22 e 23OUTUBRO

encontro de computação avançada 2025



Universidade de Aveiro, Edificio da Reitoria



























Exploring the quantum world

Inês Dutra Department of Computer Science - FCUP

































Explorations (1)

- Quantum satisfiability
 - Diogo Fernandes (participação no IJUP) + Carla Silva
 - Diogo Fernandes and Inês Dutra. 2019. Using Grover's search quantum algorithm to solve Boolean satisfiability problems: Part I. XRDS 26, 1 (Fall 2019), 64–66. DOI:https://doi.org/10.1145/3358251
 - Diogo Fernandes, Carla Silva, and Inês Dutra. 2019. Using Grover's search quantum algorithm to solve Boolean satisfiability problems, part 2. XRDS 26, 2 (Winter 2019), 68–71. DOI:https://doi.org/10.1145/3368085

HELLO WORLD

Using Grover's Search Quantum Algorithm to Solve Boolean Satisfiability Problems: Part I

BY DIOGO FERNANDES AND INÊS DUTRA

atisfiability (SAT) has been one of the most important tools in classical computing as well as one of the most difficult to improve in terms of complexity. It consists of finding if a set of propositional clauses is satisfiable, and it can be applied to solve several applications. SAT problems were the first to be proven as nondeterministic polynomial time complete (NP-complete) [1], meaning all problems that are NP are no harder

an electrical circuit, composed of wires and logic gates. These wires transfer energy as bits around the circuit, and these bits are manipulated using logical gates to realize the computation. In contrast, quantum computers use a quantum circuit. This same circuit contains wires and quantum gates, which are used to manipulate the qubits—the bits of quantum computation. These gates can be categorized into single qubits gates [3].

We can separate quantum gates into two categories: the ones that act on a single qubit, and the ones that act upon multiple qubits. This article only introduces the gates needed to explain our quantum code. These gates are shown in Figure 1.

The X gate does a simple "bit-flip," similar to what a NOT gate does in classical computing, flipping a 0 into a 1 and a 1 into a 0.

The Hadamard gate is used to create a superposition. This means that if we

HELLO WORLD

Using Grover's Search Quantum Algorithm to Solve Boolean Satisfiability Problems, Part 2

BY DIOGO FERNANDES, CARLA SILVA, AND INÊS DUTRA

we explained how to perform a quantum formulation of the classical satisfiability (SAT) problem using the well-known Grover's quantum search algorithm [1]. The quantum search operated by the classical Grover is composed by a black box (oracle model) able to acknowledge x_0 such that $f(x_0) = 1$ and f(x) = 0 for all other values of x. This feature transposed to a SAT oracle allows the execution

An example of a propositional formula can be $\alpha \lor \neg \beta \land \gamma$ where α , β , and γ are literals. A common way of solving SAT problems is to represent the problem in its conjunctive normal form. This is a structured form of SAT problems that organizes literals in a conjunction of one or more clauses, where each clause is a disjunction of literals.

1 (Var Vi)

In order to make it computable, all literals are represented as integer numbers, the negation symbol is represented as a minus ("-"), a conjunction is represented inside brackets ("(",")"), and literals inside the brackets are separated by a comma (","). Each clause is also separated by a comma. Finally, we place everything between brackets, and to illustrate, using the previous equation as a basis, we construct the formula, which uses



Explorations (2)

- IBM Q Teach Me Quantum Challenge
 - Set of introductory slides to quantum computing using python examples over IBM giskit
- M.Sc. Dissertation
 - Vanda Azevedo
 - Quantum Transfer Learning for Breast Cancer Detection (M.Sc. In Computer Science, DCC/FCUP)
- Ph.D. thesis
 - Carla Silva
 - Quantum Machine Learning: Mapping AI applications (Ph.D. in Computer Science, PDCC/FCUP)

Explorations (3)



- V Azevedo, C Silva, I Dutra (2022). Quantum transfer learning for breast cancer detection. Quantum Mach. Intell. 4, 5 (2022). https://doi.org/10.1007/s42484-022-00062-4
- C Silva, A Aguiar, I Dutra (2021). Quantum Binary Classification (Student Abstract). Proceedings of the AAAI Conference on Artificial Intelligence, 35(18), 15889-15890. https://doi.org/10.1609/aaai.v35i18.17941
- C Silva, A Aguiar, PMV Lima et al. Mapping a logical representation of TSP to quantum annealing.
 Quantum Inf Process 20, 386 (2021). https://doi.org/10.1007/s11128-021-03321-8
- C Silva, A Aguiar, PMV Lima, I Dutra (2020). Mapping graph coloring to quantum annealing, Quantum Machine Intelligence 2 (2), 1-19.
- C Silva, I Dutra, MS Dahlem (2018). Driven tabu search: a quantum inherent optimization, QML workshop at the 24th ACM SIGKDD Conference on Knowledge Discovery and Data Mining, London, UK
- QuantaLab member (Uminho), QCTalk member (UPorto)
- Recently, registered as a Deucalion user
- SMBQ 2020: https://smbq2020.dcc.fc.up.pt/



Explorations (4)

- C Botelho, L Schonhofen, H Santos, G Lucca, A Yamin, R Reiser (2025). Toward a Quantum Fuzzy
 Approach for Emotion Modeling in Parent-Child Interactivity. Proc. 17th ICAART
- C Botelho, L Schonhofen, H Santos, G Lucca, A C Yamin, R H S Reiser (2025). Quantum-Fuzzy Integration for Emotion-Aware in Computational Intelligent Systems. Proc. IEEE Int. FUZZ-IEEE
- J S Buss, B Novack, H S Santos, G Lucca, L Oliveira, A C Yamin (2025). IBM-Qiskit Simulations for Quantum-Fuzzy Interpretations of X(N)or-Connectives using Overlapping and Grouping Aggregations. Proc. FUZZ-IEEE
- E M Monks, B M P de Moura, G B Schneider, H S Santos, A C Yamin, R H S Reiser (2022). Towards Interval-Valued Fuzzy Approach to Video Streaming Traffic Classification. Proc. FUZZ-IEEE
- R R Bastos, B M P Moura, H S Santos, G Lucca, A C Yamin, R H S Reiser (2026). Enhancing a fuzzy
 system through computational intelligence-based feature selection for decision-making in cloud
 computing environments. Future Generation Computer Systems.
- R C de Moura, L de S Oliveira, G B Schneider, M L Pilla, A C Yamin, R H S Reiser (2021). Intf-HybridMem: Page migration in hybrid memories considering cost efficiency. Sustainable Computing: Informatics and Systems.



New collaborations

UFPel

- Renata Reiser
- Helida Salles
- Adenauer Correa Yamim
- Cecília Botelho

• QUANTUMHEALTH (Q4H)

Exploring Quantum Science and Technologies for better healthcare (Call: HORIZON-CL4-2025-03 — Supporting Digital Partnerships in Quantum technologies (RIA) - HORIZON-CL4-2025-03-DIGITAL-EMERGING-03) – external reader

- Henrique Martins
- Joana Camilo
- Jorge Fonseca
- Maria Moura



Machines explored

- IBM 16 (14) qubits gate-based
- D-Wave adiabatic 2048 qubits graph-based
 - Chimera and Pegasus graphs



Findings

- IBM 16 bits gate-based
 - Quantum binary classification iris and traffic datasets
 - Amplitude encoding
 - Good accuracy results with as few as 2 qubits
 - Transfer learning for breast cancer classification
 - Amplitude encoding
 - Good AUROC results with the quantum version



Findings

- Adiabatic
 - Map coloring and TSP
 - Propositional logic representation compiled to a neural network
 - Objective: minimize energy equation
 - Both simulated annealing and quantum annealing produced good solutions
 - For TSP, the quantum version shows a slight advantage when finding optimal solutions



Findings

- Extending of the qFuzzyAnalyser library
 - Integrating multivalued fuzzy logic with quantum computing through circuit-based simulations
- Evaluating of simulations on HybriD-GM hardware,
 - High-performance computing (HPC) clusters for large-scale considering supercomputing
- Quantum simulation platforms integrated to qFuzzyAnalyser specifications
 - Design of new quantum gates that model fuzzy membership degrees directly on qubits.
- Extending Int-FLBCC framework supporting server consolidation in cloudcomputing environments.
 - Integration of the Hybrid-FLBCC architecture, combining machine learning to flexible decision-making.
 - Implementation of the ANFIS-FLBCC, merging adaptive neuro-fuzzy inference mechanisms with intelligent reasoning systems.



Opportunities

- Use of HPC to improve quantum simulators
- Study of the potential of quantum machines
 - Architecture
 - Compilation
 - Software stack
 - Mapping / Encoding of applications



Acknowledgements

- Carla Silva (former PhD student)
- Vanda Azevedo (former MSc student)
- Diogo França (former BSc student)
- Marcus Dahlem (MTS-IMEC, Carla's co-supervisor)
- Ana Aguiar (FEUP-IT, Carla's co-supervisor)
- UMinho team (QuantaLab)
 - Luís Barbosa
 - Luís Paulo Santos
- FEUP
 - Rui Maranhão
- Priscila M.V. Lima (COPPE-UFRJ)

dutra@fc.up.pt

Thank you.

For more information about FCT services developed by FCCN, visit <u>fccn.pt/en</u> or scan the QRCode.



fccn.pt/en/servicos























