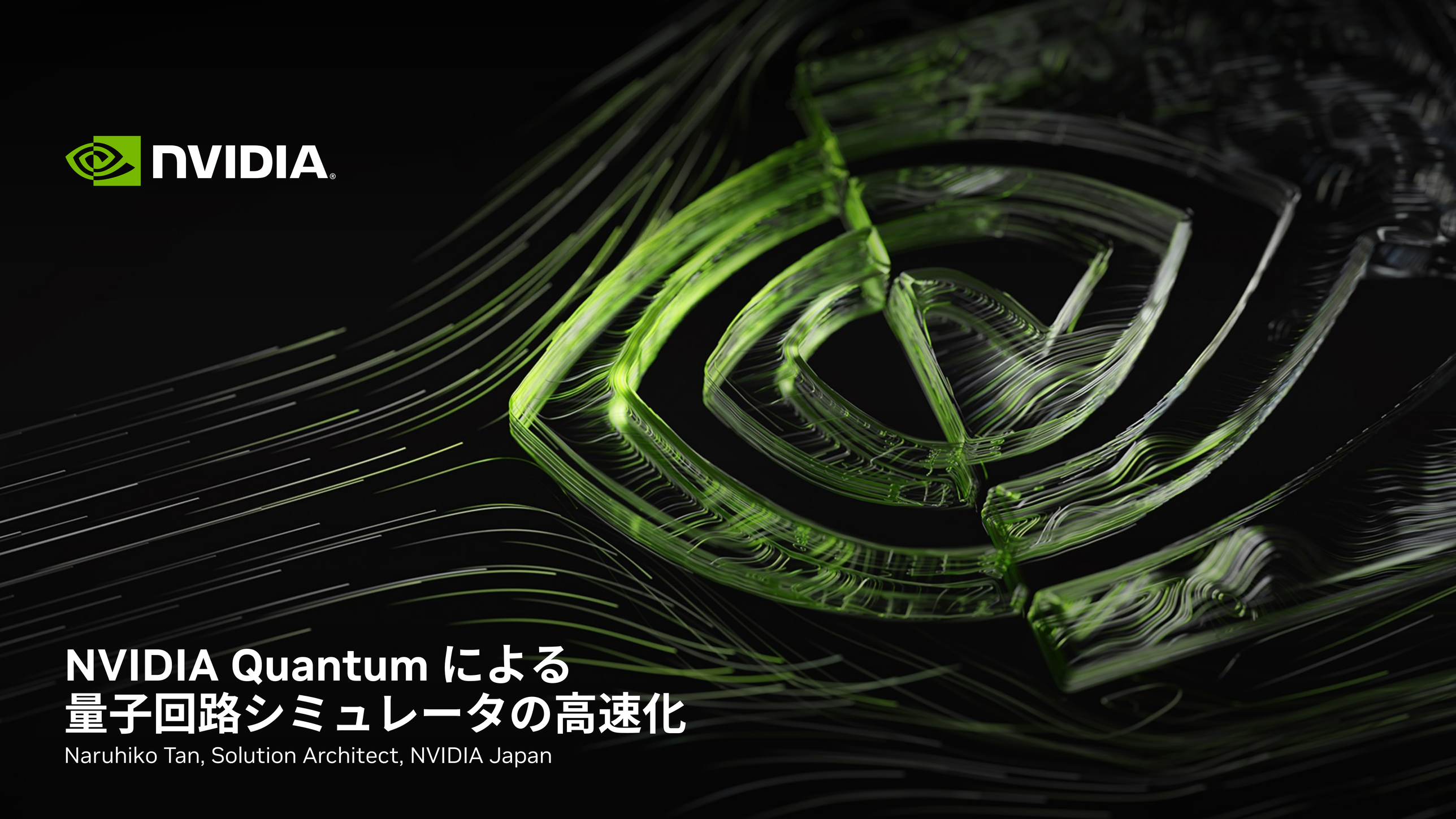


NVIDIA Quantum による 量子回路シミュレータの高速化

Naruhiko Tan, Solution Architect, NVIDIA Japan

Agenda

- State of Quantum
- Accelerated Computing for Quantum
- Summary

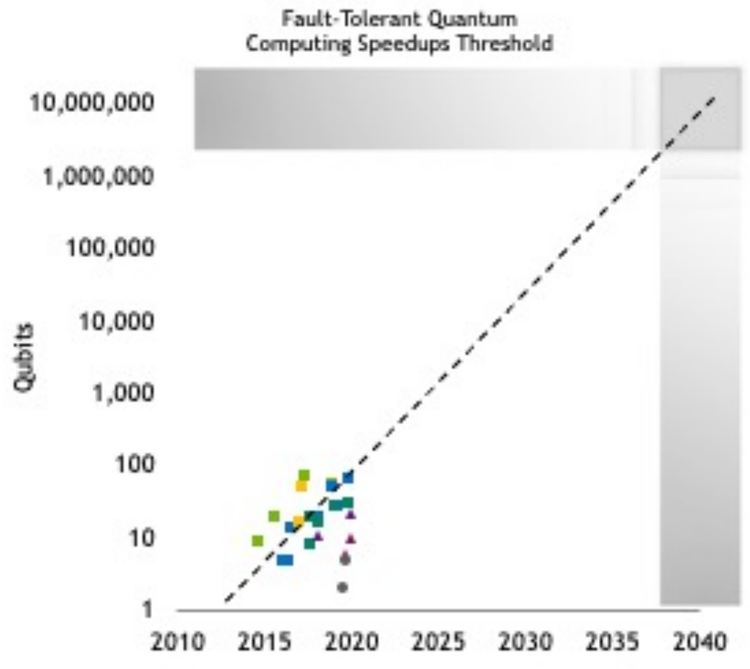
Agenda

- **State of Quantum**
- Accelerated Computing for Quantum
- Summary

Worldwide Effort Towards a New Computing Model

QUANTUM SYSTEMS SCALING EXPONENTIALLY

Useful, Fault-Tolerant Qubit Scale Could Be Achieved in 15 to 20 Years



GOVERNMENT

22+

National Quantum Initiatives

INDUSTRY

70%

Of companies have quantum Initiatives

HIGHER ED/RESEARCH

2,100+

QC Research Papers

TECHNOLOGY

250+

QC Startups

Government national initiatives source: https://qureca.com/overview-on-quantum-initiatives-worldwide-update-2022/ | Industry source: https://hyperionresearch.com/wp-content/uploads/2021/12/Hyperion-Research-QC-User-Uptake-Study-November-2021.pdf
Higher Ed/Research source: Papers published on ArXiv for “Quantum computing”, ”Quantum sensing”, and “Quantum networking” | Technology source: https://quantumcomputingreport.com/privatestartup/

NVIDIA

Challenges for Useful Quantum Computing

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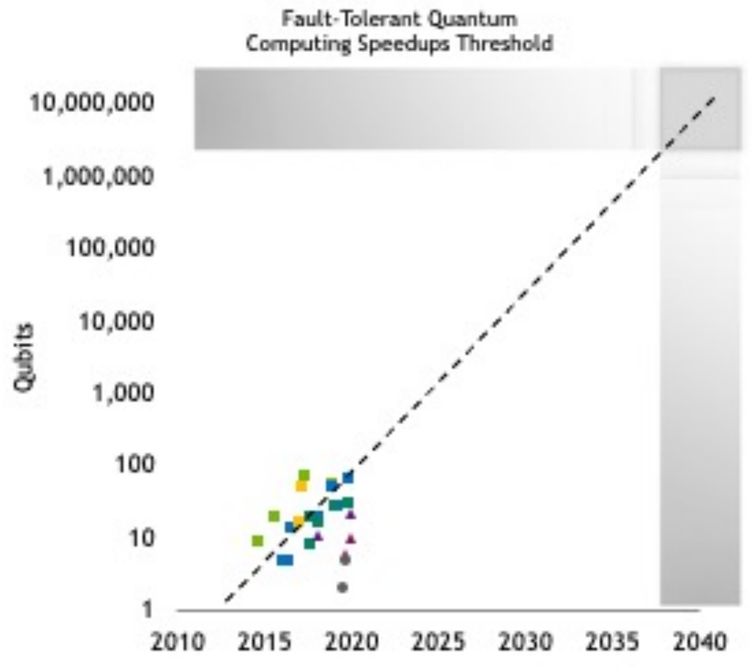


SCALE

100,000+

Total Qubits Required

ALGORITHMS

Unknown

Algorithms for Advantage

FIDELITY

1,000+

Perfect Error Corrected
Logical Qubits Required

INTEGRATION

Open

Challenge to integrate Quantum
in with Classical Supercomputing

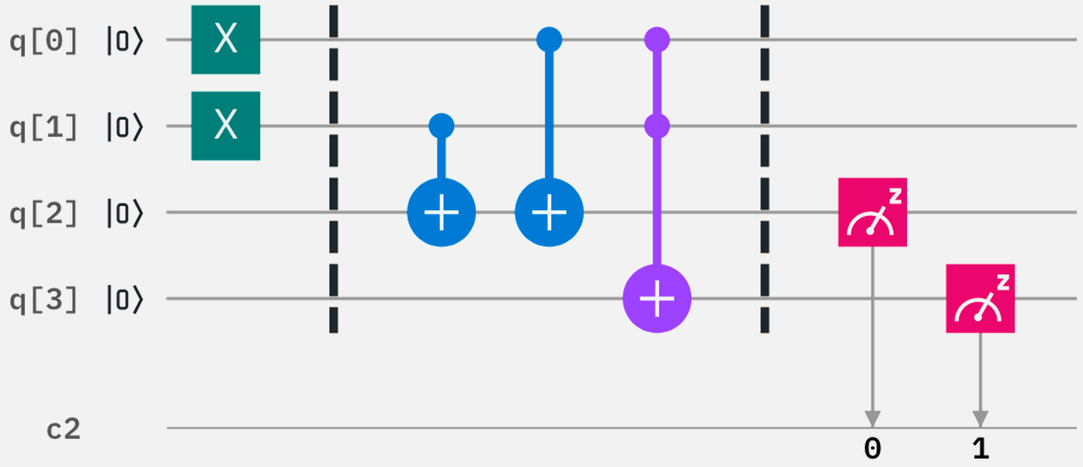
Agenda

- State of Quantum
- **Accelerated Computing for Quantum**
- Summary

GPU Supercomputing and Quantum

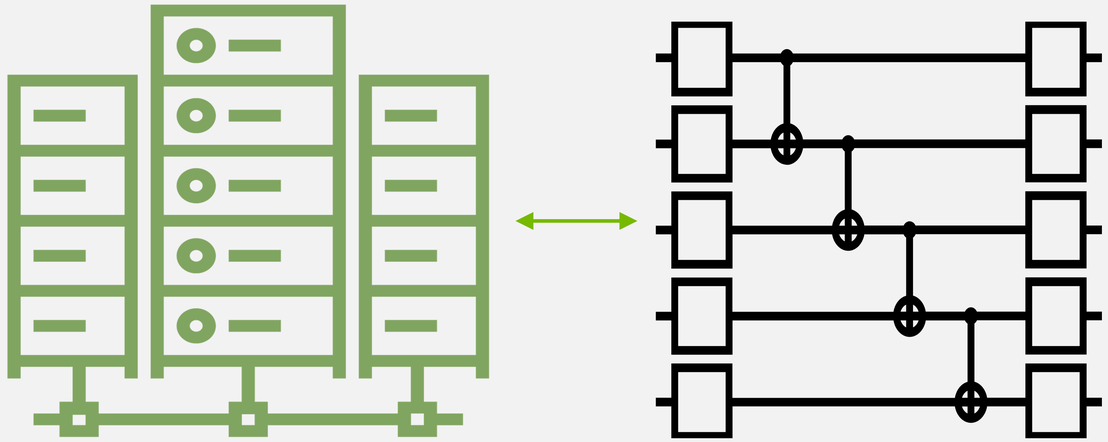
Researching the Quantum Computers of Tomorrow with the Supercomputers of Today

QUANTUM SIMULATION



- Develop algorithms at scale of valuable quantum computing
- Discover use cases with quantum advantage
- Design and validate future hardware

HYBRID QUANTUM-CLASSICAL COMPUTING

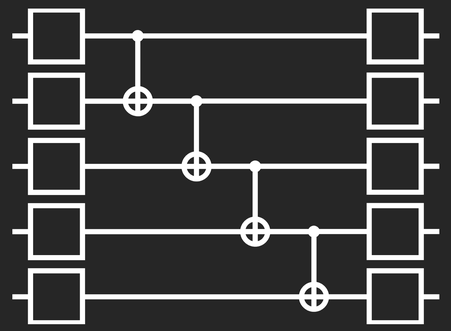


- Integrate quantum into leading accelerated applications
- Unparalleled performance and scientific productivity using the best resource for the task
- GPUs and AI to get the most out of QC

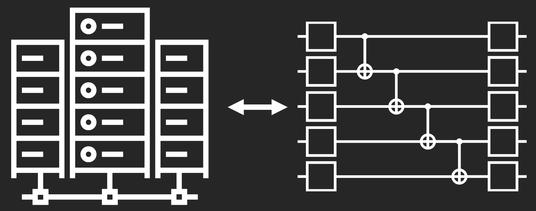
NVIDIA Quantum

Powering Quantum Simulation and Quantum-Integrated Accelerated Computing

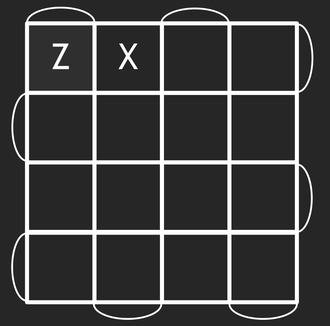
Quantum Algorithms Research



Quantum-Integrated Applications



Error Correction, Calibration, Control



cuQuantum
Accelerated Quantum Simulation

CUDA Quantum
Quantum-Classical Developer Platform

Quantum Integrated GPU Supercomputing
DGX | HGX | DGX Quantum

NVIDIA QUANTUM

Empowering the Quantum Computing Community

QUANTUM HARDWARE BUILDERS

ANYON · atom computing · Google Quantum AI · Infleqtion · IONQ

IQM · OQC · ORCA COMPUTING · PASQAL · PsiQuantum · QUANTINUUM

QUANTUM BRILLIANCE · QuEra COMPUTING INC. · rigetti · seeqc · XANADU

QUANTUM SOFTWARE AND SYSTEMS

agnostiq · CLASSIQ · HQS QUANTUM SIMULATIONS · KIPU QUANTUM · menten.AI

MULTIVERSE COMPUTING · OTI · QCWARE · KILIMANJARO QUANTUM TECH · QM ware

QUANTUM MACHINES · Qubit pharmaceuticals · STRANGEWORKS · ZAPATA

QUANTUM SIMULATION FRAMEWORKS

aws · bluequat · Cirq

Orquestra® · PENNYLANE · QIBO

Qiskit · TensorFlow Quantum · XACC QUANTUM FRAMEWORK

ENTERPRISE PARTNERS

DELL Technologies · Deloitte. · Hewlett Packard Enterprise · softserve

aws · Google Cloud · Microsoft Azure · ORACLE CLOUD Infrastructure

Johnson & Johnson · VW · BMW · GE · SIEMENS Healthineers

RESEARCH CENTERS

ABCI AI Bridging Cloud Infrastructure · Argonne NATIONAL LABORATORY · cea · CINECA · GENCI Le calcul intensif au service de la connaissance · JÜLICH Forschungszentrum · NCSA · NERSC · OAK RIDGE National Laboratory · RIKEN

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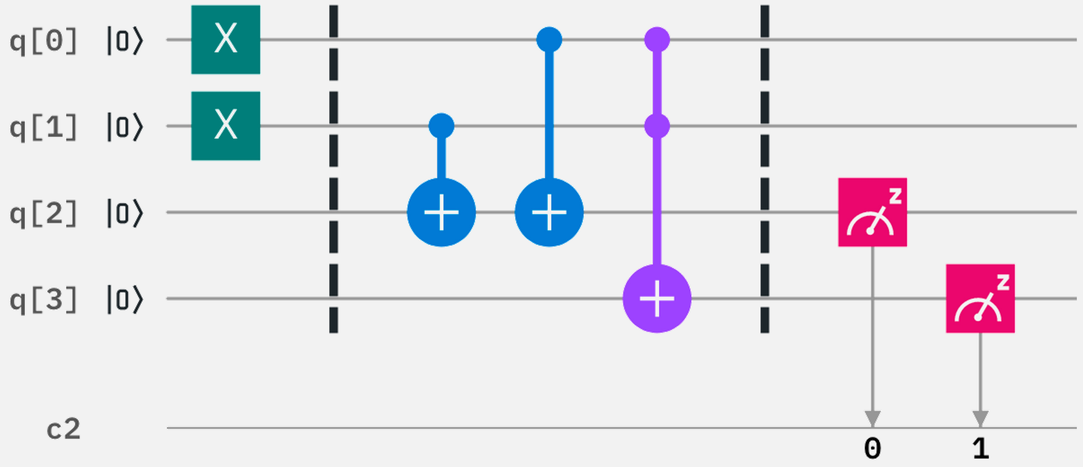

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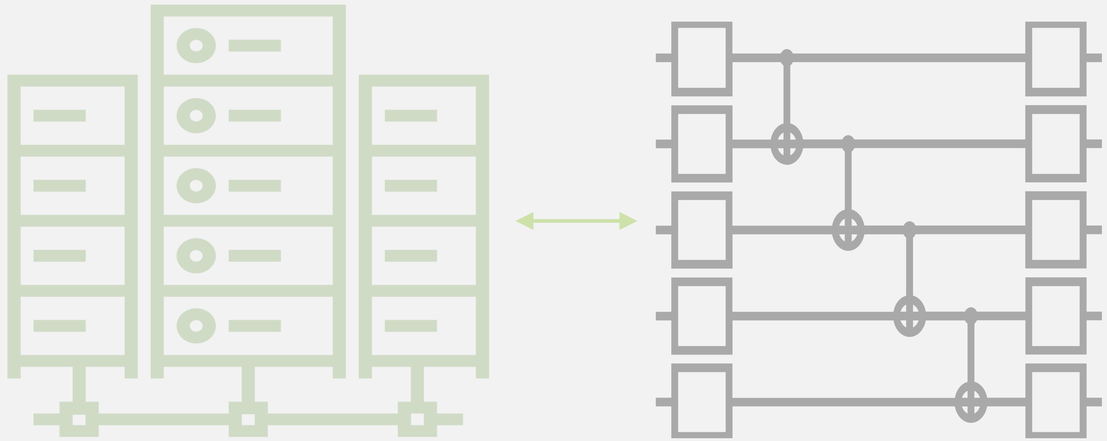

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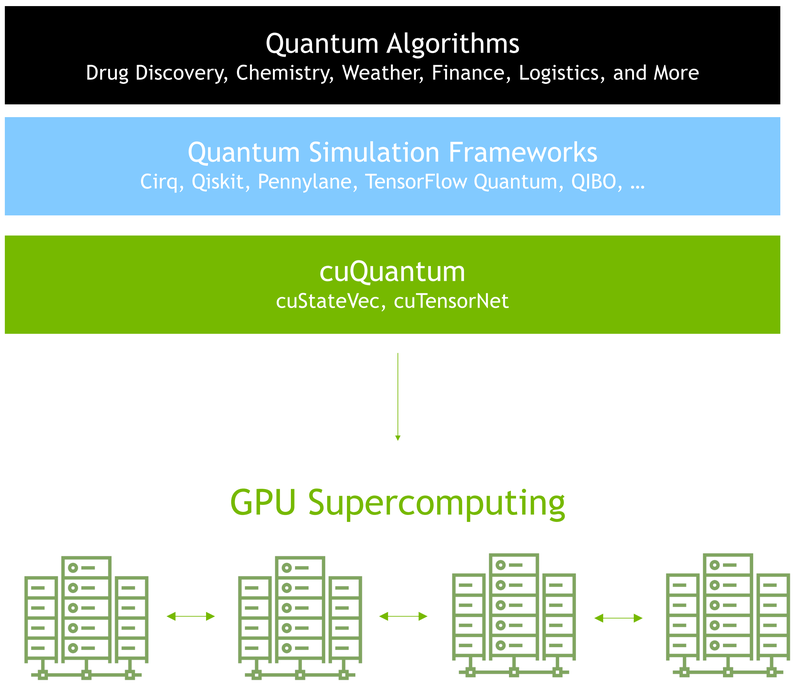
cuQuantum

Research the Quantum Computer of Tomorrow on the most Powerful Computer Today



SDK for GPU Accelerated Quantum Simulation

Simulate Ideal or Noisy Qubits with State Vector or Tensor Network methods

Supports GPU Supercomputing with Multi-Node Multi-GPU Circuit Simulation

Integrated into all leading frameworks

Optimized frameworks in cuQuantum Appliance: catalog.ngc.nvidia.com/orgs/nvidia/containers/cuquantum-appliance

- **Now available as VMI on all major Clouds**

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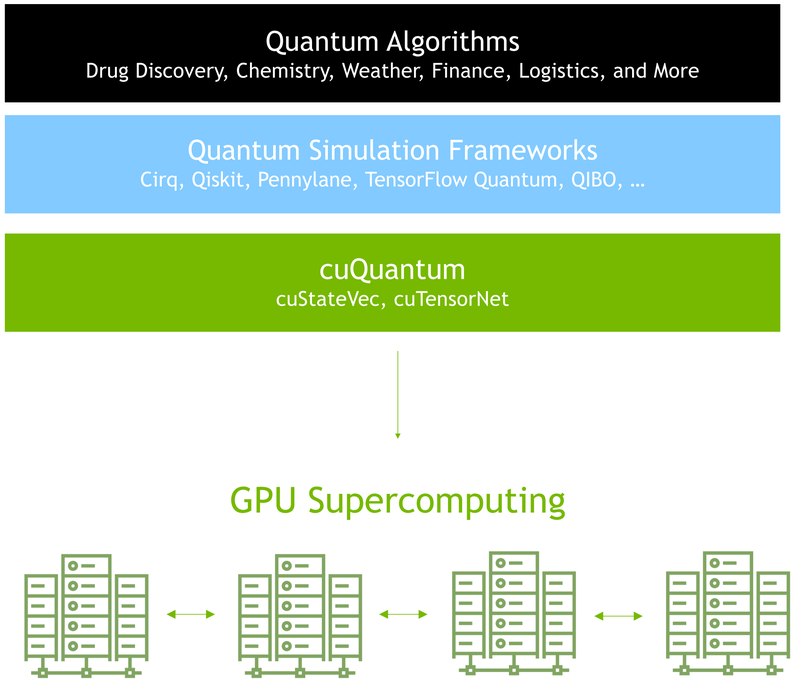

cuQuantum Accelerated Frameworks

aws
bluequat
Cirq
Orquestra®
PENNYLANE
QIBO
Qiskit
TensorFlow Quantum
XACC
QUANTUM FRAMEWORK

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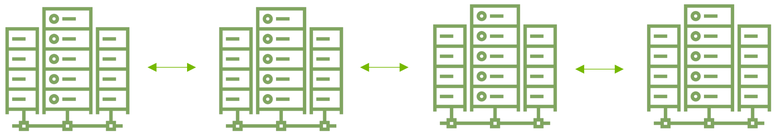
cuQuantum

Quantum Algorithms
Drug Discovery, Chemistry, Weather, Finance, Logistics, and More

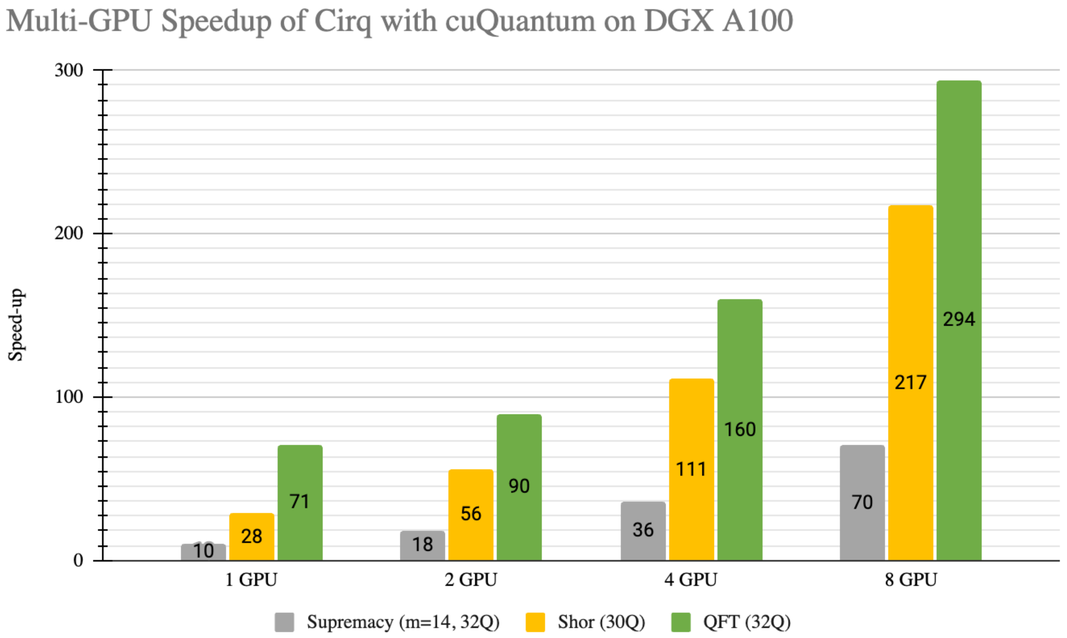
Quantum Simulation Frameworks
Cirq, Qiskit, Pennylane, TensorFlow Quantum, QIBO, …

cuQuantum
cuStateVec, cuTensorNet

GPU Supercomputing



World Class Performance



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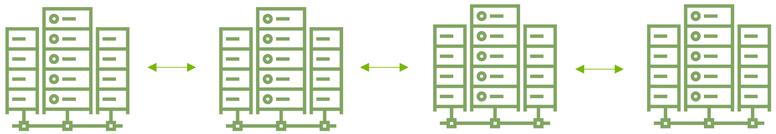
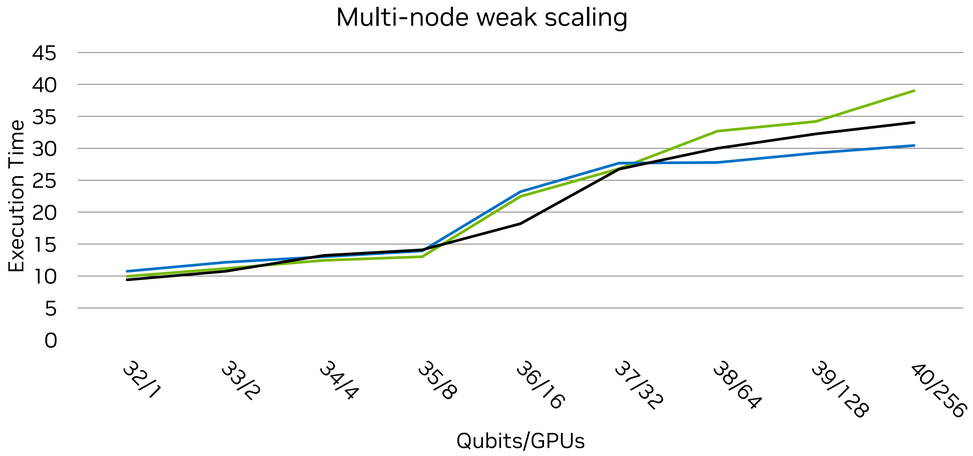


World Class Performance with Now with Multi-Node Multi-GPU



80x speedup over SotA

- Quantum Volume, depth=30
- QAOA
- Quantum Phase Estimation

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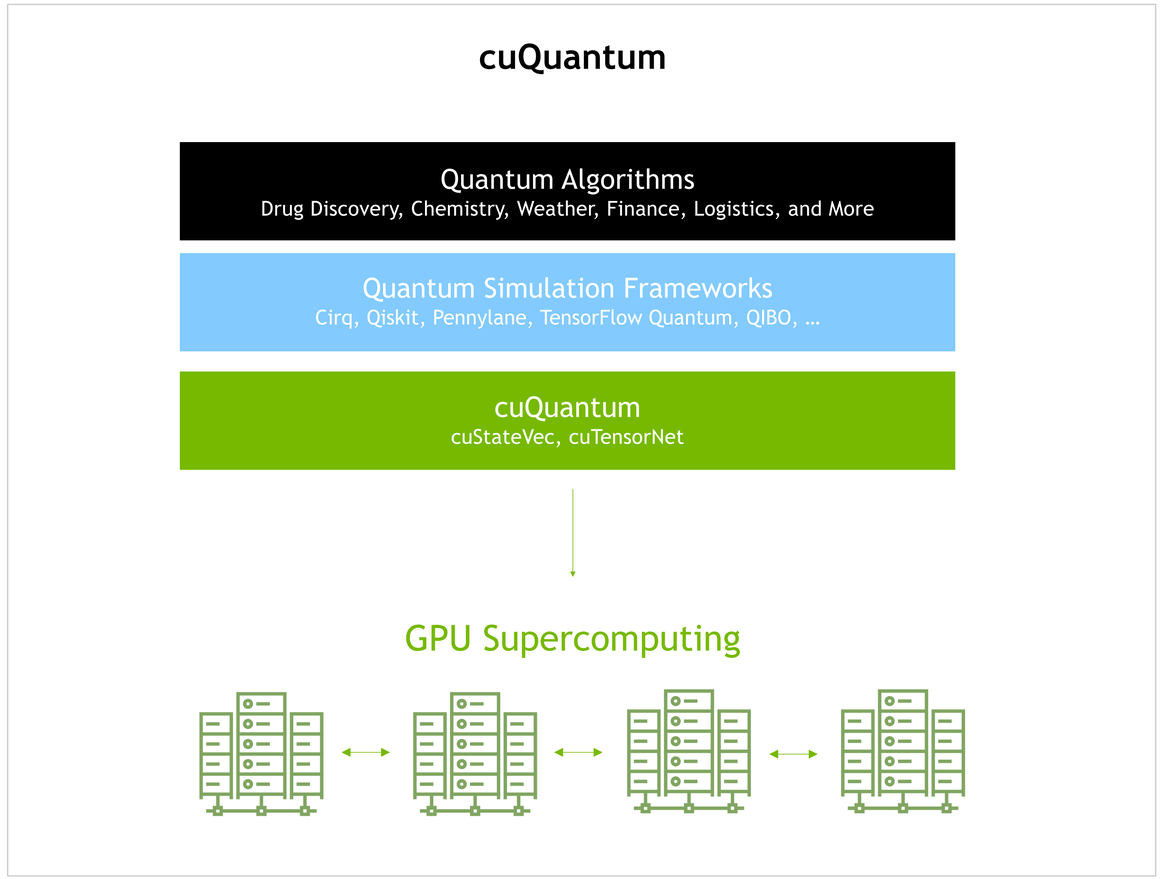

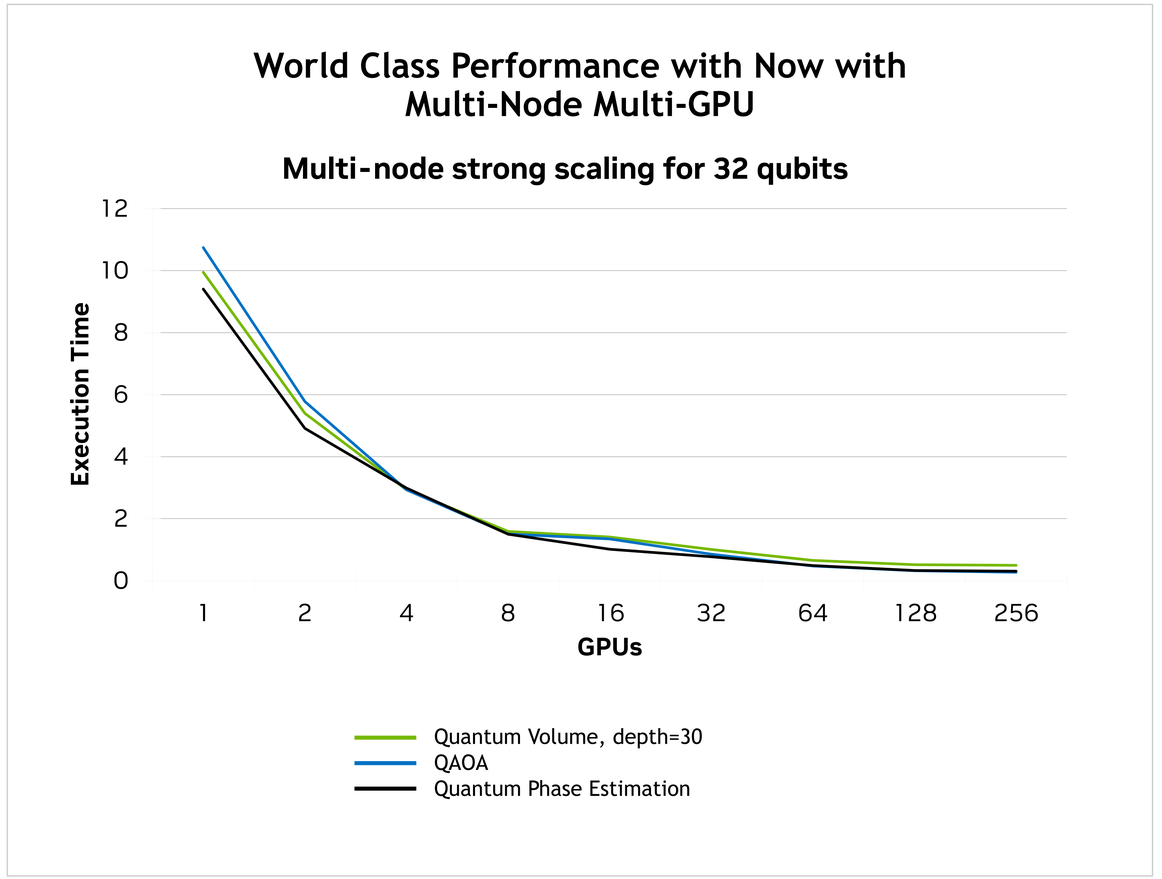

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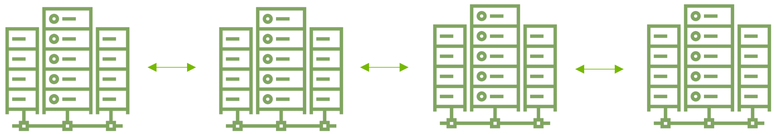
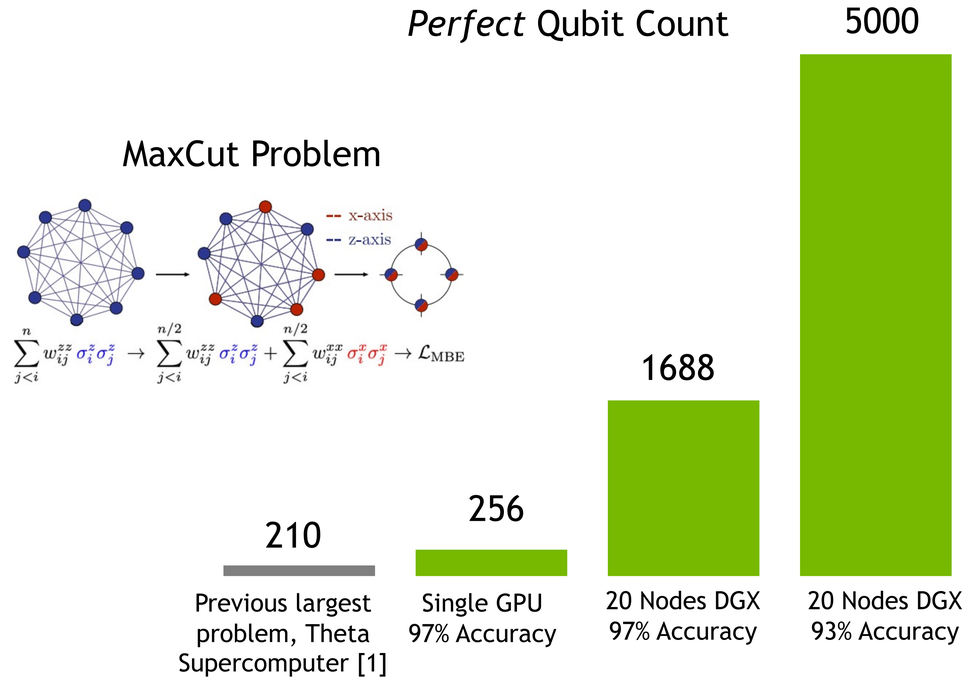


Supercomputing Simulation at FTQC Scale



[1] Danylo Lykov et al, Tensor Network Quantum Simulator With Step-Dependent Parallelization, 2020
https://arxiv.org/pdf/2012.02430.pdf

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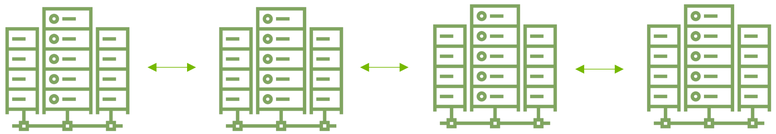

Powering Industrial Research

BMW
QAOA
Path Planning & Vehicle Options Optimization

Deloitte.
QNLP
Materials Research

GE
VQE
Carbon Capture

Johnson & Johnson
VQE
VQE applied to 7MER Protein Folding

SIEMENS Healthineers
QSVM
Medical Image Processing

softserve
QRNN | QGRU
For Portfolio Optimization
Stock Price Modeling

GPU Supercomputing and Quantum

Researching the Quantum Computers of Tomorrow with the Supercomputers of Today

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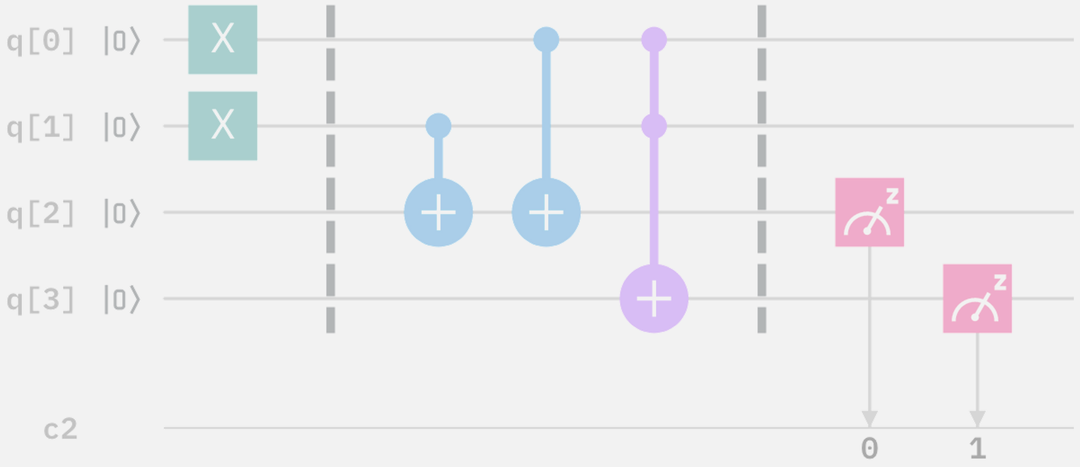

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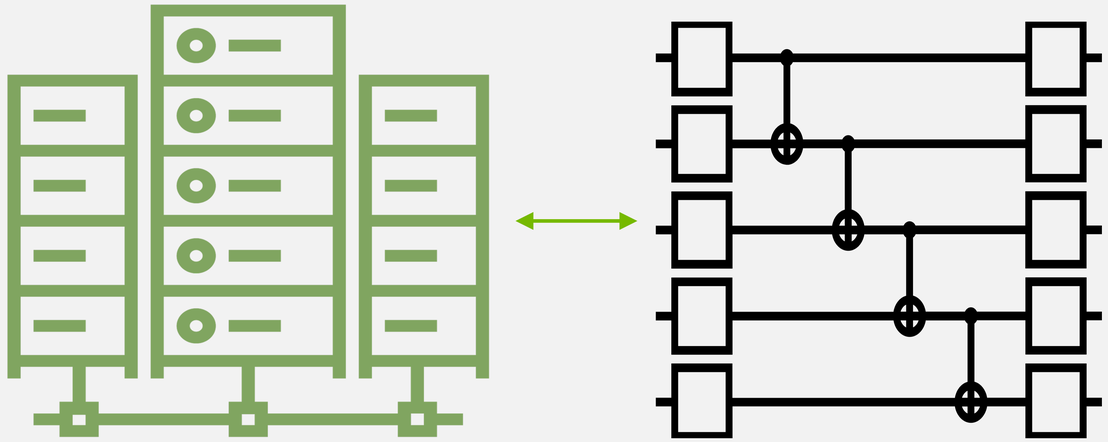

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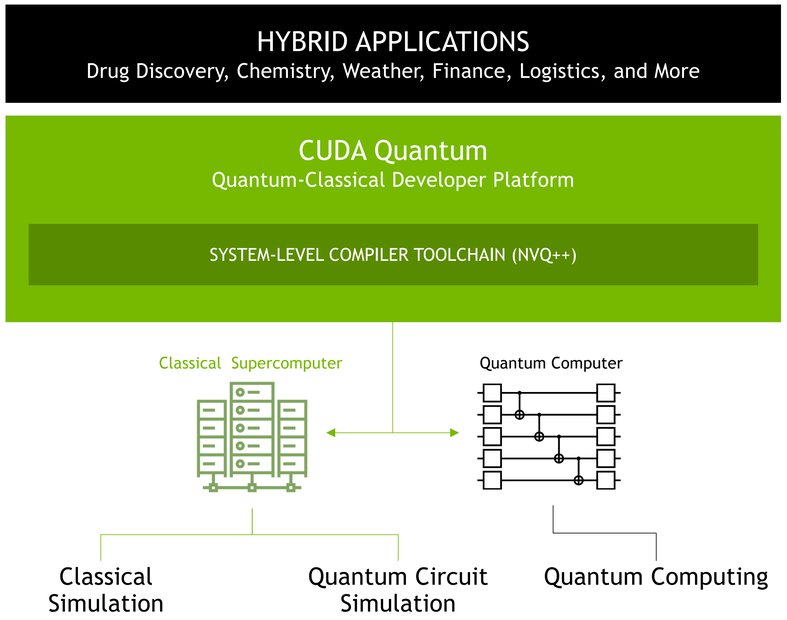
CUDA Quantum: Now Available on GitHub and NGC

A Platform For Quantum-Classical Computing

CUDA QUANTUM PLATFORM



CUDA QUANTUM FEATURES

Supports any kind of QPU, emulated or physical

Compiler for hybrid systems

Open and interoperable with today's applications

Single source C++ and Python programming model

github.com/nvidia/cuda-quantum | https://catalog.ngc.nvidia.com/orgs/nvidia/containers/cuda-quantum

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Natively Hybrid And Interoperable With GPU Supercomputing

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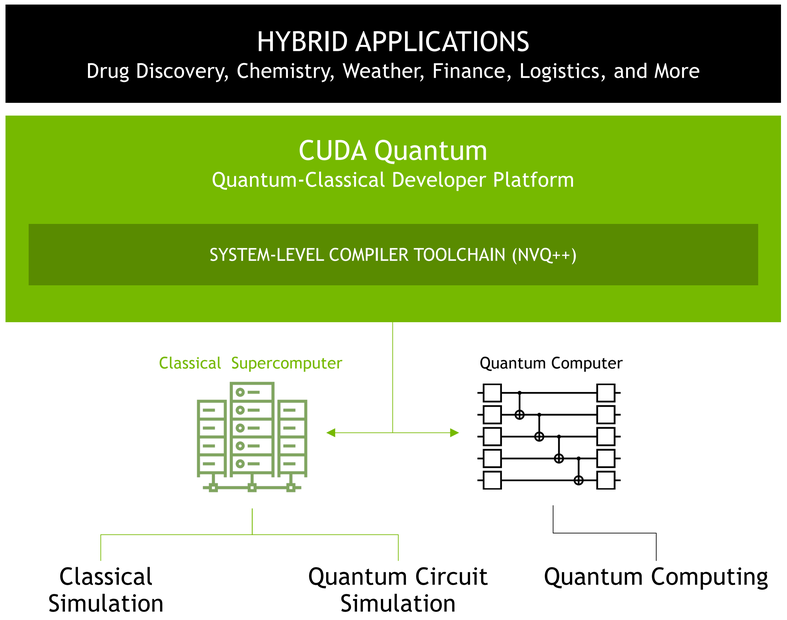

Interoperable with GPU Supercomputing

```
auto cnts = cudaq::sample(q, …);
```

ISO Standard Parallelism

```
std::sort(std::execution::par, …);
```

CUDA

```
kernel<<<…>>>(…);
cudaDeviceSynchronize();
```

OpenMP

```
#pragma omp target teams loop
for (…) …
```

OpenACC

```
#pragma acc parallel loop
for (…) …
```

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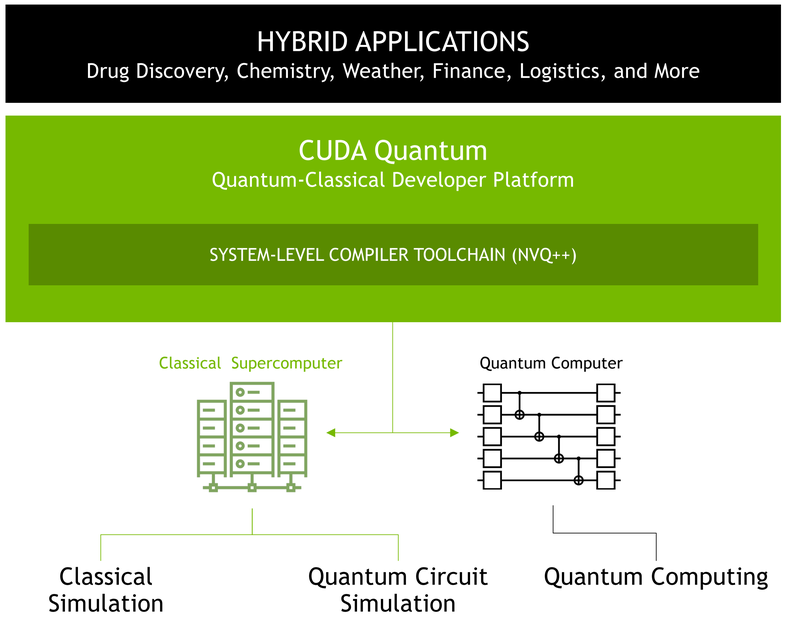

Interoperable with GPU Supercomputing

```
// Compute expectation values with QPU.
cudaq::spin_op h = ...;
std::vector<double> sig_exps;
for (auto& pauli_op : generate_pauli_permutations(h.n_qubits()))
  sig_exps.push_back(cudaq::observe(qite, pauli_op, ...));
```

```
...
// Compute LU Factorization of S_mat on the GPU.
auto dim = std::pow(2, h.n_qubits());
cusolverDnXgetrf(handle, params, dim, dim, CUDA_C_64F, S_mat,
                 lda, NULL, CUDA_C_64F,
buffer_on_device,
                 bytes_on_device, buffer_on_host,
                 bytes_on_host, info);
```

github.com/nvidia/cuda-quantum | https://catalog.ngc.nvidia.com/orgs/nvidia/containers/cuda-quantum

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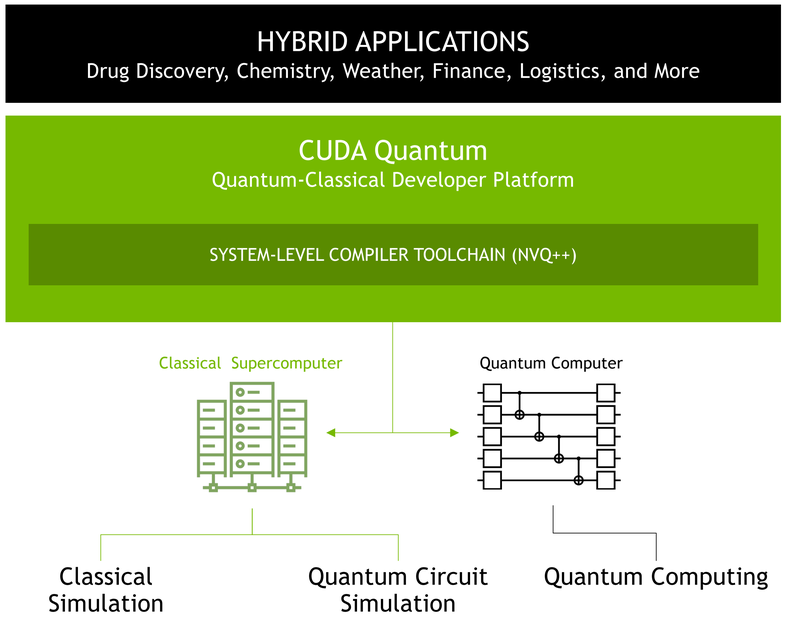
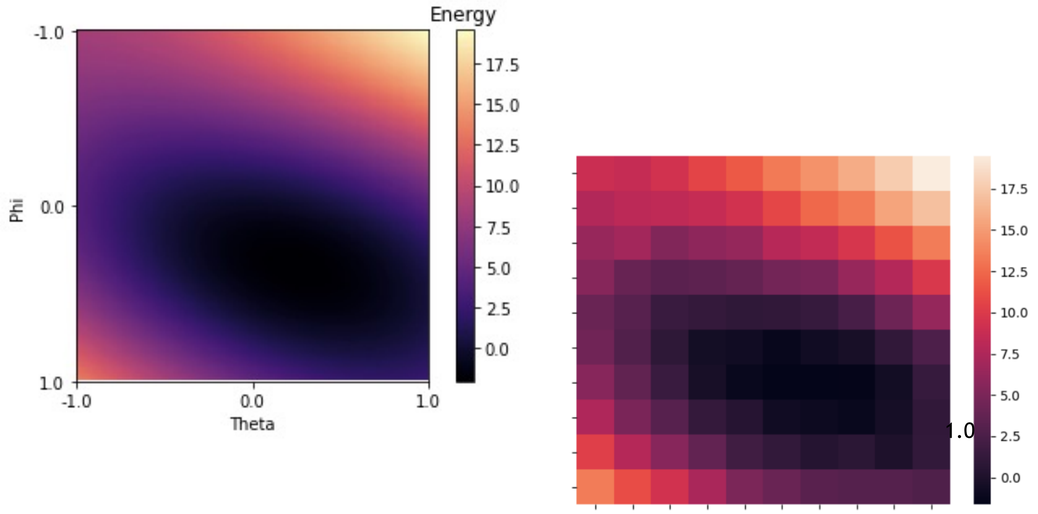
Seamlessly Target any Quantum Resource

CUDA QUANTUM PLATFORM



CUDA Quantum and Quantinuum

```
nvq++ -qpu=cuquantum vqe.cpp
```




```
nvq++ -qpu=quantinuum:h1 vqe.cpp
```

github.com/nvidia/cuda-quantum | https://catalog.ngc.nvidia.com/orgs/nvidia/containers/cuda-quantum

VQE: NVQ++/cuStateVec on A100 GPU vs Leading Pythonic Framework and SImulator with Thrust on A100 GPU

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NVIDIA Quantum

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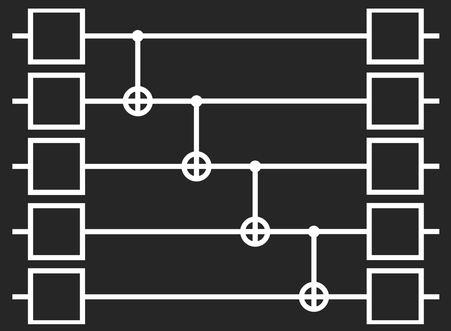
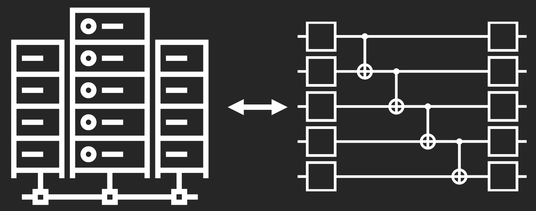


Quantum-Integrated Applications



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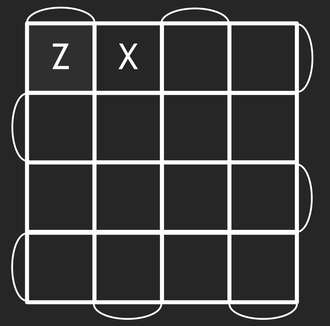

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NVIDIA