

Quantum Computing at Fujitsu

Shintaro Sato, Ph.D

Head of Quantum Laboratory

Fujitsu Research, Fujitsu Limited



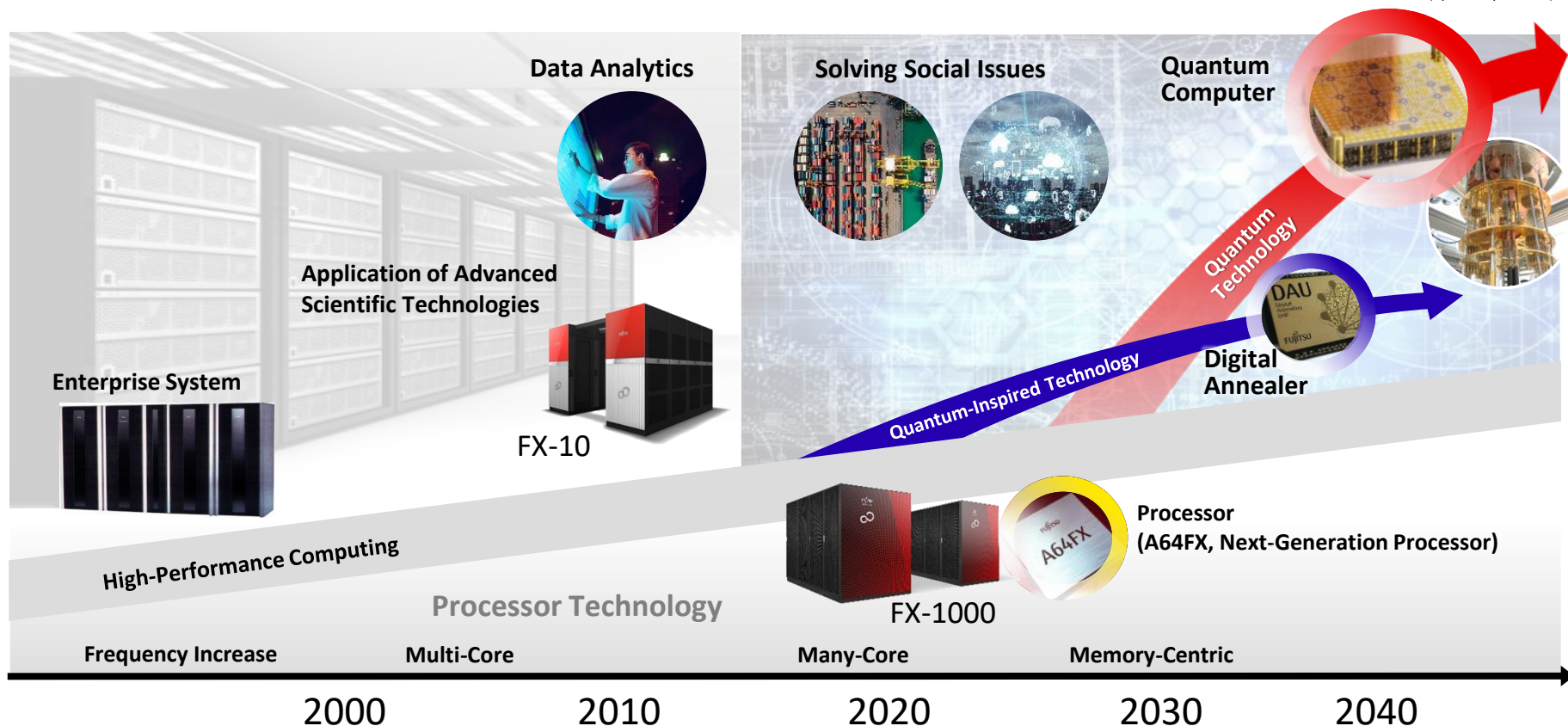
Outline

- Background
- Quantum computing
- Quantum inspired technology : Digital Annealer

Computing Technology at Fujitsu

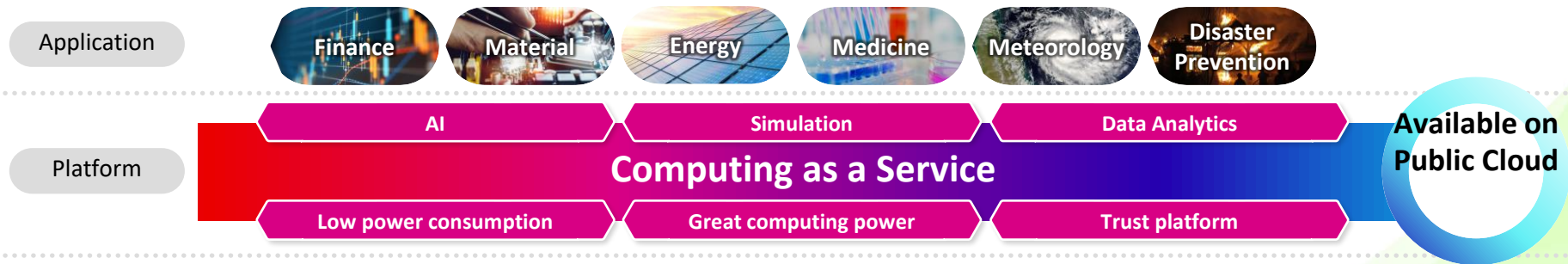


(By courtesy of RIKEN)



Computing as a Service Vision

Provide the top-class Computing Technologies “as a Service”



High Performance Computing (HPC)



A64FX Technology

Quantum-Inspired Technology



Digital Annealer



Quantum Simulator

Quantum Technology



Superconducting Qubit
Diamond Spin Qubit

Classification of Quantum Computers

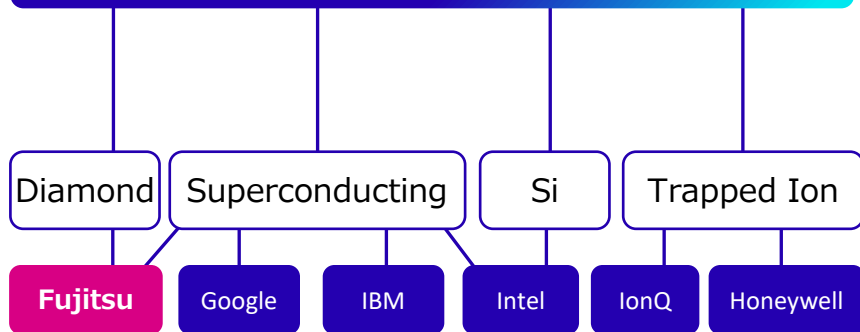
Gate based and Ising-machine based systems exist

- There are various types for gate-based systems, such as ones using superconducting circuits, silicon quantum dots, trapped ions, diamond spins

Quantum/Quantum-Inspired Computer Systems

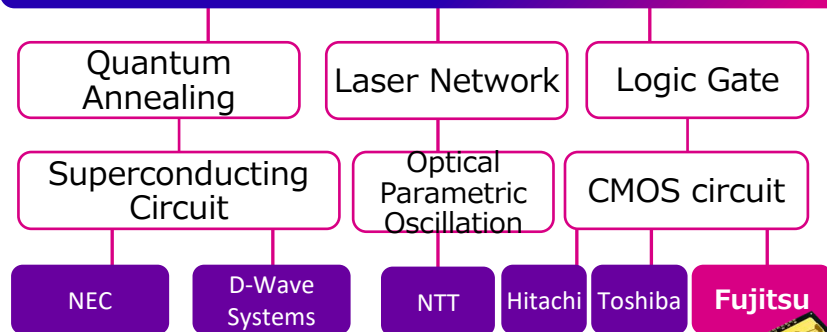
Quantum Gate Based System

Expected to solve various problems



Ising Machine Based System

For combinatorial optimization problems



Digital
Annealer



Quantum Computing

Problems Expected to be Solved

Problems requiring enormous number of calculations, such as ones related quantum chemistry and complex systems

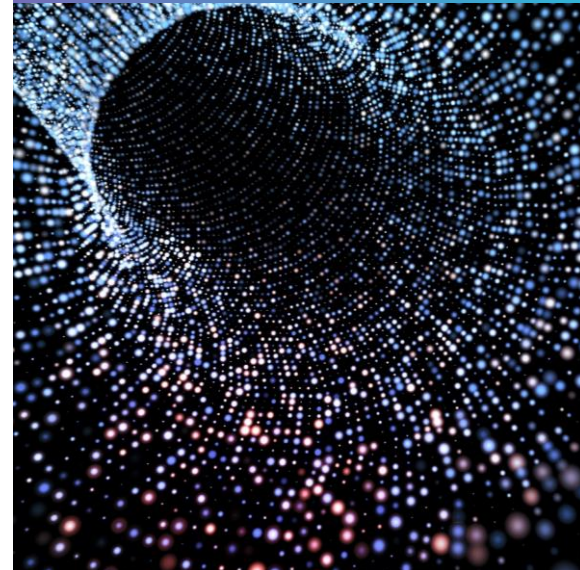
Discovery of new materials and drugs



Prediction for prices of financial products



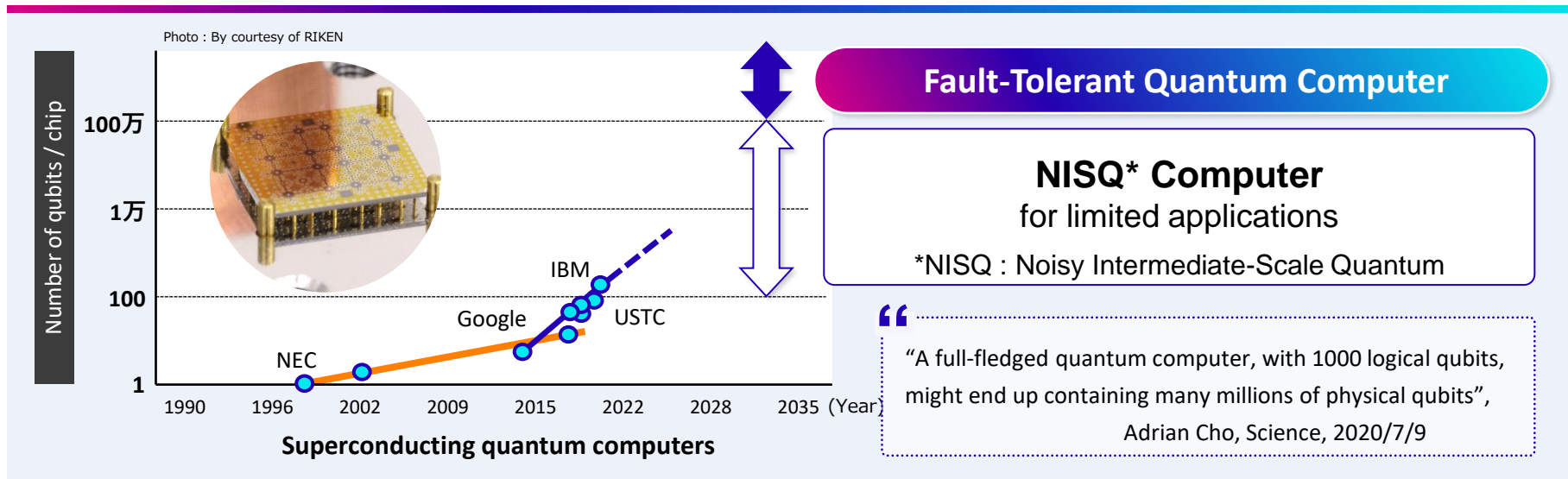
Discovery of new physical principles



Current Status and Challenges

Need more than a million qubits for fault tolerant computation

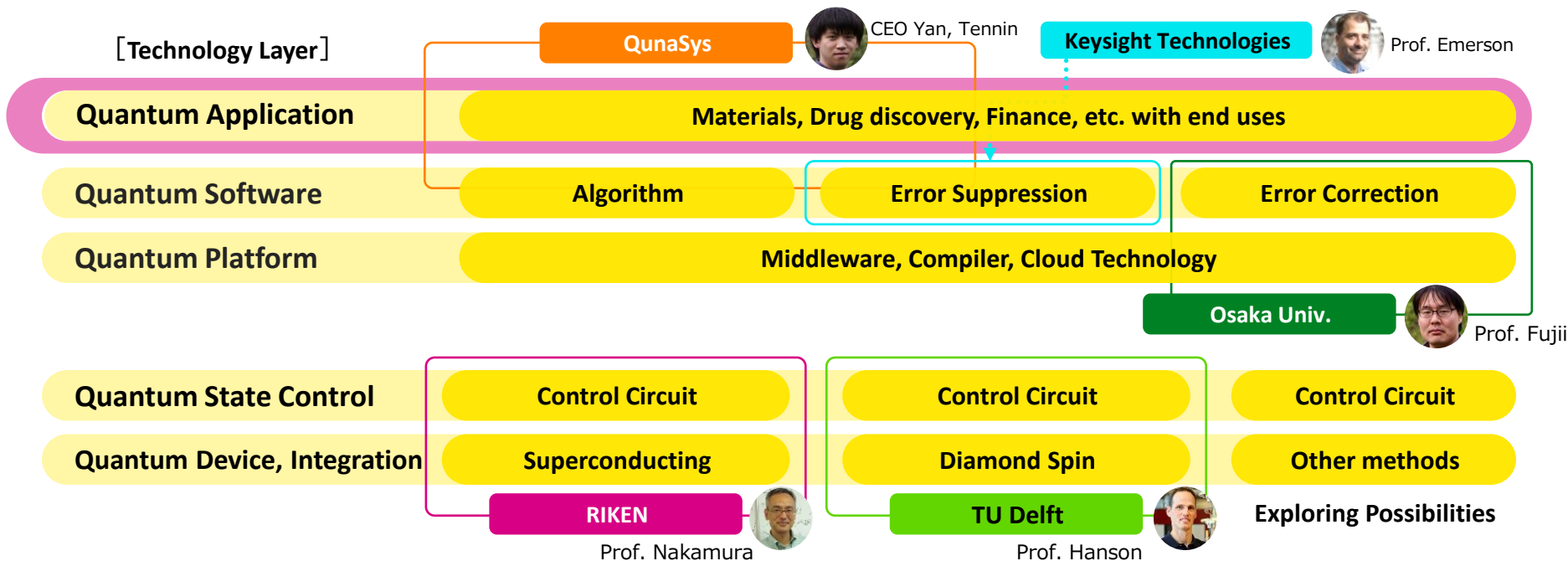
- Current number of qubits is just over 100
- For the time being, aim to apply to specific applications with small systems
- Error suppression and correction technologies are very important



Fujitsu's Strategy for Quantum Computing



- Cover all the technology with world's leading research institutions
- Put emphasis on software technologies, while working on several types of hardware
- Develop applications with end users by using a newly-developed quantum simulator



Hardware Technology : Superconducting and Diamond Spin Qubits

Superconducting

Launched RIKEN RQC-Fujitsu Collaboration Center

April 1, 2021

Mission : To develop key technologies to realize quantum computing

- To develop hardware and software technologies to realize a quantum computer with as many as 1000 qubits
- To develop applications using a prototype quantum computer



Prof. Nakamura

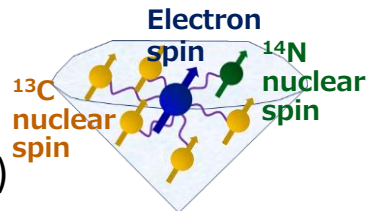
Diamond Spin

Research Collaboration with TU Delft

Spin qubit formation by introducing impurities such as nitrogen into diamond

- Higher temperature operation (1-10K) than superconducting qubits
- Gate-operations between distant qubits via light can avoid cross talk noise
- Demonstrated error correction using this technology, published in *Nature* (May, 2022)

"Fault-tolerant operation of a logical qubit in a diamond quantum processor," Abobeih, et al., Nature 606, 884–889 (2022)



Diamond-spin module

Put emphasis on error suppression/correction technologies

Launched collaboration with **Keysight Technologies Inc.** (before, Quantum Benchmark Inc.) about error suppression technology, "Randomized Compiling (RC)," and algorithms using it



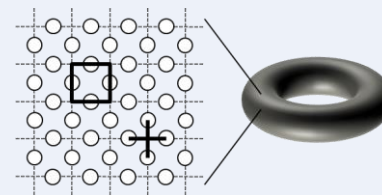
Prof. Emerson

Established **Fujitsu Quantum Computing Joint Research Division at Osaka Univ.**

Oct. 1, 2021

Work on R&D of Quantum Software for fault-tolerant quantum computing

Succeeded in simulating efficient quantum error correction using Digital Annealer in a surface code (Fujisaki *et al.*, arXiv:2203.15304)



Topological surface code for quantum error correction



Prof. Fujii

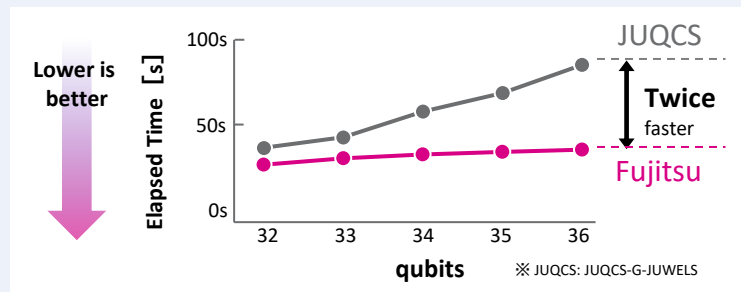
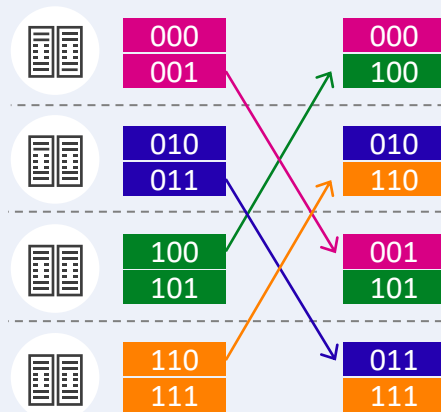
World's Fastest Quantum Computer Simulator

Have developed the world's fastest 36-qubit quantum simulator by using A64FX processors developed for Fugaku

- Twice faster than simulators developed by other companies and research institutions
- To develop applications using this simulators with end users including Fujifilm
- To release a 39-qubit quantum simulator by this September

Data relocation technique for quantum computation

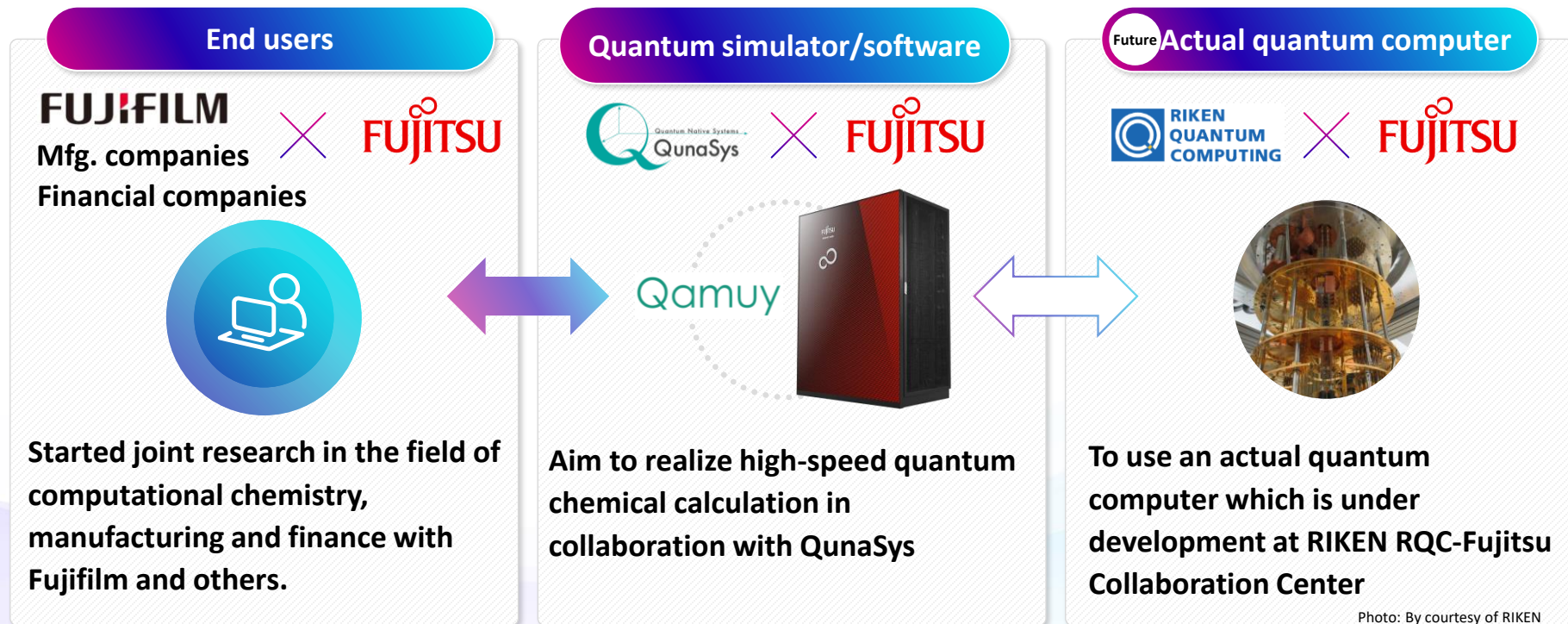
Have reduced communication time by rearranging the data in the order of gate operations on a parallel computer



**Twice-faster than JUQCS (GPU-base)
developed by Forschungszentrum Jülich**

Accelerating development of quantum applications by using quantum simulators

Advancing collaborations in the fields of materials, manufacturing, finance, etc.



About the Future

To release large-scale simulators and actual machines successively in order to solve societal problems

2022.9

To release a higher-speed and larger-scale 39 qubit quantum simulator

FY2023

To release a superconducting quantum computer (64 qubits) at the RIKEN RQC- Fujitsu Cooperation Center

FY2024~

To release of a larger-scale superconducting quantum computer (100 qubits or more) at the RIKEN RQC- Fujitsu Cooperation Center, and implement the error correction

FY2026~

To release a superconducting quantum computer with >1000 qubits



Fault-Tolerant Quantum Computer

FY 2020

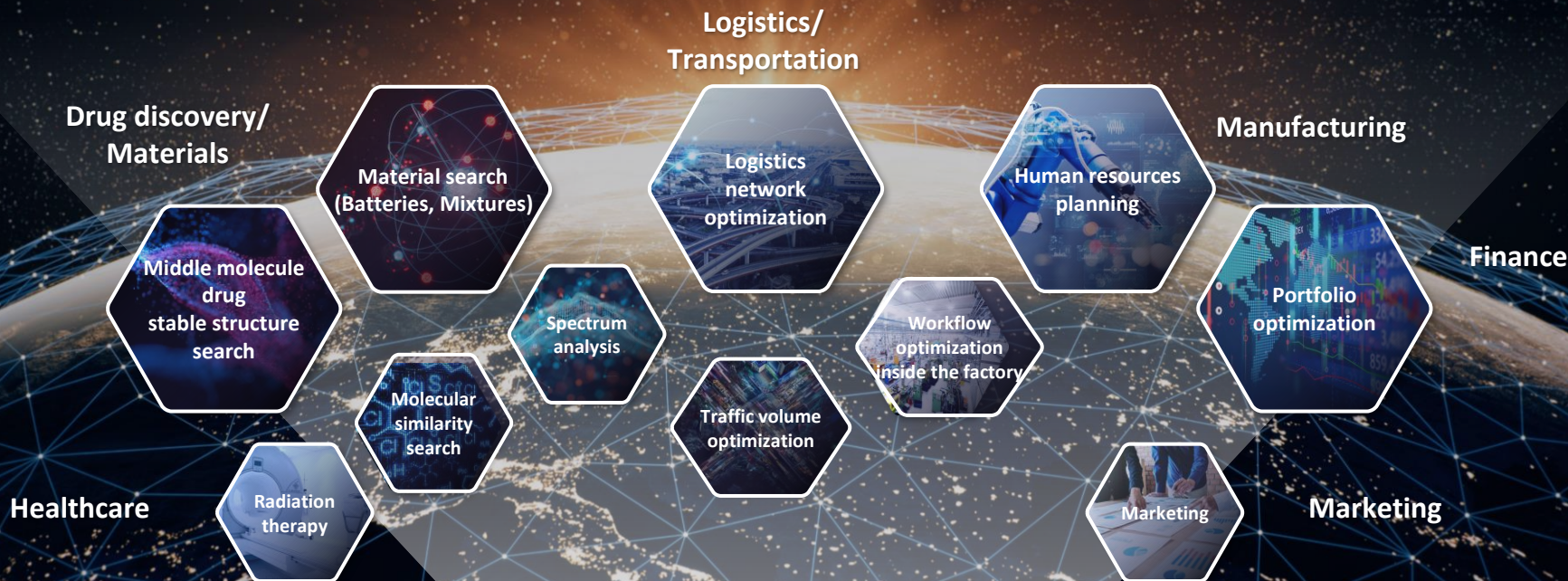
2030

Quantum-Inspired Computing: Digital Annealer

Application Areas of Digital Annealer

Commercialized as a system based on quantum-inspired technology
ahead of gate-type quantum computers

Now being used for solving various customer problems



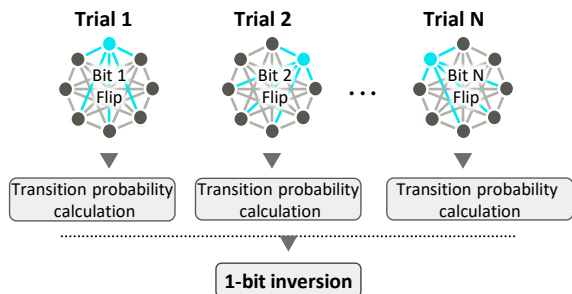
Strengths of Fujitsu's Digital Annealer

Background

- As it takes more time to apply quantum computing to practical problems, Fujitsu developed Digital Annealer (DA) as a quantum-inspired system
- DA has been used by many users due to technical superiority since its launch in 2018.

Proprietary technologies with advantages

- Hierarchical parallelization technique
- Technology for automatically adjusting constraint coefficients and annealing temperature
- Speedup technology using constraints of real-world problems to reduce its search target space

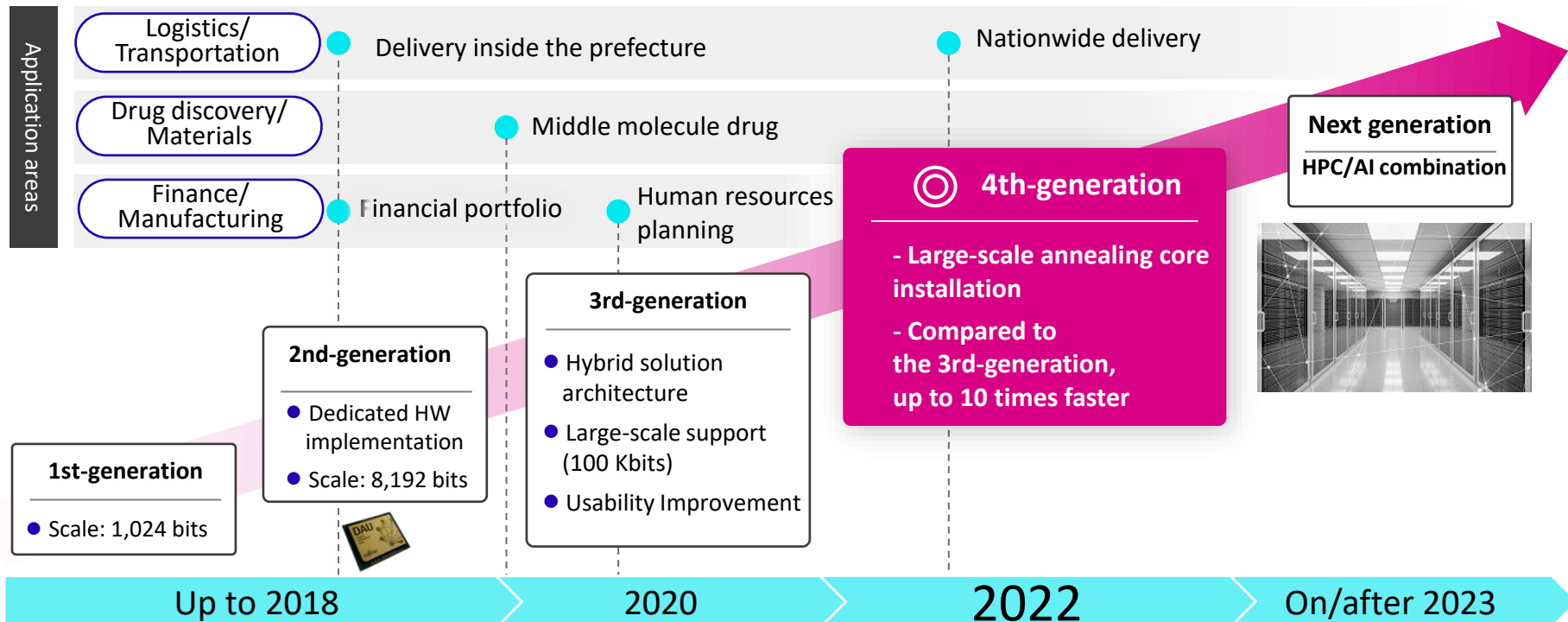


Achievements

- Number of cloud subscriptions: **131 (in Japan), 55 (outside Japan)**
- Started business application in many areas such as manufacturing, finance, and delivery planning**
- 34 press releases, including 10 with customers** including:
 - KDDI CORPORATION: Improving communication quality by optimizing base station settings
 - Showa Denko KK: Dramatically accelerating the search speed for optimal formation of semiconductor materials



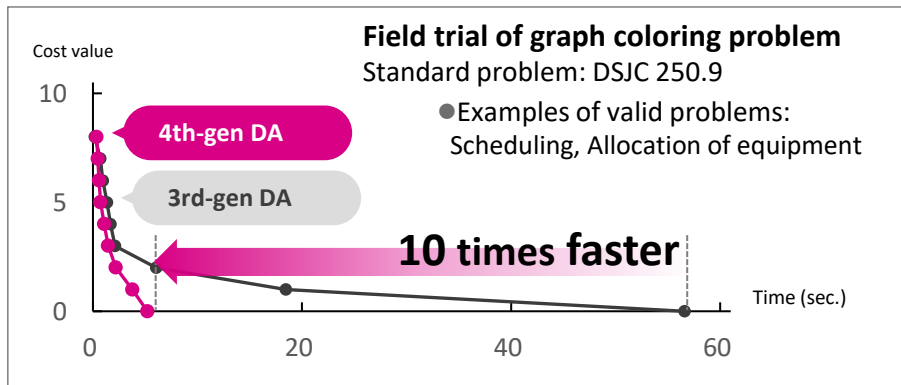
4th-Generation DA service was released in May



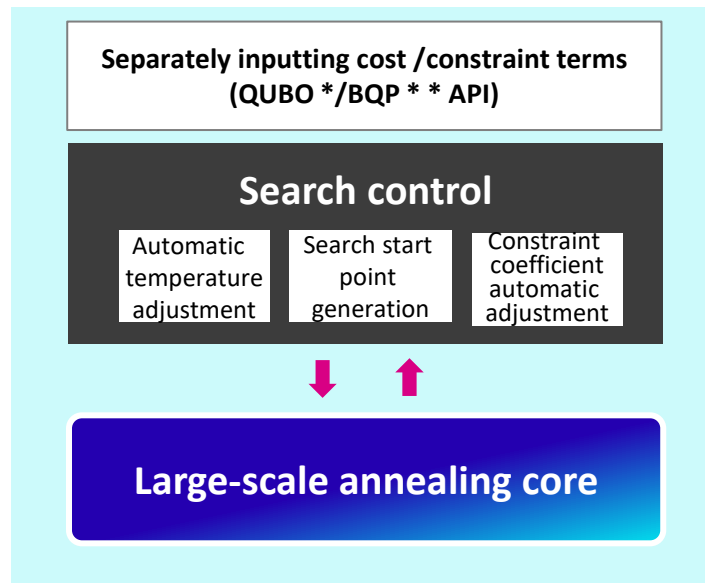
4th-Generation DA

Accelerated the processing speed further, while keeping excellent usability of the 3rd-Generation DA

- Features of the annealing core
 - Increased the target problem size to 100 Kbits and eliminated the need for partitioning a large-scale problem
 - Added the **constraint handling feature**
- Effect: Up to 10 times faster than 3rd-gen. DA



4th-Generation DA Configuration Diagram



* Quadratic Unconstrained Binary Optimization

** Binary Quadratic Programming

Comparison by Company



A large-scale annealing core gives Fujitsu a competitive edge in practical problem resolution

	Fujitsu [1]	D-Wave [3]	Toshiba [4]	Hitachi [6]	NEC [7,8]
Processor	Digital annealing unit, Multi-GPU	Quantum processing unit	FPGA, GPU	GPU	General-purpose vector processor
Basic search method/algorithm	MCMC ** Parallel tempering	Quantum annealing	Simulated bifurcation	Momentum annealing	Simulated annealing
Bit/Spin count	100,000 bits (1 million bits ^[2] by server parallelization)	Abt. 5,000 qubits	1 million bits	100,000 bits	100,000 bits
Degree of connection	Full connection	Sparse connection	Full connection	Full connection	Full connection
Coupling resolution	64-bit resolution	Analog (abt. 5-bit resolution)	2 to 32-bit resolution ^[5]	Undisclosed	Undisclosed
Constraint processing	Practical constraint handling Equality constraint (1way 1hot, 2way 1hot), Inequality constraint, Automatic coefficient adjustment	-	-	-	Equality constraint (1way 1hot)

** MCMC: Markov-Chain Monte Carlo

[1] <https://www.fujitsu.com/jp/group/labs/en/about/resources/tech/techintro.html>

[2] <https://pr.fujitsu.com/jp/news/2020/11/9.html>

[3] <https://www.dwavesys.com/solutions-and-products/systems/>

[4] <https://www.global.toshiba/jp/products-solutions/ai-iot/sbm.html>

[5] https://www.itmedia.co.jp/news/articles/1907/30/news030_3.html

[6] <https://www.hitachi.co.jp/rd/news/topics/2019/0830.html>

[7] <https://jpn.nec.com/nec-vector-annealing-service/index.html?nid=jpntop211051>

[8] Takano et al., IEICE Technical Report CAS 2019 -47, MSS 2019 -26

* According to survey by Fujitsu

© 2022 Fujitsu Limited

Applications: IT Drug Discovery

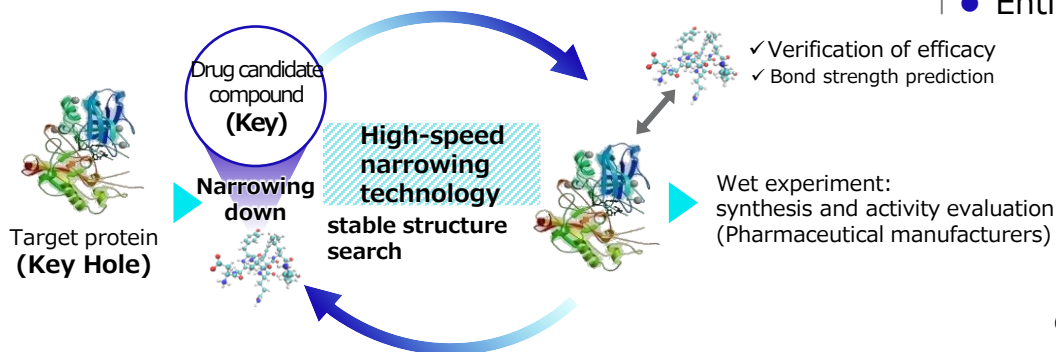
The Need for IT Drug Discovery:

- The experimental search for new drugs requires an enormous amount of trial and error
- Designing and evaluating drug candidates on a computer can significantly reduce the time and cost of new drug development

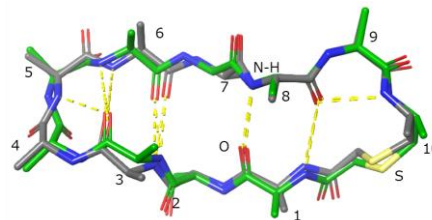


Searching for stable structures of peptides, which are candidates for mid-molecular drugs, is difficult

➡ High-speed screening technology is developed using **DA + HPC** in collaboration with PeptiDream Inc.*



- The effectiveness of DA and HPC in finding stable structures was verified.
- Experimental and calculated structures match with high accuracy of 0.73 Å in the mean square error
- Entire calculation can be completed in almost one night



Gray: experimental results
Green: calculation results

Comparison of experimental and calculated structures of cyclic peptides

Use Cases

Finance

Melco Investments, Inc.

Contribute to the steady growth of assets under management portfolio risk and return analysis

- Calculates in 10 minutes combinations of hundreds of stocks that would require an enormous amount of computation with conventional computing



Logistics

Toyota Systems Corporation

Optimization of a large-scale logistics network for parts required for automobile manufacturing

- Quickly search for combinations of routes that satisfy the requirements among candidate groups of 3 million or more routes
- Potential 2 ~ 5% reduction in total logistics costs



Seating allocation

Berlin Olympic Stadium Nürburgring

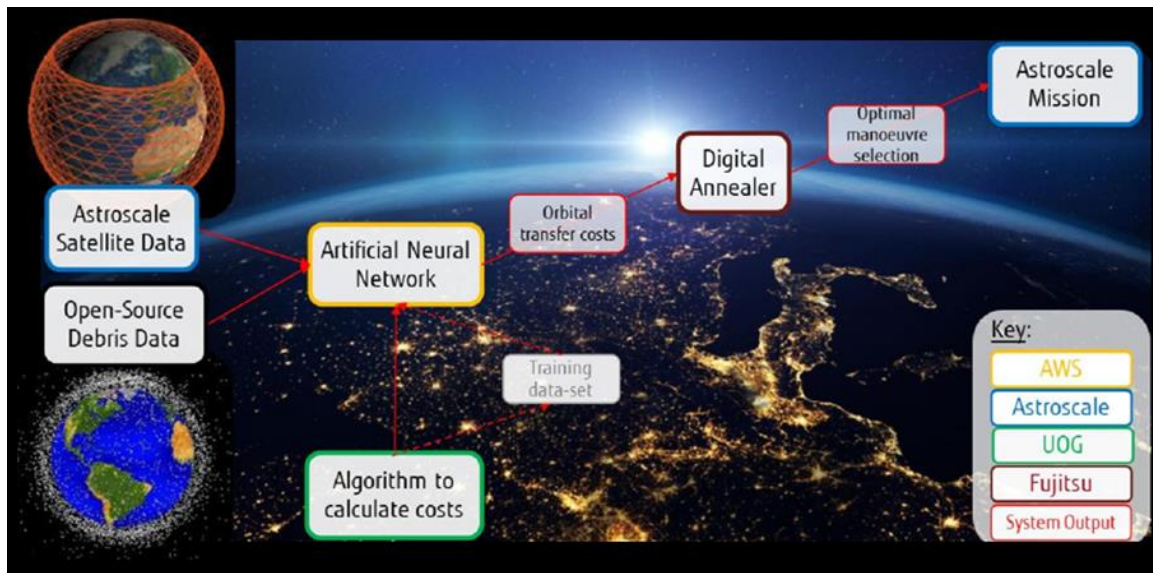
High-speed optimization of spectator seating arrangement, contributing to safe operation and profitability of sporting events

- Allocation of spectator seats in groups of 1 to 4 depending on the event with social distance
- Possibility for 60% increase in seating allocation



Optimization of spacecraft operation plans for space debris recovery

- The use of the digital annealer reduced the time to plan to **1/170000** compared to plans that were manually developed by specialized engineers.
- Plans were obtained that could reduce the fuel consumption of the recovery spacecraft by **18%** and the operation time by **25%**.



Results of DA validation

Optimizer	Expert	Beta
Satellite Options	100	100
No. of Captures	4	4
Capture Sequence	24 , 1 , 29 , 54	64 , 1 , 100 , 44
Compute Time Seconds	14400	0.083
Fuel Use (Kg)	30.7	24.9
MissionTime Days	2307	1717

Source: <https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/284/>

Concluding Remarks

We work on research and development of quantum computing in order to solve societal problems in the future

It will take some more time for quantum computer to become capable of solving real-world problems. We continue to develop technologies to realize a practical quantum computer and work together with end users to develop its applications.

Digital Annealer, a quantum inspired technology, is already in practical use and has a lot of use cases. We continue to work on customers' problems by using our DA and HPC technologies.

Thank you

