Feasibility Studies on Quantum and Other Hybrid (Collaborative) Operational Environment

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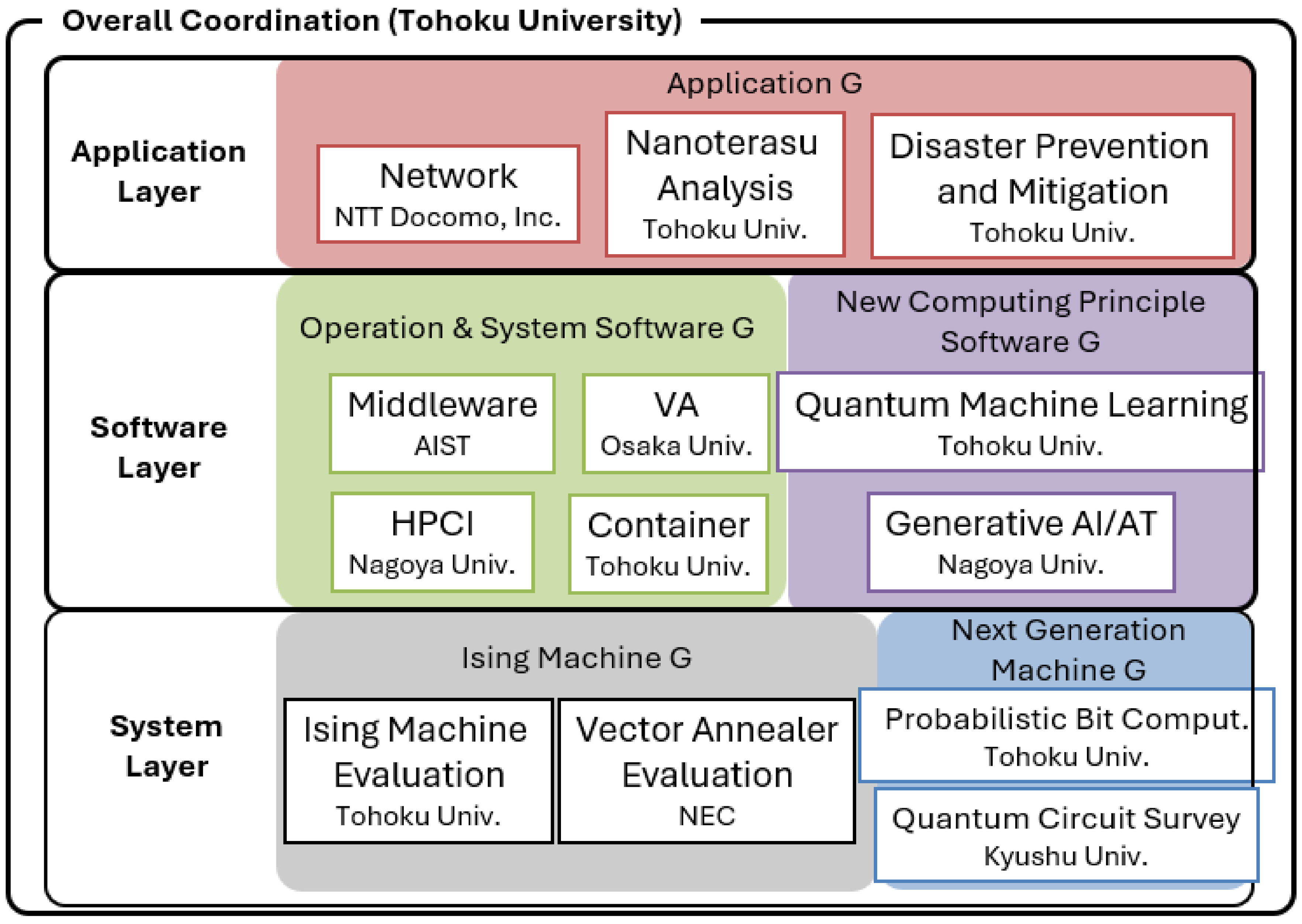
Aim of the Project

Japan was the first in the world to propose quantum annealing and, in the research and development of Ising machines—computers specialized for combinatorial optimization—possesses advanced technological capabilities across all layers, from system provision, related technologies, theoretical frameworks, and application cases to practical applications, surpassing Europe and the United States. This technological advantage holds the potential to evolve into a major industry through the creation of new business opportunities.

The aim of this research study is to construct a next-generation computational infrastructure environment by linking Ising machine technology with the forthcoming Japanese flagship system (The "Fugaku NEXT") and HPCI systems, conducting investigative research toward the realization of a hybrid collaborative operational environment.

Roles of Each Organization



Ising Machine Group

- Investigation of Ising machine technologies such as quantum/quantum-inspired annealing and pseudo-branching, as well as methods and challenges for HPCI integration.

Operation & System Software Group

- Software infrastructure and operational technologies
- Deployment, usage environment, and access methods for Ising machines.

New Computing Principle Software Group

- Investigation of libraries and tools for efficient utilization
- Quantum machine learning libraries, generative AI, and auto-tuning.

Application Group

- Applications that enhance industrial competitiveness, ensure safety and security, and enable data analysis through cutting-edge measurements.

Next-Generation Ising Machine Group

- Investigation of next-generation Ising machines
- Exploration of Ising machines using spintronics.

Auto-tuning for Quantum-Inspired Annear

Quantum-inspired computers are being developed.

- CMOS Annealing Machine (Hitachi), Digital Annealer (Fujitsu), etc.

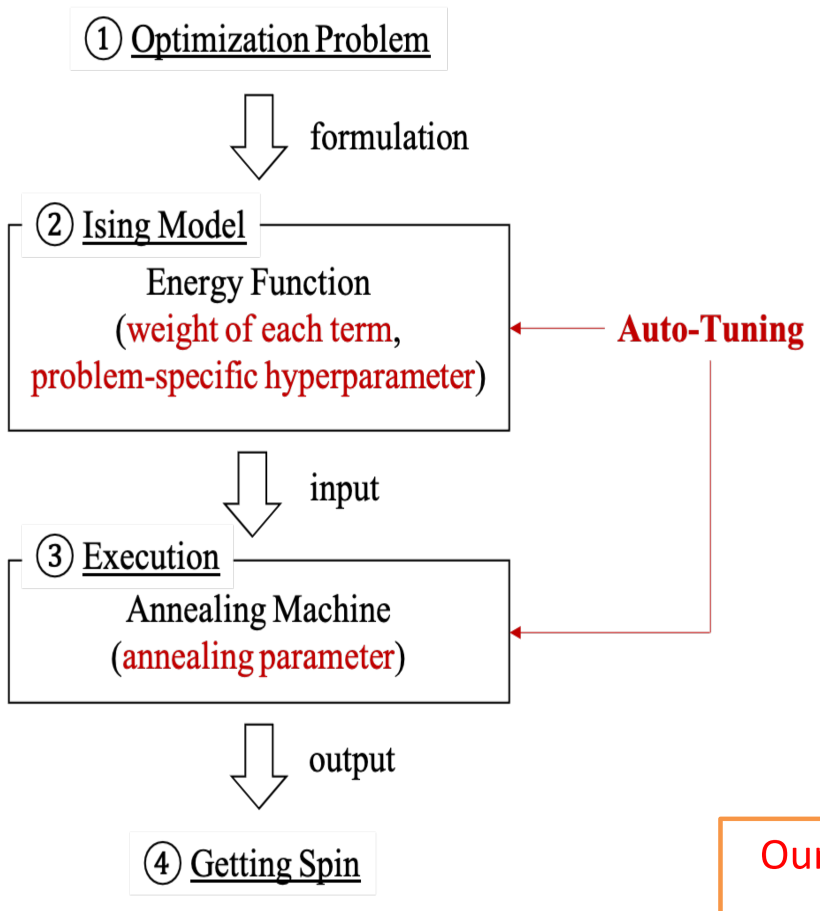
Parameters to be tuned on Annealing Machines

QUBO formula

$$H = \underbrace{w_a \sum_{(u,v)\in E} (1-x_u)(1-x_v)}_{\text{constraint}} + \underbrace{w_b \sum_{v\in V'} x_v}_{\text{cost}}$$

Parameters	Overview
Wa	Coefficient of constraint term
Wb	Coefficient of cost term
chain_strength	Strength of chain

Procedure of Auto-tuning



Case Study: A Coherent Ising Machine (CIM)

CACm (Chaotic Amplitude Control with momentum)

$$x(t+1) = x(t) + \Delta t\left(-\beta(t)x(t) + \alpha e(t)\circ\big(\Omega\phi(t)\big) + \gamma\big(x(t) - x(t-1)\big)\right)$$
$$e(t+1) = e(t) - \zeta e(t)\circ\left(x(t)^2 - 1\right)$$

Parameter	Interpretation	Range
T	Number of time steps	10~1000
β_1	Initial decay rate	0.1~10
β_2	Final decay rate	0.1~10
α	Coupling strength	0.1~10
γ	Momentum term strength	0.1~10
ξ	Rate of change of auxiliary variables	0.001~0.01

Time step size fixed at $\Delta t = 0.5$

Our Method B discovered better parameters than Optuna's Bayesian optimization with five parameters tuned simultaneously.

Results

Method	TPE	GP	CMA-ES	Random	GRID
Conven-tonal	9227	21418	6884	9767	39641
Our Proposal A	4136	4896	5564	4448	4388
Our Proposal B	**4048**	4268	4959	4717	4091

Comparison of Time to Solution (TTS) Between the Conventional Method and Our Methods A and B (Number of Trials: 100). TTS represents the average value over 10 runs. A lower TTS indicates better performance.

Auto-Tuning (AT) is performed by Optuna.

T. Hanyu et al., "Towards Generalized Parameter Tuning in Coherent Ising Machines: A Portfolio-Based Approach", arXiv, (27 Jul 2025) https://arxiv.org/abs/2507.20295

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