A Future with Quantum Computing Envisioned by Fujitsu

Shintaro Sato

Head of Quantum Laboratory

Fujitsu Research, Fujitsu Limited

Outline

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

FUJITSU

Our Purpose

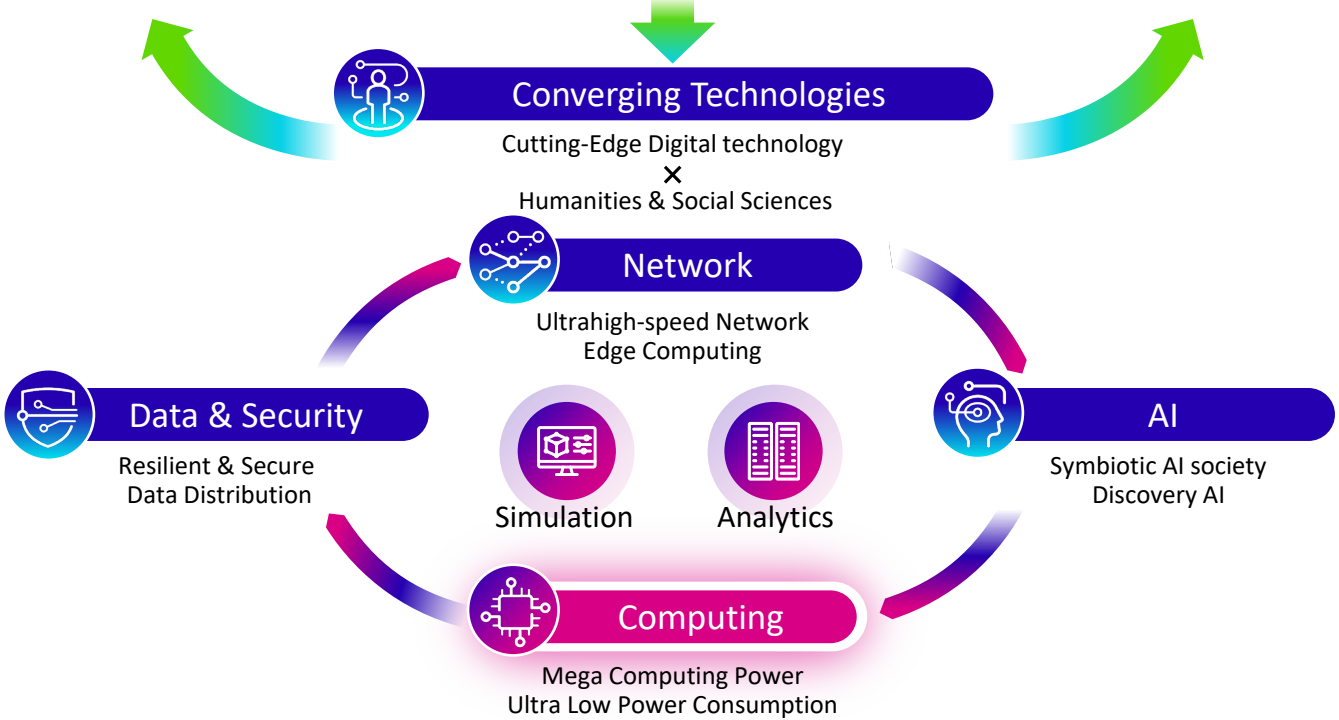
To make the world more sustainable by building trust in society through innovation

Technology Vision

Fujitsu Uvance

Sustainable Manufacturing | Consumer Experience | Healthy Living | Trusted Society

Digital Shifts | Business Applications | Hybrid IT



- Human Sensing
- Social Digital Twin

- Open Network
- Intelligent NW Orchestration
- Green Technologies

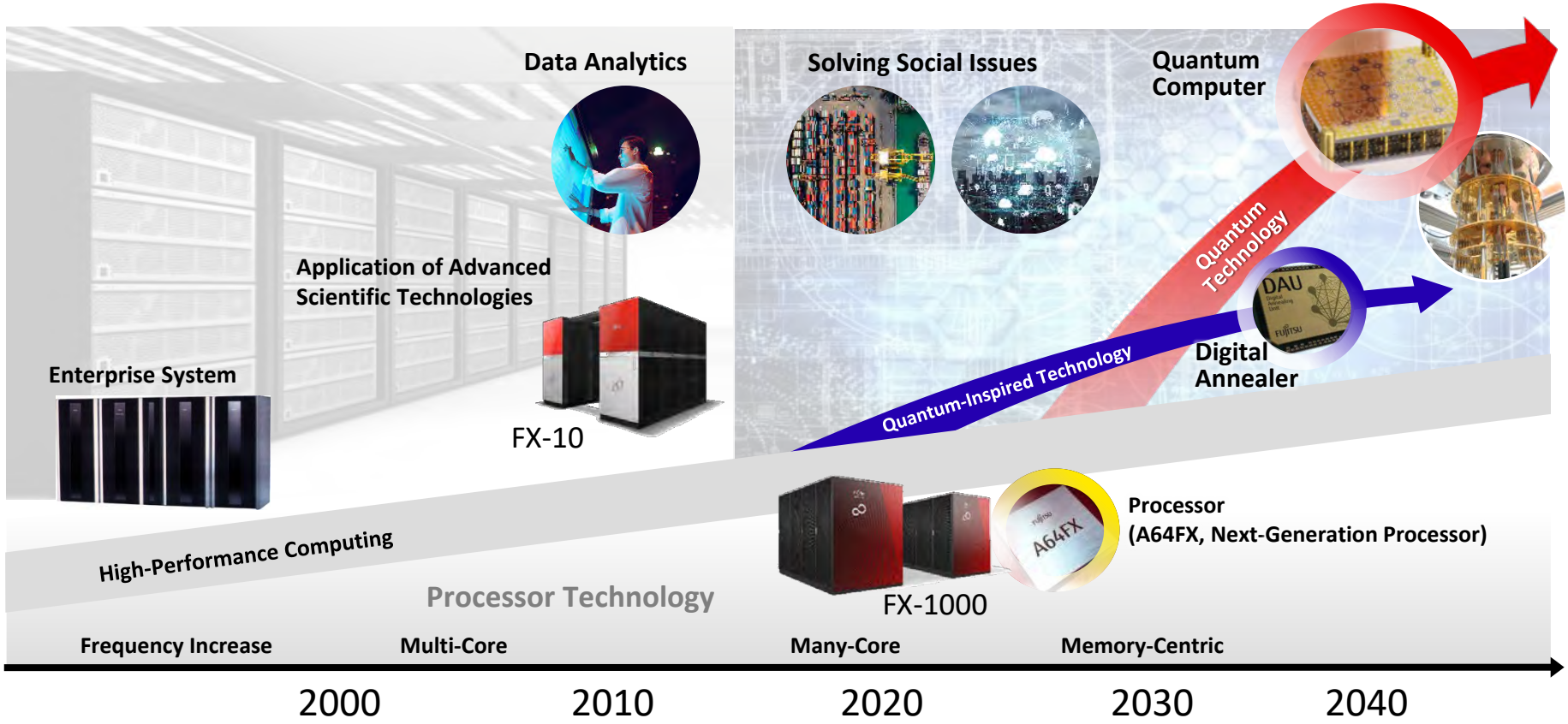
- AI ethics & Explainable AI
- AI large-scale simulation

- Digital trust technology
- Blockchain

- HPC
- Quantum Inspired
- Quantum Computer

Computing Technology at Fujitsu

(By courtesy of RIKEN)



Computing as a Service Vision

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

Application

Platform

AI | Simulation | Data Analytics

Computing as a Service

Low power consumption | Great computing power | Trust platform

Available on Public Cloud

Middleware

OS

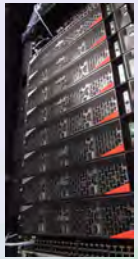
Hardware

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

- Diamond
  - Fujitsu
- Superconducting
  - Fujitsu
  - Google
  - IBM
  - Intel
- Si
  - Intel
- Trapped ion
  - Quant-inuum
- Photon
  - PsiQuantum

Ising Machine Based System
For combinatorial optimization problems

- Quantum Annealing
  - Superconducting Circuit
    - NEC
    - D-Wave Systems
- Laser Network
  - Optical Parametric Oscillation
    - NTT
- Logic Gate
  - CMOS circuit
    - Hitachi
    - Toshiba
    - Fujitsu

Digital Annealer

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Quantum Computing

What is a Quantum Computer?

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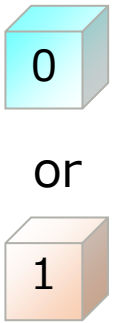
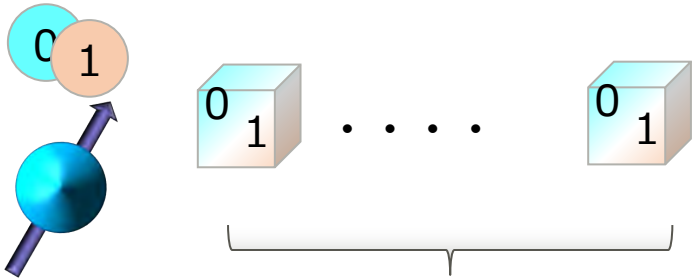
Achieve drastic speed-up of calculations using of quantum mechanical effects

Traditional bit



Quantum bit : superposition of states of “0” and “ 1 ”



Traditional : Calculating 2^N states one by one

Quantum :
- Calculating 2^N states simultaneously
- Achieve exponential acceleration by finding solutions through quantum mechanical effects

Problems Expected to be Solved

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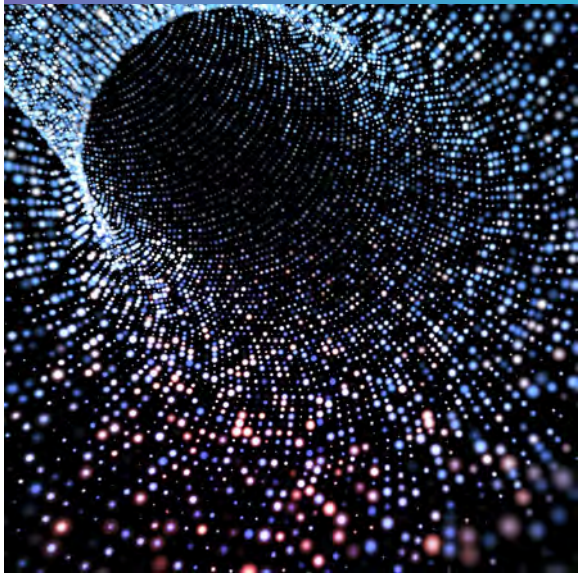
Problems requiring enormous number of calculations, such as ones related quantum chemistry and complex systems

Discovery of new materials and drugs

Prediction for prices of financial products

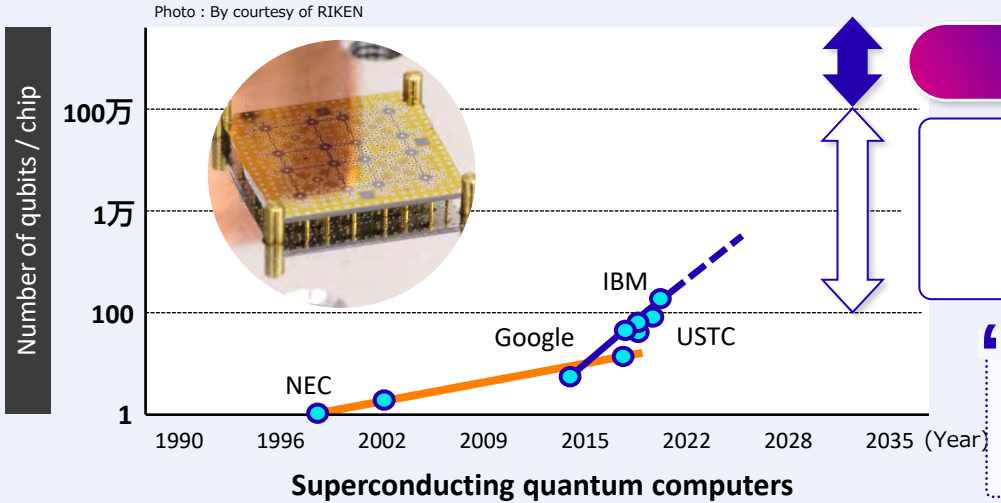
Discovery of new physical principles



Current Status and Challenges (1)

Need more than a million qubits for fault tolerant computation

- Current number of qubits is just over 400
- For the time being, aim to apply to specific applications with small systems



Fault-Tolerant Quantum Computer

NISQ* Computer
for limited applications

*NISQ : Noisy Intermediate-Scale Quantum

"A full-fledged quantum computer, with 1000 logical qubits, might end up containing many millions of physical qubits", Adrian Cho, Science, 2020/7/9

Current Status and Challenges (2)

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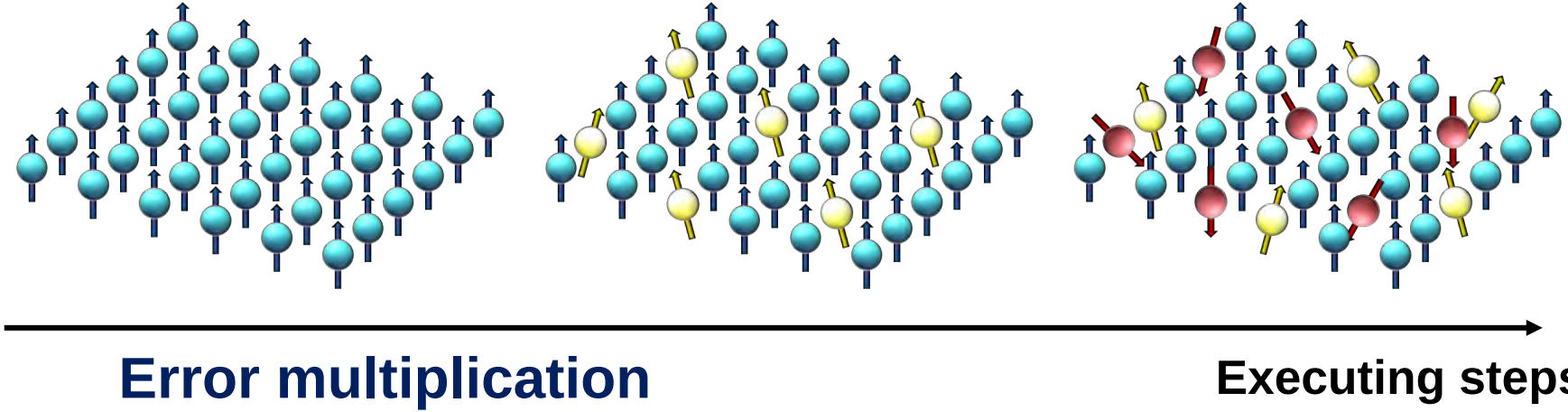
Needs software technologies for error suppression or correction

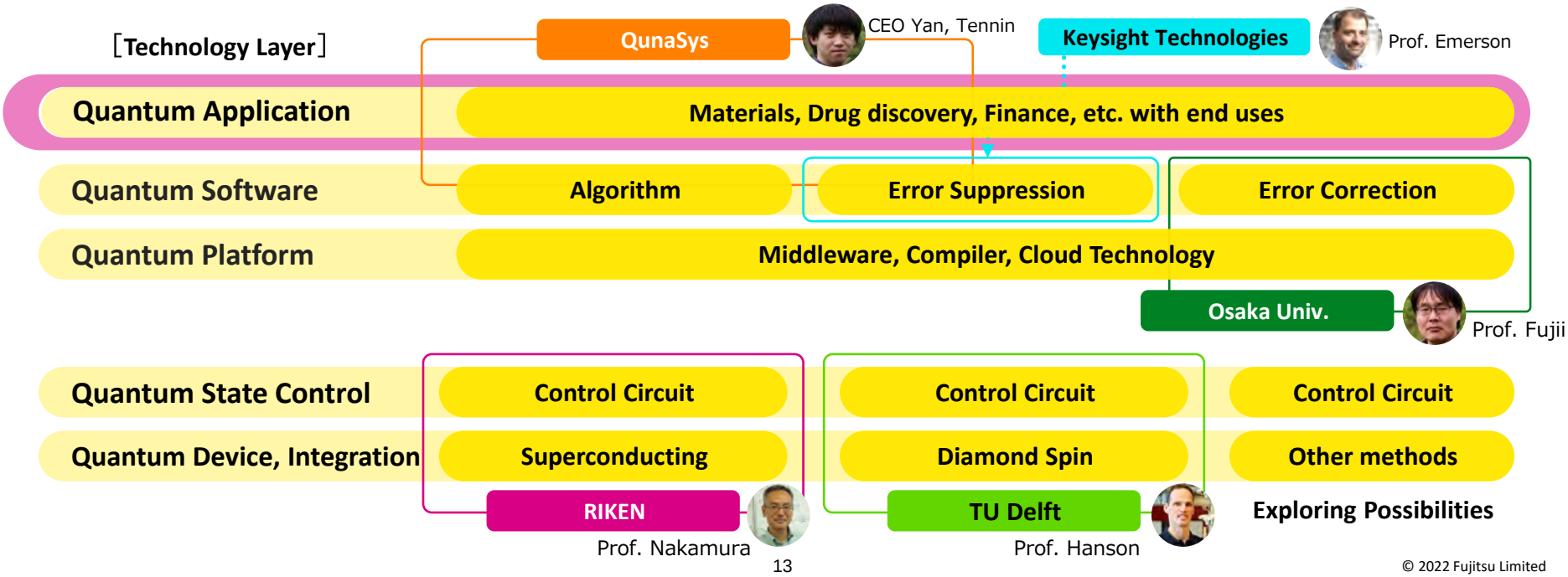
- Error rate per quantum operation is less than 1%, however the errors are piled up by the number of qubits and executing steps.



※Relative errors are schematically described by arrows deviating from the straight above

Fujitsu's Strategy for Quantum Computing

- Cover all the technology with world's leading research institutions
- Put emphasis on software technologies, whiling 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

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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

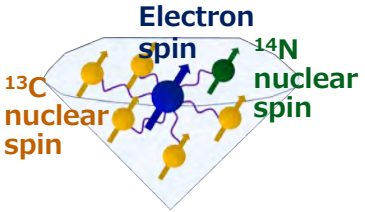
Diamond Spin

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)



Diamon-spin module

Software Technology

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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

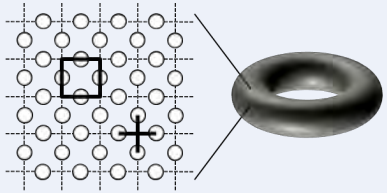
Prof. Emerson

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

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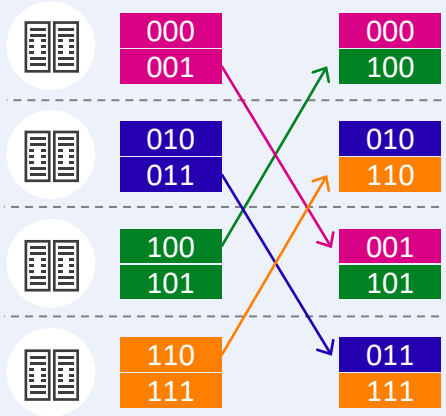
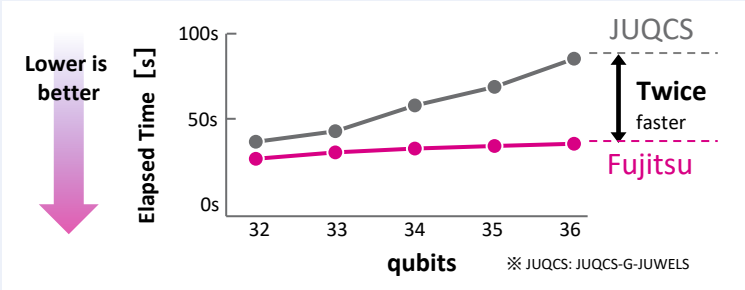
Developed the world's fastest 36-qubit quantum simulator by using A64FX processors developed for Fugaku last March

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

Imamura, et al., arXiv:2203.16044

Accelerating development of quantum applications by using quantum simulators

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

End users

FUJIFILM × FUJITSU

Mfg. companies
Financial companies

Started joint research in the field of computational chemistry, manufacturing and finance with Fujifilm and others.

Quantum simulator/software

Quantum Native Systems QunaSys × FUJITSU

Qamuy

Aim to realize high-speed quantum chemical calculation in collaboration with QunaSys

Future Actual quantum computer

RIKEN QUANTUM COMPUTING × FUJITSU

To use an actual quantum computer which is under development at RIKEN RQC-Fujitsu Collaboration Center

Photo: By courtesy of RIKEN

About the Future

FUJITSU

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

2022.9 Have developed 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

Fault-Tolerant Quantum Computer

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

FY 2020 — 2030

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Quantum-Inspired Computing: Digital Annealer

Application Areas of Digital Annealer

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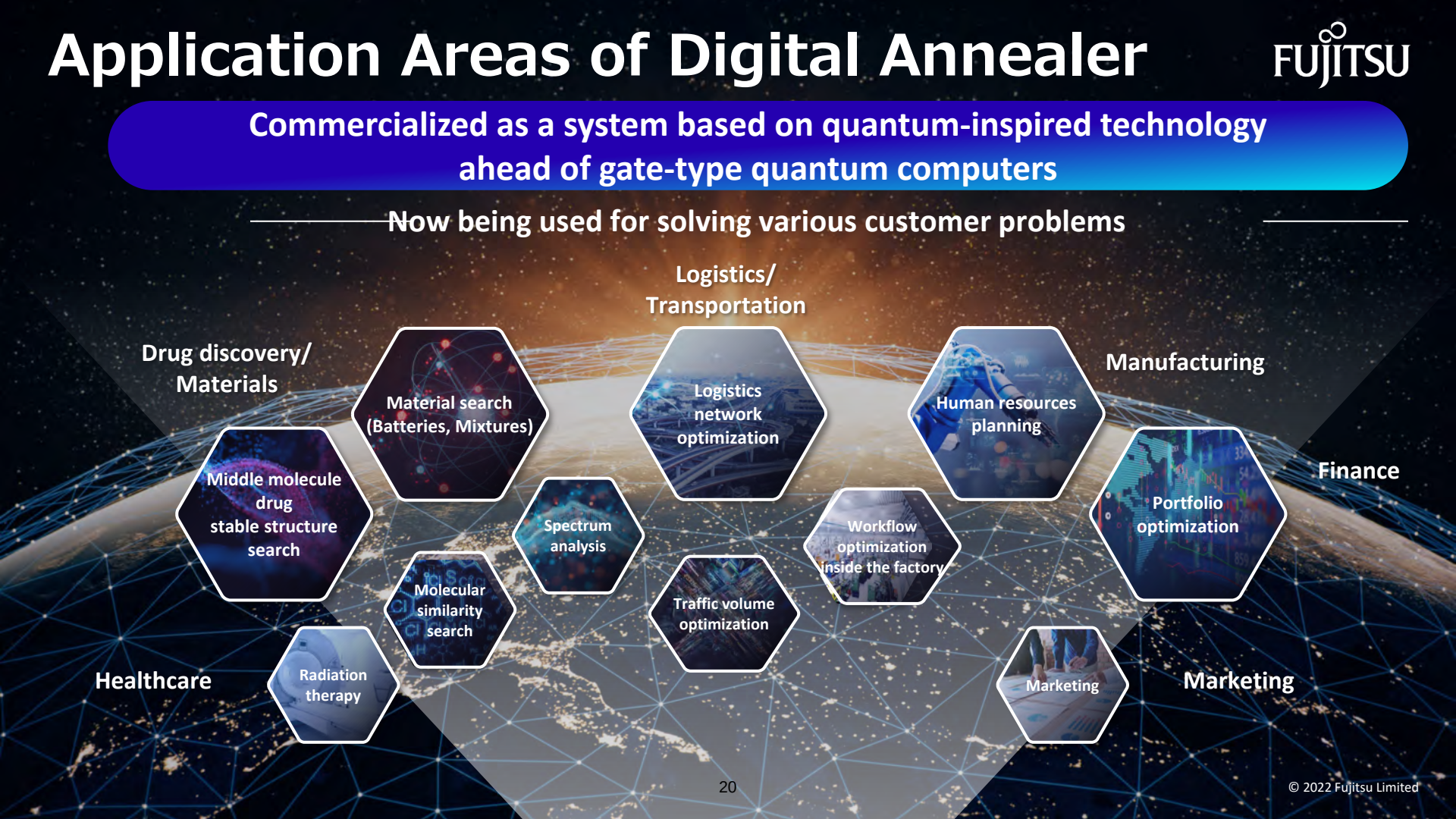
Commercialized as a system based on quantum-inspired technology ahead of gate-type quantum computers

Now being used for solving various customer problems



Strengths of Fujitsu's Digital Annealer

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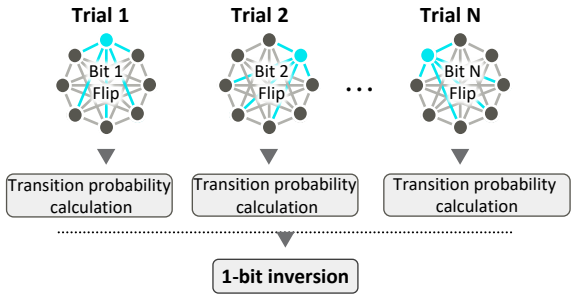
Background

- 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

Roadmap

*Roadmap content is subject to change without notice.

4th-Generation DA service was released in May

Application areas

- Logistics/ Transportation
- Drug discovery/ Materials
- Finance/ Manufacturing

Delivery inside the prefecture

Nationwide delivery

Middle molecule drug

Financial portfolio

Human resources planning

1st-generation

- Scale: 1,024 bits

2nd-generation

- Dedicated HW implementation
- Scale: 8,192 bits

3rd-generation

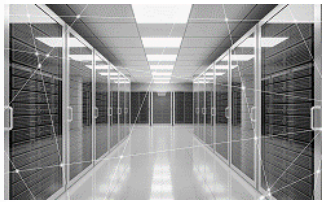
- Hybrid solution architecture
- Large-scale support (100 Kbits)
- Usability Improvement

4th-generation

- Large-scale annealing core installation
- Compared to the 3rd-generation, up to 10 times faster

Next generation

HPC/AI combination



Up to 2018 | 2020 | 2022 | On/after 2023

4th-Generation DA

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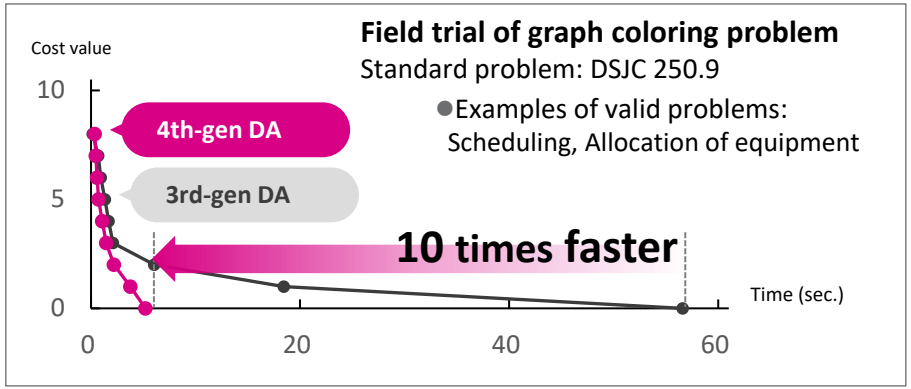
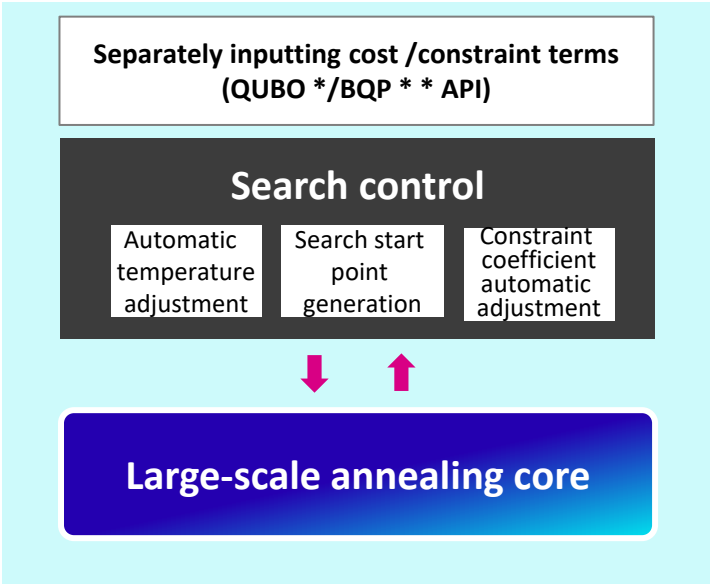
Accelerated the processing speed further, while keeping excellent usability of the 3rd-Generation DA

- 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

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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

Applications: IT Drug Discovery

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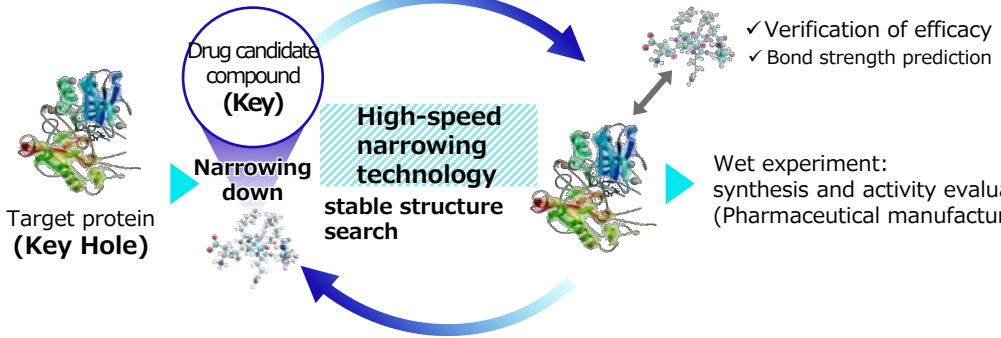
The Need for IT Drug Discovery:

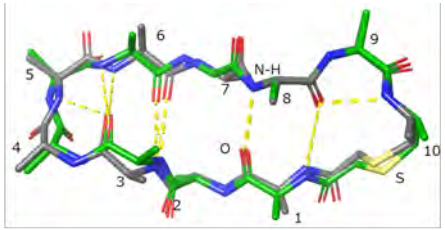
- The experimental search for new drugs requires an enormous amount of trial and error
- Designing and evaluating drug candidates on a computer can significantly reduce the time and cost of new drug development

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

➡ High-speed screening technology is developed using **DA + HPC i**n 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

* https://www.fujitsu.com/global/about/resources/news/press-releases/2020/1013-01.html

Use Cases

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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

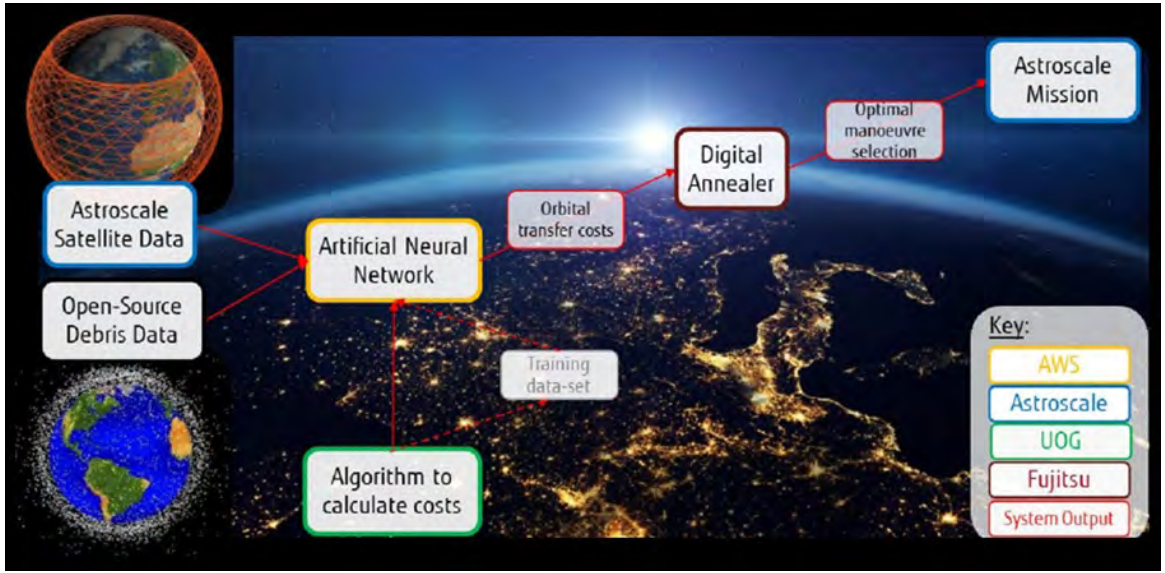
Berlin Olympic Stadium Nürburgring

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%.**



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

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

Concluding Remarks

FUJITSU

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

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