

Outline of Quantum Inspired Annealing Technology

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7/11/2024

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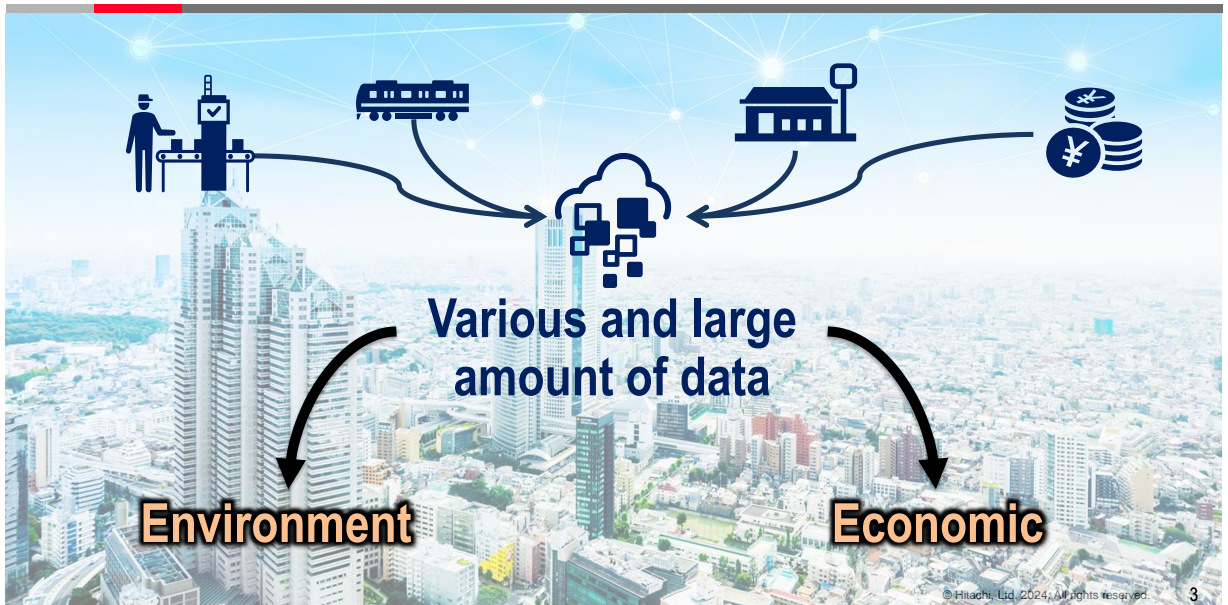
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Outline

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

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

For Social Innovation



Environmental improvement



Smart grid control



Delivery route optimization

Economical growth



Stock price forecast



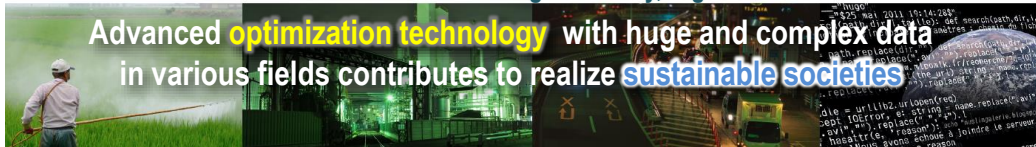
Insurance portfolio



Traffic control

MEMO	1	2	3	4	5	6	7	8	9	10	11	12
WBS 1 Summary Element 1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 1.1 Activity 1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 1.2 Activity 2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 1.3 Activity 3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 1.4 Activity 4	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 2 Summary Element 2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 2.1 Activity 1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 2.2 Activity 2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
WBS 2.3 Activity 3	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Scheduling in factory, logistics and traffic

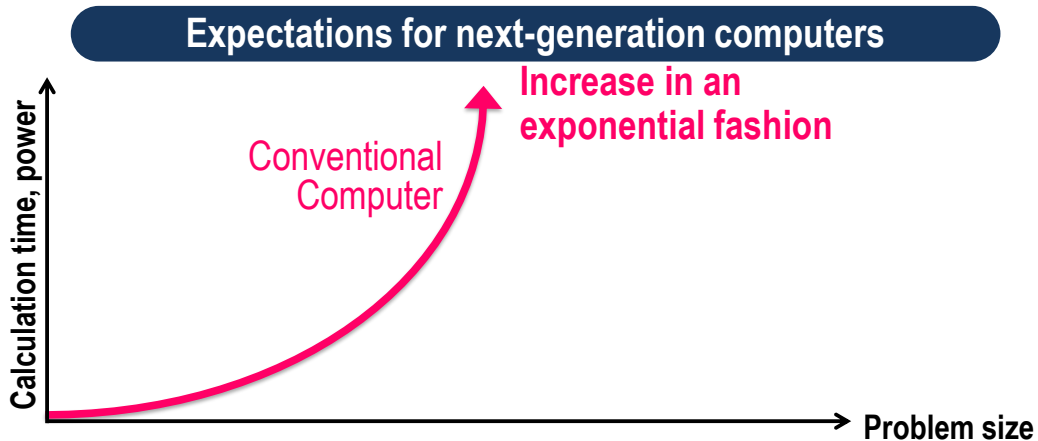


Advanced optimization technology with huge and complex data in various fields contributes to realize sustainable societies

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Calculation time and power for new applications

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



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- Background
- **Annealing machines**
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Annealing technology and quantum computing

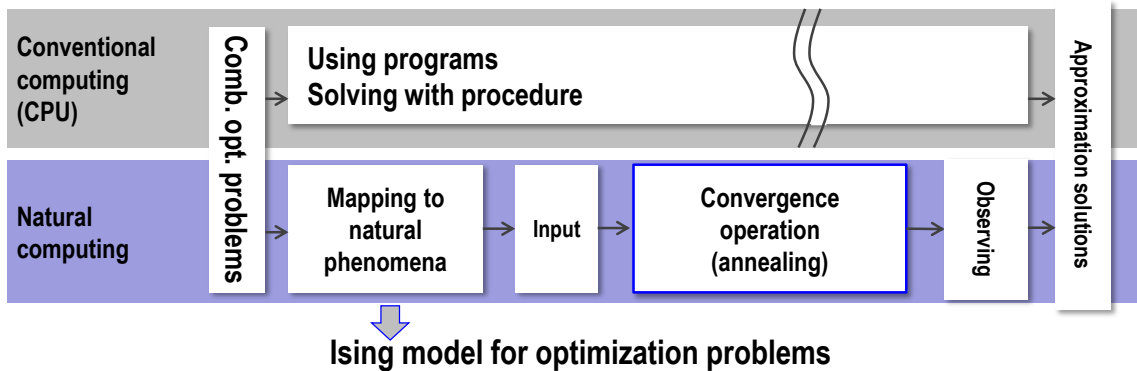
- Quantum computer is destructive technology, but still in research phase
- Annealing machines are now in practical phase

	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.)

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Natural computing with Ising model

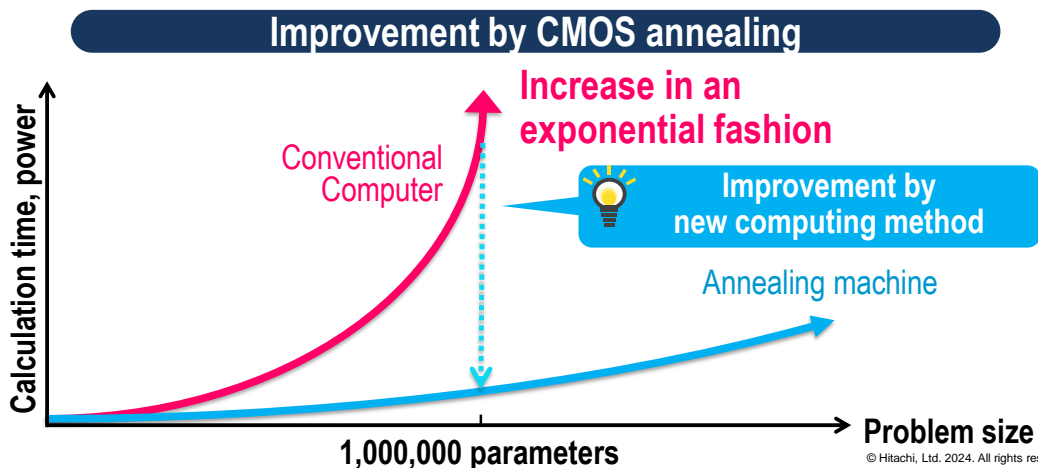
- Natural computing can be used to solve combinatorial optimization problems
- Mapping combinatorial optimization problems to Ising mode
- Solution acquired by annealing operation of Ising model



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Calculation time and power reduction by new computing

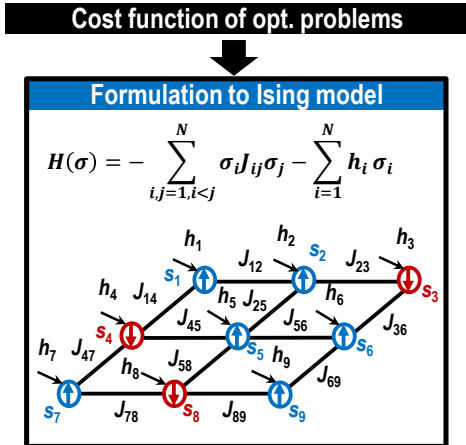
- For complex and large-scale social systems, reduction of calculation time and power is necessary



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Ising model and annealing machines

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



Optimization problems	Ising model
Cost function	Energy $H(\sigma)$
Input parameters	<ul style="list-style-type: none"> • 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

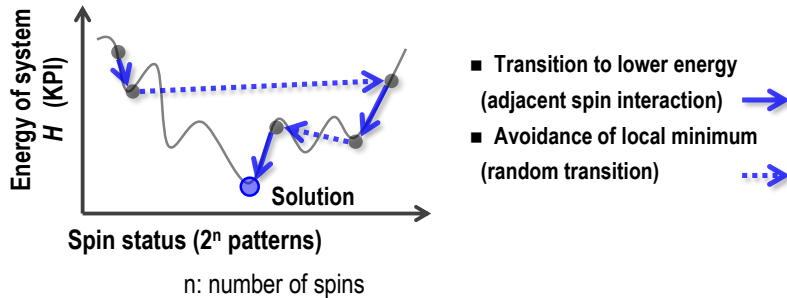
- Several non-quantum annealing machine have been developed at Japanese companies.

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

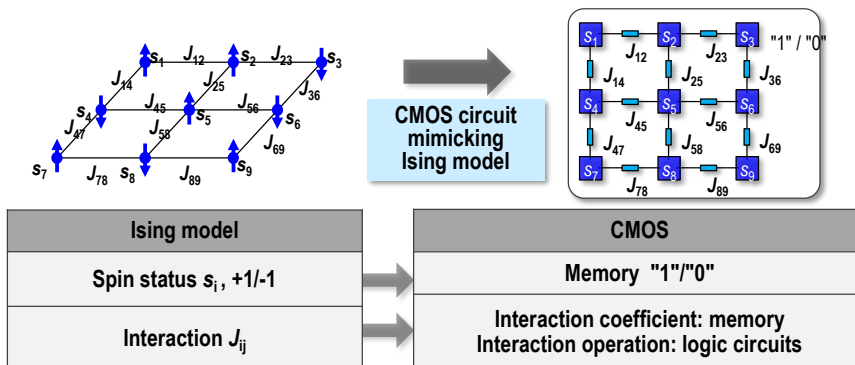


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In-memory computing for Ising model

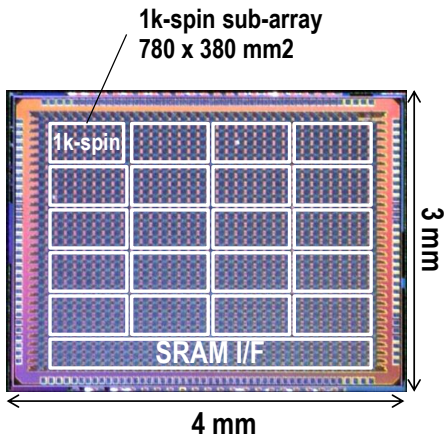
- Mimicking physical Ising model with in-memory structure
- Spin status updated by logic circuits implemented in memory



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Fabrication results: CMOS annealing chip



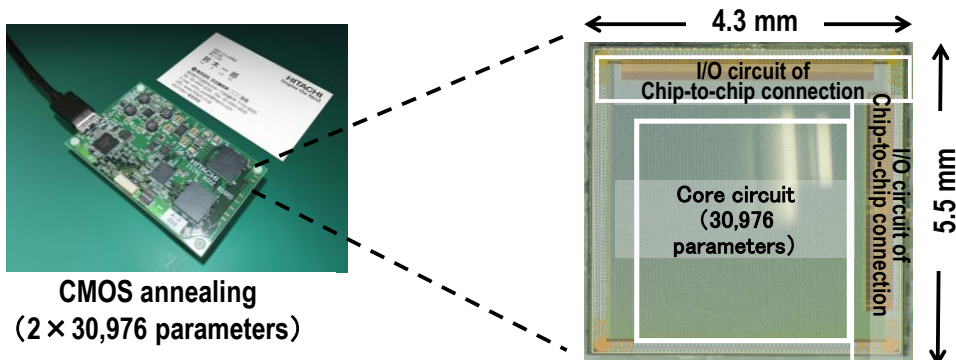
Items	Values
Number of spins	20k (80 x 128 x 2)
Process	65 nm
Chip area	4x3=12 mm ²
Number of SRAM cells	260k bits Spin value: 20k bits Interaction coefficient: 240k bits
Memory IF	100 MHz
Interaction speed	100 MHz
Operating current of core circuits (1.1 V)	Write: 2.0 mA Read: 6.0 mA Interaction: 44.6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

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Card-size CMOS annealing for edge devices

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

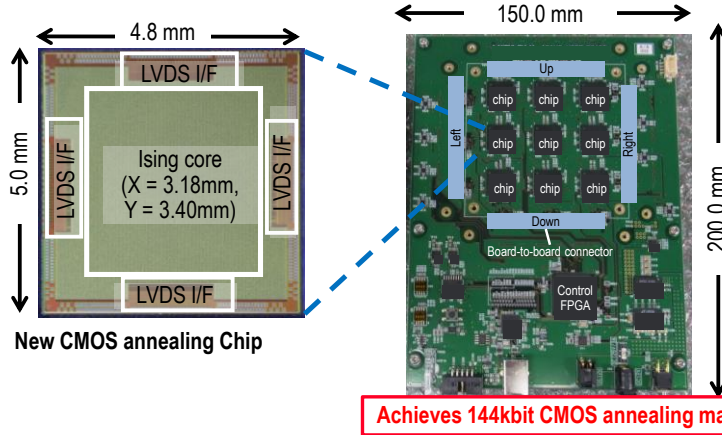


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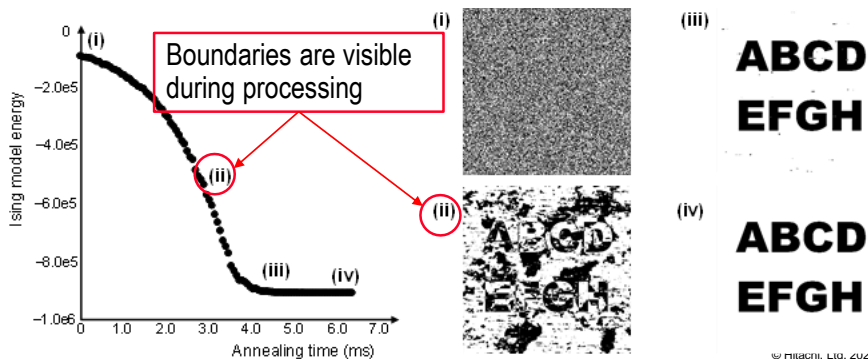
9-chip connected CMOS annealing machine

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



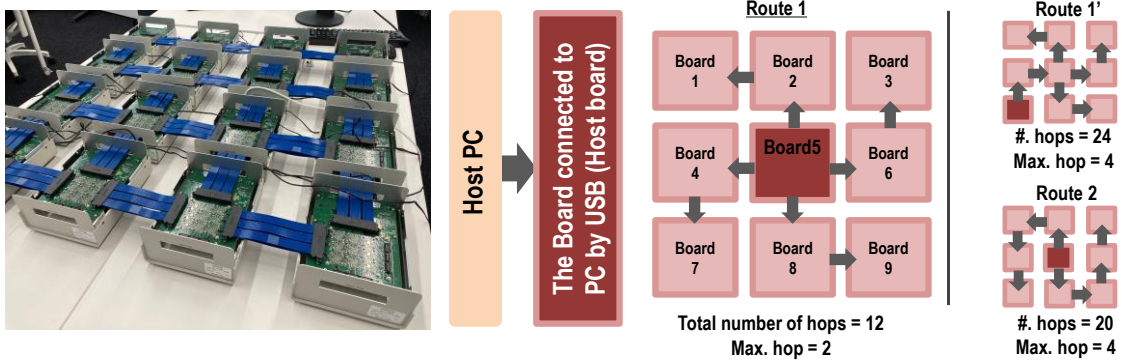
Worked as one annealing machine with 9 chips

- 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.



Larger prototype with 2.25Mbits

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



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Two types of CMOS annealing

- 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



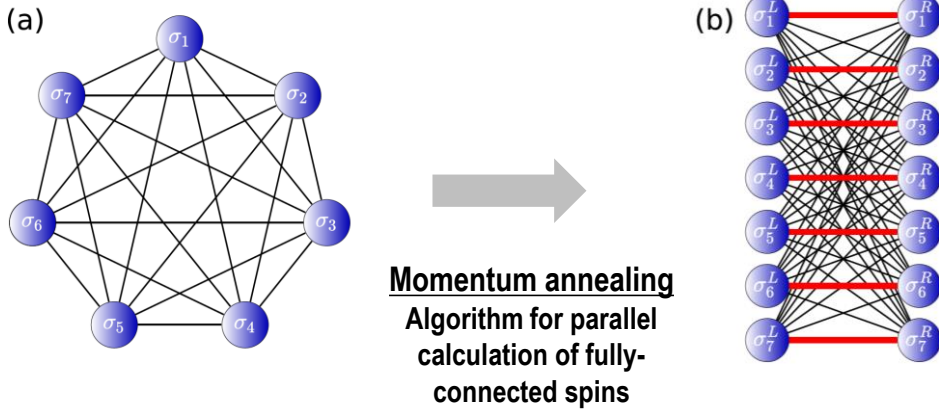
Verification machine by ASIC



Prototype by ASIC

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

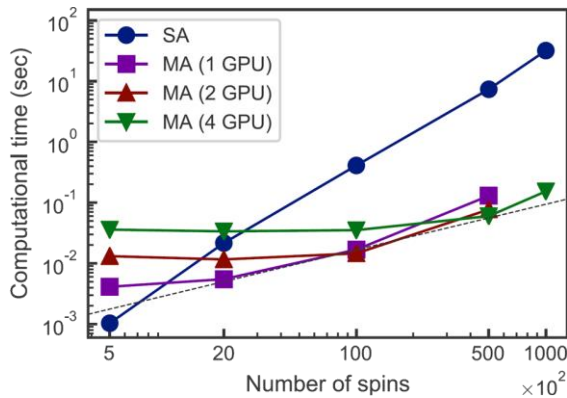


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Algorithm performance evaluation

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



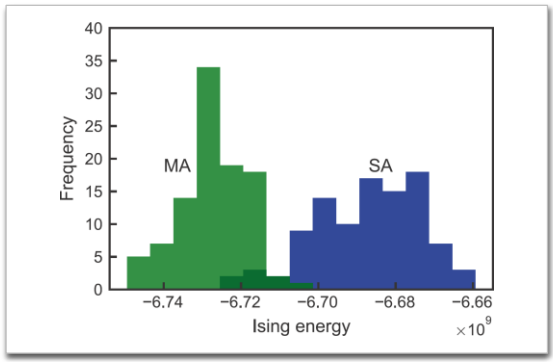
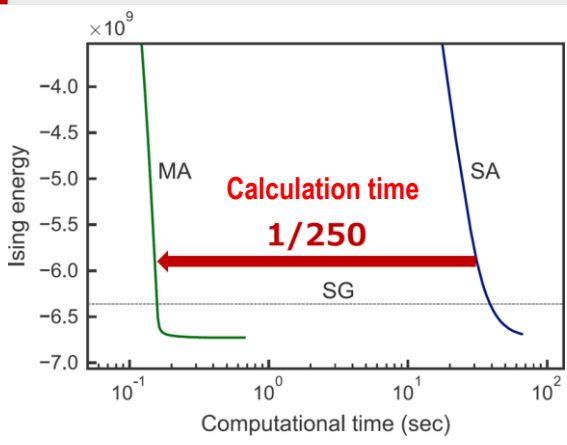
Time to reach the solution search with the same accuracy as the solution obtained by the SG method
SG method: An abbreviation for Sahni-Gonzales Algorithm, a kind of greedy method.

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Experimental results of fully coupled 100,000-spin Ising model HITACHI Inspire the Next

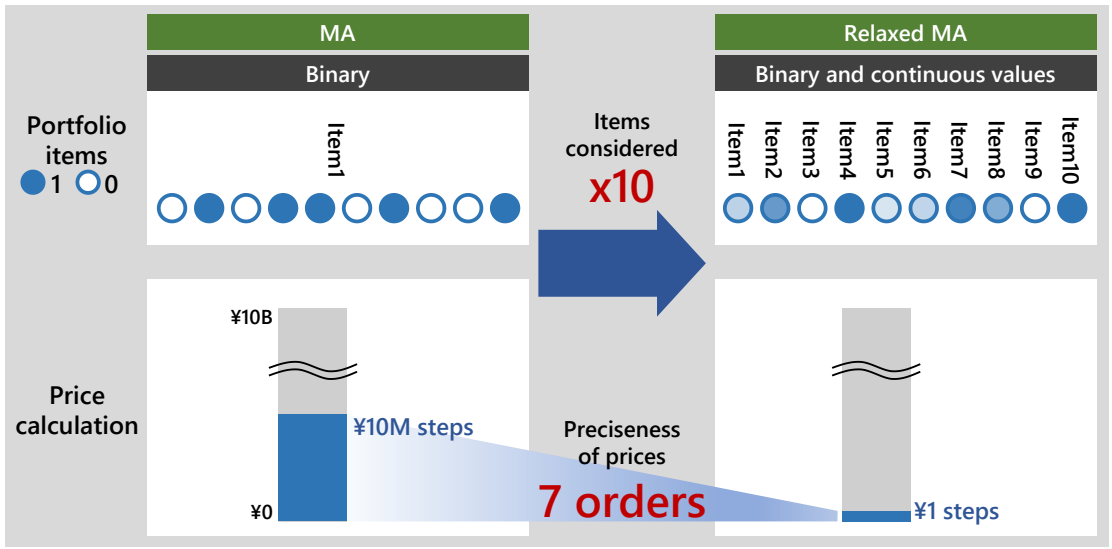
- When the number of spins is 100,000, the calculation time is 1/250 compared to SA



- 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

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Relaxed MA for continuous variables HITACHI Inspire the Next

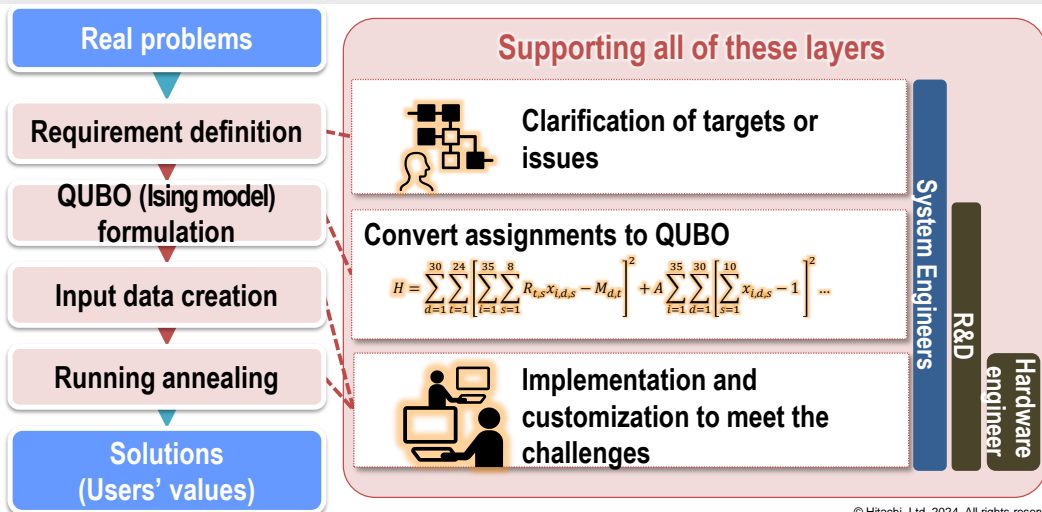


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Toward application to social innovations

Technical and business skill sets accelerate the practical application



- 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 Satisfaction

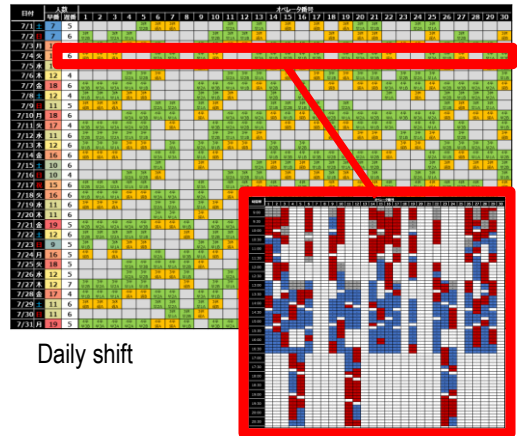
- Don't keep customers waiting
- Skill placement to reduce call forwarding

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 CORPORATION
Hitachi, Ltd

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

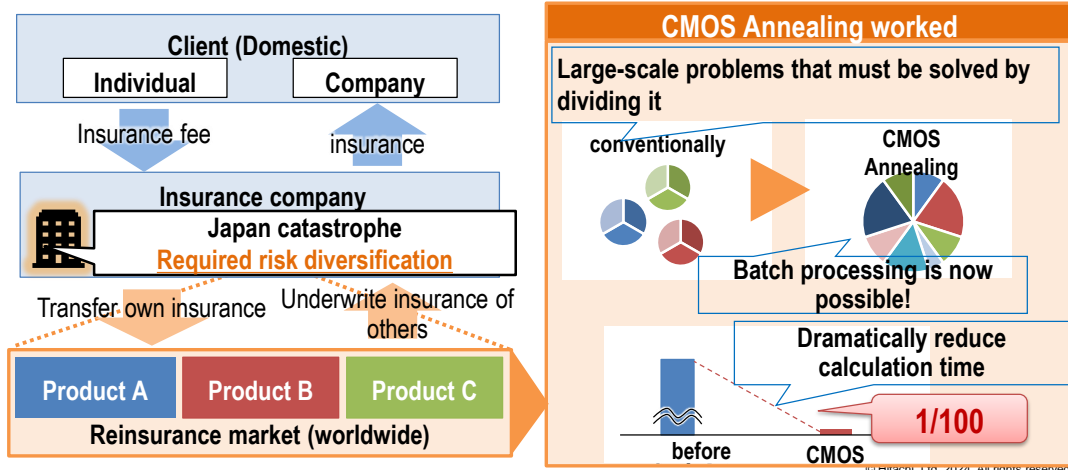
KDDI Evolva, Inc. (Head office: Shinjuku-ku, Tokyo, President: Hajime Wakatsuki, KDDI Evolva below), KDDI CORPORATION(Head office: Chiyoda-ku, Tokyo, President: Makoto Takahashi, KDDI below) and Hitachi, Ltd(Head office: Chiyoda-ku, Tokyo, President: Keiji Kojima, Hitachi below) created work shift of 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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- 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 annealing¹ 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 business².

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 providing applications launched in Oct. 2022

News Release

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Oct. 3rd, 2022
Hitachi, Ltd.

Start to providing pseudo-quantum computer “CMOS Annealing” cloud service

Not only high-speed machine performance but also applications are provided collectively and can be easily and quickly applied to actual work without advanced specialized knowledge.

application

Financial portfolio	Work shift	Production planning	Logistics	Inventory	Inventory	Picking	...
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CMOS Annealing (hardware/software) Optimization platform

Seamless support utilizing Hitachi's knowledge

CMOS Annealing cloud service

Outline of this service

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The graphic features a central diagram with icons for various industries and a lightbulb, with arrows pointing to 'improve profitability' and 'cost reduction'. Below this is a horizontal bar representing an 'application' with several categories. Underneath is a 'CMOS Annealing (hardware/software) Optimization platform' box, and at the bottom is a 'CMOS Annealing cloud service' box with a cloud icon.

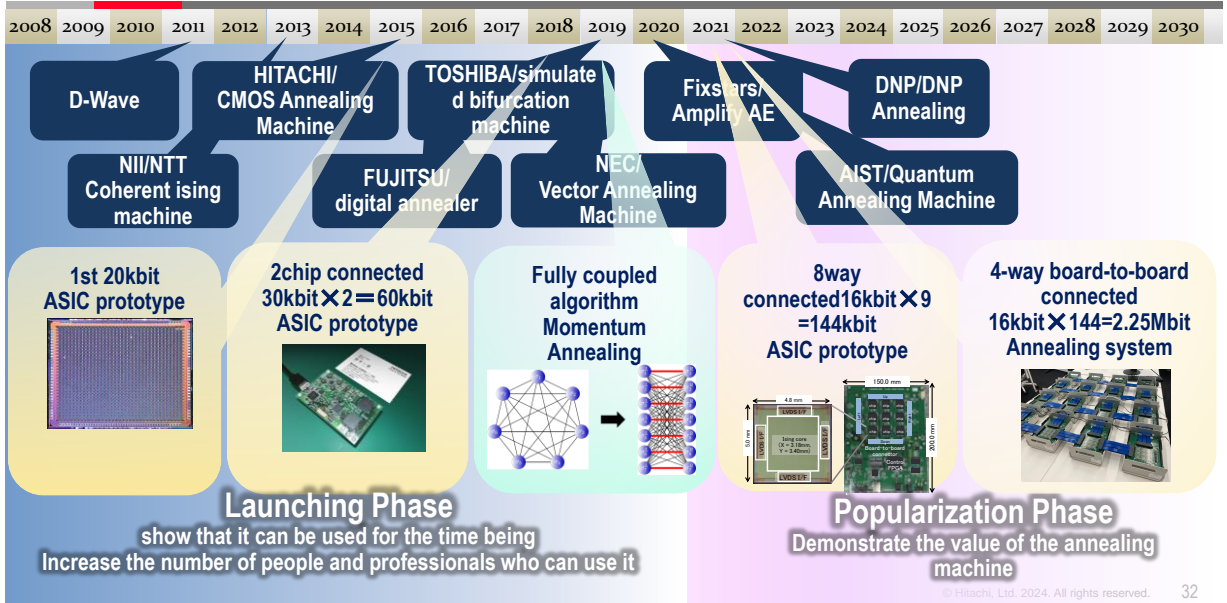
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Toward popularization of annealing machines



Annealing Cloud Web

The screenshot shows the website's navigation menu: About, Roadmap, Learn, Play, Contact. The main content area features a large heading "Annealing Cloud Web" and a sub-heading "Annealingマシンによる最適化処理を学ぼう。より良い世界をつくるために。" Below this is a URL box: <https://annealing-cloud.com/en/index.html>. At the bottom, there are four navigation buttons:

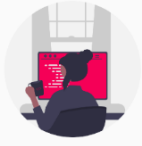
- Annealing Cloud Web とは (See details >>)
- あなたの役割から選んで学べる (See details >>)
- 最適化を解く流れから学べる (See details >>)
- 使って学ぶ Annealingマシン (See details >>)

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

CHOOSE FROM YOUR ROLES AND LEARN

In Annealing Cloud Web, learning content is categorized according to two roles in order to apply optimization technology to real-world problems.

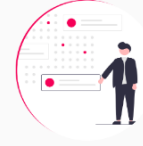
Engineer
Expert in mathematical approaches and computing technology



- Turning requirements into an optimization problem
- Choose the right method to get the solution
- Obtaining optimal solutions with Annealing Machines

Go to ACW Skills Roadmap

Business person (data strategist)
A generalist who promotes problem solving in management and business



- Set solutions to achieve their business strategy
- Clarify the requirements to achieve their own goals
- Identify the data they need to solve the problem

Go to ACW Skills Roadmap

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Annealing Cloud Web: Skills Roadmap

● 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

Understanding the optimization process of annealing machine and executing

Annealing machine and Ising model

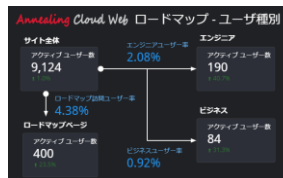
Understanding and executing optimization flow

Defining 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

ACW SKILLS ROADMAP



✓ 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.



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Challenge to popularization “Optimization”

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



Annealing Cloud Web: Web-API provided

- 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 TOKEN

Token issue request
You will need an access token when you use the Web API. To request an access token, please fill out and send the form below. The admin will send back an access token to your email.

Email:

Country:

I will not use this site or the output data for any purpose, including the development of responses of mass destruction. (See of annex section 3 (Support Contents))

I have agreed to the collection and use of personal information. (Notice 2 of the Terms of Use (Handling of Personal Information))

The following are optional to answer:

Please choose one that applies to your purpose of API:

Experiment in University/Research
 Experiment at institutions other than schools
 Hobby

Please choose the answer that best describes you:

Adult (Not a student)
 Student (Middle school or older)
 Elementary school student or younger

Did you find the API reference easy to understand?

Very easy to understand
 Somewhat easy to understand
 Neither
 Somewhat confusing

API REFERENCE V2

Web API v2
Annealing Cloud Web API provides annealing machine operations using the Ising model as a Web API that communicates via HTTP. In Web API v2, you can choose to run the ABC version (4bit), GPU (Kings graph) version (22bit/16), or GPU (Kings graph) version (22bit/16bit). Please see About CMOS Annealing Machine to learn more.

Basic usage

End point
`https://annealing-cloud.com/v2/`

Authentication method
Add the `Authorization: Bearer` to the request header and set the token. To get the API token, please **request a token**. The expiration date of the token is 30 days from when it was issued.

`Authorization: Bearer XXXXXXXXXXXXXXXXXXXXXXX`

Parameter type
Both input and output are in JSON format. Please set the input parameters in the HTTP body in the specified JSON format.

Request execution example (URL case)
\$ curl -H "Authorization: Bearer XXXXXXXXXXXXXXXXXXXXXXX" -d '{"type": "S", "tokens": [{"N": 10, "K": 1}]}'

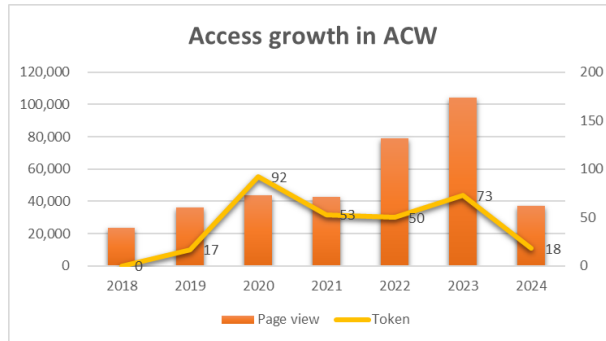
API Status
Get the status code for the result of communication. Basically, HTTP status is set to 200, except for statuses undetectable by the system such as communication error, and it is notified by `status` of response JSON.

Reference

Access record of Annealing Cloud Web

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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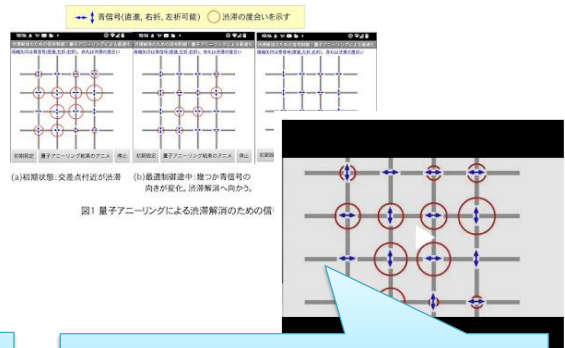
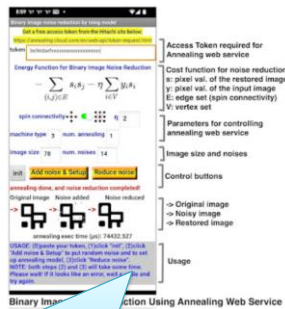
User's reaction

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

Congratulations to September's Adult Inventor!



Professor Yamamoto from Japan has created this app that uses quantum annealing, a type of quantum computing, to reduce noise in images. The app, which runs on most mobile devices, lets you experience the processing of a quantum annealing machine that is different from existing computers. Dr. Yamamoto would like to thank Dr. Masahiro Yamamoto of Hitachi, Ltd., who developed the QASOS annealing machine, for annealing various technical



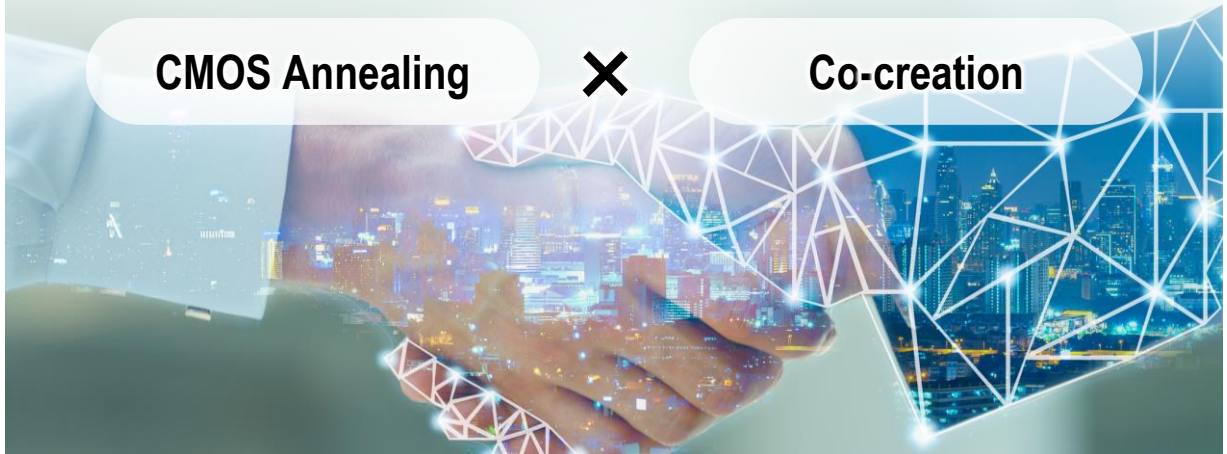
Experience it on your smartphone

Easy-to-understand visual indication of traffic congestion

<https://sparse-dense.blogspot.com>

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



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Acknowledgement

- 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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