Quantum Initiative

**T-QARD:**

Quantum computing for Tsunami evacuation

Graduate School of Information Sciences, Tohoku University

Masayuki Ohzeki
About T-QARD
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Tohoku University Quantum Annealing Research and Development

- D-Wave 2000Q is available
- Collaborations with various companies
- Active Researchers and Students

Main Team Members (will participate in AQC2018)
- Masayuki Ohzeki: Leader
- Masamichi J. Miyama: Assistant Professor
- Ryoji Miyazaki: Assistant Professor
- Shuntaro Okada (DENSO), Chako Takahashi, Shunta Arai, Takanori Suzuki

and many graduate students and undergraduates
Website (http://qard.is.tohoku.ac.jp/)

About

PROJECT

追求求めるのはOptimal Society。
日々の業務の効率化から生物の進化まで、全ての鍵を握るの
は最適化問題の解決です。

Tohoku university Quantum Annealing Research &
Development (T-QARD)は、社会に潜む最適化問題を取り出
し、最適解を提供します。我々が操る技術は量子アニーリ
ング。全ての可能性から一つの最適解を追求します。

プロの研究者と熱意のあるエンジニア・大学院生が互いのア
イディアを磨き、全てを最適化します。
Mission T-QARD

- Making core of Quantum Computing in Japan
- Application driven by Quantum annealing on D-Wave machine
- Providing quantum computing knowledge for colleagues
- Cultivation of human resources with quantum computing
Many users in Tohoku University

Starting from Lecture by **Fixstars**

- We now have many users in Tohoku University
- We have mainly, of course, the researchers and Ph. D candidates
- **Undergrads** are struggling while studying quantum mechanics and machine learning, optimization
- Educations on quantum annealing are accelerated

A look of lecture by Fixstars
NOMURA

✓ Financial holding company, along with its broker-dealer, banking and other financial services subsidiaries, provides investment, financing and related services

Mission

✓ Optimization
  ✓ Portfolio optimization problem via D-Wave 2000Q
✓ Reduction of computational cost
  ✓ Replacement of QMC with D-Wave 2000Q
Mercari

- E-commerce company founded in 2013.
- “mercari” marketplace app has grown to become the country’s largest community-powered marketplace with over JPY 10 billion in transactions carried out on the platform each month.

Mission

- Optimization
  - Various problems in mercari service
- Expansion to different research area
  - Generating new art and design
DENSO

✓ Global automotive components manufacturer.
✓ The second largest auto parts supplier in the world.

Mission

✓ Optimization
  ✓ Various problems related to automotive and industry, and in factories
✓ Machine learning
  ✓ Deep learning by quantum annealing
Material Science
TEM-CT as linear measurements

For 3D imaging, we solve “Underdetemined equation”

Then we utilize the “L1-norm minimization” for estimation
TEM-CT as linear measurements

\[ y = Ax \]

TEM-CT (Transmission Electron Microscope-Computed Tomography)
- For 3D imaging, we solve “Underdetermined equation”
- Then we utilize the “L1-norm minimization” for estimation
TEM-CT as linear measurements

\[ y = Ax \]

\[ H = - \sum_{i \neq j} J_{ij} x_i x_j - \sum_{i=1}^{N} h_i x_i \]

TEM-CT (Transmission Electron Microscope-Computed Tomography)

✓ For 3D imaging, we solve “Underdetemined equation”
✓ Then we utilize the “L1-norm minimization” for estimation
✓ Instead we employ ”Quantum Annealing” for direct optimization
We take an easier case as an exercise at the moment

We have row and column accumulative counts of atoms ("Nonogram")

Instead of L1 norm, we implement L2 norm as a regularizer

\[ r = \{0, 0, 6, 9, 11, \ldots, 9, 6, 0, 0\} \]

\[ c = \{0, 4, 7, 9, 11, \ldots, 9, 7, 0, 0\} \]

\[ H(x) = \sum_i \left( \sum_j x_{ij} - r_i \right)^2 + \sum_j \left( \sum_i x_{ij} - c_j \right)^2 + \lambda \sum_i \sum_j \left[ (x_{ij} - x_{i,j+1}) + (x_{ij} - x_{i+1,j})^2 \right]. \]
Results

✓ Divide problem for embedding
✓ Qbsolv?
✓ Use mini-batch minimization

TEM-CT (Transmission Electron Microscope-Computed Tomography)

✓ We obtain reasonable solution by use of mini-batch minimization
✓ We do not yet use Reverse annealing, which may find better solutions
Simulation of non-stoquastic Hamiltonian
**Simulation of non-stoquastic Hamiltonian**

S. Arai and M. Ohzeki to be submitted

**+ XX interaction**

✓ Non-stoquastic Hamiltonian may avoid the first-order phase transition


\[
H = - \sum_{i \neq j} J_{ij} \hat{\sigma}_i^z \hat{\sigma}_j^z - \sum_{i=1}^{N} h_i \hat{\sigma}_i^z - \Gamma \sum_{i=1}^{N} \hat{\sigma}_i^x + N \gamma \left( \frac{1}{N} \sum_{i=1}^{N} \hat{\sigma}_i^x \right)^2
\]

✓ We can map (full-connect) XX interaction into feed-back transverse field


\[
H = - \sum_{i \neq j} J_{ij} \hat{\sigma}_i^z \hat{\sigma}_j^z - \sum_{i=1}^{N} h_i \hat{\sigma}_i^z - \Gamma (m^x) \sum_{i=1}^{N} \hat{\sigma}_i^x
\]

**Simulation of XX interaction in D-Wave 2000Q**

✓ Adaptive “quantum Monte-Carlo simulation” can deal with XX interaction

✓ Instead of QMC, we implement D-Wave 2000Q quench equilibration

✓ Results are will be reported in AQC2018, sorry!
Quantum Simulation
**D-Wave 2000Q by quench equilibration**

- We obtain equilibrium state of quantum spin model efficiently.
- Recently deep neural network is found to be available for identifying phase transition


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**Quantum Simulation**

- We prepare equilibrium spin configurations as input
- Temperature and transverse field are provided as output
- Heat map of weight of DNN signals anomaly behavior of spin configurations

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2018.04.12   T-QARD: Quantum Computing for Tsunami Evacuation
D-Wave 2000Q by quench equilibration

<table>
<thead>
<tr>
<th></th>
<th>QMC</th>
<th>D-Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{\text{mean}}$</td>
<td>0.189</td>
<td>0.237</td>
</tr>
<tr>
<td>$W_{\text{var}}$</td>
<td>0.230</td>
<td>0.290</td>
</tr>
</tbody>
</table>

Critical point is measured by time $s$

Quantum Simulation
- We prepare equilibrium spin configurations as input
- Temperature and transverse field are provided as output
- Heat map of weight of DNN signals anomaly behavior of spin configurations
- We input the D-Wave 2000Q sampling data
- We obtain a similar result to the case with QMC
Tsunami Evacuation
D-Wave 2000Q as infrastructure

- multi-destination problem while avoiding congestion
- Preprocessing in classical computer for reducing candidate routes
  - Not only nearest evacuation areas but also second nearest ones
- QUBO problem is the same formulation as one by VW

\[
E(q) = \sum_s \left( \sum_{\mu} \sum_{i \in I_{\mu}} F_i(s) q_{\mu i} \right)^2 + \frac{\lambda_3}{2} \sum_{\mu} \left( \sum_{i \in I_{\mu}} q_{\mu i} - 1 \right)^2
\]

Tsunami Evacuation

- Computational time about 20 micro sec. is charming point on this application
- Mini-batch minimization should be employed
- We continue to send best choice at the moment
- When users take different route, we resend new solution for individuals
Tsunami Evactuation

- Evacuation system
**Summary**

**Tohoku university Quantum Annealing Research and Development**

- Collaboration Networks in Japan
- Activity based on D-Wave 2000Q
- Innovative applications, Nice software

**Existing Results**

- 3D imaging from TEM-CT via D-Wave 2000Q (by M. J. Miyama et al.)
- Quantum simulation by reverse annealing (by S. Arai et al)
- Adaptive Quantum Monte-Carlo simulation (by M. Ohzeki)
- Deep neural network by quantum annealing (by M. Ohzeki et al.)

**Forthcoming Results will appear in AQC2018**

- Nonstoquastic Hamiltonian with D-Wave 2000Q (by S. Arai et al.)
- Quantum simulation in comparison with analysis (by S. Okada et al.)
- Effect of penalty terms in real applications and analysis (by M. Ohzeki et al. accepted as a contributed talk)

**Forthcoming Results will appear in next QUBITS?**

- Providing evacuation routes (by T. Suzuki et al.)
- Collaboration with another company (by N. Maruyama et al.)
- and more…