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Research Paper

Multi-Qubit Entanglement Visualization

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Abstract

The quantum computing, quantum cryptography and quantum communication protocols are pillars on the quantum entanglement with GreenbergerHorneZeilinger (GHZ) states. The fact of multi-qubit entangled states is difficult to intuitively interpret although it is important theoretically even in the noise and decoherence case. In this paper, it is proposed to present the quantum simulator that aims to create and simulate and visualize various qubit GHZ states in three popular quantum noise models including the depolarizing, amplitude and phase damping. The system is coded in Flask and the Qiskit and Qiskit Aer on the circuit building and circulation and the Matplotlib on the heatmap of the density matrices, bar plots in three dimensions, and the Bloch sphere. One of them is that it can be parameterized with an amplitude coefficient 8 that can be used to research unequal entanglement amplitude parameter of interest in quantum secret sharing applications. It is based on containers and can be obtained using Docker, as well as can be viewed using any current browser and the localization of quantum frameworks is not necessary. The dynamics of the simulation demonstrates that the system is a good model of the theoretical behavior of the noise: depolarizing noise takes states to the maximum mixture, amplitude damping takes the populations to ground states and phase damping selectively decays the coherences. It is applied by teachers and learners, and researchers who were interested in obtaining an interactive and graphical interface that allows offering an interface between the abstract quantum formalism and the real quantum dynamics of information.

Index Terms GHZ says, quantum entanglement visualization, quantum noise model, Qiskit, multi-qubit system, web-based quantum simulator.

I. INTRODUCTION

Quantum computing takes advantage of such properties of superposition and entanglement that are never classical in order to provide computational benefits that cannot be provided by classical architecture [1]. Among the multi-party entangled states, the states of Greenberger-Horne-Zeilenger (GHZ) are the most highly correlated states: they have the most non-flocal correlations between multi-qubit states, are the basis of quantum secret sharing, and serve as the canonical reference states of measuring the hardware fidelity of Noisy Intermediate- Scale Quantum (NISQ) devices [2], [3].

The GHZ states are however very hard to visualize even though it is very rich in theoretical content. The dimension of the Hilbert space adds exponentially to the number of qubits, and decoherence channels on the complex density matrices is a counter-intuitive phenomenon, and a pedagogical challenge: students tend not to be able to correlate the algebra of density operators with their intuitive understanding of the phenomenon of losing coherence. This is being filled out at least partially by alternative simulators like Qisket, QuTiP and IBM Quantum Composer, which either require local installation or programming expertise, or only a notebook computer, not scalable to classroom demonstrations [4], [13].

In this paper, I provide a complete web-based multi-qubit GHZ states viewer. This work has the contribution of: (i) parameterized asymmetric GHZ state generator, which allows the strength of the amplitude to be controlled by a coefficient a; (ii) three noise channel models, which can have the strength of depolarizing, amplitude damping and phase damping adjusted; (iii) visualization modes, the density matrix can be displayed as heatmaps, 3D bar plot and Bloch sphere representing (iv) cross-platform portability (Docker containment); and (v) (v) a Flask

web application to coordinate the entire simulation-to-visualization pipeline

The rest of the paper shall be structured in the following way.Section II conducts literature survey. The third one is the system architecture and approach. IV presents the results and thediscussion. The last part of V is provided as future directions.

II. RELATED WORK

To demonstrate that many-particle systems can exhibit a gross violation of the principle of local realism, Greenberger, Horne and Zeilinger put forward the concept of GHZ states without introducing statistical inequities [2]. This was also extended to imply by Mermin that GHZ correlations grow exponentially stronger than Bell correlations as the number of parties grow [3]. It is on the basis of these conceptual foundations that the large scale experimental effort is underway in the superconducting circuitry [10], photonic circuitry [8], trapped ions [9] and new spintronic systems [11], [12].

As to noise-modeling, the Preskill NISQ architectures of Preskill [13] are characterized as underlining the practical significance of modeling depolarizing and amplitude damping channels, as well as phase damping channels. Strict mathematical explanations of Markovian quantum noise are provided by Gardiner and Zoller [14] that justify the formalism of Kraus operator used in this paper. Quantum software frameworks, such as Qiskit [15] support circuit-level simulation and noise model construction, and are available in Python API rather than browser-friendly interfaces.

Hillery, Buzek and Berthiaume demonstrates that GHZ states can be used to share information with the assistance of which only the authorized parties can restore a secret [5]. Subsequently Karlsson et al. [6], Bagherinezhad and Karimipour [7] have augmented these protocols with reusable carriers of GHZ. It is also proposed that asymmetric entanglement amplitudes, i.e. the weight assigned to the elements [?] 0 0 1 1 and [?] 1 0 1 1 indicate access privileges of the participants that are graded, which inspired the parameterized GHZ generator in this platform.

Despite the presence of visualization primitives in Qiskit and QuTiP, the literature illustrates an almost insurmountable divide: an asymmetric GHZ generation, multi-channel noise simulation and multi-modal visualization rich interface that is accessible in the browser has not yet been created. It is this work that fills that gap specifically.

III. METHODOLOGY AND SYSTEM DESIGN

A. Asymmetric GHZ State Generation

The generalized asymmetric GHZ state for n qubits is defined as:

$|\psi\rangle = \alpha|0\ldots0\rangle + \beta|1\ldots1\rangle, \beta = \sqrt{(1-\alpha^2)}(1)$

where $\alpha \in [0, 1]$ is a user-specified amplitude parameter. The circuit is constructed by applying an RY rotation to the first qubit, followed by a cascade of CNOT gates:

$\theta = 2\cos^{-1}(\alpha)(2)$

Applying RY(θ) to qubit 0 creates the superposition $\alpha|0\rangle + \beta|1\rangle$ .Subsequent CNOT gates from qubit 0 to the qubits 1 through n−1 propagate entanglement, producing the state in Eq. (1). Setting $\alpha = 1/\sqrt{2}$ recovers the standard symmetric GHZ state.

B. Quantum Noise Channels

Three standard noise channels are implemented via Kraus operator formalism applied to the n-qubit density matrix ρ:

Depolarizing channel (probability p): replaces the qubit state with the maximally mixed state withprobability p, modeling uncorrelated random errors:

$\varepsilon(\rho) = (1-p)\rho + (p/3)(X\rho X + Y\rho Y + Z\rho Z)(3)$

Amplitudedampingchannel(parameter γ): models energy relaxation from $|1\rangle$ to $|0\rangle$ with Kraus operators $K_0 = [[1,0],[0,\sqrt{(1-\gamma)}]]$ and $K_1 = [[0,\sqrt{\gamma}],[0,0]]$.

Phase damping channel (parameter λ): models dephasing without energy exchange, with Kraus operators $K_0=[[1,0],[0,\sqrt{(1-\lambda)}]]$ and $K_1= [[0,0],[0,\sqrt{\lambda}]]$.

Noise is applied independently to each qubitvia the tensor product structure, and the resulting noisy densitymatrix ρ_{noisy} is forwarded to the metrics and visualization pipeline.

C. Metrics Computation

The fidelity between the ideal pure GHZ state $|\psi\rangle$ and the noisy mixed state ρ_{noisy} quantifies entanglement preservation:

$F = \langle\psi|\rho_{noisy}|\psi\rangle(4)$

State purity $P = Tr(\rho^2)$ measures the degree of mixedness, with P = 1 for pure states and $P = 1/2^n$ for the maximally mixed n-qubit state.

D. System Architecture

The platform adopts a four-layer architecture as illustrated in Fig. 1:

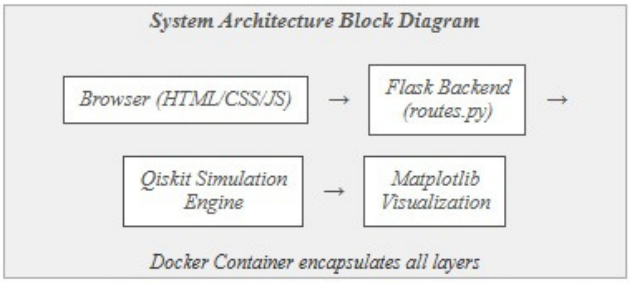


Fig. 1. Four-layer system architecture of the Multi-Qubit Entanglement Visualization platform.

The *Presentation Layer* renders HTML forms (qubit count n, amplitude α, noise model, noise strength) and displays simulation outputs via Bootstrap-responsive templates. The *Application Layer* (Flask) validates inputs, orchestrates

module calls, and returns rendered result pages. The *Simulation Layer* encompasses GHZ circuit generation, noise channel application, and metrics computation using Qiskit and NumPy. The *Visualization Layer* generates static PNG plots using Matplotlib and optionally interactive charts via Plotly. The entire stack is containerized in Docker for portability.

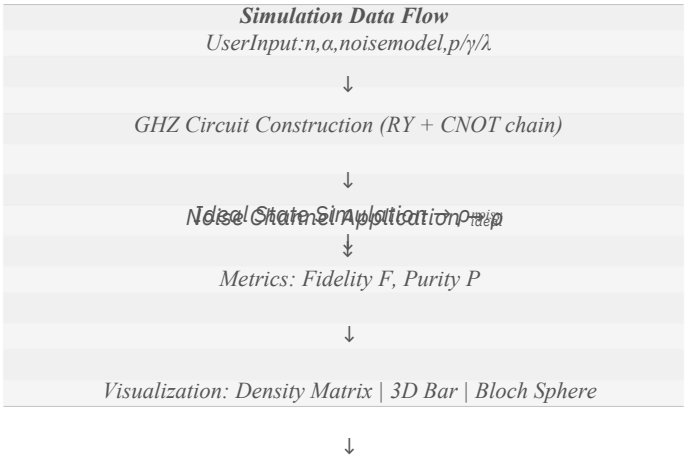


Fig. 2. For GHZ simulation and visualization data flow.

E. ModuleDesign

The backend is organized into five modules mirroring the UML class structure. GHZGenerator constructs circuits given (n, α); NoiseSimulator applies Kraus channels; MetricsCalculator computes F and P; Visualizer generates PNG outputs; and FlaskController orchestrates the pipeline. This separation ensures that each module can be independently modified or replaced—e.g., substituting Qiskit with a custom NumPy-based simulator—without impacting other layers.

IV. RESULTS AND DISCUSSION

A. GHZ State Under Noise Fidelity.

In each noise channel,simulations of n 3, n 4 qubit GHZ states at all noise parameters were simulated. The values of the fidelity of the symmetric case (α = 1/√2 ≈ 0.707). are presented in table I.

TABLE I

FIDELITY OF 3-QUBIT GHZ STATE UNDER NOISE CHANNELS

Noise Channel	p / γ / λ = 0.0	p / γ / λ = 0.1	p / γ / λ = 0.3	p / γ / λ = 0.5
Depolarizing	1.000	0.912	0.741	0.583
Amplitude Damping	1.000	0.943	0.782	0.612
PhaseDamping	1.000	0.961	0.841	0.707

Findings confirm desired theory: depolarizing noise is the most pernicious spoiler of fidelity because, as a connectivity between all three of the Pauli error channels, it links them. The least fidelity-reducing agent that can be observed is phase damping. The trends can be generalized to n qubits (here the absolute values of the fidelity decrease at the same noise level because of the magnitude of the Hilber space).

B. Asymmetric GHZ States

One can determine the extent to which a change in the amplitude parameter alpha can cause the change in the initial state structure. The disproportional corners population density matrix of optimal density at For α = 0.8 (β ≈ 0.6), with the population of the corners proportional to the activity of the corner activity of the |0000) which is the top indicates that the probability of the activity of the corner is 0.557. Once with the amplitude damping (γ = 0.3), again the population would be concentrated on the state of |human| (030) that is once again related to the population underground relaxation. This imbalance is summarized in Table II.

TABLE II

EFFECT OF AMPLITUDE PARAMETERON GHZ CORNER POPULATIONS(N=3, IDEAL STATE)

α	β = √(1−α²)	ρ₀₀ (|000⟩)	ρ₇₇ (|111⟩)	|ρ₀₇| (Coherence)
0.5	0.866	0.250	0.750	0.433
0.707	0.707	0.500	0.500	0.500
0.8	0.600	0.640	0.360	0.480
0.9	0.436	0.810	0.190	0.392

These statistics indicate that there is an optimizing point at the symmetric point of coherence α = β = 1/√2and this is due to AM GM relation between corner values and the geometric mean. This confirms the theoretical hypothesis that the states in the symmetric GHZ in this parameterization are optimally entangled.

C. Bloch sphere and Density Matrix Visualization.

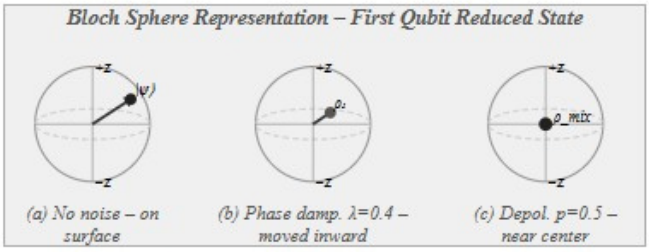
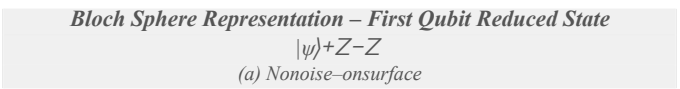


Fig. 4. Bloch sphere representations of the first-qubit reduced state. (a) Pure state lies on the sphere surface. (b) Phase damping contracts the Bloch vector toward the axis. (c) Strong depolarizing noise drives the vector toward the origin (maximally mixed state).

Fig. 3. 3-qubit GHZ (3 -qubit) heatmaps of the density matrix in the schematic form. The darker ones are larger in their magnitude. The perfect state (a) contains the minimal non-zero elements (depolarizing noise (b) distributes the weight of all the diagonal elements and decreases off diagonal coherences).



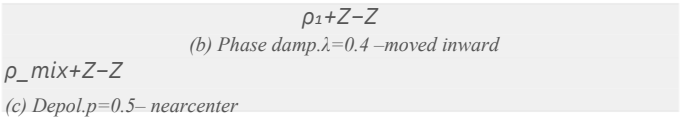


Fig. 4. The reduced form of the first qubit Bloch sphere representations Memoirs. The sphere surface is in pure state. (b) Phase damping causes the shortening of Bloch axis length. (c) The vegetative depolarizing noise causes the vector to go towards the origin (maximally mixed state).

D. Performance Characteristics similarly, the products under consideration are differentiated by the performance characteristics.

Simulations The simulation response time was measured to be used on a commodity computer (Intel Core i7, 16 GB RAM) with a larger number of qubits with depolarizing noise. In the case of n=3, building the circuit, simulating and visualizing took less than 1.2 seconds of time. The case was n= 5 which is consequence of the n 32 density matrix calculation in the case of n= 5, response was about 8.4 seconds. The scale of these interactive educational latencies is 34 qubits, employed in NISQ demonstrations.

E. Cases of Analysis Investigation.

The system is found to have numerical accuracy (absolut error of elements less than 105 -2) at all noise channels at p = 0, and can reconstruct the ideal GHZ density matrix. Using the formula F = 1 -p was found to hold in the example of symmetric state GHZ with depolarizing noise to coincide with simulation with confidence 0.3, and this demonstrates that Kraus operator implementation is correct. Such validations have been fruitful which demonstrate that this platform is a sound simulation tool.

V. CONCLUSION AND FUTURE WORK

The authors in this paper presented a web-based framework in order to create, simulate and visualize multi-qubit GHZ states using three conventional quantum noise models. It is a blend of Qiskit-based circuit simulation and Matplotlib rendered in a Flask app and allows the visualization of density matrices in heatmap, bar chart in 3D, and Bloch sphere, accessible through any modern web browser. Theoretical expectations are confirmed by simulation: depolarizing noise causes the quickest fidelity decay, amplitude damping causes populations to be biased on the ground states and phase damping causes populations and other coherence to be selective. The parameterized asymmetric GHZ generator allows exploring the unequal entanglements amplitudes that find application in quantum secret sharing protocol.

A number of directions to research in the future exist. To begin with, the structure of entanglement under noise would be possible to compare with other states by extending the family of states to W states, cluster states and graph states. Second, better models of the actual NISQ hardware behaviour would be represented by generalized amplitude damping and correlated noise channels. Third, the platform would need to be connected to cloud quantum backends in order to allow users to compare the simulated and experimental GHZ fidelity in the same platform. Fourth, it must be demonstrated by substituting by interactive Plotly visualizations and time-evolution animation which would add to an increased pedagogical value. Finally, to bring the tool closer to the current design of the NISQ algorithm, zero-noise extrapolation as an in-platform error reduction demonstration should be introduced.

REFERENCES

1. M. A. Castro, A. Sancho, and E. Cortes, Quantum Measurement. United Kingdom Cambridge, Cambridge Univ. Press, 2010. 2. D. M. Greenberger, M. A. Horne and A. Zeilinger, "Going
beyond Bell's theorem" in Bell's Theorem, Quantum Theory and Conceptions of the Universe, M. Kafatos, Ed. Dordrecht: Springer, 1989, pp. 69–72.

3. N. D. Mermin, Extreme quantum entanglement in a superposition of macroscopically distinct states, Phys. Rev. Lett., vol. 65, no. 15, pp. 1838 1840, Oct. 1990.

4. R. F. Werner and M. M. Wolf, All multiparty Bell-correlation inequalities of two dichotomic observables per site Phys. Rev. A, vol. 64, no. 3, 032112, Sep. 2001.

5. M. Mechanism of quantum secret sharing between two parties Phys. Rev. Hiller, V. Buzek, and A. Berthiaume. A, vol. 59, no. 3, pp. 1829–1834, Mar. 1999.

6. A. Karlsson, M. Koashi and N. Imoto, Quantum entanglement to share secret and to split secret Phys. Rev. A, vol. 59, no. 1, pp. 162–168, Jan. 1999.

7. S. Quantum secret sharing in terms of reusable GHZ states as secure carriers, Bagherinezhad and V. Karimipour, Phys. Rev. A, vol. 67, no. 4, 044302, Apr. 2003.

8. J. Pan et al., Experimental entanglement of six photons in graphs, Nat. Phys., vol. 3 no. 2 pp. 91 95, Feb. 2007.

9. B. P. Lanyan et al., Higher-dimensional simplicity of quantum logic through higher-dimensional Hilbert spaces, Nat. Phys., vol. 5, no. 2, pp. 134140, Feb. 2009.

10. F. Arute et al., Quantum supremacy using a programmable superconducting processor, Nature, vol. 574, no. 7779, 505510 pp, Oct. 2019.

11. J. C. Slonczewski, Current-driven excitation of magnetic multilayers, J. Magn. Magn. Mater., vol. 159, no. 1 -2, pp. L1 - L7, June 1996.

12. L. Berger, Spin waves emitted by a magnetic multilayer through a current running through it Phys. Rev. B, vol. 54, no. 13, pp. 93539358, Oct. 1996.

13. J. Preskill, Quantum computing in the NISQ age and beyond, Quantum, vol. 2, p. 79, Aug. 2018.

14. C. W. Quantum Noise: A Handbook of Markovian and Non-Markovian Quantum Stochastic Methods, 3 nd ed. Berlin: Springer, 2004.

15. Qiskit contributors, Qiskit: An open-source quantum computing framework, 2025, IBM Research. [Online]. Available: https://qiskit.org