Visualisations for Quantum Annealing Researchers

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April 25, 2017

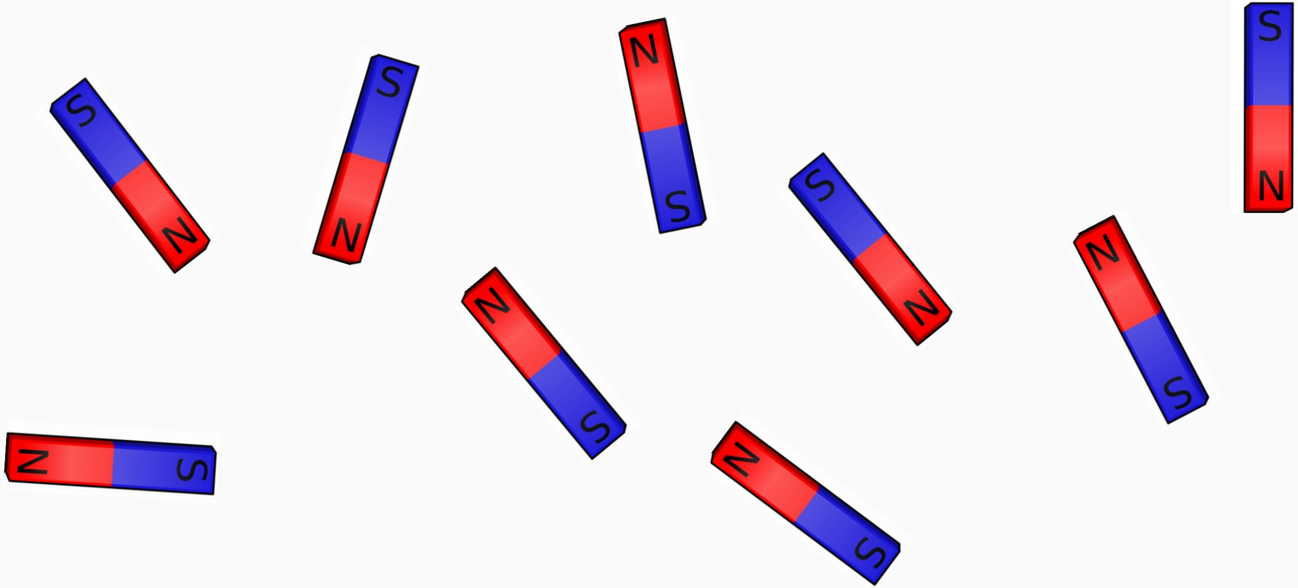
Background

- Developing tools for researchers to better investigate the quantum annealing process
- Quantum annealing is an optimization process to minimizes the energy of a physical system using quantum effects
- Design study: Future work and implementation to be continued in industry at 1QBit

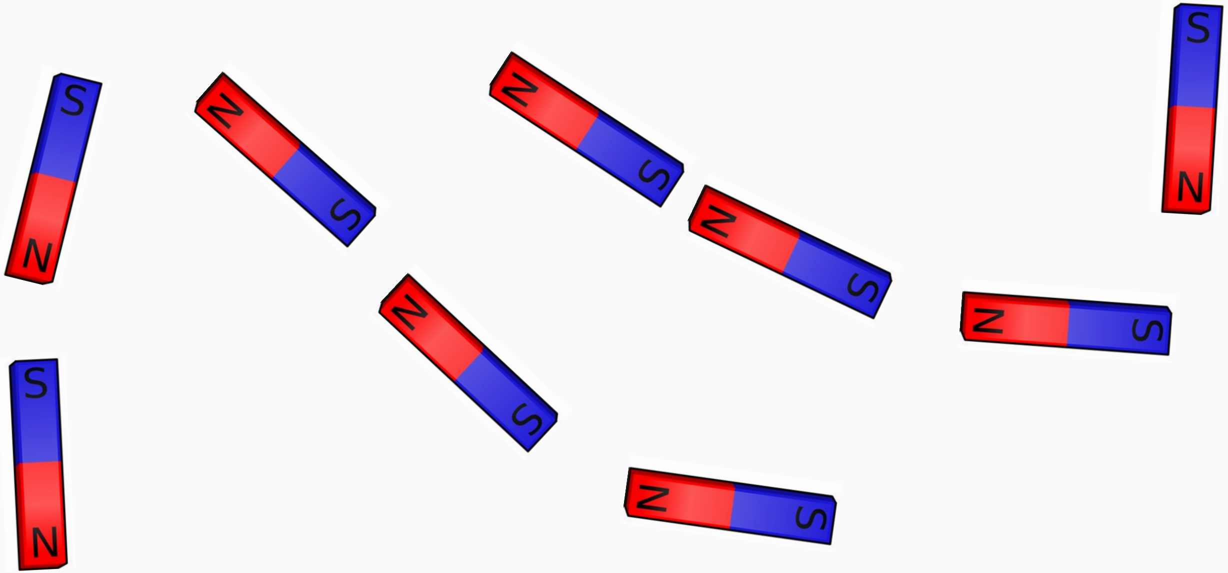
Motivation

- While the quantum annealing field is quickly expanding, relevant visualization techniques lag behind
- Researchers in the field have expressed discontent with the visualization tools available to them
- Many choices when deciding on models in the field are based on intuition, and useful visualizations are key to building a good intuition

Qubit

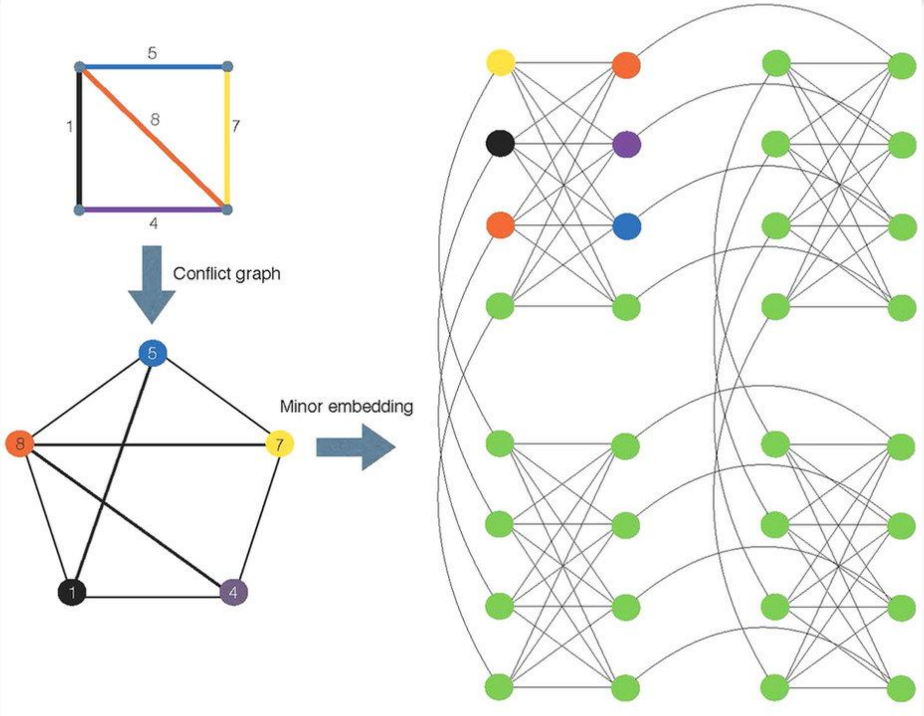


Qubit



Background on Quantum Annealing

- System to minimize: A graph
- Biases are preference to be in one state or the other
- Couplings are preference for two linked nodes to be in the same state or opposite states
- Can be in conflict, so quantum annealer minimizes that conflict, represented as the energy



Data Abstraction

What are we visualizing?

- The problem, the process, and the results

Primary sources of data:

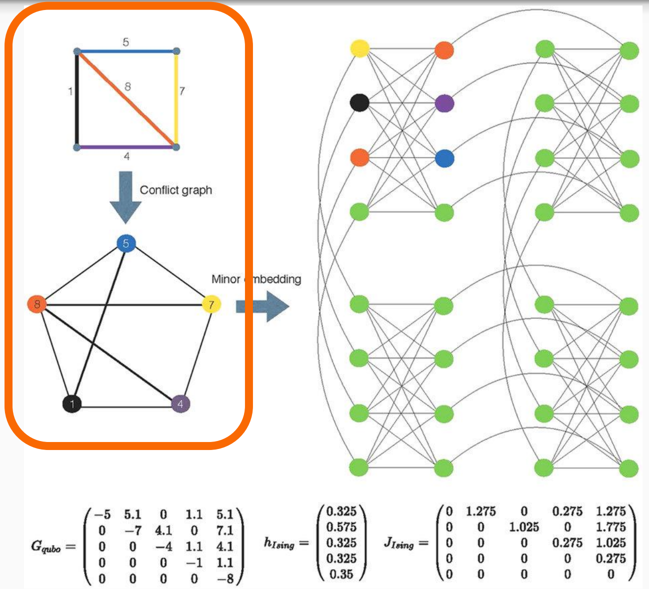
1. The original problem
2. The embedding of the problem
3. The parameters and properties of the solver
4. The results of the solver

1: Original Problem

Specific type of optimization problem (QUBO)

Can be represented as a node-link network: G(V, E),:

- V: Represent biases on each vertex. <~2000
  - Sign: **+** → 1, **-** → 0
  - Magnitude: ↑ → Stronger bias
- E: Represents bias between vertices <~5000
  - Sign: **+** → Correlation, **-** → Anticorrelation
  - Magnitude: ↑ → Stronger bias



Quantum versus simulated annealing in wireless interference network optimization
Wang, Chen, Jonckheere

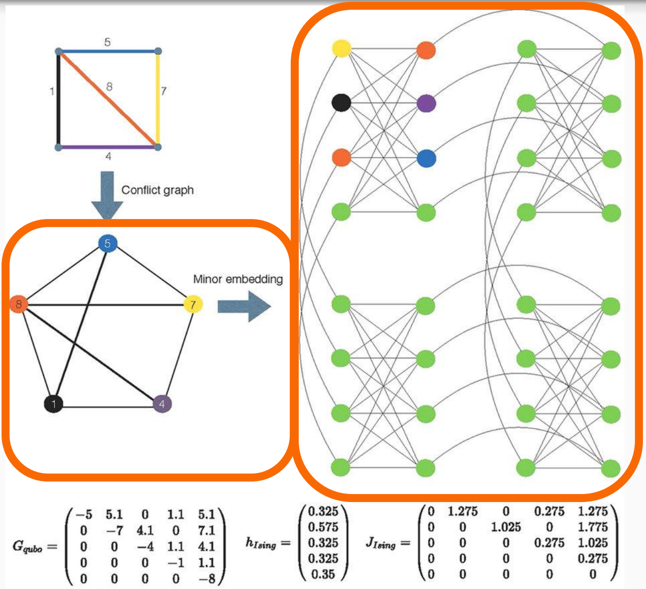
2: Embedding

Embedding:

- How to fit a densely connected problem onto a sparsely connected physical graph?

Solution: Create chains

- A single node in the original may be represented as a path of strongly correlated nodes



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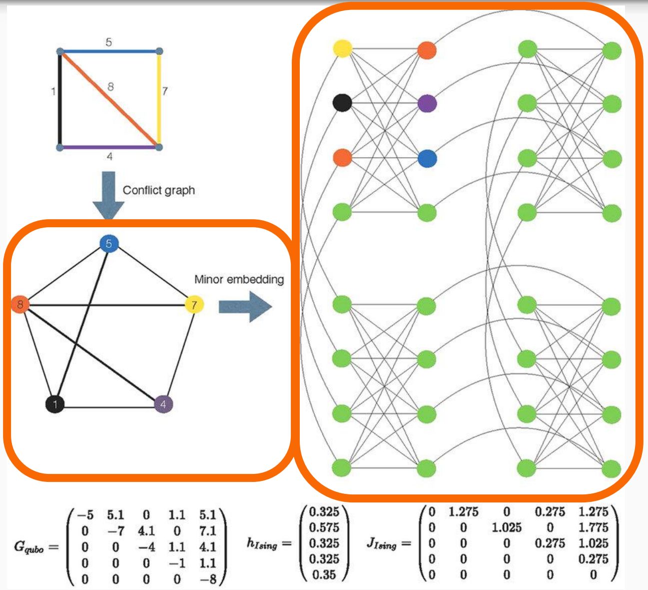
2: Embedding

Representation of embedded graph: G=(V,E,E_chain)

- E: Edges required in the original graph
- E_chain: Edges required for embedding.
  - E_chain>>0, E_chain > |E|

Quality of embedding still topic of active research.

- Maximum chain length an important metric



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3: Solver Properties and Parameters

Structure of the physical graph

- Distinct from embedding, embedding defines how much is used
- Chimera for DWave: Densely connected blocks, sparsely connected to neighboring blocks

Annealing time (On scale of microseconds)

- How long is spent finding each individual solution

4: Solver Results

A list of solutions

- Anywhere from ~50 to ~5000 solutions
- All received at the same time, using the same parameter values

Each solution is a scalar energy value, along with a dictionary

- Lower energy generally means better solution
- Dictionary is assignment of values to each variable
- Dictionary has unique energy, converse not always true

Task Abstraction

Focus:

- Compare algorithm performance
- Compare distributions of solutions
- Discover features in distribution of broken chains

Also:

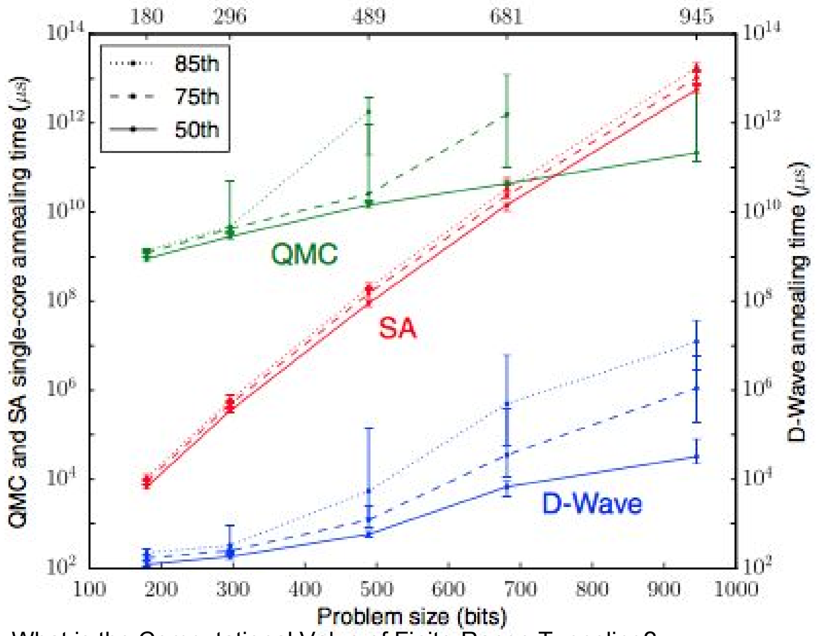
- Derive features of invariant nodes across solutions
- Discover difficulty of problem based on solutions
- Summarize topology of original and embedded graphs

Compare algorithm performance

- Is this working well?
- Strong idioms applicable across fields
- Can compare between algorithm classes, or within class while varying parameters

Pictured:

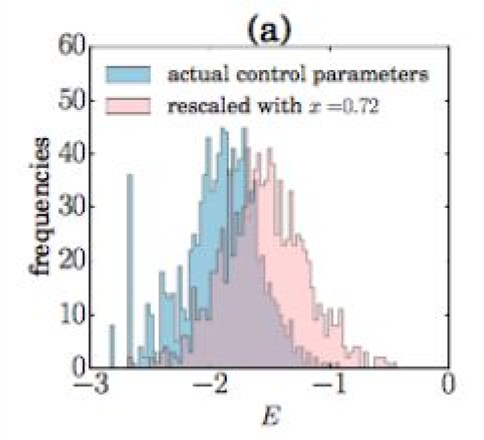
- Comparison of scaling properties for three annealing algorithms



What is the Computational Value of Finite-Range Tunneling?
Denchev, Boixo, Isakov, et al.

Compare distributions of solutions

- Strong base of previous work, i.e. Histogram
- More involved and nuanced comparison
- Domain-specific subtasks: Sub-distributions per energy
- How do results compare with known distribution?



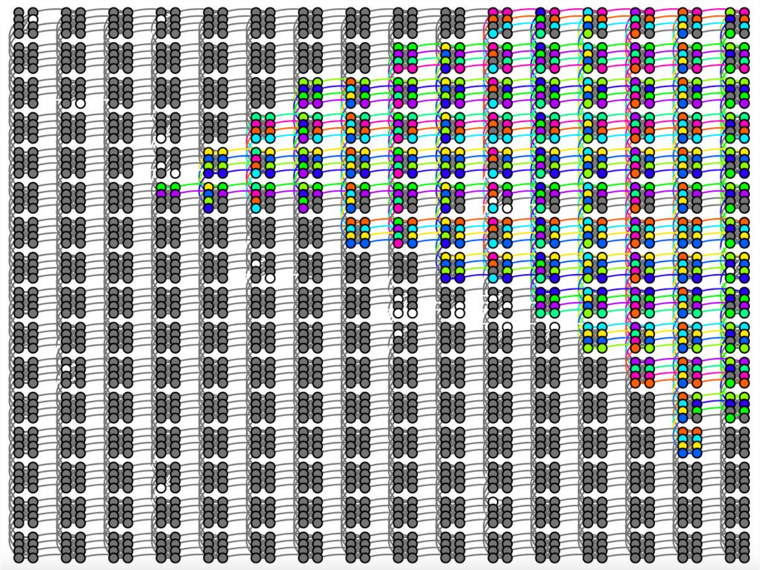
Pictured:

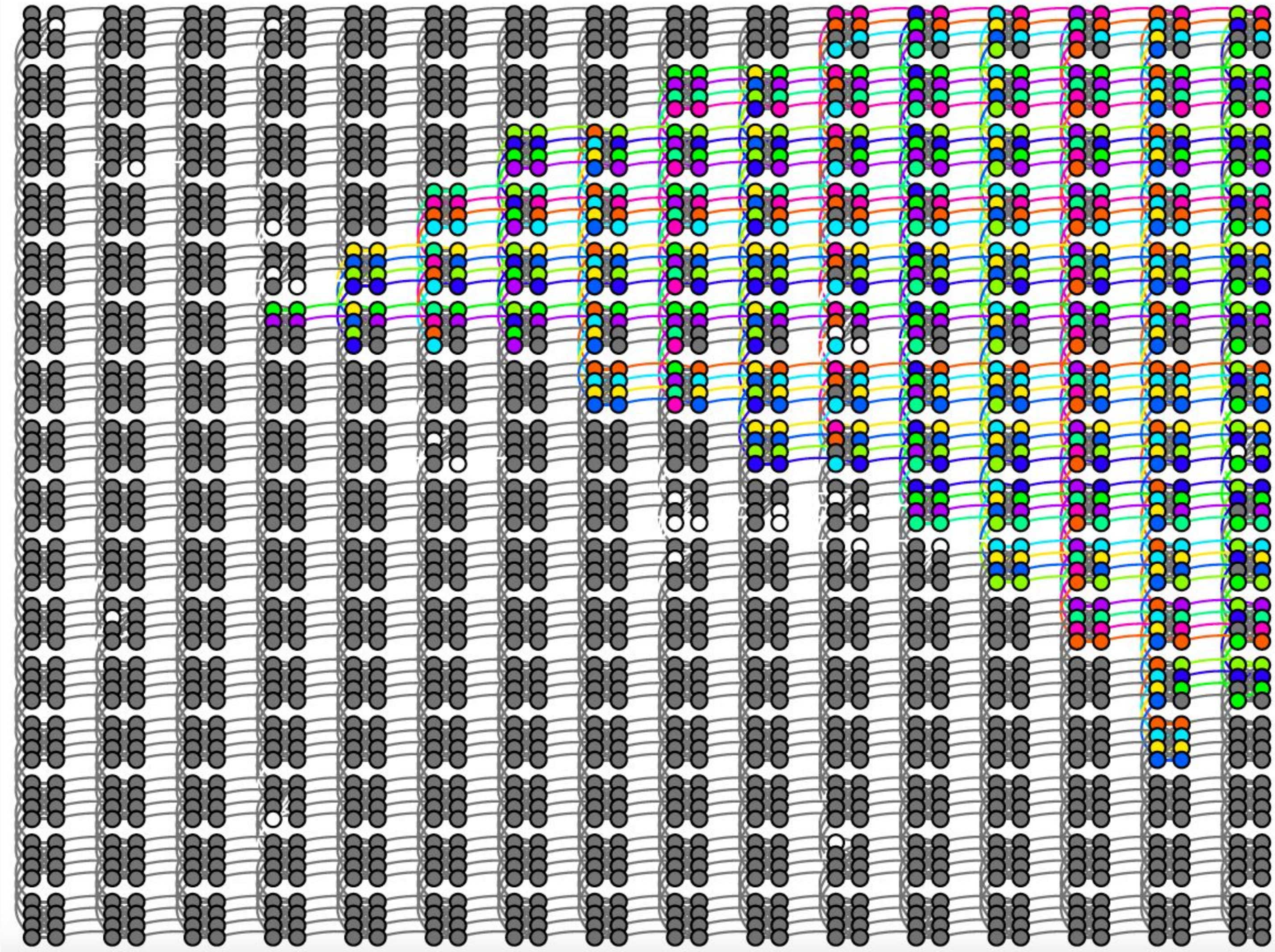
- Comparing distributions that arise from varying a parameter, holding all else constant

Estimation of effective temperatures in quantum annealers for sampling applications:
A case study with possible applications in deep learning
Benedettii, Realpe--Gomez, Biswas, et al

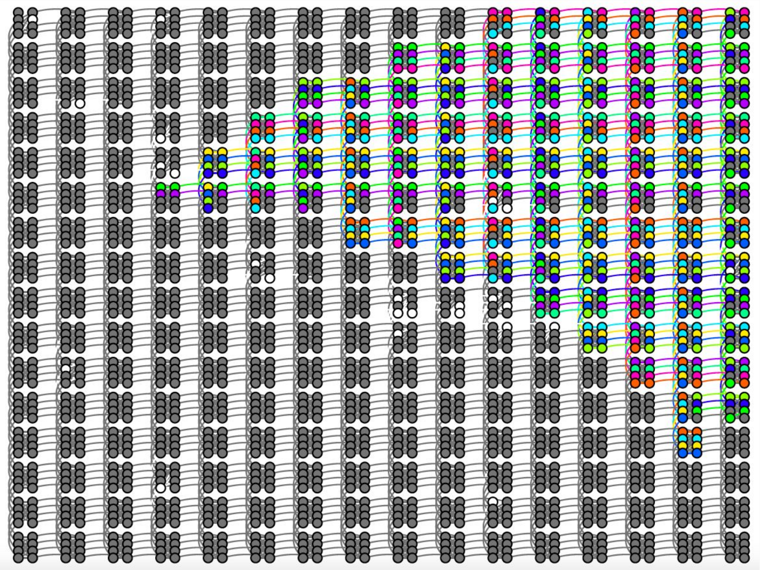
Discover features in distribution of broken chains

- Entirely specific to quantum annealing
- What embedding patterns lead to broken chains?
- How often are chains of different lengths breaking?





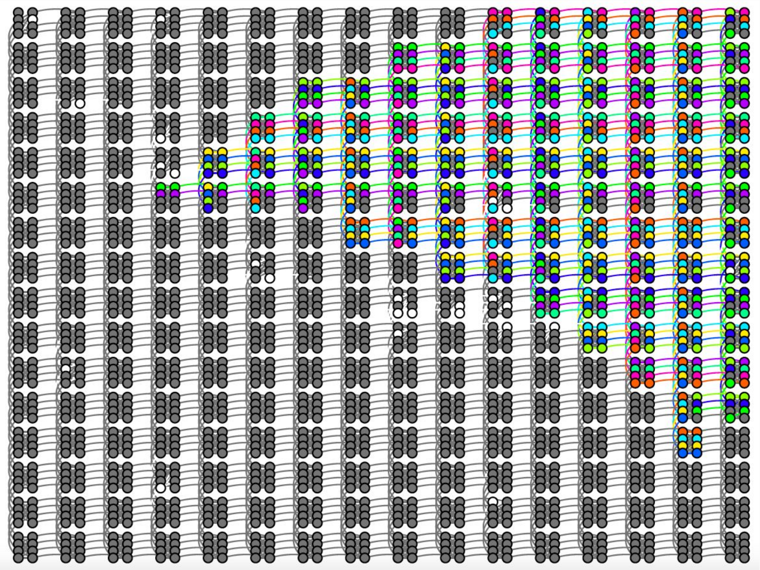
Current visualization: Broken Chains



EXPLANATION

- Qubit: Point mark
- Coupler: Connection mark
- Qubits in use: Encoded by color
- Broken qubit: Encoded by color
- Qubit in chain: Encoded by color

Current visualization methods: Chaining



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CRITIQUE

- Hard to quickly distinguish between different chains
- Which chains are stable?
- What points are the intersection of many different chains?

Redesign of the broken chain visualization

How? Overview first, detail on demand

- Overview:
  - Distribution of chain length, as well as distribution of instability.
  - Heatmap of intersections of chains, with reduced focus on specific chains
- Encode chains as enclosure marks, with outlines as well as colors.
- Interaction: Identify highly unstable and/or large chains through highlighting
- Detail view on identified chains, showing location of breaks and interactions with adjacent chains.

Future work/Conclusion

- Designing new views
  - Correspondence between original and embedded problems
- Implementation
  - Standardizing inputs and outputs
  - Connecting with tools already in use
  - Implement with extensibility in mind

Thank you!