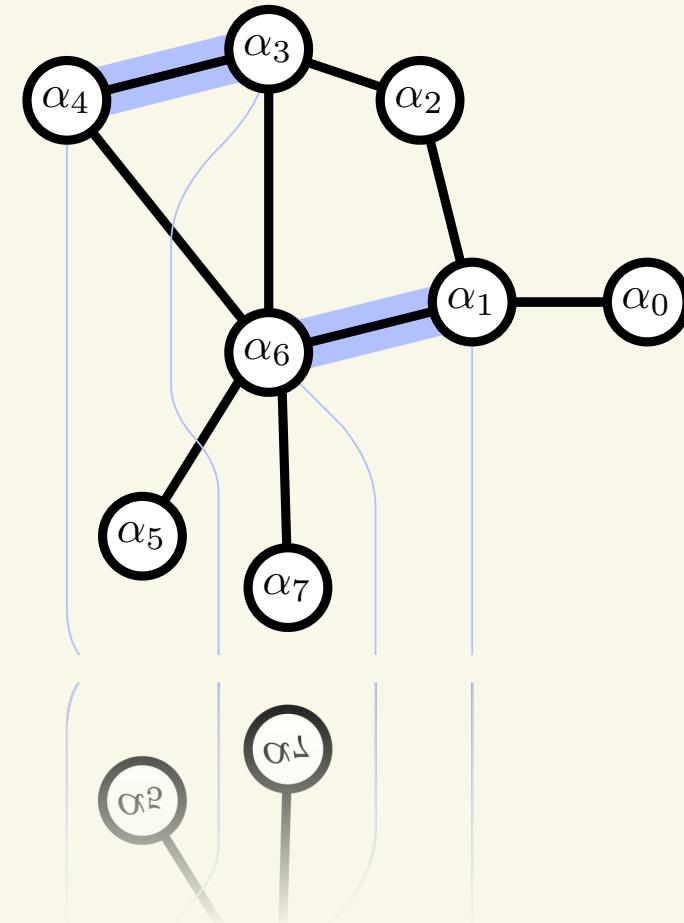


Mitchell Chiew

Portfolio for Springer Nature

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Cambridge, UK



I am an Australian student of theoretical physics currently finishing my PhD at the University of Cambridge. This portfolio contains only my own artwork, much of which has appeared in my academic writing.

Illustration has been integral to my learning process since childhood, and I have incorporated visual reasoning into my scientific writing and collaborative projects.

Through academia, I have developed my scientific art style through image editors that allow me to maintain the freedom of drawing by hand, with the goal of clearly and creatively communicating science.

<i>Samples from theoretical physics</i>	3
<i>Detail-oriented design</i>	3
<i>Illustrating the impact of new research</i>	4
<i>Vivid imagery from sketches</i>	5
<i>My design process</i>	6
<i>Reaching broader audiences</i>	7
<i>Poster gallery</i>	8–11
<i>Other samples</i>	12–14

Samples from theoretical physics

Detail-oriented design

2024

commissioned Nature Reviews Physics article (upcoming)

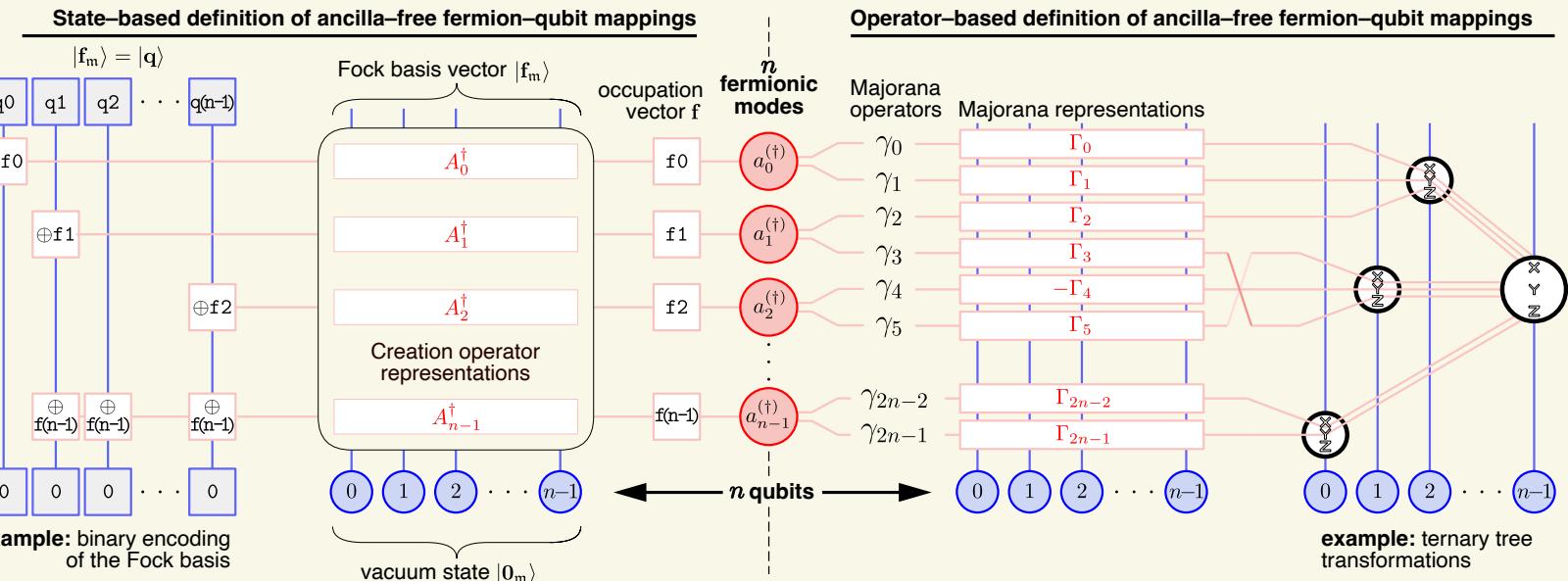
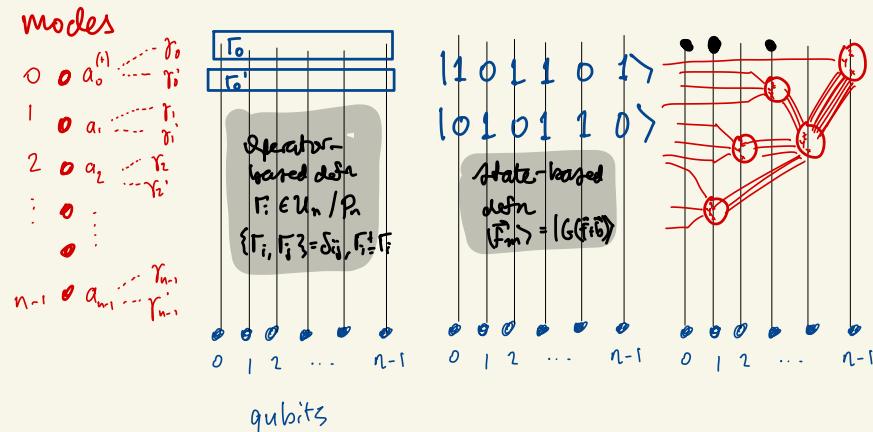
Top (sketch): hand-drawn

Bottom (final): Inkscape and Ipe

From a collaborative work with researchers from Dartmouth College, USA. I am one of the lead co-authors and the main illustrator for our draft submission to Nature Reviews Physics about fermion–qubit mappings in quantum computing.

The image works with the body text of the paper to provide an accurate numerical example of two parallel concepts.

Pauli Repn.
Affine
Tree



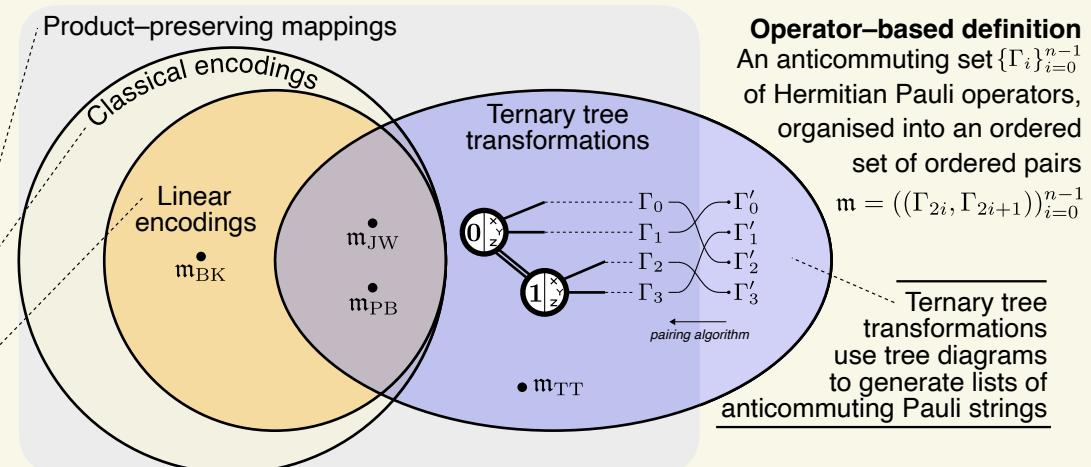
State-based definition

An orthonormal basis $\{|f_m\rangle \mid f \in \mathbb{F}_2^n\}$ encoding the Fock states

$$|f_m\rangle = \text{product states}$$

$$|f_m\rangle = \text{computational basis states}$$

$$|f_m\rangle = \begin{vmatrix} & 1 & f_0 \\ & 1 & f_1 \\ G & & f \end{vmatrix}$$

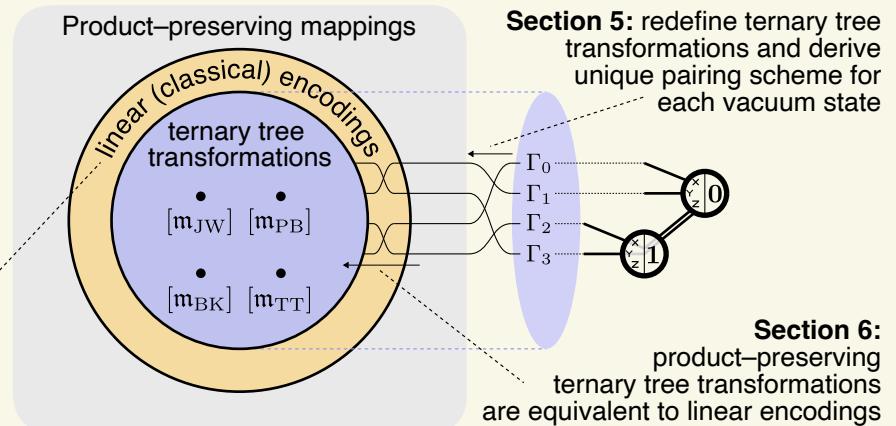


Section 2: unify state- and operator-based definitions

$$|f_m\rangle = (\Gamma_0)^{f_0} \dots (\Gamma_{2n-2})^{f_{n-1}} |0_m\rangle$$

Section 3: define equivalence between fermion-qubit mappings

Section 4: classical encodings are equivalent to linear encodings



Illustrating the impact of new research

2024

upcoming preprint

Inkscape and Ipe

These figures come from the introduction section of an upcoming preprint about quantum algorithms, for which I am the lead author.

The top figure represents the state of understanding in the literature before the work in my paper. I chose the Venn diagram format to display overlapping concepts and redundancies in their description.

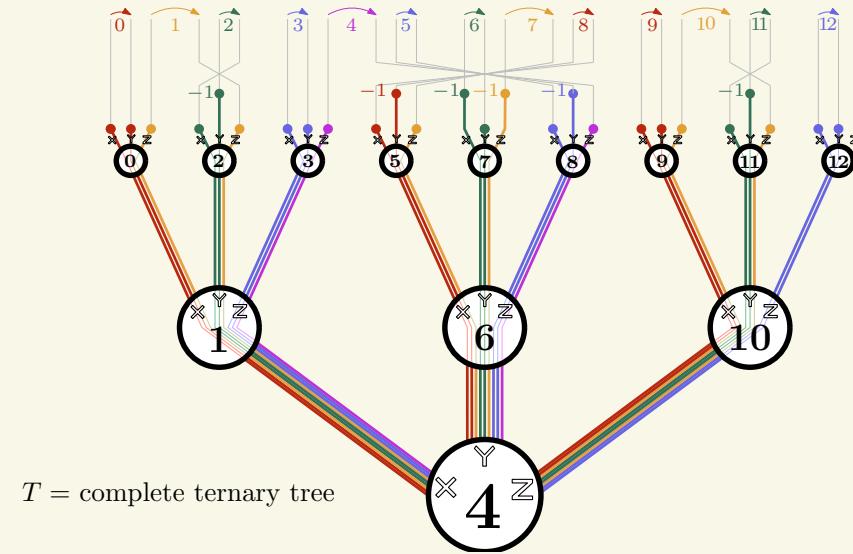
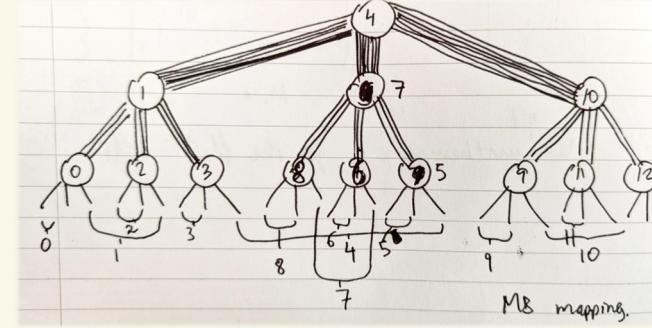
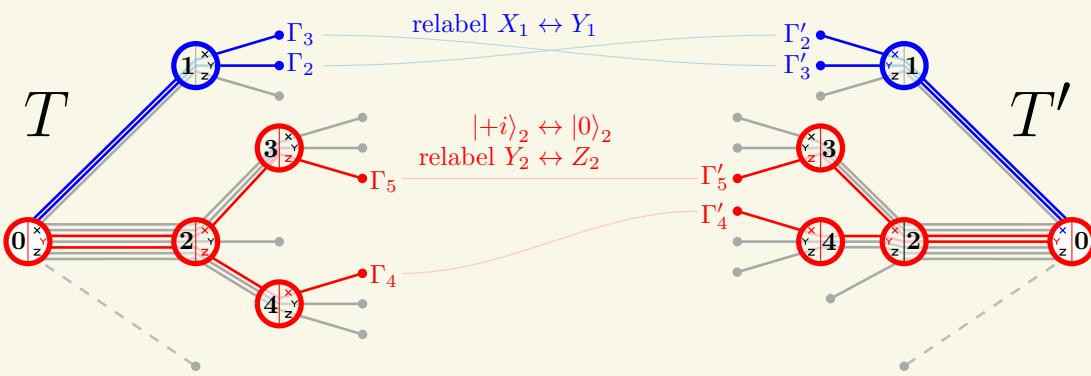
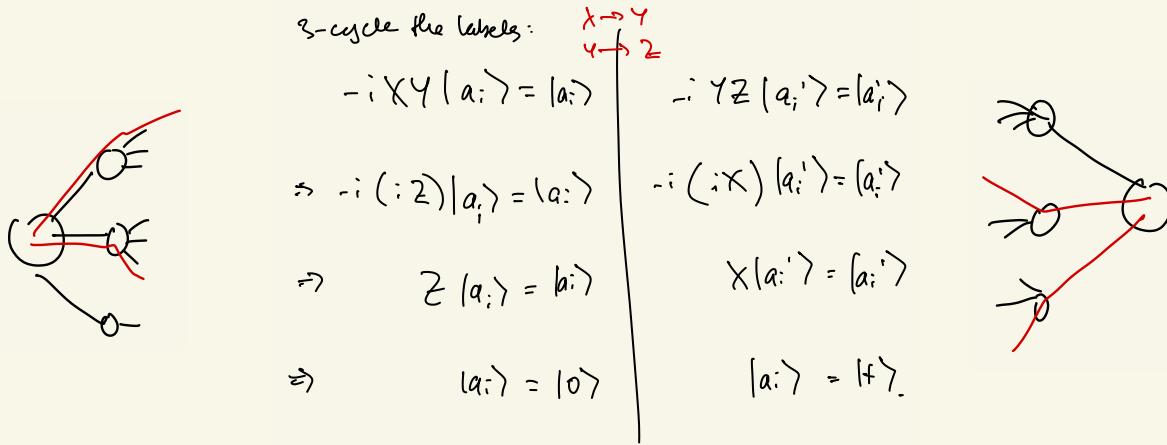
The lower figure depicts the simplification of these different concepts, and acts as a visual table of contents for my paper.

Vivid imagery from sketches
2024
upcoming preprint

Top left, top right (sketches): hand-drawn
Bottom left, bottom right (final): Ipe

I created these diagrams to illustrate technical concepts in an upcoming preprint in the field of quantum computing, for which I am the lead author. Ternary tree graphs are the mathematical backbone of a popular strategy to encode fundamental particles in quantum computers.

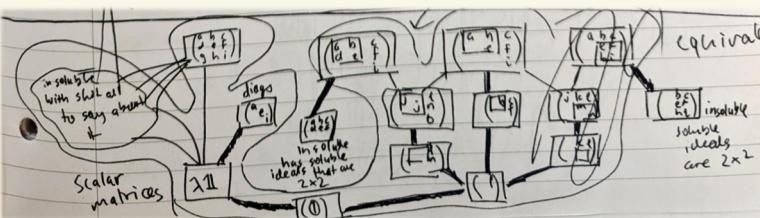
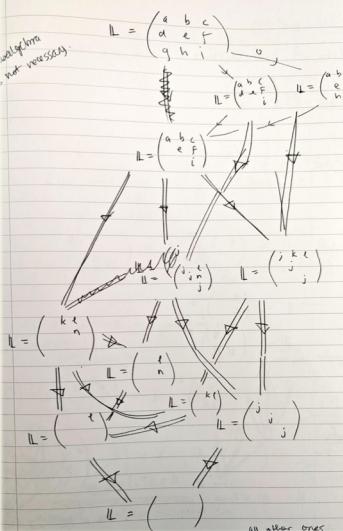
A technical detail that the images highlight are the many distinct paths through the tree, which is a level of detail missing from other illustrations in the literature.



My design process

Scientific imagery is part of my learning process, and I render my understanding through illustration. Through constant refinement of accuracy and style, I converge to a final product that tells the entire story as simply as possible.

Sketches and roughs



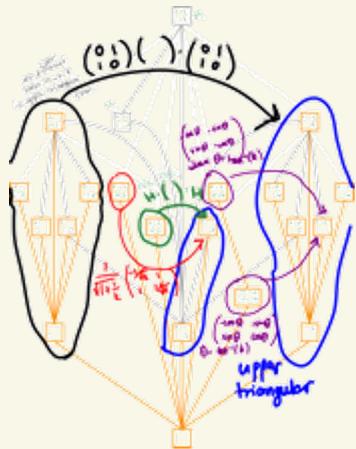
2020

personal notes

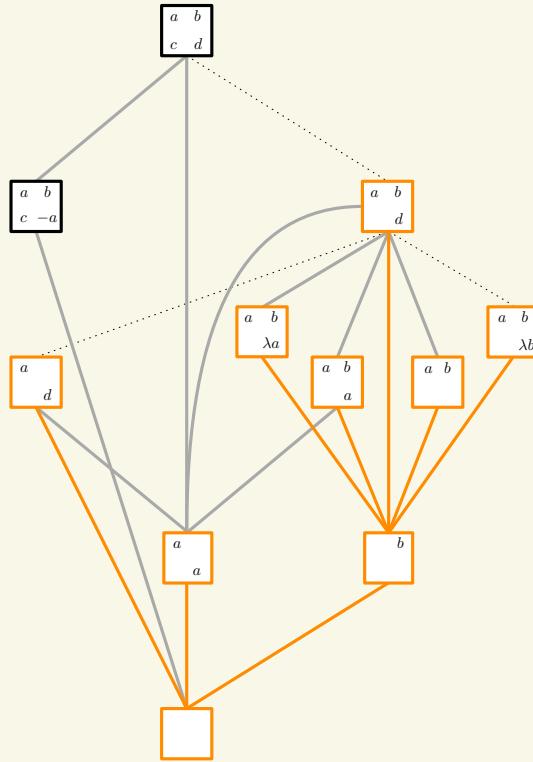
Left, bottom (sketches): hand-drawn,
Right (annotated sketch): Ipe

Notes I took while attending a virtual lecture course in pure mathematics during the lockdowns in winter 2020.

Refinement



Scientific accuracy and style



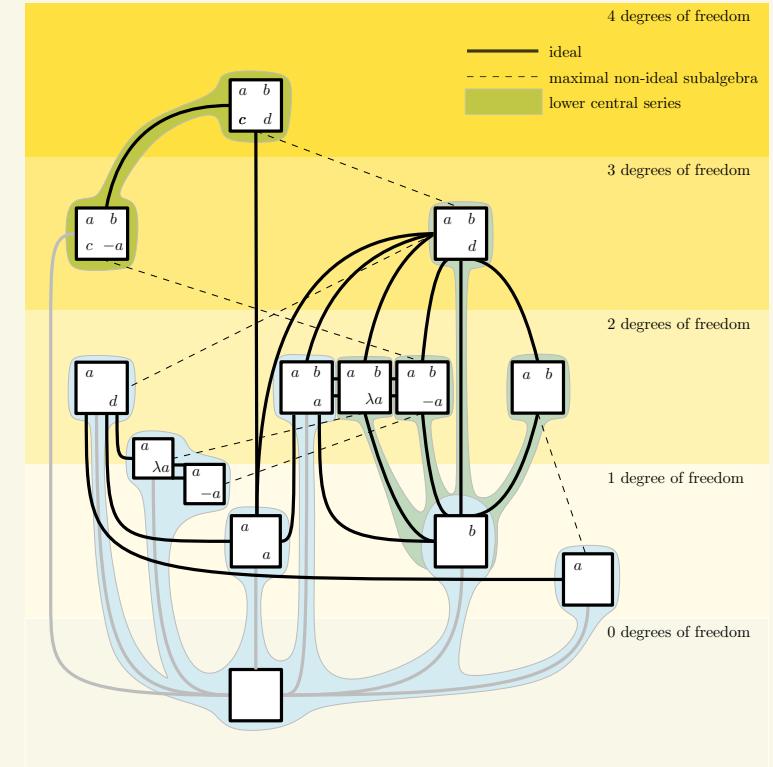
2020

personal notes

Ipe

This image was the result of repeatedly refining and simplifying my rough notes.

Final product



2020

personal notes

Ipe

The stylised final product depicts all two-dimensional Lie algebras and uses the colour gradient to distinguish different categories.

Reaching broader audiences

Hand-drawn slides with no equations

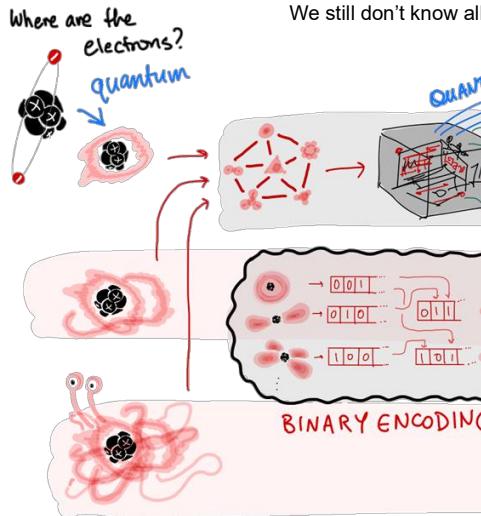
2024

public lecture in Cambridge

Hand-drawn and Powerpoint

These slides come from a presentation about my PhD work which I gave to a general audience. In preparing this work I made a commitment to draw by hand and omit any equations to create a friendly and engaging aesthetic.

THE ELECTRONIC STRUCTURE PROBLEM

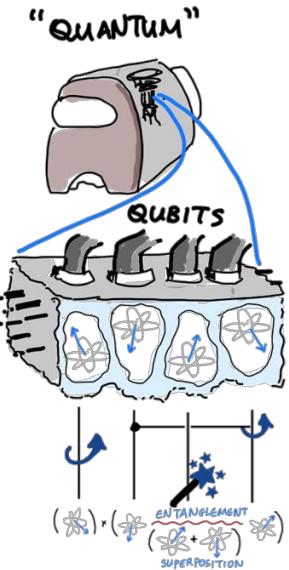
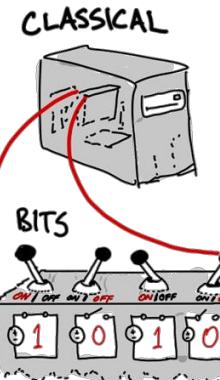
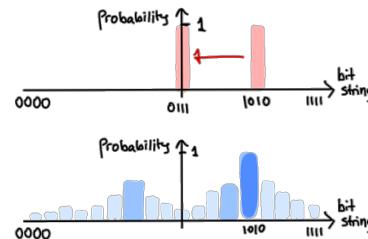


We still don't know all there is to know about the electron structure of atoms.

QUANTUM COMPUTERS

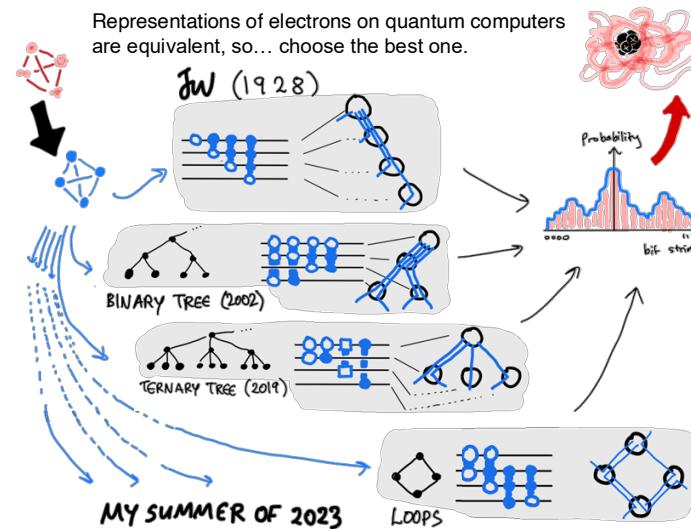
Bits are either "on" (1) or "off" (0). Algorithms operate on bits by changing their value

Qubits are a mixture of "up" (1) and "down" (0). Quantum algorithms rotate qubits. When we look at qubits, all we see are 1s and 0s!

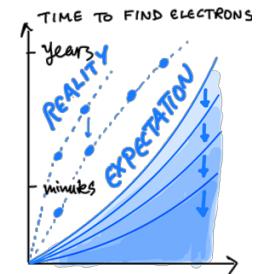


IMPROVING QUANTUM ALGORITHMS

Representations of electrons on quantum computers are equivalent, so... choose the best one.



Any improvement to quantum algorithms is important if we are ever going to get a quantum computer working.



Poster gallery

Posters are an exciting opportunity for me to collate existing bodies of illustrations and refine my research to tell a single clear story while working to a tight deadline.

More than once, creating a poster has cleared a roadblock in my research, allowing me to progress to the next stage of a problem or wrap up a project entirely.

Presenting posters at multiple conferences per year has challenged me to improve my digital illustration skillset and continue to find new ways of incorporating my artistic style into my work.

Pages 8–11 contain examples of my posters and their design process.

Masters poster 2018

*presented at the Gordon Research Conference
for Quantum Science in Easton, Massachusetts*

lpe, Inkscape and Powerpoint

My first attempt at creating a scientific poster tells the story of the value E , a user-specified parameter for a quantum algorithm. The choice of E (top-left) affects the rest of the algorithm, which the poster visually anchors using the colour red.



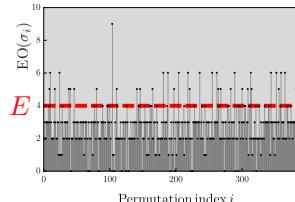
Graph comparison via nonlinear quantum computing

Mitchell Chiew¹, Kooper de Lacy^{1,2}, Chao-hua Yu^{1,3}, Samuel Marsh¹, Jingbo B Wang¹

¹ Department of Physics, University of Western Australia, Perth, WA 6009 Australia
² Department of Mathematics, University of Western Australia, Perth, WA 6009 Australia
³ State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications, Beijing, 100876 China

Graph comparison

- The task of identifying topological similarities between two graphs
- Maximum edge overlap is a useful measure of graph similarity, but complexity is $\mathcal{O}(n!)$



Nonlinear quantum computing

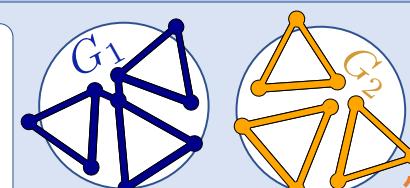
- Physical systems exhibiting nonlinear QM: Bose-Einstein condensates, optics
- The Gross-Pitaevskii equation: $i \partial_t |\psi\rangle = (H + K)|\psi\rangle$, $\langle x|K|\psi\rangle = g|\langle x|\psi\rangle|^2\langle x|\psi\rangle$
- Nonlinear quantum search:

[1] D. S. Abrams and S. Lloyd, "Nonlinear quantum mechanics implies polynomial-time solution for NP-complete and #P problems," *Phys. Rev. Lett.*, 1998.

[2] A. M. Childs and J. Young, "Optimal state discrimination and unstructured search in nonlinear quantum mechanics," *Phys. Rev. A*, 2016.

[3] K. de Lacy, L. Noakes, J. Twamley and J. B. Wang, "Non-linear quantum search," *Quantum Inf. Process.*, in press, 2018.

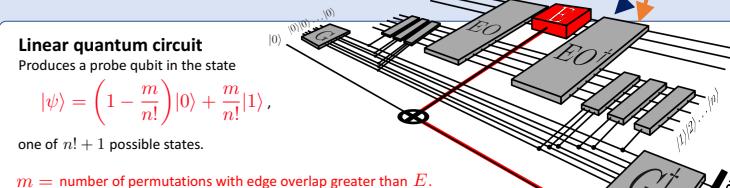
Graph adjacency matrices



Linear quantum circuit

Produces a probe qubit in the state $|\psi\rangle = \left(1 - \frac{m}{n!}\right)|0\rangle + \frac{m}{n!}|1\rangle$, one of $n! + 1$ possible states.

$m = \text{number of permutations with edge overlap greater than } E$.



Representing all permutations

Linear quantum circuit generates the state $\frac{1}{\sqrt{n!}} \sum_{\sigma \in S_n} |\sigma\rangle |0\rangle$ and marks permutations by producing $\frac{1}{\sqrt{n!}} \left(\sum_{EO(\sigma) \leq E} |\sigma\rangle |0\rangle + \sum_{EO(\sigma) > E} |\sigma\rangle |1\rangle \right)$.

Algorithm for graph comparison

```

INPUT: Graphs  $G_1, G_2$  with  $n$  vertices.
set edge overlap threshold  $E$  and  $s = n!$ .
for  $i = 1, 2, \dots, \mathcal{O}(\log(n))$  do
    use Main Procedure to determine if
         $m = 0$  or  $m > 0$ .
        if  $m > 0$  then
            increase:  $E \rightarrow E + E_{\max}/2^i$ .
        else if  $m = 0$  then
            decrease:  $E \rightarrow E - E_{\max}/2^i$ ,
            set  $s = n!$ .
        end if
    end for
return  $E$ 
OUTPUT:  $E = \text{maximum edge overlap.}$ 

```

Worst-case complexity:

- $\mathcal{O}(n^3 \log^3(n) \log \log(n))$ fundamental quantum gates
- $\mathcal{O}(\frac{1}{g} n^2 \log^3(n) \log \log(n))$ nonlinear evolution time

Nonlinear evolution in our algorithm

Main Procedure: determine if $m = 0$ or $m > 0$.

- Perform the Sub-Procedure and measure the result. Repeat this $\mathcal{O}(\log \log(n))$ times
- If any measurements result in $|1\rangle$, then $m > 0$
- Otherwise, halve s and repeat.
- If $s = 1$, then $m = 0$

Sub-Procedure:

- Generate $|\psi\rangle$
- Run nonlinear evolution for time $\mathcal{O}(\frac{1}{g} \log(n!))$
- Prepare qubit for measurement in the Main Procedure

Conclusion

Our quantum algorithm finds the **maximum edge overlap** of two graphs, each with at most n vertices. The algorithm takes only polynomial time in n . Combined with new linear quantum protocols, our results demonstrate the power of nonlinear quantum search techniques.

8

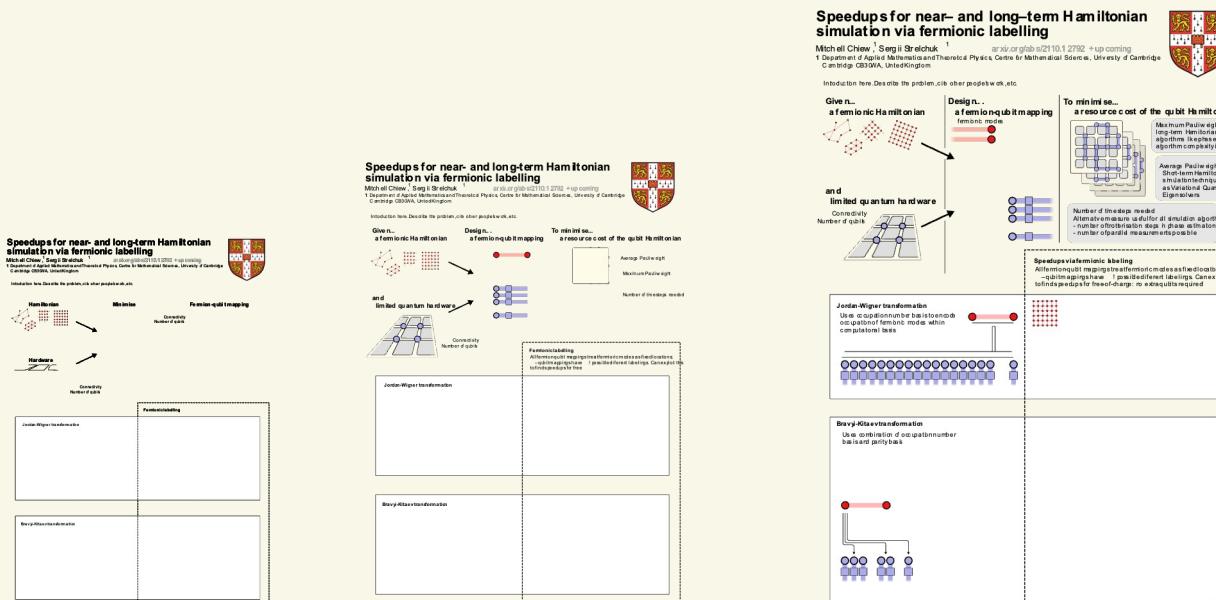
PhD poster 2023

presented at the conference Quantum Information Processing in Ghent, Belgium

Ipe and Inkscape

The design principle of the posters for my PhD work is to visually distinguish electrons (red) from the qubits, the information-carrying particles of quantum computers (blue).

This poster collates several disparate strands of my research under one banner. From conception to final product, I produced it in one working day.



Speedups for near- and long-term Hamiltonian simulation via fermionic labelling

Mitchell Chiew¹, Sergii Strelchuk¹

arxiv.org/abs/2110.12792 + upcoming

¹ Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Sciences, University of Cambridge
Cambridge CB30WA, United Kingdom

In this work we interrogate the assumed superiority of the Bravyi-Kitaev mapping over the Jordan-Wigner transform. The cornerstone of our approach is the freedom to label the fermionic modes in any order. Our analysis allows us to computationally explore the space of all fermionic labellings, searching for the optimal fermion-qubit mapping to minimise any given cost function.

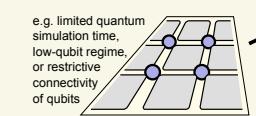


Given...
a fermionic Hamiltonian

$$H_{\text{fermion}} = \sum_{\alpha\beta} (c_{\alpha\beta}) a_{\alpha}^{\dagger} a_{\beta}$$

$$+ \frac{1}{2} \sum_{\alpha\beta\gamma\delta} (c_{\alpha\beta\gamma\delta}) a_{\alpha}^{\dagger} a_{\beta}^{\dagger} a_{\gamma} a_{\delta}$$

and limited quantum hardware



e.g. limited quantum simulation time, low-qubit regime, or restricted connectivity of qubits

$A_{\alpha} \in \{I, X, Y, Z\}^{\otimes n}$

$\{A_{\alpha}, A_{\beta}\} = 0$

$\{A_{\alpha}^{\dagger}, A_{\beta}^{\dagger}\} = 0$

$\{A_{\alpha}, A_{\beta}^{\dagger}\} = \delta_{\alpha\beta} \mathbb{1}$

Using n ancilla qubits, can achieve local fermion-qubit mappings [1, 2, 3]. But there are still gains to be in the 0-ancilla regime.

Design...
a fermion-qubit mapping

$$n \text{ fermionic modes } \{a_{\alpha}^{\dagger}, a_{\beta}\} = 0$$

$$\{a_{\alpha}, a_{\beta}\} = 0$$

$$\{a_{\alpha}, a_{\beta}^{\dagger}\} = \delta_{\alpha\beta} \mathbb{1}$$

which gives a qubit Hamiltonian

$$H_{\text{qubit}} = \sum_{\alpha\beta} (c_{\alpha\beta}) A_{\alpha}^{\dagger} A_{\beta}$$

+ $\frac{1}{2} \sum_{\alpha\beta\gamma\delta} (c_{\alpha\beta\gamma\delta}) A_{\alpha}^{\dagger} A_{\beta}^{\dagger} A_{\gamma} A_{\delta}$

at least n qubits required

Parallelisation of qubit Hamiltonian terms

Corresponds to the number of distinct timesteps required to run all Hamiltonian terms. Could reduce...

- number of trotterisation steps in phase estimation

- number of distinct measurement times in VQE

Speedups via fermionic labelling $f : \{\alpha, \beta, \dots\} \rightarrow \{1, \dots, n\}$

All fermion-qubit mappings treat fermionic modes as fixed locations;

n -qubit mappings have $n!$ possible different labellings. Can exploit this to find speedups for free-of-charge: no extra qubits required!

Given a target resource cost, which labelling is optimal?

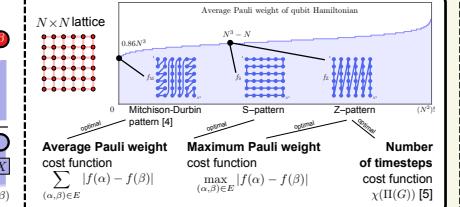
arxiv.org/abs/2110.12792

Jordan-Wigner transformation

Uses occupation number basis to encode occupation of fermionic modes within computational basis

$$a_{\alpha}^{(\dagger)} \Rightarrow \frac{1}{2} \left[\bigotimes_{k=1}^{f(\alpha)-1} Z_k \right] (X \mp Y) f(\alpha)$$

Non-local Pauli strings have weight $\mathcal{O}(n)$



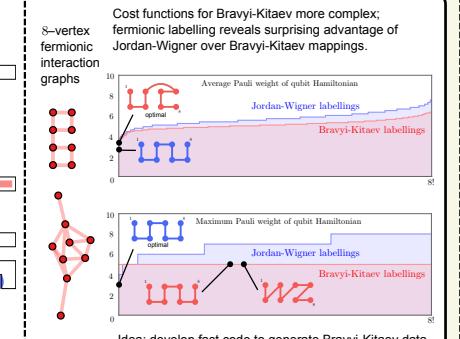
Bravyi-Kitaev transformation

Uses combination of occupation number basis and parity basis

$$a_{\alpha}^{(\dagger)} \Rightarrow \frac{1}{2} \left[(X_U(f(\alpha)) \otimes X_{P(f(\alpha)))} + (iX_U(f(\alpha)) \otimes Y_{P(f(\alpha)))}) \right]$$

qubit subsets necessary to implement creation/annihilation operators

Non-local Pauli strings have weight $\mathcal{O}(\log(n))$



[1] Verstraete and Cirac (2005), [2] Derby and Klassen (2020),

[3] Chien and Whitfield (2020), [4] Mitchison and Durbin (1986), [5] Bringewatt and Davoudi (2022)

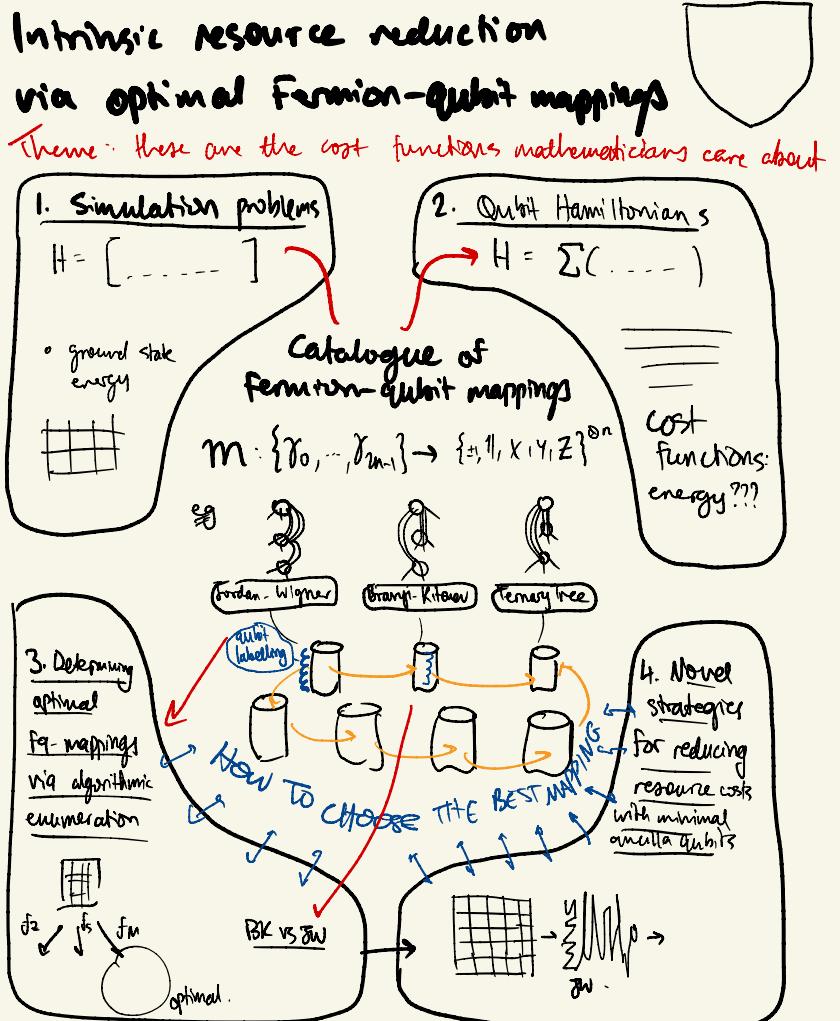
PhD poster before and after 2024

Presented at the conference
Quantum Information Processing
in Taipei, Taiwan

Left (sketch): hand-drawn
Right (final): Ipe and Inkscape

For this example, I wanted to visually anchor the idea that there are many equally valid ways to map electronic behaviour onto quantum computers. This manifests in the central, circular piece of the poster, defining and cataloguing the many ways to perform this mapping.

The red arrow shows the motivating application of converting electronic systems into information on a quantum computer.



Universal catalogue of ancilla-free fermion-qubit mappings

Mitchell Chiew¹, Sergii Strelichuk¹

¹ Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Sciences, University of Cambridge, Cambridge CB30WA, United Kingdom



arXiv:2110.12792 + upcoming
10.22331/q-2023-10-18-1145

Fermionic quantum simulation

A judicious choice of fermion-qubit mapping can drastically reduce the resource costs of simulation algorithms. There are many options.

$$H_{\text{fermion}} = \sum_{i,j=0}^{n-1} (c_{ij}) a_i^\dagger a_j + \frac{1}{2} \sum_{i,j,k,l} (c_{ijkl}^k) a_i^\dagger a_j^\dagger a_k a_l$$

$\{a_i, a_j\} = 0, \{a_i^\dagger, a_j^\dagger\} = \delta_{ij}$

Hamiltonians of interest incur much quantum simulation cost through the hopping terms.

Resource cost of simulation algorithms

By defining the physical cost of a quantum simulation algorithm, we can search for a fermion-qubit mapping that produces the most resource-efficient quantum circuit.

$$H_{\text{qubit}} = \sum_{i,j=0}^{n-1} (c_{ij}) A_i^\dagger A_j + \frac{1}{2} \sum_{i,j,k,l} (c_{ijkl}^k) A_i^\dagger A_j^\dagger A_k A_l$$

Costs can include total gate count, physical space, or clock time of the algorithm.

Restrictions can include limited quantum simulation time, or a low qubit count and connectivity.

Ancilla qubits allow local fermion-qubit mappings. But there are still gains to be made in the ancilla-free regime.

Majorana operators

$2n$ neutral fermionic operators are the building blocks of fermion-qubit mappings

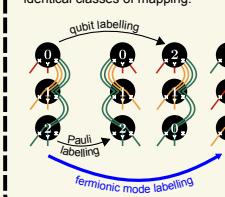
$$a_i = \frac{1}{2} (\gamma_{2i} + i\gamma_{2i+1})$$

$$\{a_i, a_j\} = 0, \{a_i^\dagger, a_j^\dagger\} = \delta_{ij}$$

$$\{\gamma_i, \gamma_j\} = 2\delta_{ij}, \quad \gamma_i^\dagger = \gamma_i$$

Catalogue of ancilla-free fermion-qubit mappings

Three symmetries relate physically identical classes of mapping:



Invertible binary matrices and computational basis mappings

Computational basis mappings act on fermionic occupation states as invertible binary matrices:

$$m : (a_0^\dagger)^{f_0} \dots (a_{n-1}^\dagger)^{f_{n-1}} |\Omega_{\text{vac}}\rangle \mapsto |M_m f\rangle$$

e.g. the Jordan-Wigner transformation acts as the identity matrix $M_{\text{JW}} = \mathbb{1}^{\otimes n}$

The balanced Jordan-Wigner transformation [4] is not a computational basis mapping, and thus has no invertible binary matrix representation.

$$T_0 \{ X \cdot Z; \cdot Y; \cdot Z; \cdot X; \cdot Y; \cdot Z \} \quad \text{qubits}$$

$$T_1 \{ Y \cdot Z; \cdot Z; \cdot X; \cdot Y; \cdot Z; \cdot X \} \quad \text{qubits}$$

$$T_2 \{ Z \cdot X; \cdot Y; \cdot Z; \cdot Y; \cdot X; \cdot X \} \quad \text{qubits}$$

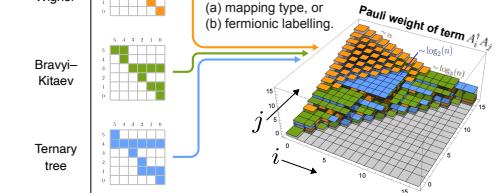
$$T_3 \{ Y \cdot X; \cdot Y; \cdot X; \cdot X; \cdot X; \cdot Y \} \quad \text{qubits}$$

$$T_4 \{ X \cdot Y; \cdot X; \cdot Y; \cdot X; \cdot Y; \cdot Y \} \quad \text{qubits}$$

$f_0 \quad f_1 \quad f_2 \quad f_3 \quad f_4$

Optimal mapping classes and fermionic labellings

Given a fermionic Hamiltonian, different mappings produce different quantum simulation circuits. Comparison of the Pauli weights of Hamiltonian terms is straightforward via invertible binary matrix formulae; can optimise for either (a) mapping type, or (b) fermionic labelling.



[1] "Über das Paulische Äquivalenzverbot", Jordan and Wigner (1928)

[3] "Optimal fermion-to-qubit mapping via ternary trees...", Jiang et al. (2020)

[2] "Fermionic quantum computation", Bravyi and Kitaev (2003)

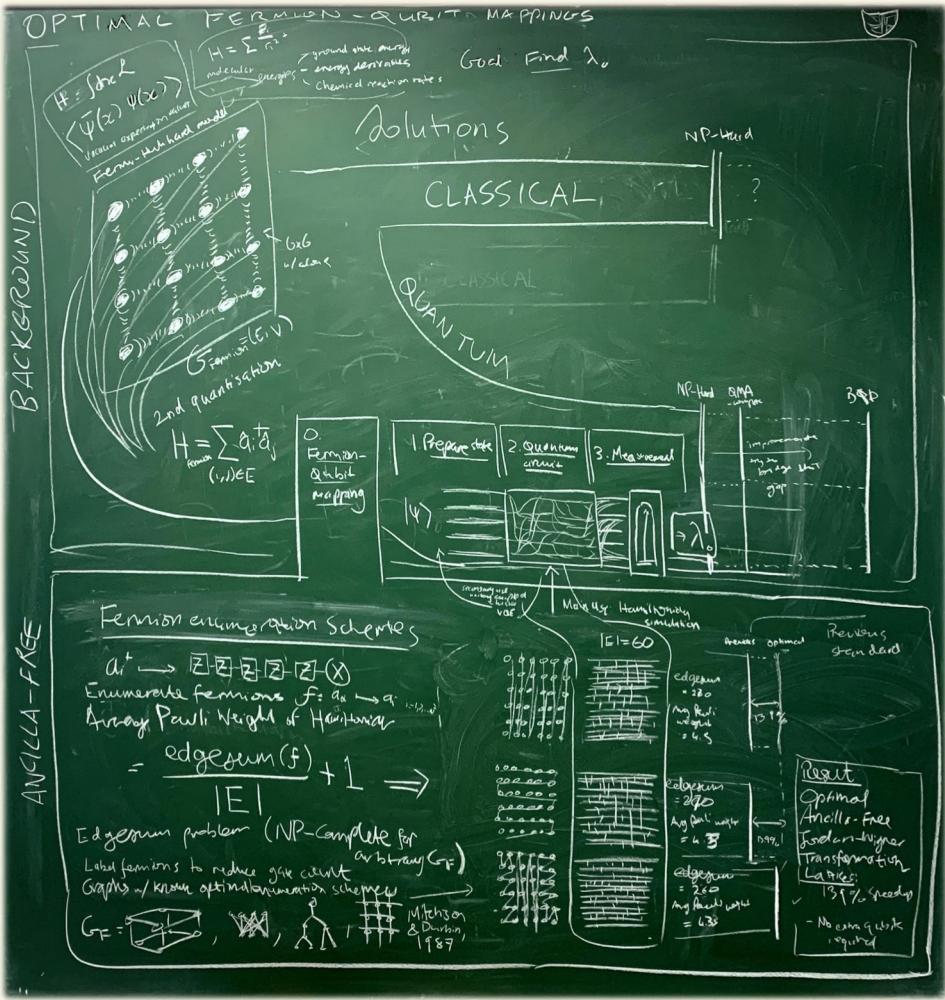
[4] "Bonsai Algorithm: Grow Your Own Fermion-to-Qubit Mappings", Miller et al. (2023)

PhD poster before and after 2022

presented at the conference
Quantum Information Processing
in Los Angeles, USA

Left (sketch): hand-drawn, chalk
on blackboard
Right (final): Ipe and Inkscape

The visual anchor for the first poster of my PhD was the advantage of quantum computing over classical methods. I sketched my idea on a blackboard first. The stylistic separation between classical and quantum computing ended up faithfully represented in the final product.



Optimal fermion-qubit mappings

Mitchell Chiew¹, Sergii Strelchuk¹
arxiv.org/abs/2110.12792
¹ Department of Applied Mathematics and Theoretical Physics, Centre for Mathematical Sciences, University of Cambridge
Cambridge CB30WA, United Kingdom



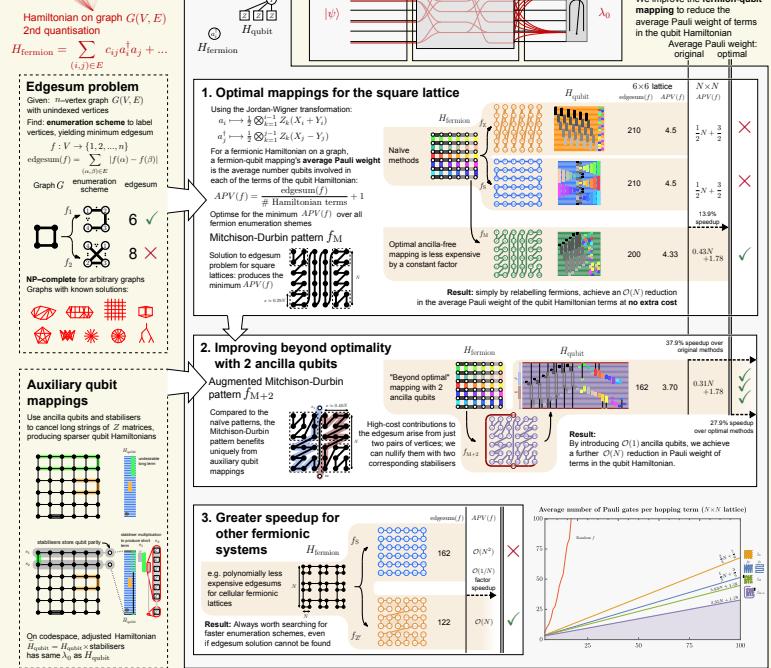
To solve difficult fermionic problems...

Quantum chemistry, electronic structure problem
 $H_{\text{fermion}} = -\sum_i \frac{\nabla^2}{2M_i} + \sum_i \frac{Z_i}{r_i^2} - \sum_{i,j} \frac{Z_i Z_j}{|R_i - R_j|} + \sum_{i,j > i} \frac{1}{|r_i - r_j|}$
 Find: ground state energy $\lambda_0 = \min_{|\psi\rangle} \langle \psi | H | \psi \rangle$,
 energy derivatives, reaction rates

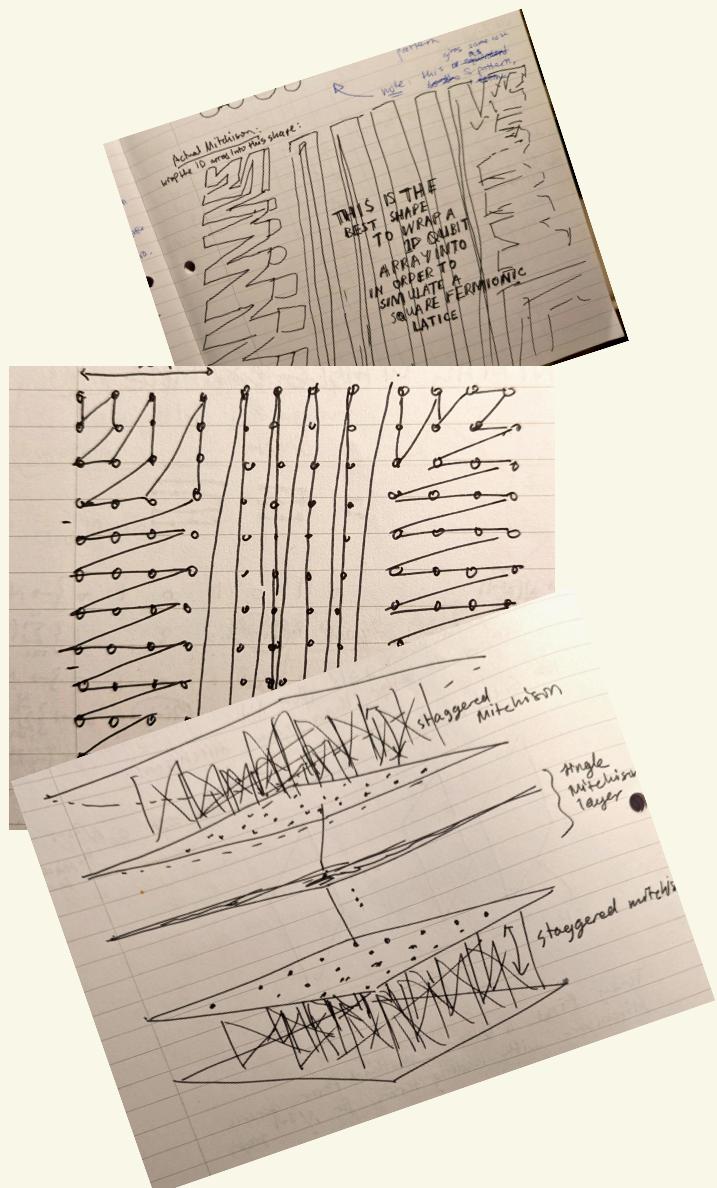
... we need to develop more efficient solutions

CLASSICAL
QUANTUM
NP-hard
After the fermion-qubit mapping, many instances of fermionic problems reduce to the local Hamiltonian problem (GMA-complete)

New research involves finding improvements to different parts of the algorithm
We improve the fermion-qubit mapping to reduce the average Pauli weight of terms in the qubit Hamiltonian
Average Pauli weight: original vs. optimal



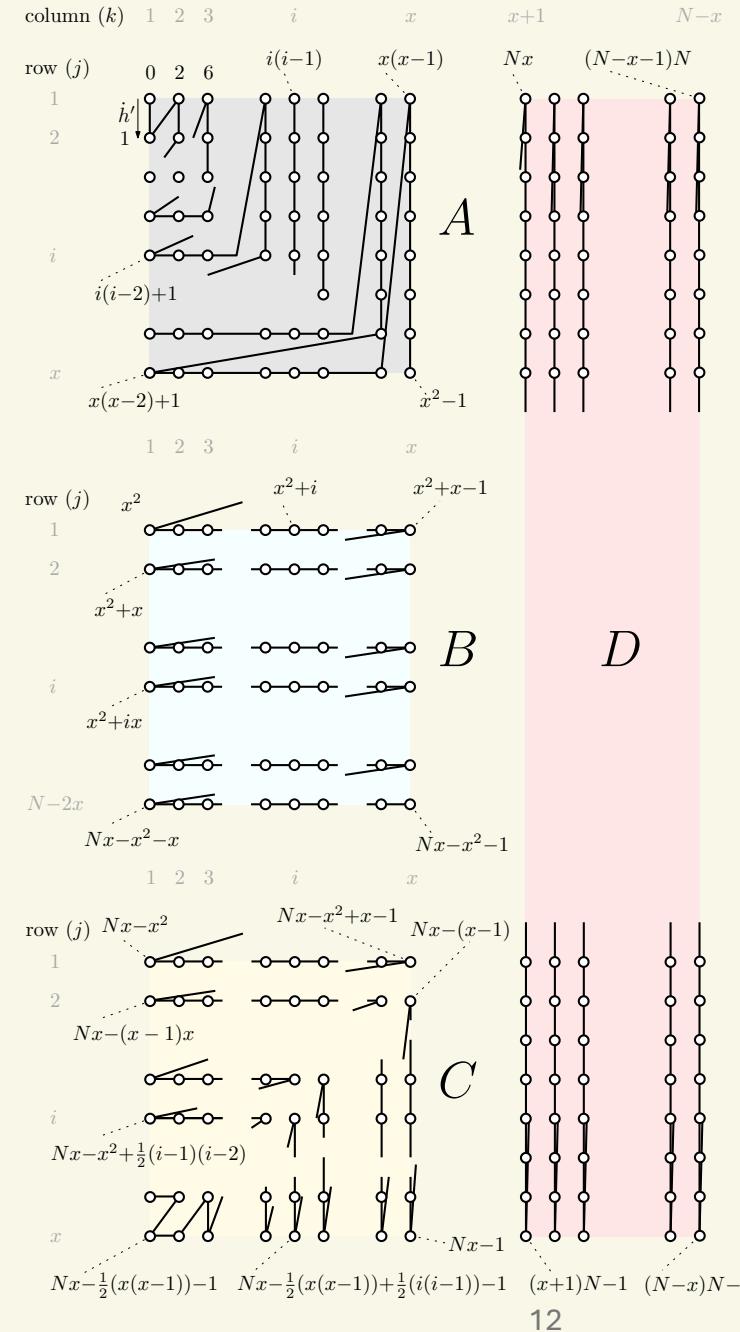
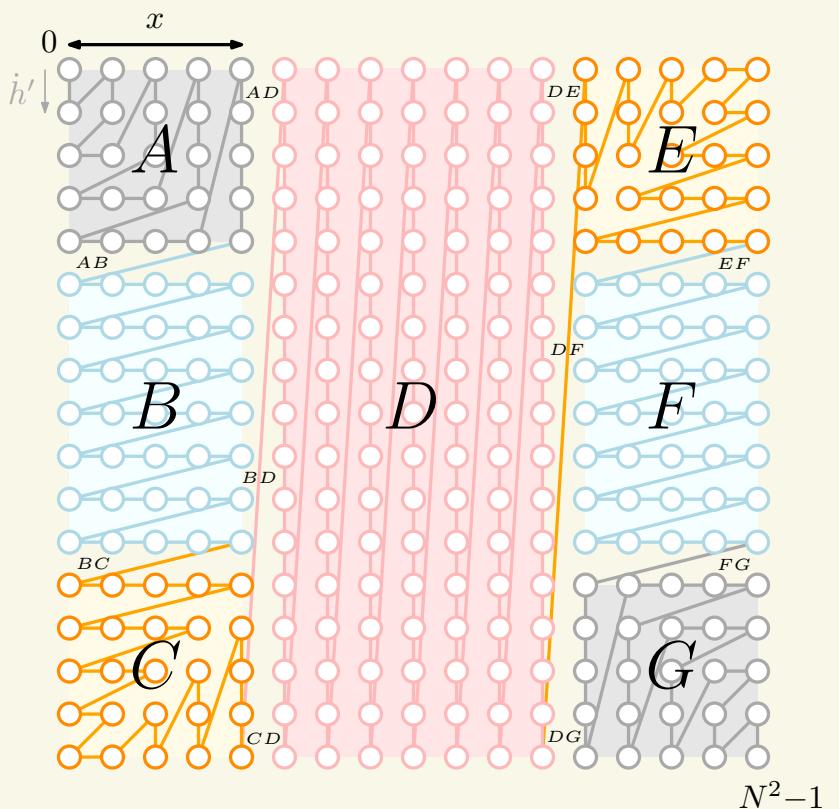
Other samples

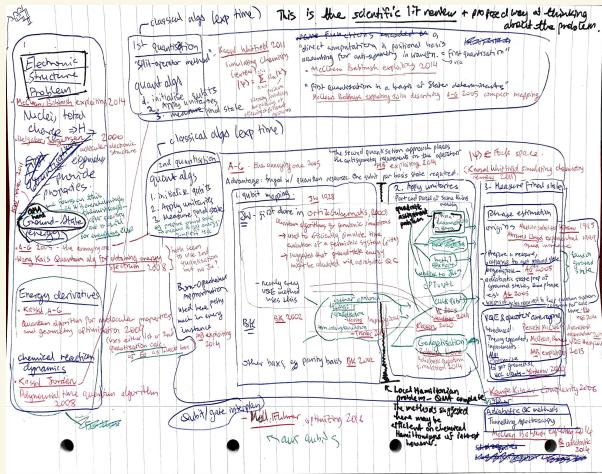
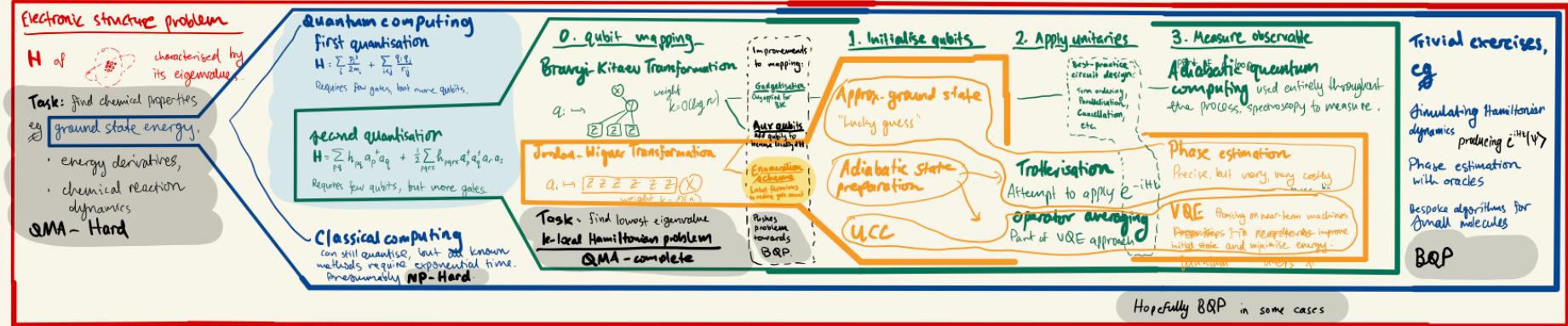


The Mitchison–Durbin pattern
2020–2021
appears in [Discovering optimal fermion-qubit mappings through algorithmic enumeration](#)

Left: (sketches): hand-drawn, chalk on blackboard
Centre and right (final): Ipe

The first project in my PhD involved studying this pattern for labelling the vertices in a square lattice. The centre image depicts a vivid visual example, while the right image gives the explicit formula for all vertex labels.

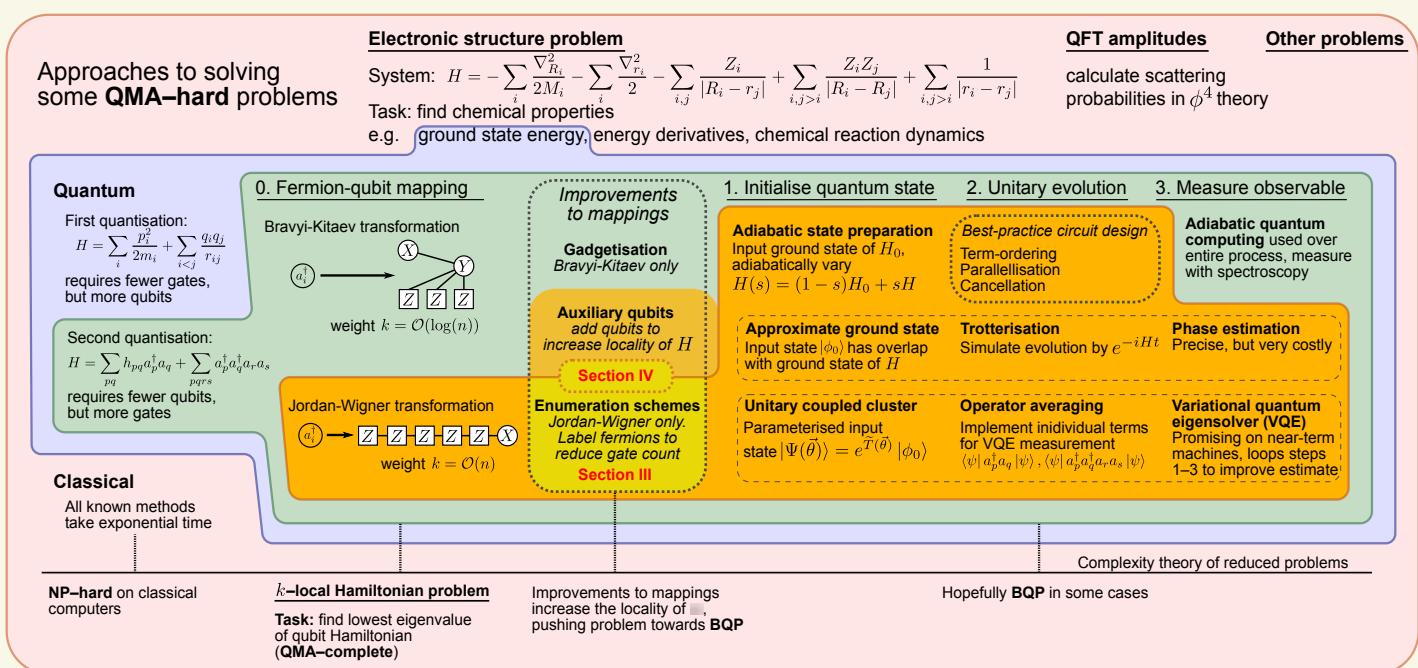




Quantum simulation algorithm survey

2020–2021

Left and top (sketches): hand-drawn
Right (final): Inkscape



The evolution of my literature review about quantum simulation algorithms, from its inception as a mind map, the final hand-drawn sketch, and its complete diagram.