Linear Algebraic Properties Of Quantum Gates As A Starting Point For Their Digital Twinning

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Abstract. Quantum circuits are one of the three universal quantum computing paradigms and by far the most popular and intuitive one, the two other being quantum walks and adiabatic quantum computing. Additionally, quantum circuits can verify the validity of computations done in special purpose paradigms like quantum annealing. From an architectural perspective the most important components of quantum circuits are quantum gates and the connectivity between them. Because of the physical properties and the limitations of existing implementations, it is paramount that quantum gate operation be digitally twinned in classical computers for verification as well as study and observation purposes. A starting point is the detailed description of their linear algebraic properties since each quantum gate corresponds to a unitary operator on a suitably defined Hilbert space. Said properties include the matrix form, the eigenvalues, the determinant, the trace, the effect of basis qubits, and their geometric interpretations, as the latter is fundamental in understanding quantum computing. Additionally, it is explored how these properties can be directly translated to proper Pythonic code.

Keywords: Quantum gates · Quantum circuits · Quantum simulation · Quantum computational paradigm · Digital twinning · Unitary operators · Hadamard gate · Phase gate · CNOT gate · Rotation gate.