FAPESP WEEK GERMANY

March 25-26th, 2025

FAPESP SÃO PAULO RESEARCH FOUNDATION

DFG Deutsche Forschungsgemeinschaft

Feedback-Based Quantum Algorithms for Optimization

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São Paulo State University (UNESP)

ALBERT EINSTEIN
SOCIEDADE BENEFICENTE ISRAELITA BRASILEIRA

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FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

Industrial Applications of Quantum Computing

- Chemicals & Petroleum
- Distribution & Logistics
- Financial Services
- Health & Life Sciences
- Manufacturing

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Algorithm Family

- Chemical Simulation
- Scenario Simulation
- Optimization
- AI/ML

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- Chemicals & Petroleum
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- Financial Services
- Health & Life Sciences
- Manufacturing

Algorithm Family

- □ Chemical Simulation
- □ Scenario Simulation
- ▲ Optimization
- ◈ AI/ML

- □ Chemical Product Design
- ▲ Vehicle Routing
- ▲ Network Optimization
- ◈ Credit/Asset Scoring
- ▲ Portfolio Management
- □ Drug Discovery
- □ Protein Structure Prediction
- ◈ Quality Control
- ▲ Factory Supply Chains
- ▲ Manufacturing Optimization
- ◈ Accelerated Diagnosis
- ◈ Genomic Analysis
- ▲ Pharmaceutical Supply Chain
- ◈ Climate Change
- □ Derivatives Pricing
- ◈ Irregular Behaviors (Fraud)
- □ Investment Risk Analysis
- ▲ Supply Chain Distribution
- ▲ Oil Transport/Traffic
- ▲ Refining Processes

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1st Hospital outside the United States accredited by the Joint Commission International, first in 1999 and has been reaccredited since then

1st Hospital in Latin American to receive Magnet designation, which reflects the quality of nursing programs

Best Hospital in the Southern Hemisphere and 22nd in the world according to Newsweek/STATA ranking

Most Innovative Organization in the country in 2024

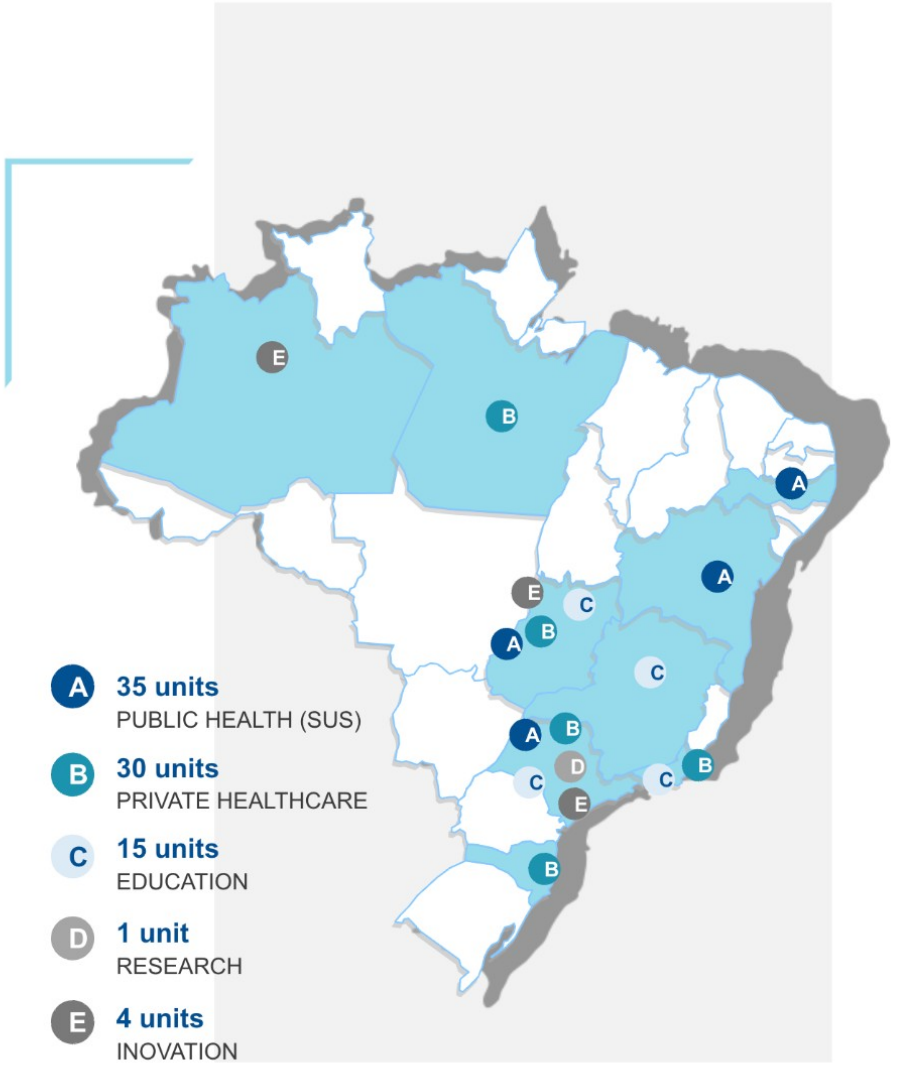
Health Care (public and private)
- **14MM** services
- **61.200** Surgeries and procedures

Research/ Innovation
- **45** researchers full time
- **1.069** research projects
- **1st** Academic Research Organization (ARO) in Brazil
- **55** Funded startups

Teaching and Education
- **23.7k** Students enrolled in multiple courses

25.102 collaborators

12.984 Doctors (clinical staff and contractors)



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FAPESP SÃO PAULO RESEARCH FOUNDATION

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QuaTI

quantum technology & information



pete

venturus

FLOODS IN BRAZIL



Aerial images of the flooding in the Taquari River, Lajeado — Released on August 5, 2023 / Portal Agora no Vale



Aerial image of flooded areas in Porto Alegre — Photo: Ricardo Stuckert / PR



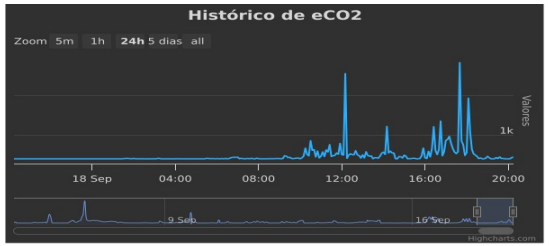
Before and after comparison of the bridge in Lajeado
Source: https://www.poder360.com.br/brasil/leia-relatorio-oficial-do-rio-grande-do-sul-sobre-chuvas



An image from NASA's Landsat 8 satellite shows the muddy Guaíba River and a flooded Porto Alegre — Photo: Landsat-NASA/Released



Rio Grande do Sul


Histórico de eCO2
Zoom 5m 1h 24h 5 dias all
Valores
1k
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Pressão
Zoom 5m 1h 24h 5 dias all
Valores
925
920
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Anemoscopio
Zoom 5m 1h 24h 5 dias all
Valores
200
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com

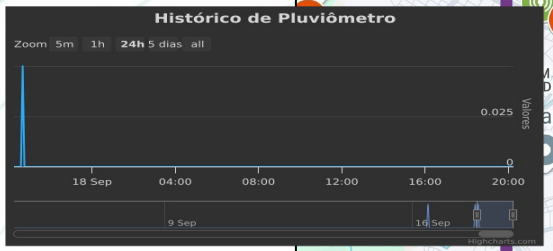

Histórico de Temperatura
Zoom 5m 1h 24h 5 dias all
Valores
20
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Umidade
Zoom 5m 1h 24h 5 dias all
Valores
50
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Luminosidade
Zoom 5m 1h 24h 5 dias all
Valores
0
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Ultravioleta
Zoom 5m 1h 24h 5 dias all
Valores
0
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com

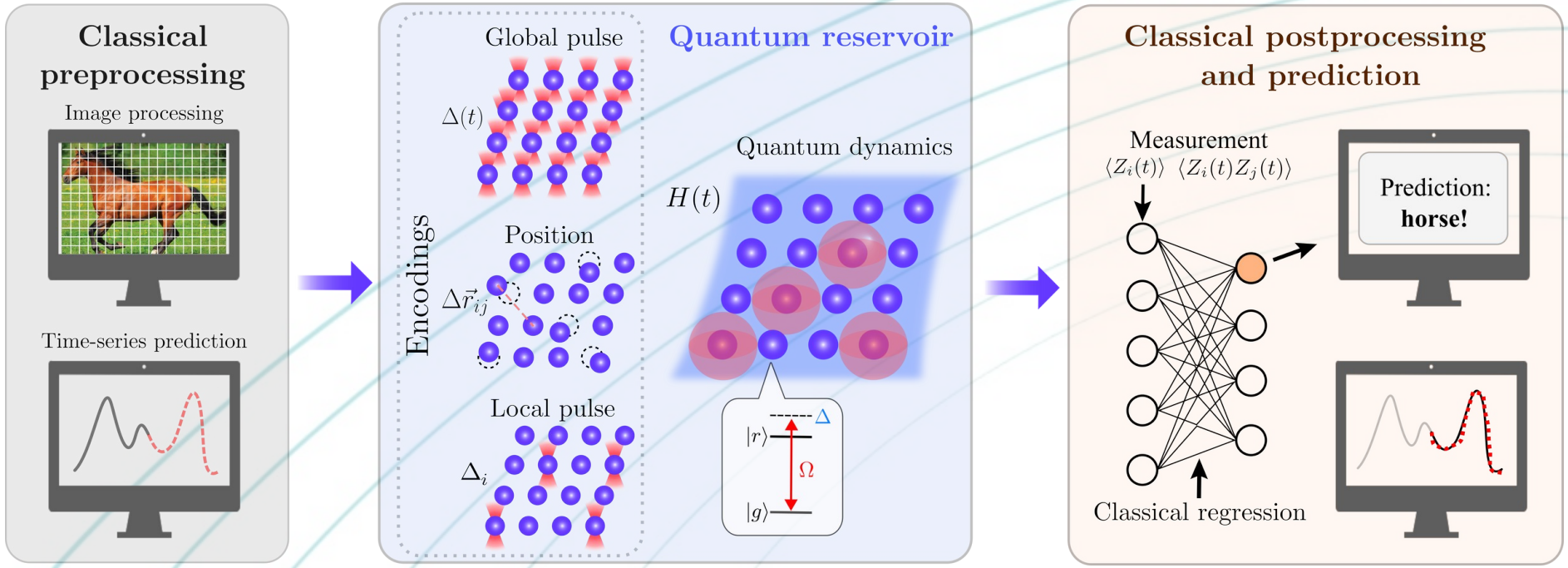

Histórico de Vento
Zoom 5m 1h 24h 5 dias all
Valores
10
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com


Histórico de Pluviômetro
Zoom 5m 1h 24h 5 dias all
Valores
0.025
0
18 Sep 04:00 08:00 12:00 16:00 20:00
9 Sep 16 Sep
Highcharts.com



Parque Ecológico de São Carlos Dr. Antônio...
USP - Universidade de São Paulo
Rodoviária São Carlos
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São Carlos
VILA IZABEL
Parque do Bicã
Terraplanagem ção e Serviços
Arena TUCA
364

QUANTUM RESERVOIR COMPUTING



[2407.02553] Large-scale quantum reservoir learning with an analog quantum computer

QuEra Computing Inc.

Moody's

TQI Exclusive: Moody's, QuEra Explore Using Quantum Computers To Better Predict Path, Intensity Of Tropical Cyclones

Exclusives, Research Matt Swayne • June 22, 2024



QuLTSF: Long-Term Time Series Forecasting with Quantum Machine Learning

Hari Hara Suthan Chittoor[1] [a], Paul Robert Griffin[1] [b], Ariel Neu
Mile Gu[2,5] [e]

[1]*School of Computing and Information Systems, Singapore Managemen*
[2]*Nanyang Quantum Hub, School of Physical and Mathematical Sciences, Nanya*
[3]*Institute of High Performance Computing (IHPC), Agency for Science, Technol*
[4]*Horizon Quantum, 29 Media Cir., #05-22/23/24 ALICE@MEDIAPOLIS*
[5]*Centre for Quantum Technologies, National University of S*
{*haric, paulgriffin*}*@smu.edu.sg, ariel.neufeld@ntu.edu.sg, thompson.jayne2@g*

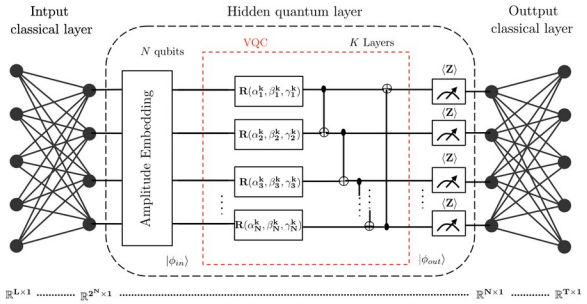


Figure 1: QuLTSF model architecture.

Methods	QuLTSF*		Linear		NLinear		DLinear		FEDformer		Autoformer		Informer	
Metric	MSE	MAE	MSE	MAE	MSE	MAE	MSE	MAE	MSE	MAE	MSE	MAE	MSE	MAE
96	**0.156**	**0.211**	0.176	0.236	0.182	0.232	0.176	0.237	0.217	0.296	0.266	0.336	0.300	0.384
192	**0.199**	**0.253**	0.218	0.276	0.225	0.269	0.220	0.282	0.276	0.336	0.307	0.367	0.598	0.544
336	**0.248**	**0.296**	0.262	0.312	0.271	0.301	0.265	0.319	0.339	0.380	0.359	0.395	0.578	0.523
720	**0.315**	**0.346**	0.326	0.365	0.338	0.348	0.323	0.362	0.403	0.428	0.419	0.428	1.059	0.741

of reduced mean squared error and mean absolute error.

Hari Hara Suthan Chittoor et al., arXiv:2412.13769

What about Quantum Optimization ???



QUBO

Quadratic Unconstrained Binary Optimizations



QUBO

Quadratic Unconstrained Binary Optimizations

1. **Max-Cut Problem**
   Partition the nodes of a graph into two sets to maximize the number of edges between them.
   ➤ *Applications:* network design, circuit layout, …

2. **Traveling Salesman Problem**
   Find the shortest possible route that visits each city exactly once and returns to the origin.
   ➤ *Applications:* logistics, route planning, drone delivery, …

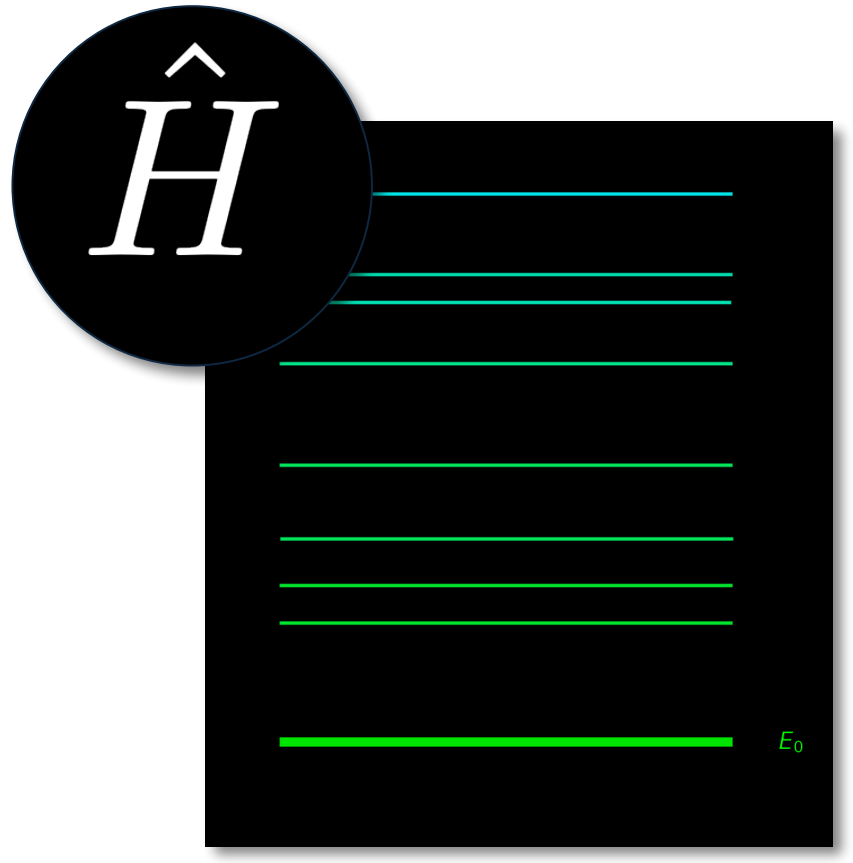
3. **Portfolio Optimization**
   Select a subset of assets that balances return and risk, possibly under budget or risk constraints.
   ➤ *Applications:* finance, asset management, …

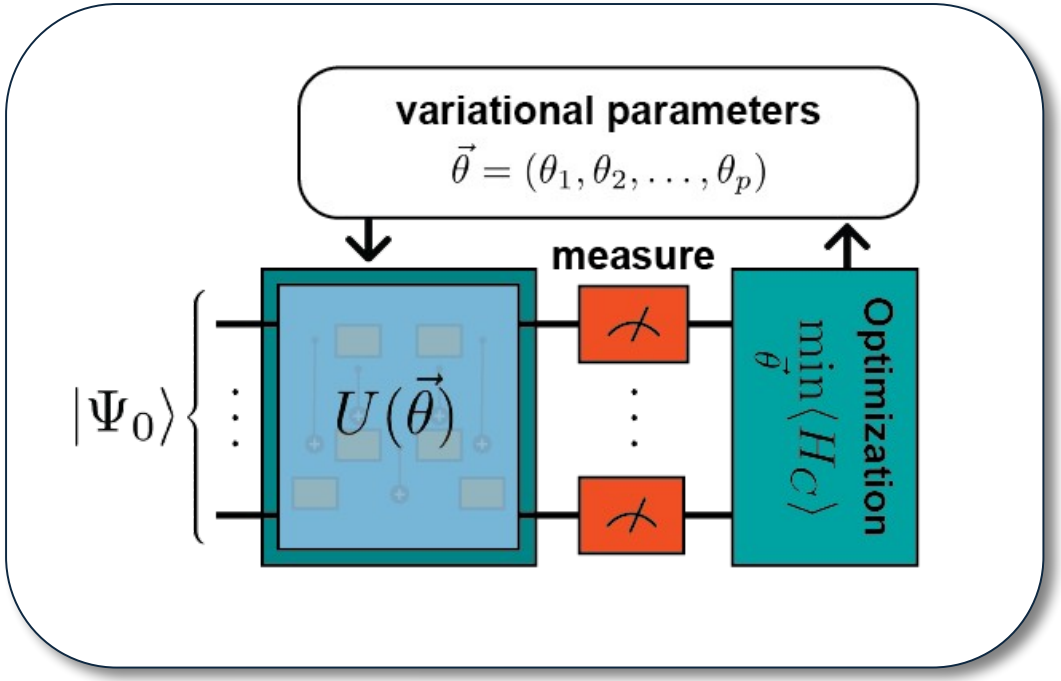
4. **Genomic Pattern Matching**
   Identify specific gene expression patterns or biomarkers by solving binary classification or matching problems.
   ➤ *Applications:* drug discovery, disease diagnostics, …

5. **…**

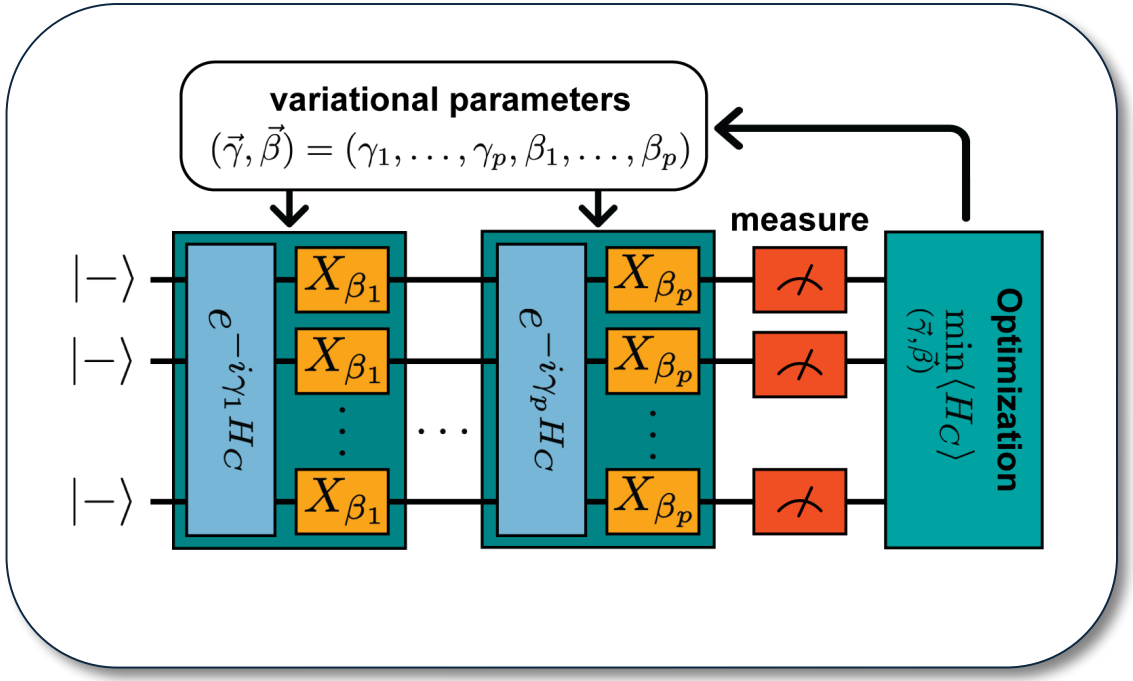
QUBO

Quadratic Unconstrained Binary Optimizations




variational parameters
$\vec{\theta} = (\theta_1, \theta_2, \ldots, \theta_p)$
measure
$|\Psi_0\rangle$
$U(\vec{\theta})$
Optimization
$\min_{\vec{\theta}} \langle H_C \rangle$

VQE


variational parameters
$(\vec{\gamma}, \vec{\beta}) = (\gamma_1, \ldots, \gamma_p, \beta_1, \ldots, \beta_p)$
measure
$|-\rangle$
$|-\rangle$
$|-\rangle$
$e^{-i\gamma_1 H_C}$
$e^{-i\gamma_p H_C}$
X_{β_1}
X_{β_p}
Optimization
$\min_{(\vec{\gamma},\vec{\beta})} \langle H_C \rangle$

QAOA

APS Physical Review Journals
All Journals Physics Magazine

Physical Review Letters

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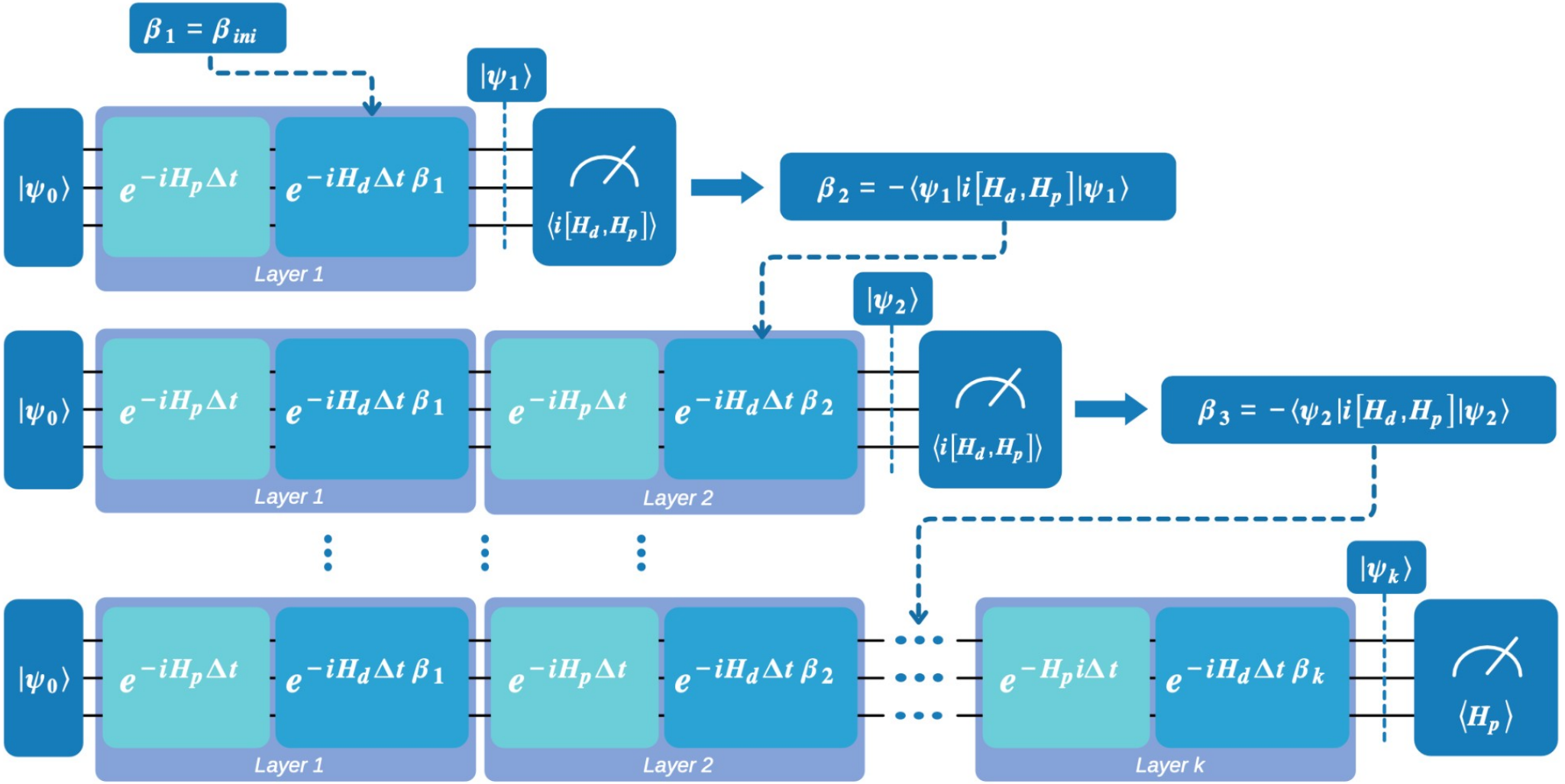
Feedback-Based Quantum Optimization

Alicia B. Magann [1,2,3], Kenneth M. Rudinger [2], Matthew D. Grace [1], and Mohan Sarovar [1]

Show more

Phys. Rev. Lett. **129**, 250502 – **Published 13 December, 2022**

DOI: https://doi.org/10.1103/PhysRevLett.129.250502


$\beta_1 = \beta_{ini}$
$|\psi_1\rangle$
$|\psi_0\rangle$
$e^{-iH_p\Delta t}$
$e^{-iH_d\Delta t\,\beta_1}$
$\langle i[H_d, H_p]\rangle$
Layer 1
$\beta_2 = -\langle\psi_1|i[H_d, H_p]|\psi_1\rangle$
$|\psi_2\rangle$
$e^{-iH_p\Delta t}$
$e^{-iH_d\Delta t\,\beta_2}$
$\langle i[H_d, H_p]\rangle$
Layer 2
$\beta_3 = -\langle\psi_2|i[H_d, H_p]|\psi_2\rangle$
$|\psi_k\rangle$
$e^{-H_p i\Delta t}$
$e^{-iH_d\Delta t\,\beta_k}$
$\langle H_p\rangle$
Layer k

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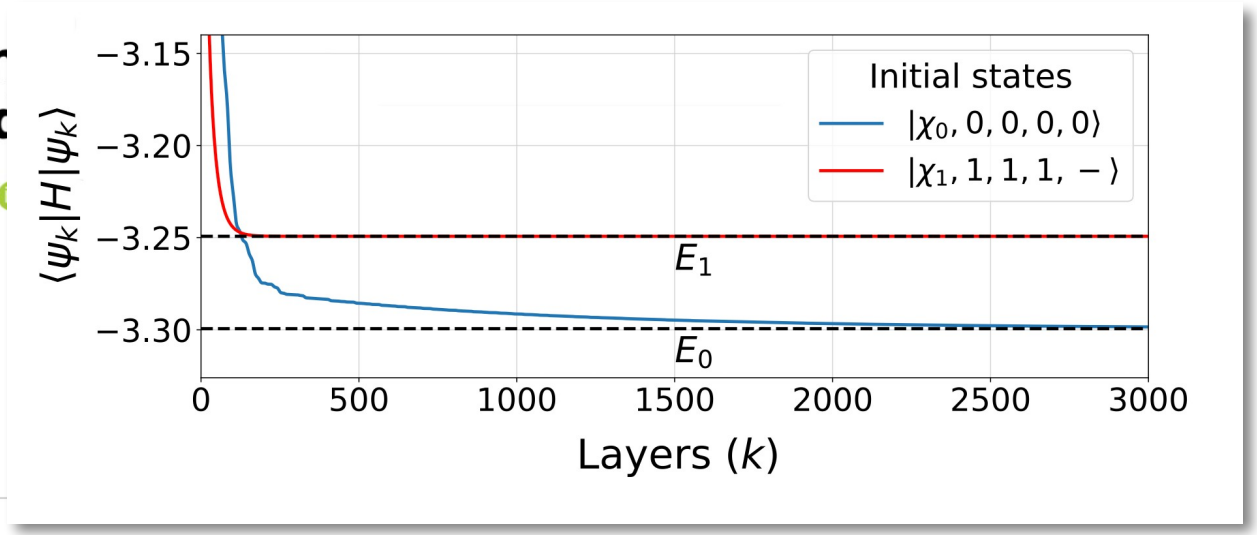
Using a feedback-based quar
properties of the ANNNI moc

G. E. L. Pexe[1,*], L. A. M. Rattighieri[1,*], A. L. Malvezzi

Show more

Phys. Rev. B **110**, 224422 – **Published 16 December, 2024**

DOI: https://doi.org/10.1103/PhysRevB.110.224422



A Feedback-Based Approach to Optimization with Reduced Circuit Depth

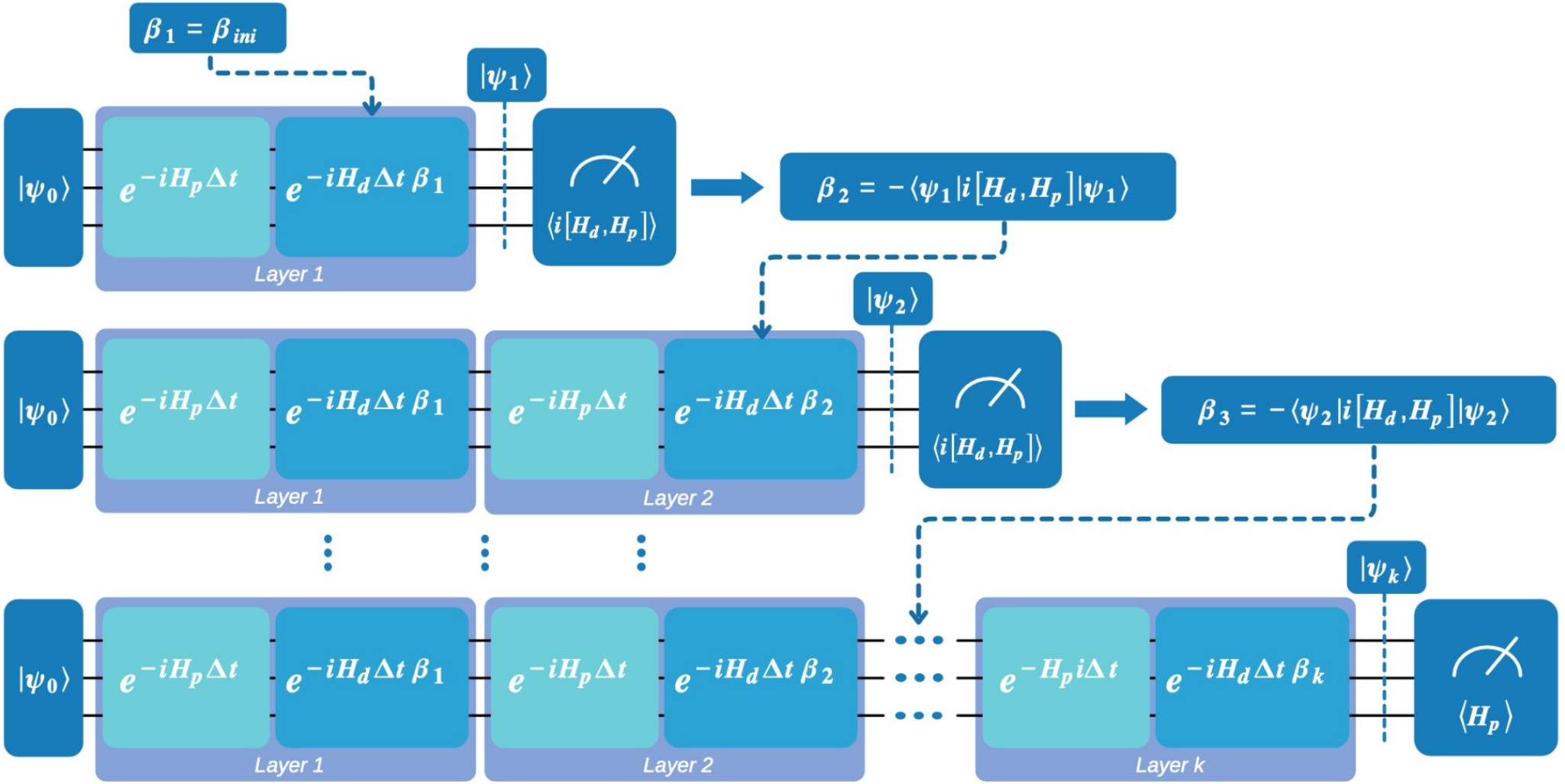
L. A. M. Rattighieri,[1,*] G. E. L. Pexe,[1,*] B. L. Bernado,[2] and F. F. Fanchini[3,1,4,†]

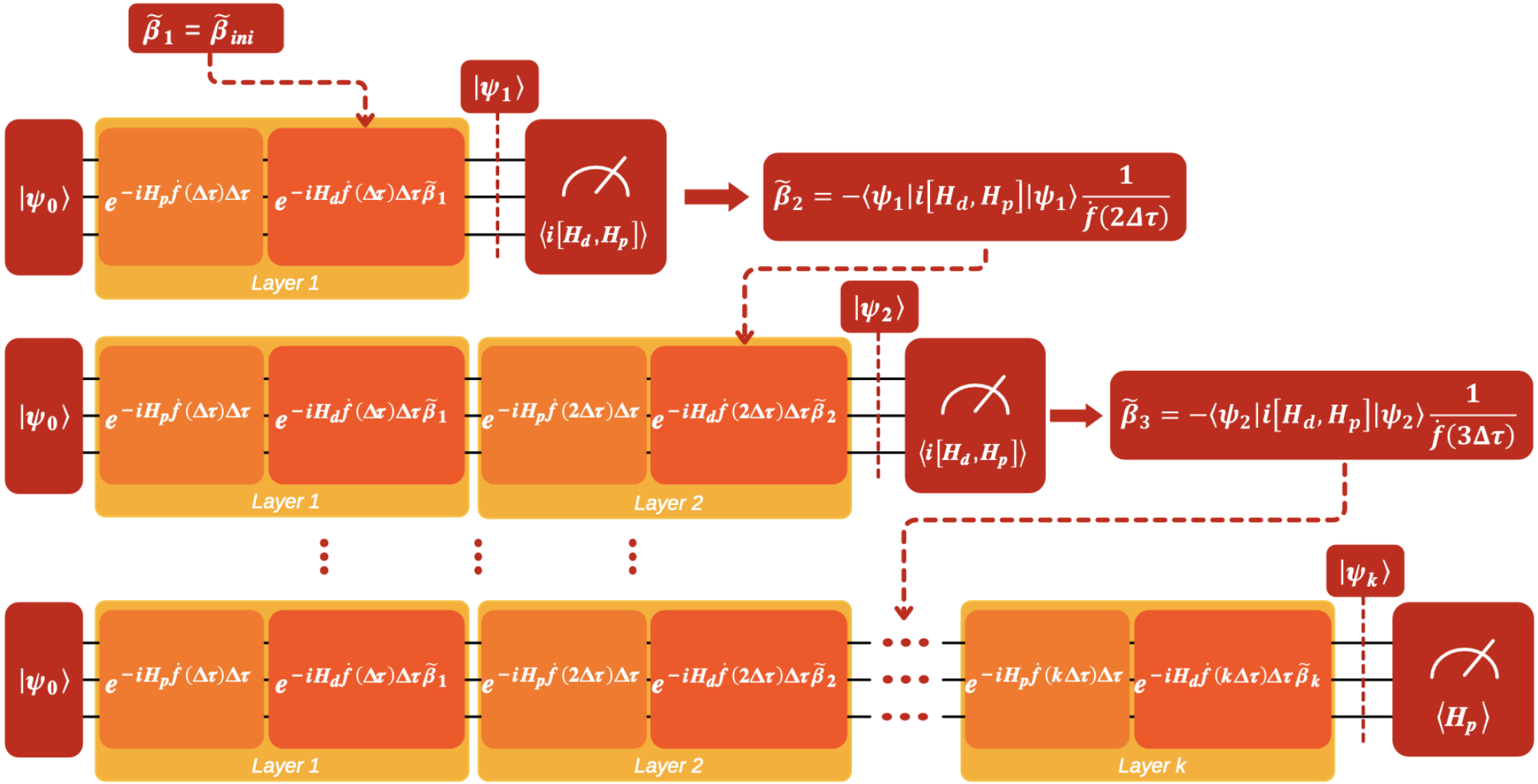
[1] *Faculty of Sciences, UNESP - São Paulo State University, 17033-360 Bauru-SP, Brazil*
[2] *Department of Physics, Federal University of Paraíba, 58051-900 João Pessoa-PB, Brazil*
[3] *Hospital Israelita Albert Einstein, 05652-900 São Paulo-SP, Brazil*
[4] *QuaTI - Quantum Technology & Information, 13560-161 São Carlos-SP, Brazil*

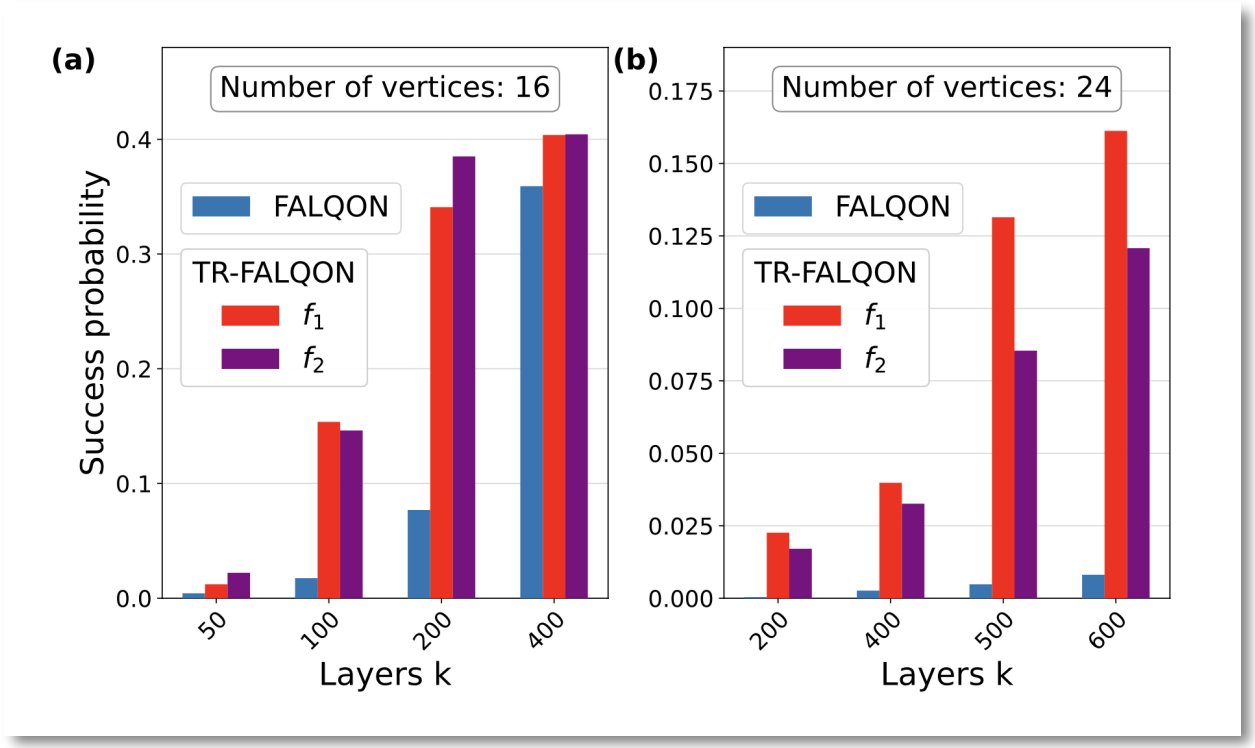
(Dated: March 22, 2025)

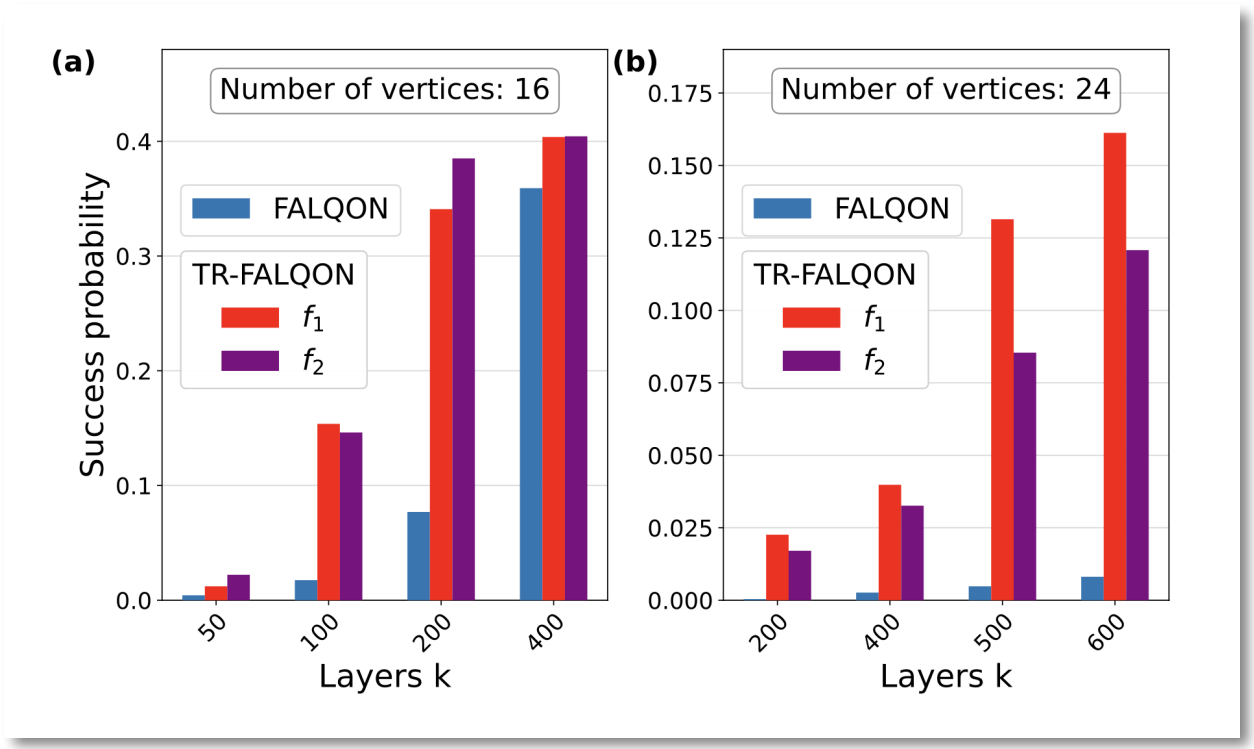
This work investigates the impact of time rescaling on the performance of the FQA and FALQON algorithms, introducing the TR-FQA and TR-FALQON variants. The algorithms were applied to both optimization problems, using the MaxCut problem, and ground-state preparation in the ANNNI model. The results indicate that TR-FALQON accelerates convergence to the optimal solution in the early layers of the circuit. In the context of state preparation, TR-FQA exhibited superior convergence compared to standard FQA, especially for larger systems, suggesting that time rescaling can reduce the need for deep circuits.

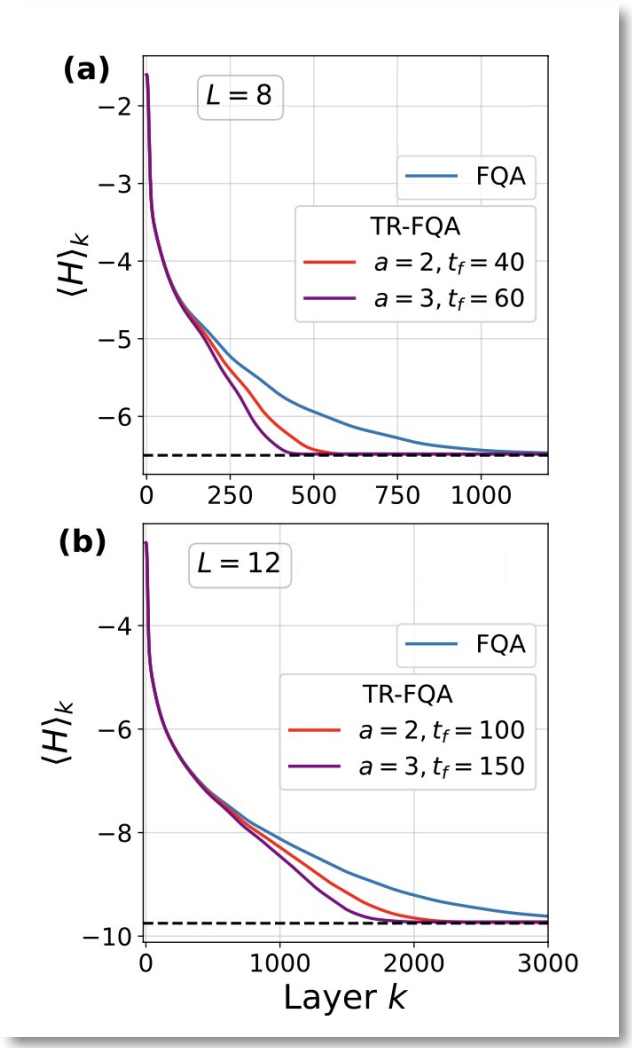
to appear on arXiv


$\beta_1 = \beta_{ini}$
$|\psi_1\rangle$
$|\psi_0\rangle$
$e^{-iH_p\Delta t}$
$e^{-iH_d\Delta t\,\beta_1}$
$\langle i[H_d, H_p]\rangle$
Layer 1
$\beta_2 = -\langle\psi_1|i[H_d, H_p]|\psi_1\rangle$
$|\psi_2\rangle$
$e^{-iH_p\Delta t}$
$e^{-iH_d\Delta t\,\beta_2}$
$\langle i[H_d, H_p]\rangle$
Layer 2
$\beta_3 = -\langle\psi_2|i[H_d, H_p]|\psi_2\rangle$
$|\psi_k\rangle$
$e^{-H_p i\Delta t}$
$e^{-iH_d\Delta t\,\beta_k}$
$\langle H_p\rangle$
Layer k


$\tilde{\beta}_1 = \tilde{\beta}_{ini}$
$|\psi_1\rangle$
$|\psi_0\rangle$
$e^{-iH_p\dot{f}(\Delta\tau)\Delta\tau}$
$e^{-iH_d\dot{f}(\Delta\tau)\Delta\tau\tilde{\beta}_1}$
$\langle i[H_d,H_p]\rangle$
Layer 1
$\tilde{\beta}_2 = -\langle\psi_1|i[H_d,H_p]|\psi_1\rangle\frac{1}{\dot{f}(2\Delta\tau)}$
$|\psi_2\rangle$
$e^{-iH_p\dot{f}(2\Delta\tau)\Delta\tau}$
$e^{-iH_d\dot{f}(2\Delta\tau)\Delta\tau\tilde{\beta}_2}$
Layer 2
$\tilde{\beta}_3 = -\langle\psi_2|i[H_d,H_p]|\psi_2\rangle\frac{1}{\dot{f}(3\Delta\tau)}$
$|\psi_k\rangle$
$e^{-iH_p\dot{f}(k\Delta\tau)\Delta\tau}$
$e^{-iH_d\dot{f}(k\Delta\tau)\Delta\tau\tilde{\beta}_k}$
Layer k
$\langle H_p\rangle$


(a)
Number of vertices: 16
Success probability
FALQON
TR-FALQON
f_1
f_2
0.0
0.1
0.2
0.3
0.4
50
100
200
400
Layers k
(b)
Number of vertices: 24
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
200
400
500
600
Layers k


(a)
Number of vertices: 16
FALQON
TR-FALQON
f_1
f_2
Success probability
0.0
0.1
0.2
0.3
0.4
50
100
200
400
Layers k
(b)
Number of vertices: 24
FALQON
TR-FALQON
f_1
f_2
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
200
400
500
600
Layers k


(a)
$L = 8$
FQA
TR-FQA
$a = 2, t_f = 40$
$a = 3, t_f = 60$
$\langle H \rangle_k$
−2
−3
−4
−5
−6
0
250
500
750
1000
(b)
$L = 12$
FQA
TR-FQA
$a = 2, t_f = 100$
$a = 3, t_f = 150$
$\langle H \rangle_k$
−4
−6
−8
−10
0
1000
2000
3000
Layer k

Quantum algorithms have the potential to profoundly transform a wide range of fields, from data science to healthcare, and even help mitigate the impacts of climate change. All signs point to progress, but only with less noisy quantum computers will it be possible to truly validate this potential and turn these promises into reality.

Thank you very much!!!