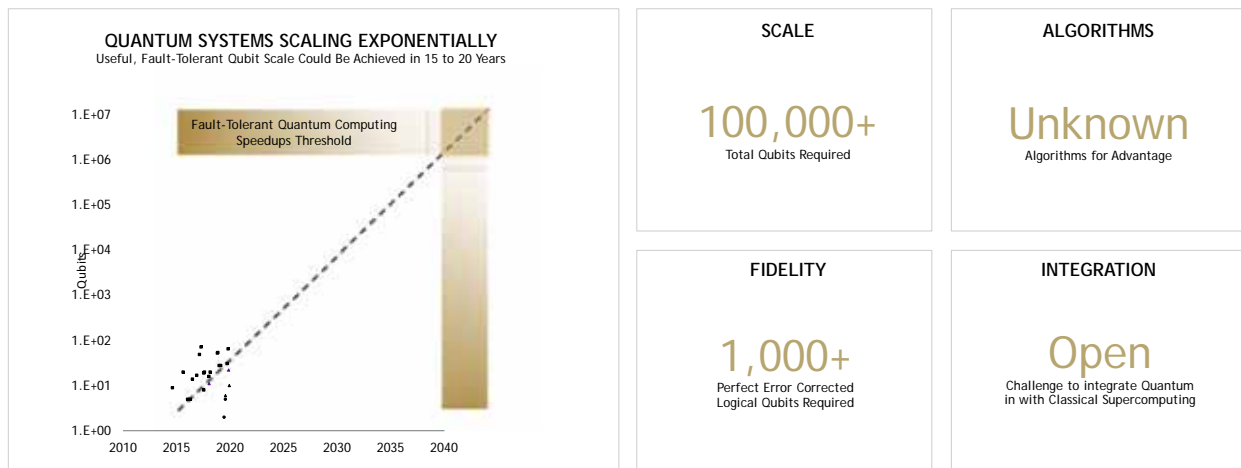




Integrated Quantum-Classical Applications with CUDA Quantum

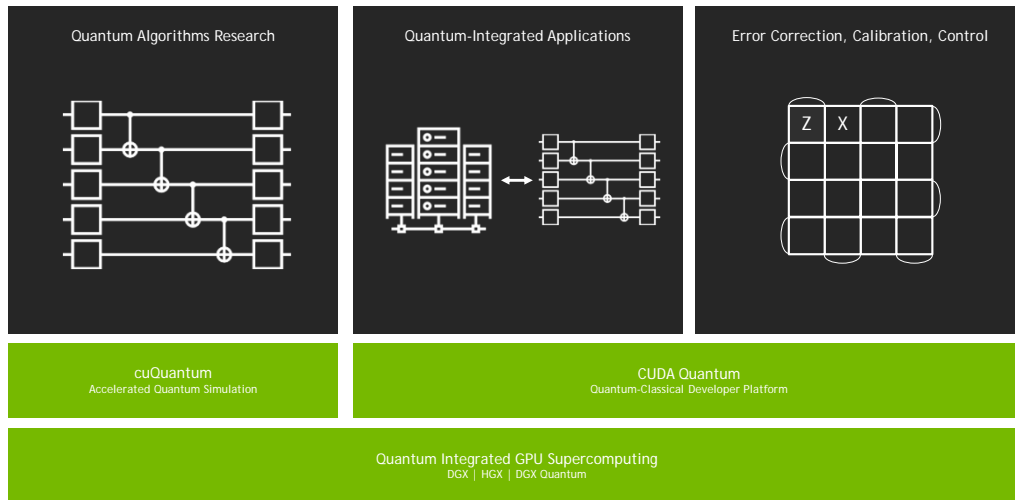
Jin-Sung Kim, PhD
Developer Relations Mgr, Quantum Computing
NVIDIA

Challenges for Useful Quantum Computing



NVIDIA Quantum

Powering Quantum Simulation and Quantum-Integrated Accelerated Computing



NVIDIA QUANTUM

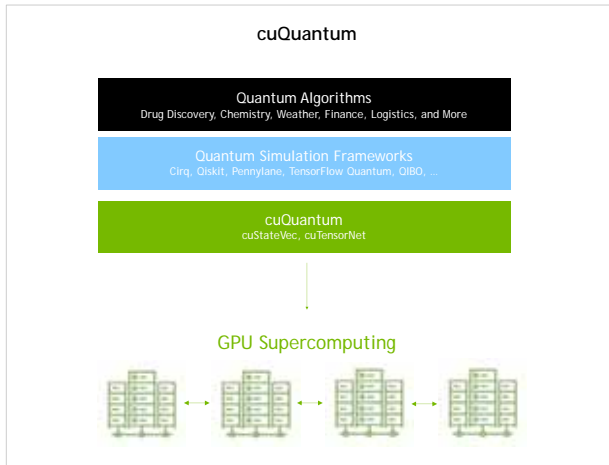
Empowering the Quantum Computing Community

The image shows a server rack with various logos categorized into five groups:

- QUANTUM HARDWARE BUILDERS:** ANYON, atom computing, Google Quantum AI, Infleqtion, IONQ, IQM, OQC, PASQAL, PsiQuantum, QUANTINUM, QUANTUM BRILLIANCE, QuEra, rigetti, seec, XANADU.
- QUANTUM SOFTWARE AND SYSTEMS:** agnostiq, CLASSIQ, HQS, KIPU, menten.AI, MATHESSE, OTI, QCWARE, QUMONIX, QM, QM QUANTUM MACHINES, Qubit, STRANGEWORX, ZAPATA.
- QUANTUM SIMULATION FRAMEWORKS:** aws, blueqat, Cirq, Orquestra, PENNYLANE, QIBO, Qiskit, TensorFlow Quantum, XACC.
- ENTERPRISE PARTNERS:** DELL Technologies, Deloitte, Hewlett Packard Enterprise, softserve, aws, Google Cloud, Microsoft Azure, ORACLE CLOUD Infrastructure, Johnson & Johnson, VW, GE.
- RESEARCH CENTERS:** ABCI, Argonne, cea, CINECA, GENCI, JÜLICH, NCSA, NERSC, OAK RIDGE National Laboratory, RIKEN.

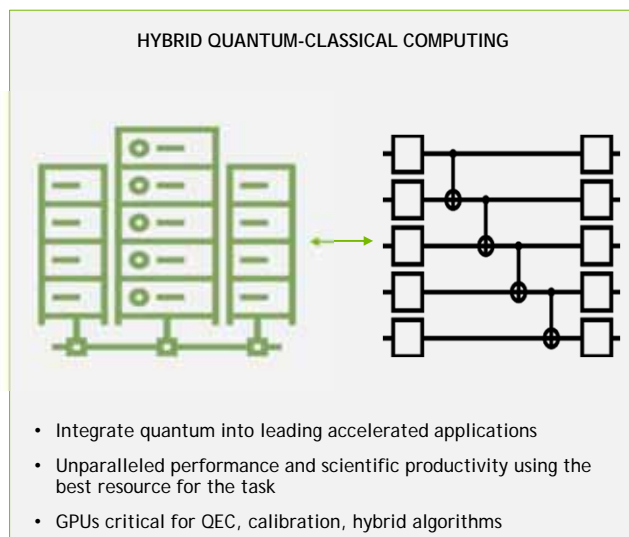
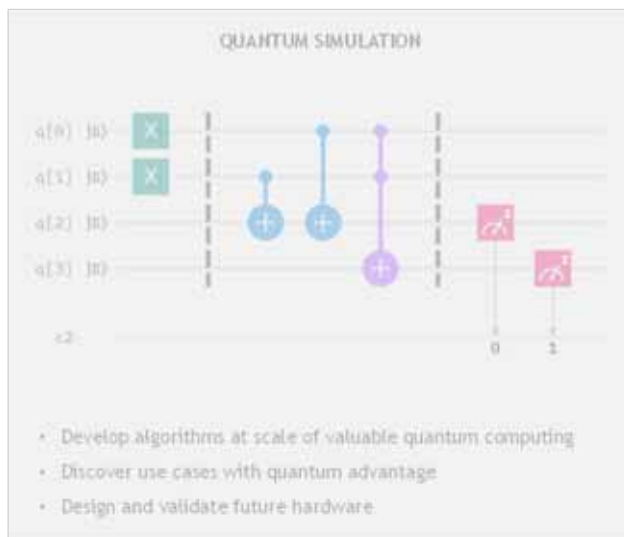
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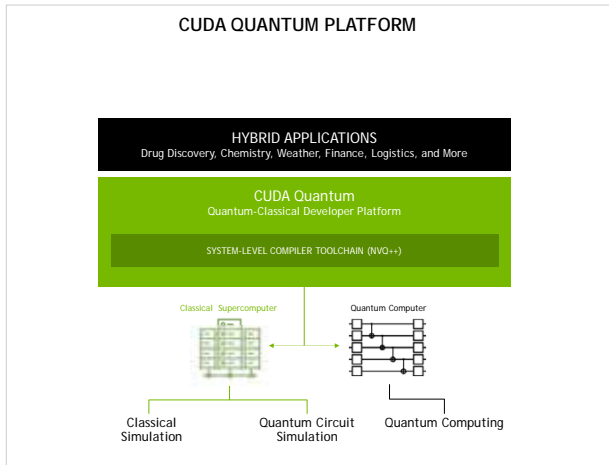
GPU Supercomputing and Quantum

Researching the Quantum Computers of Tomorrow with the Supercomputers of Today



CUDA Quantum: Now Available on GitHub and NGC

A Platform For Quantum-Classical Computing



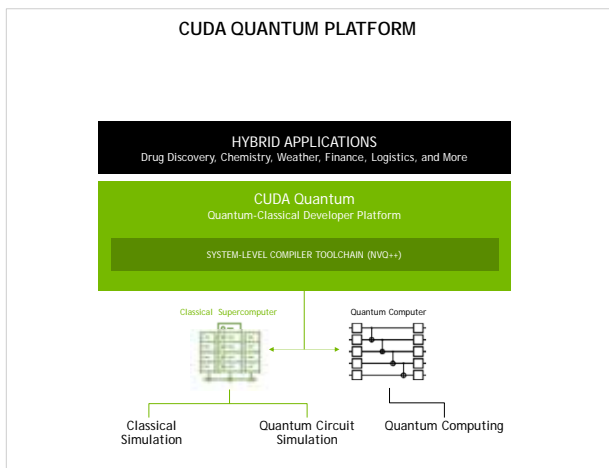
- ### CUDA QUANTUM FEATURES
- Supports any kind of QPU, emulated or physical
 - Compiler for hybrid systems
 - Open and interoperable with today's applications
 - Single source C++ and Python programming model

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



CUDA Quantum: Now Available on GitHub and NGC

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



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



CUDA Quantum: Now Available on GitHub and NGC

Natively Hybrid And Interoperable With GPU Supercomputing

CUDA QUANTUM PLATFORM

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 (...) ...
        
```

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



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CUDA QUANTUM PLATFORM

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, ...));

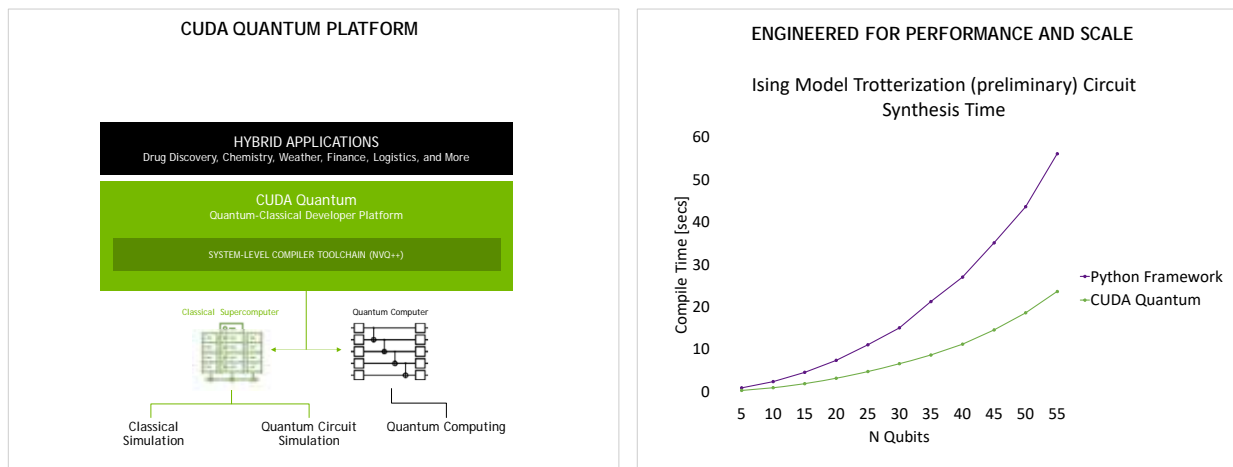
...
// Compute LU Factorization of S_mat on the GPU.
auto dim = std::pow(2, h.n_qubits());
cusolverDnXgetrf(handle, params, dim, dim, CUDA_C_64F, S_mat,
  lda, NULL, CUDA_C_64F,
  buffer_on_device,
  bytes_on_device, buffer_on_host,
  bytes_on_host, info);
        
```

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



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Delivering Unmatched Performance, Scalability, And Usability

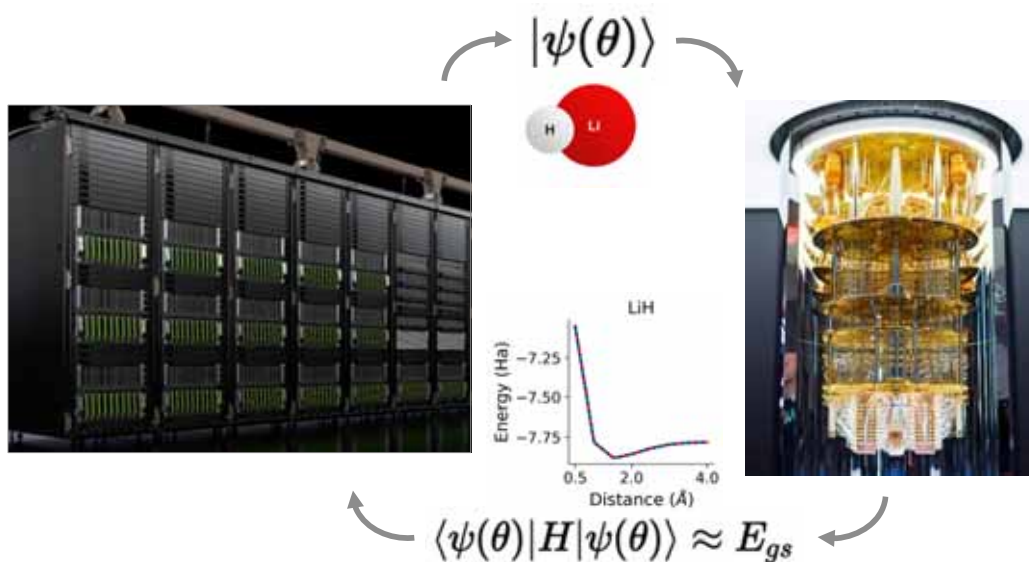


github.com/nvidia/cuda-quantum | <https://catalog.ngc.nvidia.com/orgs/nvidia/containers/cuda-quantum>

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

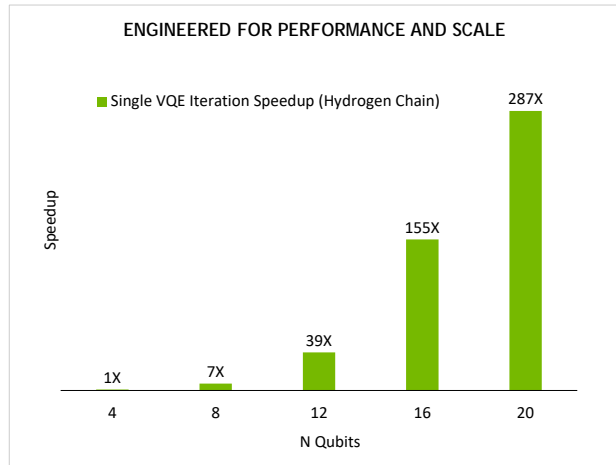
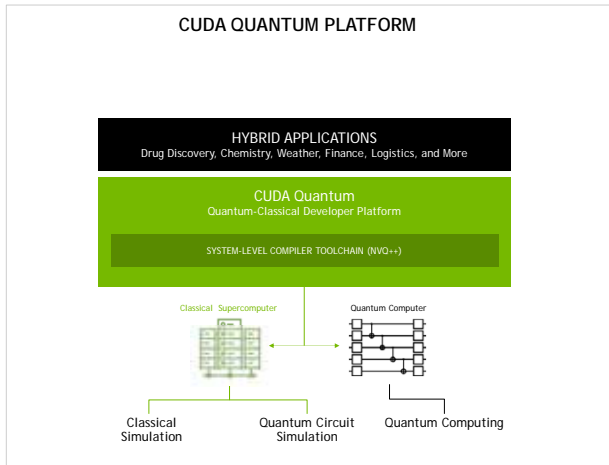


Variational quantum eigensolver (VQE)



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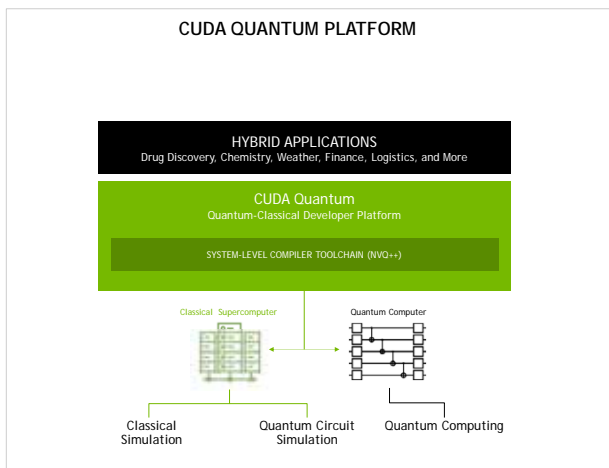
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VQE: NVQ++/cuStateVec on A100 GPU vs Leading Pythonic Framework and Simulator with Thrust on A100 GPU



CUDA Quantum: Now Available on GitHub and NGC

Natively Hybrid And Interoperable With GPU Supercomputing



```

Python and C++

DHKJMO!>P?<L

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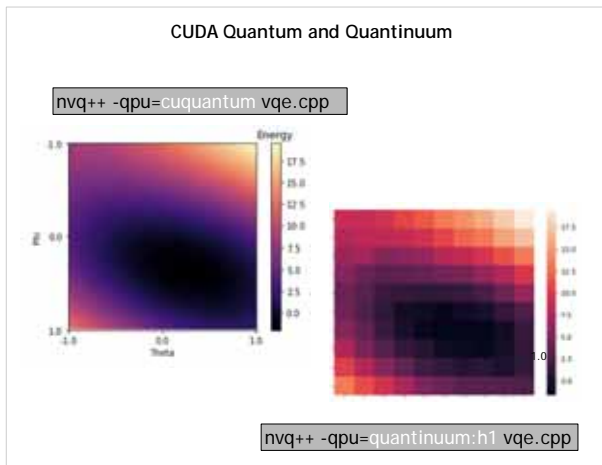
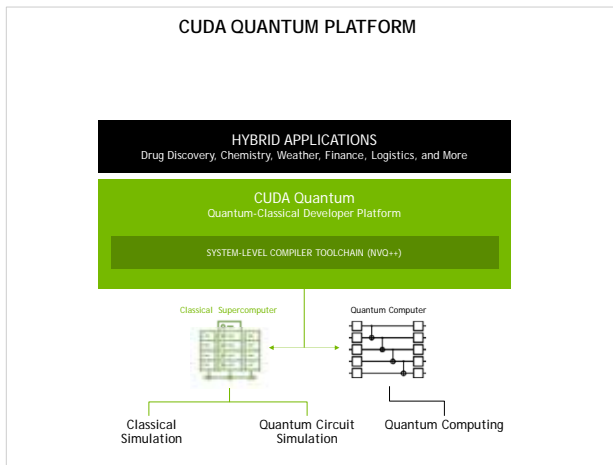
M@NPGO!`!>P?<L¢J=N@MQ@,<IN<OU¡;C¡;¡¢[_,,
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```

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



CUDA Quantum: Now Available on GitHub and NGC

Seamlessly Target any Quantum Resource



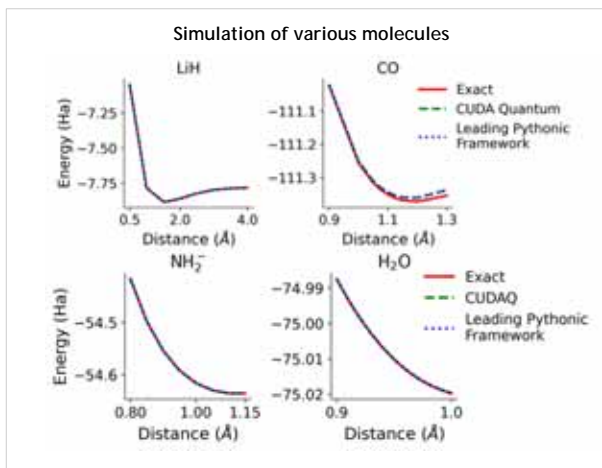
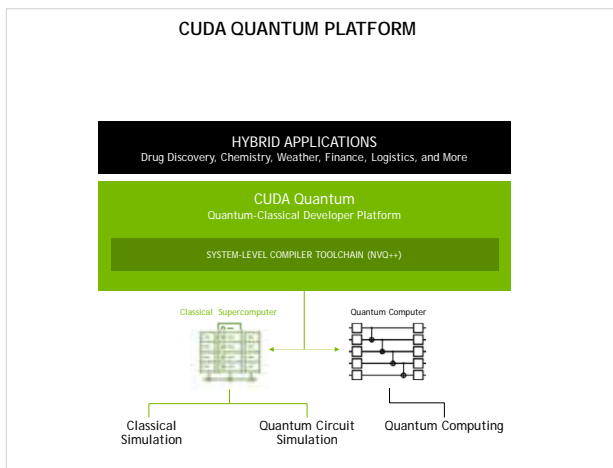
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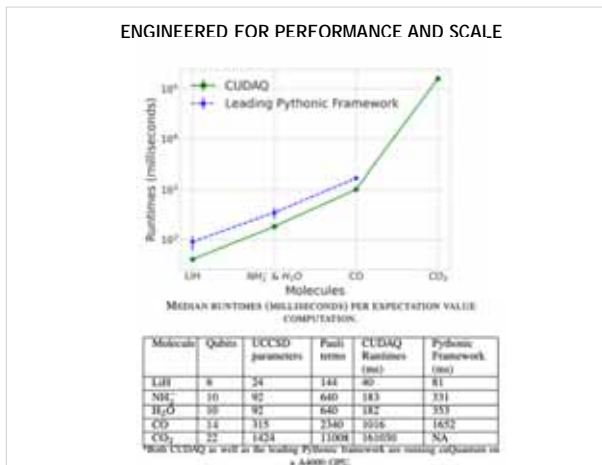
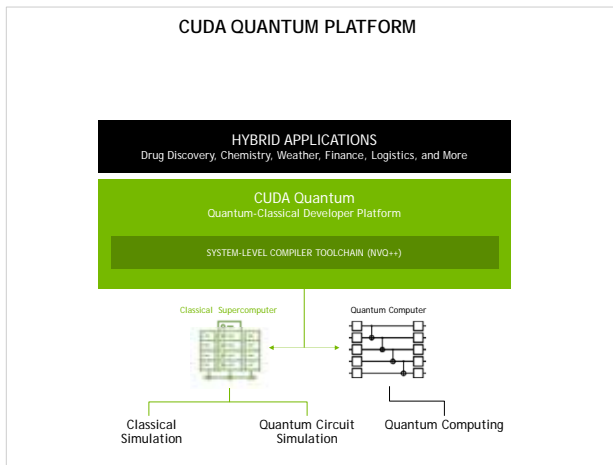
github.com/nvidia/cuda-quantum | <https://catalog.ngc.nvidia.com/orgs/nvidia/containers/cuda-quantum>

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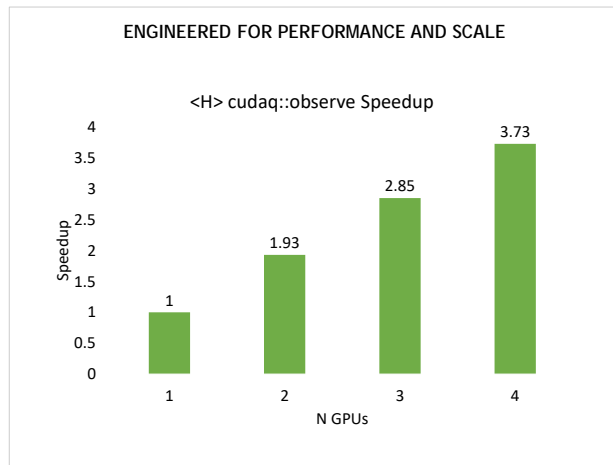
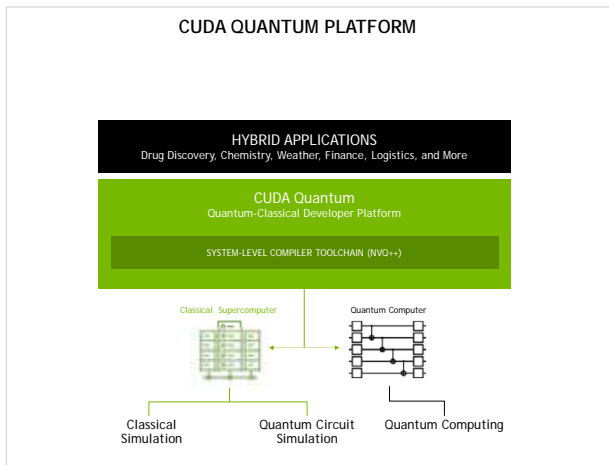
Novel Configurations with CUDA Quantum

The diagram illustrates novel configurations for quantum computing. It features a photograph of a server rack on the left and a cryogenic quantum device on the right. In the center, a quantum state $|\psi(\theta)\rangle$ is shown with parameters $\theta_0, \theta_1, \theta_2, \theta_3, \dots, \theta_j$. Below this, a chemical diagram shows Lithium (Li) and Hydrogen (H) atoms. A graph plots Energy (Ha) vs. Distance (Å) for LiH, showing a minimum energy around 2.0 Å. The equation $\langle \psi(\theta) | H | \psi(\theta) \rangle \approx E_{gs}$ is shown at the bottom. A note on the right states 'j=11,008 for CO2'.



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

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GPU Supercomputing and Quantum

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The diagram shows a quantum circuit with four qubits (q[0] to q[3]) and a classical register (c2). Qubits q[0] and q[1] start in state |0> and have X gates. Qubits q[2] and q[3] also start in state |0>. The circuit includes CNOT gates between q[0] and q[1], and q[2] and q[3]. There are also CNOT gates from q[0] to q[2] and q[1] to q[3]. The circuit ends with measurements on q[2] and q[3], which are stored in the classical register c2. The measurement results are 0 and 1.

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

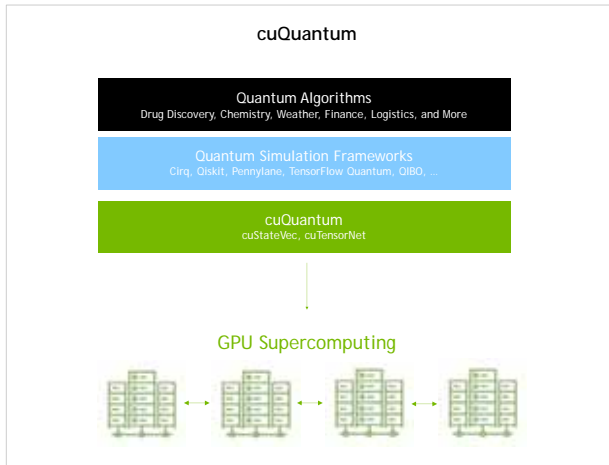
The diagram illustrates hybrid quantum-classical computing. It shows a stack of GPUs on the left, which are connected to a quantum circuit on the right. The quantum circuit consists of several qubits and gates. The GPUs are used to accelerate the simulation of the quantum circuit.

- Integrate quantum into leading accelerated applications
- Unparalleled performance and scientific productivity using the best resource for the task
- GPUs critical for QEC, calibration, hybrid algorithms



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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

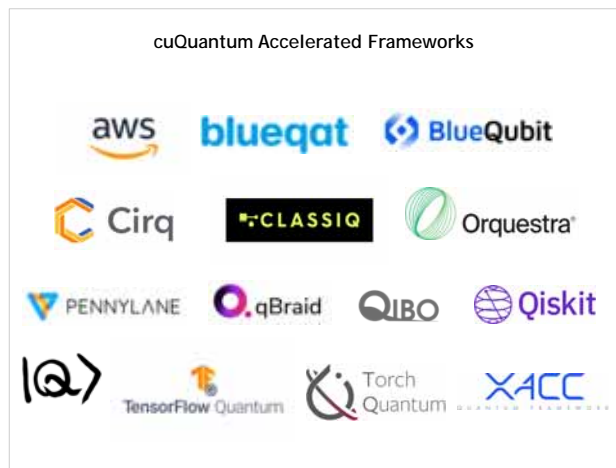
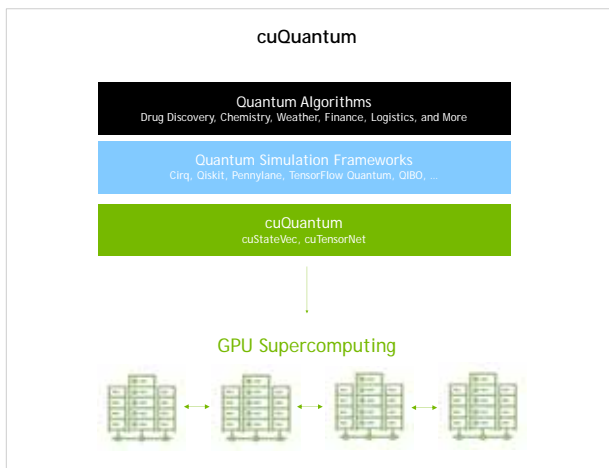
Integrated into all leading frameworks

Optimized frameworks in cuQuantum Appliance:
catalog.ngc.nvidia.com/orgs/nvidia/containers/cuquantum-appliance
Now available as VMI on all major Clouds



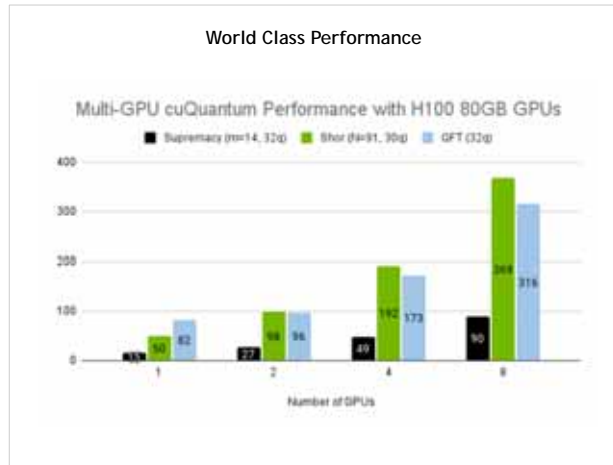
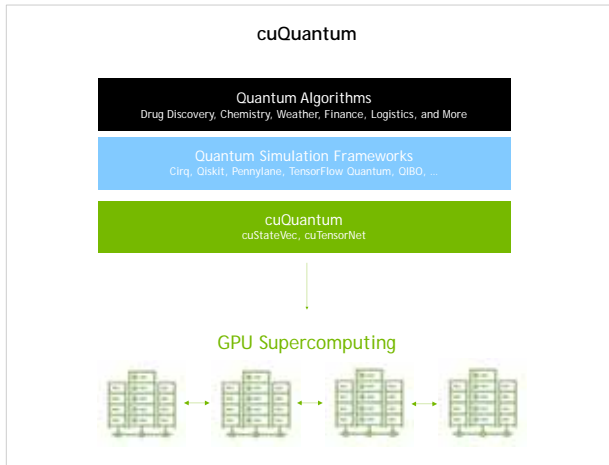
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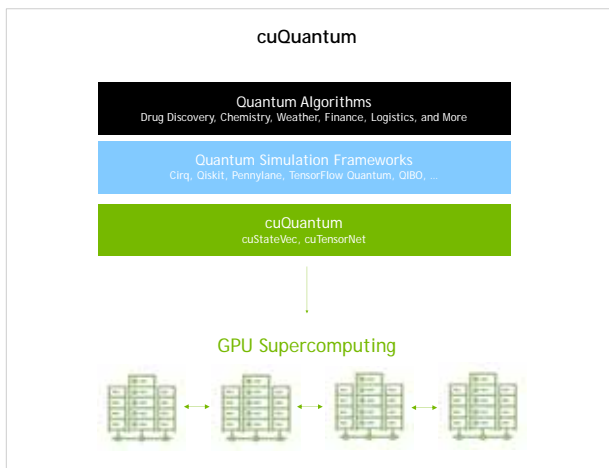
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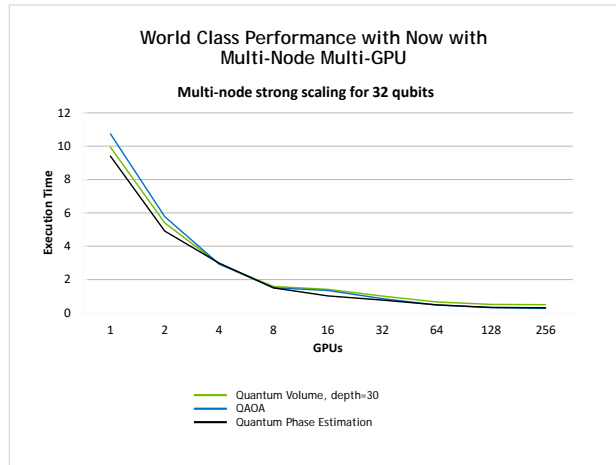
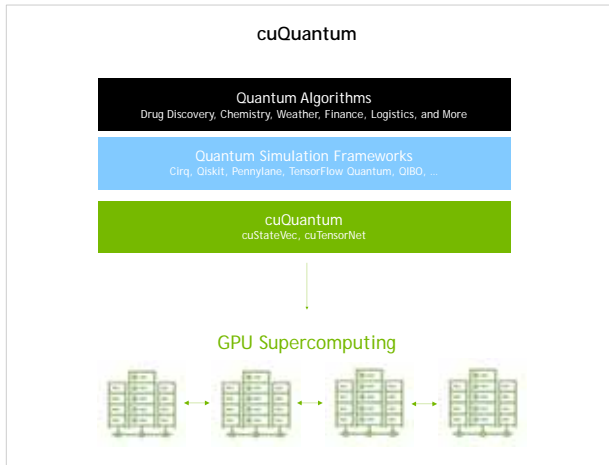
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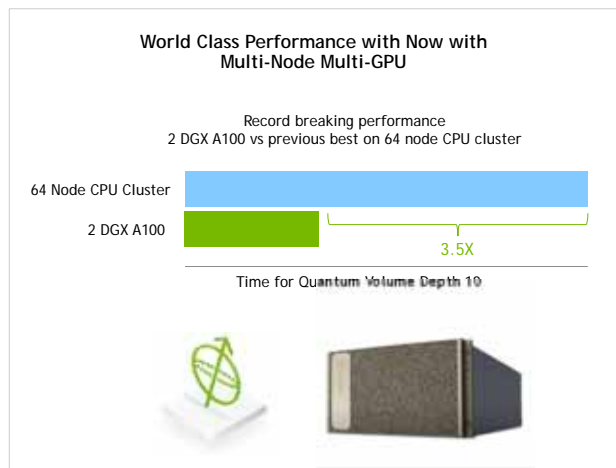
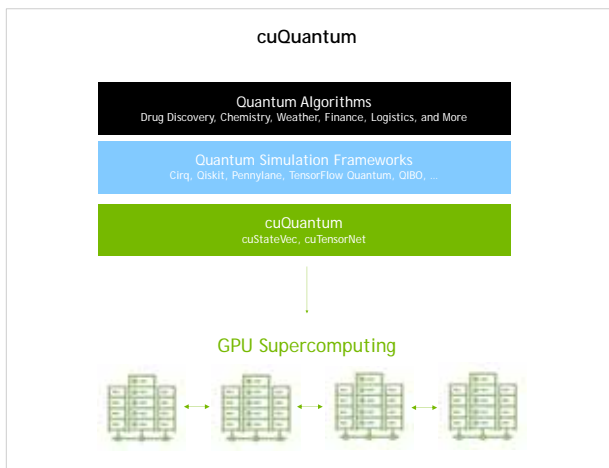
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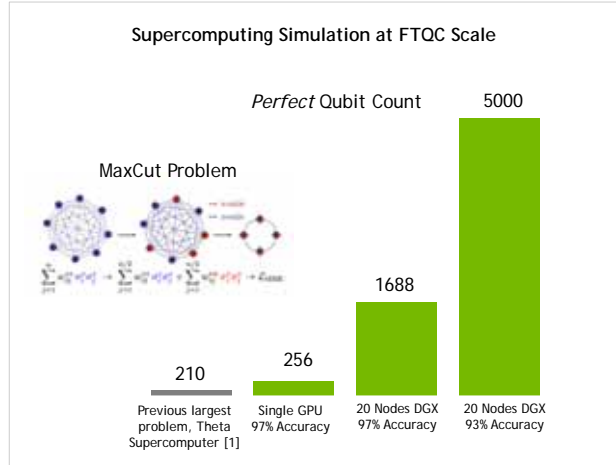
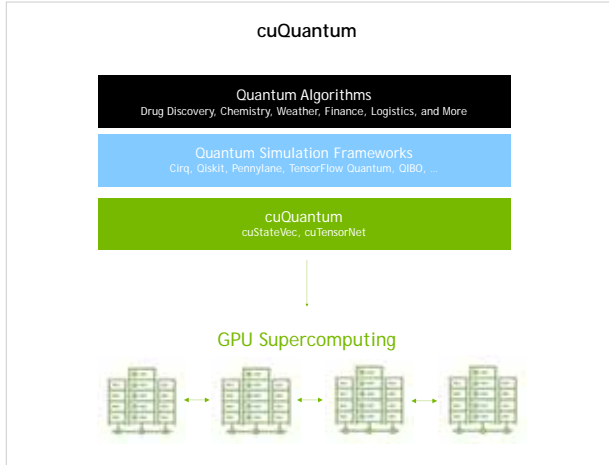
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[1] Danylo Lykov et al, Tensor Network Quantum Simulator With Step-Dependent Parallelization, 2020 <https://arxiv.org/pdf/2012.02430.pdf>



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