Connecting DWave 2X to Bayesian Inference Image Analysis

First Steps in Image Processing Using D-Wave2X

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Los Alamos NATIONAL LABORATORY EST. 1943

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Overview

April 27th, 2017

Time: 1410

- **Team and Collaboration**
- **The BIE approach to image analysis**
  - How do we use the DWave 2X with the BIE?
- **Project Goals and Accomplishments**
- **DWave 2X Hardware and Lessons Learned**
- **Toy Problems**
- **Final Results**
  - Vector Shift Calculator in the BIE
  - Compressed Sensing for Radiography
- **Conclusions and Future Work**

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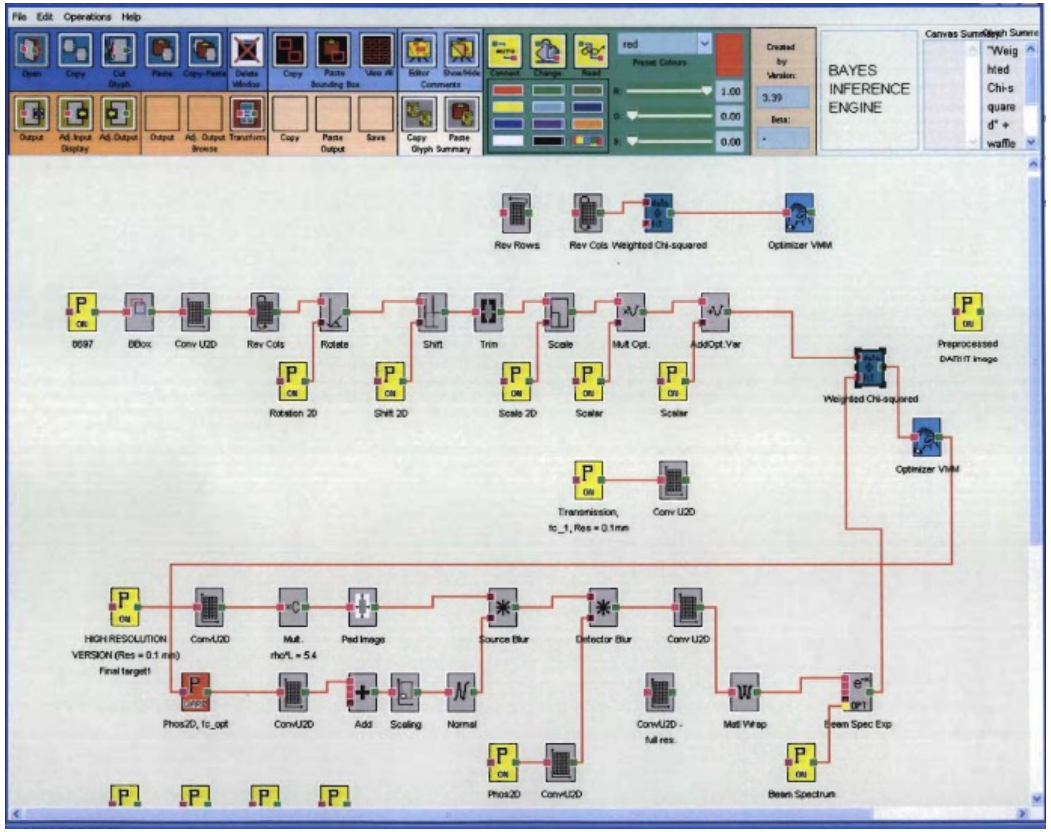
Collaboration is Key!

- Team members have a diverse knowledge basis spanning math, computer science, nuclear physics, image optimization, and radiography
- Nga’s and Garrett’s past experiences with the DWave 2X were extremely useful
- Great discussions and help on the mailing list (Thank you!)
- Thanks to Scott Pakin for an XNOR gate that works well!
- Additional thanks to Marcus Daniels, Denny Dahl, Carleton Coffrin, and many others for assistance regarding my bit selector algorithm, connectivity to the machine and so on.

Image Processing and Modeling with BIE Analysis

- **The BIE is used to match (via optimization) a parametric physics forward model with a basis image (typically a radiograph).**
  - A good match implies a well constrained and implemented physics model (a.k.a. we turned the parameter knobs correctly!)
- **Some parameters for transmission radiography**
  - Translation, rotation, magnification
  - Blur
  - Additive and multiplicative fields (scatter and gain)
- **Our final goal is to understand the physical properties of the transmission radiograph through the parameters of the forward model**

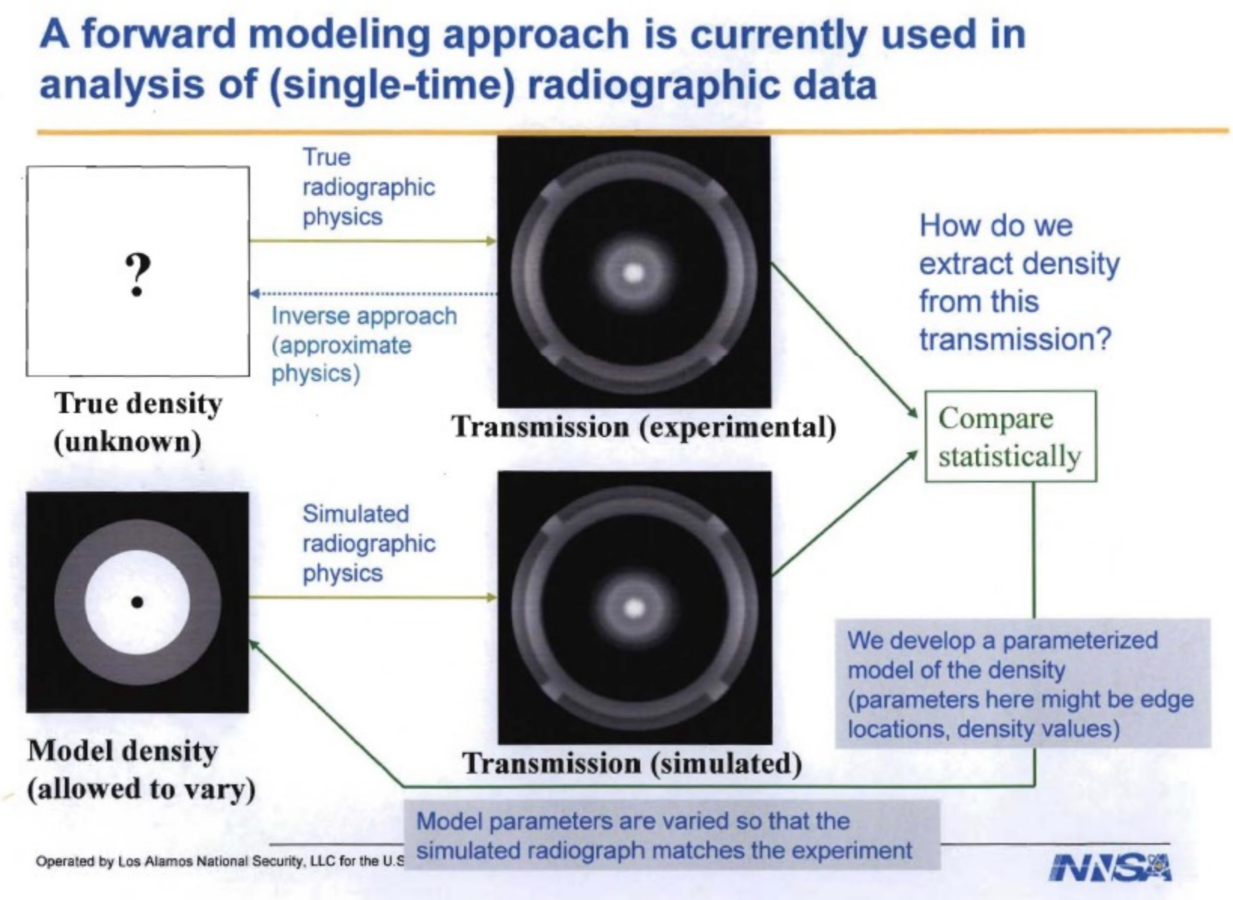


‘A snapshot of a BIE optimization canvas’
James Carroll
LA-UR-11-00201

The BIE is developed in Smalltalk and has C and Fortran interfaces!

The Road Where DWave 2X and the BIE Intersect

- **Through the perturbation of forward model parameters, we try to solve for the best conditions which minimize the difference between simulated images and experimental radiographs**
- **Where does the DWave 2X fit into this process?**
- **I think the answer is several different ways!**
  - Mechanical processes (translations, rotations)
  - Image transformation (simplification of images)
  - Feature driven identification (compressed sensing)



'An example of BIE optimization'
James Carroll
LA-UR-11-00201

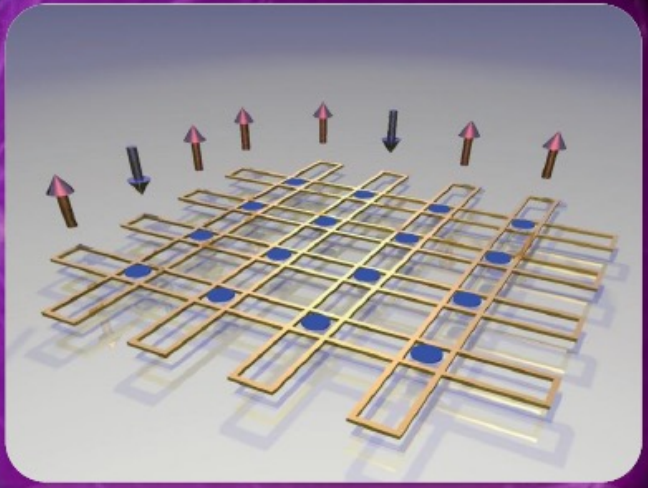
Project Goals and Accomplishments

- **Followed the KISS (Keep It Simple!) principle for this project**
- **Learned about quantum computers and how to program them**
- **Created a problem that can be solved on the machine relevant to image processing**
  - Learned about the capabilities of the chimera graph qubit and chain topology
  - Used toy problems to study the embedding process from logical to physical qubits
  - Developed a mechanical approach to solving for a cyclic shift
  - Advanced the compressed sensing approach to be useful for radiography
- **Called the DWave 2X from the BIE (Smalltalk ~> C ~> DWave 2X)**

DWave 2X Hardware and Optimization Model

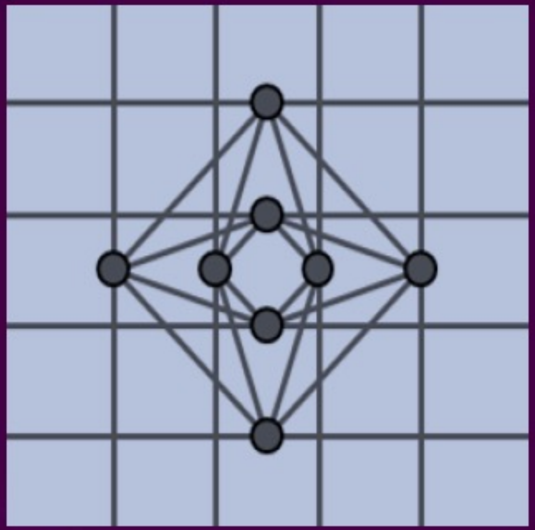
DWave 2X Hardware And Lessons Learned

Physical

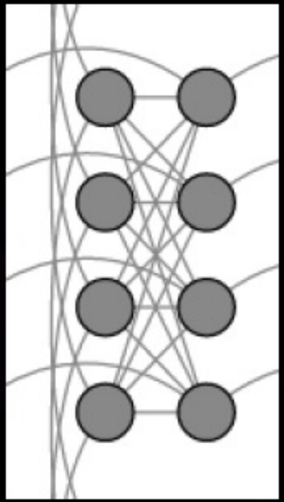


Physical connections drive the amount of “useful” qubits (from the logical side).

Our problems really do feel like they are sampling a physical device.

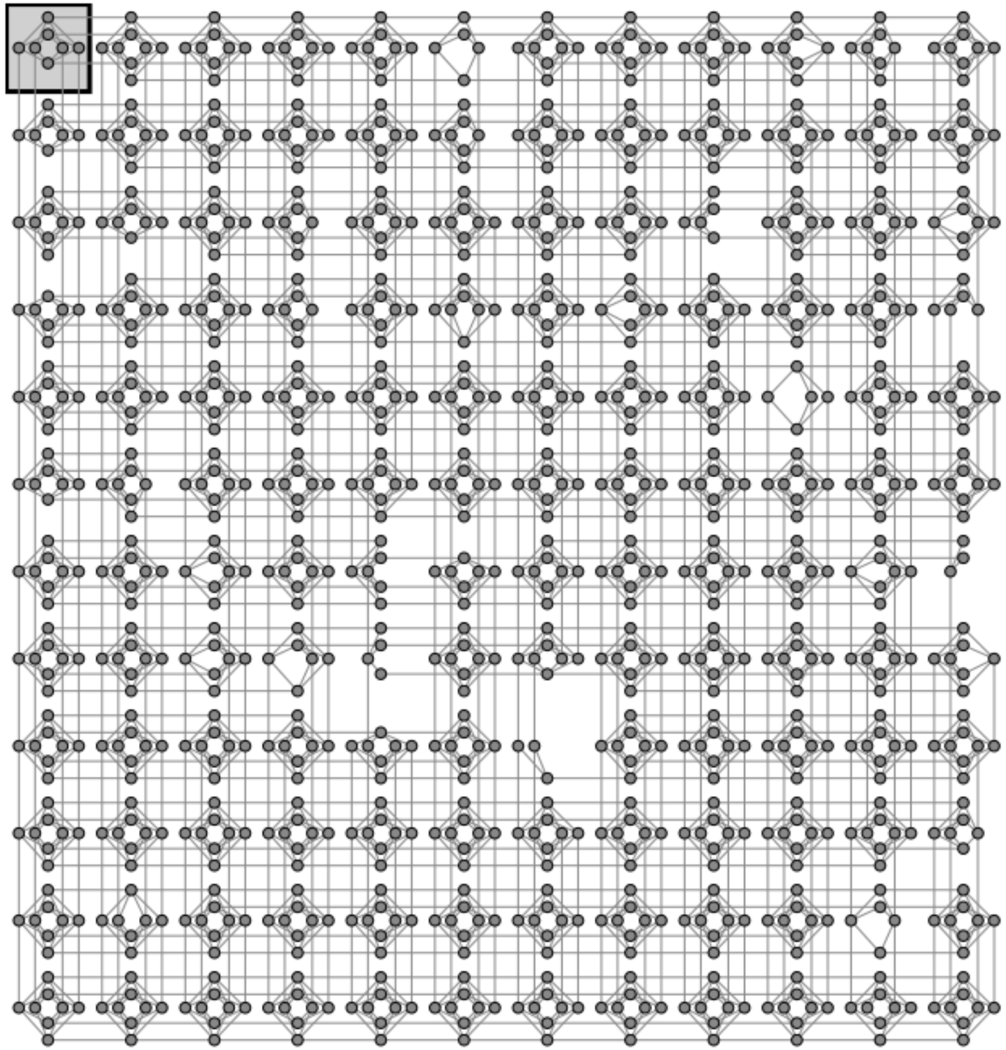


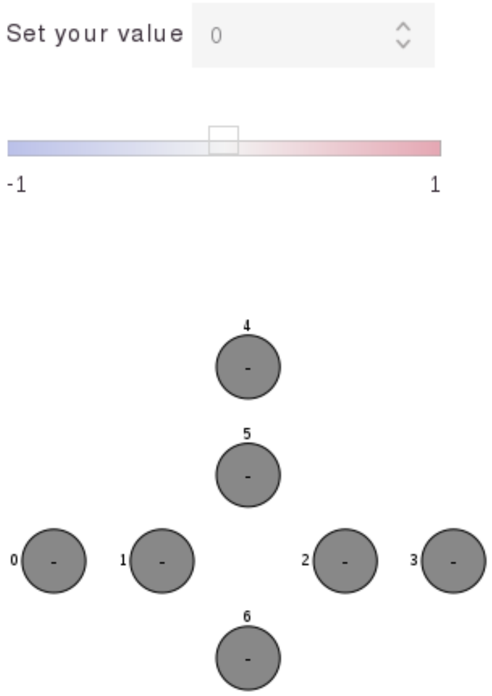
Logical: cross



Logical: column

The Full Chimera Grid, Look at those Qubits!





The calibration may result in fewer qubits available.

Programming Model Of What We Are Trying To Solve

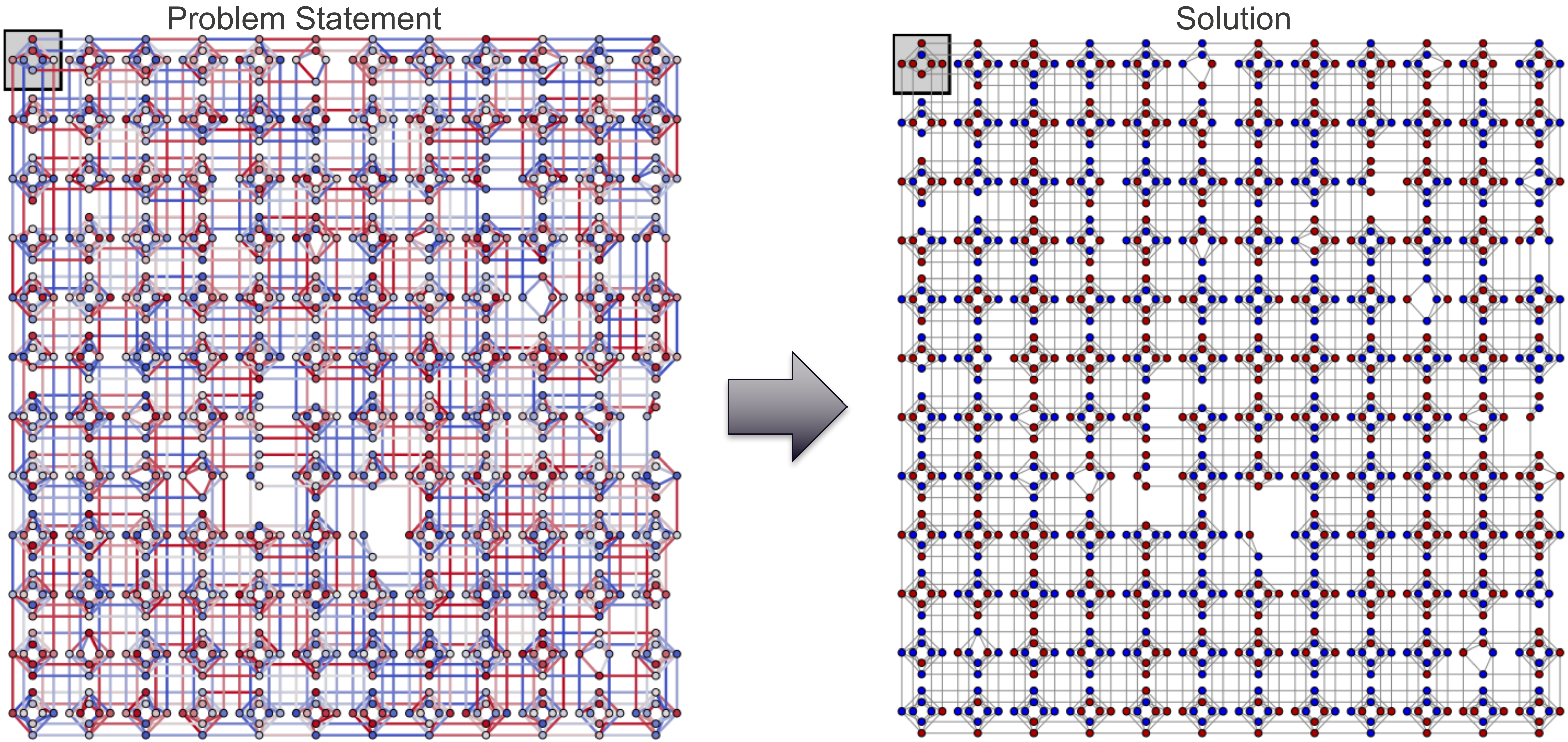
QUBIT	q_i	**Quantum bit** which participates in annealing cycle and settles into one of two possible final states: $\{0,1\}$
COUPLER	$q_i q_j$	Physical device that allows one **qubit to influence another qubit**
WEIGHT	a_i	Real-valued **constant associated with each qubit**, which influences the qubit's tendency to collapse into its two possible final states; controlled by the programmer
STRENGTH	b_{ij}	Real-valued **constant associated with each coupler**, which controls the influence exerted by one qubit on another; controlled by the programmer
OBJECTIVE	Obj	Real-valued **function which is minimized** during the annealing cycle

$$Obj(a_i, b_{ij}; q_i) = \sum_i a_i\, q_i + \sum_{ij} b_{ij} q_i\, q_j$$

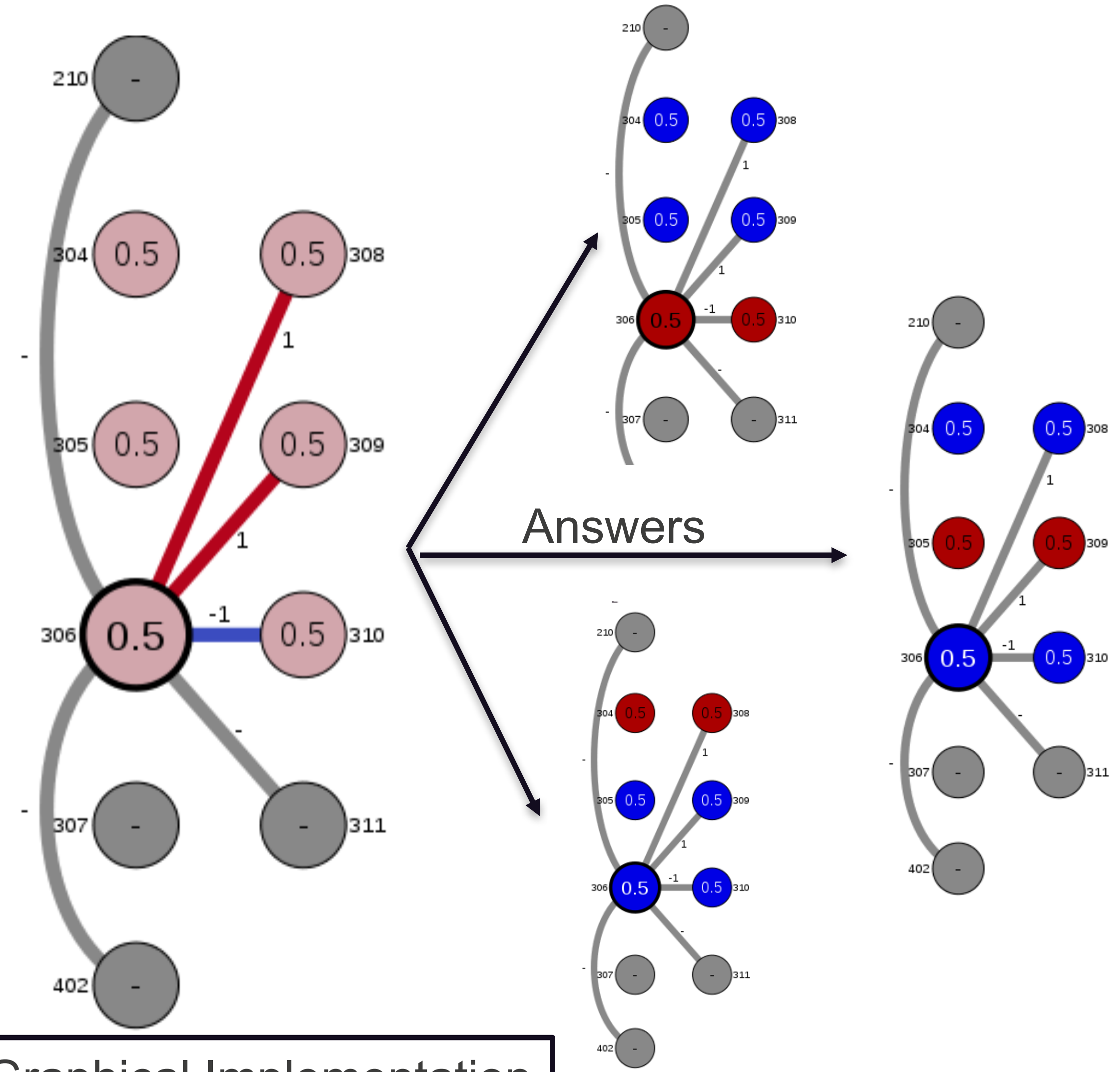
The system **samples** from the q_i that minimize the objective

Toy Problems

A Massive GUI DWave 2X Example! (Using Cubist)



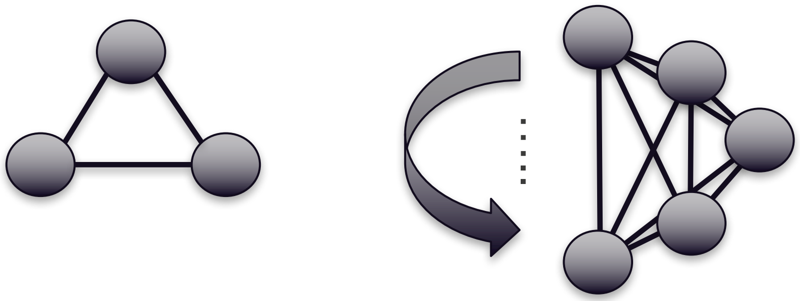
A Simple Selector Problem with 3 Qubits



Graphical Implementation

Problem – Pick 1 of N Qubits

3 Bit Selector



N Bit Selector

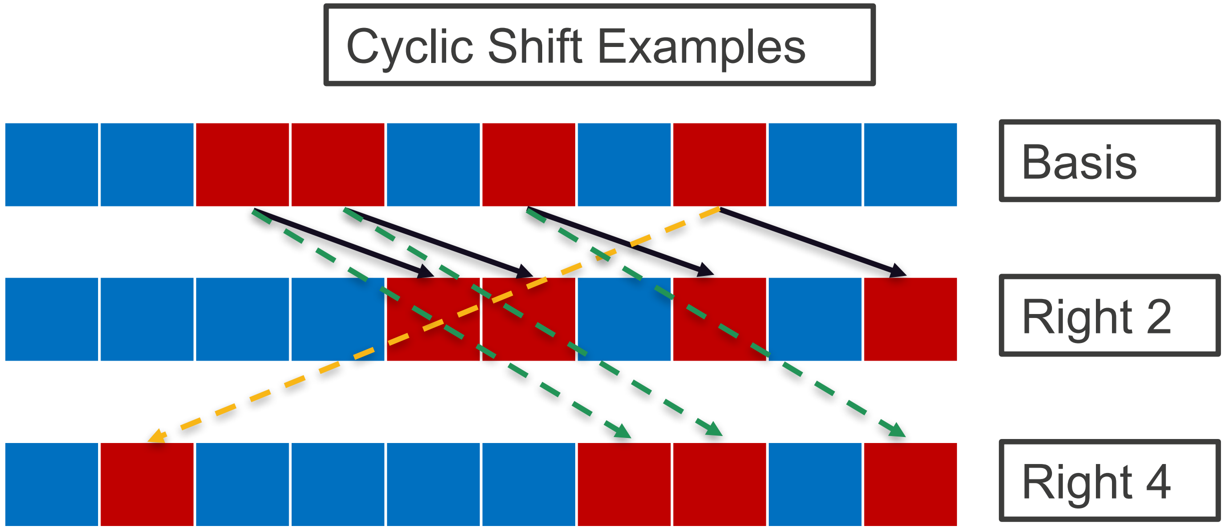
Code Results

```
In [231]: runfile('/home/joperry/Quantum/8bit_selector/
8_Bit_Selector_v1.py', wdir='/home/joperry/Quantum/8bit_selector')
4 Bit Selector using logic nodes embedding, ising space
component 0, try 0:
max overfill = 1, num max overfills = 6
max overfill = 1, num max overfills = 4
max overfill = 1, num max overfills = 4
Embedding found. Minimizing chains...
max chain size = 2, num max chains = 1, qubits used = 4
max chain size = 2, num max chains = 1, qubits used = 4
max chain size = 2, num max chains = 1, qubits used = 4
max chain size = 2, num max chains = 1, qubits used = 4
{(0, 1): 8, (1, 2): 8, (0, 0): -0.5, (1, 1): -0.5, (2, 2): -0.5, (0, 2):
8}
Doing qubo to ising
[3.75, 3.75, 3.75]
{(0, 1): 2.0, (1, 2): 2.0, (0, 2): 2.0}
5.25
[[1, -1, -1], [-1, -1, 1], [-1, 1, -1]]
[-6.75, -6.75, -6.75]
```

Final Results

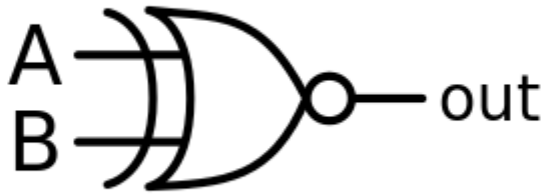
Computing a Cyclic Shift with DWave 2X

- **Main Goal: Put an image on the DWave 2X and calculate a translation difference**
- **This immediately brought up the question: how do I put an image on the DWave 2X?**
  - Considered an image to be a binary mask
  - This 2D binary array is then collapsed into a 1D vector (or collection of 1D vectors)
- **Analytically a 1D vector shift (ignoring edges) is represented by $V_A = V_B * 2^N$, where N is the shift**
- **Additionally, a cyclic shift will move the overflowing bits into the beginning or end (based on shift direction) of the vector**



Computing a Cyclic Shift with DWave 2X

- **Cyclic shifts can be computed via "brute force" comparisons of equivalence between each vector's bits**
- **An XNOR gate is the implemented structure in the DWave 2X for the bit comparison**
  - 6 Logical bits are used for each XNOR, 2 for the input vectors, and 4 for the XNOR gate
  - To simultaneously solve all shifts on one pass, the logical qubit bit size is N*N*6
    - Practically, this allows for implementations up to 9 bit vectors reliably on the DWave 2X (sometimes larger bit sizes are possible, but adjacency begins to fail after 9 bits)
- **Following the DWave 2X annealing cycles, the XNOR outputs are summed and returned**
  - A max of the XNORS for a shift set returns the most reliable shift
    - This process could also be done on the chip, but was avoided for now

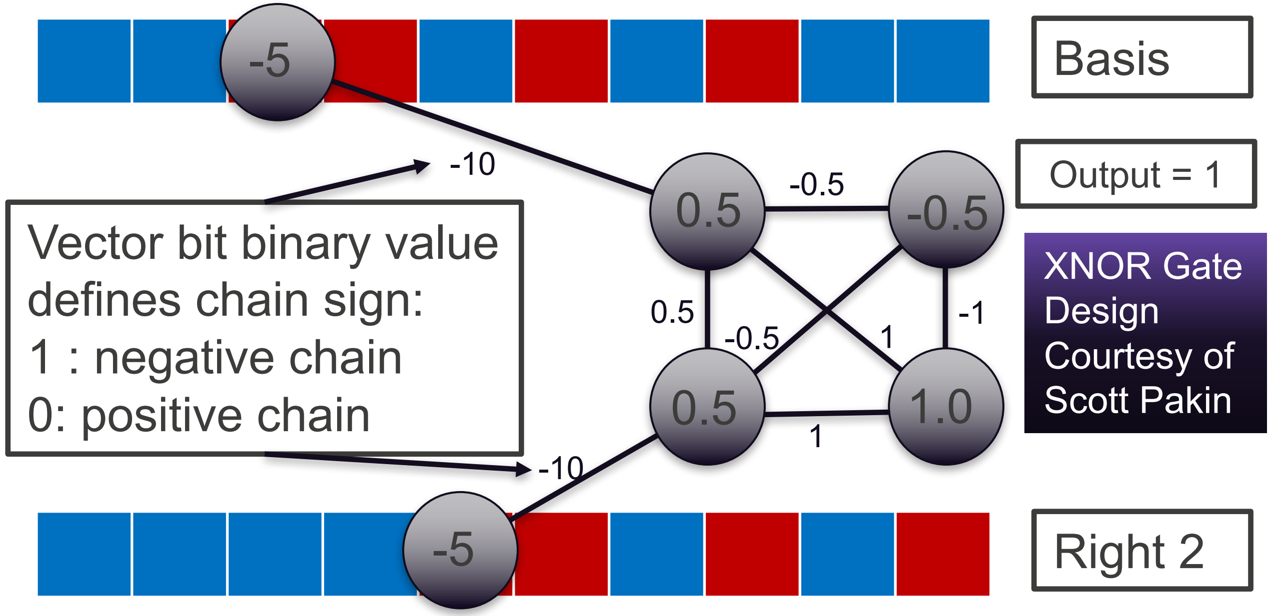


XNOR Gate

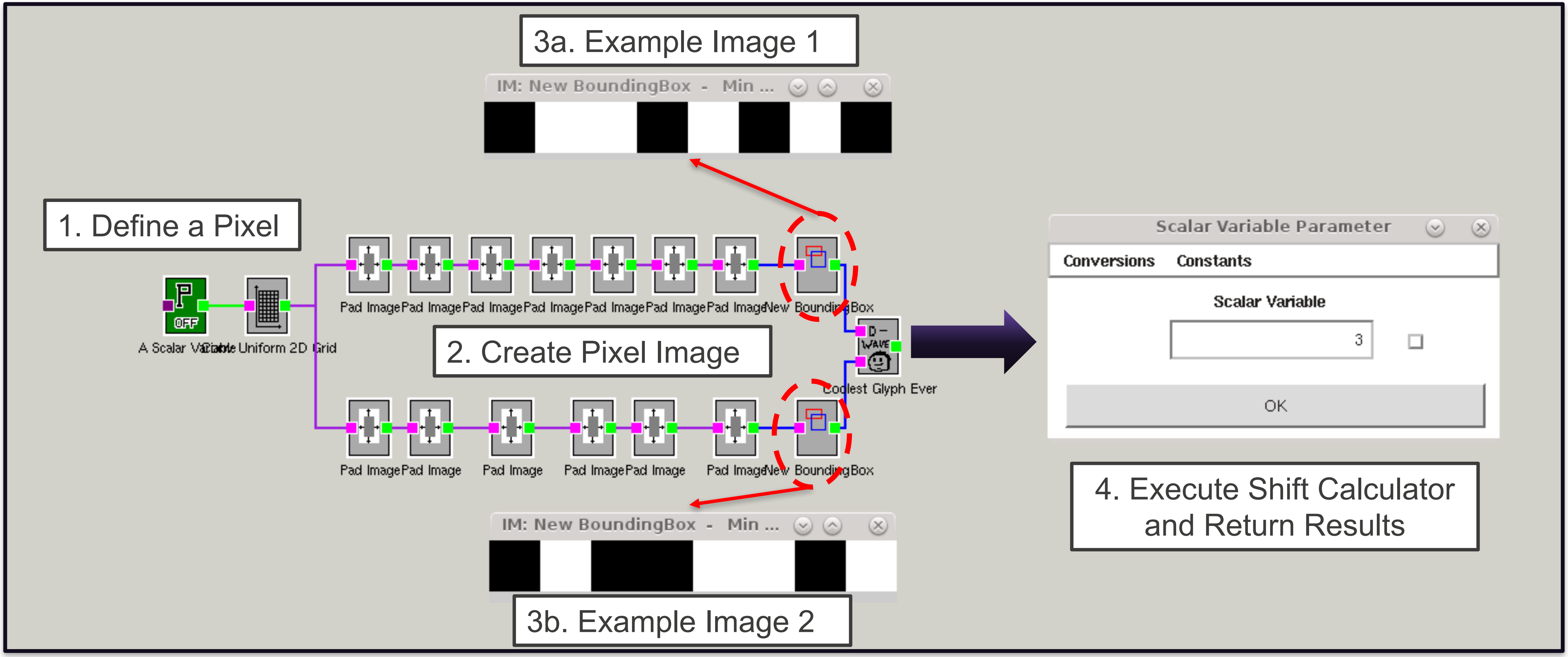
$A \cdot B + \bar{A} \cdot \bar{B}$

Logic Table

Input		Output
A	B	A XNOR B
0	0	1
0	1	0
1	0	0
1	1	1



Example: Computing a Cyclic Shift Using the BIE ~> DWave 2X Glyph



Compressed Sensing Approach: Sparse Coding

Solving a sparse-coding (SC) problem

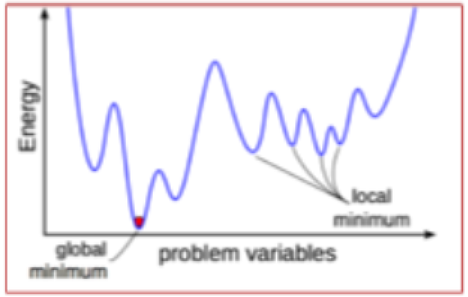
Objective function is of the form:

$$E = \min_{\{\vec{a}, \phi\}} \left[\frac{1}{2} |\vec{I} - \phi \vec{a}|^2 + \lambda ||\vec{a}||_p \right].$$

reconstruction error

***Lp*-sparseness penalty**

Olshausen and Field, Nature 381, 607 (1996)
Rozell, Johnson, Baraniuk, and Olshausen, Neur. Comp. 20, 2526 (2008)



- **non-convex problem**
- **NP-hard class**

Compressive Sensing in a Nutshell

$$[\,y\,] = [\,\Phi\,][\,\Psi\,][\,s\,]$$

L0:	NP-hard
L1:	mostly used

wide applications particularly in image processing (X-ray, CT, …), sampling, etc (c.f. Candes, Baraniuk, *Compressive Sensing*)

Setting up the DWAVE Inputs

Abel transform algorithm + **D-Wave QUBO**

Our method is applicable to e.g. X-ray images as sparse inputs

$$h = A \, f \, .$$

We obtain: $$A_{ij} = 2 \sum_{i|r_i=y_j}^{i|r_i=R} \frac{r_i \Delta_{ij}}{\sqrt{r_i^2 - y_j^2}}$$

Next: to choose (learn) domain basis:

$$f(r) = \sum_n s_n F_n(r)$$

s_n are sparse Fourier coefficients.

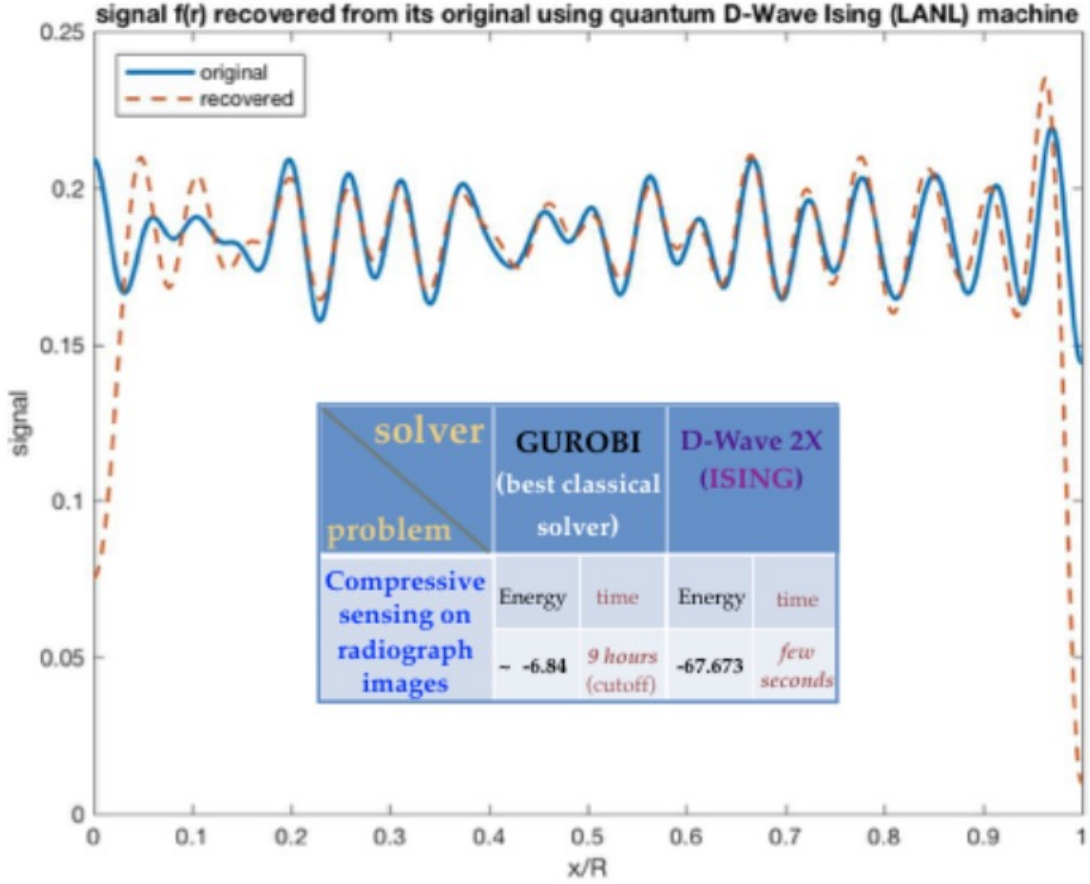
OBTAIN:

$$h = A \, F \, s \, .$$

← Ising input

Results of Compressed Sensing with DWave 2X

Results



solver / problem	GUROBI (best classical solver)		D-Wave 2X (ISING)	
Compressive sensing on radiograph images	Energy	time	Energy	time
	~ -6.84	*9 hours (cutoff)*	-67.673	*few seconds*

D-Wave 2X (Ising) pulls out ALL non-zero Fourier coefficients (frequencies)

Conclusions and Future Work

- **The DWave 2X is a fun challenge that requires a different mode of thinking**
- **Problem solving on the machine can be approached from many different directions, e.g. topologically, analytically, etc.**
- **A cyclic shift calculator was demonstrated for an 8-bit vector (tested up to 9 bits so far)**
- **A compressed sensing approach as it applies to simple radiography was shown**
- **Future Work**
  - Implement a control point model using small image regions on the DWave 2X which can be used for computing the orientation of an image (translation and rotation)
  - Continue testing the scaling properties of the cyclic bit shifter
  - Extract physical features (such as radius) from the compressed sensing approach
  - Collaborate with other DWave 2X users that are interested in image processing

Thank you!

- **Any Questions?**