Reaching the Limit of Moore's Law

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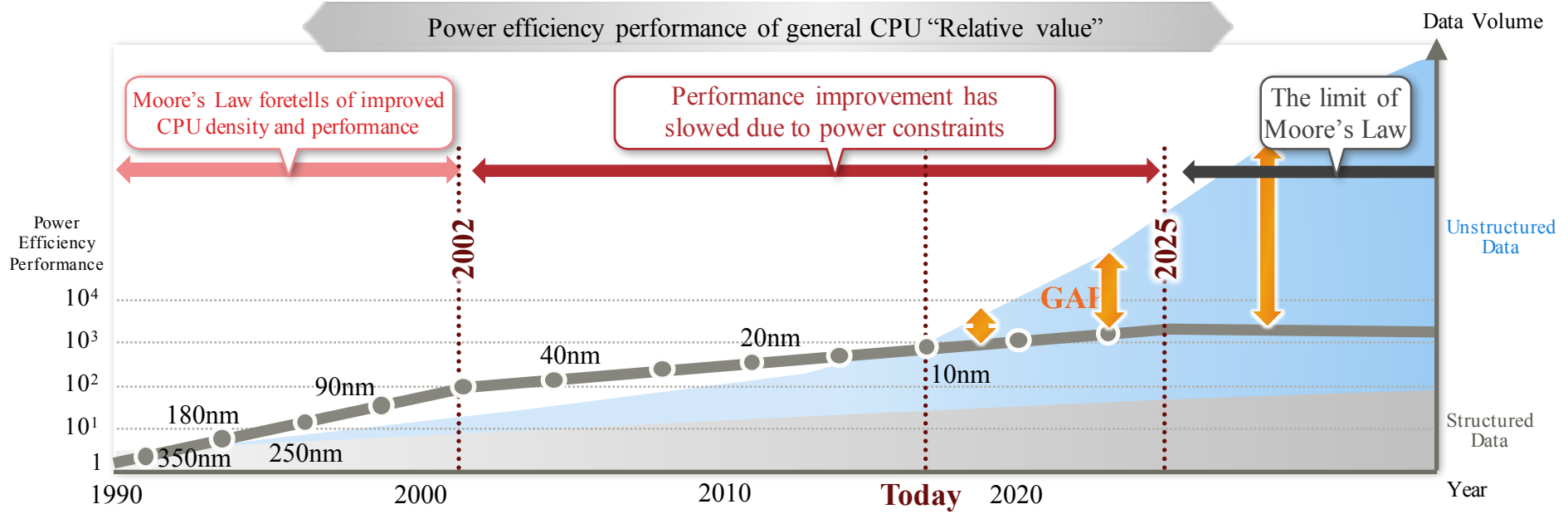
Computers must process increasingly massive and complex data at higher and higher speeds in order to support digital transformation in society and business. Moore's Law* is approaching its limit, threatening the drastic compute performance required in the coming future.



Quantum Computing is one promising prospect as a next generation computer

*Moore's Law: An empirical rule in the semiconductor industry stating that the number of transistors in a dense integrated circuit doubles every 18~24 months.

Digital Annealer

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A new architecture that solves "combinatorial optimization problems" at high speed with digital circuits inspired by quantum phenomena

Quantum Computers

Still in the research stage ...

- Difficult to maintain a quantum state
- Limits in connection and expansion

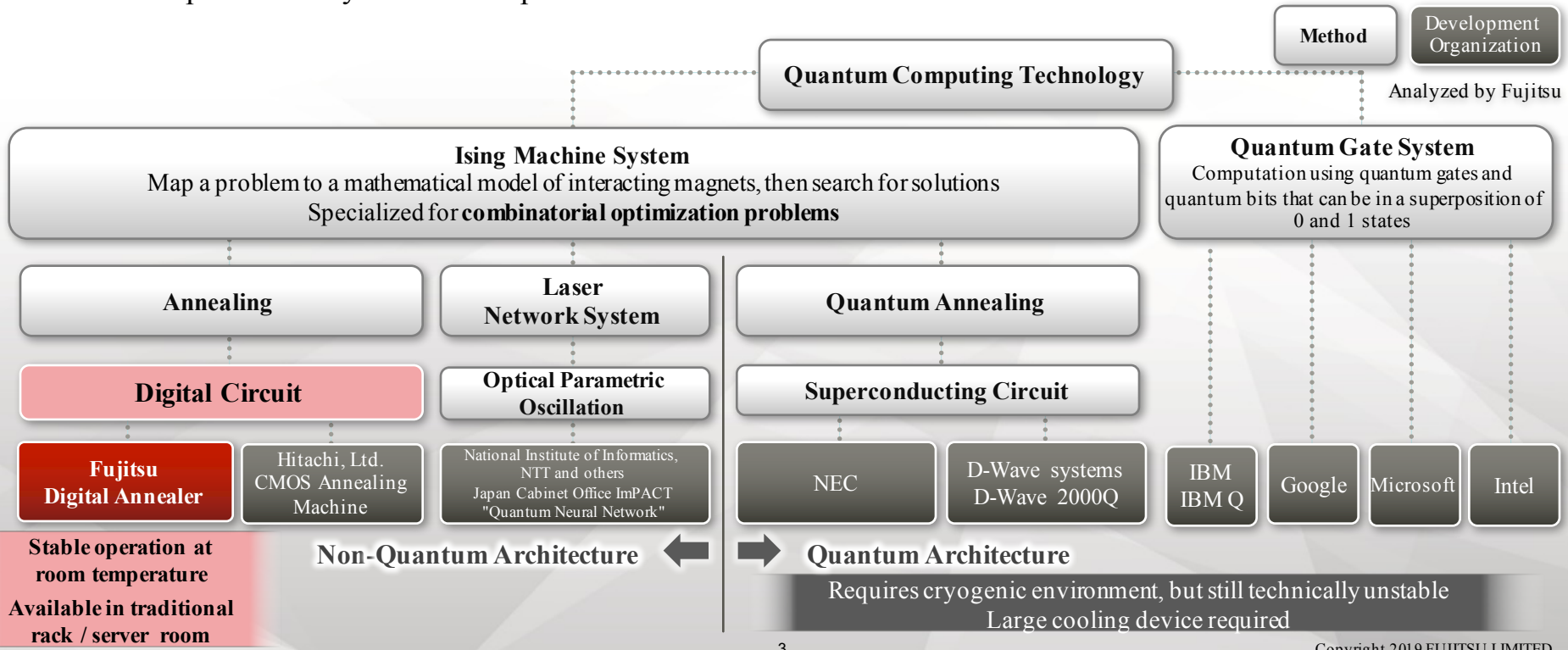
Digital Annealer

Easy to apply to actual problems

- Stable operation with digital circuit, and easy miniaturization
- Easy mapping of more complex problems with a fully-connected architecture

Digital Annealer Positioning

- Digital Annealer makes use of the annealing method, specialized for combinatorial optimization.
- Unlike quantum computers, Digital Annealer does not require an extremely low temperature environment. Digital Annealer operates stably at room temperature.



What is Quantum Annealing?

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The algorithm's name comes from the annealing process used in metallurgy

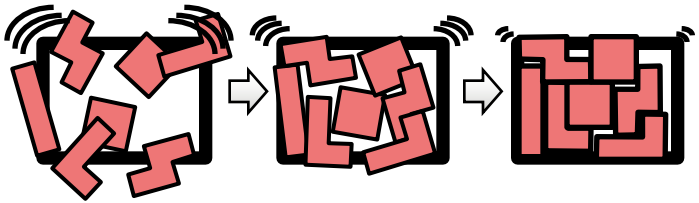
Annealing Process in Metallurgy

Metal is heated to a high temperature, and the structure stabilizes as it is slowly cooled(=low energy)

The most stable state has minimum energy ⇒ the minimum value

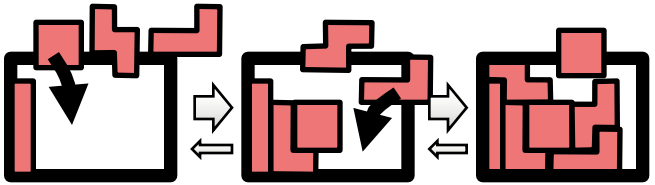
Annealing Method

Blocks are placed randomly, then the entire system is "shaken". The shaking is gradually reduced, and the shapes quickly fit together.



Classical Approach

Blocks are placed in sequence.
Process restarts if a solution is not found.
Repeated until a solution is found.



Combinatorial Optimization Problems

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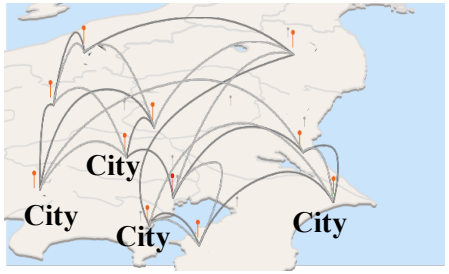
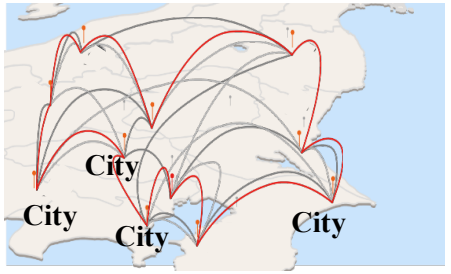
Seek *combinations* or *sequences* that satisfy given constraints, with the goal of finding the best out of all available combinations

Example:
The Traveling Salesman Problem

"Which is the shortest route that visits each city exactly once and returns to the origin city?"

Number of cities: N	Constraint	Optimal Solution
		
Choose the number of cities	Visit each city only once Evaluate based on travelling distance	Shortest route

With 5 cities ➔ 120 possible routes. With 32 cities ➔ 2.63×10^{35} possible routes

The number of combinations increases exponentially!

Use Digital Annealer to Solve Combinatorial Optimization Problems

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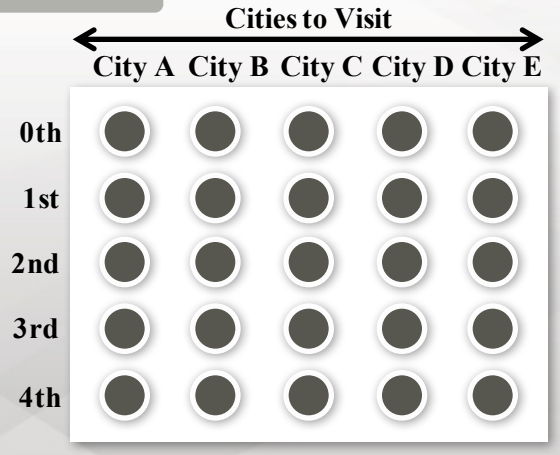
The Traveling Salesman Problem

"Which is the shortest route that visits each city exactly once and returns to the origin city?"

Formulation

1. Capture Problem in Ising Model

INPUT



Each ● represents one bit

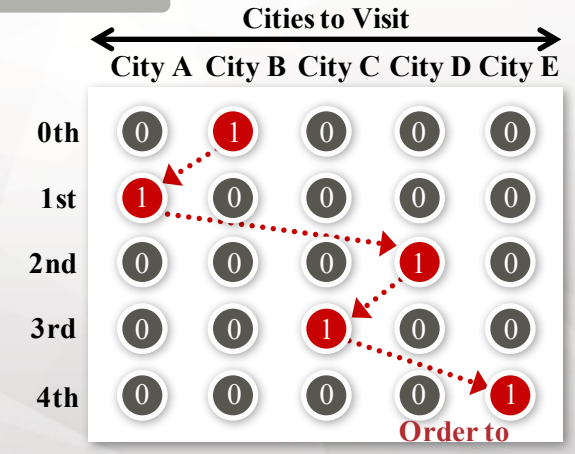
2. Build Formula

$$E = \sum_{t,i,j} d_{ij} x_{ti} x_{(t+1)j} + \alpha \sum_{t} \left(\sum_{i} x_{ti} - 1 \right)^2 + \beta \sum_{i} \left(\sum_{t} x_{ti} - 1 \right)^2$$

Create an expression to define the interaction between bits (distance between cities)

3. Execute on Digital Annealer

OUTPUT



The resulting bits show the shortest path solution

City B ⇒ City A ⇒ City D ⇒ City C ⇒ City E

Combinatorial Optimization Problems Across All Industries & Business

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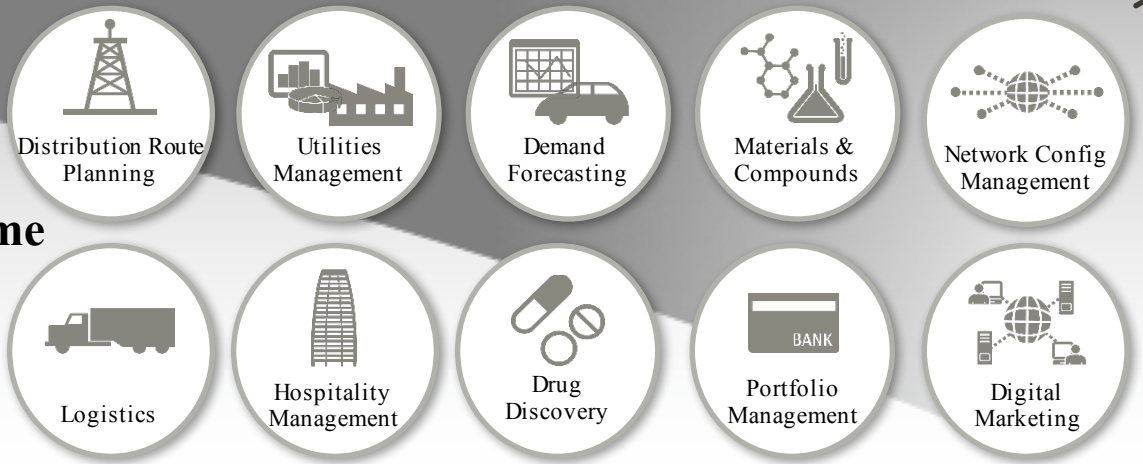
Applicable to New Areas

Advanced Healthcare

Autonomous Vehicles

New Material Development

Improve Precision and Reduce Time
to solve existing combinatorial optimization problems



Applicable Area Examples

Problem and Application Examples Well-Suited for Digital Annealer

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		Optimization Problems
1. **Molecular Similarity Search**	Selection of the similarity of all the compound	Maximum Independent Set Problem
2. **Big Data Visualization Toolkit**	Visualizing and clustering big data	Minimum Set Cover Problem
3. **Traffic Route Optimization**	Optimize route selection while minimizing route overlap to ease congestion	Candidate Overlay Problem
4. **Financial Portfolio Optimization** (QHRP Method*1)	Select investment portfolio assets based on low correlativity	Max Cut Problem
5. **Shelf Location Optimization**	Optimize shelf placement to improve factory parts pickup	

*1 QHRP: Quantum-inspired Hierarchical Risk Parity

Chemical & Pharmaceutical

1. High Precision Molecular Similarity Search for Drug Discovery

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Contributing to the development of highly effective medicines

Issues

The conventional Finger Print method determines the presence or absence of an atomic group, but does not consider the molecular shape. Thus, a precise search cannot be performed.

Finger Print: A method of representing the presence or absence of an atomic group as 0 or 1 and expressing the molecule as a Boolean vector

Technique

By converting the molecular structure to a graph and handling atomic groups as nodes and bonds as edges:

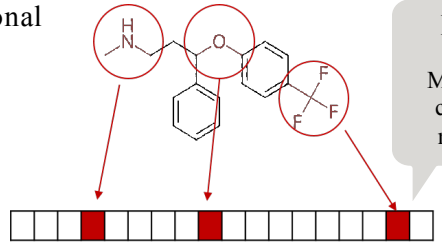
- Precision is improving by considering molecular shape
- Calculations are performed at high speed by Digital Annealer

Results

- Highly precision molecular similarity search becomes possible
- Expected to improve the efficiency of drug development leading to new highly effective medicines

Use Case

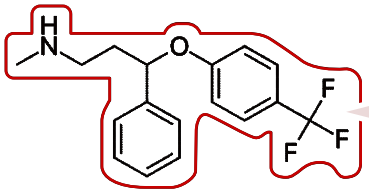
Conventional Method



Finger Print

Matching without consideration of molecular shape

Digital Annealer Benefit



Graph Theory

Highly accurate by matching molecular shapes

Combinations of atomic groups results in a huge volume of calculations → Improve efficiency with Digital Annealer

Marketing

2. High-Speed Clustering for Big Data Utilization

FUJITSU

Visualizing large-scale datasets for more accurate analysis

Issues

As the importance and prevalence of big data increases, high-speed data processing is necessary to effectively derive business insights

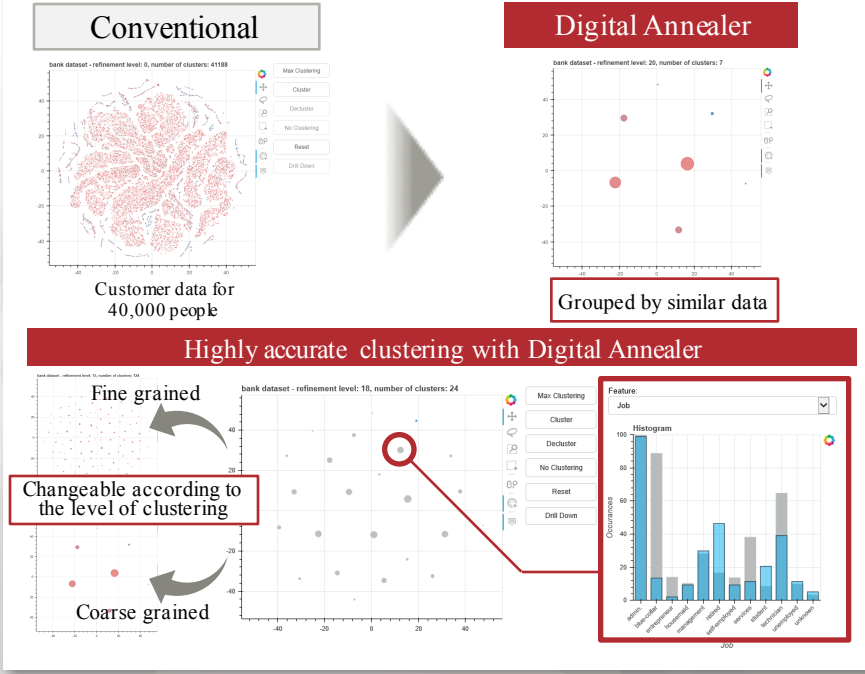
Technique

High precision clustering with hierarchical structures is implemented by compressing high dimensional data and segmenting it into portions that can be clustered

Results

- Clustering is accelerated from several hours with conventional methods to just a few minutes with Digital Annealer
- Large scale data sets can be visualized and analyzed
- The level of clustering can be changed to enhance analysis

Use Case



Logistics

3. Route Optimization to Reduce Traffic Congestion

FUJITSU

Reduce overall travel time by distributing routes throughout a city or factory to avoid congestion

Issues

With conventional routing systems, there is a tendency to assign the shortest distance route, leading to traffic congestion in the city center

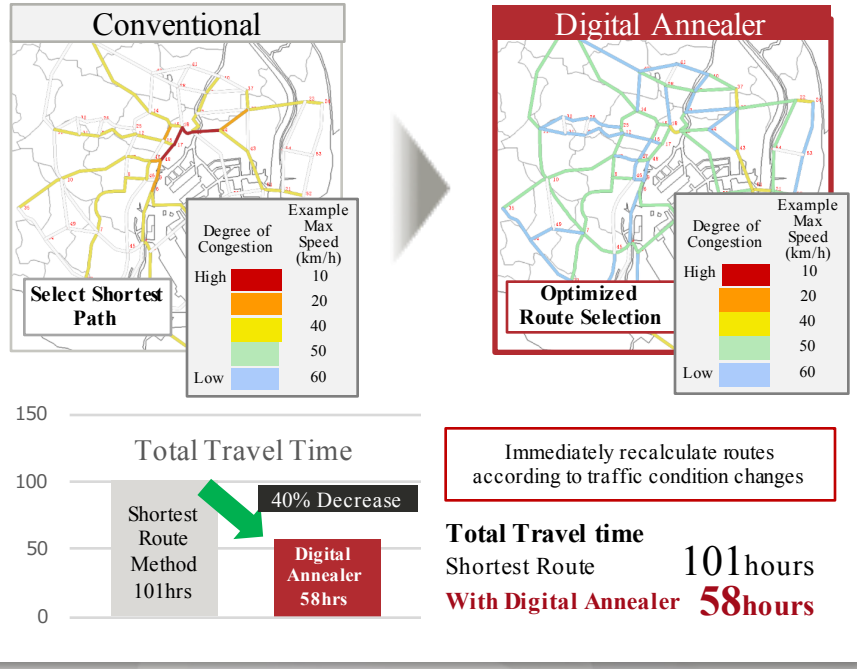
Technique

- Optimize route selection to avoid overlap
- Prioritize route option by adding conditions, such as: speed limits, number of lanes, etc.

Results

- Reduce traffic congestion by up to 40% by dispersing traffic
- Apply to cases of iterative simulation used for road development planning
- Applicable to other routing problems, such as warehouse collection and distribution, AGV (Automated Guided Vehicles), and network traffic

Use Case



Finance

4. Investment Portfolio Optimization Through Risk Diversification

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Instant clustering for the correlation of 500 stocks to compose a risk-resistant portfolio

Issues

The commonly used Minimum Variance (MV) method for portfolio optimization is susceptible to the influence of market fluctuation

Technique

Quantum-inspired Hierarchical Risk Parity (QHRP) portfolio optimization method provides for:

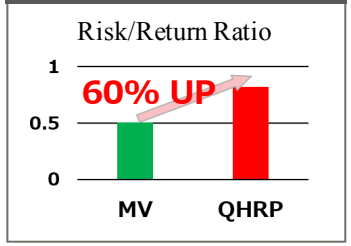
- The clustering of assets into a tree diagram based on risk correlations
- Composition of risk-diversified portfolios with low correlativity

Results

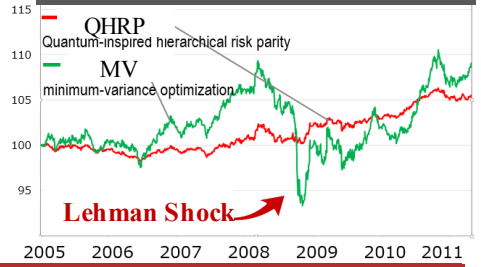
- Create portfolios with resistance to market fluctuations that continue to provide stable returns
- 60% higher Sharpe Ratio compared to MV method

Use Case

Results (Sharpe ratio comparison)



S&P500 Investment Results (2005 – 2011)



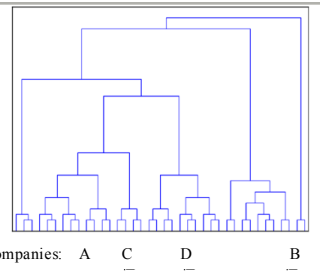
Digital Annealer Technique

Asset Price Change Variance Matrix

	Company A	Company B	Company C	…
Company A	1	0.23	0.85	
Company B	0.23	1	0.64	
Company C	0.85	0.64	1	
⋮				…

Express all correlations among assets (price changes between two assets) using variance-covariance matrices

Clustering Assets from Correlations



Manufacturing

5. Factory Parts Pick Up Optimization

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Reduce travel distance for warehouse parts pick up by up to 45%

Now in use at Fujitsu IT Products

Issues

- High-mix, low-volume factory production requires a large variety of parts for each product. Time and labor required dependent on the experience level of each worker
- Inconsistent and inefficient parts pick up process

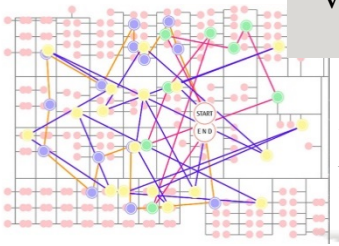
Technique

- Routes and shelf population are minimized as combinatorial optimization problems
- Correlation of frequently used shelves identified

Results

- Even inexperienced workers can realize efficient parts picking
- Travel distances reduced by up to 45% per month through route and shelf location optimization
- Optimization methods to be deployed to other factories, as well as other processes such as warehouse management

Use Case



Very complicated parts picking routes required experienced workers

Warehouse area: 1000m²
Number of parts: 3000

Digital Annealer provides optimum picking routes displayed on a tablet

Manufacturing

5. Case Study:

Factory Parts Pick Up Optimization - At Fujitsu IT Products

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Company Profile

Company Name	Fujitsu IT Products Limited
Location	1-1, Kasajima-to, Kahoku-shi, Ishikawa, 929-1196, Japan
Capital	100 million yen (wholly owned subsidiary of Fujitsu Limited)
Establishment	April 1, 2002
Employees	455 people
Industry	Manufacture of servers, supercomputers, storage systems , software, etc.

Source: http://www.fujitsu.com/jp/group/fjit/ (Japanese)

Digital Annealer Project Schedule

Discussion from September 2017 → PoC from October 2017 → Service in February 2018

Case Study: http://www.fujitsu.com/global/digitalannealer/case-studies/201804-fjit/

5. Case Study:
Factory Parts Pick Up Optimization - Configuration

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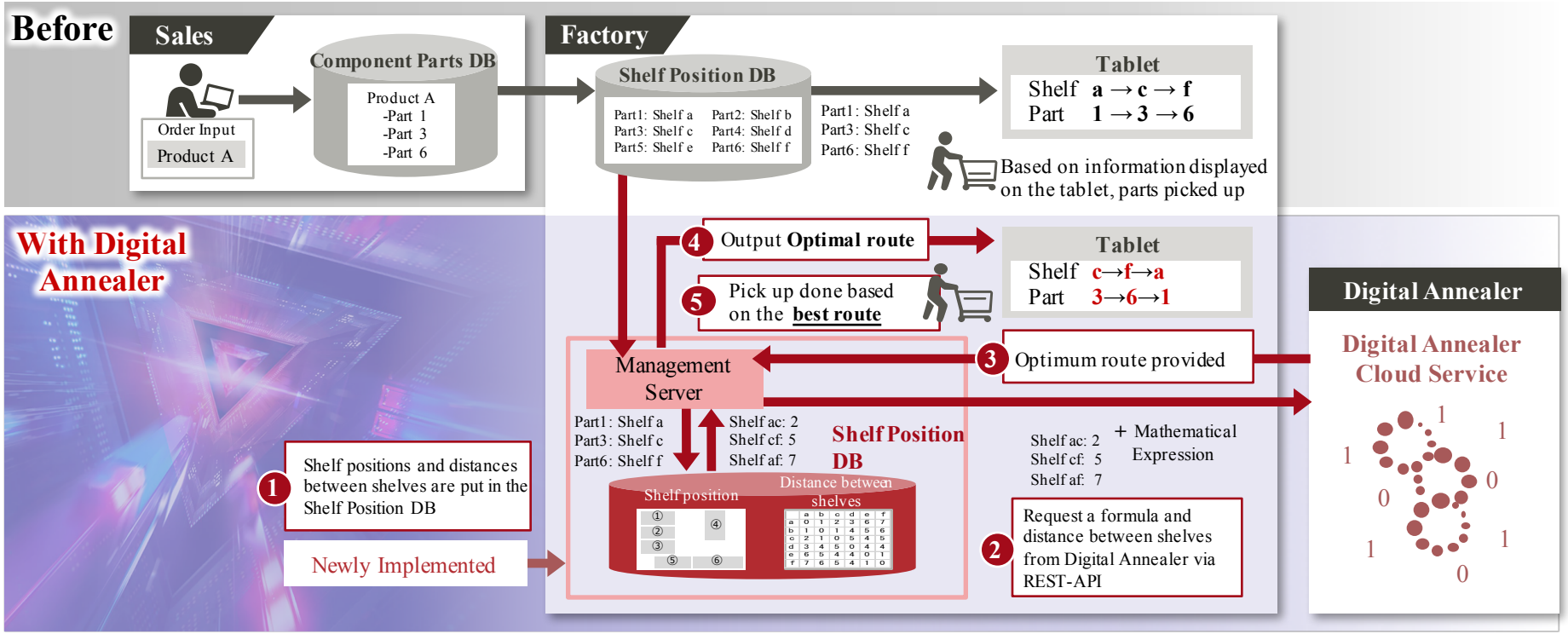
Goal: Leverage existing operation, and create a new shelf position database to use Digital Annealer to calculate optimal pick up routes



Digital Annealer Advantages

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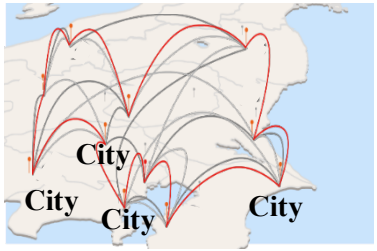
Applicable to real world problems with the stability and balance of scale, connectivity, and precision

Scale	Ready to scale up of 8,192bit problems
Connectivity	Easy to use with total bit coupling
Precision	High precision with 64bit graduations
Stability	Stable operation at room temperature with digital circuits

What Are Scale, Connectivity and Precision?



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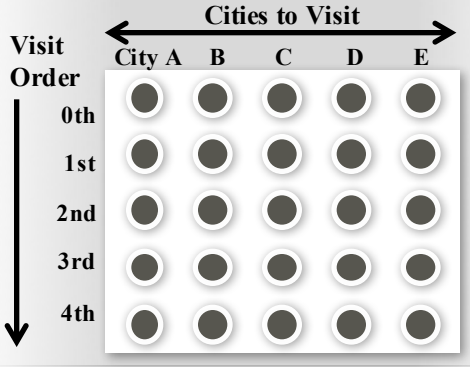
The Traveling Salesman Problem

Under the constraint that each city **must be visited only once**, find the **shortest route (minimum distance)**

Scale

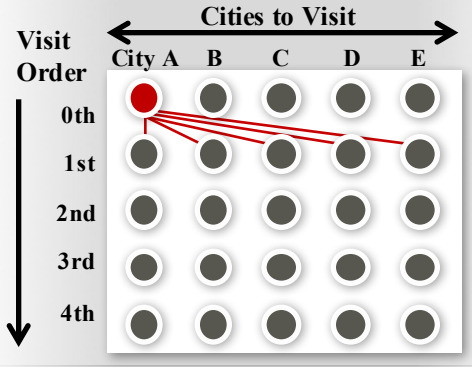
8192 bits



Scale:
Number of cities to visit that can be handled

Connectivity

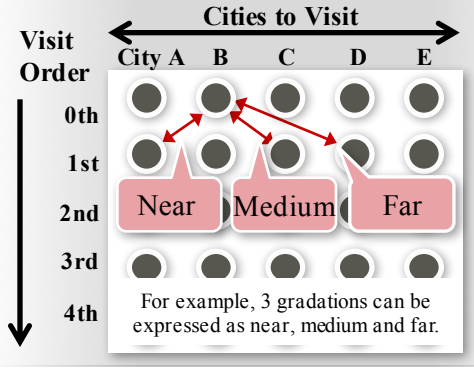
Total Coupling



Connectivity:
All distances between cities can be defined

Precision

64bit Gradations



Gradations:
Accuracy of distance between cities

Digital Annealer Features

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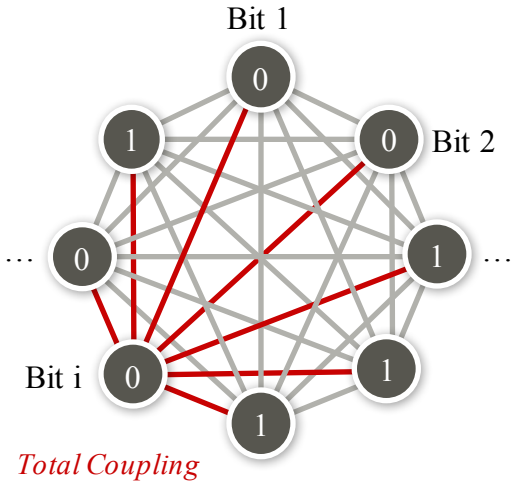
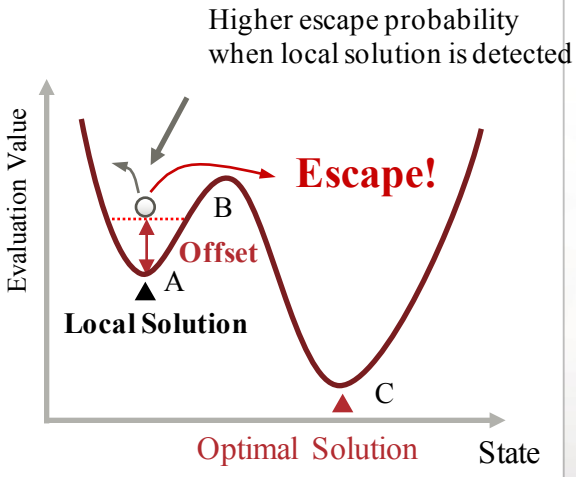
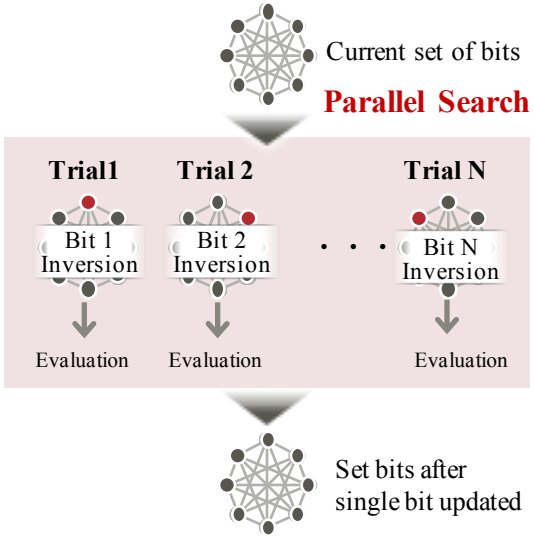
Ready for Many Business Tasks



High Speed Processing with Local Solution Escape and Parallel Search





Differentiators

- Represent large-scale problems of up to **8192 bits**
- High precision with full coupling and **2^{64} bit gradations**
- Easy to use with **fully connected** bits

- Increased escape probability from local minimum energy states using **hardware offsetting**

- Next bit inversion found using **parallel search** to increase processing speed
- Stochastic parallelism provides significant **acceleration**

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Digital Annealer

Roadmap

Digital Annealer Roadmap

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2018 — 2019

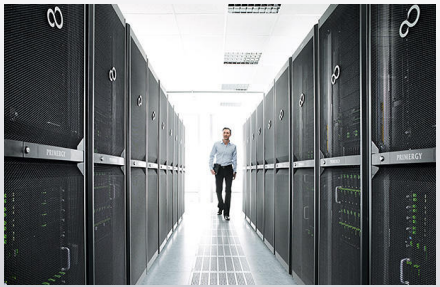
Technical Service

1st Gen Cloud **May** » 2nd Gen Cloud **Dec** On-Premises Service **4Q** **Next Generation**

Scale: **1024** bit

Precision: **16** bit

65536 Gradations



Max Scale: **8192** bit

Max Precision: **64** bit

1.845×10^{19} Gradations

Digital Annealing Unit

Large-Scale Parallel Processing

Expand applications from technical verification to real-world business value

Application Areas Surpassing the Competition - 2nd Generation

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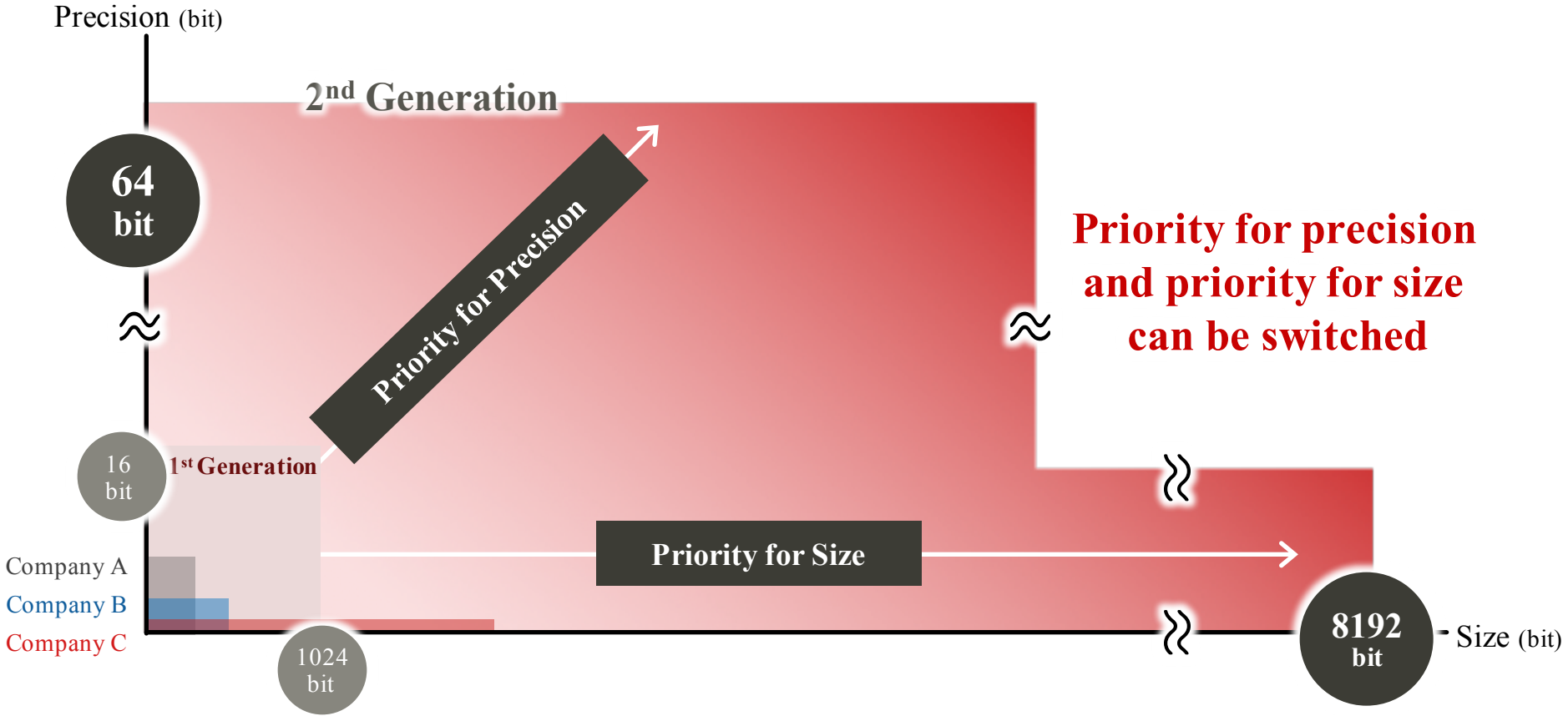

Digital Annealer Global Rollout

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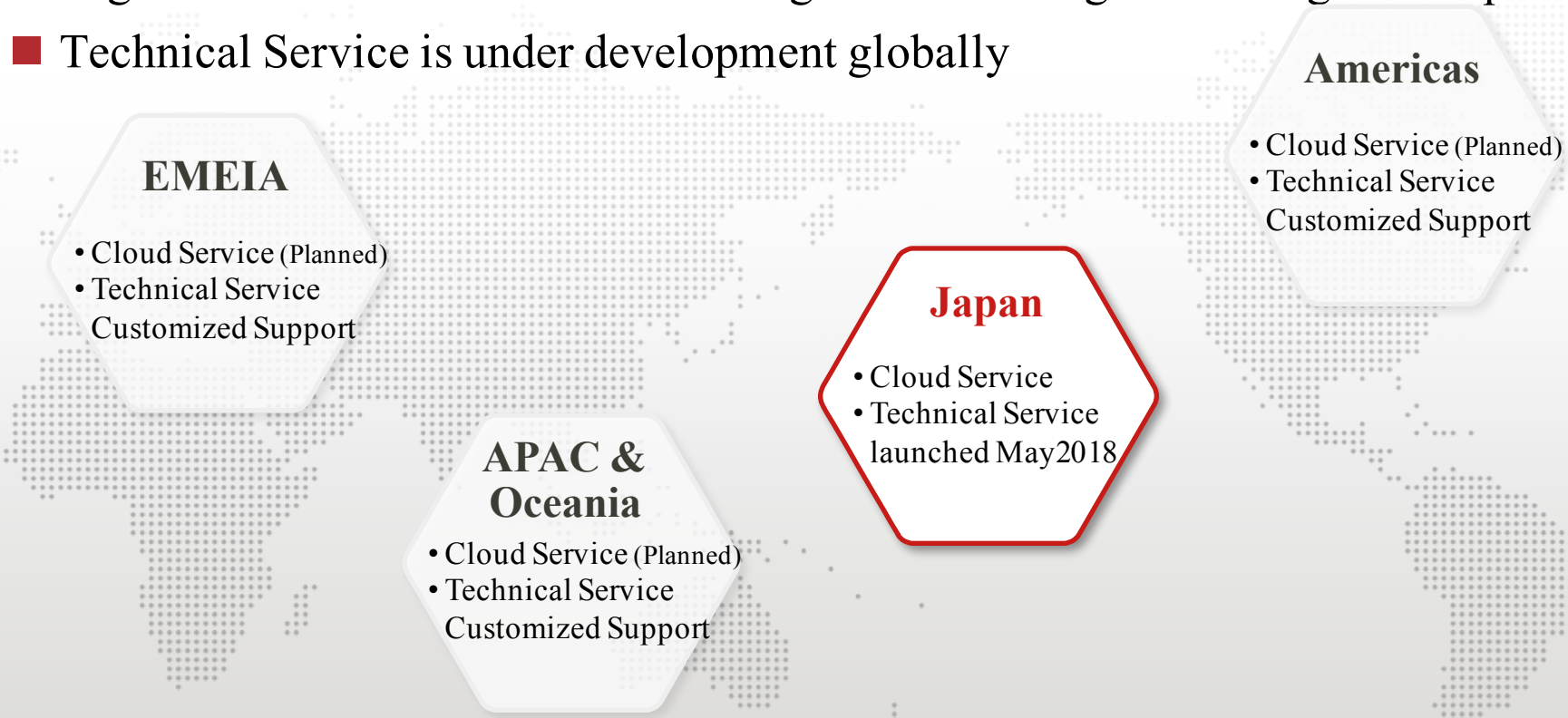
- Digital Annealer Cloud Service rolling out in each region starting from Japan
- Technical Service is under development globally



New AI Headquarters (AI HQ) - Established October 2018

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Creating a core base in Vancouver to roll out Fujitsu's AI business and accelerate the application of AI to customers worldwide using Digital Annealer as a key technology

Deployment of advanced global use cases

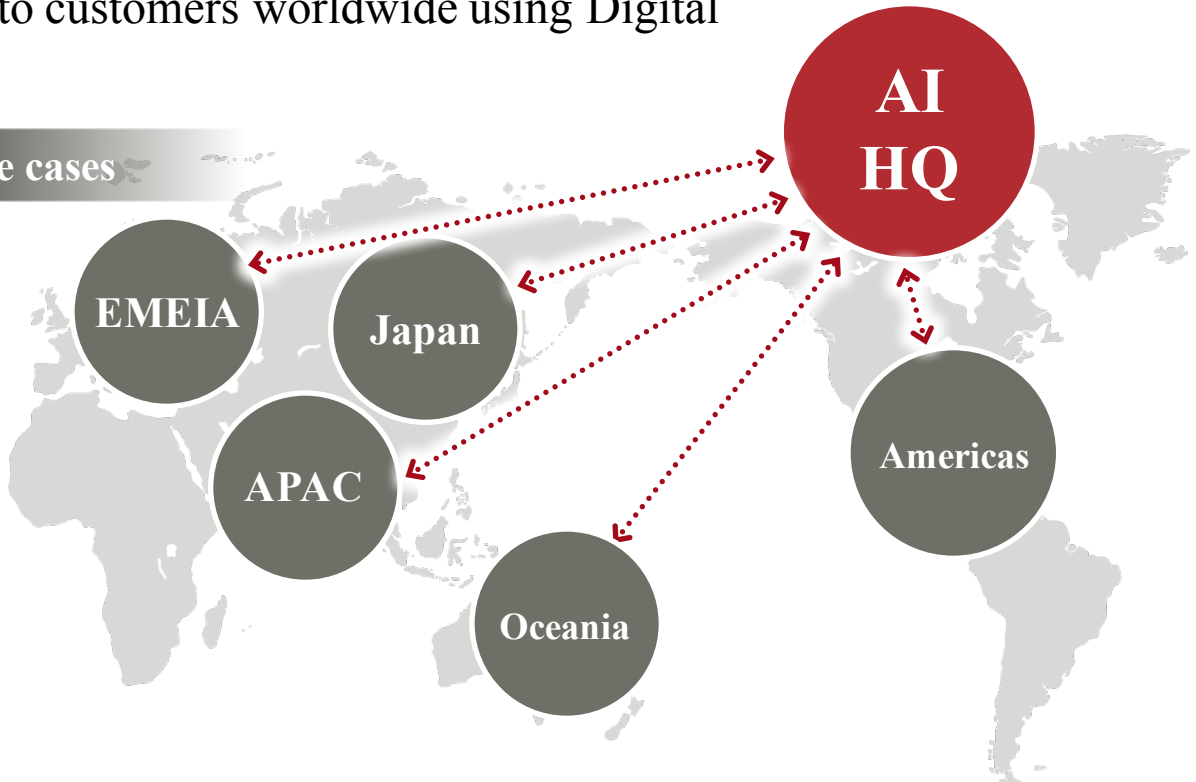
- Distribution of technology and solutions
- Expert technical support

Leading an AI ecosystem

- Expansion of platform users

Creation of AI core business

- Planning, execution, and roll out
- Company-wide AI strategies



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Digital Annealer

Partnerships

Expanding Digital Annealer Applications Through Partnerships

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UNIVERSITY OF TORONTO

Collaborative research in cutting-edge areas

Confronting new issues in society

1QBit

1QBit middleware implemented on Digital Annealer

Expansion of application areas

WASEDA University 早稲田大学

Promotion of combinatorial optimization as a way to solve societal issues

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Digital Annealer

Digital Annealer Reference Sites & Press Releases

Digital Annealer Websites:

Japanese

http://www.fujitsu.com/jp/digitalannealer/

English

http://www.fujitsu.com/global/digitalannealer/

YouTube

Digital Annealer public channel

http://www.youtube.com/channel/UCo0c9YwYOHXLwJnNA_moEJC

Press Releases

http://www.fujitsu.com/global/about/resources/news/press-releases/

January 15, 2019
Fujitsu and TC3 Promote Quantum Inspired Digital Annealer Next-Generation Architecture in Topcoder Contest

December 21, 2018
Fujitsu Launches Next Generation Quantum-Inspired Digital Annealer Service

October 2, 2018
Fujitsu Drives Quantum-Inspired Project to Help Solve NatWest's Complex Optimization Challenges

September 19, 2018
Fujitsu Laboratories and Waseda University Agree to Comprehensively Collaborate on Digital Annealer Research

September 18, 2018
Fujitsu Technology to Solve Combinatorial Optimization Problems for Medium-Sized Drug Discovery

May 15, 2018
Fujitsu Quantum-Inspired Digital Annealer Cloud Service to Rapidly Resolve Combinatorial Optimization Problems

January 29, 2018
Fujitsu Initiates Joint Research with Recruit Communications on Marketing Technologies Using "Digital Annealer"

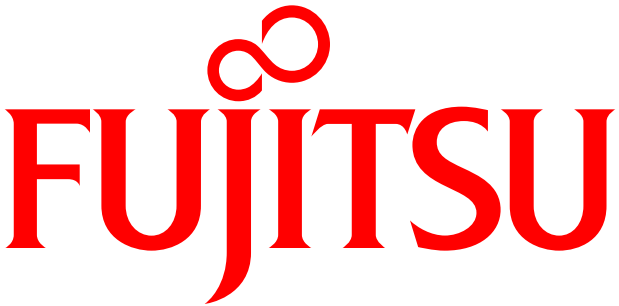
September 27, 2017
Exhibited at "CEATEC JAPAN 2017"

September 20, 2017
Fujitsu Technology Facilitates Application of Combinatorial Optimization Methods to Real-World Problems

September 20, 2017
Fujitsu Laboratories and University of Toronto Enter Strategic Partnership

May 16, 2017
Fujitsu and 1QBit Collaborate on Quantum Inspired AI Cloud Service

October 20, 2016
Fujitsu Laboratories Develops New Architecture that Rivals Quantum Computers in Utility



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