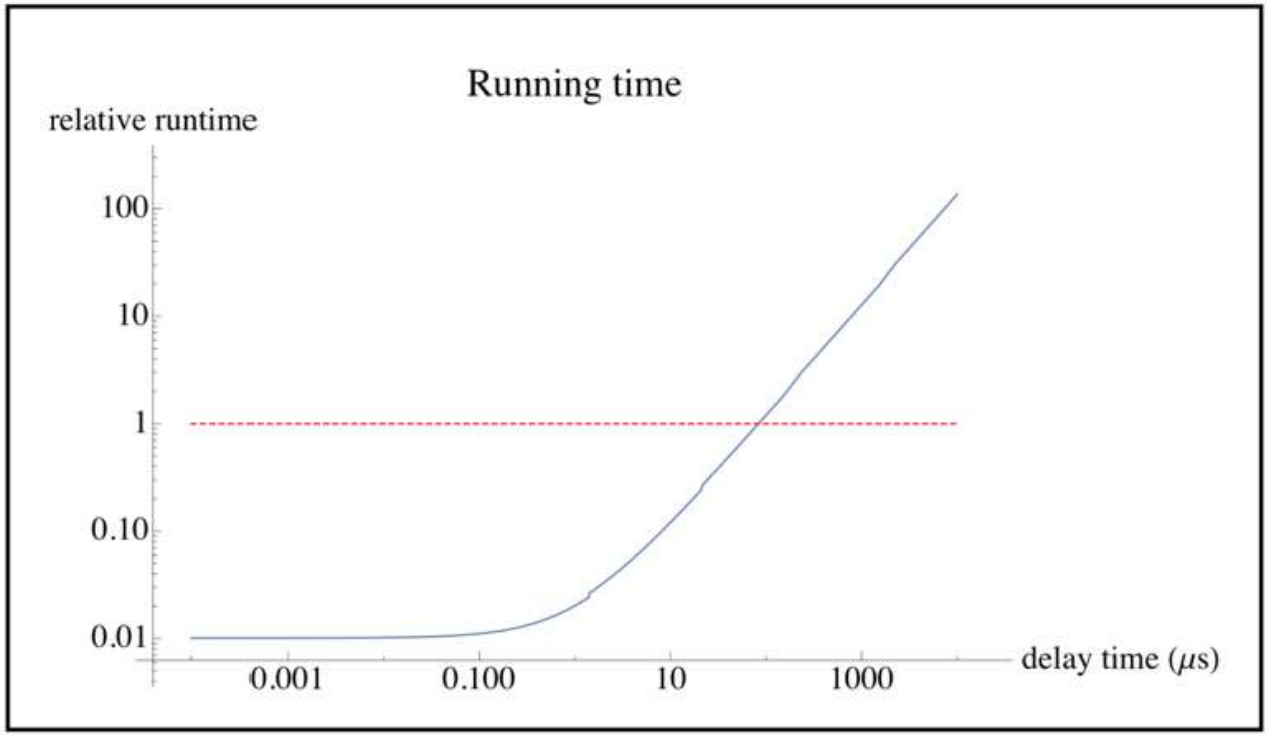
QDC for quantum computing

The advantage from QDCs is from the quantum communication delays during iterativelly call T-gates from QDCs.



QDC for quantum computing

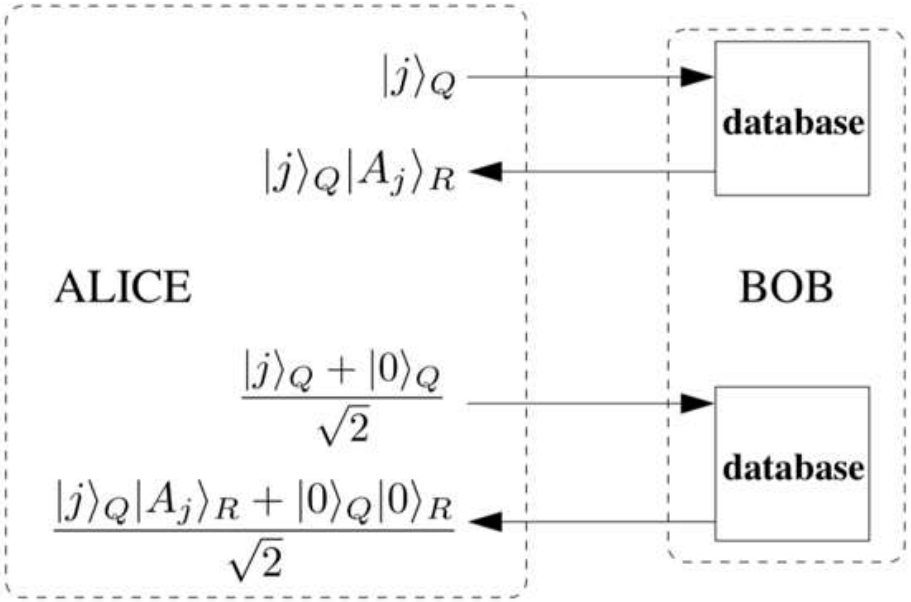
The advantage from QDCs is from the quantum communication delays during iterativelly call T-gates from QDCs.



QDC for quantum communication

QDC for quantum communication

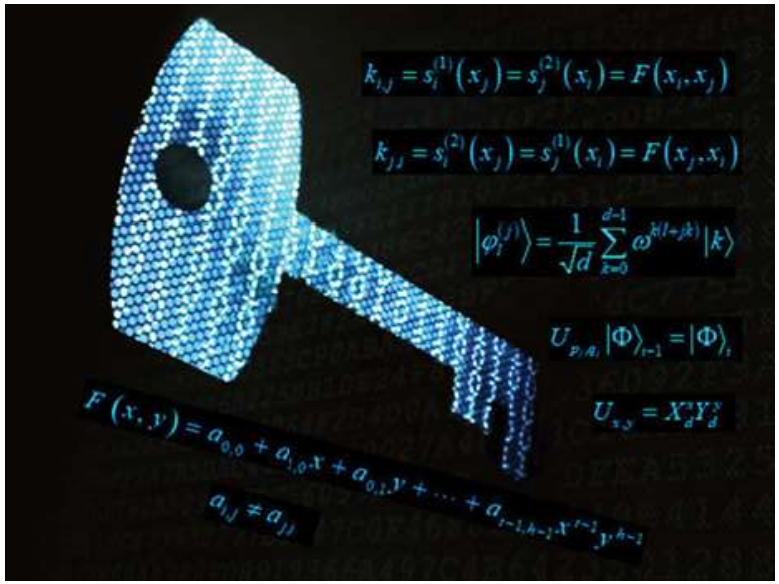
Quantum Private Query: QPQ
(Giovannetti, Lloyd, Maccone 07)
a natural application of QDC, combining QRAM and quantum teleportation.



Natural extension:
Blind Quantum Computing
Broadbent, Fitzsimons, Kashefi 08

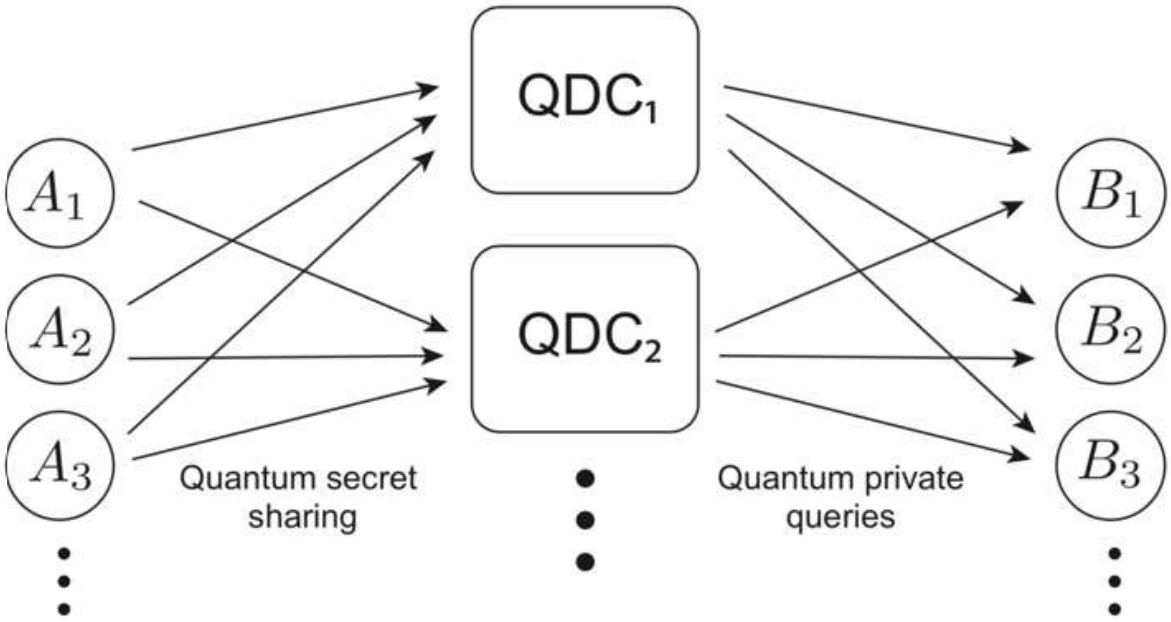
QDC for quantum communication

Quantum Secret Sharing:
Cleve, Gottesman, Lo, 99
Hillery, Buzek, and Berthiaume, 99
can be implemented using QDC



QDC for quantum communication

Multi-party private quantum communication



QDC for quantum sensing

QDC for quantum sensing

QDC could be used for quantum data compression: single subspace

$$|\psi_{\text{unary}}\rangle = \sum_{i=0}^{N-1} \alpha_i \bigotimes_{j=1}^{N} |\delta_{ij}\rangle^{D_j} \rightarrow |\psi_{\text{binary}}\rangle = \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1}$$

Step 1: using a slightly modified QRAM query

$$U\left(|0\rangle^{Q_1} \sum_{i=0}^{N-1} \alpha_i \left[\otimes_{j=1}^{N} |\delta_{ij}\rangle^{D_j}\right]\right) = \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} \left[\otimes_{j=1}^{N} |\delta_{ij}\rangle^{D_j}\right]$$

QDC for quantum sensing

QDC could be used for quantum data compression: single subspace

$$|\psi_{\text{unary}}\rangle = \sum_{i=0}^{N-1} \alpha_i \bigotimes_{j=1}^{N} |\delta_{ij}\rangle^{D_j} \rightarrow |\psi_{\text{binary}}\rangle = \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1}$$

Step 2: using QRAM for quantum data

$$\sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |0\rangle^{Q_2} \left[\otimes_{j=1}^{N} |\delta_{ij}\rangle^{D_j}\right] \rightarrow \sum_{i=0}^{N-1} \alpha_i |i\rangle^{Q_1} |1\rangle^{Q_2} \left[\otimes_{j=1}^{N} |0\rangle^{D_j}\right]$$

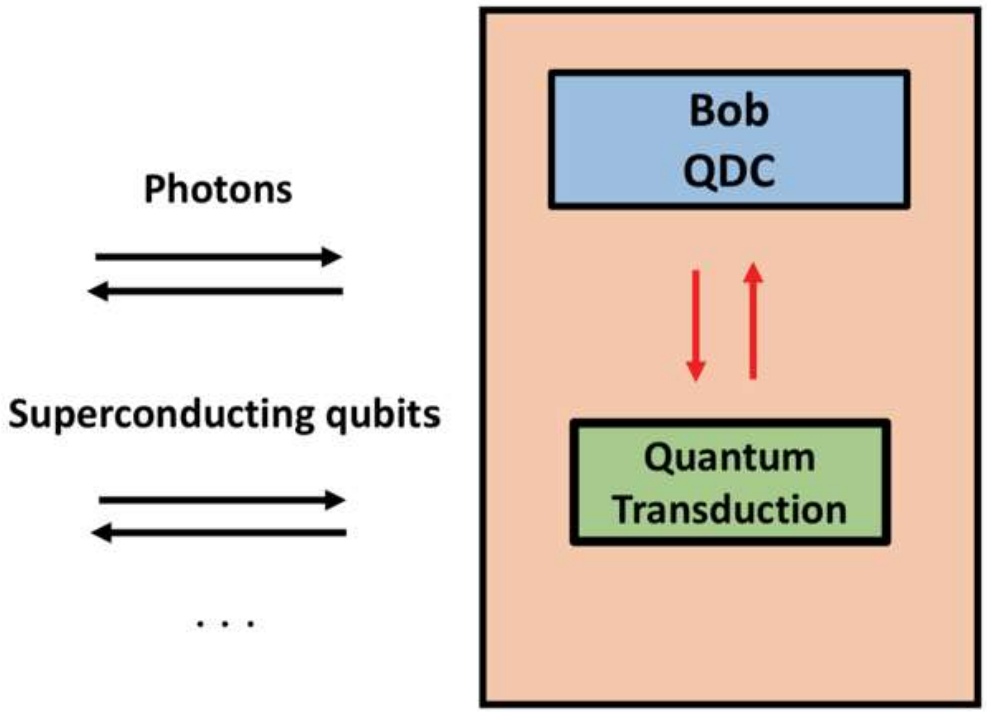
QDC for quantum sensing

Directly using the above operation for sensing:

In sensing tasks we often need to transmit states between different locations. If those states are located in the single photon subspaces, then we could do compression using QRAM. Thus, QDCs could naturally play a role in the distributive sensing by reducing the entanglement cost from N to log N.

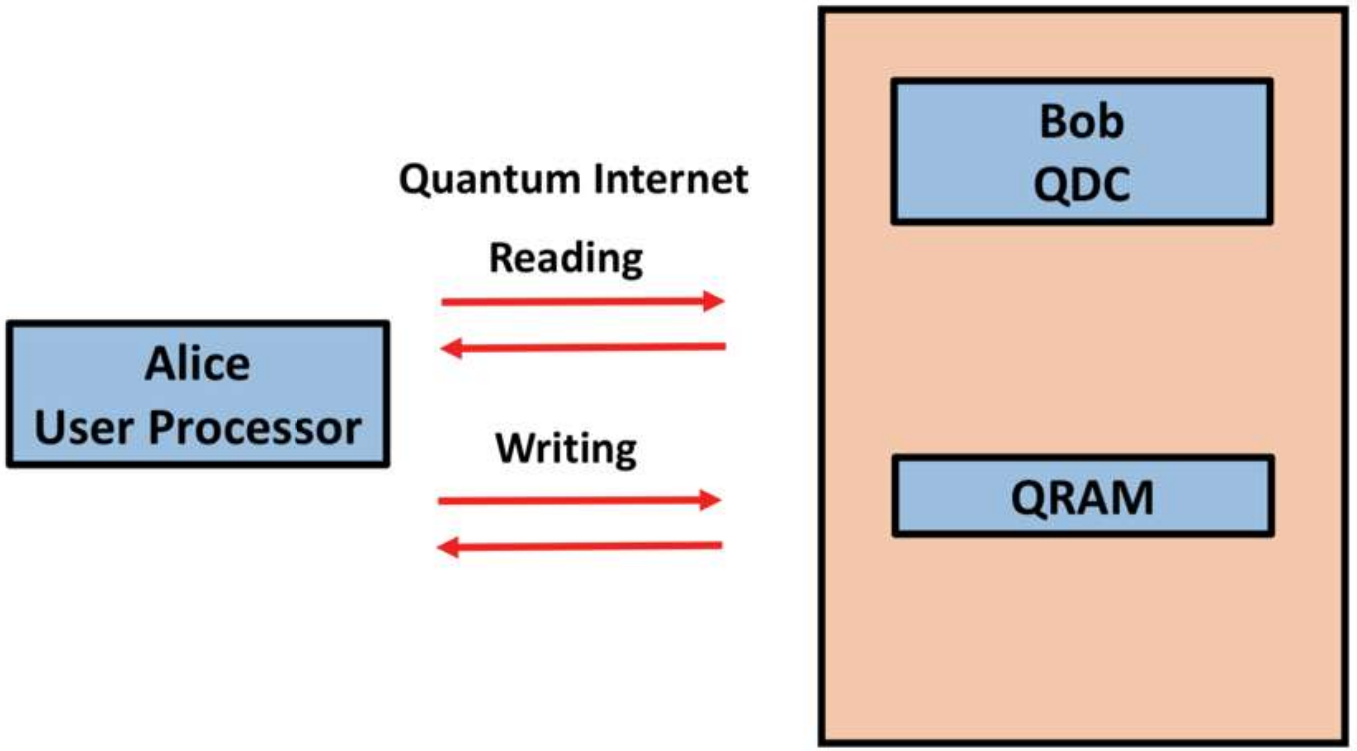
Final comments

Final comments



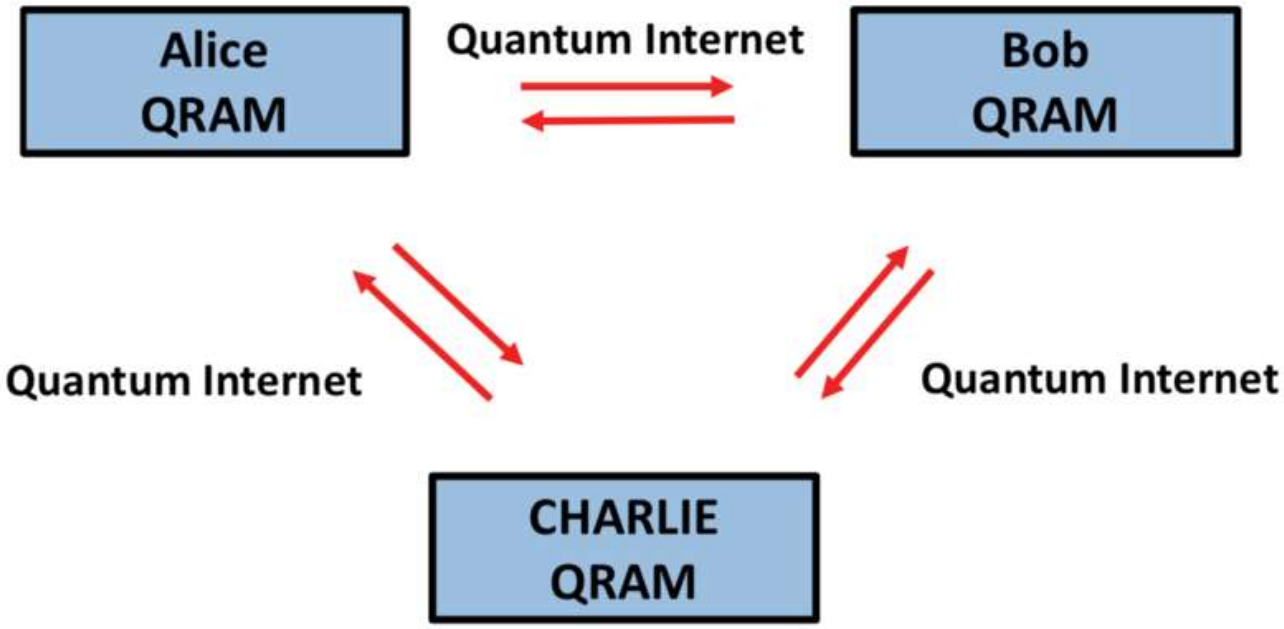
QDC could be assisted by quantum transduction

Final comments



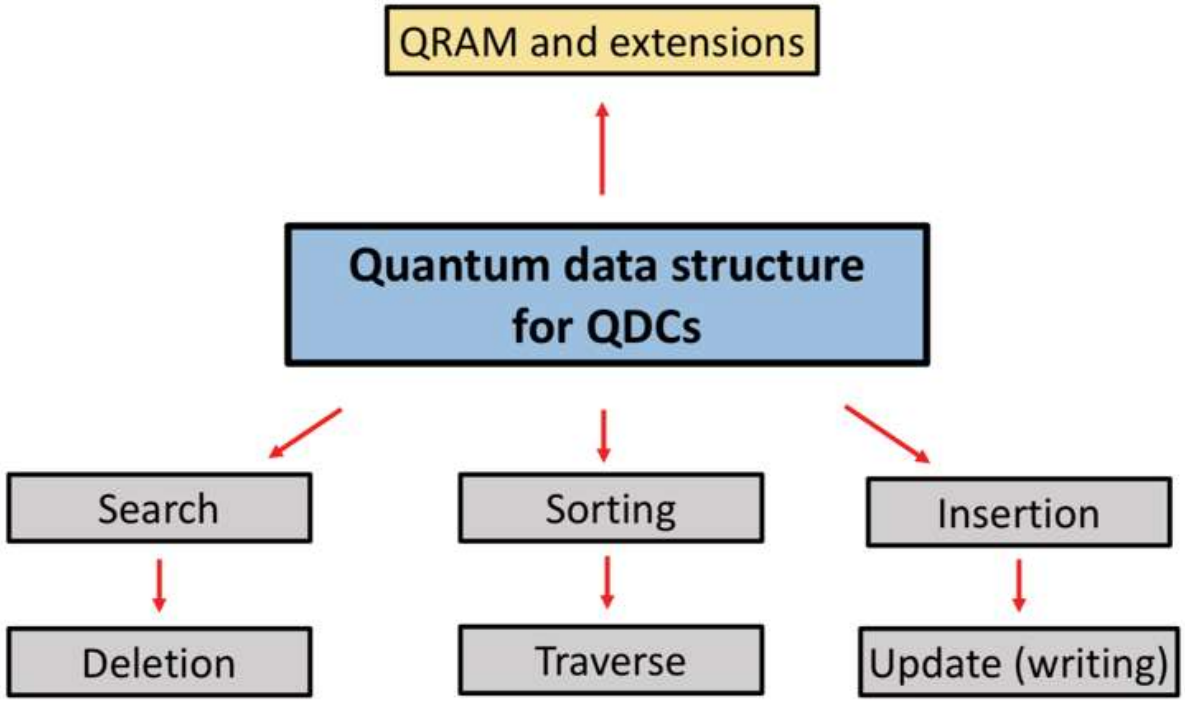
QDC could both do reading and writing

Final comments



QDC could be modular

Final comments



QDC requires novel quantum data structures

Final comments

Business

Security enhancement

merging with quantum

cloud services

ML/big data

QRAM-based algorithms

Quantum internet

Science

Physical science

Chemistry and material science

Biology, finance, climate science

QDC could benefit business, science, and big data industry

Thanks for your attendance!

Advertisement

Decentralization and enhanced data security
in Web3 against comprehensive attacks
including quantum, with the help of PQC/FHE/SE