Simulating Qubits Coupled to a Cavity
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Motivation
Scalable quantum computers must utilize arrays of qubits to hold information. Unlike classical computers, qubits are prone to noise and interference that decrease fidelity. In an array, this noise prevents functionality. The proposed solution to this is coupling multiple qubits to one cavity, while retaining fidelity. We simulate a single qubit coupled to a cavity and two qubits coupled to a cavity, as well as comparing qubit detuning to fidelity.

Theory
The relevant Hamiltonians are the Jaynes and Tavis Cummings models. The Jaynes model is when \( N = 1 \) qubit:

\[
\mathcal{H} = \hbar \omega_c \hat{a} \hat{a}^\dagger + \sum_{l=1}^{N} \hbar \omega_l \hat{\sigma}_l^\dagger \hat{\sigma}_l - g_l (\hat{a} \hat{\sigma}_l^\dagger + \hat{a}^\dagger \hat{\sigma}_l)
\]

Where \( \omega_c \) is cavity frequency, \( \omega_l \) are qubit frequencies. In the two-qubit case, qubit detuning led to drift of \( \frac{\omega_c}{2} \), where \( \Delta = \omega_c - \sum \omega_l \). Rabi oscillations for the system:

\[
\Omega(t) = \sqrt{4N g_l^2 + \Delta^2}, \quad \text{for the same } g \text{ and } \Delta \text{ for all qubits}
\]

Results
The multi-qubit simulations are accurate and tunable for the desired cavity and qubit conditions. In the single qubit case, this is also true. Both results are reflected in fig (3) and (4), in the case of single qubit detuning. However, in both cases, the Rabi analysis loses accuracy when qubits are detuned different amounts from the resonator cavity. It is suspected that the Rabi calculations are not approximated by the Tavis-Cummings model when detuning is not equal for the qubits.

References