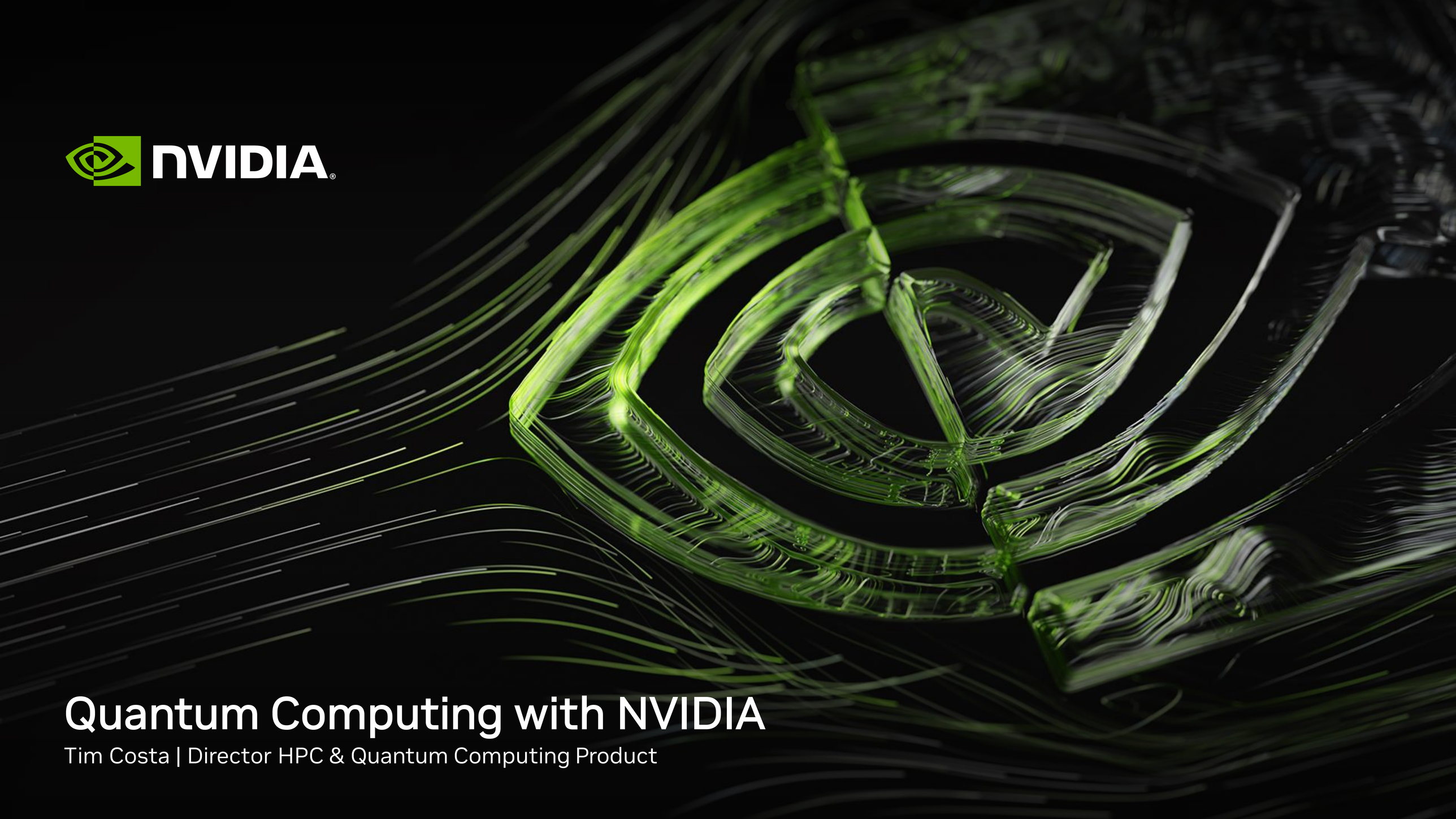


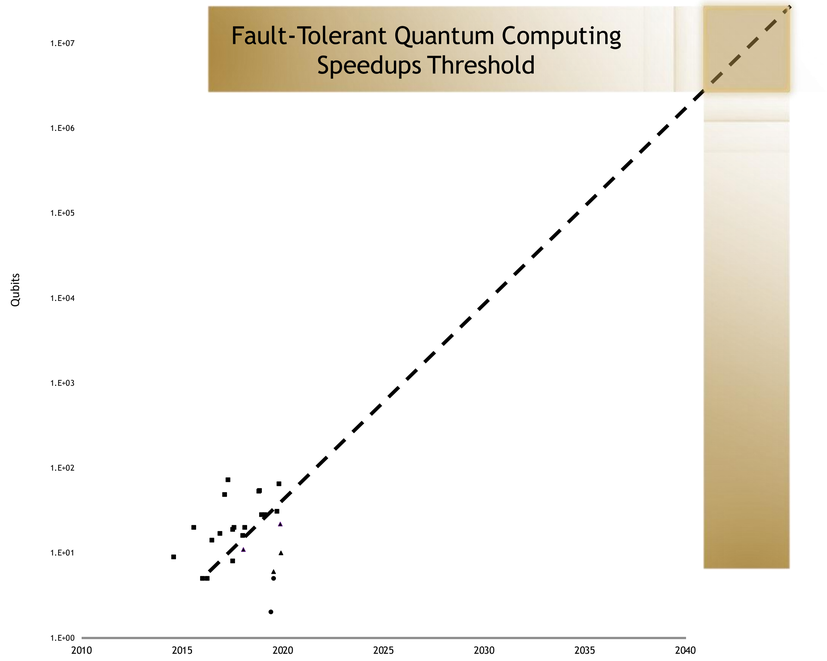
Quantum Computing with NVIDIA

Tim Costa | Director HPC & Quantum Computing Product

CURRENT STATE OF Quantum computing research

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

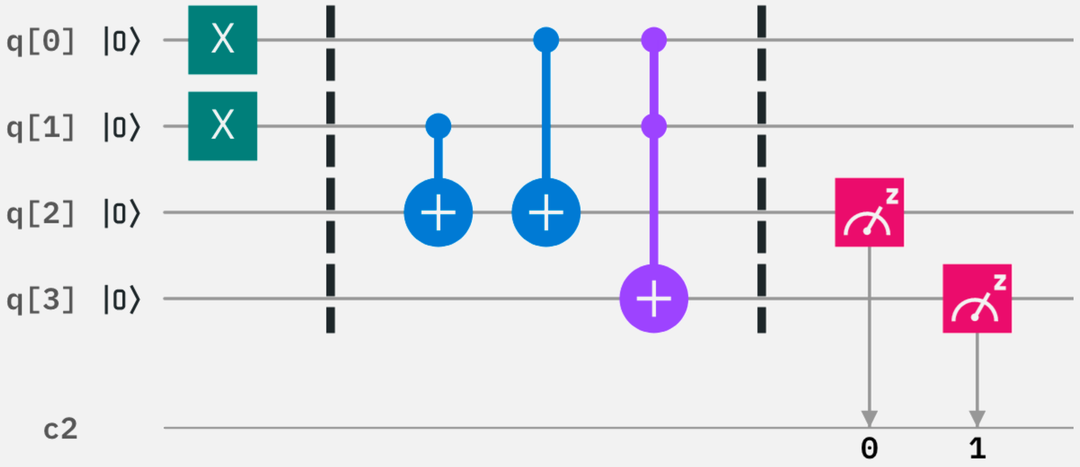
Government national initiatives source: https://qureca.com/overview-on-quantum-initiatives-worldwide-update-2022/ | Industry source: https://hyperionresearch.com/wp-content/uploads/2021/12/Hyperion-Research-QC-User-Uptake-Study-November-2021.pdf
Higher Ed/Research source: Papers published on ArXiv for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

NVIDIA

GPU Supercomputing and Quantum

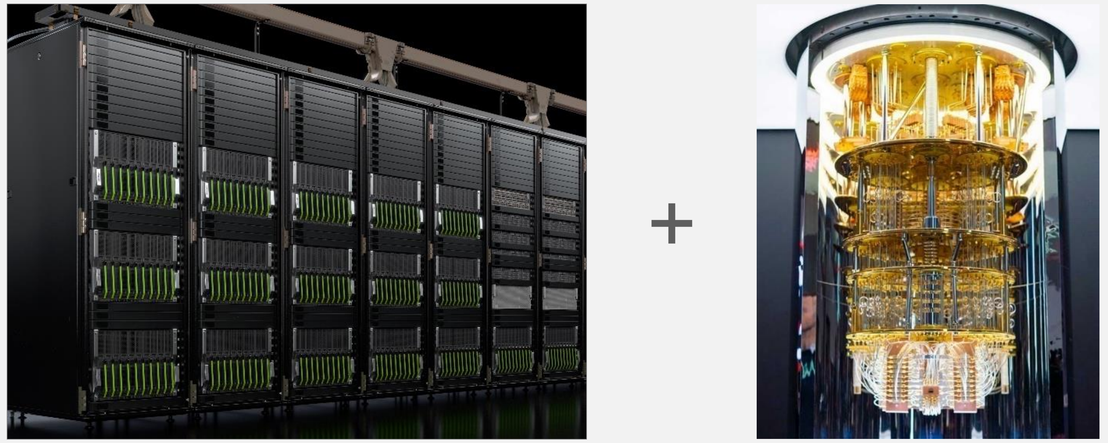
Researching the Quantum Computers of Tomorrow with the Supercomputers of Today

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



- Develop quantum applications by integrating quantum into leading accelerated applications
- Build a platform that is familiar to domain scientists
- Unparalleled performance and scientific productivity using the best resource for the task

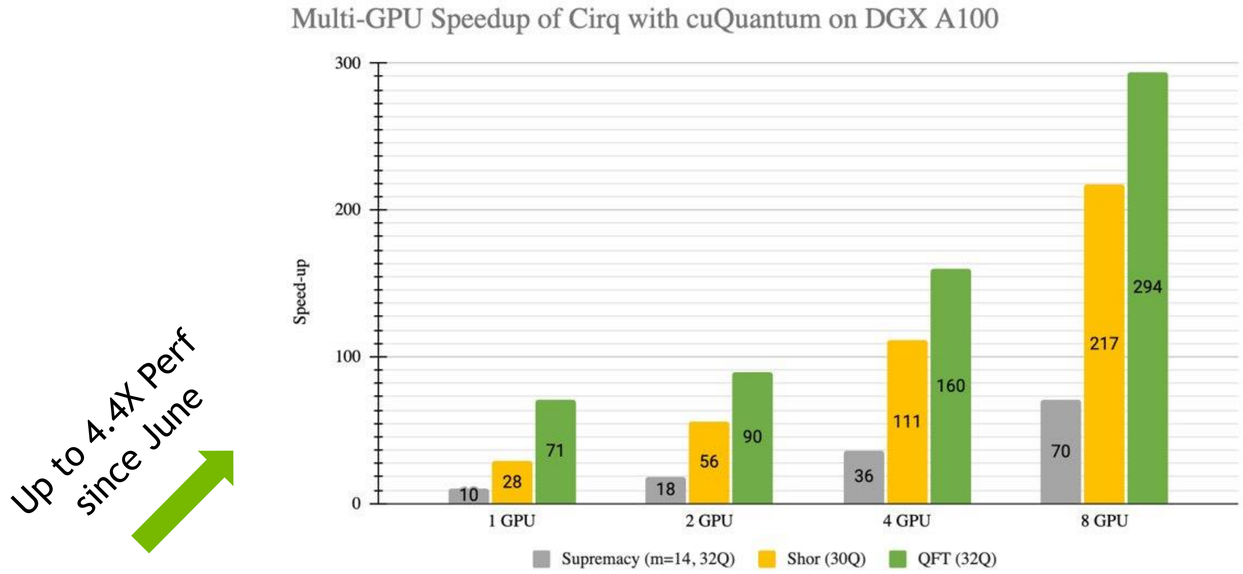
cuQuantum Appliance

Continuous Performance Improvement

Fully integrated quantum simulation solution
- State-of-the-art ***performance***
- Unmatched simulation ***scale***

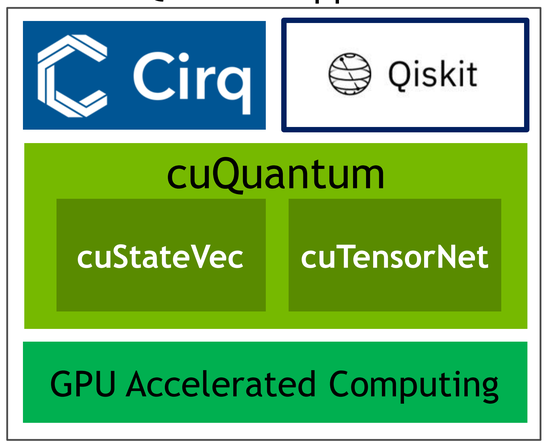
Reduce the simulation time by ***orders of magnitude***

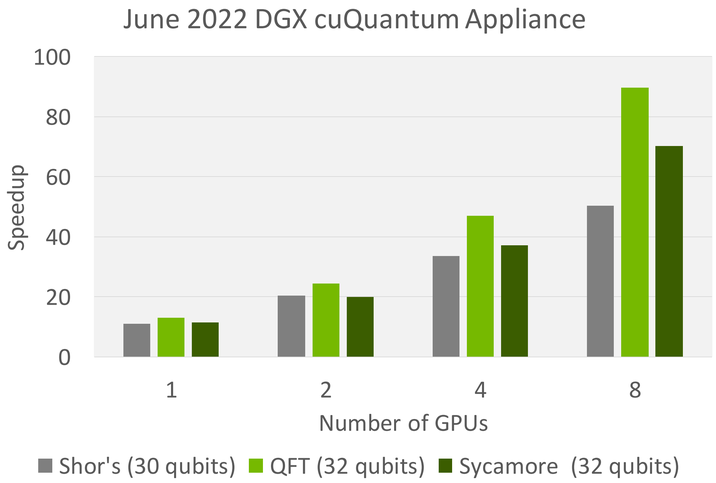
Simulate ***thousands*** of perfect or noisy qubits



Up to 4.4X Perf since June

cuQuantum Appliance





cuQuantum Appliance

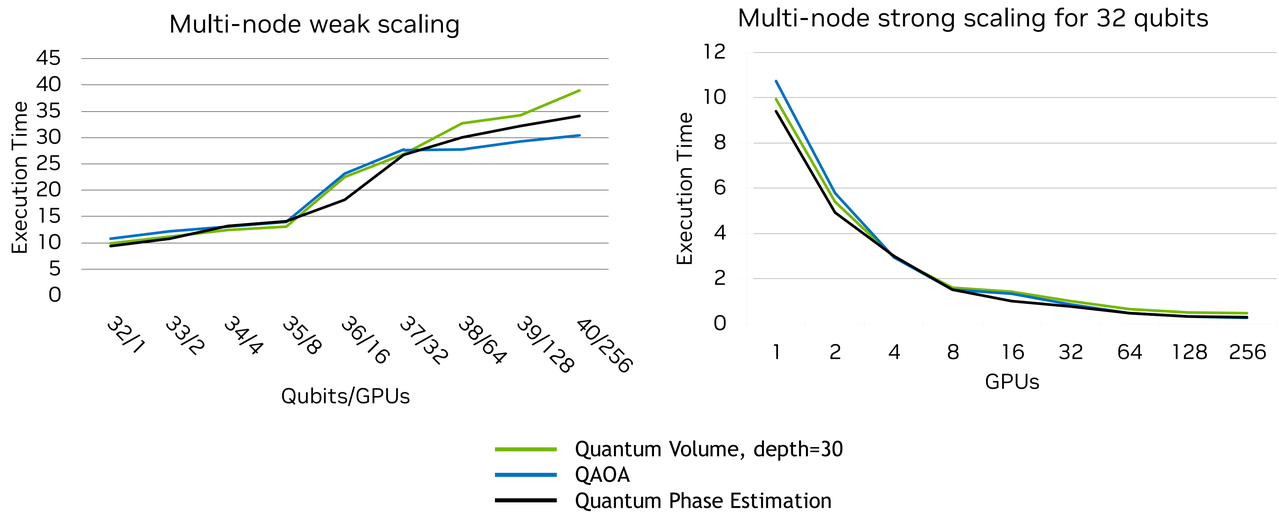
Coming in Q4: multi-node, multi-GPU support

Fully integrated quantum simulation solution
- State-of-the-art ***performance***
- Unmatched simulation ***scale***

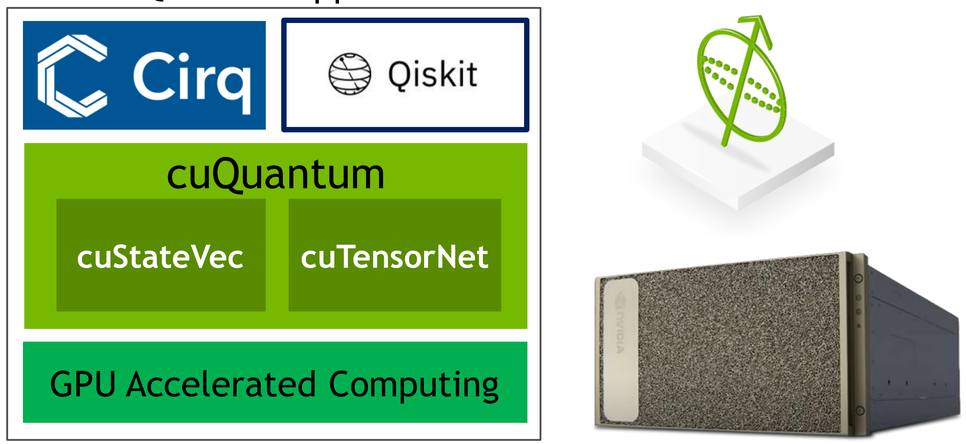
Reduce the simulation time by ***orders of magnitude***

Simulate ***thousands*** of perfect or noisy qubits

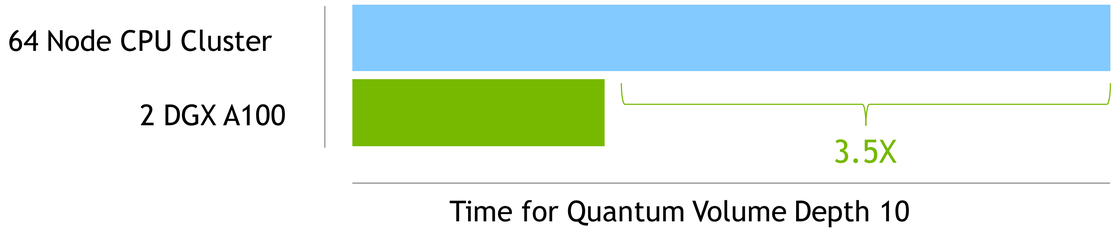
Trivially Scale Quantum Algorithms with Industry Leading Performance



cuQuantum Appliance



Record breaking performance
2 DGX A100 vs previous best on 64 node CPU cluster



NVIDIA CUQUANTUM
POWERING QUANTUM COMPUTING RESEARCH

PASQAL
Faster Quantum Algorithm for Physics-ML

100X
Faster Time-to-Solution

24X
More Circuit Depth

PASQAL

AWS & XANADU
PennyLane Integration via AWS Braket

900X
Faster Time-to-Solution

3.5X
Lower Costs

aws Amazon Braket

PENNYLANE

ZAPATA
Orquestra® Platform Integration

100X
Faster Time-to-Solution

1.5X
More qubits

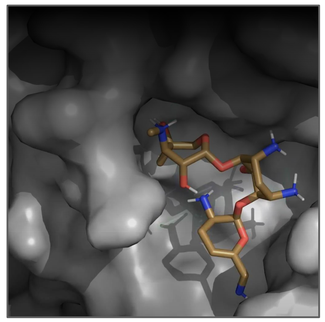
ZAPATA

Pasqal results found here: https://www.nvidia.com/gtc/session-catalog/?tab.scheduledorondemand=1583520458947001NJiE&search=henriet#/session/1636127265656001 85rl
AWS and Xanadu results and demonstration found here: https://aws.amazon.com/blogs/quantum-computing/using-embedded-simulators-in-amazon-braket-hybrid-jobs/
Zapata: CPU- AWS c5.xlarge nodes (4 vCPU, 8GB Memory), GPU-AWS p3.2xlarge nodes (1x Tesla V100 GPU w 16GB GPU Mem) with projected linear scaling of Custatevec, up to 100X faster using DGX-1 (with 8X V100s)

NVIDIA CUQUANTUM

POWERING INDUSTRIAL QUANTUM COMPUTING

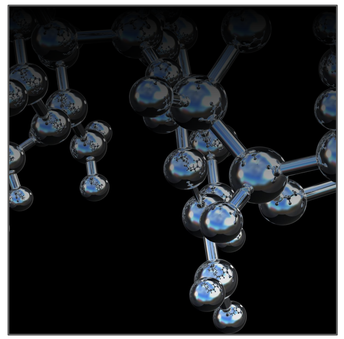
Johnson & Johnson



VQE

100X Speedup for VQE applied to 7MER Protein Folding in collaboration with Strangeworks

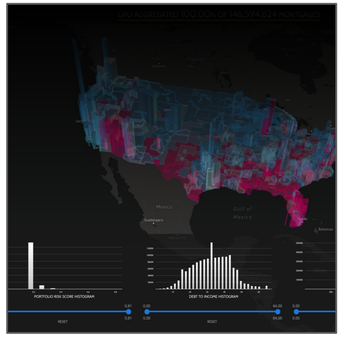
Deloitte.



QNLP

For Materials Research

softserve



QRNN & QGRU

For Portfolio Optimization and Stock Price Modeling

BMW

QAOA

For Path Planning & Vehicle Options Optimization

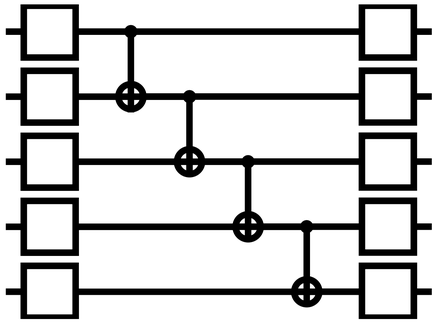
NVIDIA cuQuantum Ecosystem

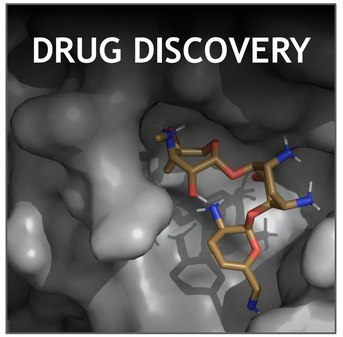
ALL VALUABLE QUANTUM APPLICATIONS WILL BE HYBRID

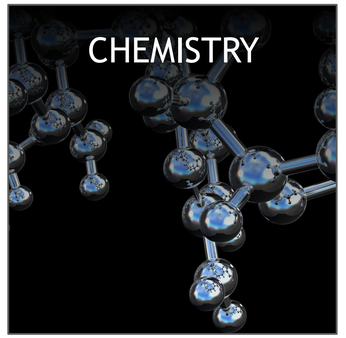
Various Scientific Domains

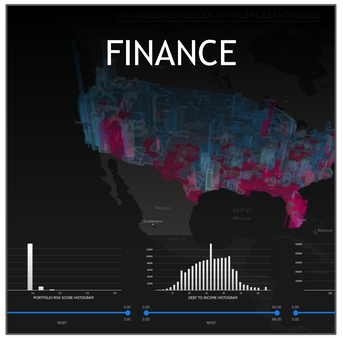
Classical Supercomputer

Quantum Computer





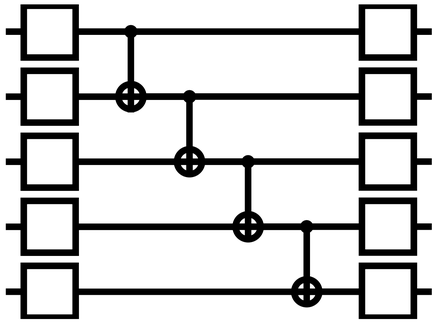




ECOSYSTEM GAPS LIMIT THE PROGRESS OF HYBRID QUANTUM APPLICATIONS

Classical Supercomputer

Quantum Computer



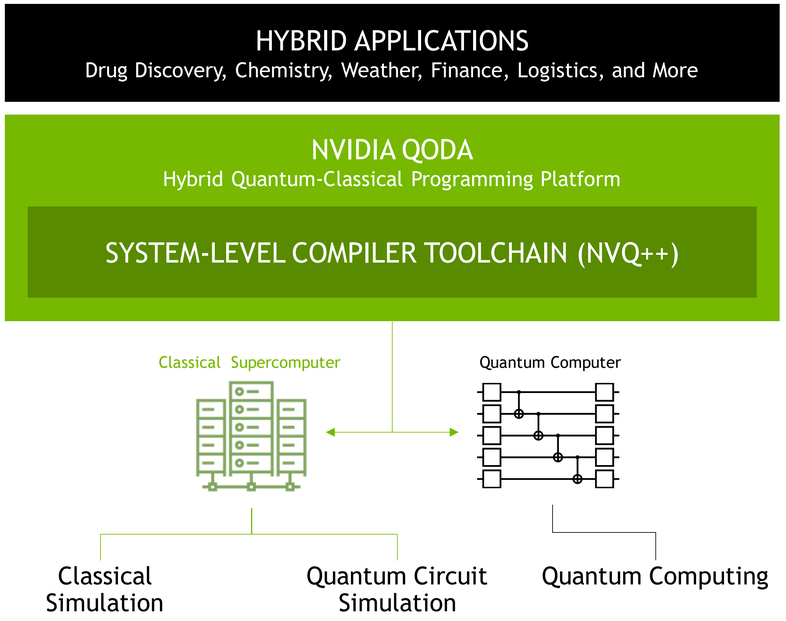
ECOSYSTEM CHALLENGES

- No Performant Software Stack
- Not Accessible To Domain Scientists
- Hybrid System Bottlenecks

Introducing NVIDIA QODA

A Platform For Hybrid Quantum-classical Computing

NVIDIA QODA PLATFORM



QODA FEATURES

Supports any kind of QPU, emulated or physical

Compiler for hybrid systems

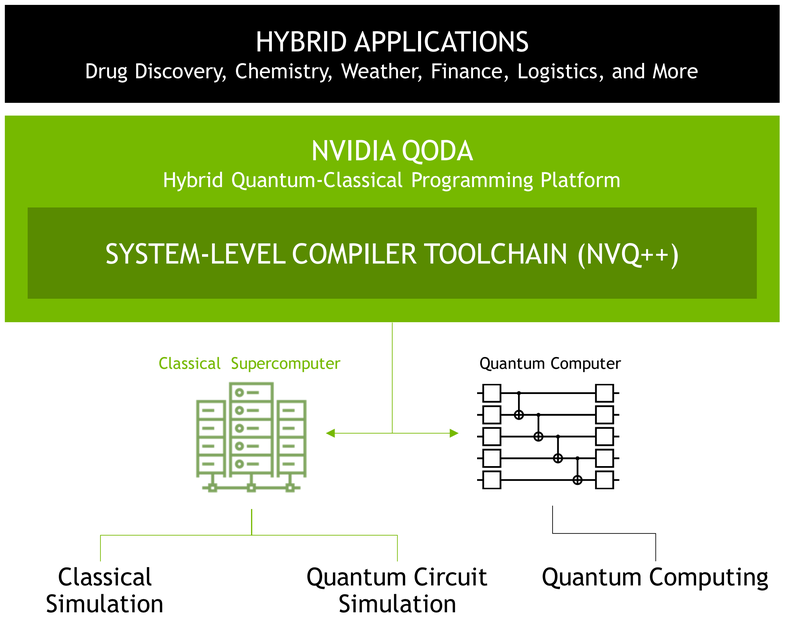
Open and interoperable with today's applications

Single source C++ and Python programming model

Introducing NVIDIA QODA

Adopted by Community's Global Leaders to Enable Quantum-Accelerated Applications

NVIDIA QODA PLATFORM



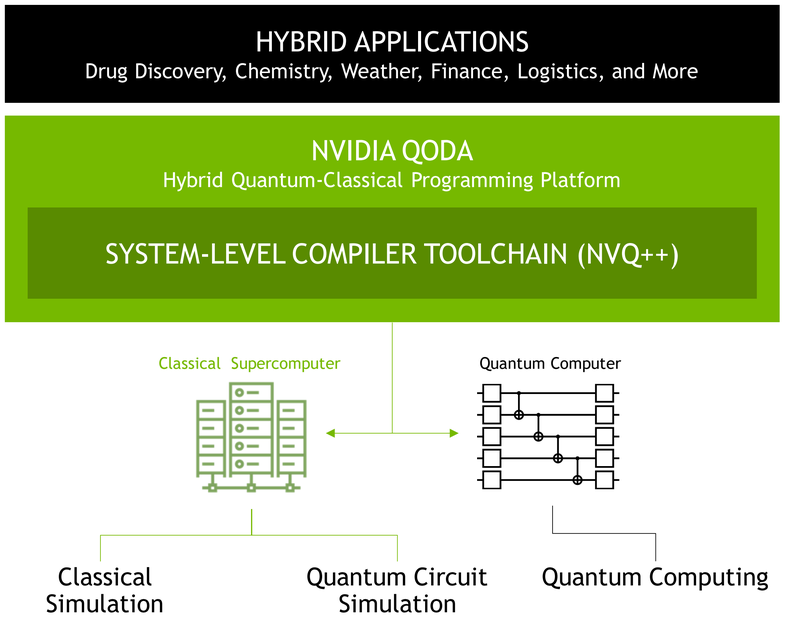
QODA PLATFORM ECOSYSTEM

IQM
PASQAL
QUANTUM BRILLIANCE
QUANTINUUM
rigetti
XANADU
Microsoft
CLASSIQ
QCWARE
ZAPATA
JÜLICH Forschungszentrum
NERSC
OAK RIDGE National Laboratory
RIKEN

Introducing NVIDIA QODA

Natively Hybrid And Interoperable With GPU Supercomputing

NVIDIA QODA PLATFORM



Interoperable with GPU Supercomputing

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

Standard Parallelism

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

CUDA

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

OpenMP

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

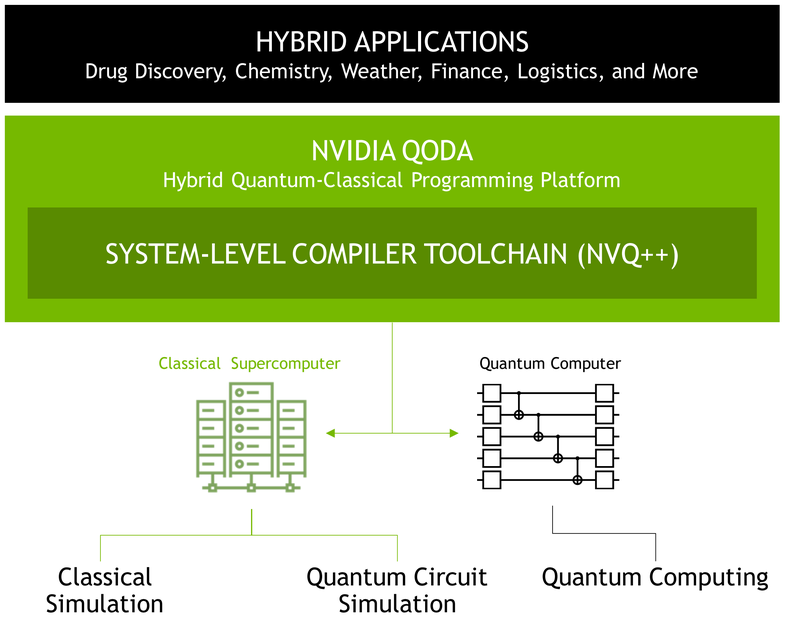
OpenACC

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

Introducing NVIDIA QODA

Natively Hybrid And Interoperable With GPU Supercomputing

NVIDIA QODA PLATFORM



Interoperable with GPU Supercomputing

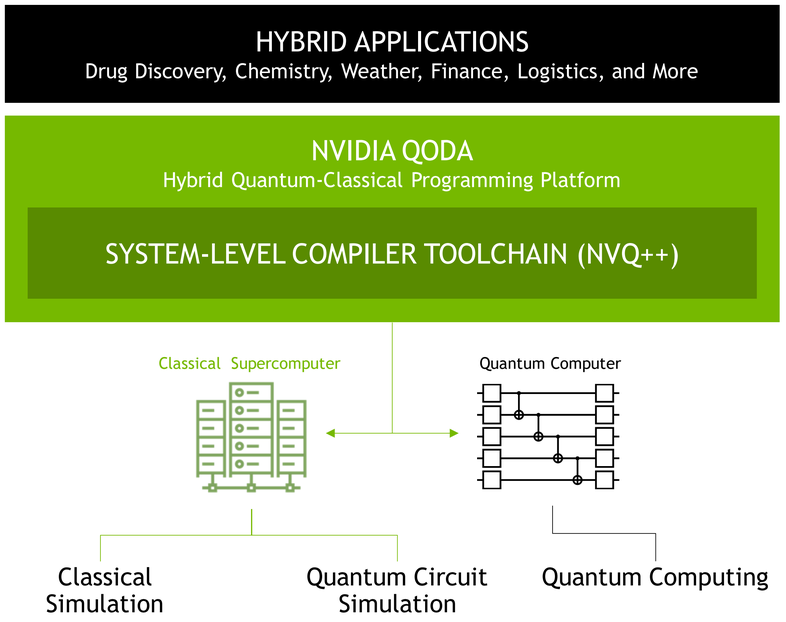
```
// Compute expectation values with QPU.
qoda::spin_op h = ...;
std::vector<double> sig_exps;
for (auto& pauli_op : generate_pauli_permutations(h.n_qubits()))
  sig_exps.push_back(qoda::observe(qite, pauli_op, h.n_qubits()));
```

```
...
// 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);
```

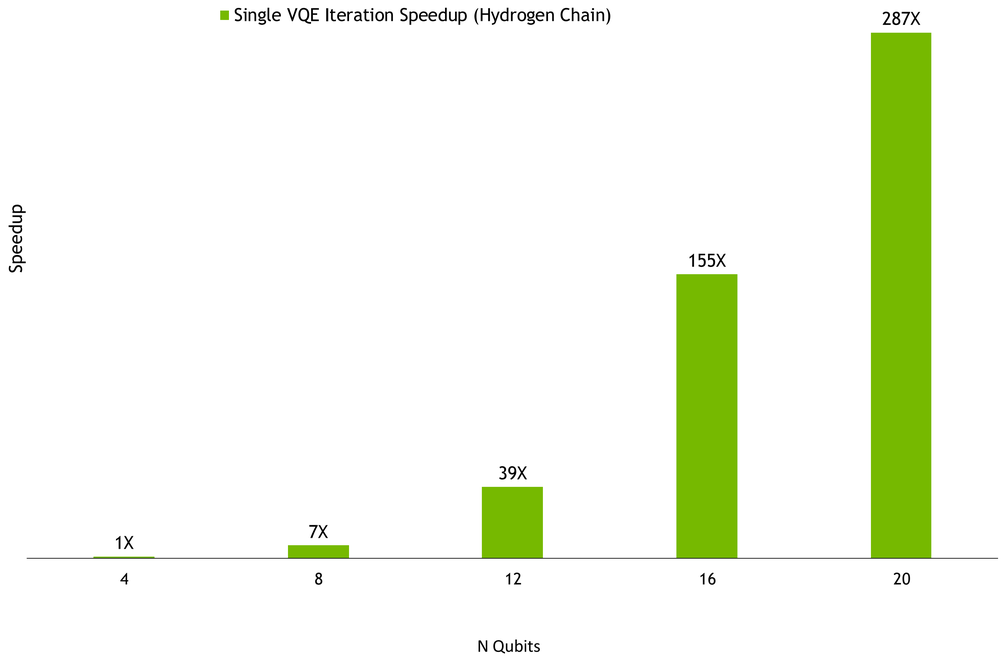
Introducing NVIDIA QODA

Delivering Unmatched Performance, Scalability, And Usability

NVIDIA QODA PLATFORM



ENGINEERED FOR PERFORMANCE AND SCALE

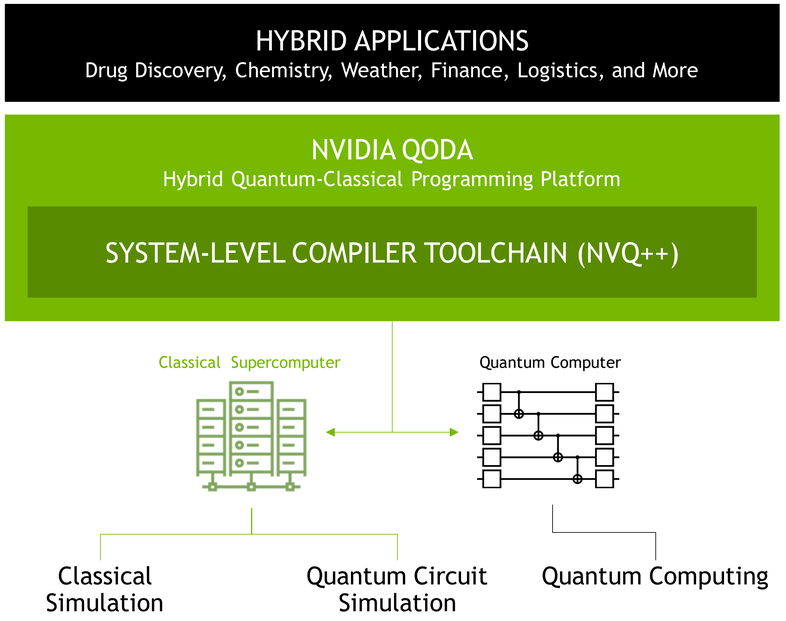


VQE: NVQ++/cuStateVec on A100 GPU vs Leading Pythonic Framework and SImulator with Thrust on A100 GPU

Introducing NVIDIA QODA

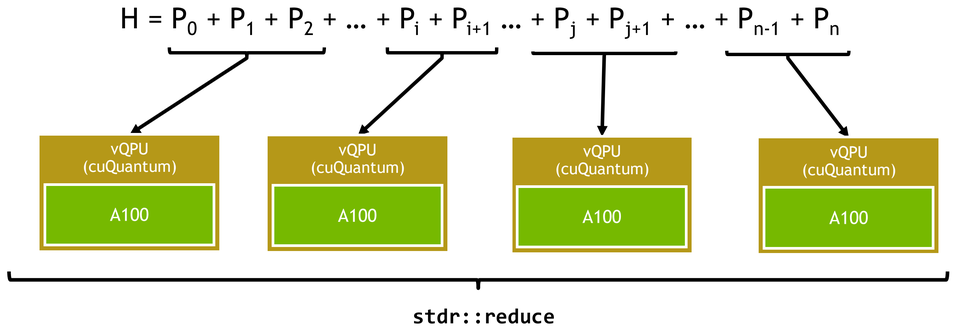
Enabling Innovative Quantum Systems Research

NVIDIA QODA PLATFORM



Experiment on Future Quantum Systems

```
std::vector<qoda::observe_sender<double>> subs;
for (auto qpu : qoda::all_qpus()) {
 auto sub_H = H.subspan(qpu.idx() * terms_per_qpu, (qpu.idx() + 1) *
terms_per_qpu);
  subs.emplace_back(
    qoda::observe_async(qpu, sub_H, ansatz, ...));
}
auto sum = stdr::reduce(std::execution::par, qoda::when_all(subs), 0.0);
```



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

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Enabling Innovative Quantum Systems Research

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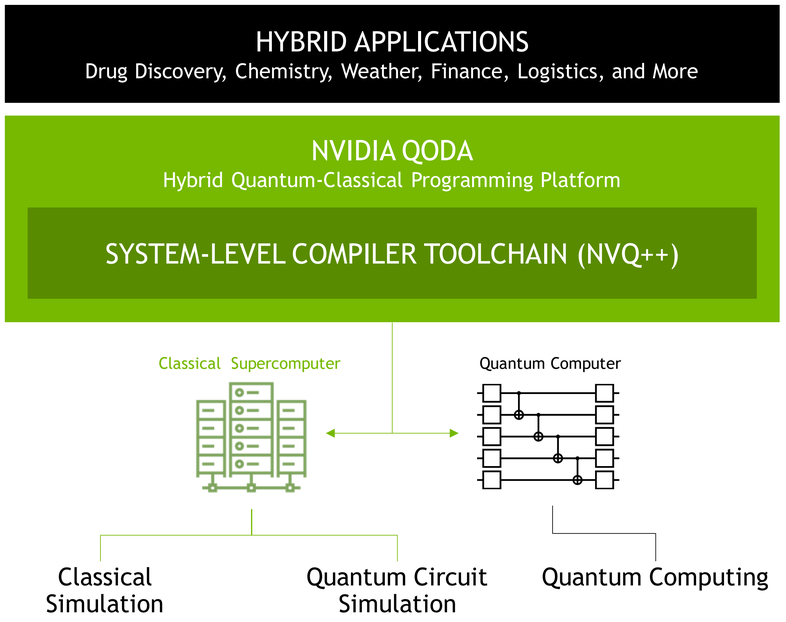
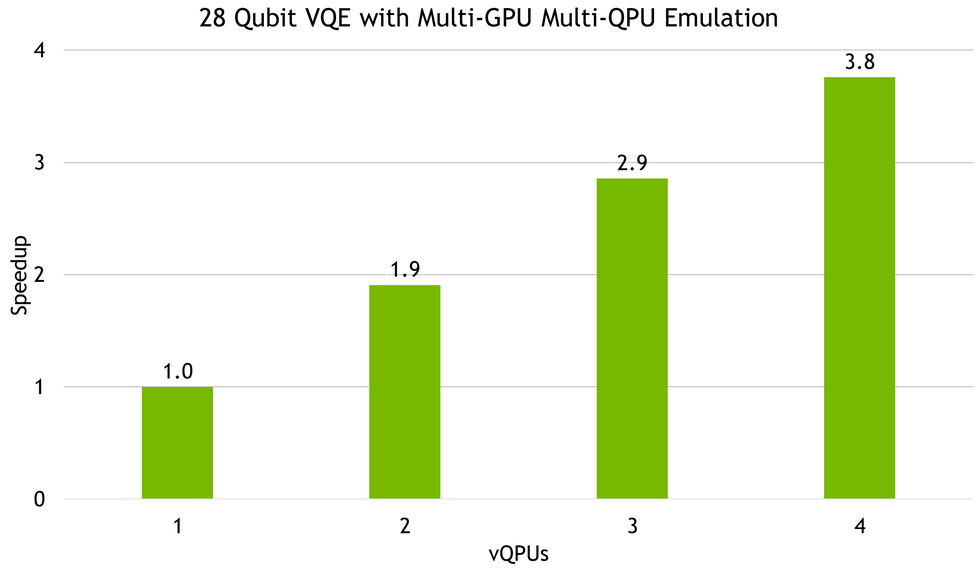


Experiment on Future Quantum Systems



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


NVIDIA