MPSoC2024

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Outline of Quantum Inspired Annealing Technology

Masanao Yamaoka
Senior Manager
Edge Computing Research Department
Quantum Application Promotion Office
Hitachi, Ltd. Research & Development Group

7/11/2024

Outline

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- Background
- Annealing machines
- Use cases of annealing machines
- Future of annealing machine

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For Social Innovation

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Optimization processing in various fields

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Environmental improvement

Smart grid control

Delivery route optimization

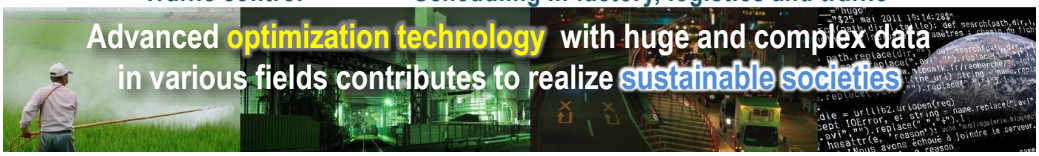
Traffic control

Economical growth

Stock price forecast

Insurance portfolio

Scheduling in factory, logistics and traffic



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Calculation time and power for new applications

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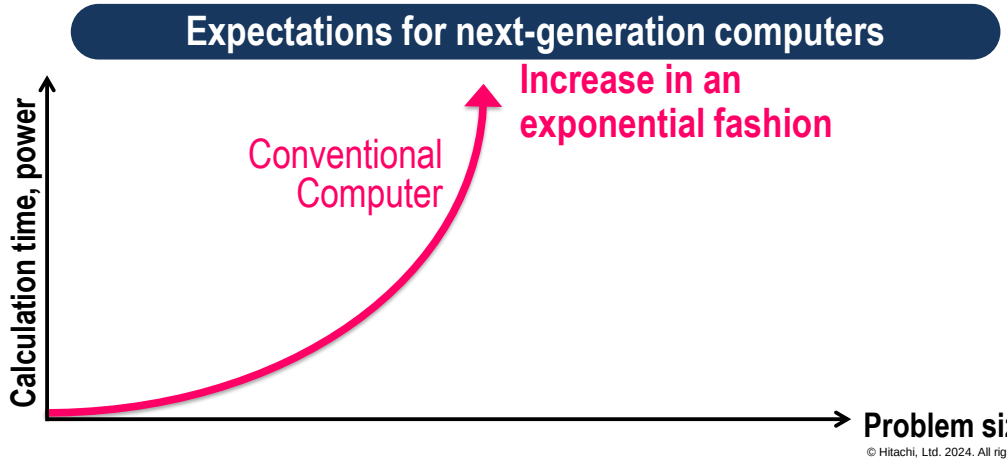
- New applications such as optimization problems require larger computation power when problem size becomes larger



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Annealing technology and quantum computing

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- **Quantum computer is destructive technology, but still in research phase**
- **Annealing machines are now in practical phase**

	Classical		Quantum	
	Gate type	Annealing type	Quantum annealing	Gate-type quantum computer
Feature	Sequential	Parallel	Massively parallel	
Application	General	Optimization	Optimization	Multipurpose
Scale	bit		Qubit	
	-	2.25M (2021)	About 5,000 (2020)	About 128 (2022)
Software	Various	Limited algorithm		
Product	CPU, GPU, etc.	CMOS Annealing (Hitachi) etc.	Coherent Ising Machine (NTT/Impact)	Quantum Annealing Machine (D-Wave)	Quantum Computer (IBM, Google, Hitachi, etc.)

Natural computing with Ising model

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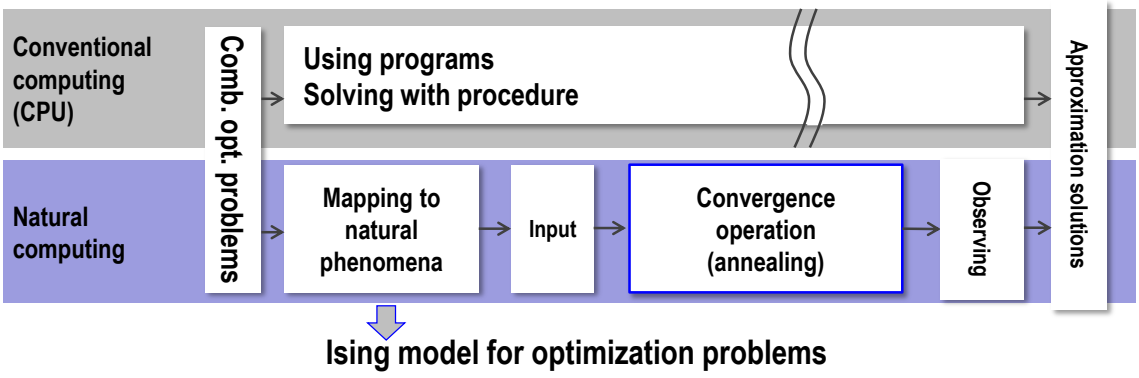
- Natural computing can be used to solve combinatorial optimization problems
- Mapping combinatorial optimization problems to Ising mode
- Solution acquired by annealing operation of Ising model



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Calculation time and power reduction by new computing

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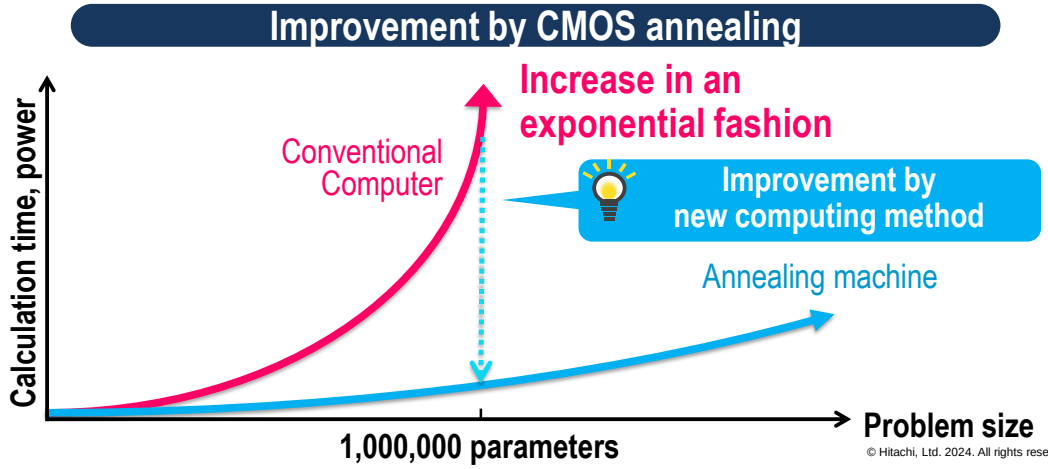
- For complex and large-scale social systems, reduction of calculation time and power is necessary



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Ising model and annealing machines

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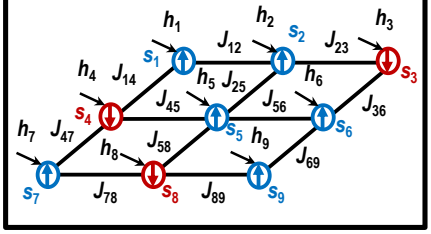
- The basis of the technology is to perform optimization calculations assuming the natural phenomenon of the ground state of the Ising model.

Cost function of opt. problems

↓

Formulation to Ising model

$$H(\sigma) = -\sum_{i,j=1,i<j}^{N} \sigma_i J_{ij} \sigma_j - \sum_{i=1}^{N} h_i \sigma_i$$



Optimization problems	Ising model
Cost function	Energy $H(\sigma)$
Input parameters	・Interaction: J_{ij} ・External field: h_i
Solution	Spin value σ_i ↑ +1/selected ↓ -1/unselected

Ground state of Ising model
= Optimum solution of problems

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Annealing machine comparison

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- Several non-quantum annealing machine have been developed at Japanese companies.

	Hitachi		D-Wave	NTT	Fujitsu	Toshiba	Tokyo Tech
Algorithm/ Method	SA	MA	QA	CIM	SA/PTSA	SB	SCA
Implementation	ASIC / FPGA	GPU	SQUID	Laser+ FPGA	ASIC / FPGA	GPU	ASIC
Number of parameters	2.3M	100k	5k	2k	8k	100k	2k
Spin-spin connection	Partial	Full	Partial	Full	Full	Full	Full

Partial connected implementation: used for real problem; traffic control, image processing
Fully connected implementation: used for virtual applications; scheduling, portfolio optimization

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CMOS annealing

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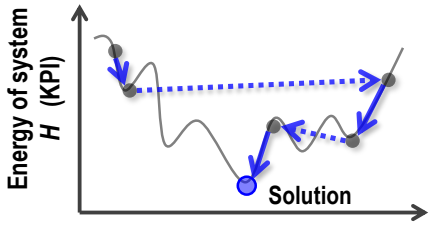
- Only digital operation, spin status stuck at local minimum status
- To avoid local minimum sticking, random status transition used
- Optimum solution not always acquired



n: number of spins

- Transition to lower energy (adjacent spin interaction)
- Avoidance of local minimum (random transition)

In-memory computing for Ising model

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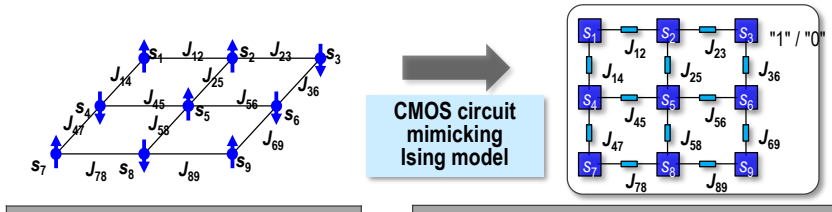
- Mimicking physical Ising model with in-memory structure
- Spin status updated by logic circuits implemented in memory



Ising model	CMOS
Spin status s_i, +1/-1	Memory "1"/"0"
Interaction J_{ij}	Interaction coefficient: memory Interaction operation: logic circuits

Fabrication results: CMOS annealing chip

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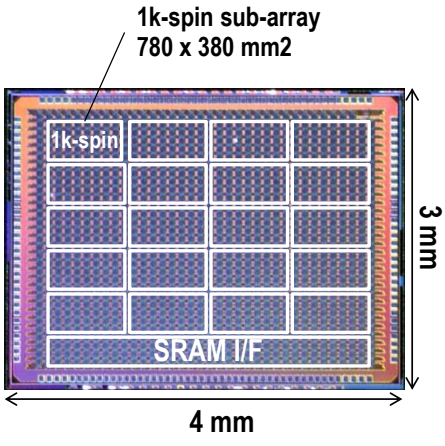

Items	Values
Number of spins	20k (80 x 128 x 2)
Process	65 nm
Chip area	4x3=12 mm^2
Number of SRAM cells	260k bits Spin value: 20k bits Interaction coefficient: 240k bits
Memory IF	100 MHz
Interaction speed	100 MHz
Operating current of core circuits (1.1 V)	Write: 2.0 mA Read: 6.0 mA Interaction: 44.6 mA

Card-size CMOS annealing for edge devices

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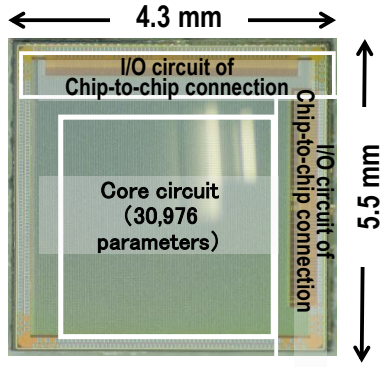
- Prototype of 30-k spin annealing chip in 40 nm CMOS process
- Card sized CMOS annealing machine equipped with 2 chips

CMOS annealing
（2×30,976 parameters）



9-chip connected CMOS annealing machine

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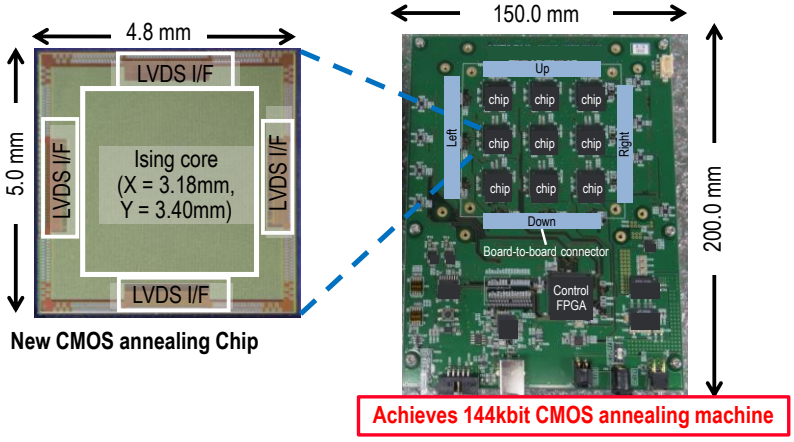
- New CMOS annealing chip showing infinite expansion
- The large size combinatorial optimization problems can be solved



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Worked as one annealing machine with 9 chips

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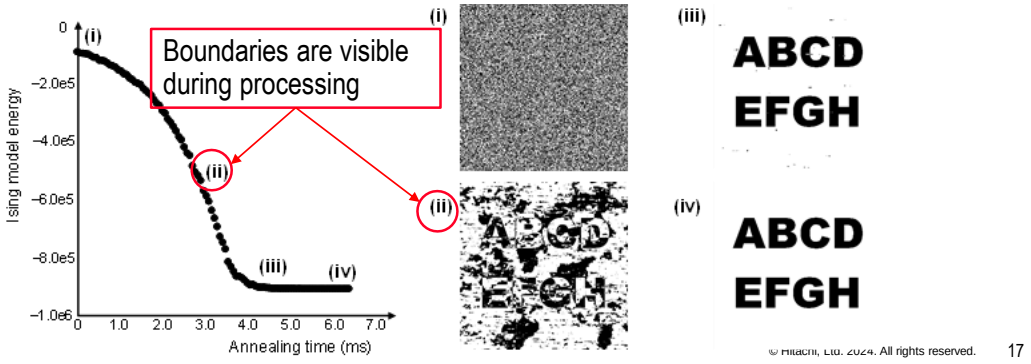
- Set to show the original image “ABCDEFGH”after processing the MAX-Cut problem
- Annealing was performed on a 9-chip connection board, and the performance as one machine was shown.



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Larger prototype with 2.25Mbits

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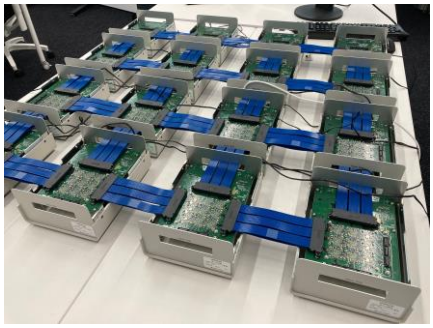
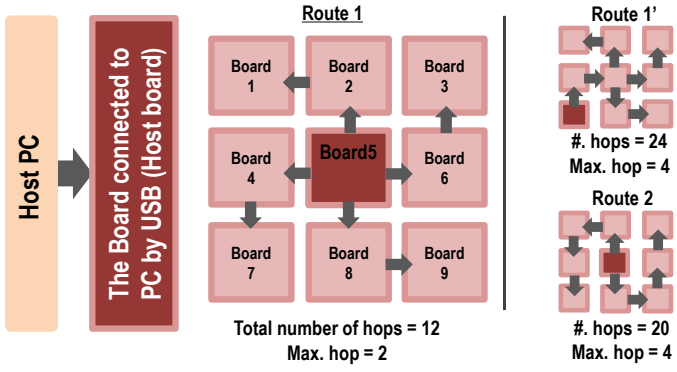
- 16 CMOS annealing boards operate as one 2.25Mbit CMOS annealing machine





Two types of CMOS annealing

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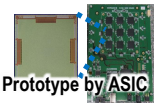
- Two implementations of CMOS annealing for different problems

	CMOS annealing	
Algorithm	Momentum Annealing (MA)	Simulated Annealing (SA)
Implementation	GPU	ASIC/FPGA
Variable connection	Fully connected	Partially connected
Number of variables	100,000	2,350,000
Suitable problem	Scheduling optimization Portfolio optimization	Reduction of traffic congestion Image noise removal

Implemented on GPU

Verification machine by ASIC



Fully-connected CMOS annealing

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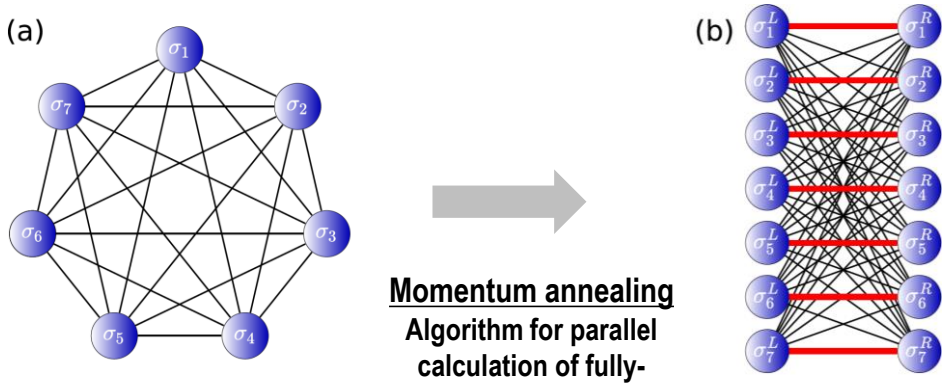
- **Fully-connected CMOS annealing is realized on general GPU by algorithmic Momentum annealing technique**



Momentum annealing
Algorithm for parallel calculation of fully-connected spins

Algorithm performance evaluation

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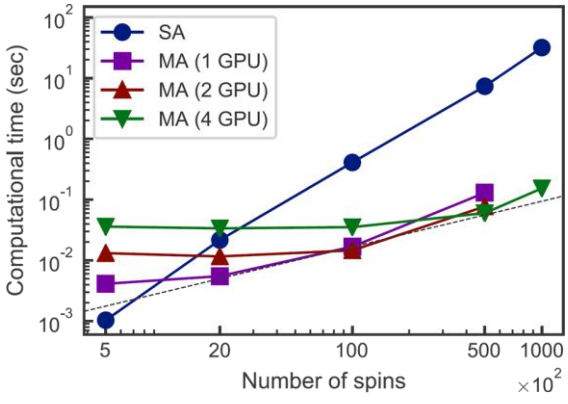
- **As the problem scale increases, the difference in calculation time between SA and MA increases.**



Time to reach the solution search with the same accuracy as the solution obtained by the SG method
SG method: An abbreviation for Sahni-Gonzales Algorithm, a kind of greedy method.

Experimental results of fully coupled 100,000-spin Ising model

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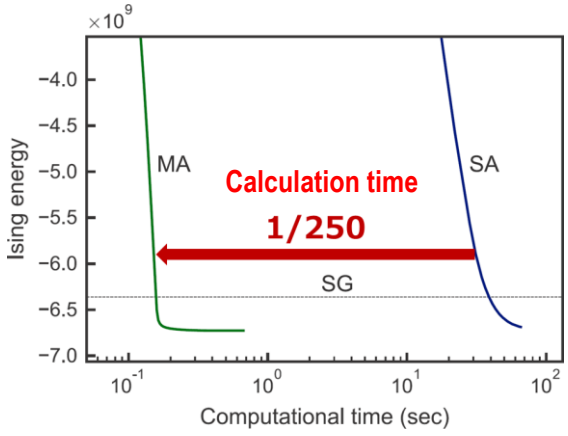
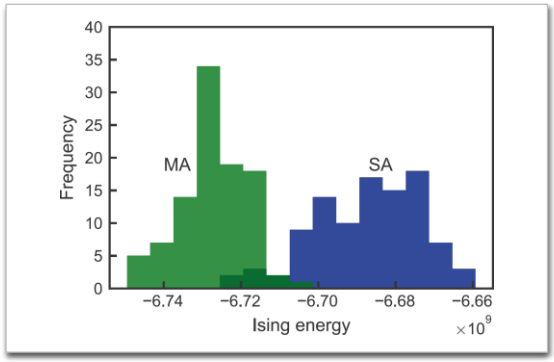
- **When the number of spins is 100,000, the calculation time is 1/250 compared to SA**





- SA: Running parallel programs using the optimal number of threads on IBM POWER8
- MA: Executed by NVIDIA Tesla P100 x 4 connected to NV Link

Relaxed MA for continuous variables

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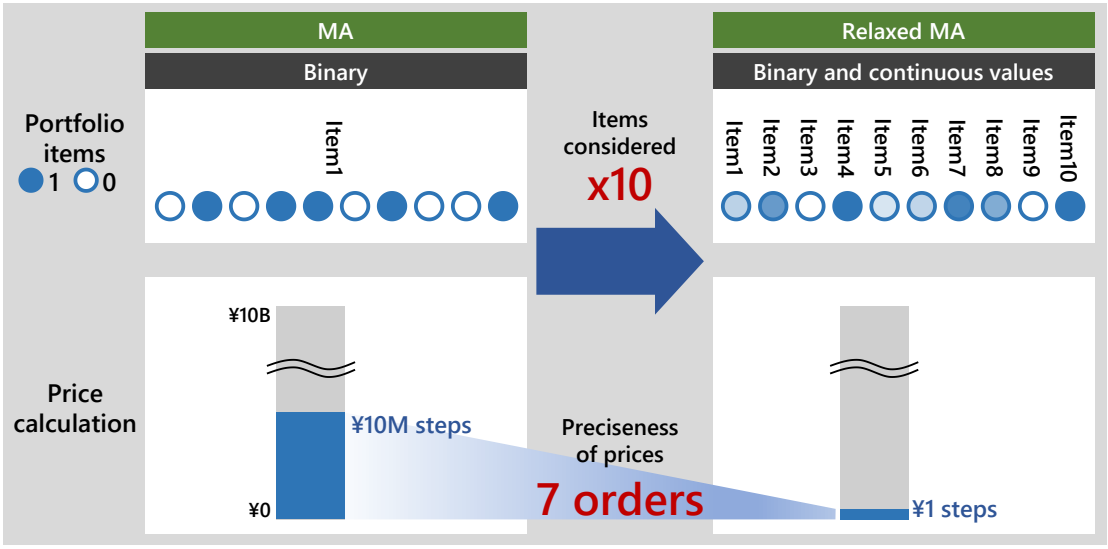

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- **Use cases of annealing machines**
- Future of annealing machine

Toward application to social innovations

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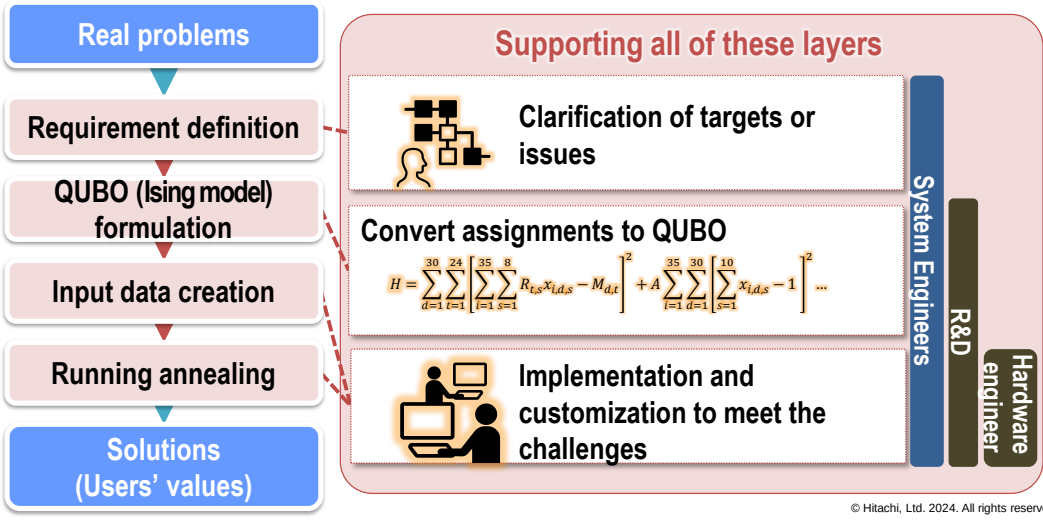
Technical and business skill sets accelerate the practical application



Shift scheduling with annealing machine

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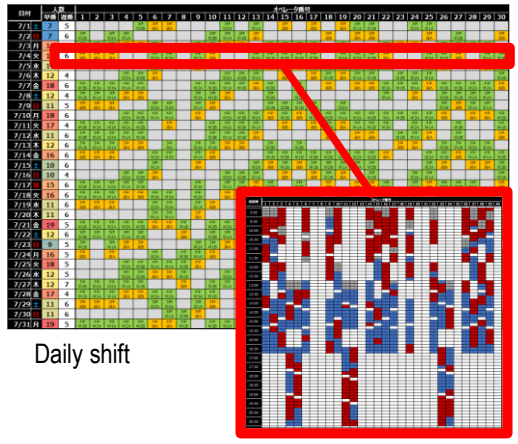
● It is possible to create a large-scale work shift while satisfying various requests.

Profit
- With the minimum required staff
- Allocate the extra time for other tasks

Customer Sutisfaction
- Don't keep customers waiting
- Skill placement to reduce call forwarding

Staff Satisfaction
- Consider the operator's wishes
- Prohibit early shifts after late shifts

Low
- Maximum number of working days
- Forbid long-term work



Daily shift

Time unit shift

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Collaboration with users for work shift optimization

● Started commercialization of work-shift optimization solution

Aug. 26th, 2022
KDDI Evolva, Inc.
KDDI CORPOLATION
Hitachi, Ltd

Quantum-related technology shortens work shift creation time by more than 5 hours, successful in business verification

KDDI Evolva, Inc. (Head office: Shinjuku-ku, Tokyo, President: Hajime Wakatsuki, KDDI Evolva below), KDDI CORPOLATION(Head office: Chiyoda-ku, Tokyo, President: Makoto Takahashi, KDDI below) and Hitachi, Ltd(Head office: Chiyoda-ku, Tokyo, President: Keiji Kojima, Hitachi below) created work shift of call center staffs engaged in message support work automatically by using quantum-related technology*1 at Jun. 2022, then verified (The verification below) the application of it to actual work at Jul. 2022.
According to the verification, we confirmed that managers can shorten time to work shift creation by more than 5 hours. Furthermore, in a survey conducted after the application of actual work, more than 90% staffs respond positive opinion. The three companies aim to commercialize it from FY2023 onward.

Hitachi news release Aug. 26, 2022: https://www.hitachi.co.jp/New/cnews/month/2022/08/0826.html

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Example of portfolio optimization

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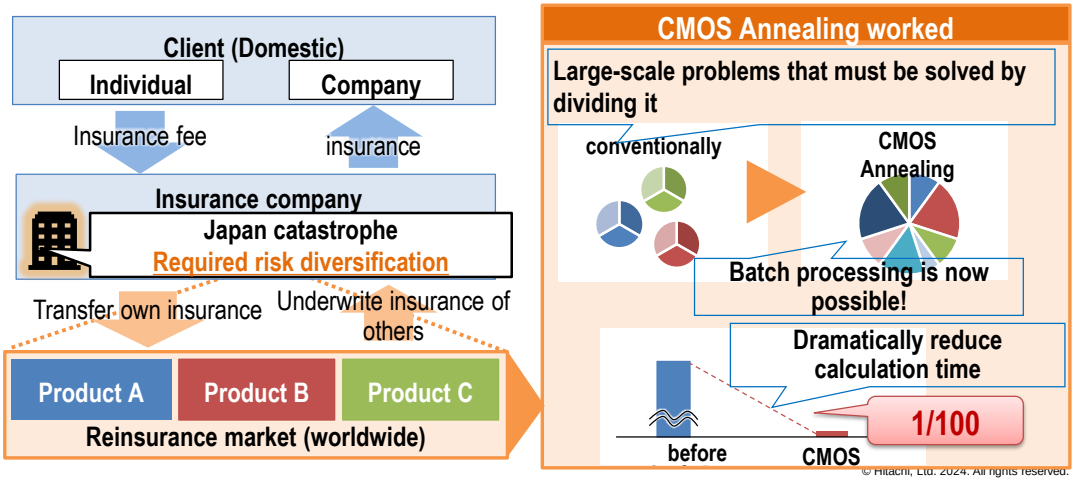
- Optimization of a large non-life insurance portfolio in the reinsurance market



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Collaboration with users for reinsurance portfolio optimization

- Sompo Japan Insurance Inc. has started applying CMOS annealing at a practical level to optimize reinsurance portfolio

Mar. 29th, 2022
Sompo Holdings, Inc.
Sompo Japan Insurance Inc.
SOMPO RISK MANAGEMENT
Hitachi, Ltd

Sompo Japan started to use the pseudo-quantum computer to insurance underwriting in business

Sompo Holdings, Inc. (Group CEO: Shogo Sakurada, Sompo Holdings below), Sompo Japan Insurance Inc. (President: Giichi Shirakawa, Sompo Japan below), SOMPO RISK MANAGEMENT(President: Junichi Sakurada, SOMPO RISK below) and Hitachi, Ltd(President: Keiji Kojima, Hitachi below) agreed to start practical use the CMOS annealing*1 that simulates the quantum computer developed by Hitachi to insurance underwriting of Sompo Japan. It is the first case of applying the pseudo-quantum computer to practical use of Insurance company's core business*2.

The four companies will promote the digital transformation of non-life insurance business using CMOS annealing and will accelerate co-creation for new social value by coordinating various data and technology of each company.

Hitachi news release Mar. 29, 2022 https://www.hitachi.co.jp/New/cnews/month/2022/03/0329d.html

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CMOS annealing cloud with applications

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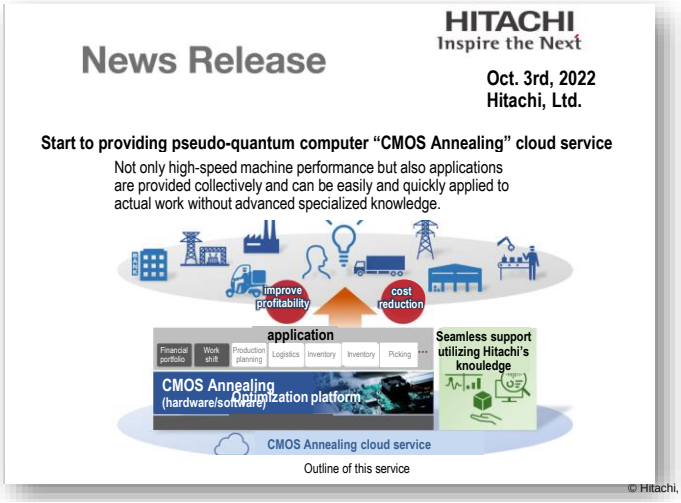
- CMOS annealing cloud providing applications launched in Oct. 2022



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Toward popularization of annealing machines

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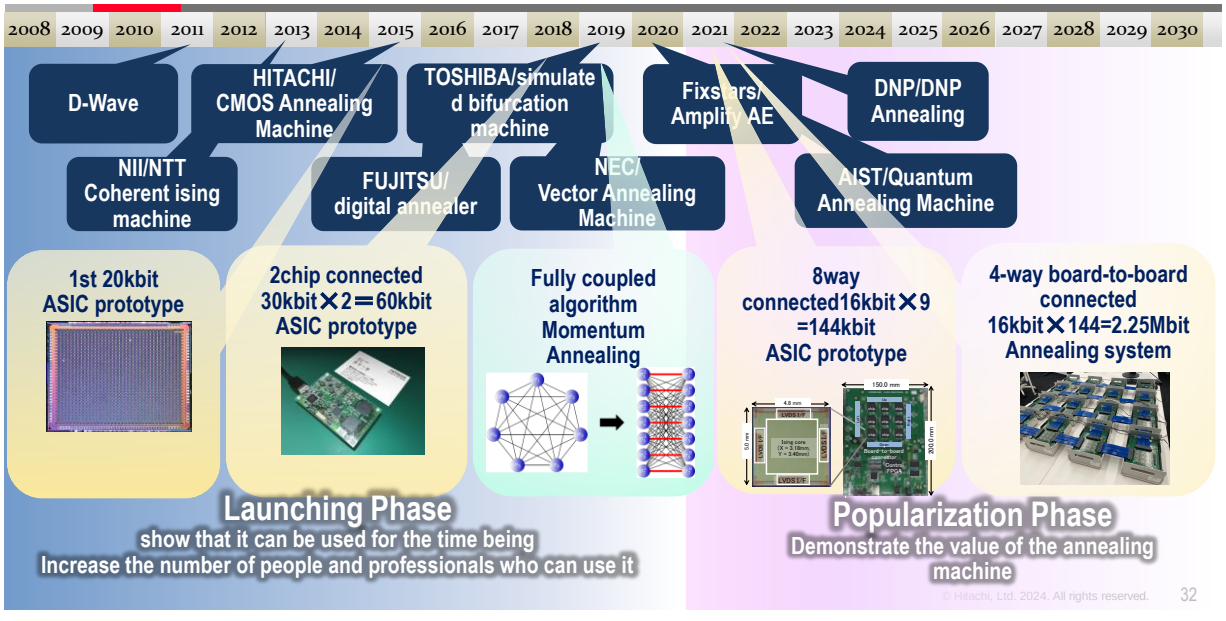

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Annealing Cloud Web

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Challenge to popularization “Optimization”

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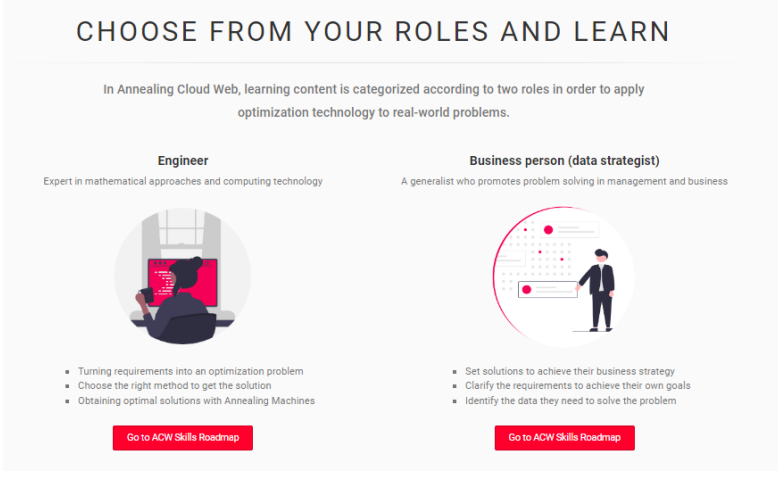
● **Defining skills which are essential for both “businessperson” and “engineer” in optimization fields**



Annealing Cloud Web: Skills Roadmap

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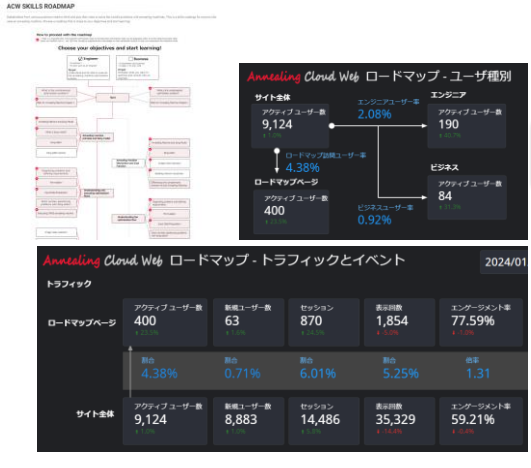
● **We have enabled the visualization of the chosen role and the level of skill acquired for both users and administrators.**

✓Engineer
・Formulate a problem based on a real-world problem and obtain a solution through optimization processing

Understunding the optimization process of annealing machine and excecting

- Annealing machine and Ising model
- Understunding and excecting optimization flow
- Deffining an issue as an optimization problem and converting it into an Ising model
- Solving quadratic and discrete problems to solve social issues.
- Applying learning to practice



✓ Business
・Organize information and consult with engineers to achieve business goals

You can consult with an engineer by verbalizing what you want to optimize.

You can consult with an engineer by verbalizing what you want to optimize.

- Understanding the optimization flow
- Examples of problem-solving
- To solve social issues.

Challenge to popularization “Optimization”

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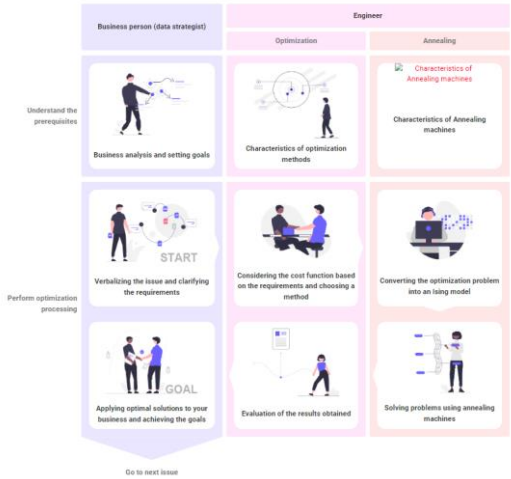
- The workflow for applying optimization processing to real-world problems was defined and visualized for learners.



Annealing Cloud Web: Web-API provided

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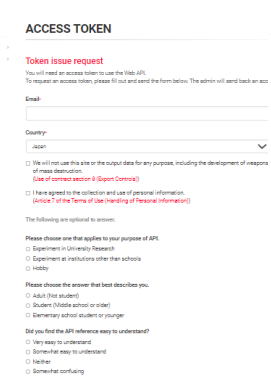
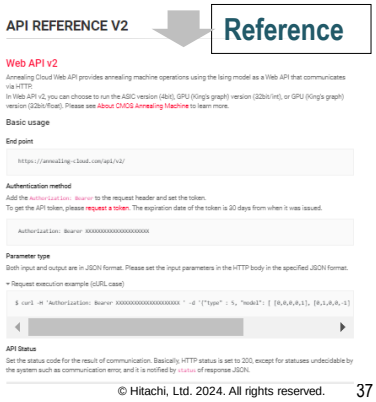
- You can access the CMOS annealing machine using the API
- Get tokens with just your email address and use two machines for a month

You can request a token from here





- It is FREE to use annealing machine for one month (as many times as you want)

Access record of Annealing Cloud Web

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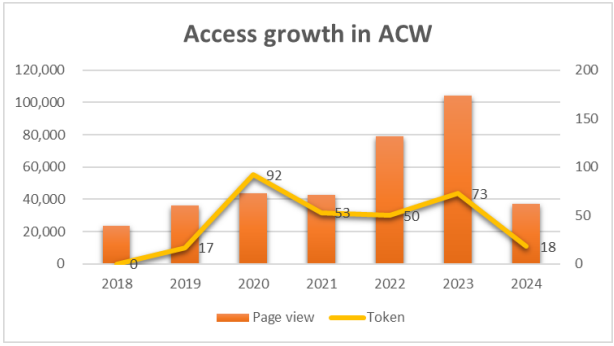
2024/7/9

Year	2018	2019	2020	2021	2022	2023	2024	Total
Session	5,784	16,654	21,439	23,139	27,518	28,919	15,537	138,990
Page view	23,836	36,166	43,668	42,780	79,161	104,520	37,099	367,230
PV/Session	4.12	2.17	2.04	1.85	2.88	3.61	2.39	2.64
Token request	0	17	92	53	50	73	18	303

*PV:Page View



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User's reaction

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- Professor Yamamoto Fujio of Kanagawa Institute of Technology uses ACW to create application
- MIT APP Inventor Winner

Experience it on your smartphone

Easy-to-understand visual indication of traffic congestion

https://sparse-dense.blogspot.com

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Collaboration for new value creation

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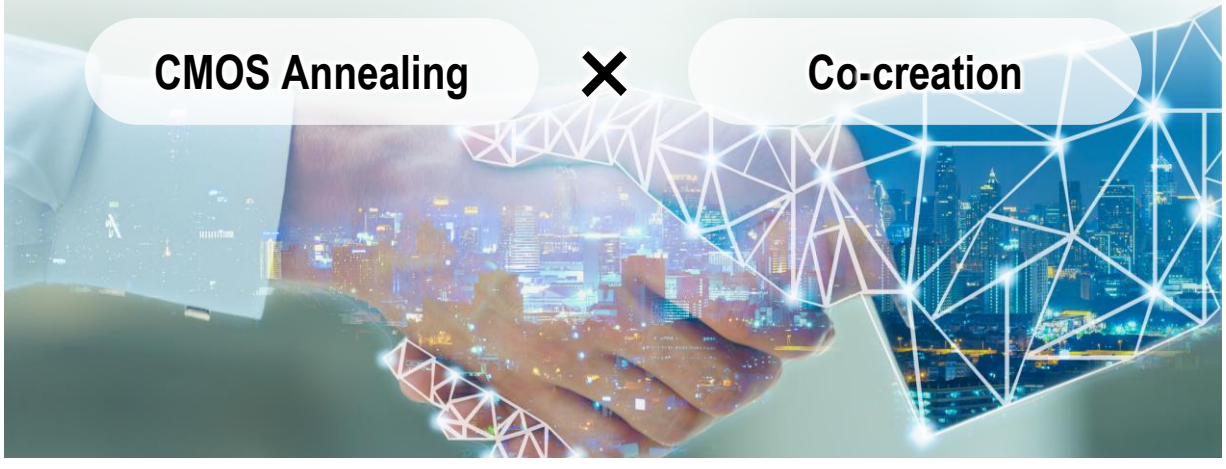
- For social innovation we create new values together with annealing machine users



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Acknowledgement

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- Part of this work is based on results obtained from a project, JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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