Quantum Task Offloading with the OpenMP API

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Abstract

Most of the widely used quantum programming languages and libraries are not designed for the tightly coupled nature of hybrid quantum-classical algorithms, which run on quantum resources that are integrated on-premise with classical HPC infrastructure. We propose a programming model using the API provided by OpenMP to target quantum devices, which provides an easy-to-use and efficient interface for HPC applications to utilize quantum compute resources. We have implemented a variational quantum eigensolver using the programming model, which has been tested using a classical simulator. We are in the process of testing on the quantum resources hosted at the Leibniz Supercomputing Centre (LRZ).

The (Sad) Current State

- Quantum programs consist of sequence of gates, applied on single or multiple Qubits
- Currently most popular way to compile and program quantum circuits is via Python libraries
  - ➢ e.g., Qiskit, Cirq, Pennylane…

Qiskit Cirq PENNYLANE

- Combined with pay-as-you-go cloud access to quantum resources
  - ➢ Low adoption barrier
- Disadvantages:
  - ➢ High latency
  - ➢ Security
  - ➢ Python not optimal for classical HPC performance

Intermediate Representations

- Facilitate optimizations
- Used to target different hardware backends
  - ➢ OpenQASM: Assembly/C like language for describing quantum circuits
  - ➢ QIR: Based on LLVM IR

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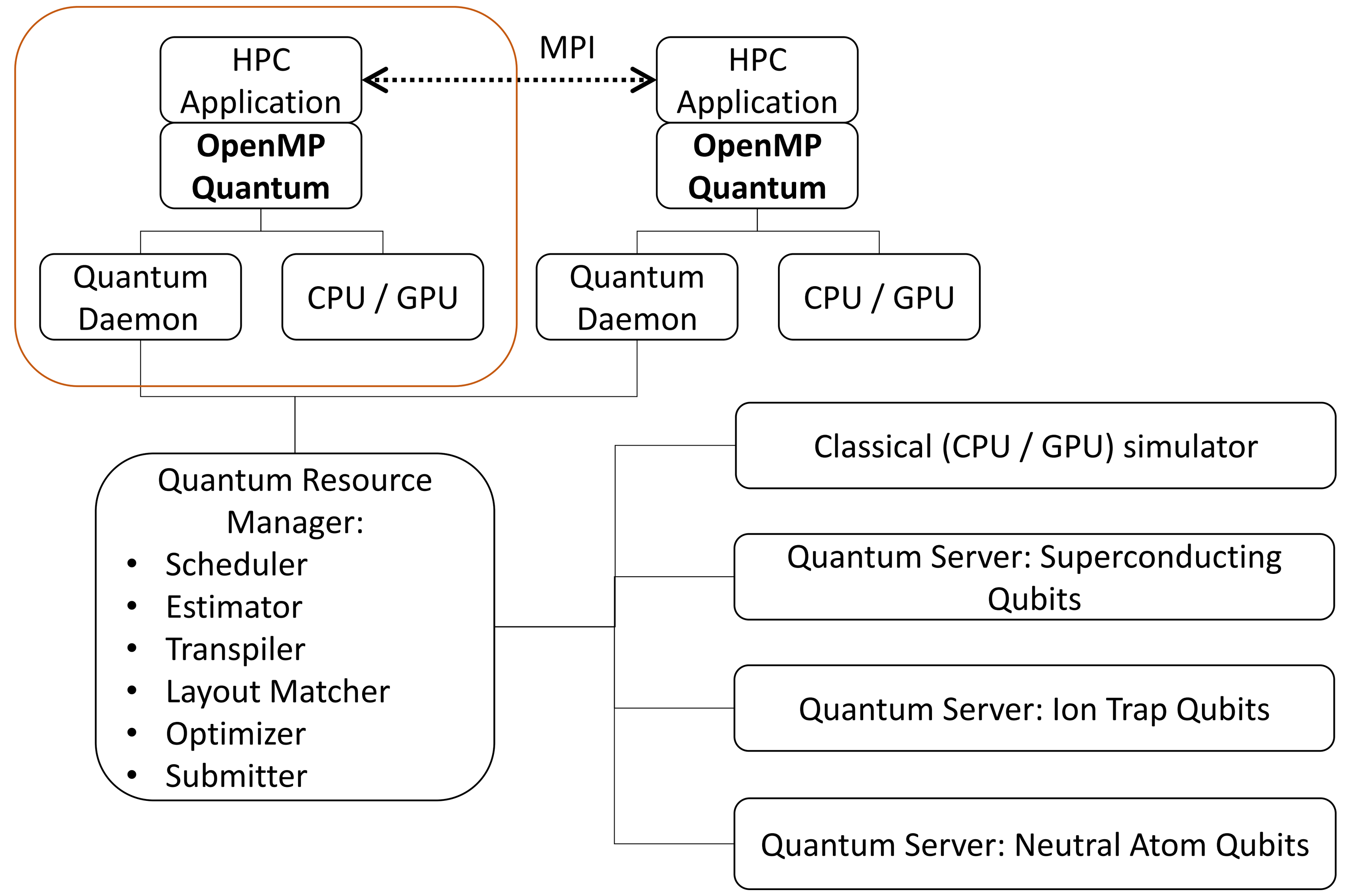
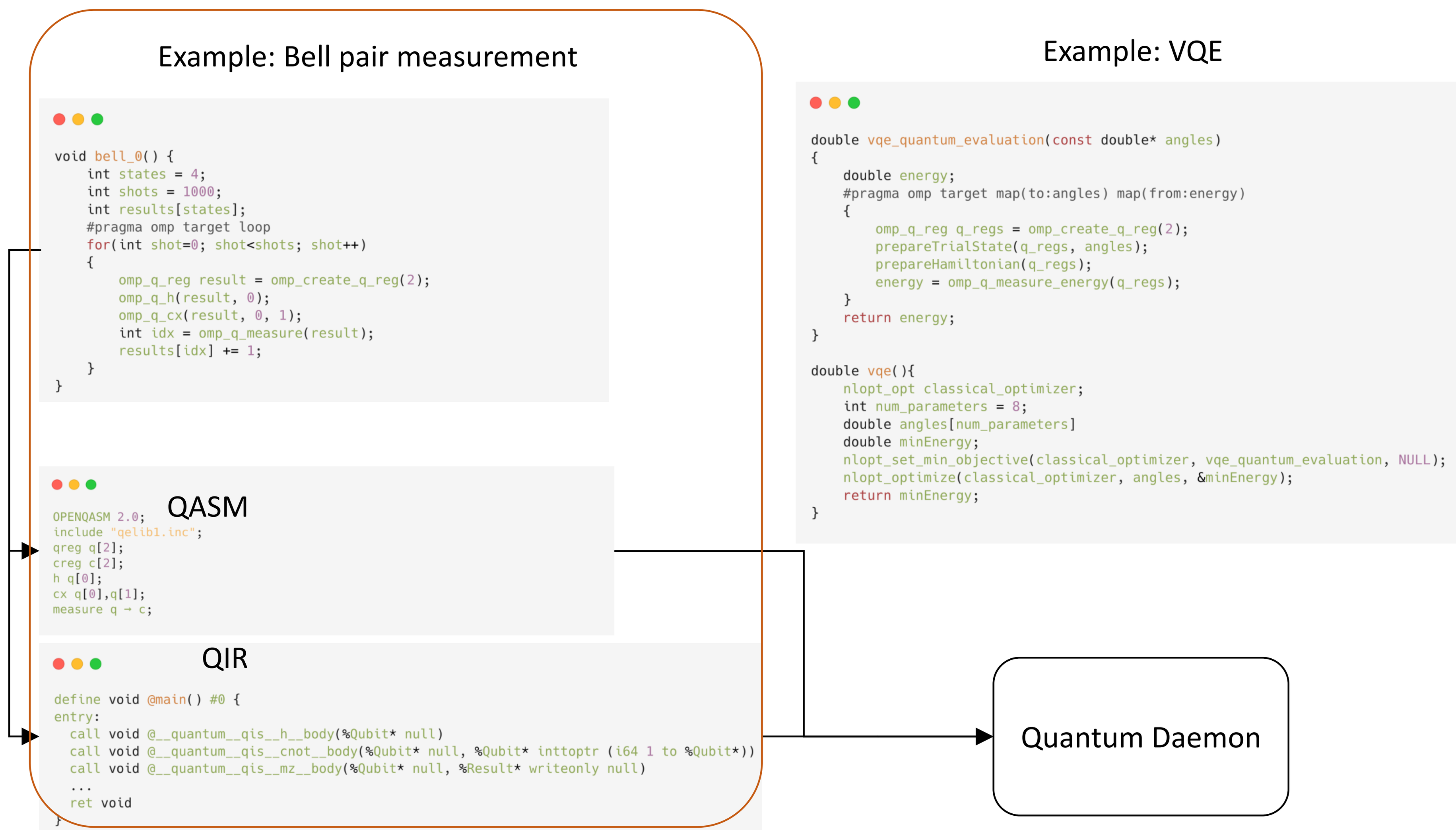
Hybrid Quantum-Classical Computing

- Hybrid algorithms are well suited to Noisy Intermediate-Scale Quantum (NISQ) computers
- Example: Variational Quantum Algorithms (VQAs) combine short-depth parametrized quantum circuits with classical variational loop
- Tightly coupled hybrid algorithms require low latency
- Classical components are computationally intensive
  - ➢ Requires classical HPC system
  - ➢ Benefit from optimizations from traditional compiled programs (usually in C/C++ or Fortran, and parallelized with MPI/OpenMP)
- Future systems (e.g. Euro-Q-Exa hosted by Leibniz Supercomputing Centre) provide on-premise integration
  - ➢ Quantum resources in close physical proximity to classical HPC infrastructure



OpenMP Quantum

- OpenMP provides flexible target interface
  - ➢ Send/receive data to target device
  - ➢ Execute control flow of target region
- Widely adopted for other accelerators, e.g., GPUs
- Implement quantum target offloading using the OpenMP API
- Transpile to OpenQASM or QIR
- Synchronising execution (default)
  - ➢ Suited to tightly coupled hybrid algorithm
- Asynchronous execution (via `nowait`)
  - ➢ Allow quantum resource manager allocation
- Implemented Variational Quantum Eigensolver (VQE) algorithm
  - ➢ Tested on classical simulator
  - ➢ Test on physical superconducting qubits at LRZ in progress



Example: Bell pair measurement

```
void bell_0() {
    int states = 4;
    int shots = 1000;
    int results[states];
    #pragma omp target loop
    for(int shot=0; shot<shots; shot++)
    {
        omp_q_reg result = omp_create_q_reg(2);
        omp_q_h(result, 0);
        omp_q_cx(result, 0, 1);
        int idx = omp_q_measure(result);
        results[idx] += 1;
    }
}
```

QASM

```
OPENQASM 2.0;
include "qelib1.inc";
qreg q[2];
creg c[2];
h q[0];
cx q[0],q[1];
measure q → c;
```

QIR

```
define void @main() #0 {
entry:
  call void @__quantum__qis__h__body(%Qubit* null)
  call void @__quantum__qis__cnot__body(%Qubit* null, %Qubit* inttoptr (i64 1 to %Qubit*))
  call void @__quantum__qis__mz__body(%Qubit* null, %Result* writeonly null)
  ...
  ret void
}
```

Example: VQE

```
double vqe_quantum_evaluation(const double* angles)
{
    double energy;
    #pragma omp target map(to:angles) map(from:energy)
    {
        omp_q_reg q_regs = omp_create_q_reg(2);
        prepareTrialState(q_regs, angles);
        prepareHamiltonian(q_regs);
        energy = omp_q_measure_energy(q_regs);
    }
    return energy;
}

double vqe(){
    nlopt_opt classical_optimizer;
    int num_parameters = 8;
    double angles[num_parameters]
    double minEnergy;
    nlopt_set_min_objective(classical_optimizer, vqe_quantum_evaluation, NULL);
    nlopt_optimize(classical_optimizer, angles, &minEnergy);
    return minEnergy;
}
```

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