QC WARE

Q2B

2017

ISTI Rapid Response Calls developed a diverse user base for the Dwave 2X Quantum Annealer “Ising” at LANL

- **Special-purpose device**
- **Solves a particular optimization problem:**

$$\arg\min_{\sigma}\left(\sum_{i=1}^{N} h_i\sigma_i + \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} J_{i,j}\sigma_i\sigma_j\right)$$

for $\boldsymbol{\sigma_i} \in \{-\mathbf{1}, +\mathbf{1}\}$, $\boldsymbol{h_i} \in \mathbb{R}$, and $\boldsymbol{J_{i,j}} \in \mathbb{R}$

- **But there’s a *lot* that one can express in that form…**

~10 publications in 2017

http://www.lanl.gov/projects/national-security-education-center/information-science-technology/dwave/index.php

ISTI Rapid Response DWave Project (Dan O’Malley): Nonnegative/Binary Matrix Factorization

- **Low-rank matrix factorization**
  - $A \approx BC$ where $B_{i,j} \geq 0$ and $C_{i,j} \in \{0,1\}$
  - $\begin{bmatrix} \quad A \quad \end{bmatrix} \approx \begin{bmatrix} B \end{bmatrix} \begin{bmatrix} \quad C \quad \end{bmatrix}$
- **Unsupervised machine-learning application**
  - Learn to represent a face as a linear combination of basis images
  - Goal is for basis images to correspond to intuitive notions of parts of faces
- **“Alternating least squares”**

1. Randomly generate a binary C
2. Solve $B = \arg\min_X \parallel A - XC \parallel_F$ classically
3. Solve $C = \arg\min_X \parallel A - BX \parallel_F$ on the D-Wave
4. Repeat from step 2

- **Results**
  - **The D-Wave NMF approach results in a sparser C (85% vs. 13%) and denser but more lossy compression than the classical NMF approach**
  - **The D-Wave outperforms two state-of-the-art classical codes in a cumulative time-to-target benchmark when a low-to-moderate number of samples are used**

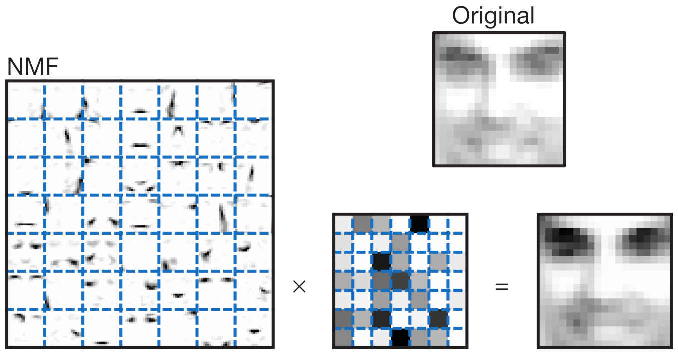
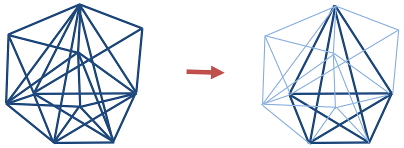


Image credit: Lee & Seung, *Nature* (1999)

ISTI Rapid Response DWave Project (Hristo Djidev): Efficient Combinatorial Optimization

- ## Objectives
  - Develop D-Wave (DW) algorithms for NP-hard problems

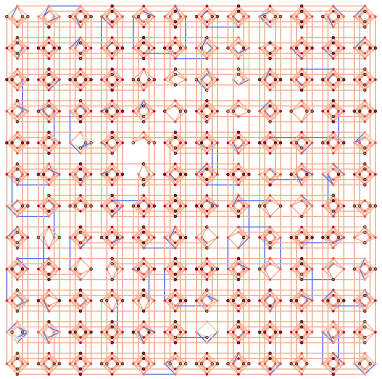
    Focus: the max clique (MC) problem:



orig. graph → clique of max size

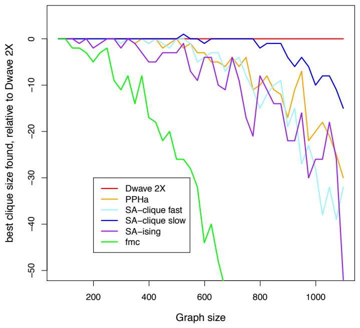
  - Study scalability/accuracy issues and ways to mitigate them
  - Characterize problem instances for which D-Wave may outperform classical alternatives
- ## Results
  - The MC problem can be solved accurately and fast on DW
    - but so can classical methods
    - no quantum advantage for typical problem instances fitting DW (of size ~45)

- Running on larger (Chimera-like) graphs
  - Chimera graph is modified by merging a set of randomly selected edges into a vertex
  - Resulting graphs of sizes upto 1000 are used as inputs to MC problem

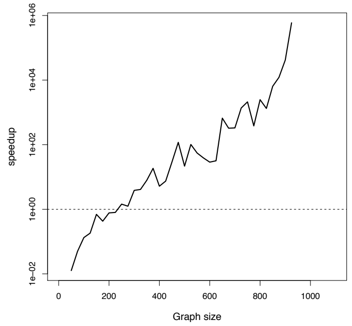


  - DW beats simulated annealing, its classical analogue, by a factor of more than 10^6

Quality comparison



Speed comparison



  - In order to see a quantum advantage for the MC problem, graph sizes should be > 300

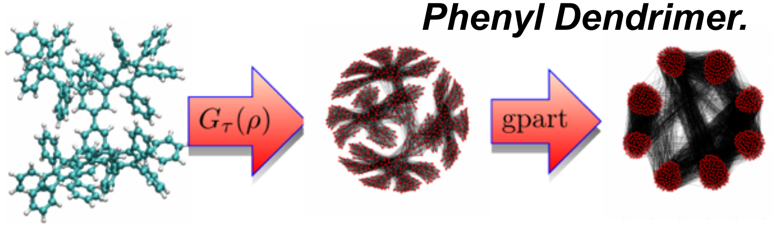
ISTI Rapid Response DWave Project (Sue Mniszewski): Quantum Annealing Approaches to Graph Partitioning for Electronic Structure Problems

- Motivated by graph-based methods for quantum molecular dynamics (QMD) simulations
- Explored graph partitioning/clustering methods formulated as QUBOs on D-Wave 2X
- Used *sapi* and hybrid classical-quantum *qbsolv* software tools
- Comparison with *state-of-the-art* tools
- High-quality results on benchmark (Walshaw), random, and electronic structure graphs

Graph	N	Best	METIS	KaHIP	qbsolv
Add20	2395	596	723	613	602
3elt	4720	90	91	90	90
Bcsstk33	8738	10171	10244	10171	10171

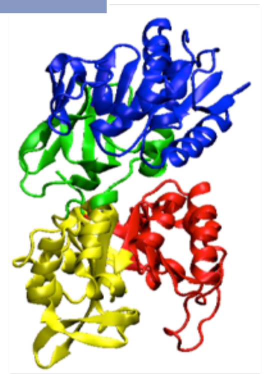
Minimize edge counts between 2 parts on Walshaw graphs.

k-Concurrent Partitioning for Phenyl Dendrimer.



k-parts	METIS	qbsolv
2	705	706
4	20876	2648
8	22371	15922
16	28666	26003

k-Concurrent clustering for IGPS Protein Structure: resulting 4 communities share common sub-structure. Comparable to classical methods.



VOLKSWAGEN

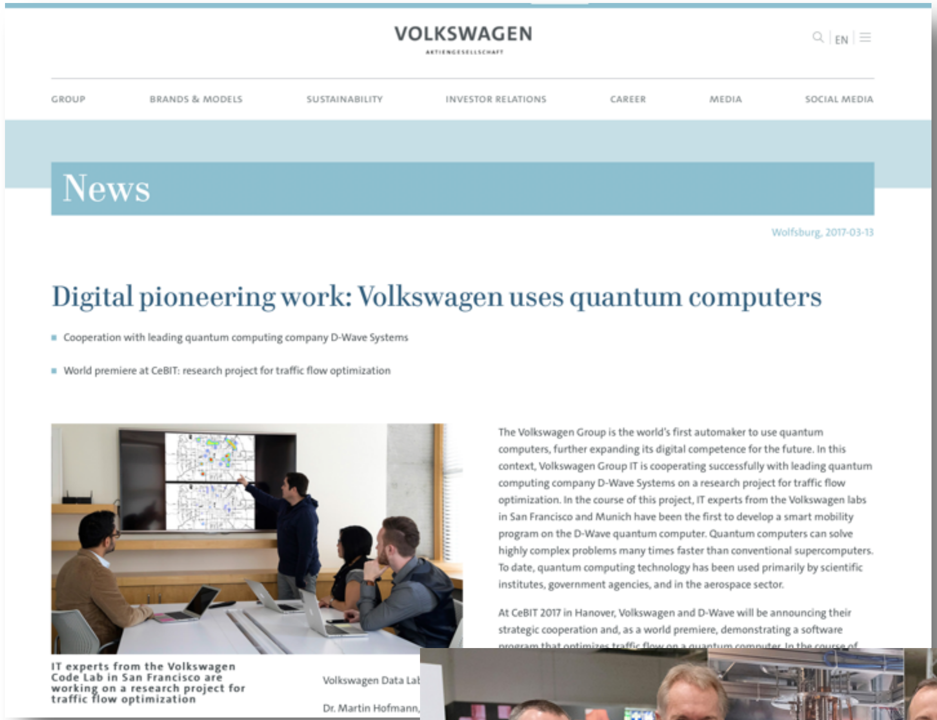
AKTIENGESELLSCHAFT

Quantum Computing at Volkswagen:

Traffic Flow Optimization using the D-Wave Quantum Annealer

D-Wave Users Group Meeting - National Harbour, MD

27.09.2017 – Dr. Gabriele Compostella



VOLKSWAGEN

GROUP | BRANDS & MODELS | SUSTAINABILITY | INVESTOR RELATIONS | CAREER | MEDIA | SOCIAL MEDIA

News

Wolfsburg, 2017-03-13

Digital pioneering work: Volkswagen uses quantum computers

- Cooperation with leading quantum computing company D-Wave Systems
- World premiere at CeBIT: research project for traffic flow optimization

The Volkswagen Group is the world's first automaker to use quantum computers, further expanding its digital competence for the future. In this context, Volkswagen Group IT is cooperating successfully with leading quantum computing company D-Wave Systems on a research project for traffic flow optimization. In the course of this project, IT experts from the Volkswagen labs in San Francisco and Munich have been the first to develop a smart mobility program on the D-Wave quantum computer. Quantum computers can solve highly complex problems many times faster than conventional supercomputers. To date, quantum computing technology has been used primarily by scientific institutes, government agencies, and in the aerospace sector.

At CeBIT 2017 in Hanover, Volkswagen and D-Wave will be announcing their strategic cooperation and, as a world premiere, demonstrating a software

IT experts from the Volkswagen Code Lab in San Francisco are working on a research project for traffic flow optimization

Volkswagen Data Lab

Dr. Martin Hofmann,

AW Automotive World

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Research project successful: Volkswagen IT experts use quantum computing for traffic flow optimization

March 20, 2017

Volkswagen collabore avec le canadien DWave pour tester l'informatique quantique

SYLVAIN ARNULF | AUTOMOBILE, INFORMATIQUE, SIMULATION |
PUBLIÉ LE 20 MARS 2017 À 20H12

TWITTER | FACEBOOK | LINKEDIN | GOOGLE + | EMAIL

Volkswagen profite du Cebit 2017 à Hanovre pour dévoiler un partenariat avec la société canadienne DWave. Objectif : exploiter la puissance de calcul de l'informatique quantique pour résoudre des problèmes de la vie (automobile) de tous les jours.

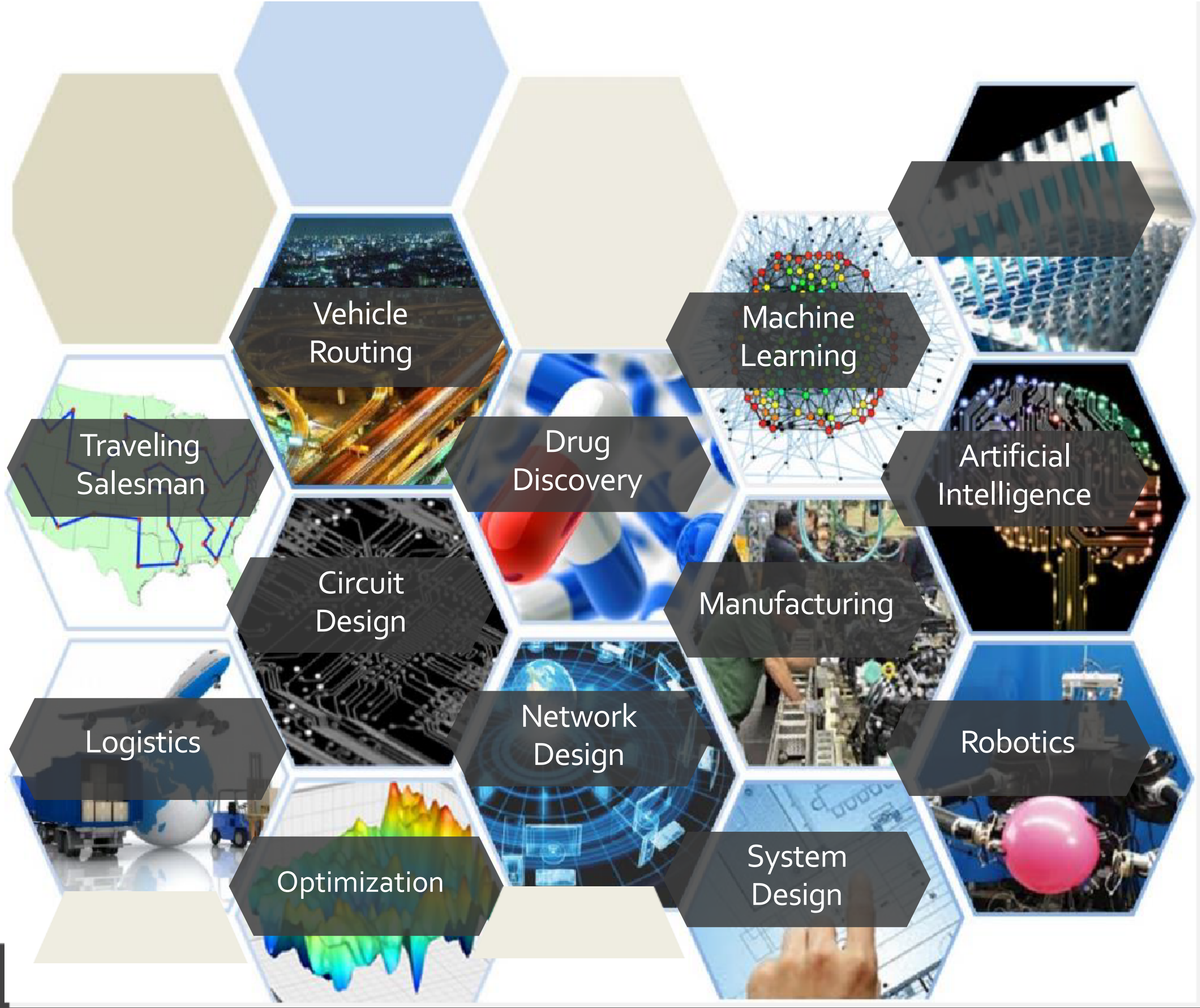
HETEROGENEOUS QUANTUM COMPUTING FOR SATELLITE OPTIMIZATION

GIDEON BASS

BOOZ ALLEN HAMILTON

September 2017

QUANTUM ANNEALING HAS MANY REAL-WORLD APPLICATIONS



CONCLUSIONS

- As problems and datasets grow, modern computing systems have had to scale with them. Quantum computing offers a totally new and potentially disruptive computing paradigm.
- For problems like this satellite optimization problem, heterogeneous quantum techniques will be required to solve the problem at larger scales.
- Preliminary results on this problem using heterogeneous classical/quantum solutions are very promising.
- Exploratory studies in this area have the potential to break new ground as one of the first applications of quantum computing to a real-world problem

Display Advertising Optimization by Quantum Annealing Processor

Shinichi Takayanagi*, Kotaro Tanahashi*, Shu Tanaka†

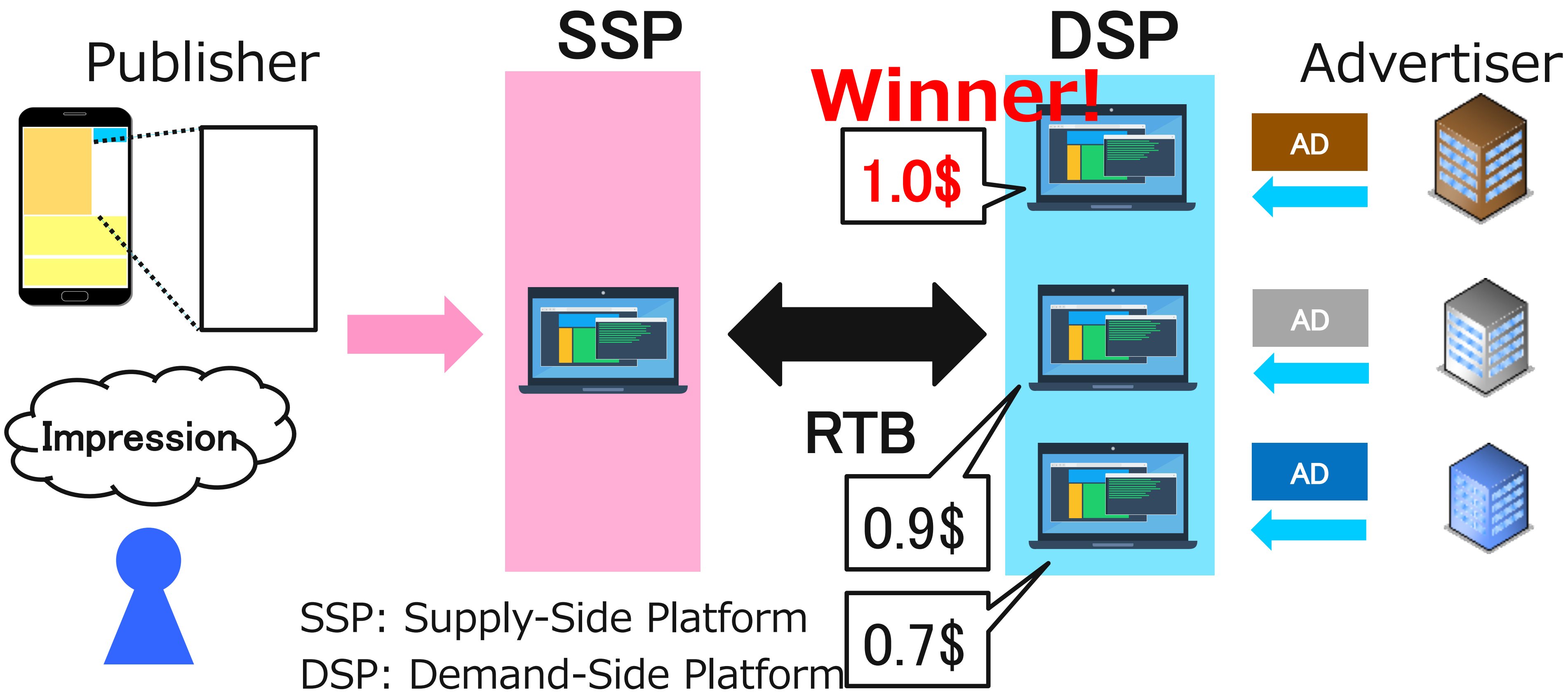
*Recruit Communications Co., Ltd.

† Waseda University, JST PRESTO

RECRUIT

Recruit Communications

Behind the Scenes



SSP: Supply-Side Platform
DSP: Demand-Side Platform
RTB: Real Time Bidding

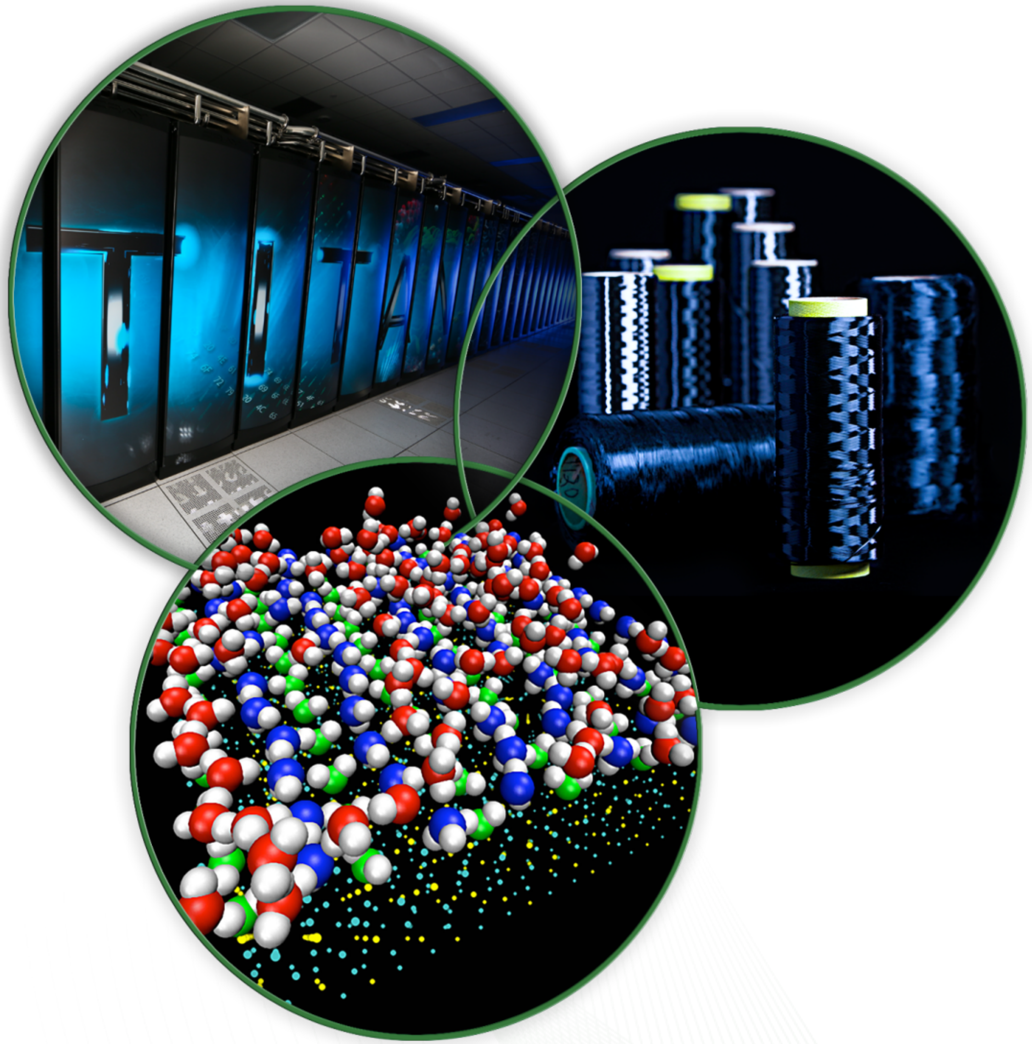
4. Summary

- Budget pacing is important for display advertising
- Formulate the problem as QUBO
- Use D-Wave 2X to solve budget pacing control optimization problem
- Quantum annealing finds a better solution than the greedy method.

A Study of Complex Deep Learning Networks on High Performance, Neuromorphic, and Quantum Computers

Thomas E. Potok[1], Catherine Schuman[1], Steven R. Young[1], Robert M. Patton[1], Federico Spedalieri[2], Jeremy Liu[2], Ke-Thia Yao[2], Garrett Rose[3], and Gangotree Chakma[3]

[1] *Oak Ridge National Laboratory*
[2] *USC Information Sciences Institute*
[3] *University of Tennessee*



A Study of Complex Deep Learning Networks on High Performance, Neuromorphic, and Quantum Computers

There are currently 3 main challenges in Deep Learning

The First:

The first is how to train models with complex topologies that are closer representations of nature. Current deep learning networks limit the scale and complexity of the neuron models they use. While very successful in solving challenging classification problems, these neuron models are not comparable to those produced by nature. Early deep learning models proposed networks which contained intra-layer connections, but proved to be intractable to train on conventional computer systems. We believe that quantum computing may offer a potential solution with the ability to sample from complex probability distributions like those generated by neural networks that contain intra-layer connections.

Adiabatic Quantum Programming at ORNL: Workflow Environments and HPC Integration APIs

Q^x Branch

Quantum Machine Learning for Election Modelling

Election 2016: Case study in the difficultly of sampling

Survey finds Hillary Clinton has 'more than 99% chance' of winning election over Donald Trump

The Princeton Election Consortium found Ms Clinton has a projected 312 electoral votes across the country and only 270 are needed to win

Rachael Revesz New York | @RachaelRevesz | Saturday 5 November 2016 16:44 GMT | 106 comments

Where did the models go wrong?

ELECTION2016

FORECAST

PRESIDENT SENATE

By Natalie Jackson and Adam Hooper
Additional design by Alissa Scheller

PUBLISHED MONDAY, OCT. 3, 2016 12:56 P.M. EDT
UPDATED TUESDAY, NOV. 8, 2016, 12:43 A.M. EST

Photos: Getty

In the event of a tie, the newly elected House of Representatives will elect the president, and the newly elected Senate will elect the vice president.

CNN Money U.S. + Business Markets Tech Media Personal Finance Sma

A model that has correctly predicted the winner of every U.S. presidential race since Ronald Reagan in 1980 is forecasting a big victory for Hillary Clinton.

Clinton is expected to get 332 electoral votes, while Trump is predicted to get just 206, according to the Moody's Analytics model, which is based on three economic and three political factors.

Forecasting elections on a quantum computer

- Quantum computing research has shown potential benefits (speedups) in training various deep neural networks[1-3]

- Core idea: Use QC-trained models to simulate election results. Potential benefits:
    - More efficient sampling / training
    - Intrinsic, tuneable state correlations
    - Inclusion of additional error models

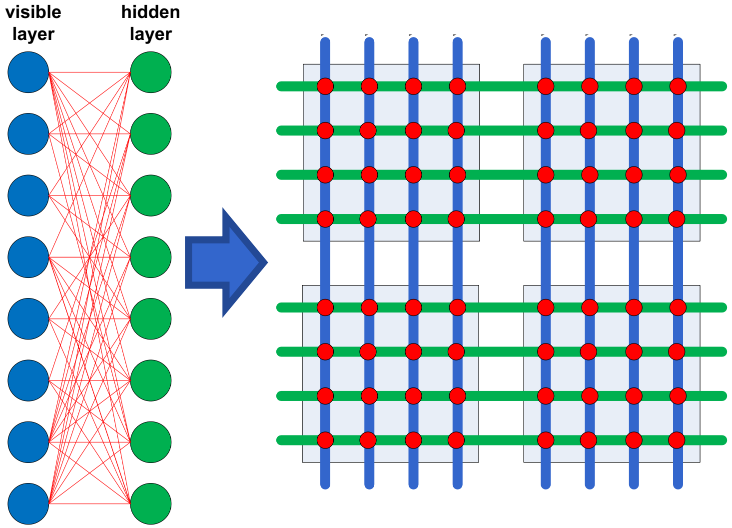
1. Adachi, Steven H., and Maxwell P. Henderson. "Application of quantum annealing to training of deep neural networks." *arXiv preprint arXiv:1510.06356* (2015).
2. Benedetti, Marcello, et al. "Estimation of effective temperatures in quantum annealers for sampling applications: A case study with possible applications in deep learning." *Physical Review A* 94.2 (2016): 022308.
3. Benedetti, Marcello, et al. "Quantum-assisted learning of graphical models with arbitrary pairwise connectivity." *arXiv preprint arXiv:1609.02542* (2016).

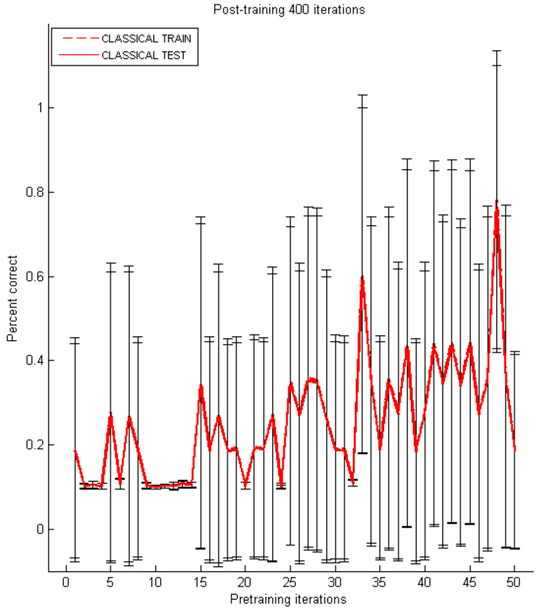
Summary

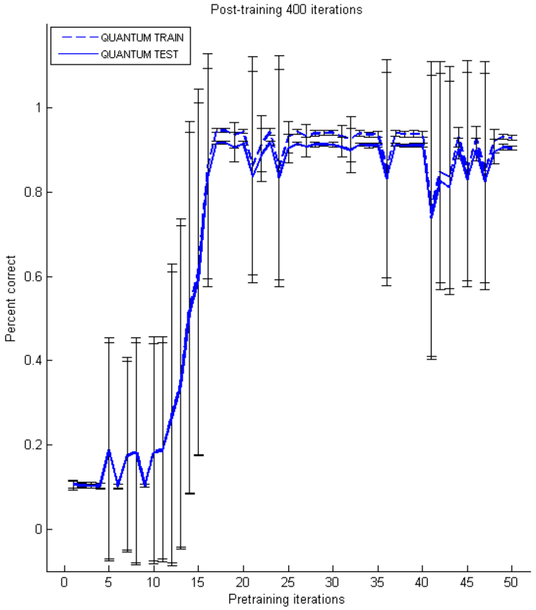
- The QC-trained networks were able to learn structure in polling data to make election forecasts in line with the models of 538
- Additionally, the QC-trained networks gave Trump a much higher likelihood of victory overall, even though the state's first order moments remained unchanged
    - Ideally in the future, we could rerun this method using correlations known with more detail in-house for 538
- Finally, the QC-trained networks trained quickly, and since each measurement is a simulation, each iteration of the training model produced 25,000 simulations (one for each national error model), which already eclipses the 20,000 simulations 538 performs each time they rerun their models

Quantum Enabled Machine Learning

Supervised Learning: Improving Neural Network Training







Adachi, Steven H., and Maxwell P. Henderson. "Application of Quantum Annealing to Training of Deep Neural Networks." *arXiv preprint arXiv:1510.06356* (2015).

Opportunities and challenges in quantum-enhanced machine learning in near-term quantum computers

Alejandro Perdomo-Ortiz

Senior Research Scientist, Quantum AI Lab. at NASA Ames Research Center and at the University Space Research Association, USA

Honorary Senior Research Associate, Computer Science Dept., UCL, UK

Funding:

CAMBRIDGE QUANTUM COMPUTING LIMITED

Office of the Director of National Intelligence
IARPA
BE THE FUTURE

QUANTUM ENHANCED OPTIMIZATION

Perdomo-Ortiz, Benedetti, Realpe-Gomez, and Biswas. **arXiv:1708.09757** (2017). To appear in the Quantum Science and Technology (QST) invited special issue on "What would you do with a 1000 qubit device?"

QUBITS D-wave User Group 2017
National Harbor, MD, September 28, 2017

Generative Modeling for Machine Learning on the D-Wave

Sunil Thulasidasan
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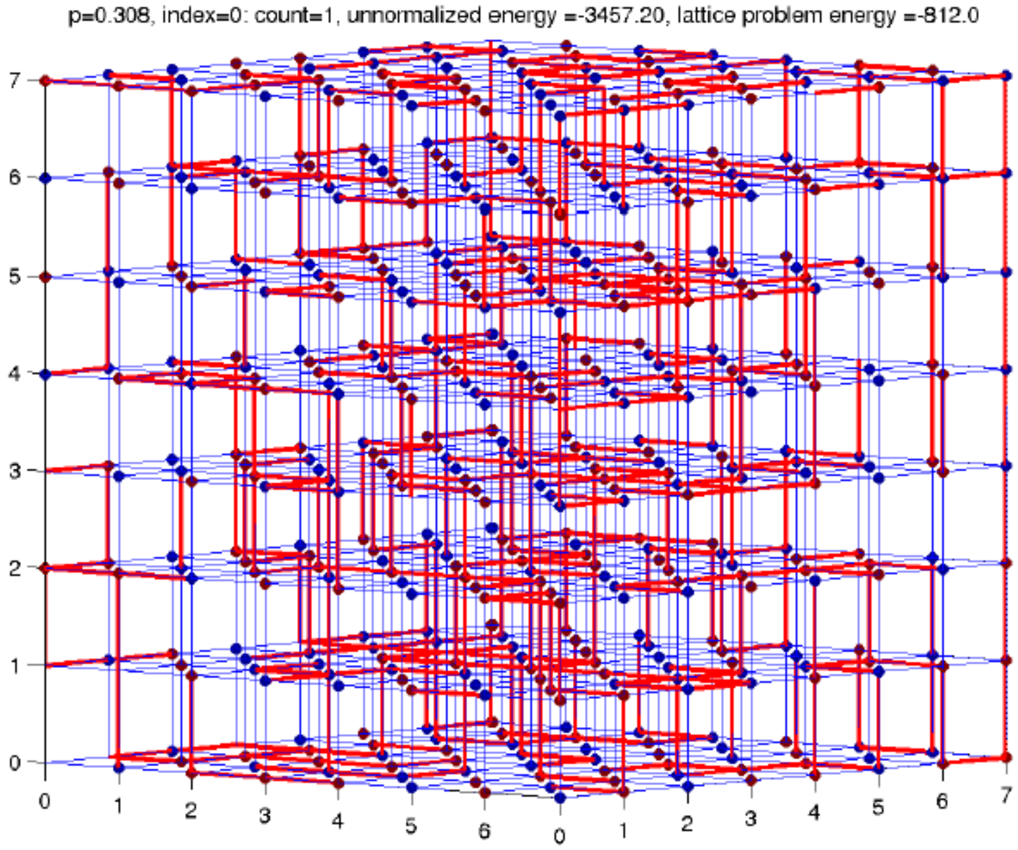
LA-UR-16-28813

Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

D-Wave as a Boltzmann Sampler

- D-Wave is a physical Boltzmann machine
- In theory, should give samples from a Boltzmann distribution (parameterized by some *effective* temperature) after annealing
- Approach: Instead of Gibbs's sampling, map RBM onto D-Wave and sample from solution states

Disordered ($p = 0.308$) lattice



- AFM bonds (blue lines) with a high concentration of FM bonds (red lines).
- No ordering of spins (blue dot=↑, red dot =↓).

For More Information See

D-Wave Users Group Presentations:

- https://dwavefederal.com/qubits-2016/
- https://dwavefederal.com/qubits-2017/

LANL Rapid Response Projects:

- http://www.lanl.gov/projects//national-security-education-center/information-science-technology/dwave/index.php

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