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Constantine 1 University – Frères Mentouri

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Conformément à la décision n° **34/D3C/2026** du **23 Mars 2026** autorisant la soutenance d'une thèse de doctorat, le Vice-doyennat chargé de la post-graduation, de la recherche scientifique et des relations extérieures, annonce la soutenance publique d'une thèse de doctorat le :

Jeudi 21 Mai 2026 à 16 HOO

Lieu : Salle de conférences sise au Campus Chaab Erssas
Université Constantine 1 Frères Mentouri.

Filière : PHYSIQUE

Spécialité : Physique mathématique et quantique, particules élémentaire et gravitation

Doctorant : TOUNSI Abdellah

Sur le thème : « Topological quantum Matter and Topological Quantum Computation ».

Devant le jury d'examen :

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Abstract

This thesis explored the theoretical foundations and computational applications of anyon models through the framework of monoidal tensor categories. We began by introducing key physical processes: fusion, braiding, and twisting, and highlighted the role of twisting and the S-matrix for practical evaluation of anyon model properties.

We then introduced the braid group to describe anyonic statistics and proposed the novel concept of *similar braids*, which aids in optimizing topological quantum gate compilation. A sparse encoding method using identical anyon charges was developed, along with a computational framework for deriving braid operations via braiding and knitting matrices.

Building on this, we developed TQSim, a simulator capable of handling fusion basis computation, braid matrices, and arbitrary braid sequence simulation. The simulator was applied to the Fibonacci anyon model, where we examined fusion structures, gate compilation strategies - including Solovay-Kitaev and an enhanced brute-force method based on algebraic techniques - and the role of the weave set - a braid group's normal subset - in enabling efficient multi-qubit gate compilation.

We further introduced an *injection* scheme for two-qubit gate compilation and demonstrated its application in simulating Greenberger-Horne-Zeilinger (GHZ) states. The thesis's main contribution is the *controlled-injection* method, which enables efficient compilation of three-qubit gates like Deutsch and Toffoli by leveraging Fibonacci fusion rules and non-computational states. This method significantly reduces the braid length and the number of required two-qubit gates compared to standard quantum circuit decompositions. Overall, this work provides theoretical and computational tools to support the development of efficient topological quantum computing using anyonic systems.

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