Delivering Superior Quantum Performance on NP-hard Graph Problems via Subject-matter-expert APIs

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CRNCH Summit

Delivering quantum advantage at its earliest moment will enable better/faster problem solving. Delivering it via subject-matter-expert APIs, which Mukai is targeting, will also democratize that benefit.

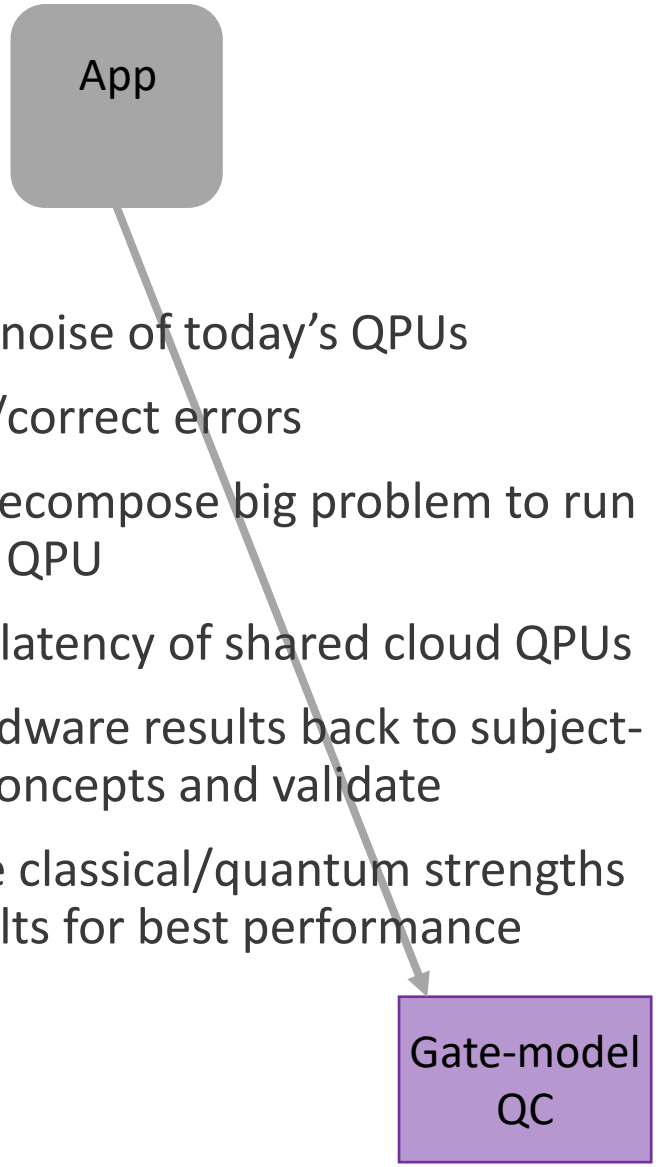
Agenda

- Context
- Making a path plausible
- Making a path actual
- One use case - community detection

Analyst Context

- Challenged by rapidly growing volume, variety, and velocity of data
- Challenged by needing to gain deeper insights from the data
- The potential performance of unusual new processors appears to offer a path forward, but how to use them?

Programmer Context



Necessary tasks to use a QPU

- For each app portion, decide whether best for QPU or classical
- If possible, shrink/reduce/simplify portion before mapping to QPU
- Map QPU portion to circuit or QUBO
- Create near-optimal circuit or QUBO
- Map to native hardware (native gates, topology)

- Tolerate noise of today's QPUs
- Tolerate/correct errors
- Shrink/decompose big problem to run on small QPU
- Tolerate latency of shared cloud QPUs
- Map hardware results back to subject-matter concepts and validate
- Combine classical/quantum strengths and results for best performance

- Calibrate QAOA/VQE for my problem, target QPU
- Track hybrid execution for progress/errors
- Find/use best QPU(s) for my problem
- Update these steps when new QPU released (every 7 weeks in last year)

Quantum Computing Context

- Fault-tolerant QPUs suitable for real-world problems appear to be a decade away
- Constrained optimization appears likely to benefit from earlier QPUs
- QPUs will be so limited for the foreseeable future that hybrid quantum/classical execution will be the only practical path
- QPUs have major medium- and low-level differences
- New QPUs being made publicly available about every 7 weeks
- Best techniques at the QPU level are evolving rapidly

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One Possible Path

- Focus on **constrained optimization**, a valuable subset of the problems QPUs can solve
- Expose APIs at the subject-matter-expert level, leaving vast design freedom underneath to optimize problems effectively for a given QPU
- Deliver superior classical performance compared to non-quantum-inspired solvers
- Focus intensely on morphing the user's problem so the QPU is most able to deliver useful results
- Deliver now and get empirical feedback

Mukai: Simplicity Shrouding Complexity

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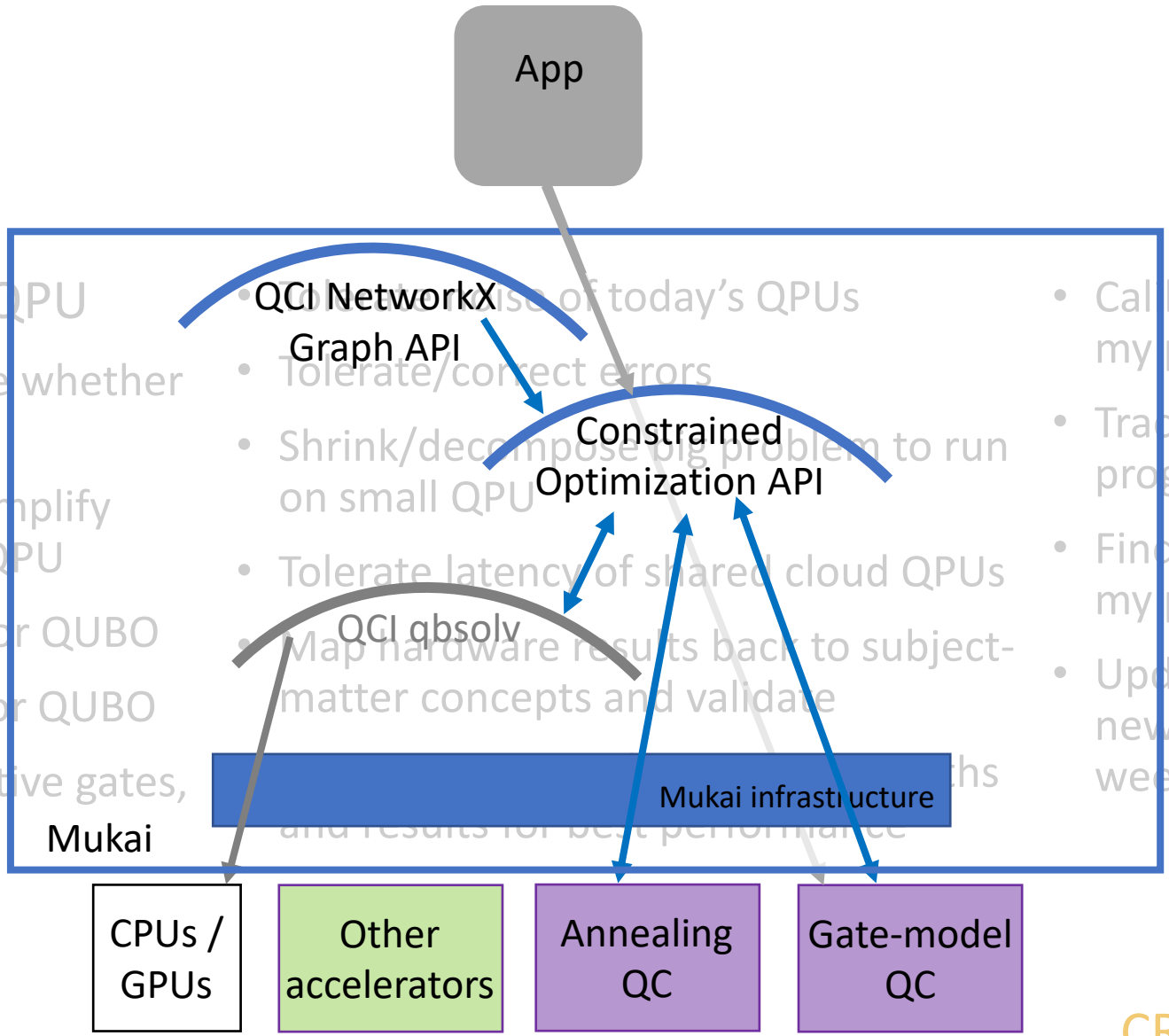

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Plausibility: Superior Classical Performance and Value of Preprocessing

					Bespoke-QUBO			Constrained-optimization		
Graph	**|V|**	**|E|**	**Smallest previously known cut**	**Cut from reference [2]**	**cut**	**diversity (by cut)**	**sample time (s)**	**cut**	**diversity (by cut)**	**sample time (s)**
add20	2,395	7,462	596	647	595	595 x3 596 x51	32	595	x1	–
3elt	4,720	13,722	90	90	90	90 x77	140	90	x32	22
bcsstk33	8,738	291,583	10,171	10,171	10,162	10,162 x1 10,164 x2 10,166 x1	184	10,162	x1	11
vibrobox	12,328	165,250	10,343	na	na	na	na	10,334	x18	3,040
4elt	15,606	45,878	139	na	139	x1	7,379	139	x1	1,514
cti	16,840	48,323	334	na	334	x1	7,408	334	x4	210
memplus	17,758	54,196	5,499	na	6,190	x1	7,413	5,537	x1	10,809
bcsstk30	28,924	1,007,284	6,394	na	6,389	6,389 x1 6,391 x1 6,394 x2	7,846	6,375	x1	2,013

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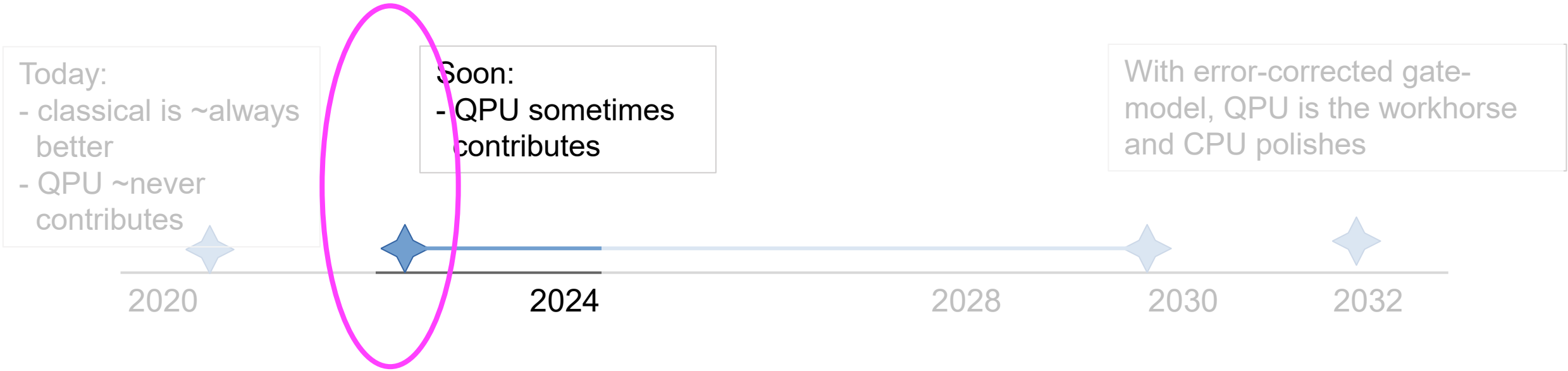
Chukwu et al., https://arxiv.org/pdf/2006.15067v1.pdf

Plausibility: QPU Speed and Quality of Samples



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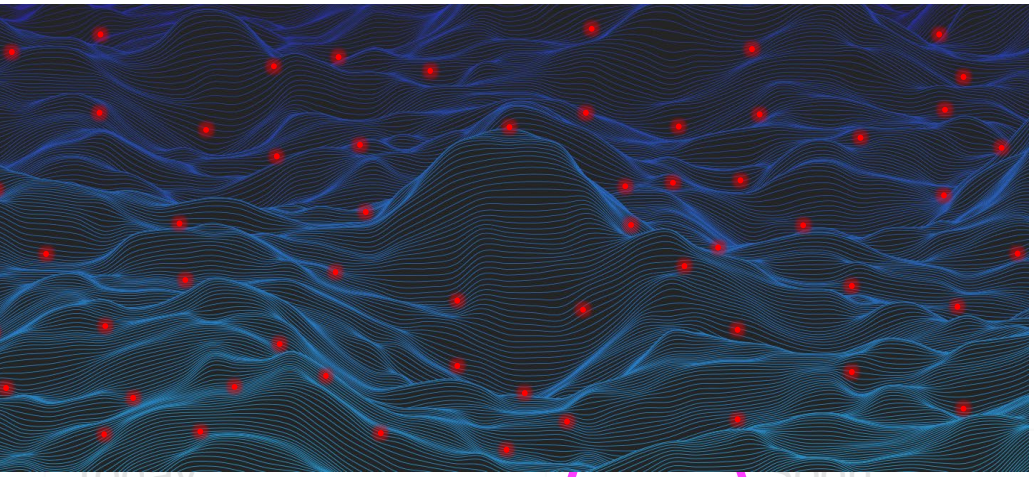
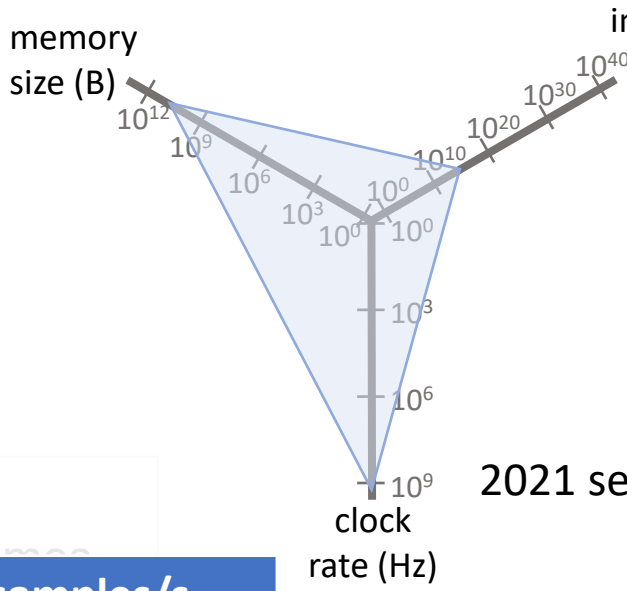
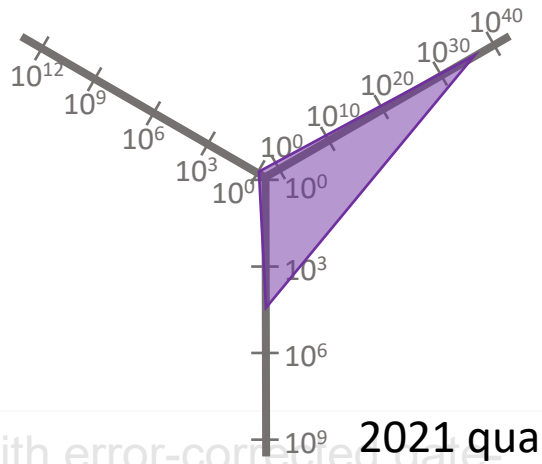


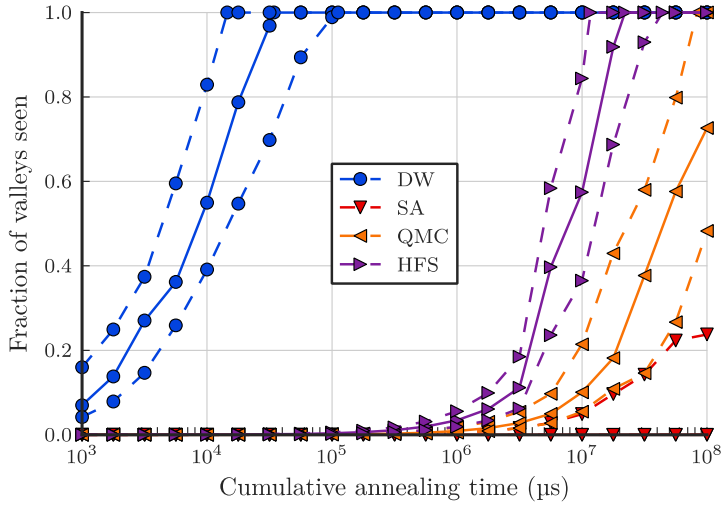


2021 server



2021 quantum (64-qubit)

	Samples/s	Unique elite samples/s
classical (100 cores)	10^9/s	10^{-3} - 10^0 /s
quantum (1 QPU)	10^1-10^3/s	10^1 - 10^2 /s



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Today and Tomorrow

- Mukai is a constrained-optimization quantum cloud platform exposing subject-matter-expert APIs that deliver strong performance today (classically)
  - Constrained-optimization (QuOIR) and graph (QCI NetworkX) APIs, Python-based
  - Execution is targeted to classical or quantum solver with 1 argument; call otherwise identical, so QPU-agnostic, enables QPU comparisons, and avoids technology lock-in
  - Have sampled constrained optimization problems up to 110K variables and 8K constraints classically
  - Current support for Rigetti, IonQ, and D-Wave QPUs, with problems limited to QPU size
  - Documentation and Jupyter notebooks at https://docs.qci-prod.com

- Next Steps
  - Enable solving (big) real-world problems with small QPUs
  - Combine early QPU contributions with strong classical performance
  - Deliver better QPU performance
  - Connect with more QPUs

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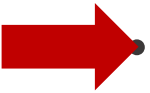
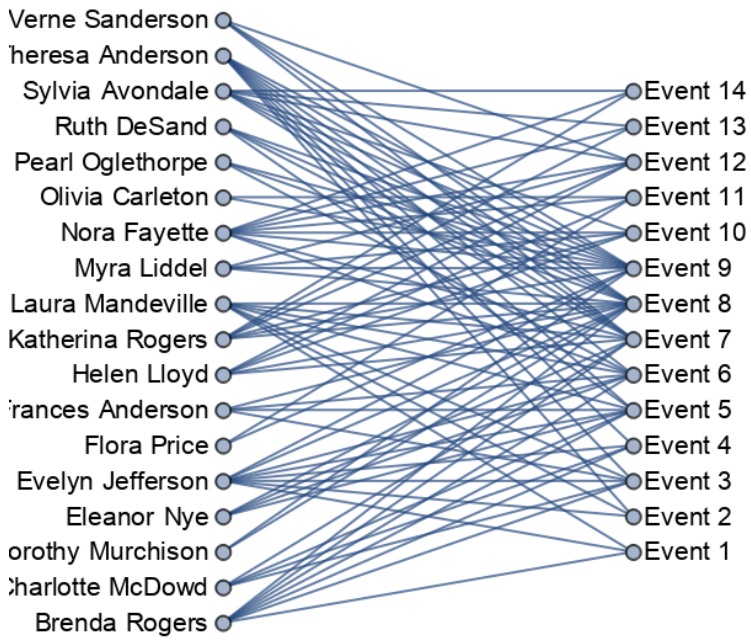


Community Detection: A Next-generation Analytic Tool

- Community detection (CD) is a powerful unsupervised machine learning technique developed over the past 15 years; identifies community-defining data dimensions itself
- Typical algorithm is local to avoid computational complexity. The QCI NetworkX implementation is global, so it can find the best solution, and can exploit a QPU
- Supports both graphs with homogeneous (unipartite) and heterogeneous vertices (bipartite)
- Validated on public graphs (e.g., Southern Women) and on clinical trial data
- Delivering better modularity than other methods, with fast execution times



Call to Action

- If you care about your SMEs being able to deploy weird processors quickly with full performance, make that need known
- Realize the necessity of software with strong high-level transformations in delivering full performance and fund/buy it

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