Solving vehicle Routing Problem using Quantum Annealing

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Kraków Quantum Information Seminar (Webinar)
17.03.2020

Agenda

- ➔ Adiabatic quantum computers, quantum annealing algorithms and their applications
- ➔ Solving VRP using quantum annealing
- ➔ Where to learn more?
- ➔ Building quantum computing ecosystem

Adiabatic quantum computers, quantum annealing algorithms and their applications

Adiabatic quantum computers

An **adiabatic process** - a process that does not involve the transfer of heat or matter into or out of a thermodynamic system. In an adiabatic process, energy is transferred to the surroundings only as work.
(Source: https://en.wikipedia.org/wiki/Adiabatic_process)

Adiabatic quantum computers

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Adiabatic quantum computer:
"First, a (potentially complicated) Hamiltonian is found whose ground state describes the solution to the problem of interest. Next, a system with a simple Hamiltonian is prepared and initialized to the ground state. Finally, the **simple Hamiltonian is adiabatically evolved** to the desired complicated Hamiltonian. By the adiabatic theorem, the system remains in the ground state, so at the end the state of the system describes the solution to the problem." (Source: https://en.wikipedia.org/wiki/Quantum_annealing)

Adiabatic quantum computing has been shown to be **polynomially equivalent to conventional quantum computing in the circuit model**. ("Adiabatic Quantum Computation is Equivalent to Standard Quantum Computation", D. Aharonov et al, https://arxiv.org/pdf/quant-ph/0405098.pdf)

Adiabatic quantum computers

A classical Hamiltonian is a mathematical description of some physical system in terms of its energies. We can input any particular state of the system, and the Hamiltonian returns the energy for that state. For most non-convex Hamiltonians, finding the minimum energy state is an NP-hard problem that classical computers cannot solve efficiently. For the D-Wave system (one of realizations of quantum annealing), the Hamiltonian may be represented as

$$\mathcal{H}_{ising} = \underbrace{-\frac{A(s)}{2}\left(\sum_i \hat{\sigma}_x^{(i)}\right)}_{\text{Initial Hamiltonian}} + \underbrace{\frac{B(s)}{2}\left(\sum_i h_i \hat{\sigma}_z^{(i)} + \sum_{i>j} J_{i,j}\hat{\sigma}_z^{(i)}\hat{\sigma}_z^{(j)}\right)}_{\text{Final Hamiltonian}}$$

The Hamiltonian is the sum of two terms, the *initial Hamiltonian* and the *final Hamiltonian*:

- Initial Hamiltonian (first term) - The lowest-energy state of the initial Hamiltonian is when all qubits are in a superposition state of 0 and 1. This term is also called the *tunneling Hamiltonian*.
- Final Hamiltonian (second term) - The lowest-energy state of the final Hamiltonian is the answer to the problem that we are trying to solve. The final state is a classical state, and includes the qubit biases and the couplings between qubits. This term is also called the *problem Hamiltonian*.

Source: https://docs.dwavesys.com/docs/latest/c_gs_2.html

Quantum annealing

Ising Model

The Ising model of ferromagnetism traditionally used in statistical mechanics. Variables are “spin up” (↑) and “spin down” (↓), states that correspond to +1 and −1 values (atomic “spins” or magnetic dipole moments). Relationships between the spins, represented by couplings, are correlations or anti-correlations. The objective function (Hamiltonian) expressed as an Ising model is as follows:

$$\mathrm{E}_{ising}(\boldsymbol{s}) = \sum_{i=1}^{N} h_i s_i + \sum_{i=1}^{N} \sum_{j=i+1}^{N} J_{i,j} s_i s_j$$

where the linear coefficients corresponding to qubit biases are h_i, and the quadratic coefficients corresponding to coupling strengths are $J_{i,j}$.

Source: https://docs.dwavesys.com/docs/latest/c_gs_2.html

Adiabatic quantum computers

The **time complexity for an adiabatic algorithm** is the time taken to complete the adiabatic evolution which **is dependent on the gap in the energy eigenvalues (spectral gap) of the Hamiltonian**. Specifically, if the system is to be kept in the ground state, the energy gap between the ground state and the first excited state of H(t) provides an upper bound on the rate at which the Hamiltonian can be evolved at time t. When the spectral gap is small, the Hamiltonian has to be evolved slowly. The runtime for the entire algorithm can be bounded by:

$$T = O\left(\frac{1}{g_{min}^2}\right)$$

where g_{min} is the minimum spectral gap for H(t).

(Source: https://en.wikipedia.org/wiki/Adiabatic_quantum_computation)

Adiabatic quantum computers

AQC is a possible method to get around the problem of **energy relaxation** (related to quantum decoherence). Since the quantum system is in the ground state, interference with the outside world cannot make it move to a lower state. If the energy of the outside world (...) is kept lower than the energy gap between the ground state and the next higher energy state, the system has a proportionally lower probability of going to a higher energy state. Thus the system can stay in a single system eigenstate as long as needed.

(Source: https://en.wikipedia.org/wiki/Adiabatic_quantum_computation)

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Solving combinatorial optimization problems

In **combinatorial optimization problems**, we search for the best of many possible combinations. Optimization problems include scheduling challenges, such as “Should I ship this package on this truck or the next one?” or “What is the most efficient route a traveling salesperson should take to visit different cities?”

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Physics can help solve these sorts of problems because we can frame them as energy minimization problems. **A fundamental rule of physics is that everything tends to seek a minimum energy state.** Objects slide down hills; hot things cool down over time. This behavior is also true in the world of quantum physics. Quantum annealing simply uses quantum physics to find low-energy states of a problem and therefore the optimal or near-optimal combination of elements.

Simply: finding minimal “energy state” for a given optimization problem (encoded as entanglement of qubits).

Source: https://docs.dwavesys.com/docs/latest/c_gs_2.html

Quantum annealing

“Quantum annealing - starts from a quantum-mechanical superposition of all possible states (candidate states) with equal weights. Then the system evolves following the time-dependent **Schrödinger equation**, a natural quantum-mechanical evolution of physical systems. The amplitudes of all candidate states keep changing, realizing a quantum parallelism, according to the time-dependent strength of the transverse field, which causes quantum tunneling between states. If the rate of change of the transverse-field **is slow enough**, the system stays **close** to the ground state of the instantaneous Hamiltonian (**adiabatic quantum computation)**. If the rate of change of the transverse-field is accelerated, the system may leave the ground state temporarily but produce a higher likelihood of concluding in the ground state of the final problem Hamiltonian, i.e., adiabatic quantum computation. The transverse field is finally switched off, and the system is expected to have reached the ground state of the classical **Ising model** that corresponds to the solution to the original optimization problem. An experimental demonstration of the success of quantum annealing for random magnets was reported immediately after the initial theoretical proposal.”

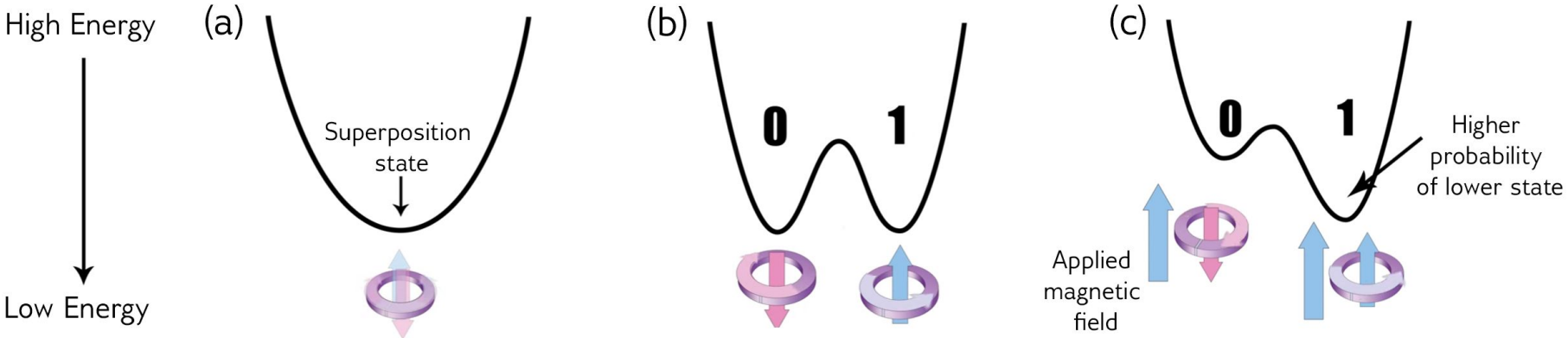
(Source: https://en.wikipedia.org/wiki/Quantum_annealing)

Because no real-world computation can run in perfect isolation, **quantum annealing** may be thought of as the real-world counterpart to **adiabatic quantum computing**, a theoretical ideal.

Quantum annealing

“To begin, there is just one valley (a), with a single minimum. The quantum annealing process runs, the barrier is raised, and this turns the energy diagram into what is known as a *double-well potential* (b). Here, the low point of the left valley corresponds to the 0 state, and the low point of the right valley corresponds to the 1 state. The qubit ends up in one of these valleys at the end of the anneal. (...)

Everything else being equal, the probability of the qubit ending in the 0 or the 1 state is equal (50 percent). We can, however, control the probability of it falling into the 0 or the 1 state by applying an external magnetic field to the qubit (c). This field tilts the double-well potential, increasing the probability of the qubit ending up in the lower well. The programmable quantity that controls the external magnetic field is called a *bias*, and the qubit minimizes its energy in the presence of the bias.”



Source: https://docs.dwavesys.com/docs/latest/c_gs_2.html

Quantum annealing

Quadratic Unconstrained Binary Optimization (QUBO) problems are traditionally used in computer science. Variables are TRUE and FALSE, states that correspond to 1 and 0 values. A QUBO problem is defined using an upper-diagonal matrix Q, which is an N x N upper-triangular matrix of real weights, and x, a vector of binary variables, as minimizing the function:

$$f(x) = \sum_i Q_{i,i} x_i + \sum_{i<j} Q_{i,j} x_i x_j$$

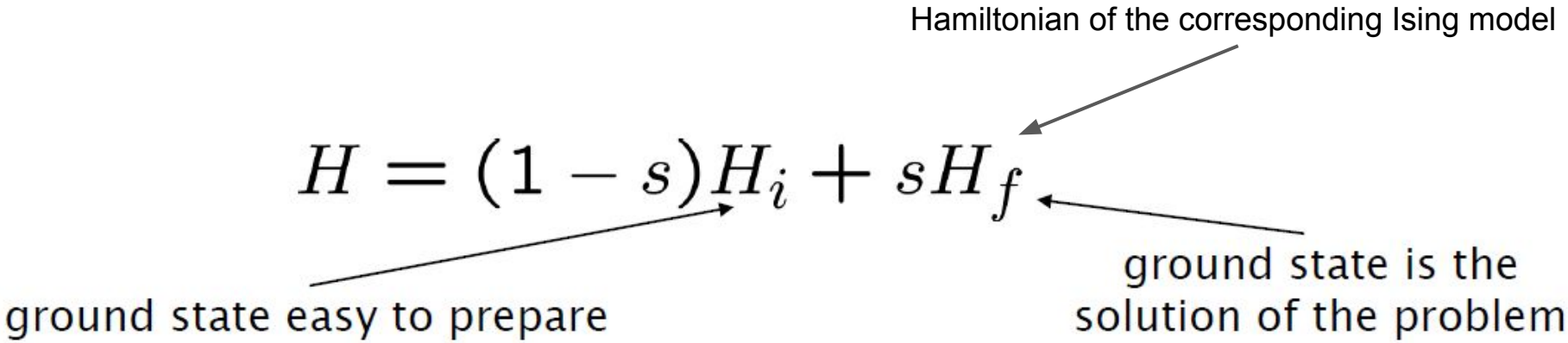
where the diagonal terms $Q_{i,i}$ are the linear coefficients and the nonzero off-diagonal terms are the quadratic coefficients $Q_{i,j}$. This can be expressed more concisely as

$$\min_{x \in \{0,1\}^n} x^T Q x$$

Source: https://docs.dwavesys.com/docs/latest/c_gs_2.html

Solving combinatorial optimization problems

➔ Quantum annealing



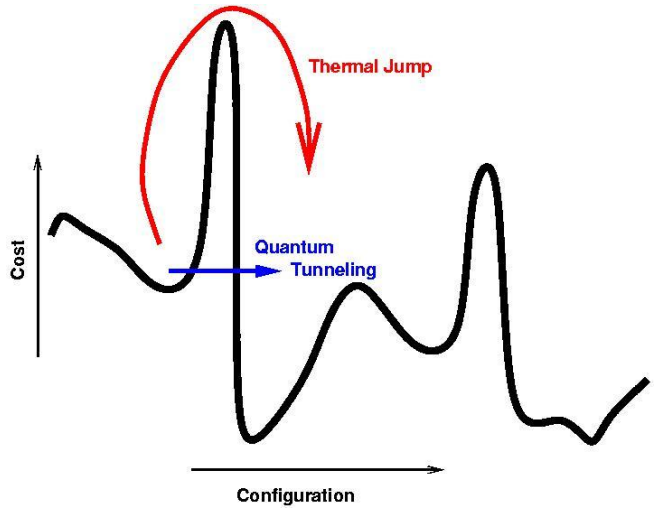
Adiabatic theorem:
if we change *s* **slow enough** the final state will be the solution of our problem

In practice: s can be changed by modifying a strength of the magnetic field.

Solving combinatorial optimization problems

➔ Quantum tunneling

By controlling the strength of a magnetic field (slow enough) we change the landscape: we start from the ground state of a quantum system that is easy to prepare and thanks to quantum tunneling we end up in a (global) minimum of a quantum state corresponding to our problem.



Nice explanation from D-Wave: https://www.youtube.com/watch?v=UV_RICAc5Zs

Applications in transportation

Volkswagen Uses Quantum Computing to Fight Beijing Traffic

Volkswagen teamed with D-Wave Systems to run a traffic-flow algorithm on a quantum computer, with encouraging results.

BY STEPHEN EDELSTEIN MARCH 30, 2017

Volkswagen and Google to bring quantum computing benefits to cars

Posted Nov 8, 2017 by Darrell Etherington (@etherington)

Optimizing routes of fleets of taxis in Beijing

“Traffic Flow Optimization Using a Quantum Annealer”

Florian Neukart, Gabriele Compostella, Christian Seidel, David von Dollen, Sheir Yarkoni, Bob Parney (Volkswagen + D-Wave)

https://www.frontiersin.org/articles/10.3389/fict.2017.00029/full

Quantum annealing - suitable for solving complex combinatorial optimization problems

- ➔ We build a road network and have routes from real GPS data (T-Drive, taxis in Beijing))
- ➔ For each car we add 2 possible routes between source and destination (cars may share road segments)
- ➔ Travel time is proportional to the function (square) of a number of cars on a route (simplification)
- ➔ We want to minimize the total travel time

Optimizing routes of fleets of taxis in Beijing

- q_{ij} - 0 or 1 (car i takes route j)

$$\begin{aligned} 0 &= \left(\sum_{j \in \{1,2,3\}} q_{ij} - 1 \right)^2 \\ &= -q_{i1} - q_{i2} - q_{i3} + 2q_{i1}q_{i2} + 2q_{i2}q_{i3} + 2q_{i1}q_{i3} + 1 \end{aligned}$$

- B_s - set of q_{ij} associated with routes that share street segment s

$$\text{cost}(s) = \left(\sum_{q_{ij} \in B_s} q_{ij} \right)^2$$

$$\text{Obj} = \sum_{s \in S} \text{cost}(s) + \lambda \sum_i \left(\sum_j q_{ij} - 1 \right)^2$$

Optimizing routes of fleets of taxis in Beijing

$$\text{Obj} = \sum_{s \in S} \text{cost}(s) + \lambda \sum_{i} \left(\sum_{j} q_{ij} - 1 \right)^2$$

$$\text{Obj}(x, Q) = x^T \cdot Q \cdot x$$

Given the matrix *Q*, finding binary variable assignments to minimize the objective function is equivalent to minimizing an Ising model (model of ferromagnetism), which is NP-hard.

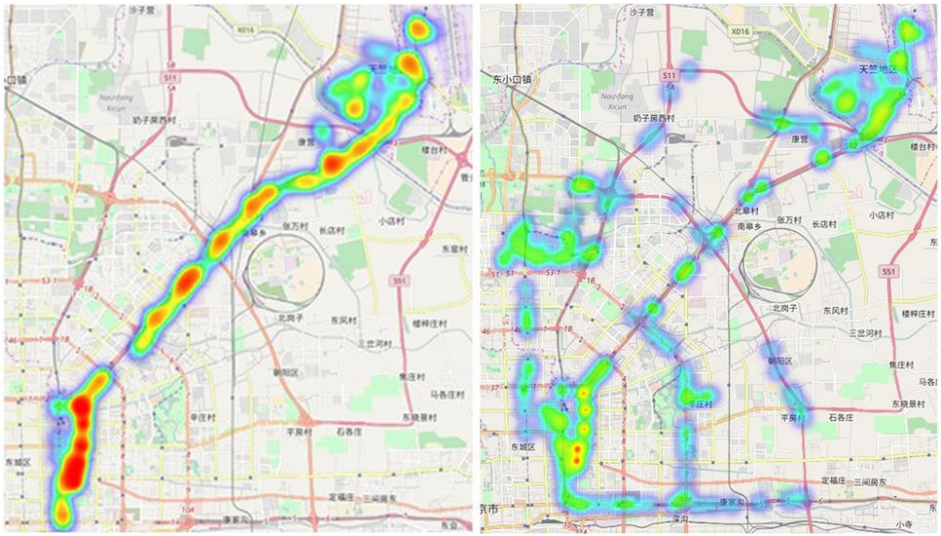
It can be solved using quantum annealing on D-Wave (in this case: D-Wave 2X QPU)

Optimizing routes of fleets of taxis in Beijing

418 cars,1254 logical variables (3^{418} possible solutions)

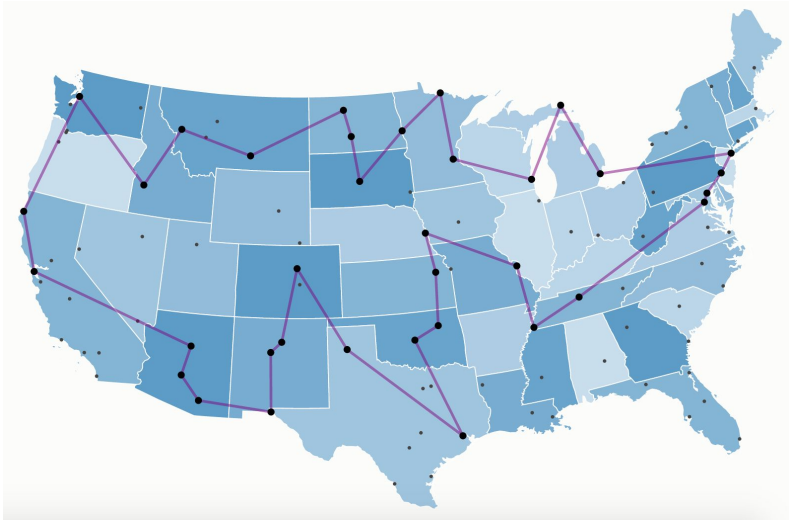
Result: relatively small number of streets that are heavily occupied

Time of computations: 22 seconds



Improving logistics

➔ Solving Travelling Salesman Problem and similar NP-hard problems (Vehicle Routing Problem, Pickup and Delivery problem, vanpooling)



Source: http://examples.gurobi.com/traveling-salesman-problem

Solving Vehicle Routing Problem

$V = \{1, 2, \ldots, M\}$ - identifiers of vehicles

$K = \{1, 2, \ldots, N, N+1\}$ - identifiers of nodes (N+1 - depot)

$O = \{O_1, O_2, \ldots, O_N\}$ - orders

$C_{i,j}$ - cost of travel from node **i** to node **j** (for $i,j \in K$), $C_{i,i} = 0$

$x_{i,j,k}$ = **1** if in a given setting the vehicle i visits the node j as k-th location on its route (**0** otherwise)

For each vehicle i: $x_{i,N+1,0} = 1$, $x_{i,j,0} = 0$ for $j < N + 1$ (the depot is always the initial (0-th) location)

if $x_{i,N+1,L} = 1$ for some L then for $W > L$ $x_{i,j,W} = 0$ (the depot is always the last location on each route)

Solving Vehicle Routing Problem

Let's consider a binary function:

$$A(y_1, y_2, \ldots, y_n) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} 2y_i y_j - \sum_{i=1}^{n} y_i$$

where $y_i \in \{0,1\}$ for $i \in \{1,\ldots, n\}$. It is easy to prove that the minimum value of $A(y_1, y_2, \ldots, y_n)$ is equal to -1 and this value can be achieved only if exactly one of $y_1, y_2, \ldots, y_n$ is equal to 1.

$A(y_1, y_2, \ldots, y_n) = (y_1 + y_2 + \ldots + y_n - 1)^2 - 1$

Solving Vehicle Routing Problem

$$C = \sum_{m=1}^{M} \sum_{n=1}^{N-1} \sum_{i=1}^{N+1} \sum_{j=1}^{N+1} x_{m,i,n} x_{m,j,n+1} C_{i,j} +$$

$$\sum_{m=1}^{M} \sum_{n=1}^{N} x_{m,n,1} C_{N+1,n} + \sum_{m=1}^{M} \sum_{n=1}^{N} x_{m,n,N} C_{n,N+1}$$

Solving Vehicle Routing Problem

To assure that each delivery is served by exactly one vehicle and exactly once, the following term should be included in our QUBO formulation:

$$Q = \sum_{k=1}^{N} A(x_{1,k,1}, x_{2,k,1}, \ldots, x_{1,k,2}, \ldots, x_{M,k,N}) + \\ + \sum_{m=1}^{M} \sum_{n=1}^{N} A(x_{m,1,n}, x_{m,2,n}, \ldots, x_{m,N+1,n})$$

Solving Vehicle Routing Problem

Full QUBO Solver (FQS)

By definition of VRP, QUBO representation of this optimization problem is

$$QUBO_{VRP} = A_1 \cdot C + A_2 \cdot Q$$

for some constants A_1 and A_2, which should be set to ensure that the solution found by quantum annealer minimizes Q to ensure satisfiability of the aforementioned constraints.

Solving Capacitated Vehicle Routing Problem

Average Partition Solver (APS)

We decrease the number of variables for each vehicle by assuming that every vehicle serves approximately the same number of orders - up to A+L deliveries, where A is the total number of orders divided by the number of vehicles and L is a parameter (called “limit radius”), which controls the number of orders.

The number of variables is lower which simplifies computations.

Solving Capacitated Vehicle Routing Problem

DBSCAN Solver (DBSS)

Hybrid algorithm which combines quantum approach with a classical algorithm (Recursive DBSCAN).

DBSS uses recursive DBSCAN as a clustering algorithm with limited size of clusters. Then TSP is solved by FQS separately (we can just assume the number of vehicles equal to 1).

If the number of clusters is equal to (or lower than) the number of vehicles, the answer is known immediately. Otherwise, the solver runs recursively considering clusters as deliveries, so that each cluster contains orders which in the final result are served one after another without leaving the cluster.

We also concluded that by limiting the total sum of weights of deliveries in clusters, this algorithm can solve CVRP if all capacities of vehicles are equal.

Solving Capacitated Vehicle Routing Problem

Solution Partitioning Solver (SPS)

This algorithm divides TSP solution found by another algorithm (e.g., FQS) into consecutive intervals, which are the solution for CVRP.

Let d_1, d_2, …, d_N be the TSP solution for N orders, let P_v be a capacity of the vehicle v, let $w_{i,j}$ be the sum of weights of orders d_i, d_i+1, d_i+2, ... , d_j (in the order corresponding to TSP solution) and let $cost_{i,j}$ be the total cost of serving only orders d_i, d_i+1, ... , d_j. Also, let $dp_{i;S}$ be the cost of the best solution for orders d_1, d_2, d_3, …, d_i and for the set of vehicles S. Now, the dynamic programming formula for solving CVRP is given by:

$$dp_{i,S} = \min_{v \in S, 0 \leq j \leq i, w_{j+1,i} \leq P_v} \{dp_{j,S \setminus \{v\}} + cost_{j+1,i}\}$$

where $cost_{i,j} = 0$ and $w_{i,j} = 0$ for $i > j$

Solving Capacitated Vehicle Routing Problem

Solution Partitioning Solver (SPS)

To speed up computations, we can apply a heuristic:

1. Instead of set S of vehicles, consider a sequence v_1, v_2, ..., v_M of vehicles and assume that we attach them to deliveries in such an order.
2. Now, our dynamic programming formula is given by:

$$dp_{i,v_k} = \min_{0 \le j \le i, w_{j+1,i} \le P_{v_k}} \{dp_{j,\{v_1,\ldots,v_{k-1}\}} + cost_{j+1,i}\}$$

3. To count this dynamic effectively, we can observe that:

$$\forall_{i<j, 1 \le k \le M} (dp_{i-1,v_k} + cost_{i,j}) - (dp_{i-1,v_k} + cost_{i,j-1}) = C_{j-1,j} + C_{j,N+1} - C_{j-1,N+1}$$

We can now select some random permutations of vehicles and perform dynamic programming for each of them.

Results of experiments

We ran experiments using D-Wave's Leap platform and 2 solvers: qbsolv (on QPU or CPU) and hybrid solver (on QPU and CPU at the same time).

We prepared several datasets:

- Christofides1979 - a standard benchmark dataset for CVRP, well-known and frequently investigated by the scientific community (14 tests with different number of vehicles, capacities and number of orders).
- A dataset built by us based on a realistic road network of Belgium, acquired from the OpenStreetMap service (51 tests).

Results of experiments

- It doesn't make sense to run experiments on QPU
- SPS (with qbsolv run on CPU) gives the best results among "quantum" algorithms
- We compared SPS with some classical metaheuristics for CVRP well-known in the scientific literature (e.g., simulated annealing (SA), bee algorithm (BEE), evolutionary annealing (EA), DBSCAN with simulated annealing (DBSA))

Test name	SPS	SA	BEE	EA	DBSA
CMT11	25.54	23.62	36.18	16.52	19.94
CMT12	26.84	53.06	20.24	20.68	21.37
CMT13	25.97	86.72	34.66	35.05	19.44
CMT14	26.83	52.52	20.23	20.23	22.8
CMT3	25.13	48.3	28.38	28.82	-
CMT6	17.58	48.3	15.42	28.82	15.82
CMT7	29.42	41.4	27.89	31.68	23.18
CMT8	26.5	51.16	26.67	28.09	19.4
CMT9	34.14	76.34	44.25	42.81	-

Table 6. Comparison of results achieved by Solution Partitioning Solver (SPS) and classical algorithms (SA - simulate annealing, BEE- Bee algorithm, EA - evolutionary annealing, DBSA - DBSCAN with simulate annealing) on a benchmark dataset Christofides79.

Results of experiments

	type	deliveries	SPS	Simul. Ann.	Bee	Evolution
clustered1-1	average	57	69850	66379	60876	48923
	best	57	69080	52119	56358	48152
clustered1-2	average	55	77173	74341	81438	54719
	best	55	75530	59947	68772	53490
group1-1	average	42	158919	156217	153495	137989
	best	42	155388	146526	142774	135593
group1-2	average	54	171732	145380	145325	137626
	best	54	165043	141065	140947	136307
range-6-1	average	47	71670	68003	67234	59937
	best	47	68459	62312	64404	59827
range-6-2	average	50	80490	84380	83915	73651
	best	50	79640	79574	85917	73051
range-8-12-1	average	50	142008	146553	142835	129069
	best	50	140170	136369	127372	126555
range-8-12-2	average	50	146798	137628	145332	129048
	best	50	143598	135493	136776	128803
range-8-12-3	average	46	105544	105051	98366	92792
	best	46	101577	99004	94423	91921
range-8-12-4	average	51	147993	143309	148900	128316
	best	51	145559	140088	128575	124405
range-8-12-5	average	50	146719	143516	145685	134162
	best	50	143993	139784	139796	133245
range-8-12-6	average	50	146984	148194	150121	136326
	best	50	141467	138781	139400	134692
range-5-1	average	50	81728	68900	69052	67896
	best	50	72527	67984	68022	67691
range-5-2	average	50	81759	69342	68564	67981
	best	50	76868	67958	67780	67716

Acknowledgement

The presented research was carried out within the frame of the project “Green LAst-mile Delivery” (GLAD) realized at the University of Warsaw with the project partners: Colruyt Group, University of Cambridge and Technion. The project is supported by EIT Food, which is a Knowledge and Innovation Community (KIC) established by the European Institute for Innovation & Technology (EIT), an independent EU body set up in 2008 to drive innovation and entrepreneurship across Europe.

EIT Food is supported by the EIT
a body of the European Union

Acknowledgement

Michał Borowski

Katarzyna Karnas

Mateusz Błajda

Krystian Król

Artur Matyjasek

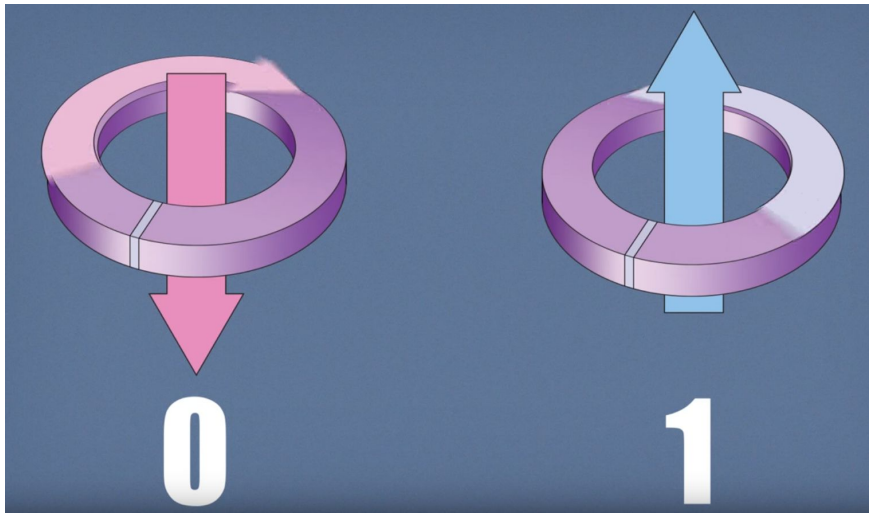
Damian Burczyk

Miron Szewczyk

Michał Kutwin

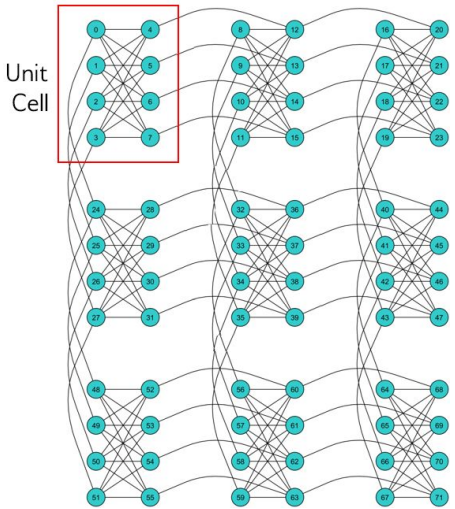
How Quantum Annealing Works in D-Wave Systems

The quantum bits—also known as *qubits*—are the lowest energy states of the superconducting loops that make up the D-Wave QPU. These states have a circulating current and a corresponding magnetic field. As with classical bits, a qubit can be in state of 0 or 1. But because the qubit is a quantum object, it can also be in a superposition of the 0 state and the 1 state at the same time. At the end of the quantum annealing process, each qubit collapses from a superposition state into either 0 or 1 (a classical state).



How Quantum Annealing Works in D-Wave Systems

The D-Wave QPU is a lattice of interconnected qubits. While some qubits connect to others via couplers, the D-Wave QPU is not fully connected. Instead, the qubits interconnect in an architecture known as *Chimera*. The Chimera architecture comprises sets of connected *unit cells*, each with four horizontal qubits connected to four vertical qubits via couplers. Unit cells are tiled vertically and horizontally with adjacent qubits connected, creating a lattice of sparsely connected qubits.



Source: https://docs.dwavesys.com/docs/latest/c_gs_4.html

D-Wave's new architecture: Pegasus

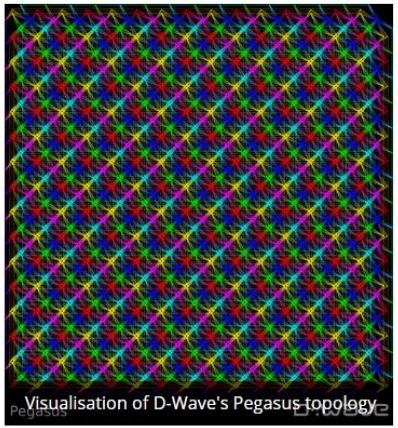
D-Wave announces next generation platform with 5000 qubits, due mid-2020

By Paul Hill · Feb 27, 2019 12:04 EST

3

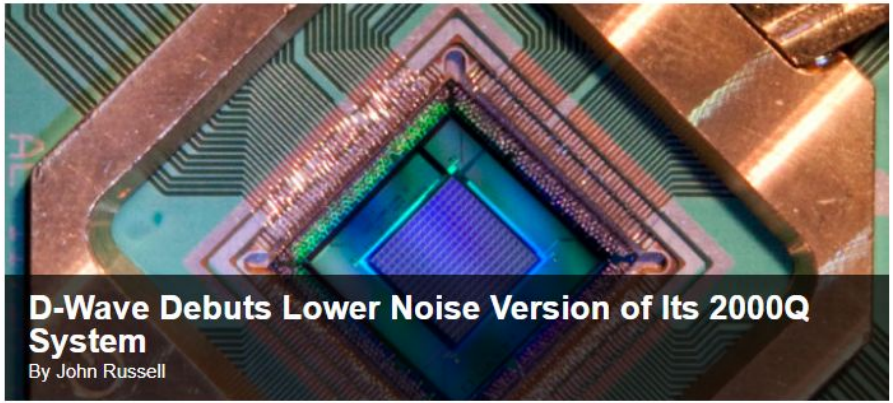
The firm, D-Wave Systems Inc., has announced a preview of its next-gen quantum computing platform that includes a new processor with 5000 qubits (up from 2000), improved qubit coherence, and hybrid software and tools that "further commercial quantum application development."

The company explained that customers will be able to run and build applications on the next-gen platform by purchasing hours of use through the Leap cloud service. Additionally, D-Wave is also selling installations at customer sites for entities that want more permanent access to the hardware. While the complete system will be ready by mid-2020, the firm will introduce components of the platform even earlier via QPU and software updates through the cloud.



Visualisation of D-Wave's Pegasus topology

Source: https://www.neowin.net/news/d-wave-announces-next-generation-platform-with-5000-qubits-due-mid-2020



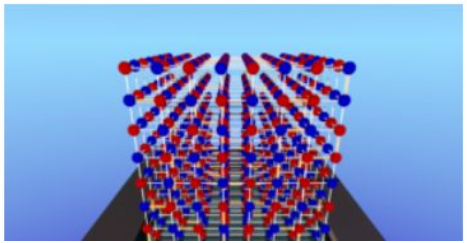
D-Wave Debuts Lower Noise Version of Its 2000Q System

By John Russell

May 15, 2019

Quantum computing pioneer D-Wave Systems today announced access to a lower noise version of its 2000Q system as part of its Leap quantum computing cloud service. The advance is part of an 18-month technology roadmap detailed in February during which the company plans to introduce new underlying fab technology, reduced noise, increased connectivity, 5000-qubit processors, and an expanded toolset for creation of hybrid quantum-classical applications.

D-Wave says the new noise reduction technology produces a 25x performance on one type of problem (spin glass application) and released a white paper – *Improved coherence leads to gains in quantum annealing*



Source: https://www.hpcwire.com/2019/05/15/d-wave-debuts-lower-noise-version-of-its-2000q-system

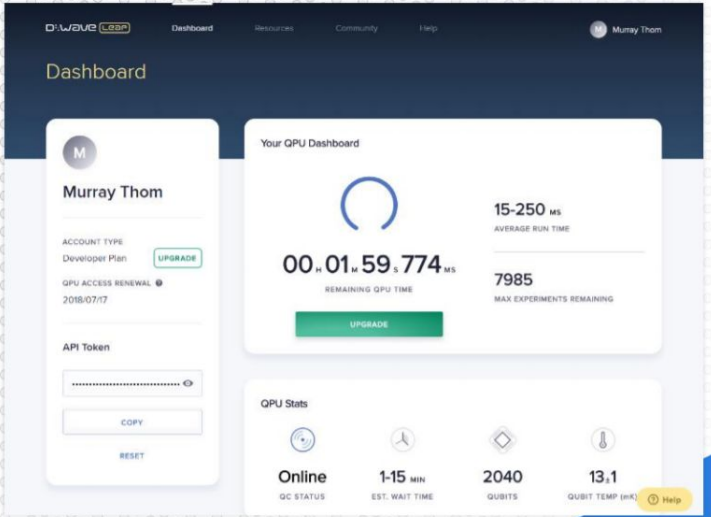
D-Wave's Leap

D-Wave Leap™

Cloud Service and Quantum Application Environment

Expanding the Developer Community

Real-Time Cloud Access
Integrated Open Source SDK
Demos and Reference Code
Community Support
Online Training



D-Wave

Controversy

“Many researchers remain sceptical about the long-term potential of such machines, whose approach differs from that of other nascent quantum computers.”
(https://www.scientificamerican.com/article/d-wave-scientists-line-up-for-world-rsquo-s-most-controversial-quantum-computer)

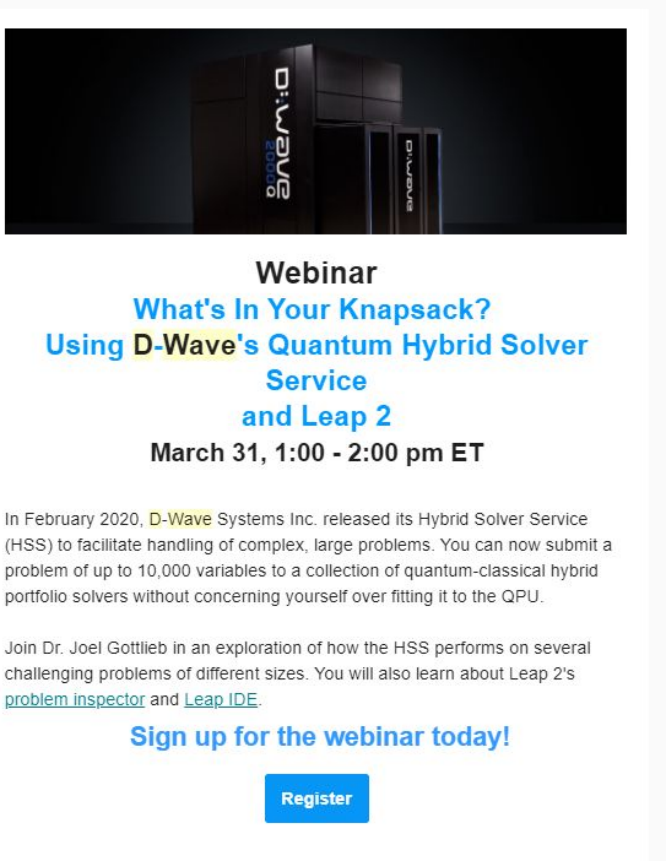
“The remaining contention lies in how useful of a quantum computer the D-Wave machine is, and some researchers still question whether D-Wave’s approach will yield a significant computation increase.”
(https://labs.mwrinfosecurity.com/blog/d-wave-why-all-the-controversy/)

The problem is that in case of D-Wave’s machine the quantum state doesn’t evolve slow enough (so it doesn’t find global optimum), but sometimes it can still find quite good solutions.

Where to learn more?

Where to learn more?

- ➔ D-Wave's website: https://www.dwavesys.com/home
- ➔ Leap: https://cloud.dwavesys.com/leap



Building quantum computing ecosystem

Building QC awareness / community

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  - Approx. 40-60 people per meeting, max. attendance: ~80 people (7.10.2019, Jacob Biamonte)
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- QWorld & QPoland

QWorld

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QWorld

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WELCOME TO QWORLD!

QWorld was established by five quantum cousins during QDrive project in July 2019. At the moment, QWorld has six channels for working on different target groups and people:

QCousins, QWomen, QJunior, QKitchen, QUniversity, and QMentor Training.

Our main aim is to have an open access and public global ecosystem for quantum technologies and quantum software by the year 2025 so that each interested hardworking individual, group, institute, or region can be easily part of the ecosystem.

We are looking for enthusiastic individuals, groups, institutions, organization, and companies to take part in QWorld or to work and operate together.

Join us/Invite us/Collaborate with us.

QCousins

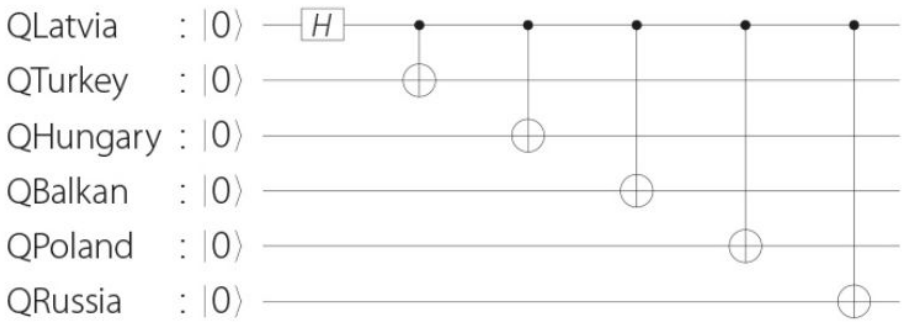
Q W O R L D

ENTANGLING QCOUSINS

We invite everyone
to be part of the second
quantum revolution!

With the success of the QDrive project (summer 2019), we are taking the next step.

We are now six QCousins (QLatvia, QTurkey, QHungary, QBalkan, QPoland, and QRussia) looking for entangling with new ones. Potential new QCousins should invite some of the present QCousins, and organize a public educational event together with them. We aim to expand our scope globally by having 50+ QCousins by the end of 2023.



QPoland

➔ Website: http://qworld.lu.lv/index.php/qpoland

QPoland is a QCousin organized by quantum computing researchers and educators from Poland. We organized the first workshops in May 2019 (in Kraków and Warsaw) in collaboration with QLatvia and officially entered the initialization phase on 11.11.2019 (the 101st anniversary of regaining independence by Poland). Among QPoland members are representatives of, i.a., Warsaw Quantum Computing Group, Institute of Theoretical and Applied Informatics of the Polish Academy of Sciences, Center for Theoretical Physics of the Polish Academy of Sciences, Faculty of Mathematics, Informatics and Mechanics of the University of Warsaw, Warsaw School of Economics.

Members:

- Paweł Gora *(Coordinator)*
- Adam Glos
- Jarosław Miszczak
- Adam Sawicki
- Oskar Słowik
- Jacek Karwowski
- Jakub Nowak
- Kamil Hendzel
- Dawid Kopczyk
- Sebastian Zając

QPoland

- Website: http://qworld.lu.lv/index.php/qpoland
- Contact: qpolandgroup@gmail.com
- Facebook group: https://www.facebook.com/groups/qpoland
- Facebook page: https://www.facebook.com/QPoland-110308580421373
- Twitter: QPolandCousin
- Internal mailing list
- Slack: https://qpoland.slack.com
- We had in plans 3 workshops (02.2020 in Wrocław, 03.2020 in Warsaw, 04.2020 in Poznań), but we have to wait due to COVID-19 outbreak

Business / Funds

We have recently established “Quantum AI Foundation”: http://www.qaif.org.pl

We are a charity organization aiming to **support development and collaboration in science and new technologies, especially Artificial Intelligence and Quantum Computing**, but also other fields on Mathematics and Computer Science. The Foundation achieves its goals by, e.g., organizing special meetings, lectures and workshops.

Board: Paweł Gora (Founder & Chairman), Dawid Kopczyk, Mateusz Macias, Michał Kutwin
Advisory Board: Lech Mankiewicz, Adam Sawicki, Michał Krasiński

If you would like to support us, feel free to contact us!

Thank you for your attention!

- Questions?
  - p.gora@mimuw.edu.pl
  - warsaw.quantum@gmail.com
- www: http://www.mimuw.edu.pl/~pawelg

"Logic can get you from A to B, imagination will take you everywhere"
A. Einstein

*"The sky is **NOT** the limit"*

Thank you for your attention!

Let’s stay in touch:

Paweł Gora: p.gora@mimuw.edu.pl
WQCG: warsaw.quantum@gmail.com

Mailing list: https://groups.google.com/forum/#!forum/warsaw-quantum-computing-group

Facebook Group: https://www.facebook.com/groups/285214992075232

Facebook fanpage: https://www.facebook.com/Warsaw-Quantum-Computing-Group-1936160966506139

YouTube channel: https://www.youtube.com/channel/UCoQAyPU5KQEpMOMDUN0j3IQ/videos