QuantumSkynet: A High Dimensional Quantum Computing Simulator

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Abstract: Recent advances in high dimensional quantum computing systems demonstrate the feasibility of this paradigm. Here, we introduce QuantumSkynet, a cloud-based high dimensional quantum computing simulator. This platform allows simulations of qudit-based quantum gates and circuits.

The simulation of noise and error plays an essential role in the development of quantum algorithms. These simulations require the use of classical computers to analyze quantum circuits numerically and provide verification of a proper function of a quantum computer up to the limits of classical computational capacities. The number of classical simulators of quantum computing is rapidly growing [4], and many of them are ready for high-performance computing systems. However, all of these simulators are qubit-based that relay on the superposition of just two possible states, 0 and 1.

Recent advances in high dimensional quantum states open new possibilities to devise new kinds of quantum computers. These states, also called qudits, allow the encoding of quantum information in d possible levels or dimensions. The experimental demonstration of high dimensional quantum gates using photonic platforms proved the feasibility of this paradigm of quantum computation [2, 1]. The emergence of this technology should be accompanied by the tools required by quantum computer scientists to take advantage of the high dimensionality. Here, we present QuantumSkynet, the first high dimensional quantum computing simulator, that allows quantum scientists to evaluate, analyze, and tune high dimensional quantum algorithms in a cloud-based environment.

The quantum state of a qudit is given by $|\psi\rangle = \sum_{k=0}^{d-1} \alpha_k |k\rangle$ where d is the number of dimensions and α_k are the qudit complex amplitudes, which meet $\sum_{k=0}^{d-1} |\alpha_k|^2 = 1$. A high dimensional quantum gate that operates on n qudits of dimension d can be represented by a unitary matrix of size $d^n \times d^n$.

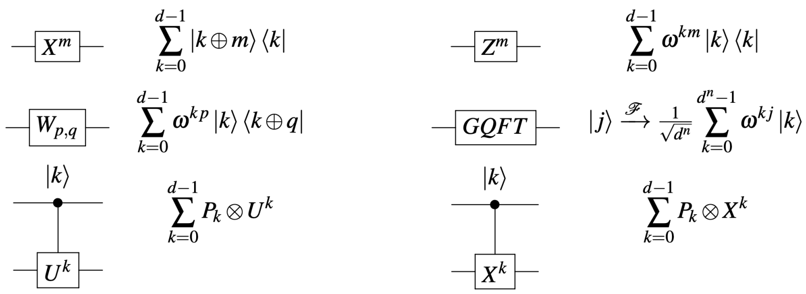
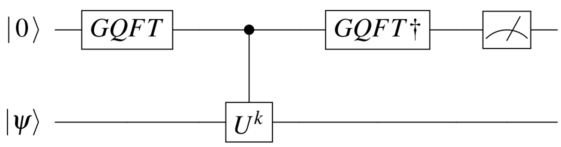


Fig. 1. High dimensional quantum gates available in QuantumSkynet.

In Fig. 1 we show the quantum gates provided by QuantumSkynet with their respective matrix equation to build an arbitrary high dimensional quantum algorithm. Here, we show single-qudit gates X^m, Z^m and $W_{p,q}$, multiple-qudit gates $GQFT$ and $GQFT^\dagger$, and the controlled gates U^k and X^k. The X^m and Z^m are generalized versions

for d dimensions of the qubit-based X and Z gate, respectively, raised to the m power. The $W_{p,q}$ gates are the generalized d-dimensional Weyl operators. The $GQFT$ and $GQFT^\dagger$ gates are the generalized versions for n qudits of d dimensions of the Quantum Fourier Transform and its inverse. In the gates Z^m, $W_{p,q}$ and $GQFT$, ω is define as $e^{\frac{2\pi}{d}i}$. In the controlled gate U^k, the target qudit is transformed k times by a user-defined arbitrary unitary operation U, where k is the state of the control qudit. The control gate X^k is a specific version of the control gate U^k in which the unitary operation is the d-dimensional X gate. This last gate is commonly called SUM gate.
Additionally, QuantumSkynet allows the user to define an arbitrary input high dimensional quantum state and any unitary matrix for custom gates. The user can also get the amplitude matrix, probability vector and density matrix at any stage of the circuit.
Quantum Phase Estimation is a quantum algorithm widely used as subroutine of other quantum algorithms. The use of qudits can help reduce the resources needed to achieve a given accuracy or probability of success [3].
QuantumSkynet was used to simulate the high dimensional quantum phase estimation algorithm represented by the following circuit:



(1)

Where $|0\rangle$ y $|\psi\rangle$ are qudits with any number of dimensions and U is the unit operator to which the phase of its respective eigenvector $|\psi\rangle$ will be estimated. To perform the test, the generalized Z Pauli gate was taken as U and 3 different qutrits were taken as $|\psi\rangle$ that correspond to the eigenvectors of the unitary operator Z of 3 dimensions as it appears in [3]. The final amplitude matrix calculated by QuantumSkynet for the differents eigenvectors shows the following results:

Eigenvector	Result	τ
$\|0\rangle$	$\|00\rangle$	0
$\|1\rangle$	$\|11\rangle$	1
$\|2\rangle$	$\|22\rangle$	2

The phase ϕ to be found is equal to $2\pi\tau/3$. Therefore, the values of the phases found by QuantumSkynet for the respective eigenvectors of the 3-dimensional matrix Z were 1, $2\pi/3$ and $4\pi/3$.

References

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