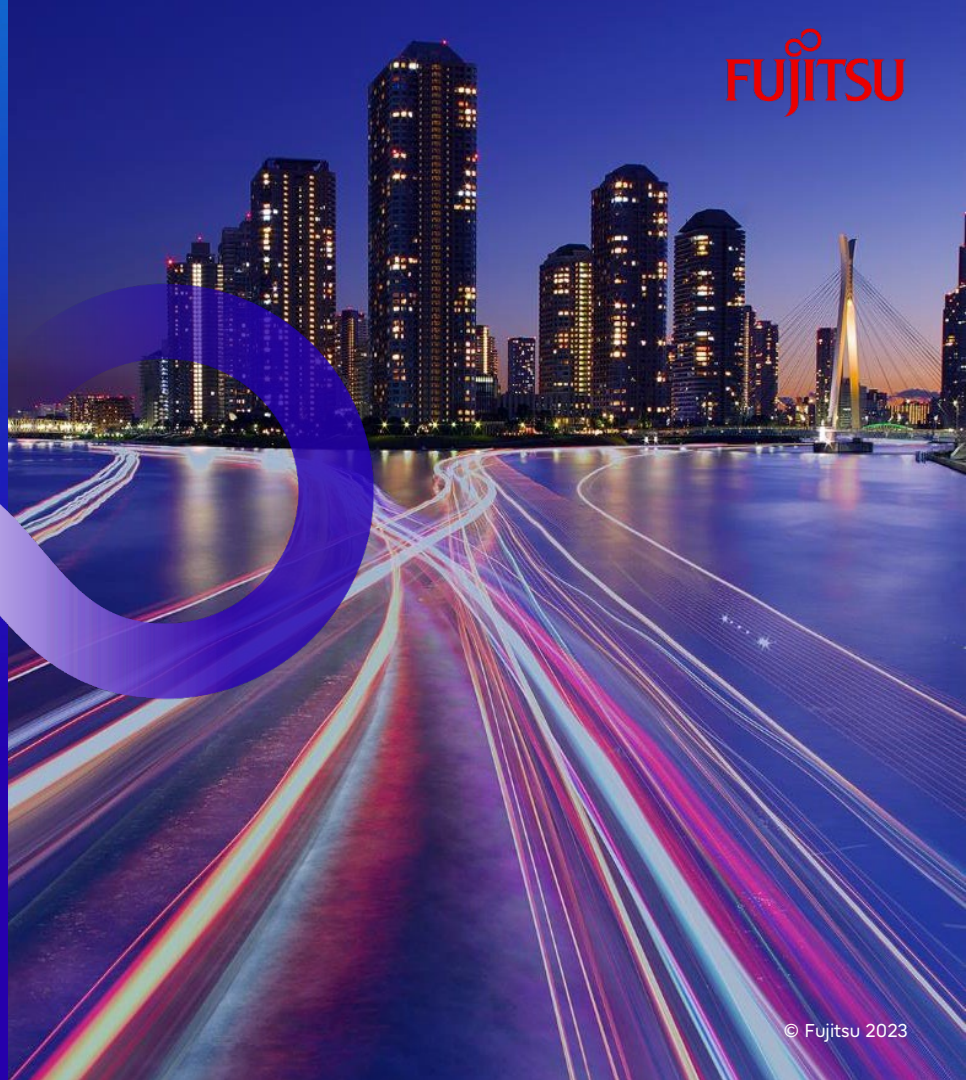
Quantum (Inspired) Computing

Unlocking value through solving complex problems



Name

Title

Fujitsu Company

Quantum (Inspired) Computing

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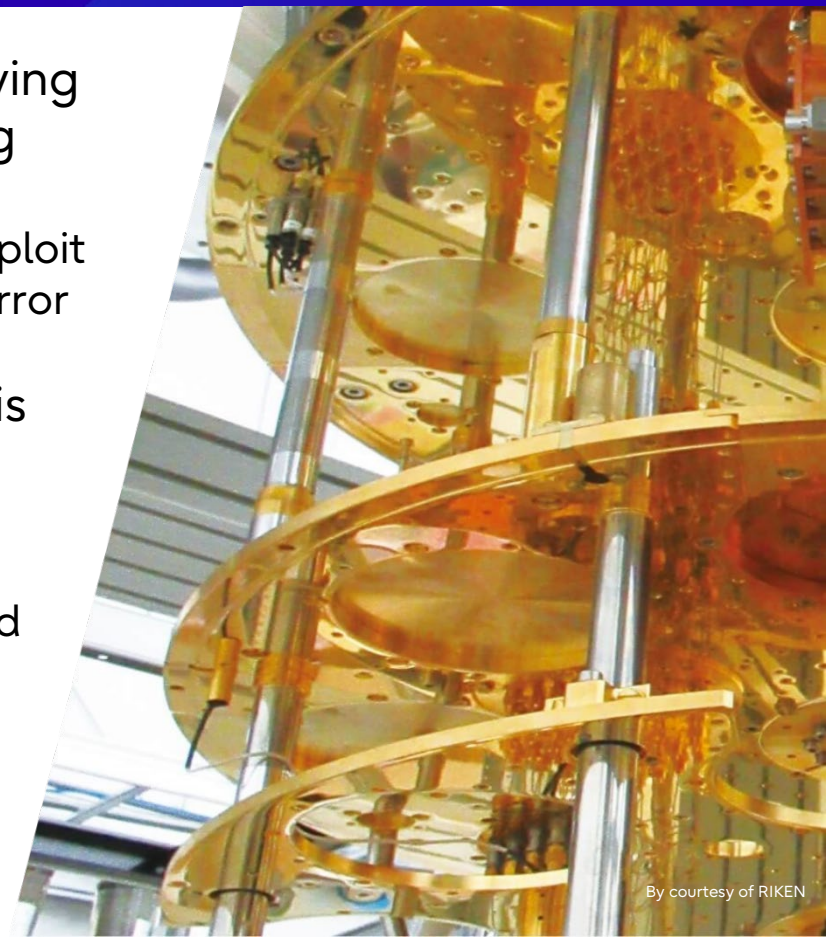
- Quantum Computing holds promise for solving the most complex challenges and unlocking new business advantage
  - **BUT** it will last years or decades until it will exploit its full potential (number of qubits required, error correction, …)
- Fujitsu's approach to Quantum Computing is three prong
  - Quantum-Inspired: **Solve** large, industry-relevant optimization challenges **today**
  - Quantum Computer Simulator: Search for and **start** development of quantum algorithms
  - Quantum Gate: **Develop** Superconducting Quantum Gate Computer for **hybrid** quantum computing



By courtesy of RIKEN

Unlocking Value from Quantum (Inspired) Computing

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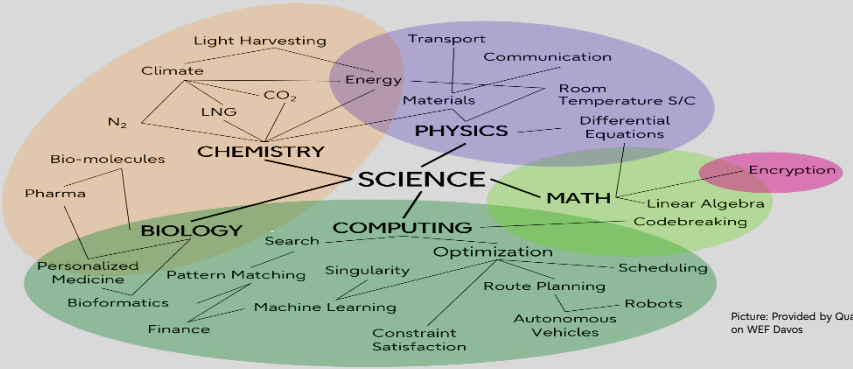
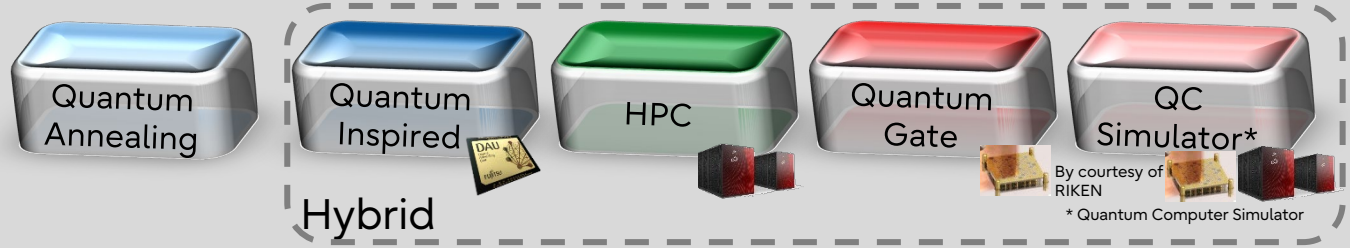
Value Assessment, integration into business processes, ...

Business Problem-led





Technology-led

Fidelity, error correction, number of qubits, ...

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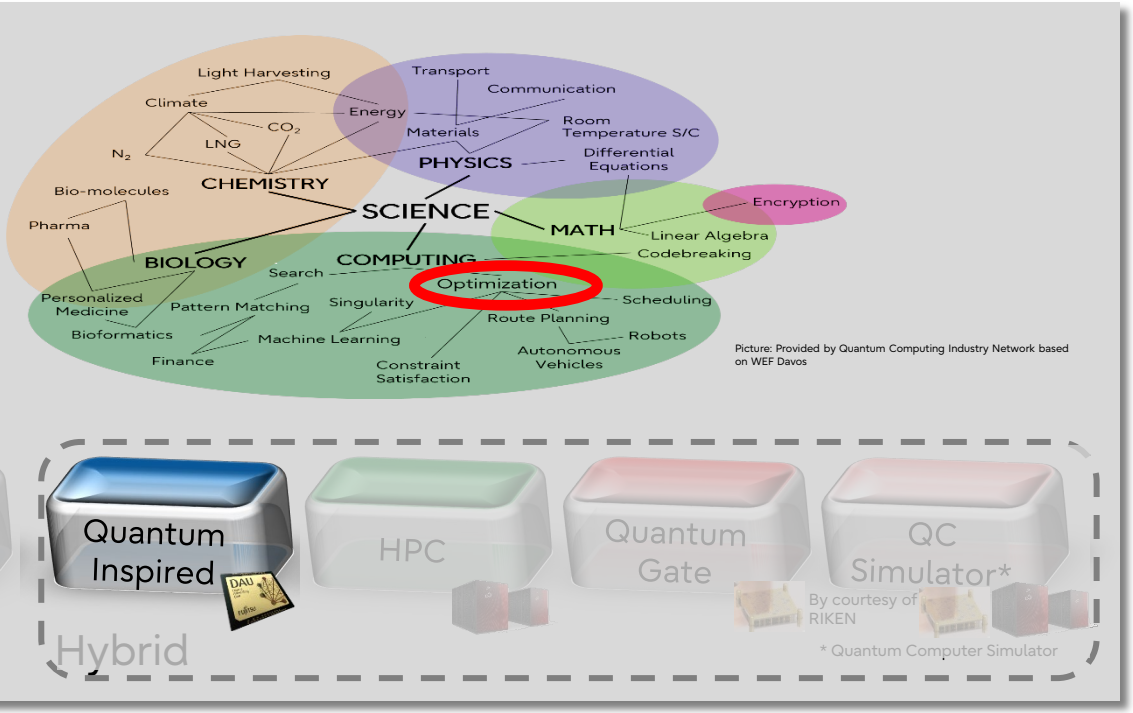
Business Problem-led



Quantum Inspired: The use of computational methods inspired by the principles of quantum mechanics

(source: encyclopedia.com)

FUJITSU Quantum-Inspired Computing

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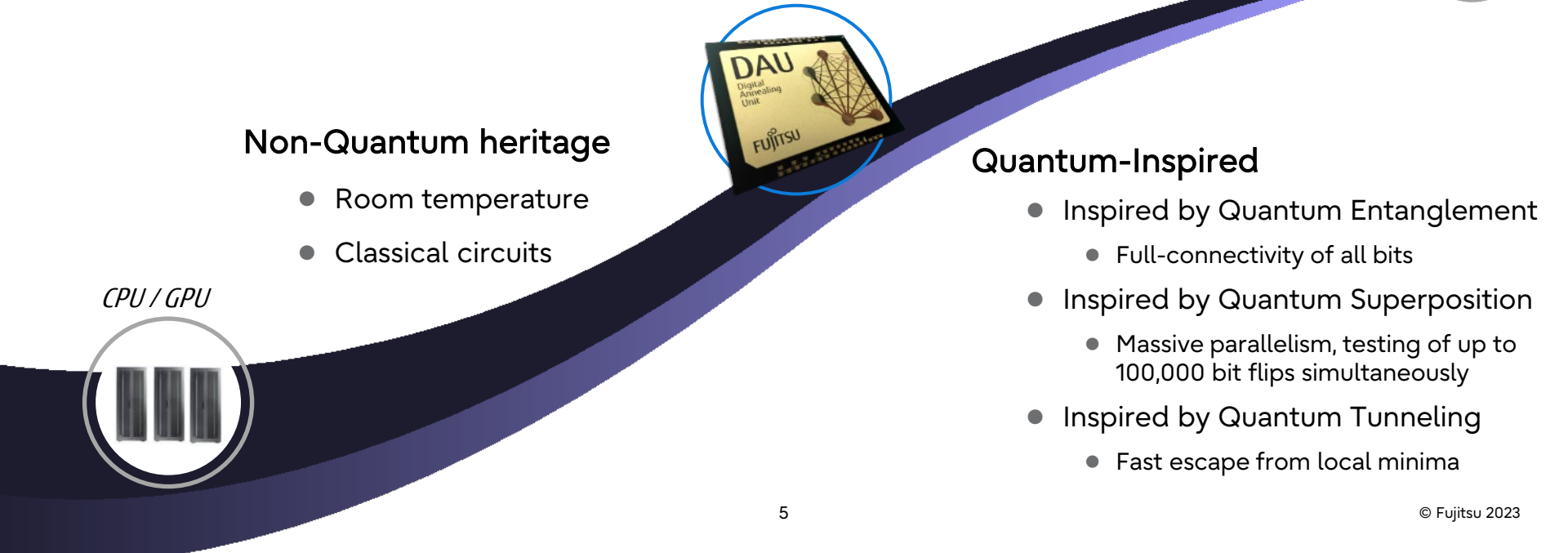
Digital Annealer - An available future-proof on-ramp to Quantum Computing for solving real-world combinatorial optimization problems today

Quantum Computer



CPU / GPU

Non-Quantum heritage

- Room temperature
- Classical circuits

Quantum-Inspired

- Inspired by Quantum Entanglement
  - Full-connectivity of all bits
- Inspired by Quantum Superposition
  - Massive parallelism, testing of up to 100,000 bit flips simultaneously
- Inspired by Quantum Tunneling
  - Fast escape from local minima

Combinatorial Optimization Problems

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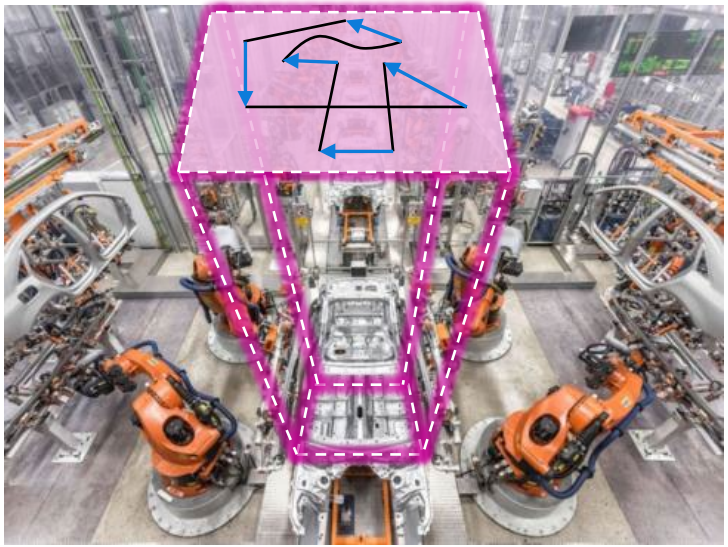
Example: Welding robots optimization



Find best welding directions and optimal roundtrip between endpoints

# seams	10	65
Possibilities	1.86×10^{8}	2.34×10^{108}

Typical problem characteristics

- Decisions being made are natively binary ("yes" or "no")
  - Does this robot perform this task at that time?
- The fitness of one decision depends on the state of other decisions
  - Is robot 1 in the working area of robot 2?
- The problem is difficult to solve
  - Huge number of possibilities / dependencies

Where Digital Annealer scores best

- Real time demands
- Solution quality demands
- Problems of higher order (quadratic)

Optimization problems are ubiquitous

- 2/3 of QUTAC use cases can be formulated as QUBO or QAOA

Quantum-Inspired Optimization Projects (Excerpt)

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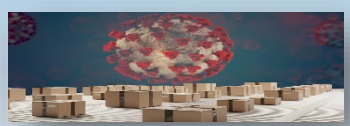
	Hamburg Port Authority	United States Army Analytics Group	Deutsche Bahn	Nippon Yusen Kabushiki Kaisha (NYK)
Use Case	Traffic Light Optimization	Logistics Optimization	Real-Time Schedule Optimization	Car Carrier Optimization
Situation	• 20,000 trucks/day • 35 intersections 	• 10 inventory centers • 15 staging centers • 500 Demand regions • 5 PPE Categories 	• 70,000 path candidates • $10^{20.357}$ possible schedules 	• 10^{2000} (un)loading patterns • 7000 cars, 12 decks • 60 car types, 10 ports 
Results	↓ 20% travel time ↓ 9% CO2	↑ 90% improvement	↓ 2h -> 4min compute time ↑ 10% more path request approvals	↓ 4,000h planning time

Quantum-Inspired Optimization Projects (Excerpt)

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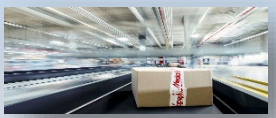
	MediaMarktSaturn Retail Group	Deutsche Telekom	Astroscale	Hospitals
Use Case	Supply Chain Optimization	Automatic Cell Planning	Disposal of Space Debris	Surgery Capacity Optimization
Situation	• 400 stores • 4 vehicle types • Time windows, vehicle capacity, daily travel time / vehicle 	• Site selection problem: An area requires additional sites to improve coverage and service quality 	• Optimize the flight path of spacecrafts for space debris disposal missions 	• Surgeries contribute about 60% of a hospital's total revenue • Hospital Operation Rooms represent major cost centers 
Results	↓ 4,7% delivery costs	↓ 37x compute time ↑ 40% quality	↓ Fuel usage ↑ Efficiency of debris collection.	↓ Calculations in seconds

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Digital Annealer / Quantum Inspired Computing

Technology

Combinatorial Optimization and Quantum

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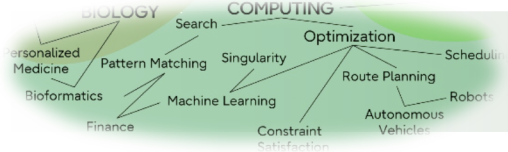
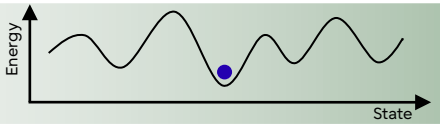




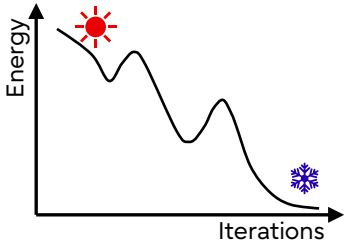
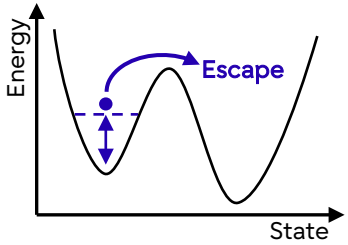
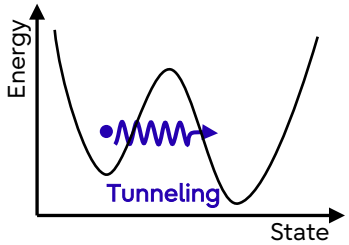
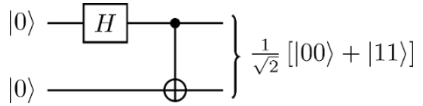
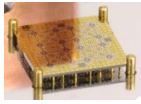
Optimization as search for energy minimum

Any real valued function $E(X)$

$$E(X) = \sum_{i=1}^{N} b_i x_i + \sum_{i=1}^{N} \sum_{j=1}^{i-1} w_{ij} x_i x_j$$

Binary Polynomial QUBO

Variational Quantum Algorithm (QAOA)

Simulated Annealing	Digital Annealing	Quantum Annealing	Quantum Gate Computing
			
 Classical Computer	 Digital Annealer	 Quantum Annealer	 Quantum Gate Computer By courtesy of RIKEN

Digital Annealer in a Nutshell

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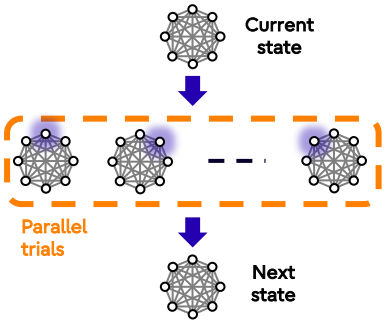
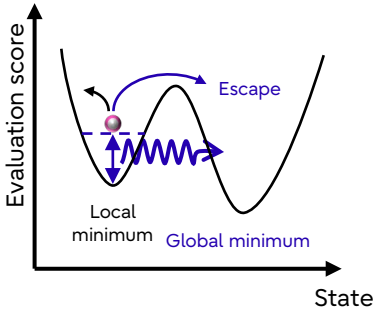
- Special purpose hardware architecture for solving combinatorial **optimization problems**.
- Problem formulation as **QUBO**.
- **Markov Chain Monte Carlo** (MCMC) algorithm as basis to search for minimum of energy function.
- **Speed-Up** due to **hardware** implementation of MCMC.
  - Parallel search
  - Dynamic offset energy
  - Parallel tempering

$$E(\boldsymbol{x}) = \sum_{i=1}^{N} b_i x_i + \sum_{i=1}^{N} \sum_{j=1}^{i-1} w_{ij} x_i x_j \qquad x_i \in \{0,1\}$$

$$p(\boldsymbol{x}, \boldsymbol{x}') = \begin{cases} 1 & E(\boldsymbol{x}') \leq E(\boldsymbol{x}) \\ \exp\left(\dfrac{-\left(E(\boldsymbol{x}') - E(\boldsymbol{x})\right)}{T}\right) & E(\boldsymbol{x}') > E(\boldsymbol{x}) \end{cases}$$





Workflow Digital Annealing

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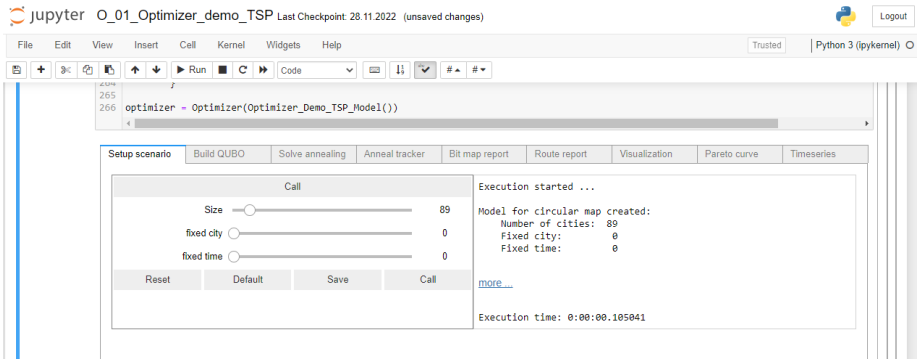
$$E(X) = \sum_{i=1}^{N} b_i x_i + \sum_{i=1}^{N} \sum_{j=1}^{i-1} w_{ij} x_i x_j$$

$$X = (x_1, x_2, \dots x_N) \in \{0,1\}^N$$
$$b_i \in \mathbb{R},\ w_{ij} \in \mathbb{R}\ (i, j = 1, \dots N)$$

DADK framework

- Create, manipulate, solve QUBOs using DA
- Rapid prototyping
- Load business data
- Visualize results



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