Quantum Databases for Dynamical Data Processing

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QUANTUM TECHNOLOGY INITIATIVE

Exemplary *non-classical* phenomena in quantum mechanics

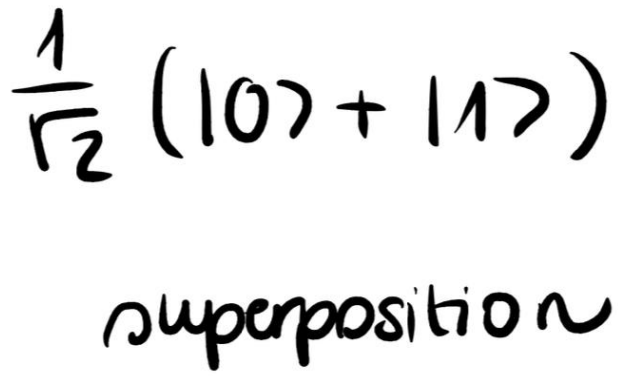
$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

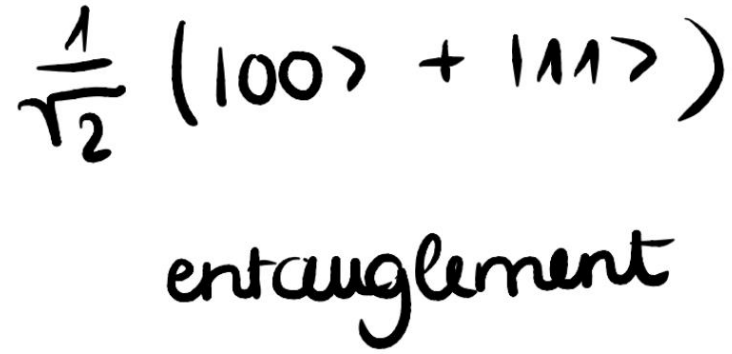
superposition

$$\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

entanglement

Exemplary *non-classical* phenomena in quantum mechanics

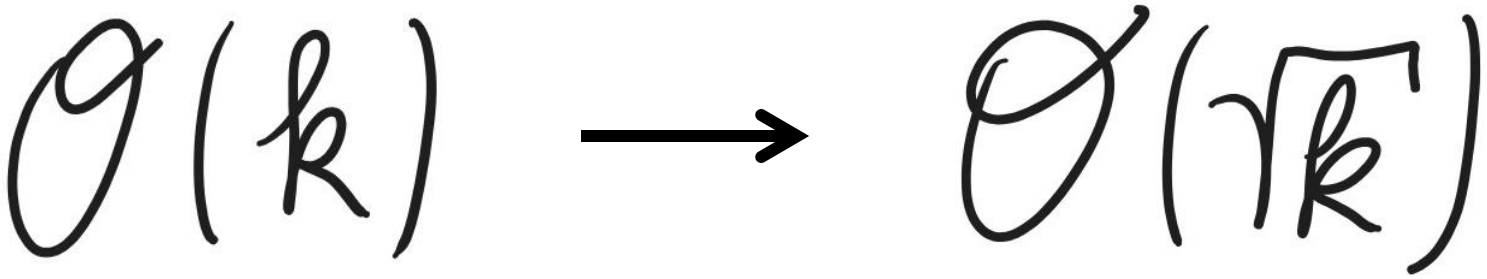




→ e.g., quantum computing allows for a speed-up for **unstructured search**

Grover, Lov K. "A fast quantum mechanical algorithm for database search." *Proceedings of the twenty-eighth annual ACM symposium on Theory of computing*. 1996.

Grover's search algorithm for an unstructured database



⟶ **quadratic speed-up** for unstructured search

$$[\text{element}_0, \ldots, \text{element}_j, \ldots, \text{element}_{k-1}] \longrightarrow \frac{1}{\sqrt{k}} \sum_{j=0}^{k-1} |\text{element}_j\rangle$$

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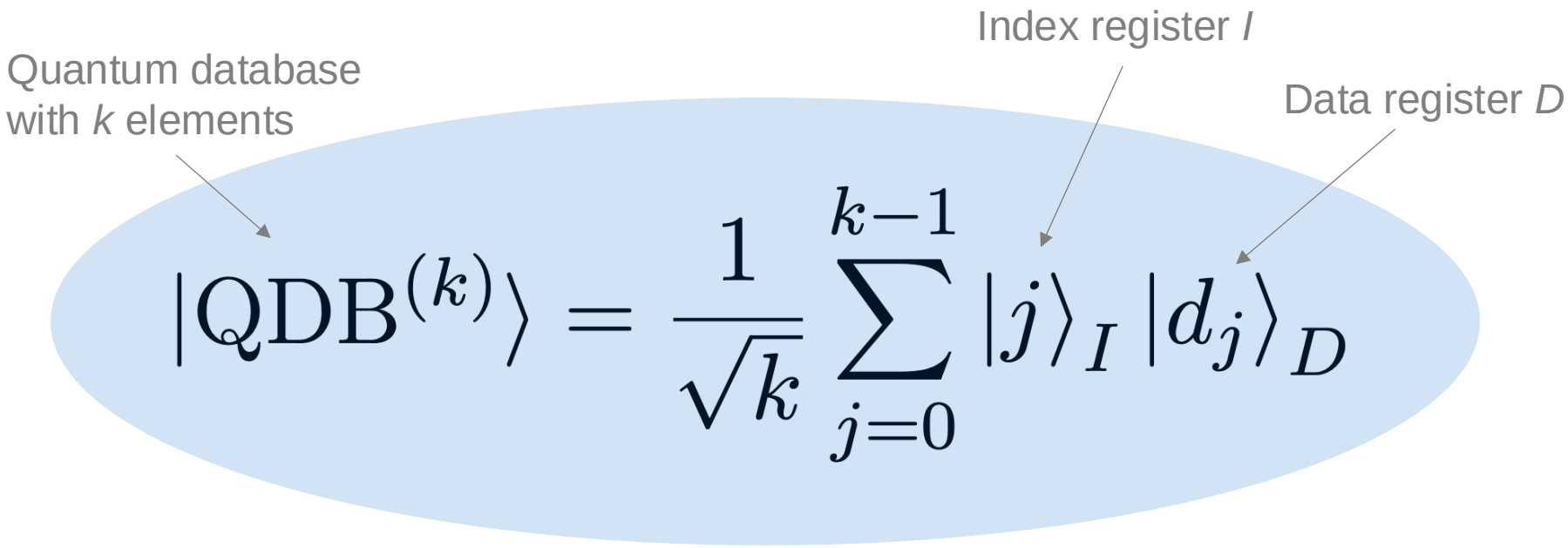
Formal Definition of a Quantum Database



Rieger, Carla, et al. "Operational Framework for a Quantum Database." *arXiv preprint arXiv:2405.14947* (2024).

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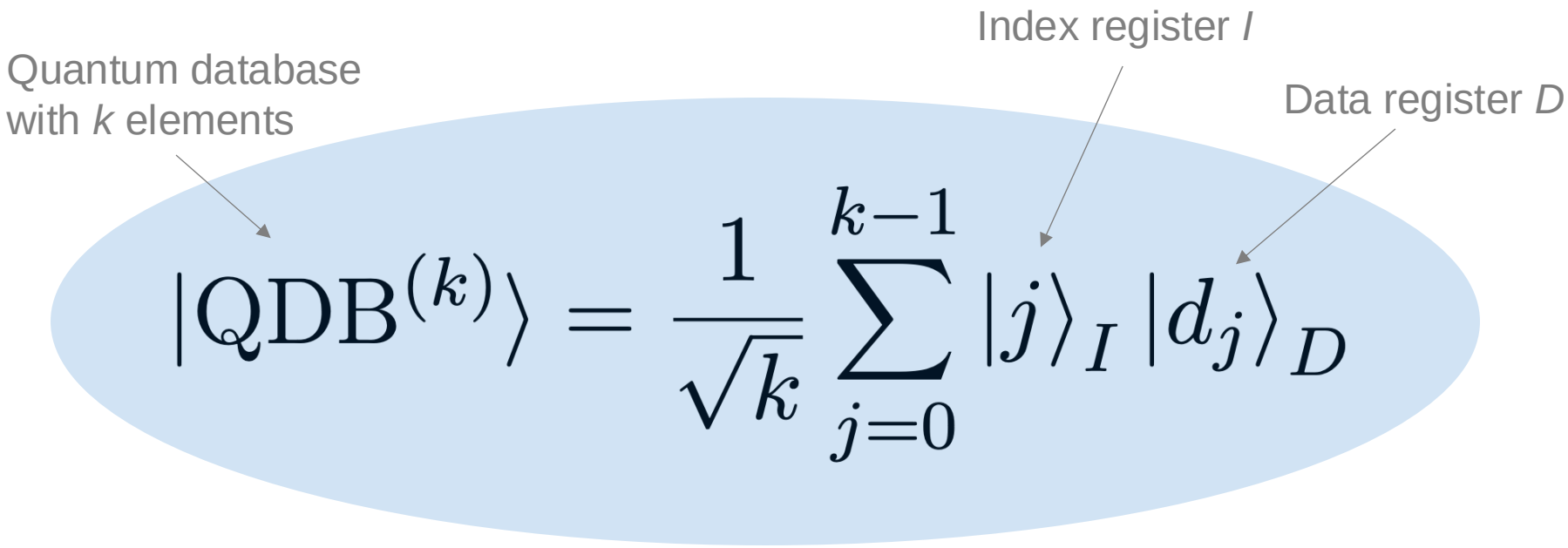

→ **Task:** define operations on this superposition of (orthogonal) data states $|d_j\rangle$

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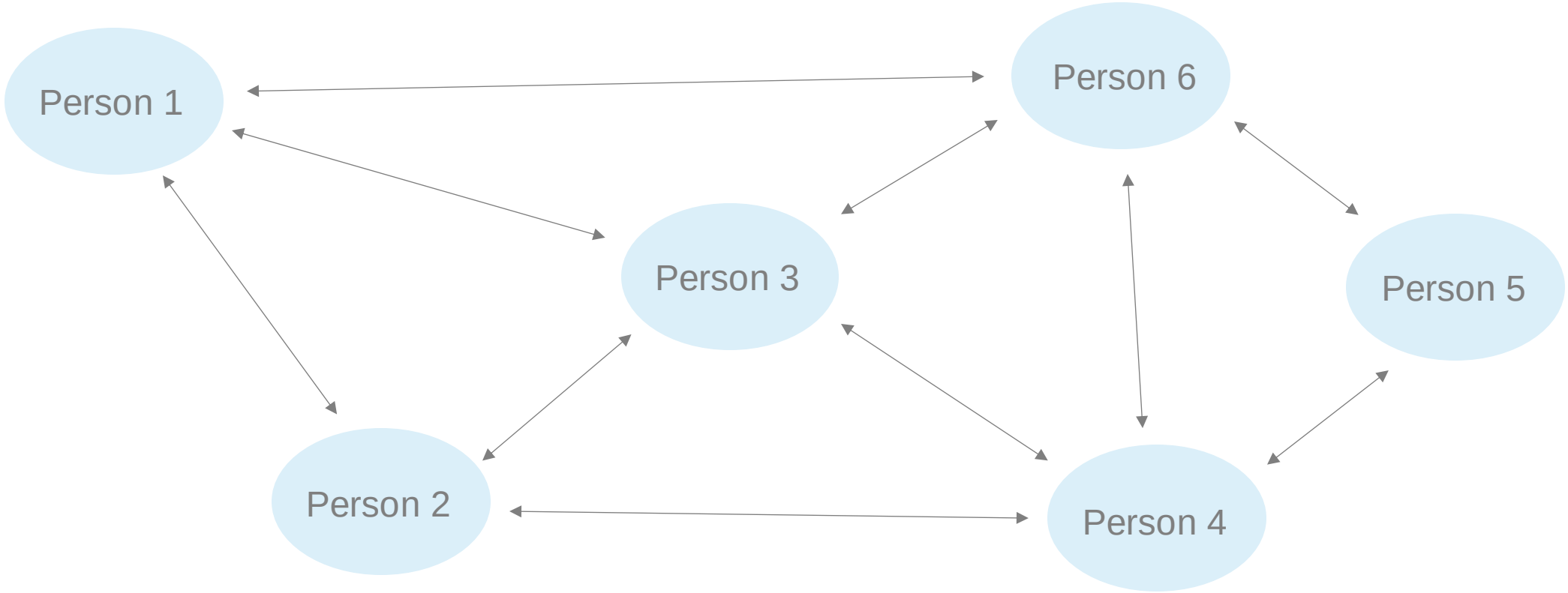
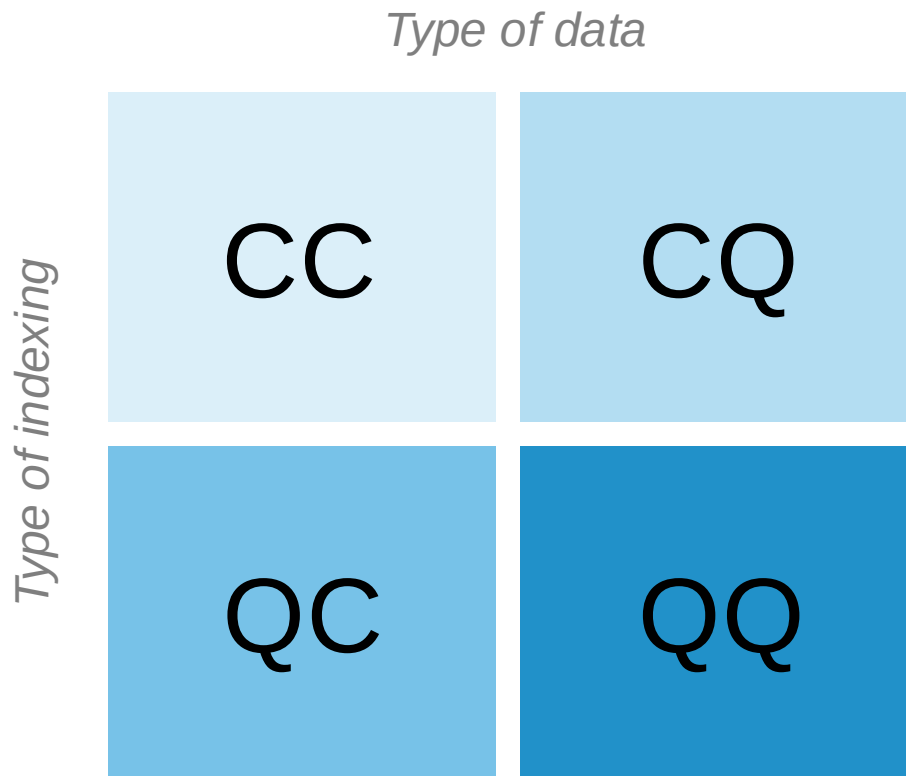
Data and its inherent *structure*



Schematic of a graph database
(e.g., a social network)

The different types of *data* and *indexing*

First letter: index type,
Second letter: data type



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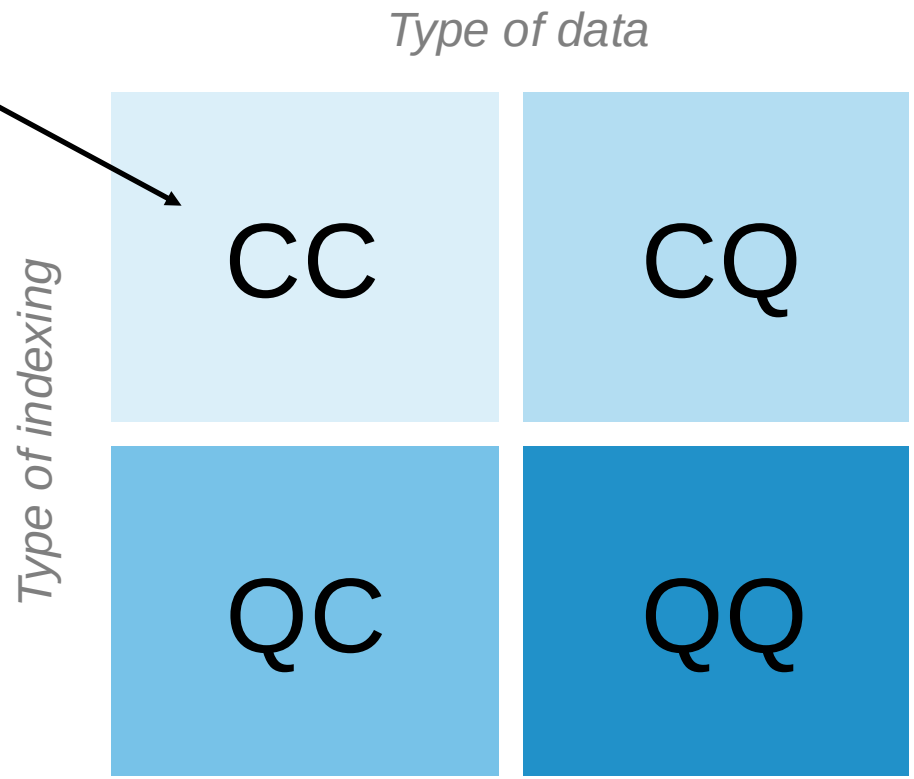
Classical scenario
e.g., **classically indexed** array



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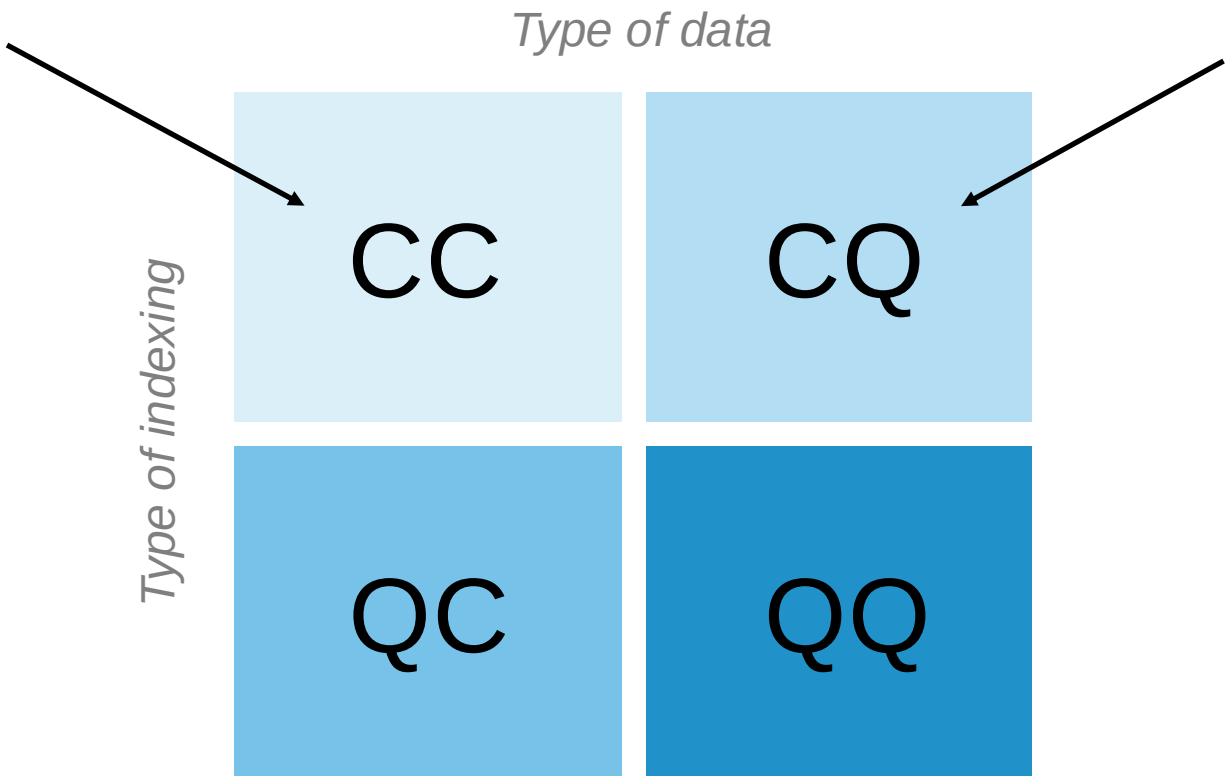

Classically indexed quantum states, linear number of quantum resources

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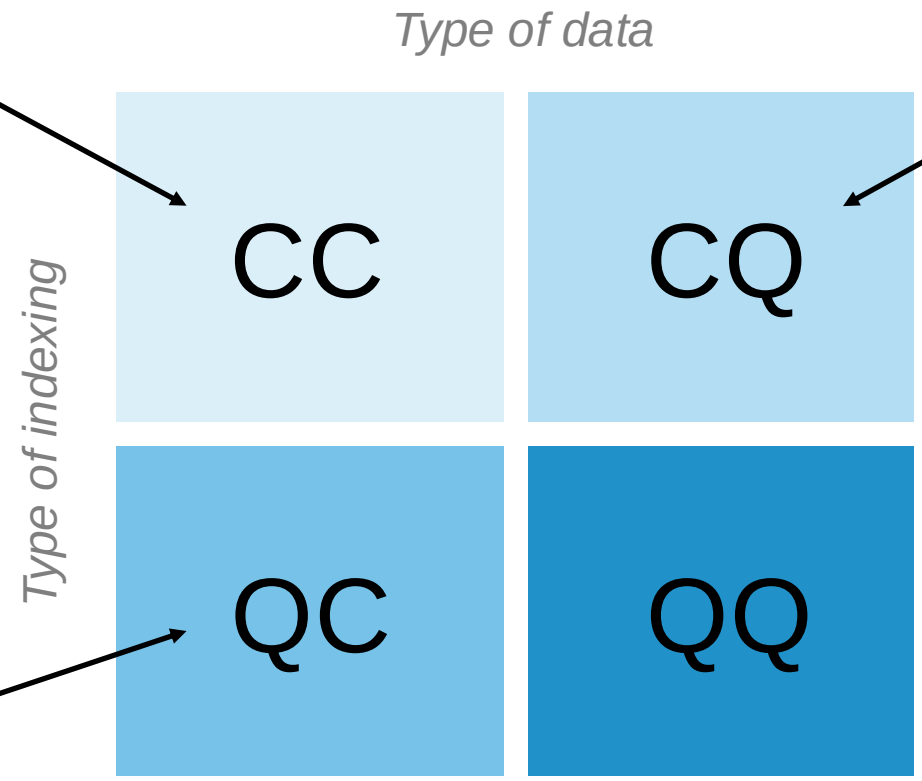

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Orthogonal states
correlated to indices in a **superposition**
with known basis

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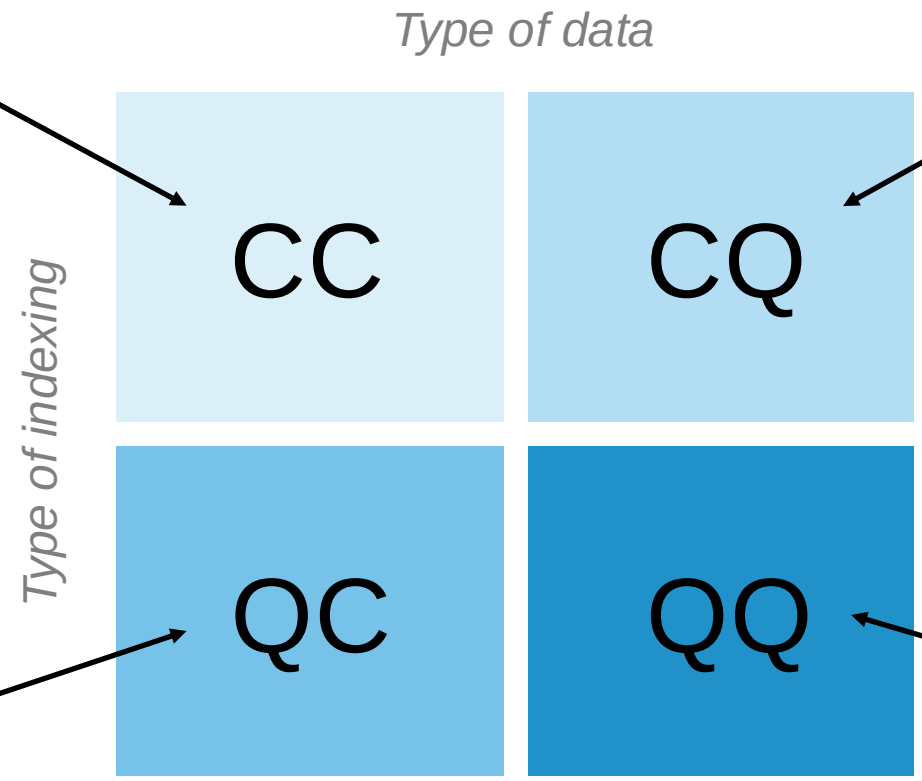

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Quantum data (general non-orthogonal states) in a **superposition**

Rieger, Carla, et al. "Operational Framework for a Quantum Database." *arXiv preprint arXiv:2405.14947* (2024).

Working on *data* in a superposition - *Extension*

$$|\mathrm{QDB}^{(k)}\rangle = \frac{1}{\sqrt{k}} \sum_{j=0}^{k-1} |j\rangle_I \, |d_j\rangle_D$$

QDB state is updated in **quantum software**

Finish the experiment after *some* time

Extract global properties from quantum superposition state

Read-in data state to quantum processing unit

$|d_j\rangle_D$

Experiment extracting data at each **timestep *j*** (can be of unknown length)

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Other quantum database operations - *Overview*

Write operation: $|QDB^{(k)}_{\neq f}\rangle + \frac{1}{\sqrt{k}}|f\rangle_I|0\rangle_D \xmapsto{W(f)} |QDB^{(k)}_{\neq f}\rangle + \frac{1}{\sqrt{k}}|f\rangle_I|d_f\rangle_D$ ~ INSERT

Read-out operation (or consider a projective mmt.): $|QDB^{(k)}\rangle|0\rangle_A \xmapsto{G(f)} |QDB^{(k)}_{\neq f}\rangle|0\rangle_A + \frac{1}{\sqrt{k}}|f\rangle_I|d_f\rangle_D|d_f\rangle_A$ ~ SELECT

Remove operation: $|QDB^{(k)}\rangle = \frac{1}{\sqrt{k}}\sum_{j=0}^{k-1}|j\rangle_I|d_j\rangle_D \xmapsto{R(f)} \frac{1}{\sqrt{k-1}}\sum_{\substack{j=0\\ j\neq f}}^{k-1}|j\rangle_I|d_j\rangle_D$ ~ DELETE

Permute operation: $|QDB^{(k)}\rangle \xmapsto{P_\pi} \frac{1}{\sqrt{k}}\sum_{j=0}^{k-1}|\pi(j)\rangle_I|d_j\rangle_D = \frac{1}{\sqrt{k}}\sum_{j=0}^{k-1}|j\rangle_I|d_{\pi^{-1}(j)}\rangle_D$

→ Investigation of a set of poly-time quantum algorithms that mimic classical database algorithms

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Thank you!

Are there any questions?

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Federal Ministry of Education and Research

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