3.5 Year PhD Progress Review

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Agenda

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1. Introduction
2. Aims and Objectives
3. Key Contributions
4. Results
5. Thesis Update
6. Thesis Completion Plan
7. Feedback!

Introduction

Introduction

1. We focus on the addressing the challenges in **Variational Quantum Algorithms (VQAs)**; a class of quantum algorithms that are expected to be run on near-term quantum devices (NISQ).
2. Among prominent VQAs, **Quantum Approximate Optimization Algorithm (QAOA)** and **Variational Quantum Eigensolver (VQE)** are widely studied.
3. The main area of focus in this thesis is to study the instance dependence of QAOAs to better understand and stress test its performance.

MaxCut Problem

Partition a graph $G = (V, E)$ into two sets S and $V \setminus S$ such that the number of edges between the two sets is maximised.

$$\max_{\mathbf{x}} \sum_{(i,j)\in E} w_{ij}(1 - x_i x_j)$$

where $x_i \in \{-1, 1\}$ and w_{ij} is the weight of edge (i, j).

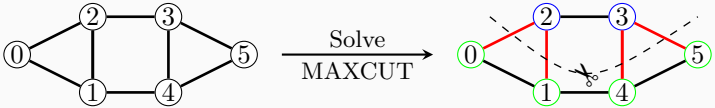

Figure 1: An example of a six-node MaxCut problem

QAOA + Our Focus

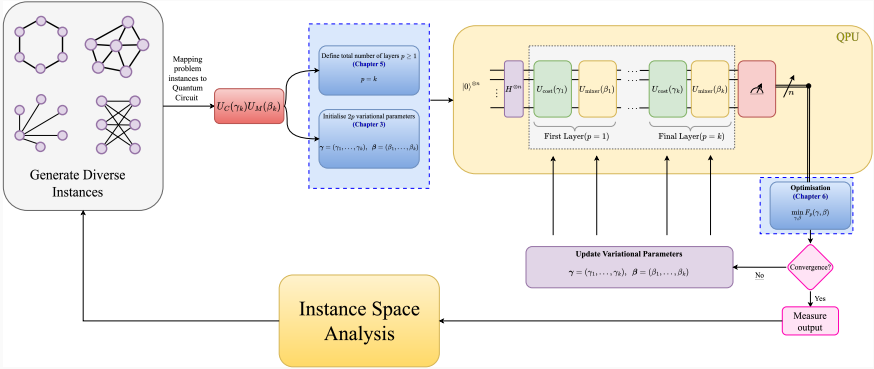

Figure 2: A schematic representation of the parameter optimisation process in QAOA.

Aims and Objectives

Aims and Objectives

1. **Instance Characteristics:** How do the characteristics of specific problem instances influence QAOA performance, and can a tailored strategy based on these characteristics enhance algorithm efficiency? or can we simply transfer from one class of instances to another?
2. **Parameter Initialisation:** How do initial parameter settings influence QAOA efficiency, and are optimal parameters instance-dependent?
3. **Circuit Depth Selection:** What is the optimal number of layers for QAOA, considering the trade-off between resource requirements and performance? What is the impact of instance characteristics on the dependence between layers p and $p+1$?
4. **Classical Optimisers:** Which classical optimisers are most effective in the hybrid optimisation phase of QAOA, and how do they impact solution quality?

Key Contributions

- **Instance Space Analysis (ISA) for QAOA Parameter Initialisation**
  - First ISA conducted in the quantum context to identify instance characteristics that influence QAOA performance.
  - *Submitted to INFORMS IJOC. Almost complete with revisions*
- **Development of Quantum Instance-Based Parameter Initialisation (QIBPI)**
  - A new approach to parameter initialisation leveraging specific problem instance characteristics to enhance the efficiency and performance of QAOA.
  - *Included in submission to INFORMS IJOC.*

Key Contributions (continued)

- **Comprehensive test suite of MaxCut Instances for QAOA alongside a feature library**
  - We construct a comprehensive and diverse library of MaxCut instances that have yet to be studied by existing research. We also build a feature library to capture that diversity.
  - *Included in submission to INFORMS IJOC.*
- **Exploration of Layer Depth in QAOA Circuits**
  - Approach for selecting optimal circuit layer depths based on problem instance characteristics. Leveraging ISA.
  - *Presenting the findings at OPTIMA-CON 2024.*

Key Contributions (continued)

- **Comparative Analysis of Classical Optimisers for QAOA using ISA**
  - We offer insights into the performance of different gradient-based and non-gradient based optimization techniques and the influence of instance characteristics on those optimisers.
- **Quantum instance space analysis for the resupply optimisation problem**
  - Application of ISA and QAOA / Variational Quantum Eigensolver in solving the resupply delivery problem.
  - *Presented at AIP 2021 and Quantum Australia 2022.*

Key Contributions (continued)

- **A FastAPI for Parameter Initialisation of the QAOA algorithm**
  - We develop an API that enables researchers to quickly initialize QAOA parameters from recent literature.
  - *Intend to submit to SoftwareX.*
  - *Publicly available here: QAOA Parameter Initialisation API.*
- **Development of Software for Managing Experimental Workloads**
  - A toolkit for automated and reproducible research experiments on HPC clusters, enhancing research scalability and reproducibility in computational research.

Results

Results

Lets look at some results from the Instance Space Analysis (ISA) and Quantum Instance-Based Parameter Initialisation (QIBPI) interactively!

Link here: ISA Visualisation

Thesis Update

Thesis Update

Writing has started (~100 pages through...)

- **Chapter 1: Introduction**
  - Complete (Draft Stage)
- **Chapter 2: Background and Preliminaries on Quantum Algorithms**
  - Writing in progress (60-70% Complete)
- **Chapter 3: Instance Space Analysis for QAOA Parameter Initialisation**
  - Almost Complete, Needs Revision (Update Results)
- **Chapter 4: Evolving Instances for QAOA Using Genetic Algorithms**
  - Writing in progress, Needs Revision (Update Results)

Thesis Update (continued)

- **Chapter 5: The Role of Circuit Depth in QAOA**
  - Results Complete, Writing Not Started
- **Chapter 6: Evaluating Classical Optimisers for QAOA**
  - Results Complete, Writing Not Started
- **Chapter 7: Conclusions and Future Work**
  - Conclusion, Not Started

Thesis Completion Plan

Month 1: June

Primary Focus in June: Submit revision to INFORMS and finalise SoftwareX submission

- Finalise revisions for INFORMS and submit (by June 15th)
- Compile parameter initialisation API submission
- Based on revisions, complete remainder of background

Thesis Writing and revising:

- **Chapter 2:** Complete writing (30-40%), review and edit
- **Chapter 3:** Revise and update results, finalise chapter
- **Chapter 4:** Complete writing, revise and update results, review and edit

Month 2: July

Primary Focus: Thesis Writing and revising

- **Chapter 5:** Start and complete writing, review and edit
- **Chapter 6:** Start and complete writing, review and edit
- **Chapter 7:** Draft conclusion, review all chapters for consistency

Other tasks

- Submit SoftwareX paper
- OPTIMA-CON presentation
- Conduct any additional experiments required for thesis completion

Month 3: August

Primary Focus: Thesis Writing and revising

- Final revisions and edits
- Prepare and hopefully submit!

Thank you!