3.5 Year PhD Progress Review

Vivek Katial

2024-05-28

Agenda

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1. Introduction

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2. Aims and Objectives

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3. Key Contributions

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4. Results

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5. Thesis Update

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6. Thesis Completion Plan

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7. Feedback!

Introduction

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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).

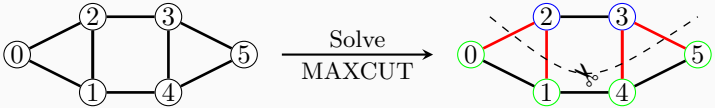

Figure 1: An example of a six-node MaxCut problem

QAOA + Our Focus

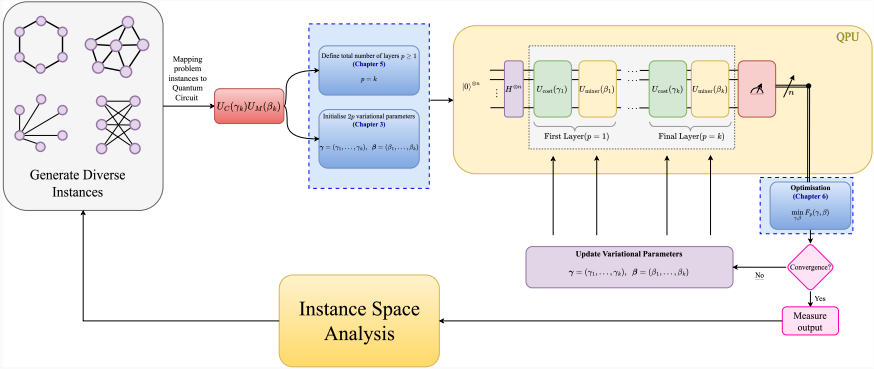

Figure 2: A schematic representation of the parameter optimisation process in QAOA.

Aims and Objectives

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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

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  - *Presenting the findings at OPTIMA-CON 2024.*

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- **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

Instance Space Analysis (ISA)

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix} = \begin{bmatrix} -0.5225 & 0.2301 \\ -0.5939 & 0.7398 \\ 0.3977 & -0.2637 \\ -0.1423 & -0.2023 \\ -0.0091 & 0.5056 \\ 0.4226 & -0.0190 \\ 0.0843 & 0.6528 \\ -0.0033 & -0.0937 \\ -0.2002 & -0.3513 \\ 0.3448 & -0.3839 \end{bmatrix}^{\top} \begin{bmatrix} \text{algebraic connectivity} \\ \text{average distance} \\ \text{clique number} \\ \text{diameter} \\ \text{maximum degree} \\ \text{maximum weighted degree} \\ \text{number of edges} \\ \text{radius} \\ \text{skewness weight} \\ \text{weighted average clustering} \end{bmatrix}$$

Instance Space Analysis (ISA) – Sources

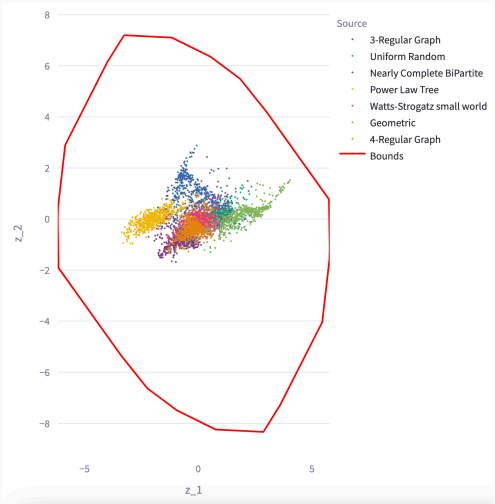

Figure 3: Source Distribution for MaxCut Instances

Instance Space Analysis (ISA) – Features

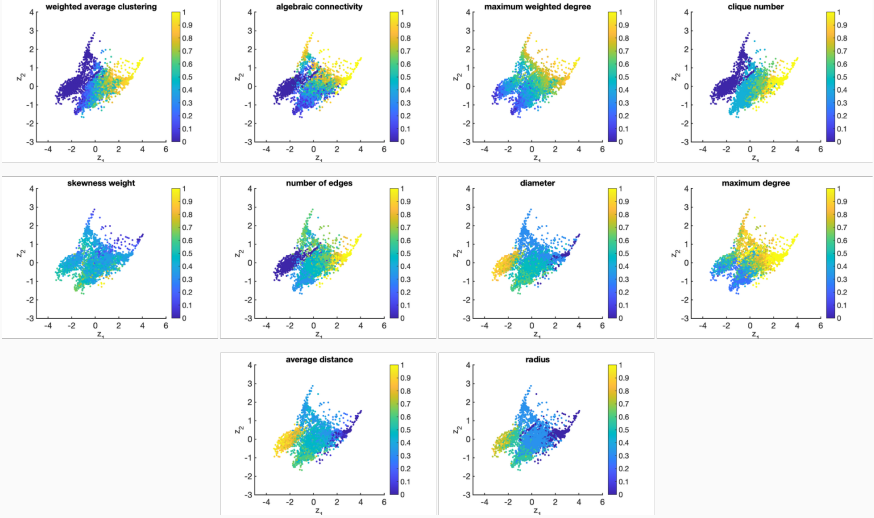

Figure 4: Feature Distribution for MaxCut Instances

Instance Space Analysis (ISA) – Algorithm Performance

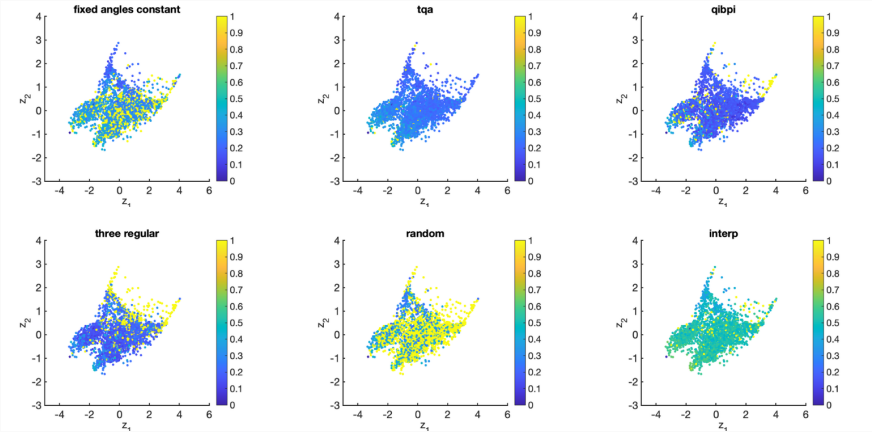

Figure 5: Algorithm Performance for MaxCut Instances (globally normalised)

Instance Space Analysis (ISA) – Algorithm Footprints

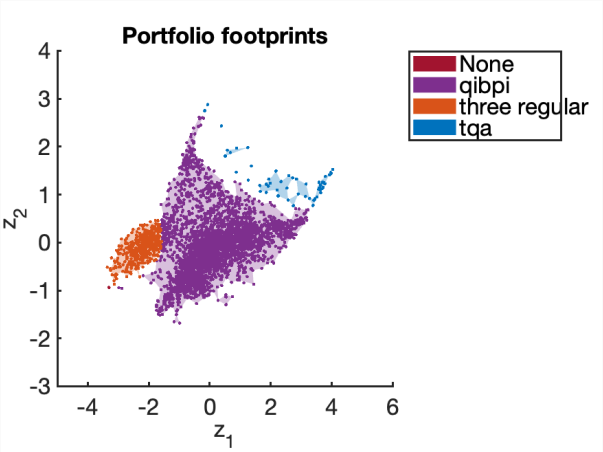

Figure 6: Algorithm Footprints for MaxCut Instances

Instance Space Analysis (ISA) – SVM

Algorithm	Avg Perf (all instances)	Std Perf (all instances)	Probability of Good
Constant	34323.017	47394.475	0.032
INTERP	6082.428	22217.419	0.001
QIBPI	6749.427	25023.466	0.709
Random	62812.688	48268.844	0.005
3-Regular	16989.979	37511.188	0.448
TQA	2138.589	14257.964	0.111
Oracle	27.734	59.506	1.000
SVM Selector	4998.899	21721.862	0.767

Table 1: Performance Metrics for Different Algorithms

Results

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Lets look at results from other experiments interactively!

Link here: ISA Visualisation

Thesis Update

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

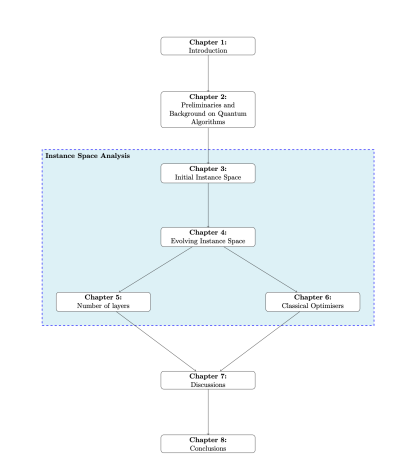

Figure 7: Thesis Structure

Thesis Update

- **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

Thesis GANTT Chart

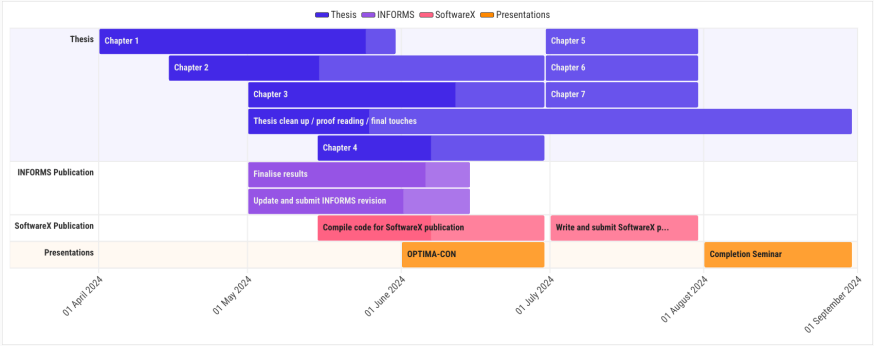

Figure 8: PhD GANTT Chart

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

- Finalise revisions for INFORMS and submit (by June 15th)

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- **Chapter 7:** Draft conclusion, review all chapters for consistency

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Other tasks

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

Month 3: August

Primary Focus: Thesis Writing and revising

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- Prepare and hopefully submit!

Feedback and Questions for Discussion

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1. **Stipend and Scholarship:** My current scholarship ends in June 2024 (next week). I've applied for the COVID-19 productivity-loss extension but haven't received a response yet. Any support would be appreciated. I applied for the shorter extension (*16 weeks instead of 26*), but I'm open to suggestions or advice. This extension would last until 23rd September, which I believe is more than enough time to get everything done. Link here .

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Thank you!