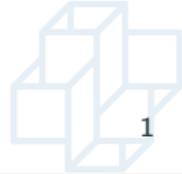


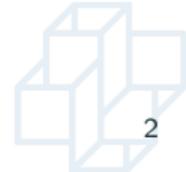
arXiv Review 16/09 - 11/10

October 14, 2024

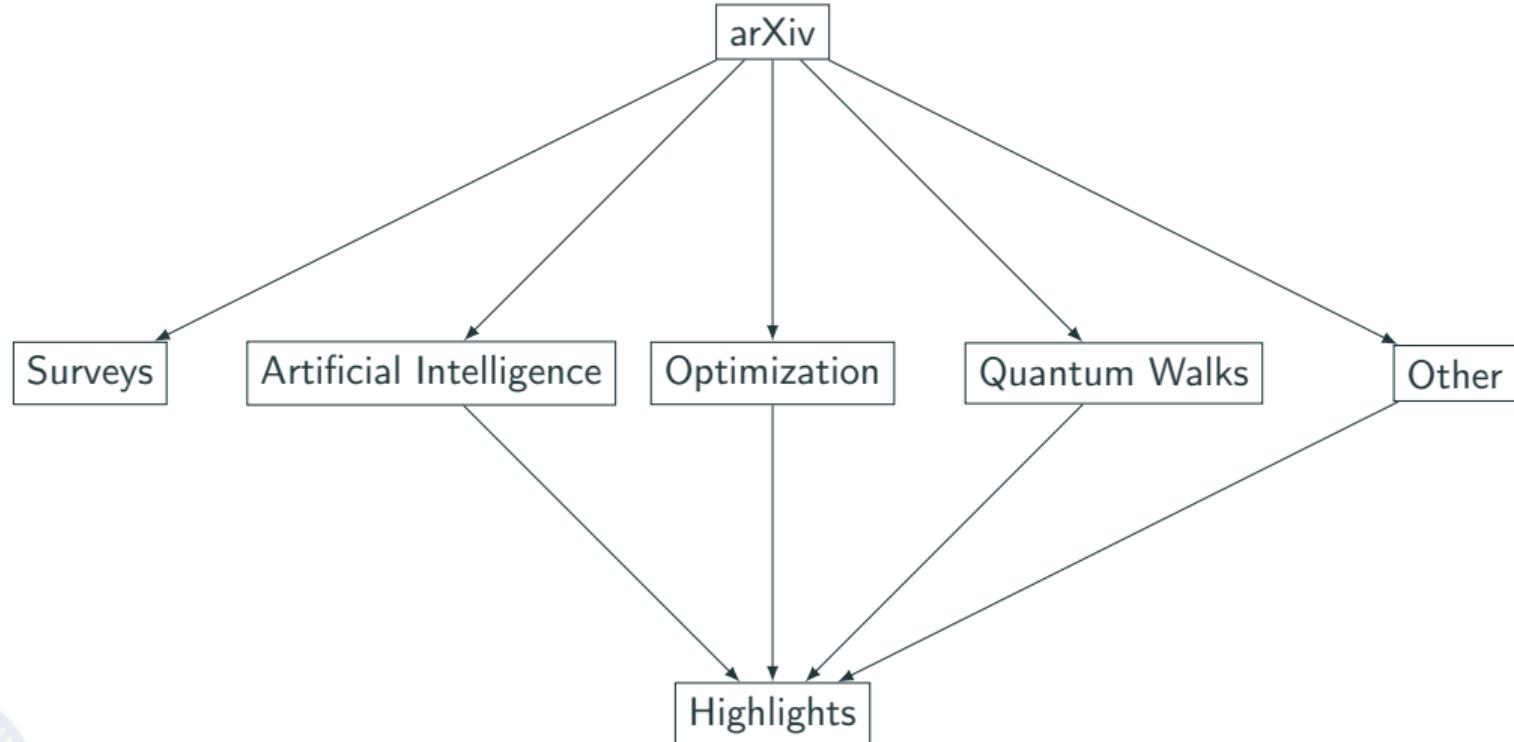


Presentation at

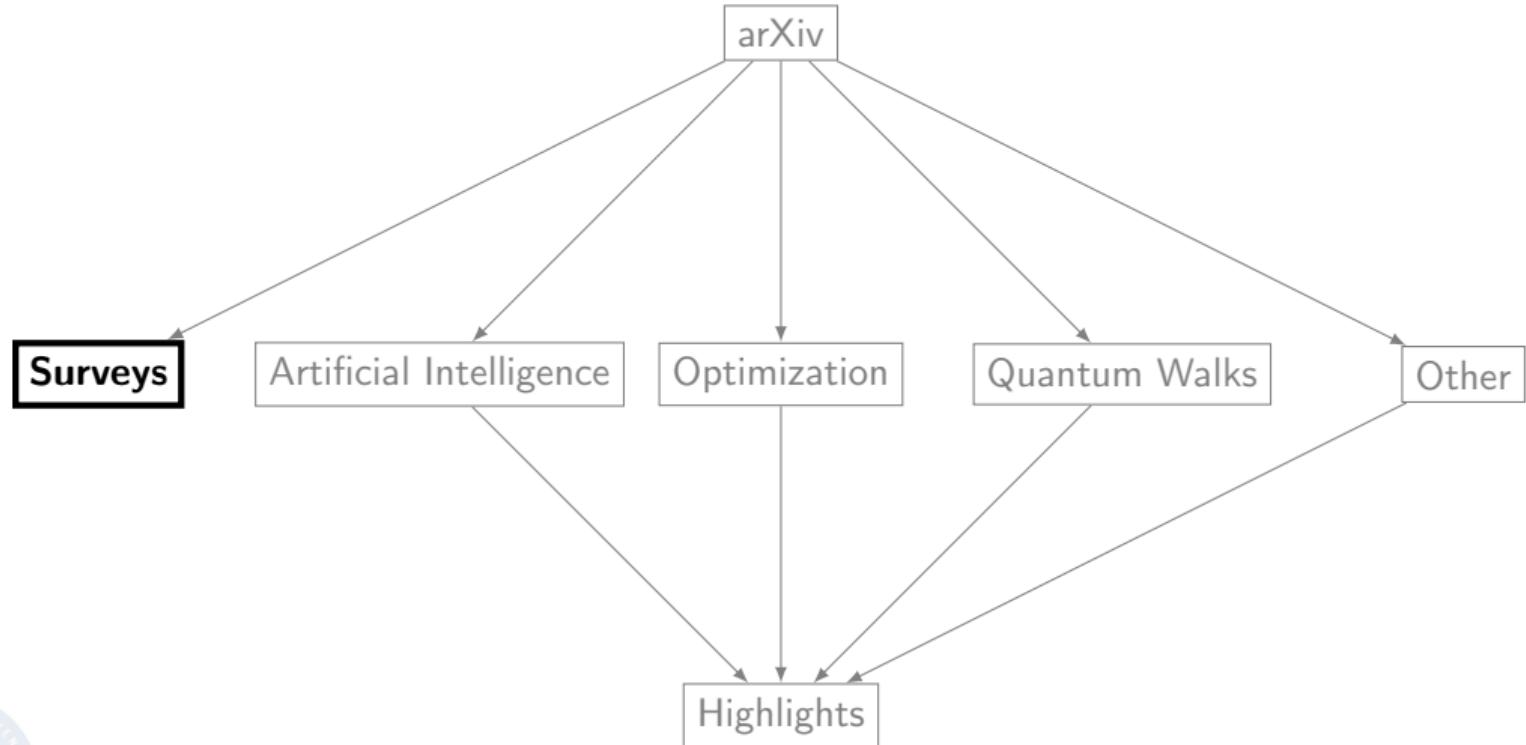
gustavowl.github.io



Summary



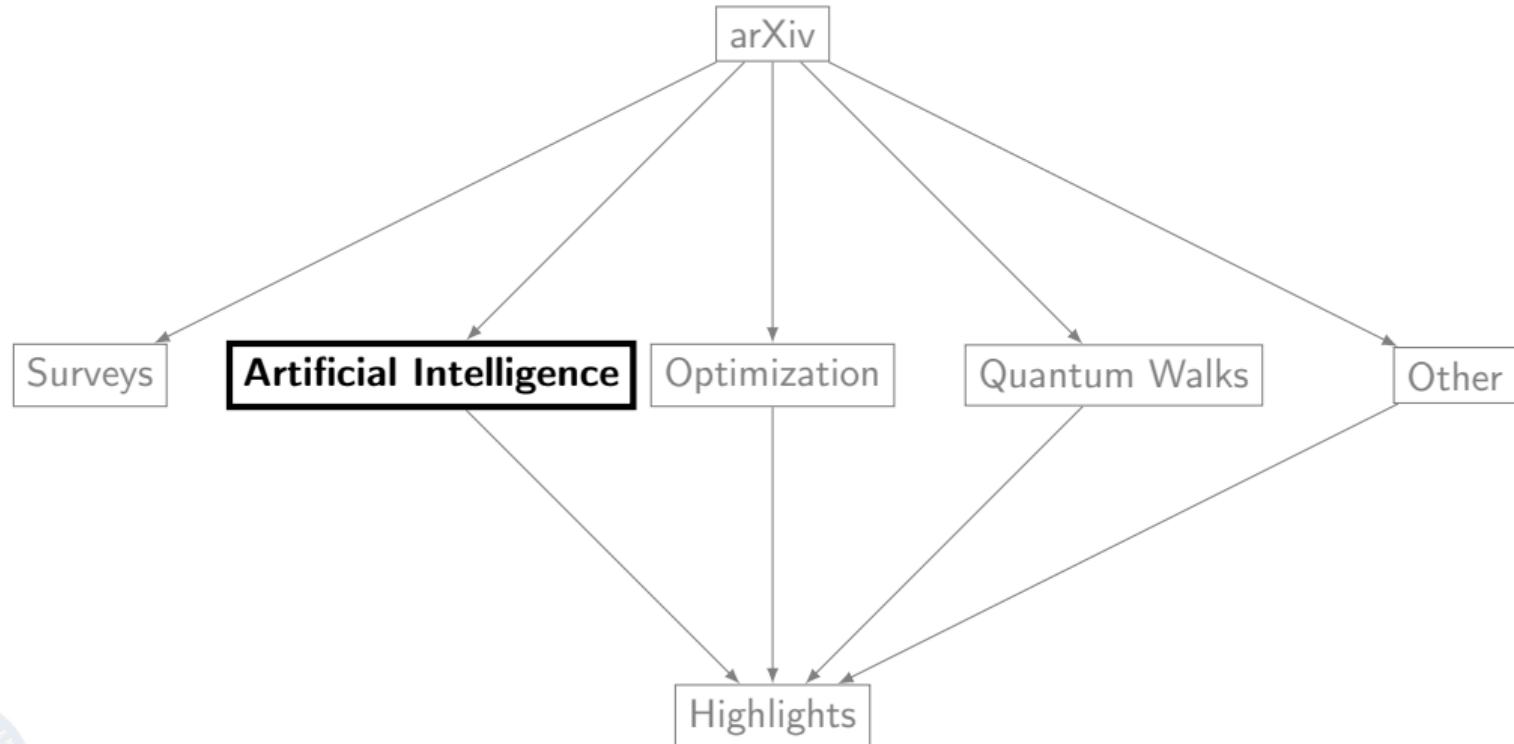
Surveys



- Simulating fluid flows with quantum computing;
- Quantum Computing for Automotive Applications: From Algorithms to Applications;
- Distributed Quantum Computing: Applications and Challenges;
- IBM Quantum Computers: Evolution, Performance, and Future Directions;
- Google Quantum AI's Quest for Error-Corrected Quantum Computers.



Artificial Intelligence



- Scalable and interpretable quantum natural language processing: an implementation on trapped ions;
- **Quantum continual learning on a programmable superconducting processor.**



Scalable and interpretable quantum natural language processing: an implementation on trapped ions

Tiffany Duneau^{1,2}, Saskia Bruhn^{1,*}, Gabriel Matos^{1,*}, Tuomas Laakkonen¹,
Katerina Saiti³, Anna Pearson^{1,*}, Konstantinos Meichanetzidis¹, Bob Coecke¹

¹Quantinuum, ²University of Oxford, ³Leiden University

- Implementation of QDisCoCirc for NLP;
- Toy datasets;
- Classical training (small instances) → generalisation → Quantum evaluation (large instances);



Quantum continual learning on a programmable superconducting processor

Chuanyu Zhang^{1,*}, Zhide Lu^{2,3,*}, Liangtian Zhao^{4,*}, Shibo Xu¹, Weikang Li^{2,5}, Ke Wang¹, Jiachen Chen¹, Yaozu Wu¹, Feitong Jin¹, Xuhao Zhu¹, Yu Gao¹, Ziqi Tan¹, Zhengyi Cui¹, Aosai Zhang¹, Ning Wang¹, Yiren Zou¹, Tingting Li¹, Fanhao Shen¹, Jiarun Zhong¹, Zehang Bao¹, Zitian Zhu¹, Zixuan Song⁶, Jinfeng Deng¹, Hang Dong¹, Pengfei Zhang^{1,6}, Wenjie Jiang², Zheng-Zhi Sun², Pei-Xin Shen⁷, Hekang Li⁶, Qiujiang Guo^{1,6,8}, Zhen Wang^{1,8}, Jie Hao^{4,†}, H. Wang^{1,8}, Dong-Ling Deng^{2,3,8,‡} and Chao Song^{1,8,§}

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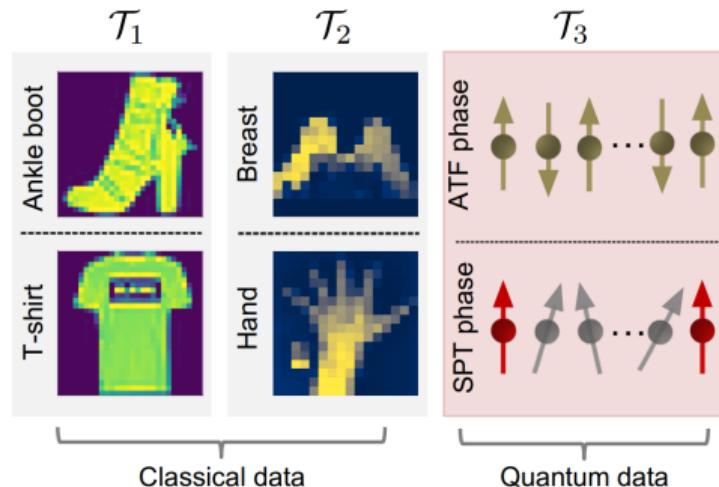
⁷*International Research Centre MagTop, Institute of Physics,
Polish Academy of Sciences, Aleja Lotników 32/46, PL-02668 Warsaw, Poland*

⁸*Hefei National Laboratory, Hefei 230088, China*

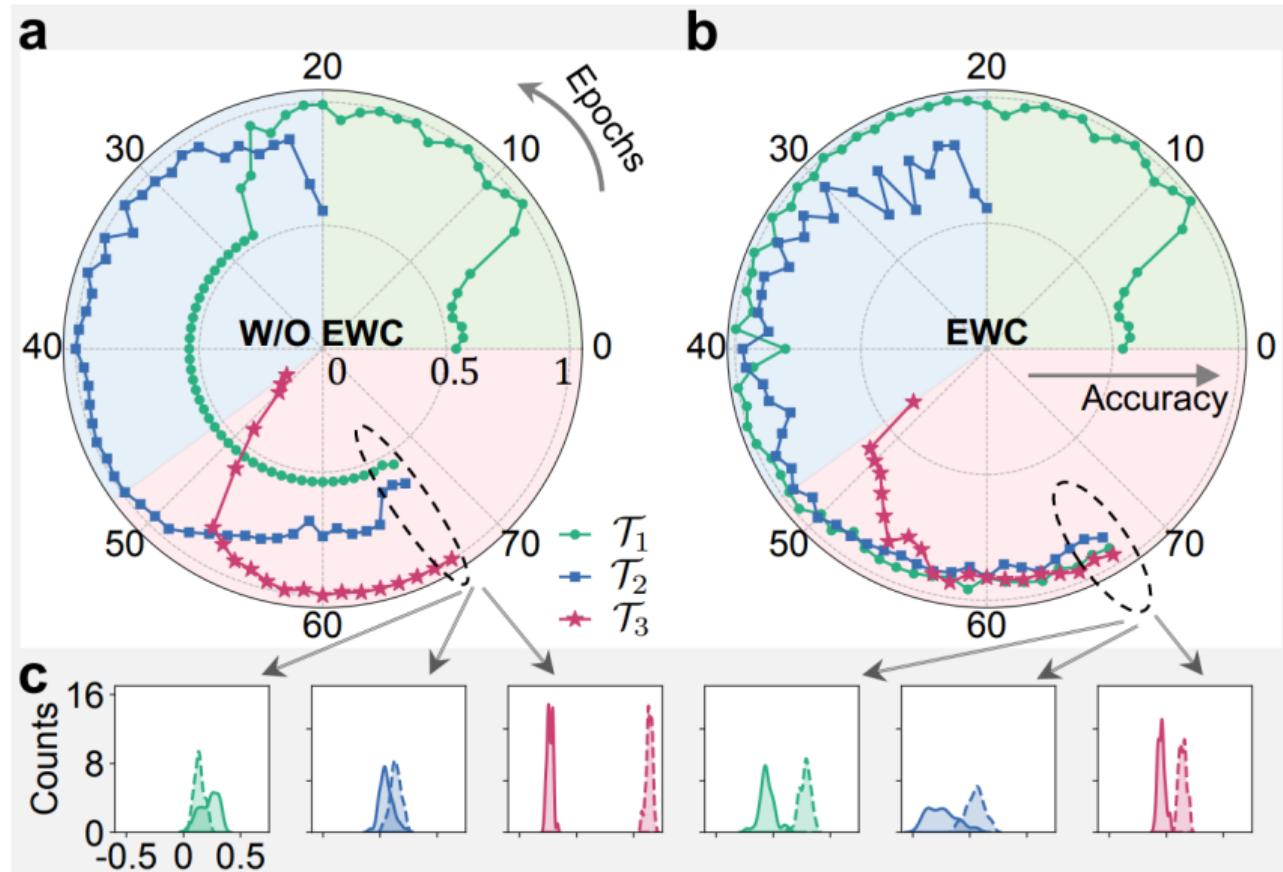


Artificial Intelligence – Quantum continual learning

- Continual Learning (lifelong learning);
- Forgetting problem;
- Tackled with Elastic Weight Consolidation (EWC);
- Datasets:
 - \mathcal{T}_1) T-shirts and ankle boots;
 - \mathcal{T}_2) MRI scans of Hands and breasts;
 - \mathcal{T}_3) Antiferromagnetic and symmetry-protected topological phases.

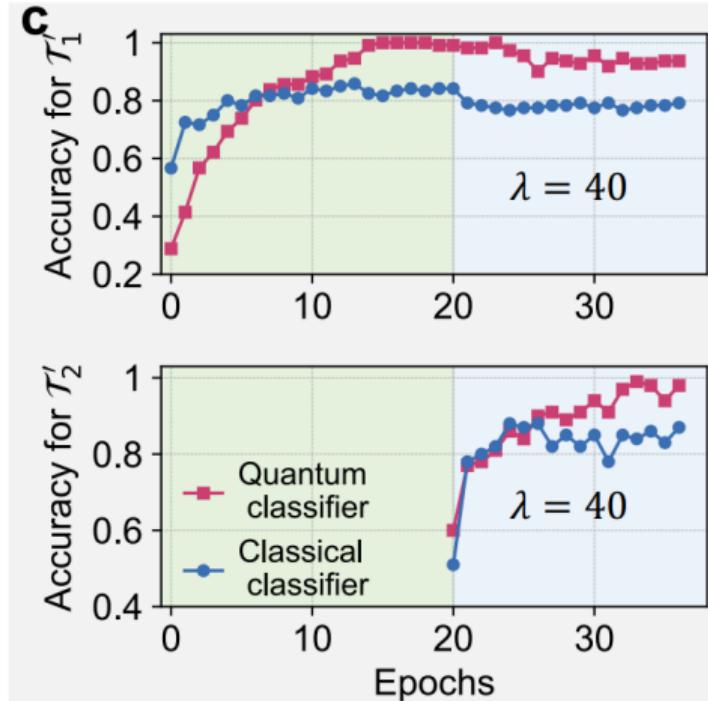


Artificial Intelligence – Quantum continual learning

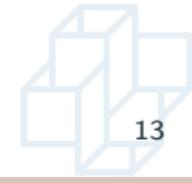
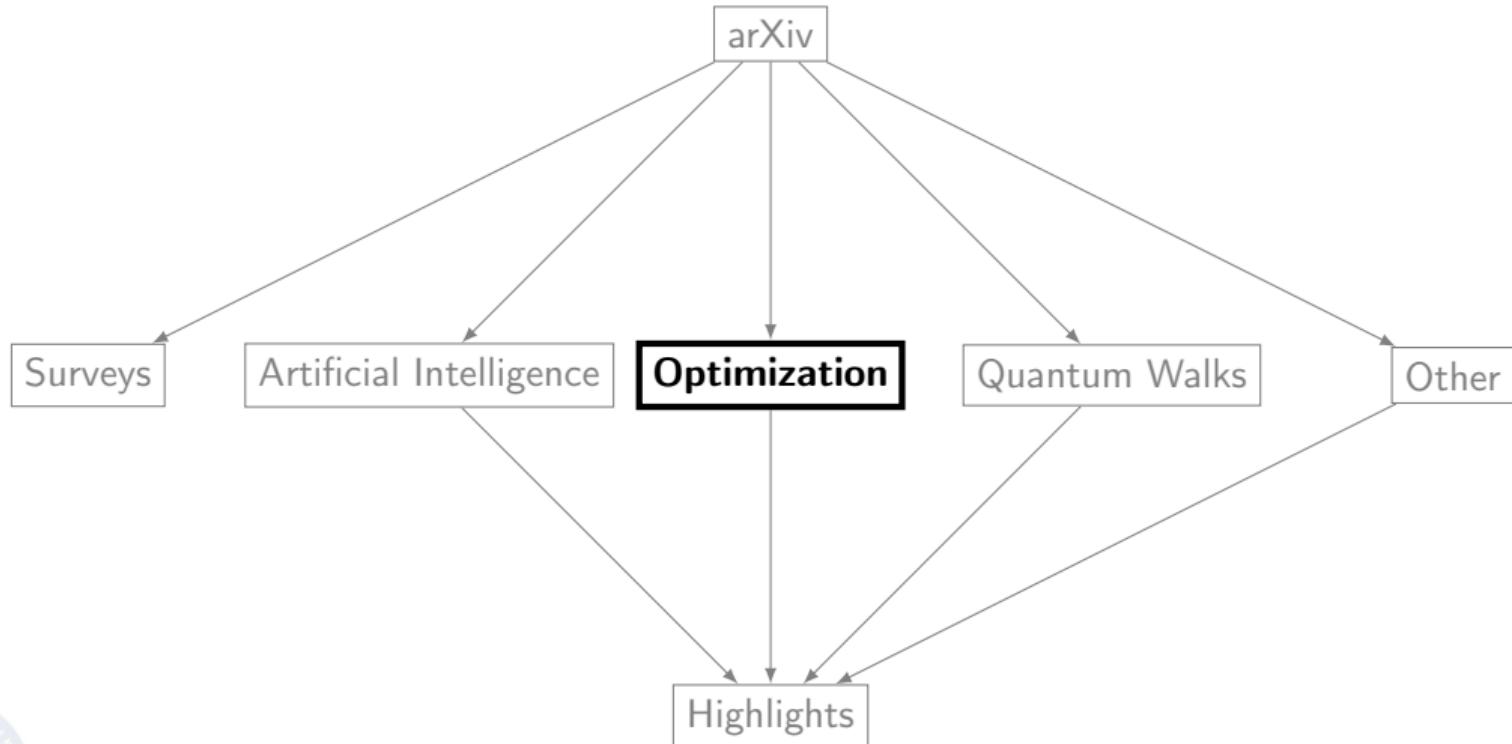


Artificial Intelligence – Quantum continual learning

- Potential quantum advantages;
- Datasets:
 - \mathcal{T}'_1) An engineered quantum task;
 - \mathcal{T}'_2) MRI scans of Hands and breasts.



Optimization



- Solving Combinatorial Optimization Problems on a Photonic Quantum Computer;
- Convergence guarantee for linearly-constrained combinatorial optimization with a quantum alternating operator ansatz;
- **The Better Solution Probability Metric: Optimizing QAOA to Outperform its Warm-Start Solution.**



Solving Combinatorial Optimization Problems on a Photonic Quantum Computer

Mateusz Słysz^{1,2}[0000-0003-3124-9899], Krzysztof Kurowski¹[0000-0002-4478-6119],
and Grzegorz Waligóra²[0000-0003-2108-1113]

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² Poznań University of Technology

Institute of Computing Science
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- Comparison of quantum architectures;
- Binary Bosonic Solver algorithm;
- Max-Cut (95% of optimality for all instances);
- Job-Shop Scheduling Problem (repeated previous results on real QC).



Optimization – QAOA⁺ Convergence

Convergence guarantee for linearly-constrained combinatorial optimization with a quantum alternating operator ansatz

Brayden Goldstein-Gelb¹ and Phillip C. Lotshaw²

¹*Brown University, Providence, RI 02912, USA*

²*Quantum Information Science Section, Oak Ridge National Laboratory, Oak Ridge, TN 37381, USA**

- Convergence for QAOA⁺ mixing operators in terms of graphs;
- Generalize approaches for
 - Unconstrained optimization;
 - Constrained optimization with symmetric linear constraints;
- Simulations.



The Better Solution Probability Metric: Optimizing QAOA to Outperform its Warm-Start Solution

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Reuben Tate

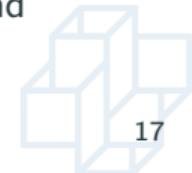
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Stephan Eidenbenz

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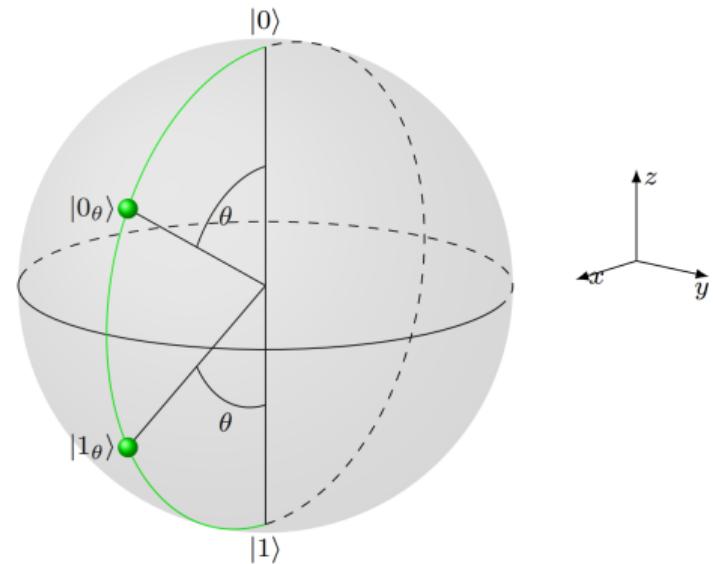
- Numerical investigation of Warm-Start QAOA;
- 3-regular Max-Cut problems;
- WS-QAOA outperforms theoretical lower bounds;

- Best initial state is the one found classically;
- Propose BSP-optimized WS-QAOA improving initial state;
- Best initial state is *not* the one found classically.

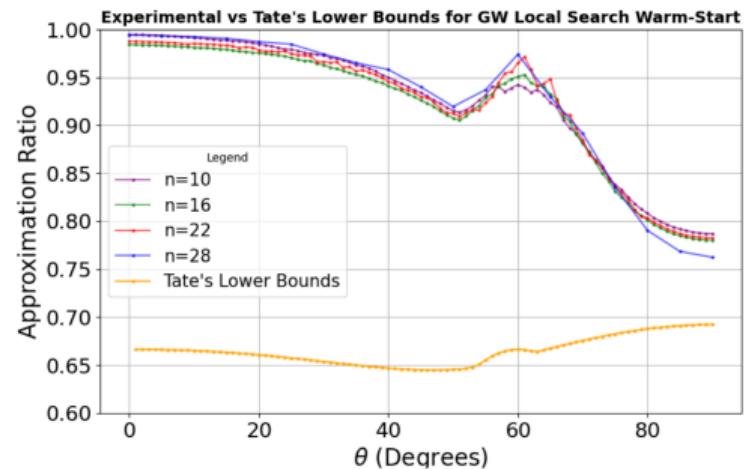
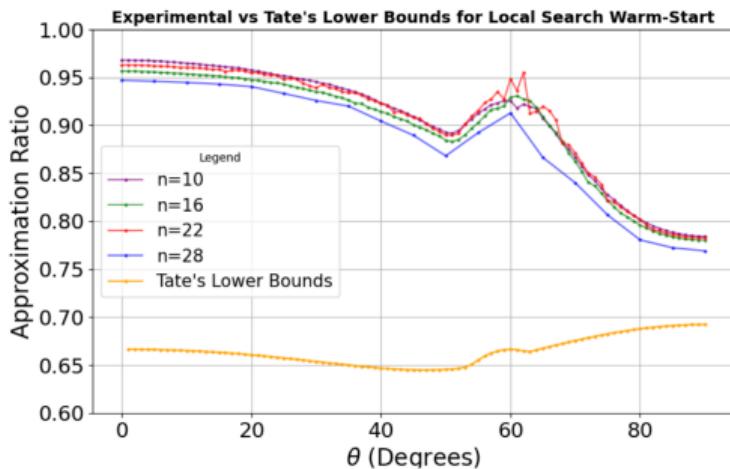


Optimization – BSP QAOA

- Generate random 3-regular graphs;
- For each graph, generate multiple locally optimal;
- b gives vertices in each part;
- Simulate single round of QAOA for $|b_{\{0^\circ, \dots, 90^\circ\}}\rangle$;
- Approximation ratio: $\text{cut}(b)/\text{Max-Cut}(G)$.



Optimization – BSP QAOA



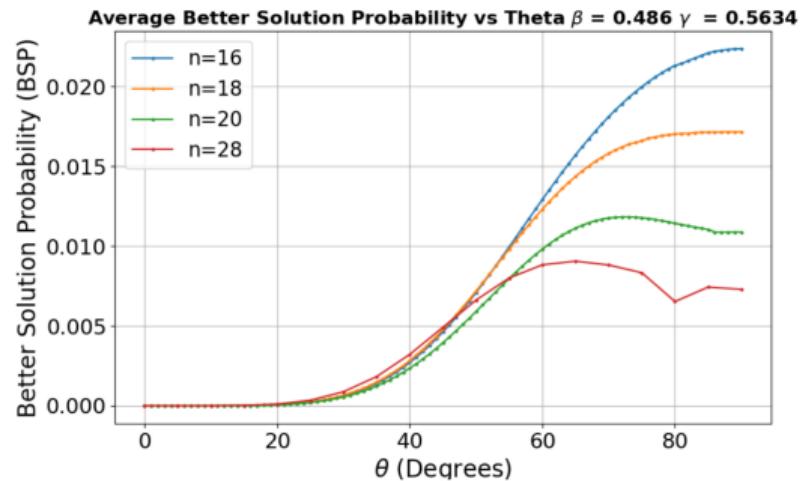
Optimization – BSP QAOA

- Given initial solution b ;
- WS-QAOA output

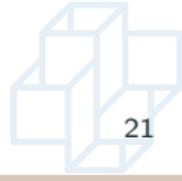
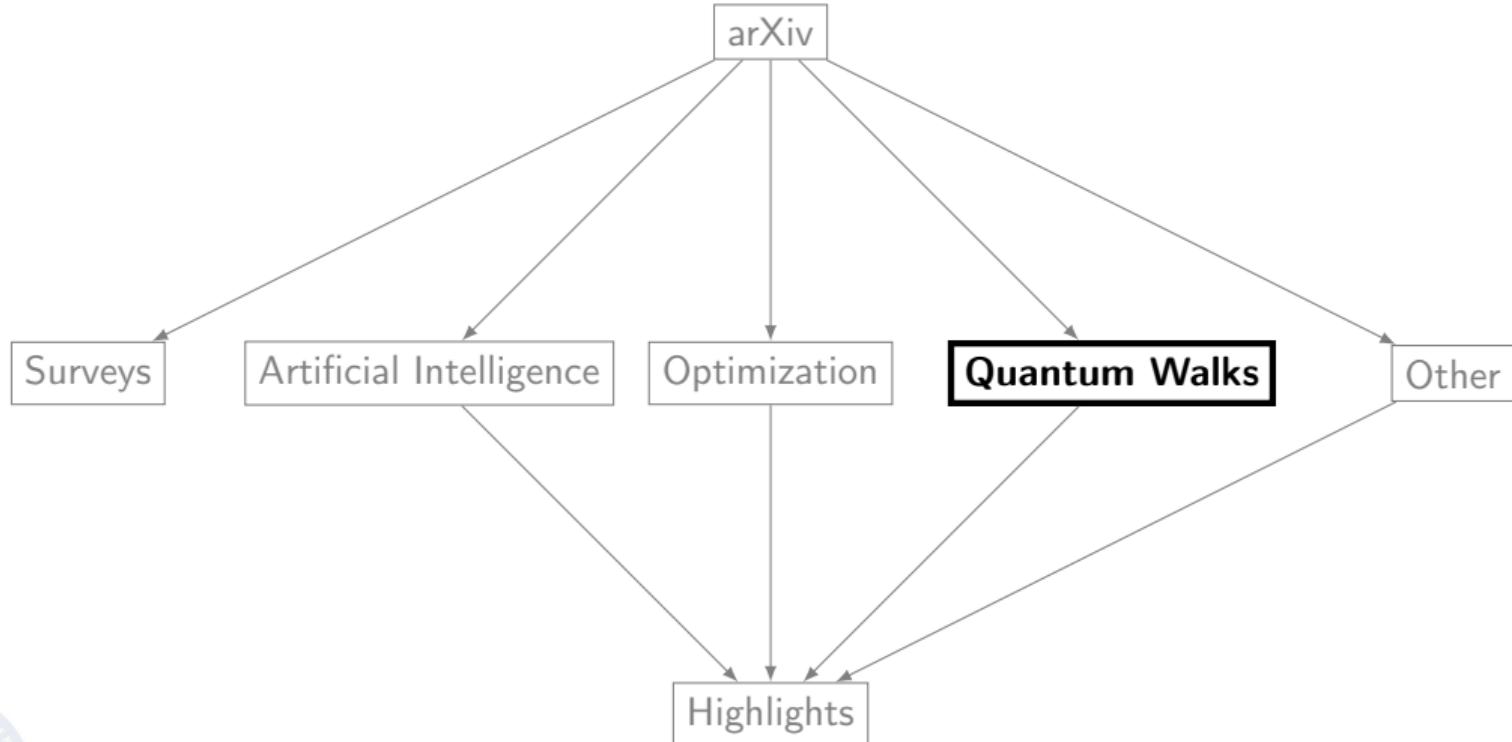
$$|\psi\rangle = \sum_{x \in \{0,1\}^n} c_x |x\rangle ;$$

- New metric:

$$\text{BSP} = \sum_{\substack{x \in \{0,1\}^n \\ \text{cut}(x) > \text{cut}(b)}} |c_x|^2.$$



Quantum Walks



- Impact of Bivariate Gaussian Potentials on Quantum Walks for Spatial Search;
- Quantum Walk Search on Complete Multipartite Graph with Multiple Marked Vertices;
- Quantum property testing in sparse directed graphs.



Impact of Bivariate Gaussian Potentials on Quantum Walks for Spatial Search

Franklin de L. Marquezino ^{†,‡} and Raqueline A. M. Santos [†]

[†] Centre for Quantum Computer Science, University of Latvia, Latvia

[‡] Federal University of Rio de Janeiro, Brazil

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Quantum Walk Search on Complete Multipartite Graph with Multiple Marked Vertices

Ningxiang Chen, Meng Li,* and Xiaoming Sun

*State Key Lab of Processors, Institute of Computing Technology,
Chinese Academy of Sciences, Beijing 100190, China and*

School of Computer Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

- Similar to Thomas Wong's results;
- Quadratic speedup;
- $N_i = N_j, \forall i, j;$
- Marked;
 - $m_i = m_j, \forall i, j;$
 - $m_1 \neq 0, m_2 = \dots = m_n = 0.$



Quantum property testing in sparse directed graphs

Simon Apers^{*1}, Frédéric Magniez^{*1}, Sayantan Sen^{†2}, and Dániel Szabó^{*1}

¹Université Paris Cité, CNRS, IRIF, Paris, France

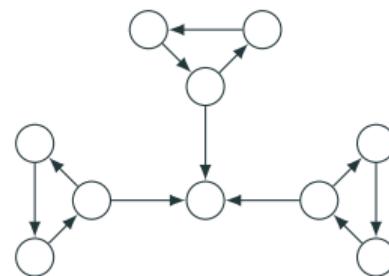
²Centre for Quantum Technologies, National University of Singapore, Singapore

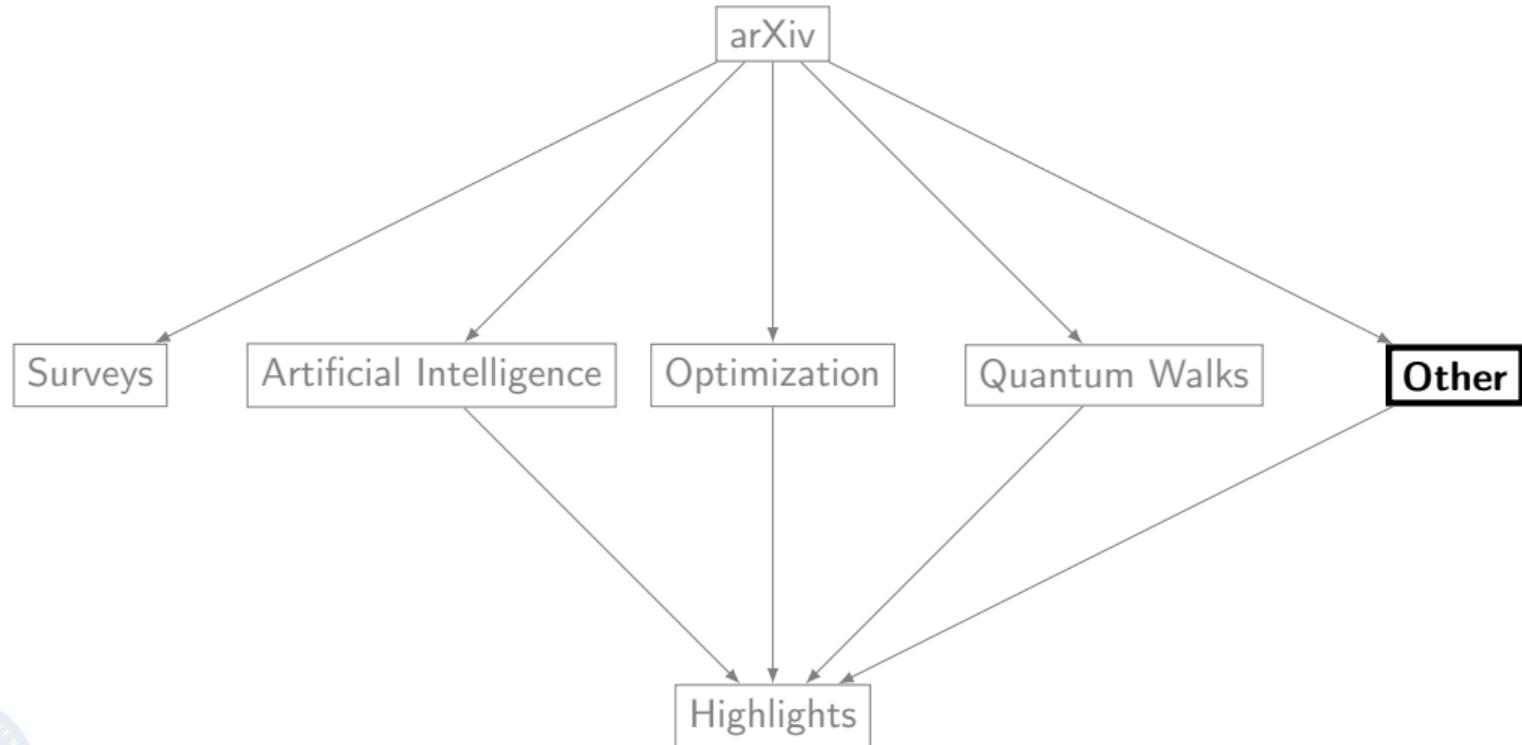
- Initiate study property testing in sparse digraphs;
- Property testing in unidirectional model;



Quantum Walks – Property Testing

- Algorithm to check if G is H -free;
- H is a k -source-subgraph;
- Algorithm (for $k = 2$) and $m = |V(H)|$:
 - 1) Sample $S \subset V(G)$ s.t. $|S| = \Theta(N^{1/3})$;
 - 2) BFS with m -depth $\forall v \in S$;
 - 3) Grover over $V \setminus S$ to find remaining vertices;
 - 4) Output True or False.
- Query complexity: $O\left(N^{\frac{1}{2}\left(1 - \frac{1}{2^k - 1}\right)}\right)$;
- Dual polynomial framework;
 - $\tilde{\Omega}\left(N^{\frac{1}{2}\left(1 - \frac{1}{k}\right)}\right)$





- Curve-Fitted QPE: Extending Quantum Phase Estimation Results for a Higher Precision using Classical Post-Processing;
- H-DES: a Quantum-Classical Hybrid Differential Equation Solver;
- **Parallel Quantum Signal Processing Via Polynomial Factorization.**



Curve-Fitted QPE: Extending Quantum Phase Estimation Results for a Higher Precision using Classical Post-Processing

See Min Lim^{1,*}, Cristian E. Susa^{2,†} and Ron Cohen^{3‡}

¹*Department of Physics, National University of Singapore, Singapore*

²*Department of Physics and Electronics, University of Córdoba, 230002 Montería, Colombia and*

³*Classiq Technologies, Tel Aviv, Israel*



H-DES: a Quantum-Classical Hybrid Differential Equation Solver

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Henri de Boutray, Karla Baumann, and Frédéric Holweck

ColibriTD, 91 Rue du Faubourg Saint Honoré, 75008 Paris, France

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- Transform the problem of solving partial DEs into optimization problem;
- Capable of solving (non-)linear DEs;
- Extensive review of other algorithms for solving DEs;



Parallel Quantum Signal Processing Via Polynomial Factorization

John M. Martyn¹, Zane M. Rossi², Kevin Z. Cheng,² Yuan Liu^{3, 4, 5} and Isaac L. Chuang^{6, 2, 6}

¹*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

²*Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

³*Department of Electrical and Computer Engineering,
North Carolina State University, Raleigh, NC 27606, USA*

⁴*Department of Computer Science, North Carolina State University, Raleigh, NC 27606, USA*

⁵*Department of Physics, North Carolina State University, Raleigh, NC 27606, USA*

⁶*Department of Electrical Engineering and Computer Science,
Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

- Grand Unification of Quantum Algorithms;
- Application to distributed quantum computing;
- More feasible to QSP during NISQ era.



Other – Parallel QSP

- Phases $\vec{\phi} = (\phi_0, \dots, \phi_d)$;

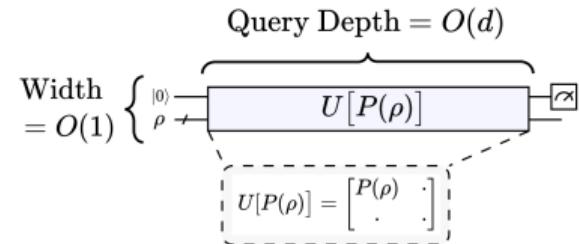
$$U_{\vec{\phi}}(x) = \begin{bmatrix} P(x) & iQ(x)\sqrt{1-x^2} \\ iQ^*(x)\sqrt{1-x^2} & P^*(x) \end{bmatrix}$$

- where

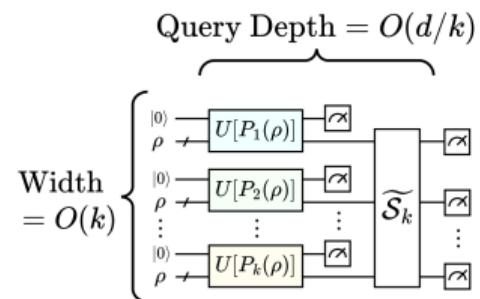
- 1) $\deg(P) \leq d$, $\deg(Q) \leq d - 1$;
- 2) $\text{prty}(P(x)) = d$, $\text{prty}(Q(x)) = d - 1$;
- 3) $|P(x)|^2 + (1 - x^2)|Q(x)|^2 = 1$,
 $\forall x \in [-1, 1]$.

- Codify polynomials in a block of $U_{\vec{\phi}}$;
- Extensible to polynomial transformation of Hermitian operator.

a) Standard QSP:



b) Parallel QSP:



Other – Parallel QSP

- Cyclic shift

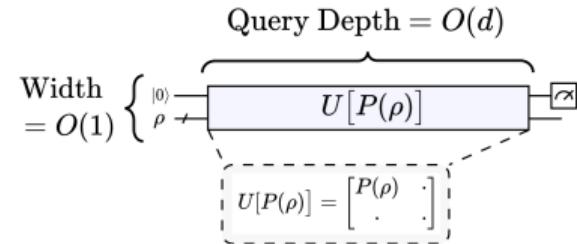
$$S_k |\psi_1\rangle \cdots |\psi_k\rangle = |\psi_k\rangle |\psi_1\rangle \cdots |\psi_{k-1}\rangle ;$$

- Identity

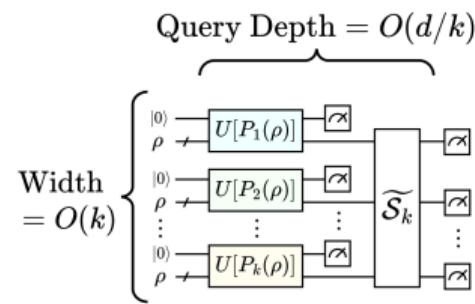
$$\text{tr} \left(S_k \bigotimes_{j=1}^k \rho_j \right) = \text{tr} \left(\prod_{j=1}^k \rho_j \right) ;$$

- Estimate trace by measuring the expectation value of S_k .

a) Standard QSP:



b) Parallel QSP:



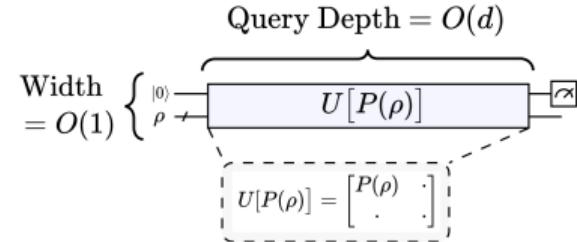
Other – Parallel QSP

Theorem III.1 (Parallel QSP). *Provided access to a density matrix ρ and a block encoding thereof, the parallel QSP circuit executed across k threads enables the estimation of the quantity*

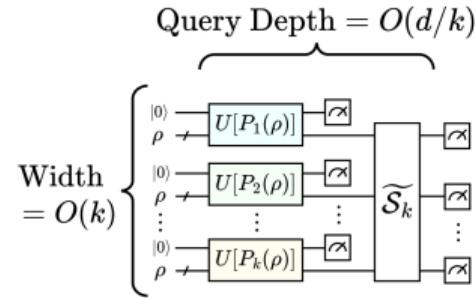
$$z = \text{tr} \left(\rho^k \prod_{j=1}^k |P_j(\rho)|^2 \right), \quad (21)$$

where each $P_j(\rho)$ is a block-encoded polynomial implemented with QSP. More specifically, z can be estimated to additive error ϵ by running the parallel QSP circuit $O(\frac{1}{\epsilon^2})$ times, where the requisite query depth is $2 \max_j \{\deg(P_j)\}$ and the circuit width is $O(k)$.

a) Standard QSP:



b) Parallel QSP:



Thank You!

gustavowl.github.io

