Digital Annealer Introduction

July5, 2019

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shaping tomorrow with you

FUJITSU Quantum-Inspired Computing Digital Annealer

Fujitsu Limited

Patent pending including related technology

Reaching the Limit of Moore's Law

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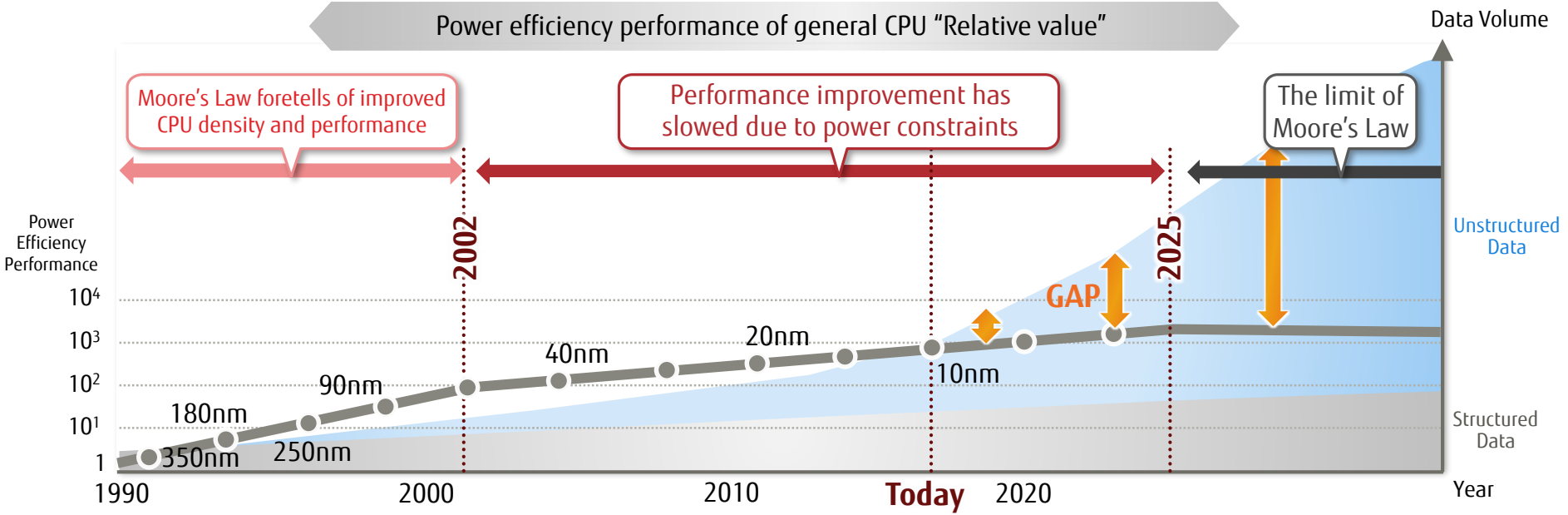
Computers must process increasingly massive and complex data at higher and higher speeds in order to support digital transformation in society and business. Moore's Law* is approaching its limit, threatening the drastic compute performance required in the coming future.



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

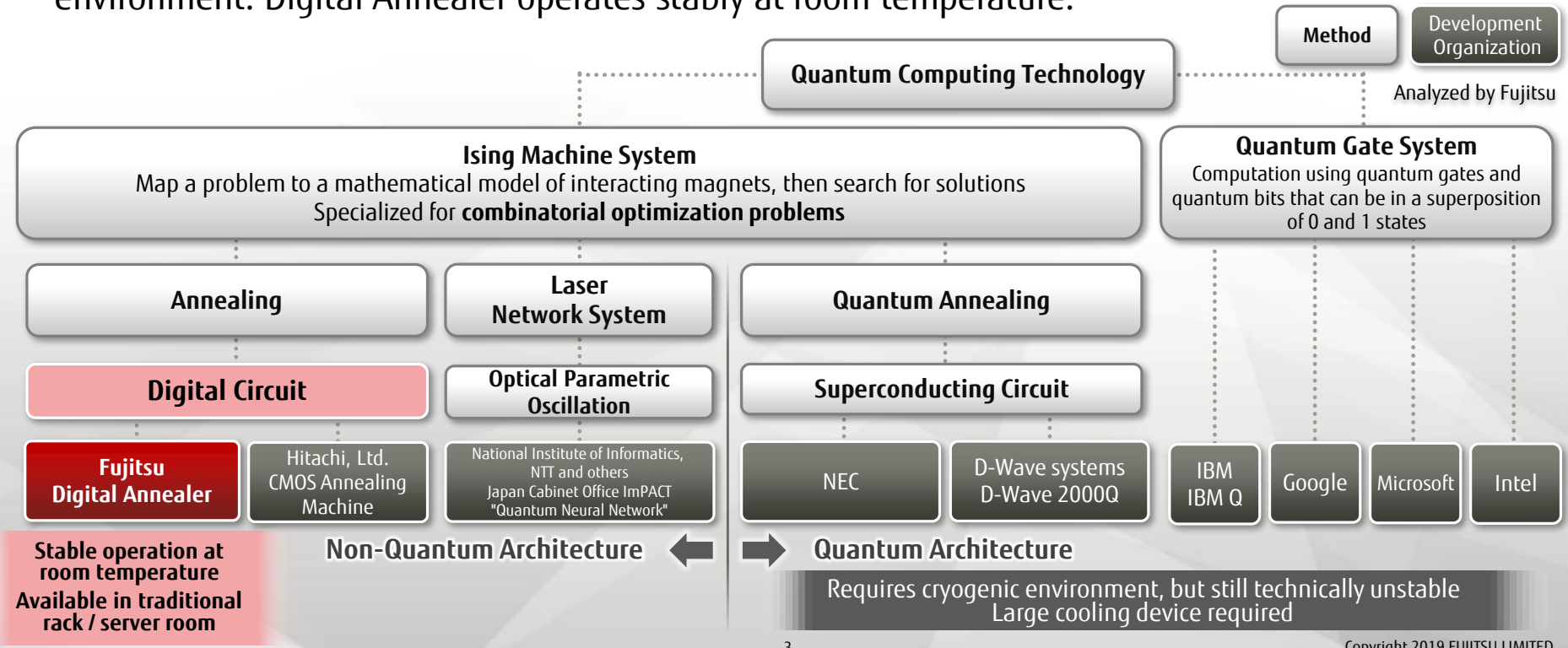
Digital Annealer

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 the Annealing Method?

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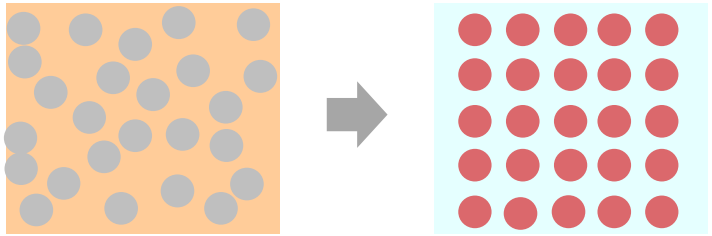
An algorithm based on the "annealing" metal processing phenomenon

Annealing Phenomenon

When brought up to high temperature then gradually cooled, the structure of metal becomes stable (low energy).

Metal State

= Unstable = Stable

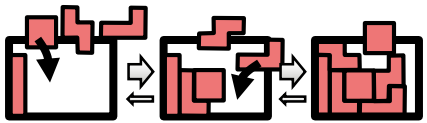


High Temperature
High energy = Unstable atoms

Low Temperature
Low energy = Stable atoms

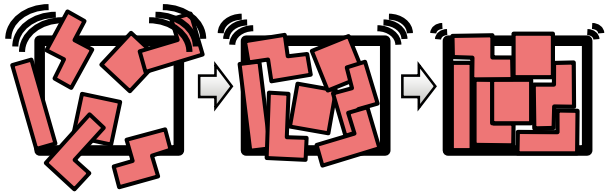
Round-Robin Method

Check all combinations by moving up in order to go back down if a combination does not work



Annealing Method

Find a way to quickly fit all the pieces by first shaking the whole system, then gradually reducing the shaking



When exploring optimal solutions, first search all solutions including those far from optimal, and then gradually close in to an optimal solution.

Combinatorial Optimization Problems

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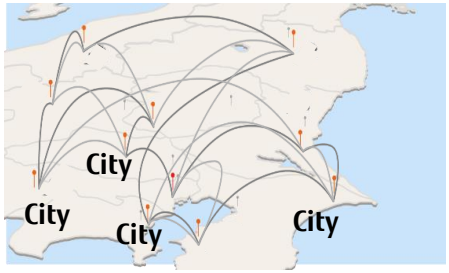
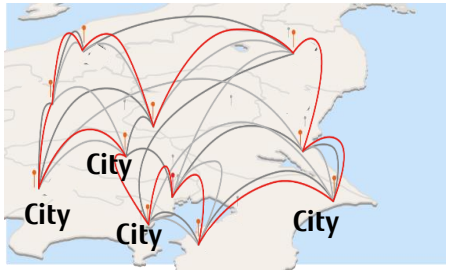
Seek *combinations* or *sequences* that satisfy given constraints, with the goal of finding the best out of all available combinations

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!

Solving Combinatorial Optimization Problems – An Example (1)

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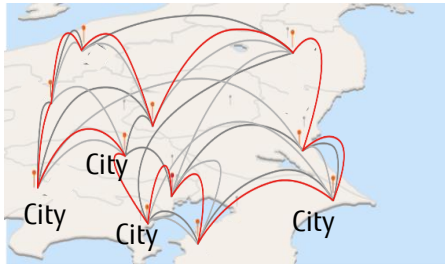
Traveling Salesman Problem

Find the **shortest-distance route** (shortest path) that visits **every city exactly once** and then returns to the starting point

1. Define an Optimum Solution for the problem to be solved

Optimum Solution:

Shortest total distance route



With the Traveling Salesman Problem, the shortest route (minimum value) is defined as the optimum solution, but optimum solutions for combinatorial optimization problems can also be defined as maximum values depending on the type of problem.

NEXT Which pieces of information are combined in order to lead to the shortest route?

2. Define Variables and Constraints

In order to find the shortest route, combine the Variables:

Order to visit **&** **Cities** to visit

Variables are the elements of the problem that must be defined in order to seek optimum solutions.

Define Constraints for the problem:

visit every city exactly once

NEXT After defining an optimum solution, variables & constraints, how is the problem formulated for Digital Annealer?

Solving Combinatorial Optimization Problems – An Example (2)

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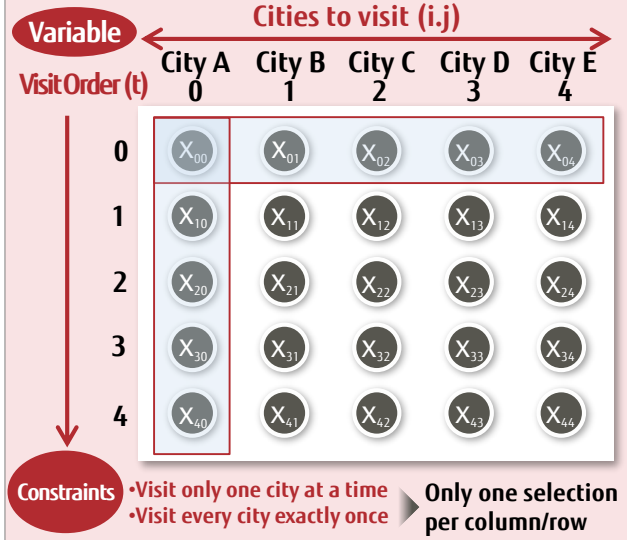
Traveling Salesman Problem

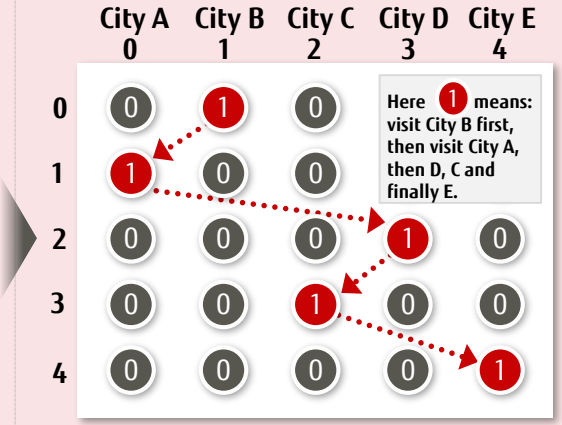
Find the **shortest-distance route** (shortest path) that visits **every city exactly once** and then returns to the starting point

3. Create a formula that can be solved with Digital Annealer

Create an Ising model for formularization

Ising Model: Used to express the interactions of variables with "spins" of either 0 or 1.





- Each ● represents a single bit
- 2nd generation Digital Annealer supports up to 8,192 bits

- A bit can be 0 (in the city) or 1 (not in the city)
- 1 represents the city to visit on the nth leg of the route (i.e. the optimum solution)

➔ Digital Annealer seeks solutions to this type of problem

4. Use Digital Annealer to find solutions

Send formula to Digital Annealer to obtain optimum solution (values)

Objective Function

E = Function to minimize/maximize energy

$$E = \sum_{t,i,j} d_{ij} x_{ti} x_{(t+1)j} +$$

Variables

t: Visit order
i j: City to visit

Constraint Terms

Constraint — Visit only one city at a time:

$$\alpha \sum_t \left(\sum_i x_{ti} - 1 \right)^2 +$$

Constraint — Visit every city exactly once:

$$\beta \sum_i \left(\sum_t x_{ti} - 1 \right)^2$$

Combinatorial Optimization Problems Across All Industries & Business

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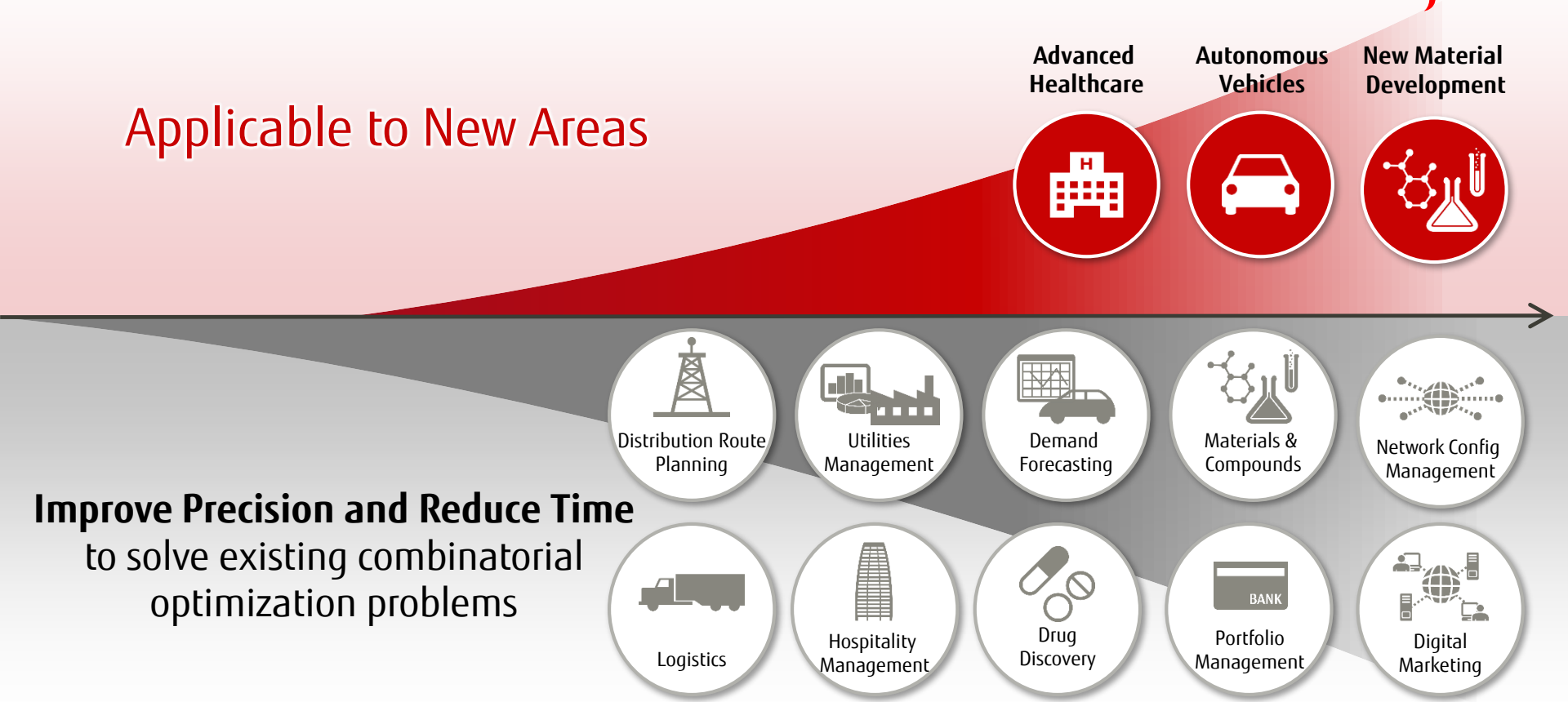
Applicable to New Areas



Improve Precision and Reduce Time
to solve existing combinatorial optimization problems

Applicable Area Examples

Digital Annealer Application Cases

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Search for molecular similarity

Seek overall similarity of compounds

Big Data Visualization Toolkit

Clustering of big data for visualization

Traffic Optimization

Select non-overlapping distribution routes for vehicles driving to each destination from multiple departure locations

Investment Portfolio (QHRP)

Select investment portfolio assets which are not affected by correlations

Optimizing HR Planning

Develop HR planning according to staff requests, capabilities, desired schedule, attendance conditions, etc

Production Planning Optimization

Optimize overall operation scheduling of multiple machines performing tasks with interrelated sequences

Optimizing Inventory Allocation

Optimize combinations parts and products to meet destination requirements

Optimizing Flow Line in Factory

Select optimal shelf arrangement and parts pick up routes within factories

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:

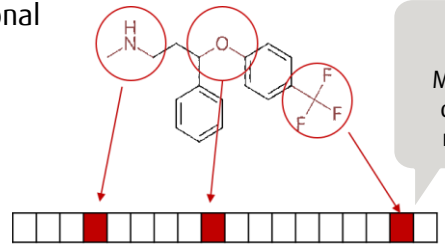
- Precision is improving by considering molecular shape
- Calculations are performed at high speed by Digital Annealer

Results

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

Use Case

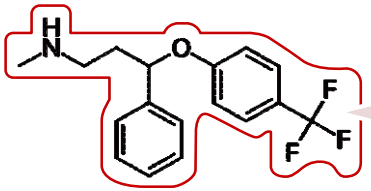
Conventional Method



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

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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

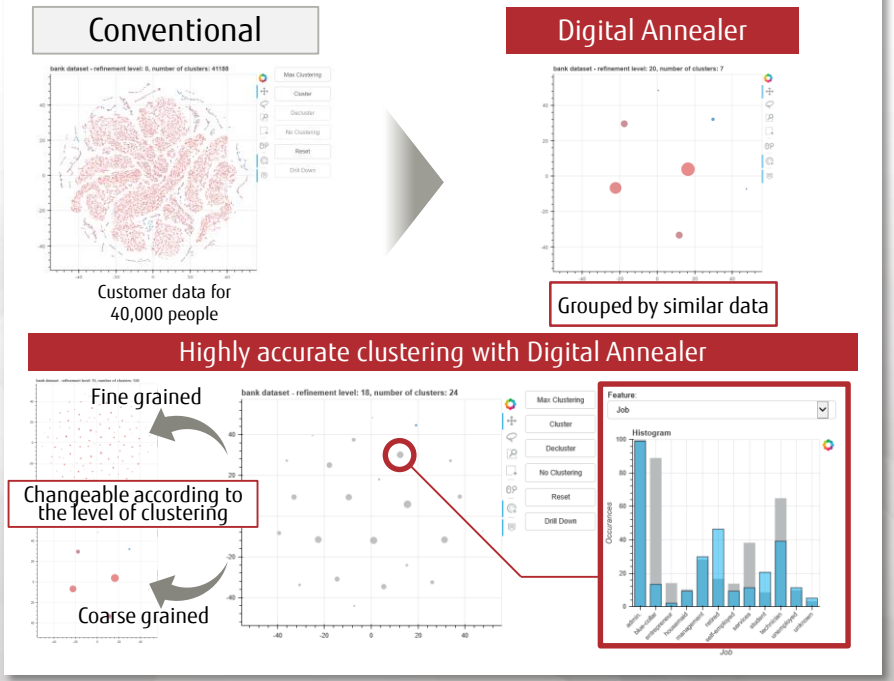
Technique

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

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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

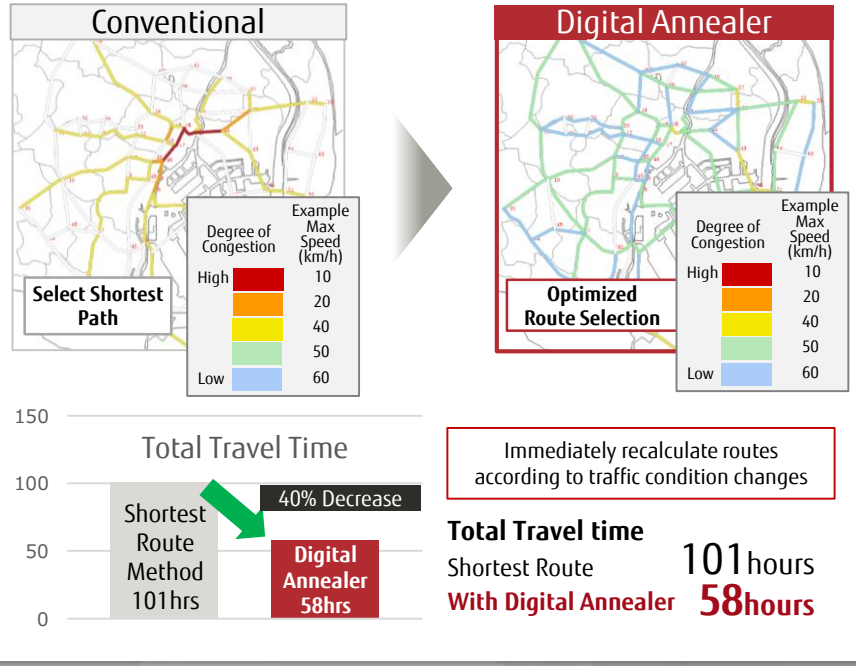
Technique

- Optimize route selection to avoid overlap
- Prioritize route options 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:

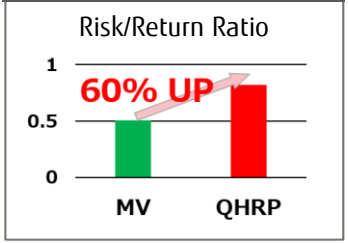
- The clustering of assets into a tree diagram based on risk correlations
- Composition of risk-diversified portfolios with low correlativity

Results

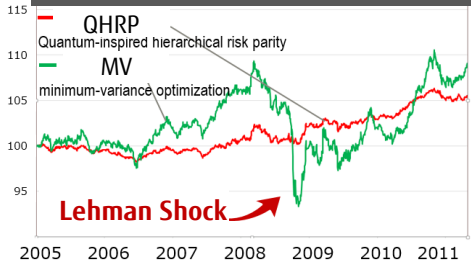
- Create portfolios with resistance to market fluctuations that continue to provide stable returns
- 60% higher Sharpe Ratio compared to MV method

Use Case

Results (Sharpe ratio comparison)



S&P500 Investment Results (2005 – 2011)



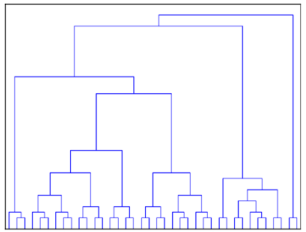
Digital Annealer Technique

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. Manpower Management

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Optimize manpower management and eliminate dependencies on individual skills

Issues

- Securing correct manpower difficult due to increases in conditions to be considered
- Difficult to quickly respond to sudden changes in scheduling conditions
- Manpower management-related shift planning dependent on specialist skills

Technique

- Digital Annealer's 8192-bit scale & 64-bit gradations handle detailed requirements simultaneously: e.g. preferred dates, consecutive day work restrictions, and 5-day work week
- High-speed processing allows for prompt recalculation when staffing conditions change

Results

- Shift planning requirement reduced from 34 staff to 29 after optimization
- Work dependent on individual skills reduced, and shift planning completed quickly
- Applicable to work style reform in various industries.

Use Case

Shift Planning Example

		Monday				Tuesday					Saturday				Sunday				
Planned Workload		220				220					200				180				
Worker ID	Capacity per day	T1	T2	T3	T4	T1	T2	T3	T4		T1	T2	T3	T4	T1	T2	T3	T4	Work days per staff
0	(008):	×	×	×	×	×	×	◎	○		×	×	×	×	×	×	×	◎	4
8	(012):	×	×	×	○	×	×	○	○		○	○	○	×	×	○	×	○	0
24	(005):	×	×	×	○	○	○	×	×		×	×	○	○	×	○	○	○	0
25	(014):	○	○	○	×	○	×	×	×		×	○	○	○	○	○	×	○	0
32	(010):	◎	×	×	×	◎	○	×	×		×	○	×	◎	×	◎	×	×	5
33	(012):	-	◎	×	○	○	◎	×	×		◎	×	○	×	×	○	×	◎	5
Workload (gap from plan)		221 (1)				222 (2)					199 (-1)				180 (0)				# of workers: 29 (-5)

◎: Determined Shift, ○: Preferred, ×: Not Preferred

Before:
34 Workers Required

With Digital Annealer:
29 Workers Required

Manufacturing

6. Production Control Scheduling

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Optimize equipment allocation to reduce production process time

Issues

- Varied product types leads to different process times, requiring efficient utilization of equipment to reduce production times
- Allocation is time consuming as jobs are allocated manually

Technique

- High-speed processing enables instant optimization, even when sudden machine failures occur or jobs requests change
- Digital Annealer's 8192-bit scale & 64-bit gradations handle multiple jobs, varying process times, and process-combination conditions

Results

- Efficient equipment allocation leads to a 30% reduction in processing time
- Allocation plans created quickly and without the need for specialist skills
- Applicable to equipment verification and the purchasing of new equipment
- Also applicable to various industries with scenarios consisting of the combination of multiple processes

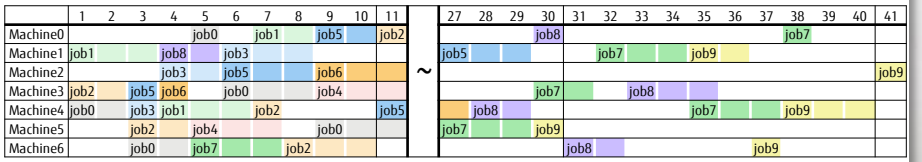
Use Case

Job Process Table

	Process0		Process1		Process ~	Process5		Process6	
	Machine	Time	Machine	Time		Machine	Time	Machine	Time
job0	4	2	6	2		1	3	2	3
job1	1	3	4	3		2	1	6	3
job2	3	2	5	2		1	2	2	3
~	~				~	~			
job7	6	3	2	3		4	3	0	1
job8	1	2	5	2		6	2	3	3
job9	3	3	0	2		4	3	2	1

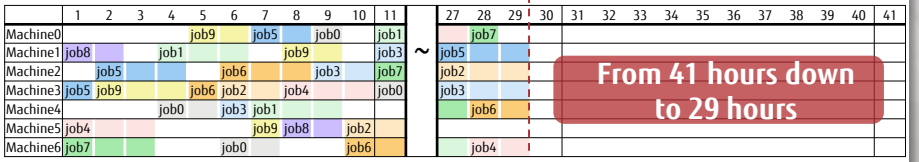
- Each job proceeds in order of process number
- Each machine can process only 1 job at a time
- Job processing time varies depending on machine/process

Job Allocation - Before



Job Allocation – with Digital Annealer

30% Reduction



From 41 hours down to 29 hours

Manufacturing

7. Inventory Allocation Optimization

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Optimize parts allocation and inventory for the assembly of multiple product models

Issues

- Due to increases in product type variation, complexity growing for parts selection from inventory. Enormous time required to create production parts combinations.
- Manual optimization difficult due to complexity

Technique

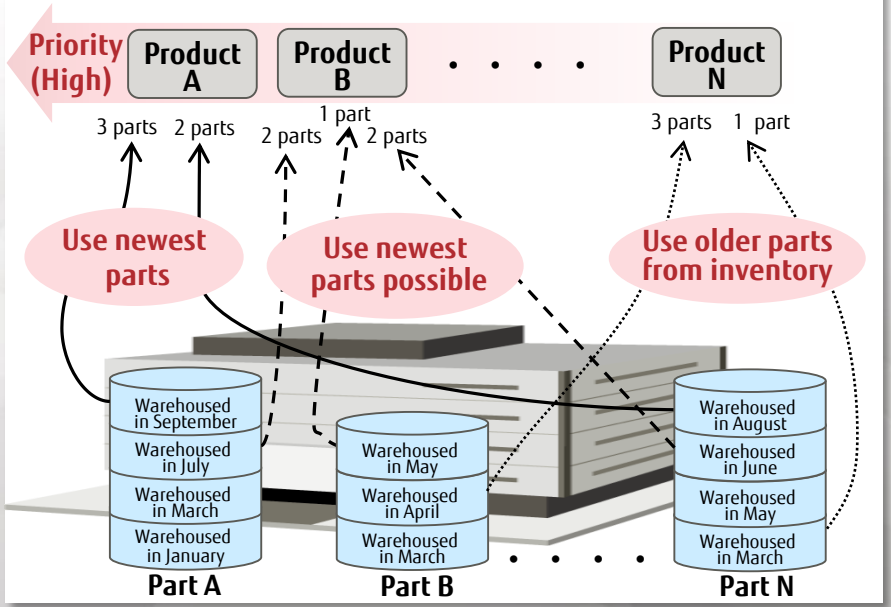
- Digital Annealer's 8192-bit scale & 64-bit gradations handle large variety of products, parts and production conditions
- High-speed calculation enables real-time parts allocation

Results

- Real-time recognition of parts that meet conditions, improving efficiency of inventory and quality control
- Eliminate work dependent on specialist skills
- Also applicable to retail and distribution warehouses

Use Case

- Prioritize allocation to products with high unit price and profit
- Prioritize allocation to high-demand products



Manufacturing

8.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

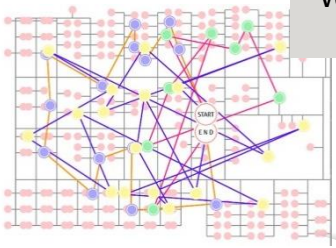
Technique

- 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

8. 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/

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

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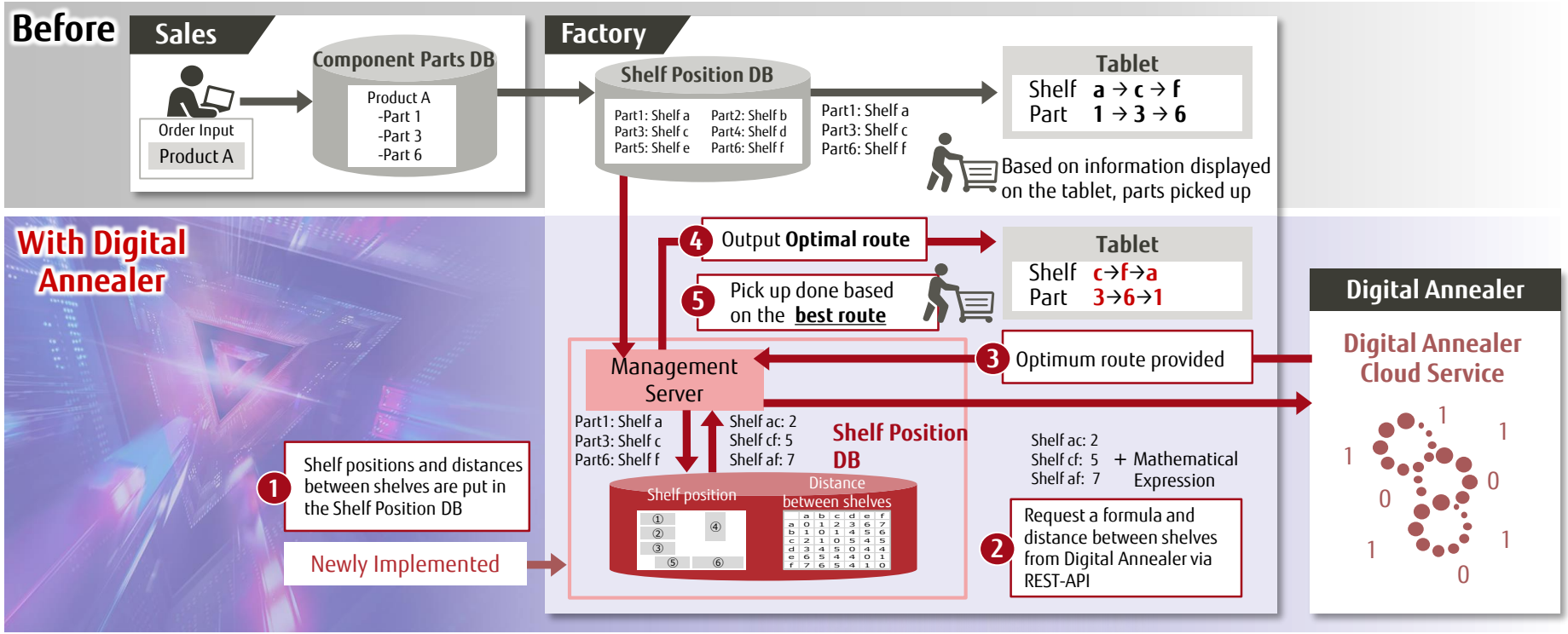
Goal: Leverage existing operation, and create a new shelf position database to use Digital Annealer to calculate optimal pick up routes



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 for 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

Unique Technology Improves Optimum Solution Accuracy

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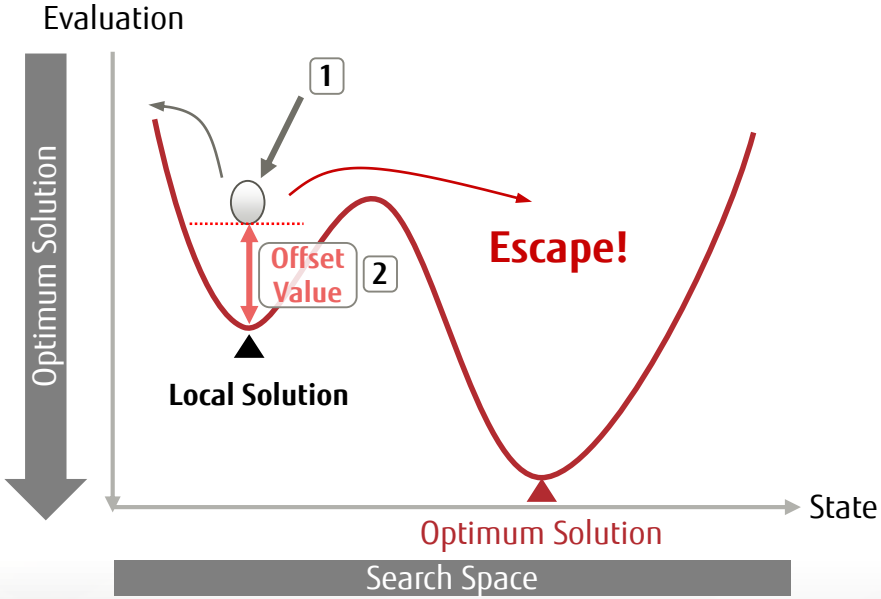
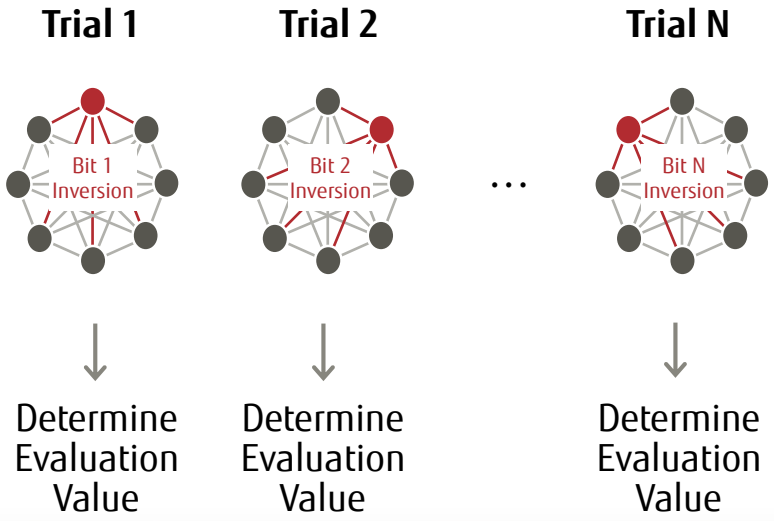
Digital Annealer increases the probability of finding optimum solution



1 Detect localized solution reached
2 Apply offset value

Encourage escape from local solutions, leading to optimum solution

Rapidly find optimum solution with Digital Annealer parallel evaluation



Evaluating the bit inversions for each trial in parallel, leads rapidly to the optimum solution

Specification Comparison

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

	Digital Annealer (2nd generation)	Company A	Company B
Implementation Technology	Digital Circuit (Using existing technology)	Superconductive Circuit (Cryogenic cooling required)	Non-Linear Optical (1km ring device)
Number of Bits	**8192**	2048	2048
Amount of Coupling	Total Coupling	6 - Partly Coupled (64bit total coupling equivalent)	Total Coupling
Evaluation Accuracy	64bit Gradations	32 Gradations	3 Gradations

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shaping tomorrow with you

Digital Annealer

Services Overview

Digital Annealer Service Overview (Japan Market)

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- Cloud Service & Technical Service launched in May 2018
- On-Premises Service launched in February 2019

Deliver high speed processing for combinatorial optimization problems

Support for Digital Annealer utilization

FUJITSU Quantum-Inspired Computing Digital Annealer

Cloud Service

FUJITSU Quantum-Inspired Computing Digital Annealer

On-Premises Service

Digital Annealer

Technical Service

Combinatorial Optimization Problems Faced in Actual Business

FUJITSU Quantum-Inspired Computing Digital Annealer

Digital Annealer Cloud Service

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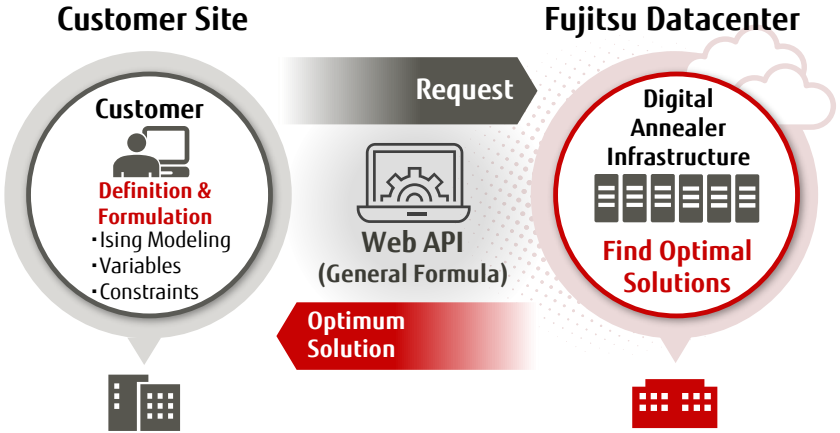
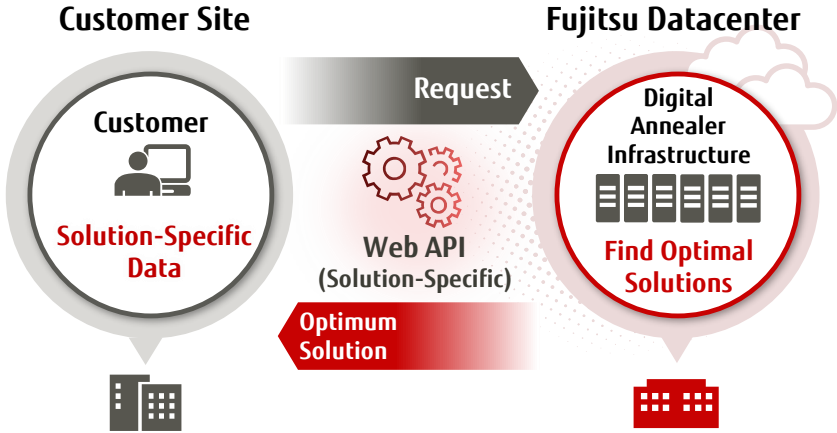
General Formula Type
(QUBO API)

Submit Ising model (QUBO) formulas through Web API



Solution-Specific Type
(Optimization Solutions API)

Submit solution-specific data and receive optimal solution



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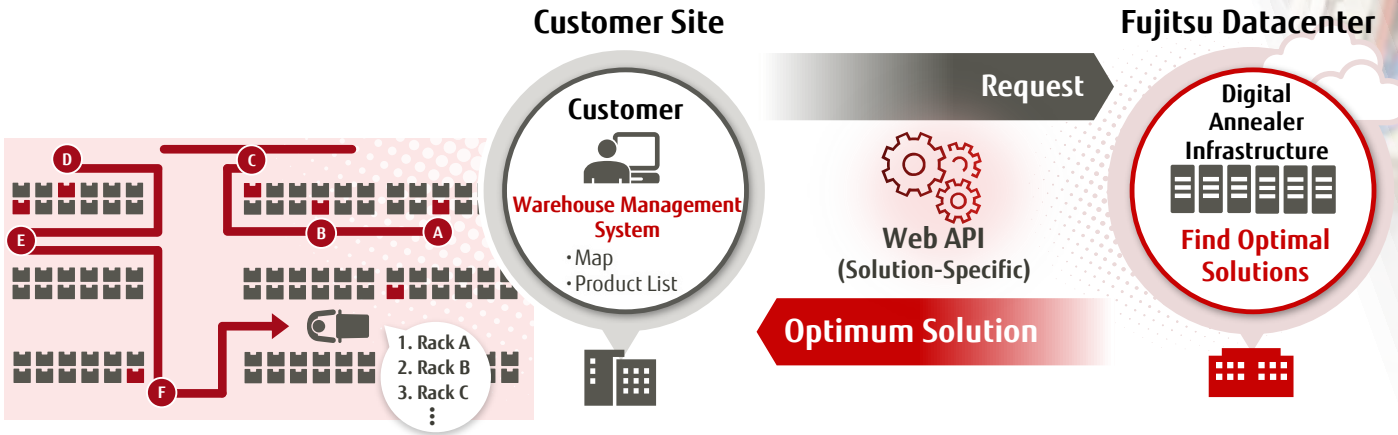
Optimization Solution API

Warehouse Pickup Optimization API

A Web API service that finds the shortest distance route for picking up specified products from multiple locations within a warehouse

- A list of products to pickup is input and the optimal pickup order is output
- Supports up to 32 locations with the same priority
- Warehouse map files (coordinate data) are pre-registered in the cloud



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Cloud Service Menu (Japan Domestic Market Only)

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Service Type	Fee		Remarks
General Formula Type (QUBO API)	**Premium**	**Basic fee (fixed monthly)**	Usage time is not limited
	Standard	**Basic fee (fixed monthly)** + **Metered rate (by usage)**	Processing time is metered (calculated in seconds; data transfer time is not included)
Solution-Specific Type (Optimization Solutions API)	**Warehouse Pickup Optimization API**	**Individual quotation**	

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Cloud Service Web APIs

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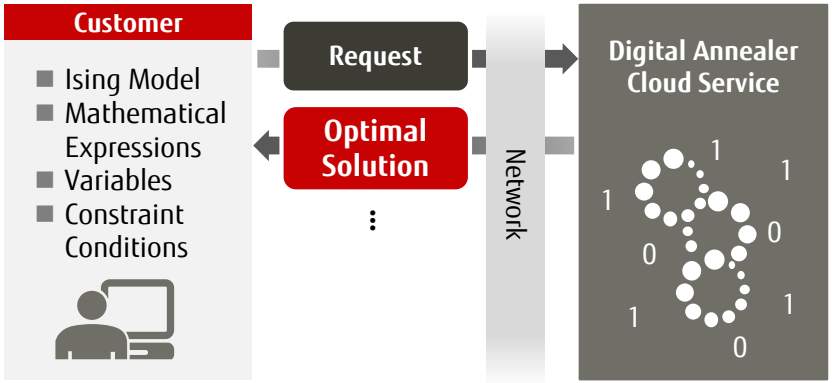
Synchronous Web API (basic) and Asynchronous Web API (optional) offerings:

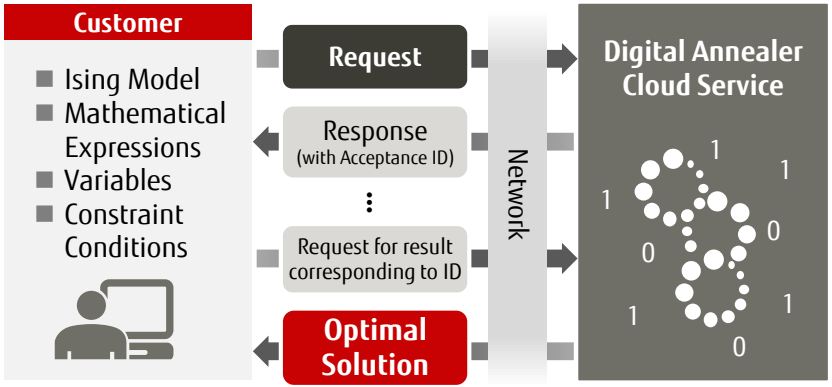
Synchronous Web API



The API requests calculation results synchronously.
The API returns when the calculation process has completed.

The problem is processed in real time

Asynchronous Web API



A calculation request is issued and the API returns.
A separate request is issued to obtain the calculation result.

Multiple requests can be made for large problems

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Help Desk Service

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Service Details for Digital Annealer Cloud Service Subscribers:

Service Hours	**Weekdays 9:00-17:00 (JST) *Closed on Japanese holidays**
Inquiry Contact Method	**Email**
Language	**Japanese**
Acceptable Questions	• **Questions about specifications, settings and usage of the Digital Annealer Cloud Service** • **Questions, investigation, workarounds when the Digital Annealer Cloud Service does not function correctly**

Trouble Notification

Detail: **Notification from the time the issue occurs, functions impacted, etc.**

Method: **Portal/Email**

Maintenance Notification

Detail: **Notification of Digital Annealer Cloud Service planned or emergency maintenance date/time, functions impacted, etc.**

Method: **Portal/Email**

Service Detail / Update Guide

Detail: **Notification of new functionality and improvements made to the Digital Annealer Cloud Service**

Method: **Portal/Email**

Important Notes

Inquiries received outside service hours will be processed after 9:00am on the following business day

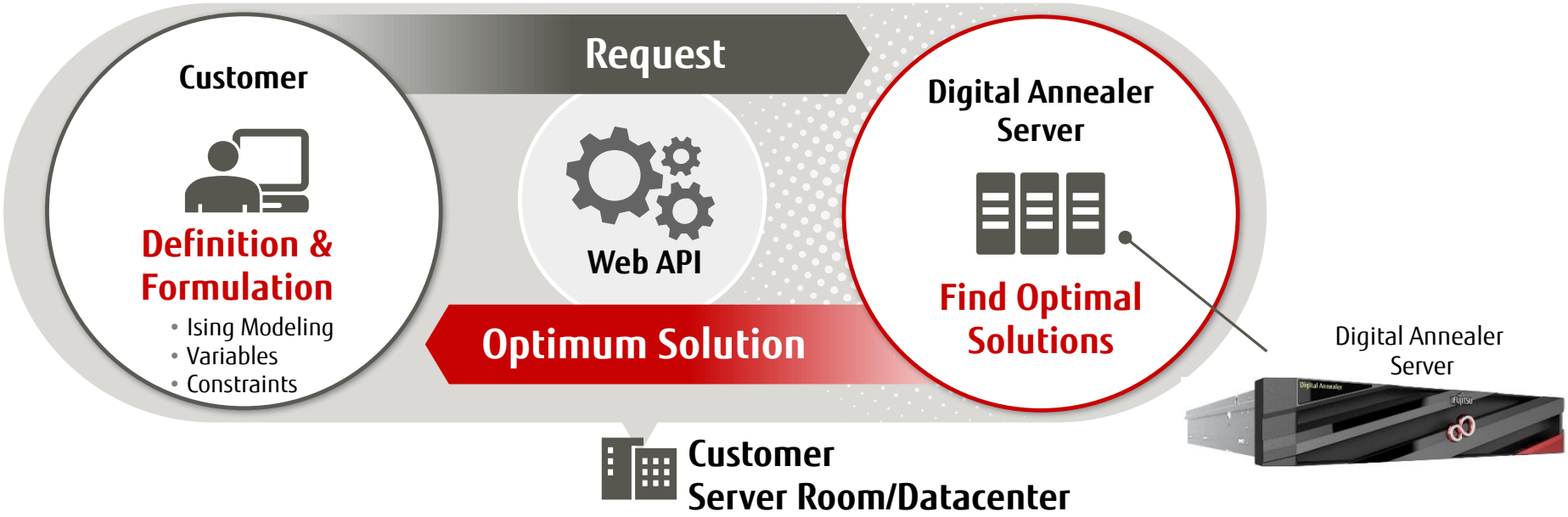
The following inquiries are **excluded** from the Help Desk Service:

- Processing speed tuning (performance evaluation resulting from customer's APP design, implementation and operation, etc.)
- Consulting (advice on creation, design, implementation and operation of mathematical models)
- Disclosure of information related to our cloud service environment and logs
- Calculation result accuracy

Service Fee	**Calculated as 5% of the Web-API usage service fee**

Digital Annealer On-Premises Service Offering

- Digital Annealer Server installed at the Customer site for a monthly subscription
- Supporting 8,192-bit full connectivity and flexible partitioning for parallel operation and scaling to match problem size and precision requirements.



Contact sales for availability of the on-premises model in your region

Digital Annealer Technical Service

Digital Annealer Technical Service - Outline

FUJITSU

Technical experts with advanced mathematics knowledge and data analysis capabilities support you in resolving your optimization problems

Digital Annealer Technical Service

Implementation Phase | **Operation Phase**

Assessment	Deployment Support	Implementation	Operation
Convert customer issues into formula	Apply formulation to customer issues	Application implementation	Maintenance, Support

Training	Training for Engineers
Tuning Support	Tuning Support Service

Complete support from introduction to operation, leveraging Digital Annealer for customer business

Digital Annealer Technical Service

Digital Annealer Technical Service Details

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Formulation Verification

Verify the customer's problem can be converted to a combinatorial optimization problem, and generate a mathematical model to solve with Digital Annealer.

Development Support

PoC planning for customer Digital Annealer use. Evaluate mathematical model implementation and results. Support requirements definition for customer Digital Annealer deployment.

Implementation

Develop and deploy application for use with Digital Annealer: Deploy on customer systems, establish connection to Digital Annealer, process input / output data, and perform post processing of output.

Operation

Answer questions and solve problems for the deployed Digital Annealer application.

Training

F2F instructor-led Digital Annealer training:

- Basic: Digital Annealer features and mechanisms
- Hands-on: Solve optimization problems using Digital Annealer Cloud Service

Tuning Support

Problem solving support including parameter tuning for Digital Annealer Cloud Service customers.

Digital Annealer Technical Service

Digital Annealer Project Example

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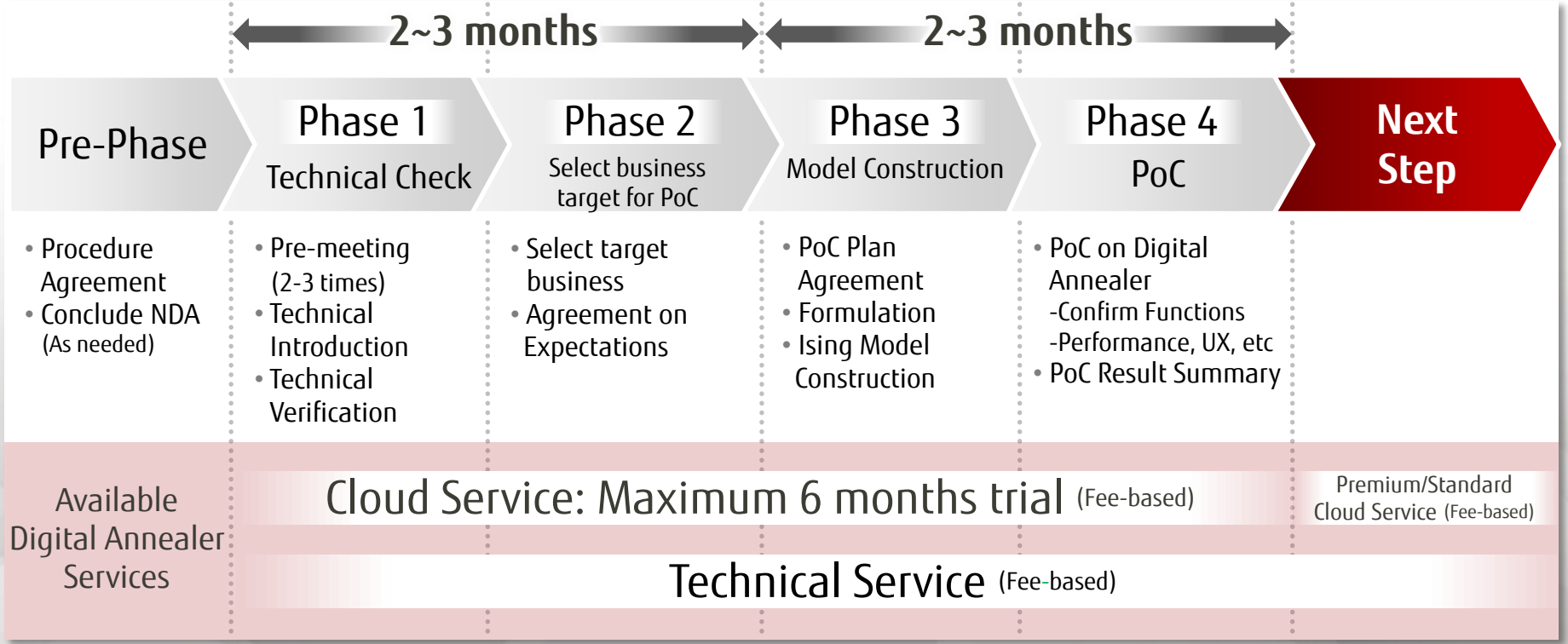
Typical Project Duration: 4-6 months



Digital Annealer Case Studies

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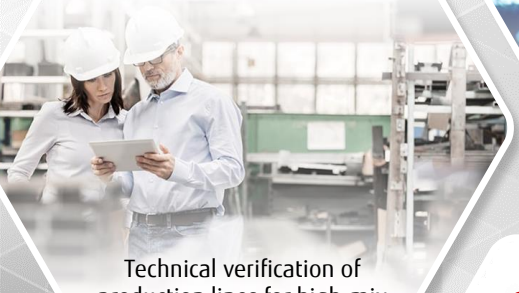
Fujifilm Corporation

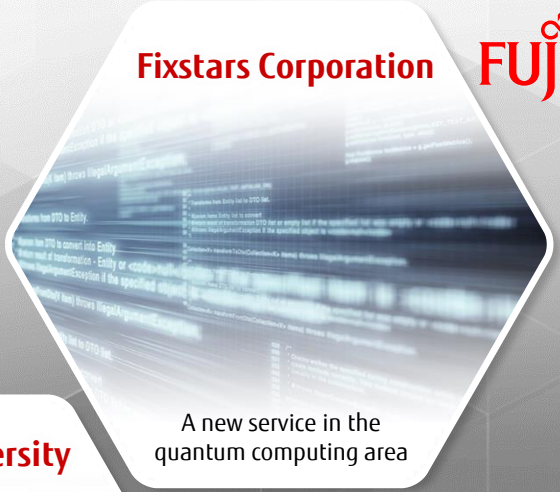


Technical verification of production lines for high-mix low-volume models in factories

Mitsubishi UFJ Trust Investment Technology Institute Co., Ltd.

Technical verification of portfolio optimization in asset management

Fixstars Corporation



A new service in the quantum computing area

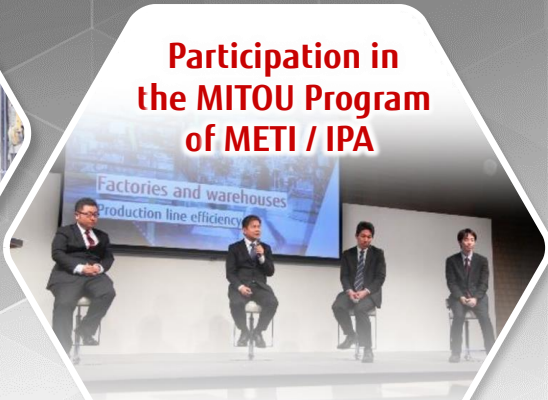
Touhoku University

Solving combinatorial optimization problems to control Automated Guided Vehicles (AGVs)

Recruit Communications Co., Ltd.

New marketing technology research and development for real-world business problems

Participation in the MITOU Program of METI / IPA



Using Digital Annealer to foster talent and start-up companies in technical fields

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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**

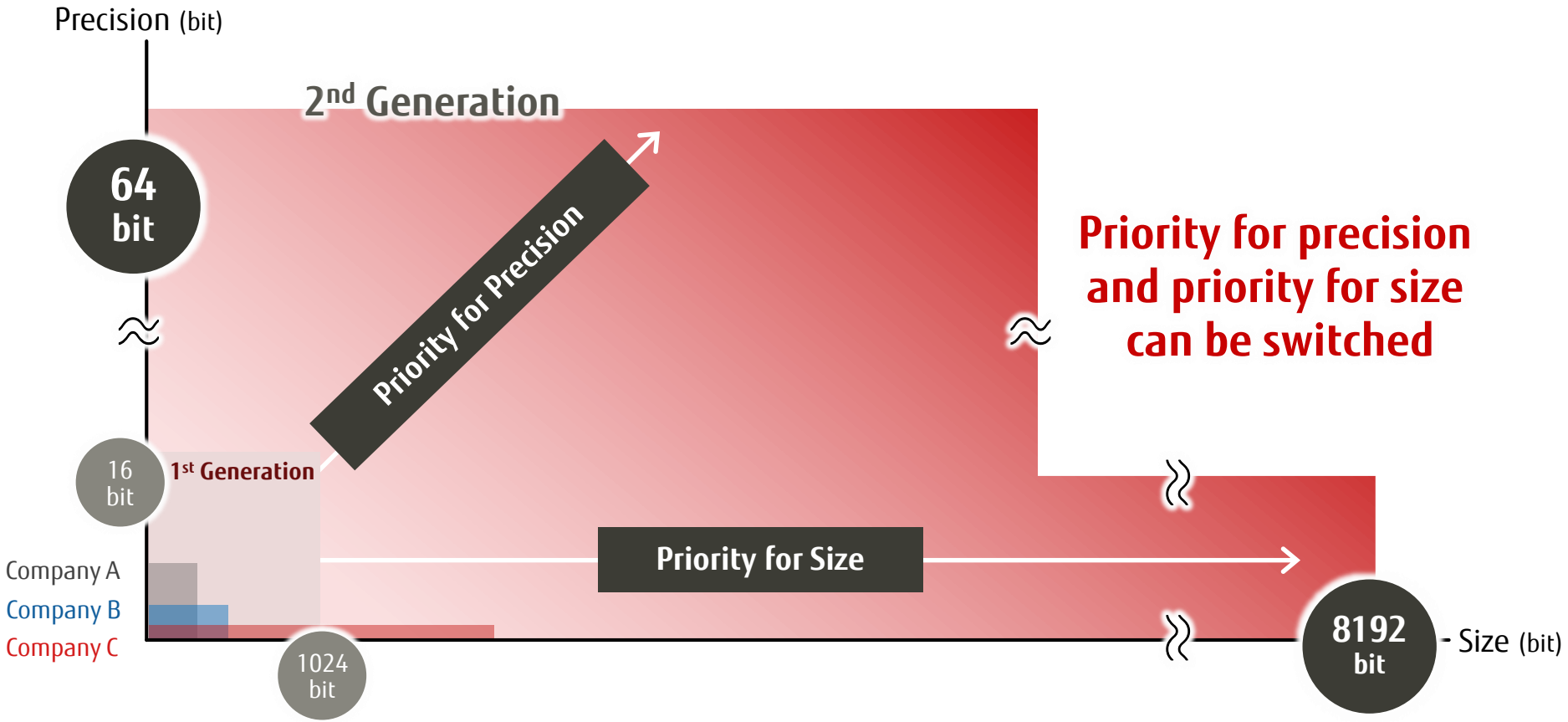
1.845×10^{19} Gradations

Digital Annealing Unit

Large-Scale Parallel Processing

Expand applications from technical verification to real-world business value

Application Areas Surpassing the Competition - 2nd Generation



Application Areas Surpassing the Competition – Next Generation

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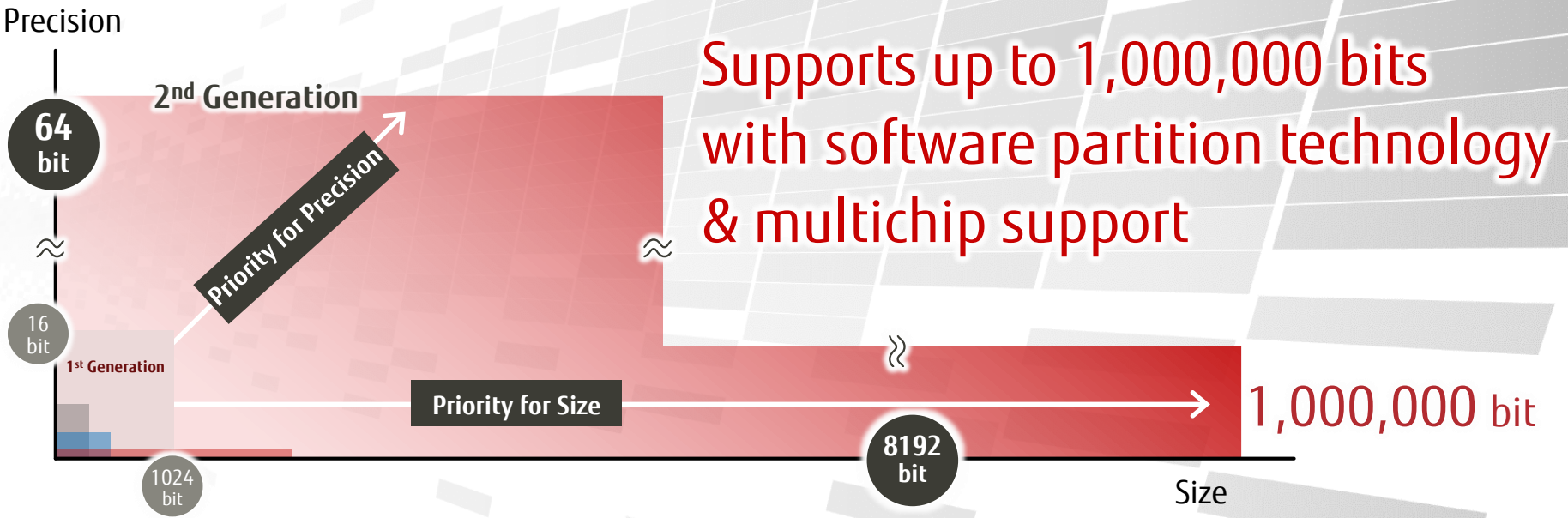
2019

Develop further large-scale application technology



Supports up to 1,000,000 bits with software partition technology & multichip support

Tackling Extremely Large Scale Problems

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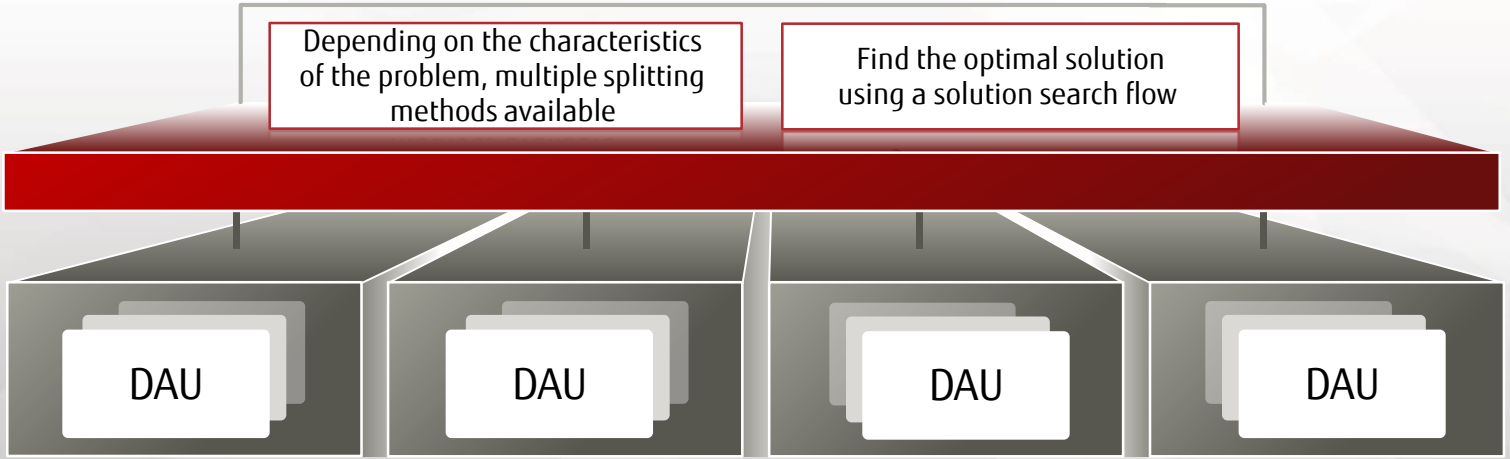
Fujitsu is developing a problem-splitting method to solve extremely large-scale problems

This method extracts a portion of a problem according to problem characteristics; processing each portion on Digital Annealer, then assembling the output from multiple calculations to derive the total optimal solution using search flow.

- This method allows a single 2nd generation (8192 bit) Digital Annealer to solve 100,000 bit scale problems
- Further software and hardware enhancements will expand the scale to 1 million bits (planned for CY2019)

Large scale problems split into manageable portions by software

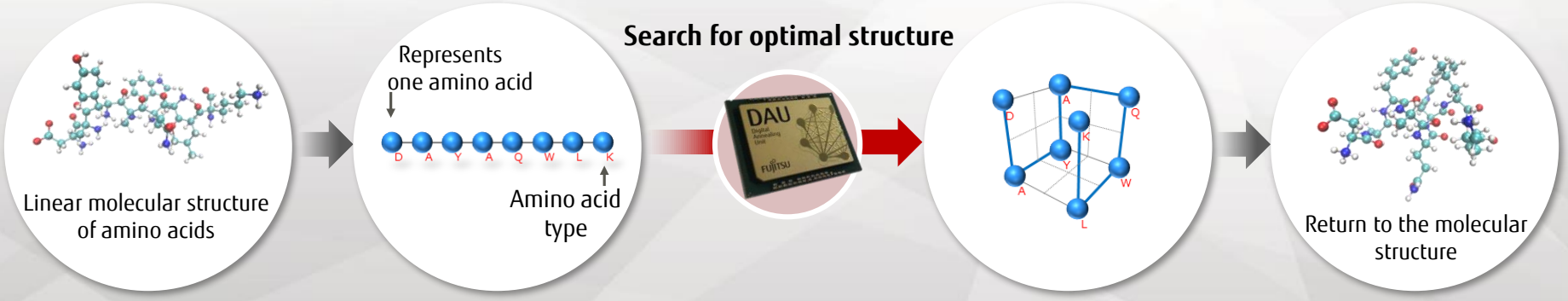


Hardware technology links multiple Digital Annealer Units (DAUs) to execute large scale parallel processing

Accelerate the Development of Middle Molecule Medicine

- Apply Digital Annealer + the problem-splitting method for simulation to find stable structure middle molecule drug candidates jointly with ProteinQure Inc.
- Effectiveness demonstrated with 30K bit scale problem

Search for the most stable structure binding relationship within amino acids, when each amino acid is modeled and placed on a lattice point



Drug candidate search can be drastically shortened from 6 months to just a few days, accelerating the development of middle molecule medicine

Digital Annealer Global Rollout

FUJITSU

- Global service now available
- On-Premises Service launched in 2019 (Global launch planned)

EMEIA
- Cloud Service
- Technical Service

Launched in FY 2019*

APAC / Oceania
- Cloud Service
- Technical Service

Launched in FY 2019*

Japan
- Cloud Service
- Technical Service
- On-Premises Service

Now Available

Americas
- Cloud Service
- Technical Service

Now Available

*Please contact us regarding the service start date in each country.

New AI Headquarters (AI HQ) - Established October 2018

FUJITSU

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

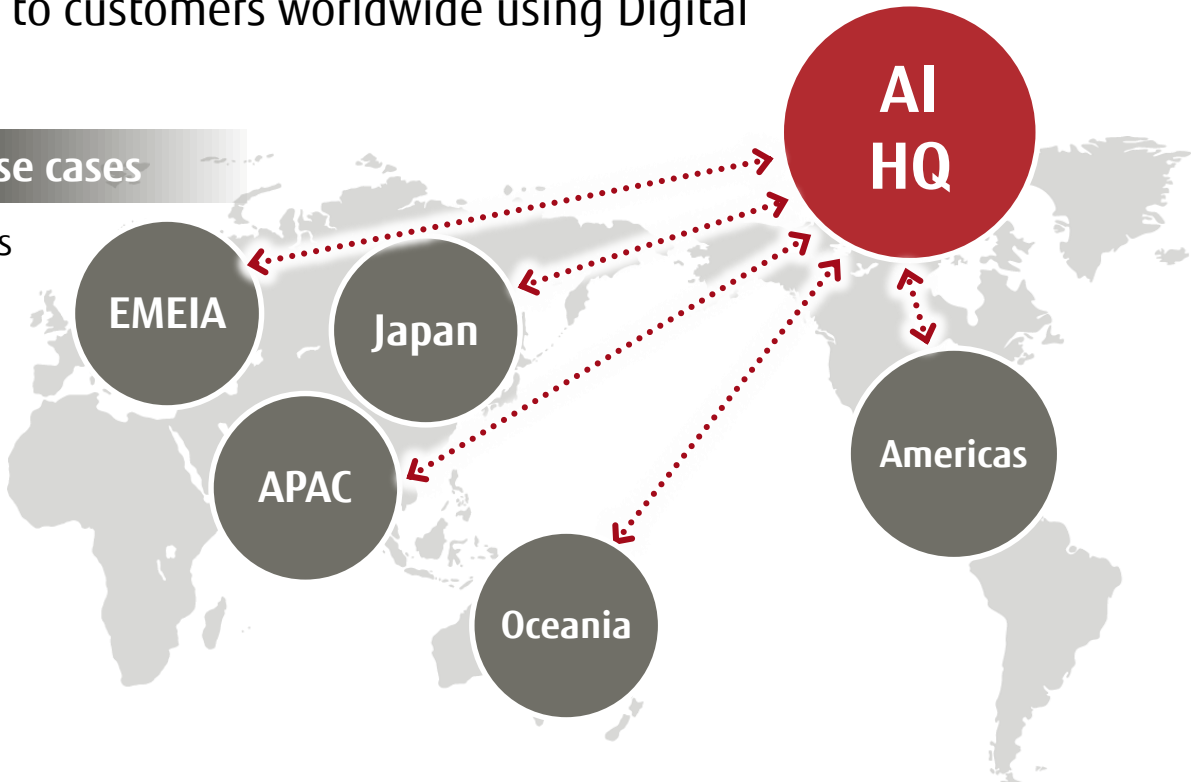
- Distribution of technology and solutions
- Expert technical support

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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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

FUJITSU

Digital Annealer

Partnership with 1QBit

- The world's #1 vendor of software for quantum computers
- Conducting joint business around the world
- Digital Annealer incorporated in 1QBit Cloud Service in FY2019

Digital Annealer

Middleware

Mathematical formulas and algorithms for computation

1QBit

Hardware

The processing power to solve problems with high speed and high precision

Partnership with University of Toronto

- World-class research university in the fields of AI and quantum computing
- New joint research center established with the University of Toronto in November, 2017:

  Fujitsu Co-Creation Research Laboratory at the University of Toronto
- Joint research in smart transportation, networks, finance, and healthcare fields

Joint Research with the University of Toronto - Cancer Radiation Therapy

UNIVERSITY OF TORONTO FUJITSU

- Huge computational load required for simulation before a treatment plan can be made.
- Current technology needs multiple hours to a few days to calculate the combinatorial optimum.

➔**Digital Annealer takes only a few minutes**

Huge number of irradiation patterns (number of combinations) with variations such as range, direction, and intensity of irradiation

Even when the beams are from only one direction, the number of combinations would be: 10^{150}

In case of irradiation against a $1cm^2$ tumor with a precision of $1mm^2$ and 32 intensity levels from one direction

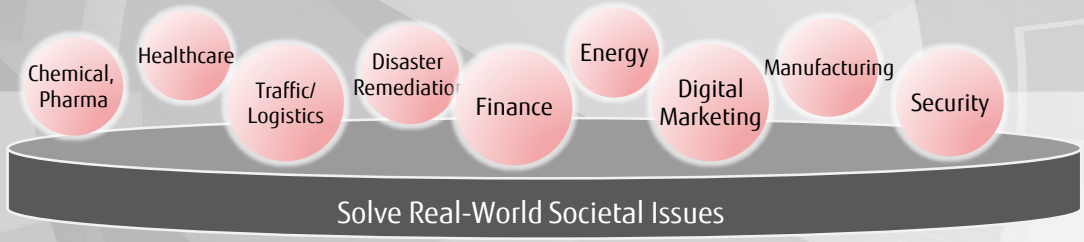
Partnership with Waseda University

Comprehensive Collaborative Activity Agreement Established

WASEDA University 早稲田大学

FUJITSU

- Starting in April 2019: Collaborative research using Digital Annealer to solve real-world combinatorial optimization problems
- Drawing research topics from Waseda University's entire body of research
- Joint research site opened in March 2018: *Fujitsu Co-Creation Research Laboratory at Waseda University*



Joint research into solving combinatorial optimization problems with Digital Annealer

WASEDA University | Research Topics | FUJITSU | Private Company

Candidate Topics

Finance	Stock Price Fluctuation Prediction
Digital Marketing	Data Analytics
Traffic/ Logistics	Delivery Optimization

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_moEJQ

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"

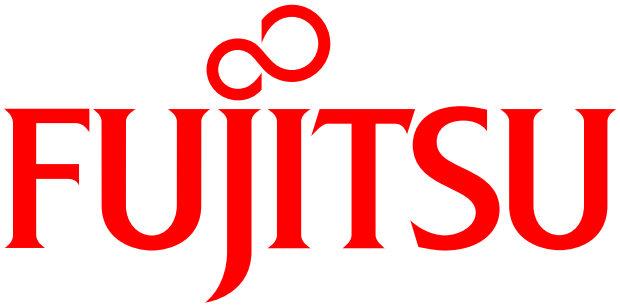
September 27, 2017
Exhibited at "CEATEC JAPAN 2017"

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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