Day Final

Team 12: CYCU_Quantum

OpenACC
More Science, Less Programming

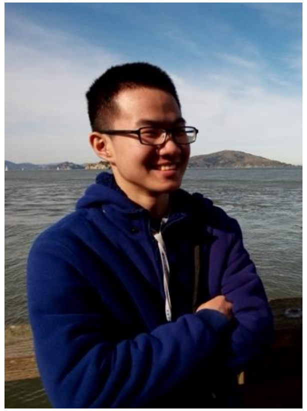
Team 12

CYCU_Quantum

Team Members

Chang Yen Jui
Quantum Information Center
Chuang Yuan Christian University

Wang Wei Ting
Department of Physics
National Taiwan University



Su Zheng Wei
Quantum Information Center
Chuang Yuan Christian University

Team Members

Pika Wang

Ikko Hamamura

Anderson Meng

Quantum Stochastic Walks (QSW) and **Quantum Navigation in graph network**

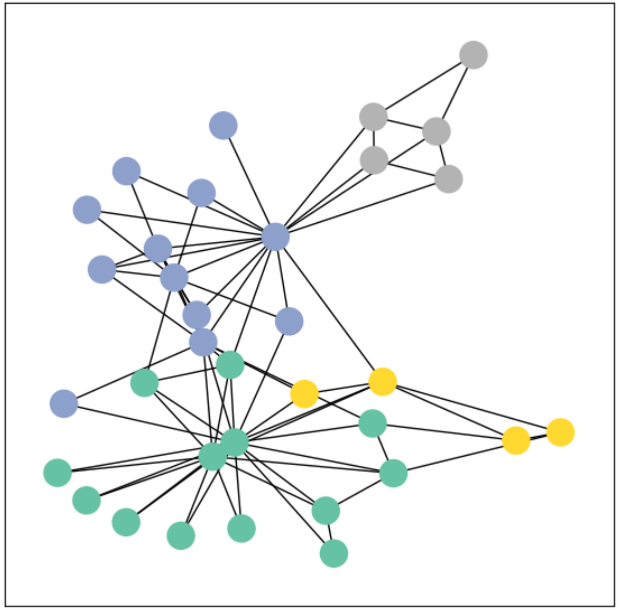
- What is a graph network?

Graph networks are specifically designed to capture the dependencies and relationships between nodes in a graph, making them ideal for tasks that involve graph-structured data. A graph consists of three main elements:

1. ***Nodes (vertices):*** Represent individual entities or data points. Each node is associated with a set of features, which can be numerical, categorical, or textual.

2. ***Edges:*** Connect pairs of nodes, representing relationships or interactions between them. Edges can also have features, such as weights or labels.

3. ***Graph Structure****:* The topology of the graph, including the nodes and edges, is used to propagate information between nodes.

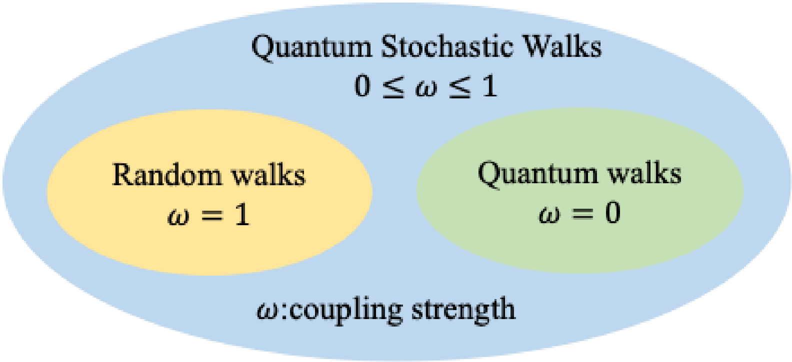


Quantum Stochastic Walks (QSW) and **Quantum Navigation in graph network**

- Scientific driver for the chosen algorithm.

The **Quantum Stochastic Walks (QSW)** and **Quantum Navigation** algorithms are inspired by the need to enhance computational efficiency and insight in graph-based problems. Traditional algorithms, such as classical random walks or PageRank

1. **Handling Complex Dependencies:** Graph networks with intricate topologies require methods that can leverage global and local interactions effectively.
2. **Resolving Ambiguities:** Classical algorithms are limited by degeneracies and lack mechanisms to capture subtle differences in node importance.
3. **Improving Efficiency:** Classical methods are constrained by convergence time and scalability in large networks, while quantum-inspired techniques provide faster convergence and unique stationary solutions.



Quantum Stochastic Walks (QSW) and **Quantum Navigation in graph network**

- What's the algorithmic motif?

The core algorithmic motif of **Quantum Stochastic Walks (QSW)** is **hybrid dynamics**, where:

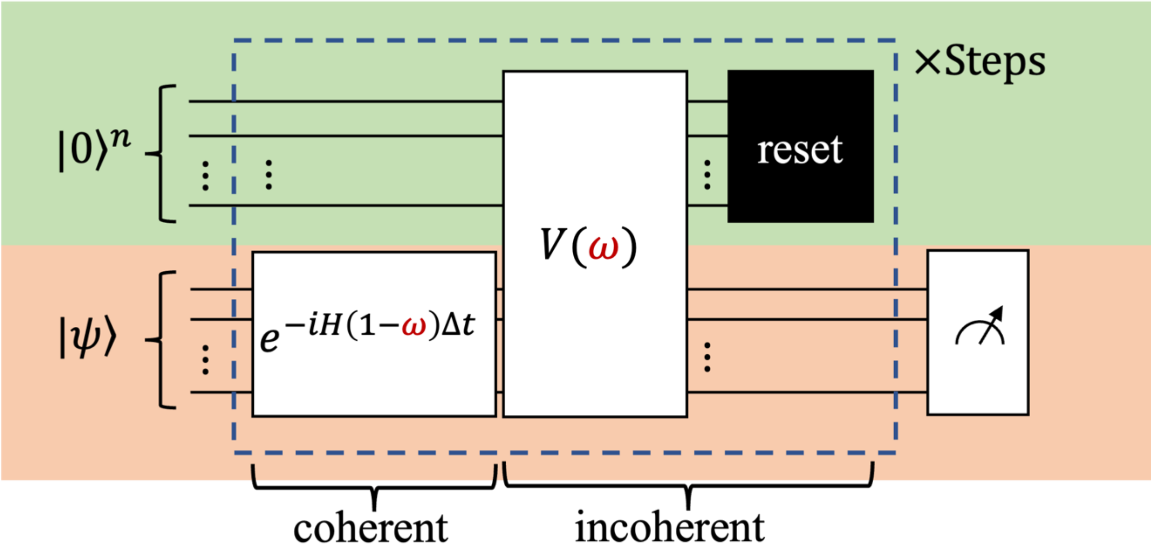
- **Quantum Coherence**: Introduced via Hamiltonian dynamics to enable interference, offering a global view of the network.
- **Classical Diffusion**: Incorporated through stochastic transitions to ensure irreversibility and convergence to a stationary state.

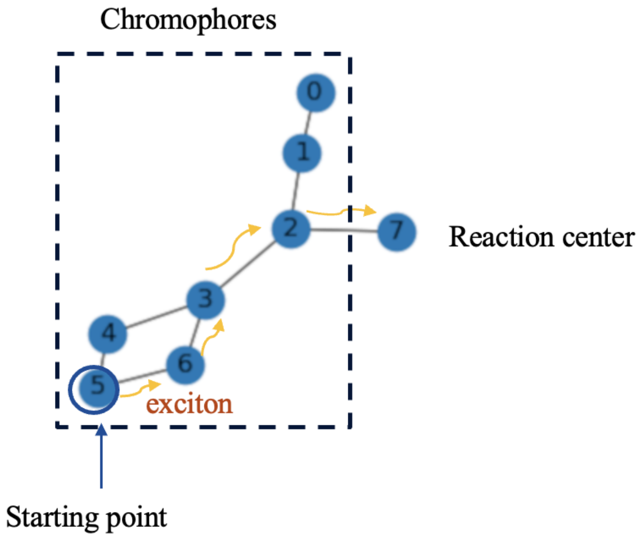
- What parts are you focused on?
  - Leverage GPU capabilities to accelerate computations, especially matrix operations and iterative processes involved in Quantum Stochastic Walks (QSW) and Quantum Navigation.
  - Optimize parallel processing to handle large-scale graphs efficiently, reducing runtime for tasks like adjacency matrix updates, eigenvalue computations, and convergence of hybrid quantum-classical dynamics.

Evolution and Strategy

- What was your goal for coming here?

Photosynthetic light-harvesting simulation

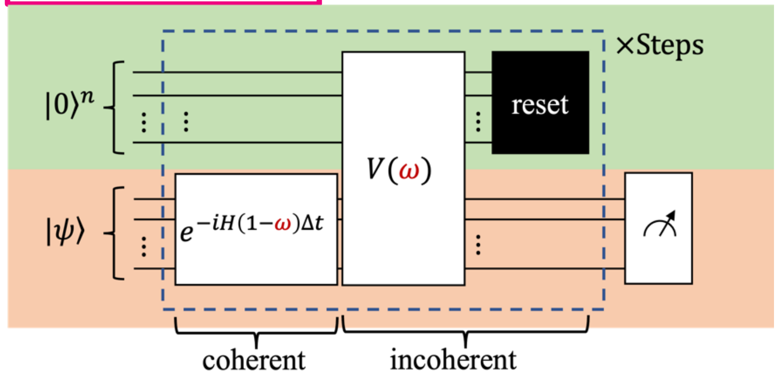




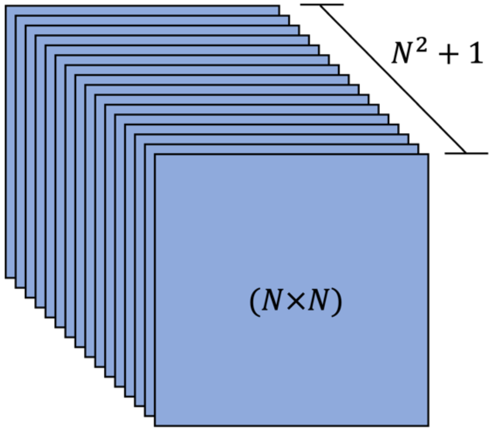
Evolution and Strategy

How did this strategy change?
To better leverage GPU capabilities to accelerate computations, we apply the algorithm to identify and rank nodes in large-scale networks.

Quantum Circuit



$$V = \begin{pmatrix} M_0 & * & \cdots & * \\ M_1 & * & \cdots & * \\ \vdots & \vdots & \ddots & \vdots \\ M_K & * & \cdots & * \end{pmatrix}$$



Operator Sum

$$\rho(t+\Delta t) = \sum_k M_k(\omega) U\big((1-\omega)\Delta t\big)\rho(t)U^\dagger\big((1-\omega)\Delta t\big)M_k^\dagger(\omega)$$

Model of Quantum Page Rank

Allowing **superposition** and **interference** effects.

Incoherence part

Lindbladian operator

$$L_{ij} = G_{ij}|i\rangle\langle j|$$

(G is Google matrix)

Coherence part

Hamiltonian

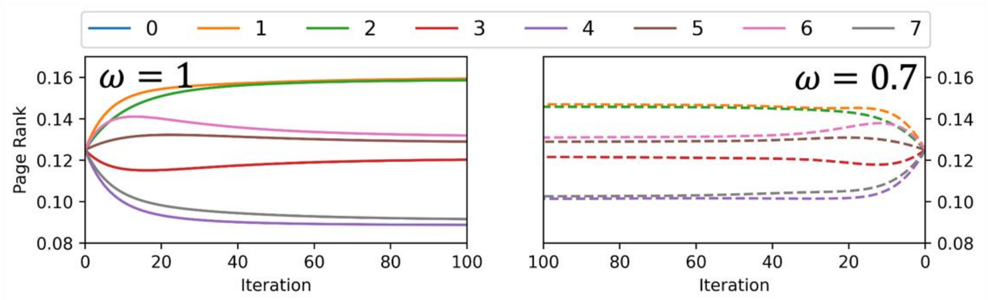
$$H_{ij} = \begin{cases} 1 \text{ if } i \text{ and } j \text{ are connected} \\ 0 \text{ otherwise.} \end{cases}$$

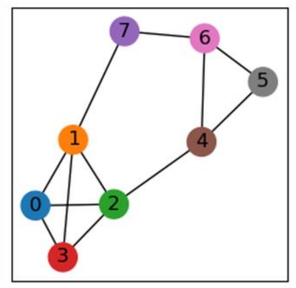
Coupling strength ω

$(1 - \omega)$

Quantum Page Rank

Quantum stochastic walk dynamics





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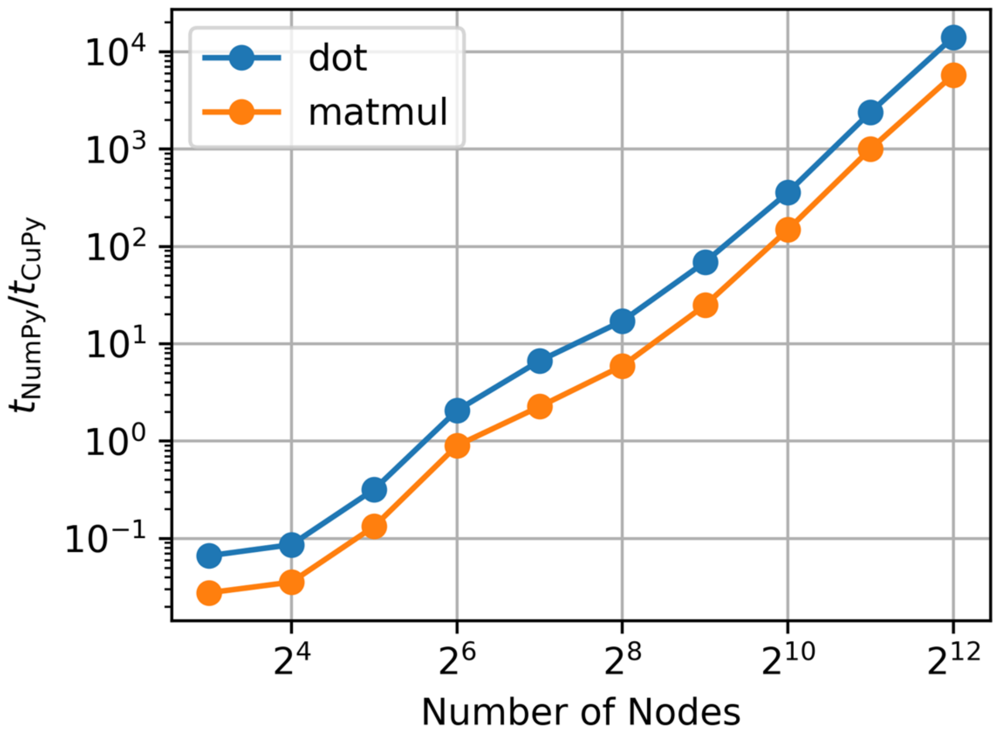
Results and Final Profile

The properties of page rank Lindbladian operators make the operator-sum can be calculated more efficiently, by doing the tensor contraction.

NumPy (64-CPU) CuPy (1-GPU)



Testing Graph:

Binomial graph with probability p=0.3 for edge creation

Energy Efficiency

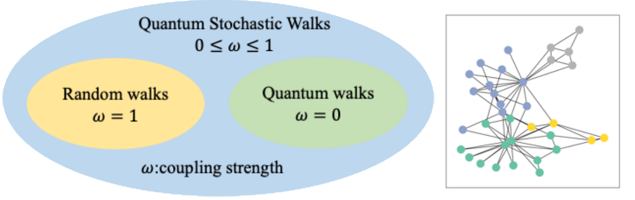
INPUTS	
# CPU Cores	64
# GPUs (A100)	1
Application Speedup	10000.0x
Node Replacement	40000.0x

GPU NODE POWER SAVINGS			
	AMD Dual Rome 7742	**8x A100 80GB SXM4**	**Power Savings**
Compute Power (W)	44,000,000	6,500	43,993,500
Networking Power (W)	1,857,469	93	1,857,376
Total Power (W)	**45,857,469**	**6,593**	45,850,876
Node Power efficiency	**6955.6x**		

ANNUAL ENERGY SAVINGS PER GPU NODE			
	AMD Dual Rome 7742	**8x A100 80GB SXM4**	**Power Savings**
Compute Power (kWh/year)	385,440,000	56,940	385,383,060
Networking Power (kWh/year)	16,271,430	814	16,270,616
Total Power (kWh/year)	**401,711,430**	**57,754**	**401,653,676**
$/kWh	0.18		
Annual Cost Savings	72,297,661.69		
3-year Cost Savings	216,892,985.07		
Metric Tons of CO_2	284,772		
Gasoline Cars Driven for 1 year	61,453		
Seedlings Trees grown for 10 years	4,707,381		

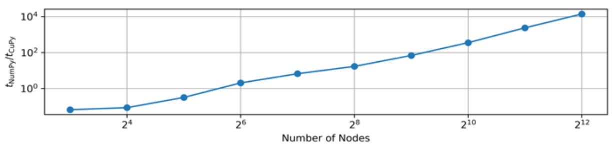
(Required) Create a storyline for publication on NCHC's website.

Quantum PageRank: Harnessing Quantum Stochastic Walks



中原大學 團隊來自 張慶瑞及張晏瑞老師帶領的實驗室， 將 pagerank 加速了 10000 倍！ ！

量子頁面排名算法（Quantum PageRank）作為量子隨機行走（Quantum Stochastic Walks）的一項應用，在經典頁面排名算法（PageRank）的基礎上融入了量子相關性。作為傳統的網頁排序的擴展，量子頁面排名算法不僅可以透過參數的調整得到傳統演算法的結果，更算法利用量子力學的疊加、干涉和去相干特性，對複雜網絡結構進行更深入的分析，為網頁排名提供更精確的依據。我們團隊通過 CuPy 實現了 GPU 加速，並顯著降低了計算時間，因此大幅提升了在處理大規模圖（如社交網絡和推薦系統）時的運算效率和可擴展性。這一研究主題展現了量子理論與經典計算的深度融合，以開放量子系統為靈感，連結量子物理、資訊科學和大數據，為量子計算與量子機器學習的未來發展奠定了堅實基礎。



報告投影片連結 (由國網上傳到 github)

Thank You

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