# Quantum computing with qubits embedded in trapped-ion qudits

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Due to the progress in developing quantum computing hardware platforms, more and more attention is being paid to quantum computing with d-level quantum systems, qudits [1-4]. Since most physical systems typically used as quantum information carriers have more than two levels, the idea of using the increased computational space to perform quantum algorithms is being actively studied. Moreover, prototypes of qudit-based quantum processors with photons, superconducting circuits, and trapped ions have already been presented [1,4].

In our work [2], we focus our attention on trapped-ion-based qudits as an efficient experimental control of such systems with up to 8 levels with high enough gate fidelities has been shown, and experimental results for systems with even higher level numbers have been presented. In particular, we develop methods for compiling qubit algorithms to the set of native gates for trapped-ion qudits of various experimentally relevant dimensionalities (d=3,...,8). For qutrits (d=3), we show how the third level simplifies multi-qubit gate decompositions. For ququarts (d=4), we explain how to obtain a universal gate set for embedded in ququarts' space qubit pairs. Further, we extend this approach to 5,6 and 7-level qudits and demonstrate how each additional level of a qudit (compared to the first 4 levels) helps to reduce the circuit width and depth in multiqubit gate decompositions. Finally, we discuss how to construct a universal set of gates with triples of qubits embedded in quocts (d=8).

The main feature of the developed methods is the use of qudit extensions of the Mølmer-Sørensen gate as a basic two-particle operation. It makes our results directly applicable to existing prototypes of qudit-based trapped-ion processors and allows one to implement qubit algorithms with qudit-based trapped-ion hardware.

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References

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