Contents

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Architecture of SX-Aurora TSUBASA

SX-Aurora TSUBASA

Controlling | **Processing**

Standard X86/Linux Server

intel

X86 CPU

Linux OS

Library

Tools

APP

VE OS

Vector Engine

-Vector Processor
-1.5TB/s Memory Access
-Low Power 200W

Vector CPU

Vector compiler

VE library

VE tools

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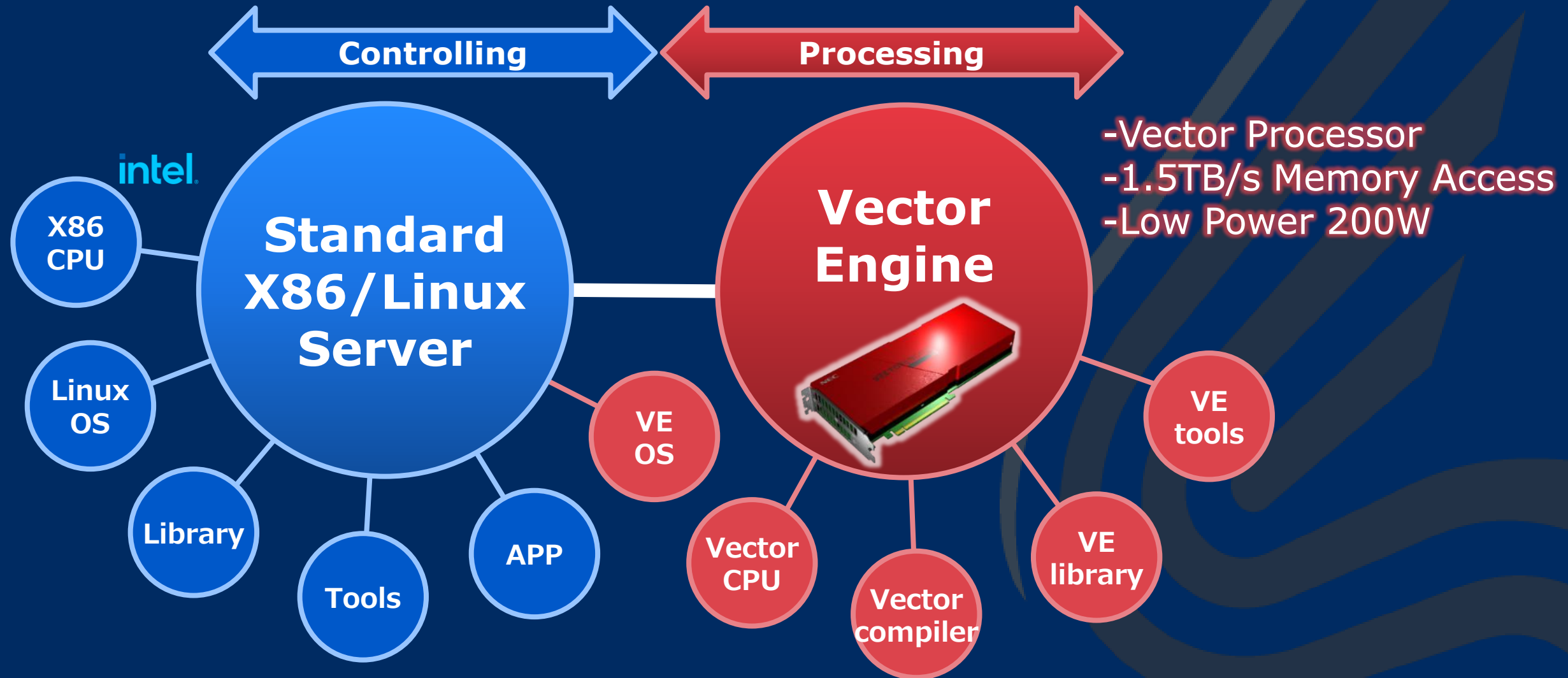
VE20 Processor

VE20 Specifications

Processor Version	Type 20A	Type 20B
Cores/processor	10	8
Core performance	307GF (DP) 614GF (SP)	
Processor performance	3.07TF (DP) 6.14TF (SP)	2.45TF (DP) 4.91TF (SP)
Cache capacity	16MB	
Cache bandwidth	3TB/s	
Cache Function	Software Controllable	
Memory capacity	48GB	
Memory bandwidth	1.53TB/s	
Power	~300W (TDP) ~200W (Application)	

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Roadmap

Subject to change

Premium HPC (Liquid cooling system)

VE20A
10C/3.07TF,
1.53TB/s memory bandwidth

VE30
16C/4.91TF,
2.45TB/s memory bandwidth

VE10 VE10E

VE40 VE50

Mainstream (Air cooling, discrete)

VE20B
8C/2.45TF,
1.53TB/s memory bandwidth

※Planning (Subject to change)

2019   2020   2021   2022   2023   2024   2025   2026

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Benchmarks

Relative performance
(normalized by ICX)

HPL
(GFLOPS): ICX 1.0, VE20 1.3, VE30 2.2

STREAM
(GByte/s): ICX 1.0, VE20 4.4, VE30 6.5

Stencil (Himeno)
(GFLOPS): ICX 1.0, VE20 4.3, VE30 9.6

Higher is better

■ ICX : Intel Xeon Gold 6326 x2 sockets
■ VE20 : NEC SX-Aurora TSUBASA VE20B x1 socket
■ VE30 : NEC SX-Aurora TSUBASA VE30A x1 socket

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NEC's Strategy for Quantum Computing and HPC

Quantum Computing Map

NEC Products: Simulated Annealer (Vector Annealer, VA) and D-Wave
NEC R&D: Quantum Annealing Computer and Quantum Gate Computer

Quantum Computing
(Broadly defined to include quantum behavior)

Annealing method, etc.
Solves combinatorial optimization problems
by means of the Ising model or other statistical physics model

Quantum gate method
Performs calculations by replacing
classical computer bits with qubits

| Quantum Computer | Digital Circuits | Optical | Quantum Computer | Digital Circuits |

| D-Wave | NEC | NEC | Hitachi | Fujitsu | Toshiba | NTT | NEC | RIKEN UTokyo | IBM | Google | Rigetti | Intel | Quna Sys | Nvidia | ··· |

product   R&D   product

R&D

*Based on NEC's survey.　(Due to limited space, not all institutions are covered.)

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Why is NEC Focusing on Quantum Computing?

- Both HPC and Quantum technologies will be used for higher sustained performance
- NEC develops HPC, Simulated Annealing on Aurora, Quantum Annealer and Quantum Gate

For higher sustained performance, NEC continuously combine HPC and new cutting edge technologies

- ◆ **Step1: Annealing on HPC resource**
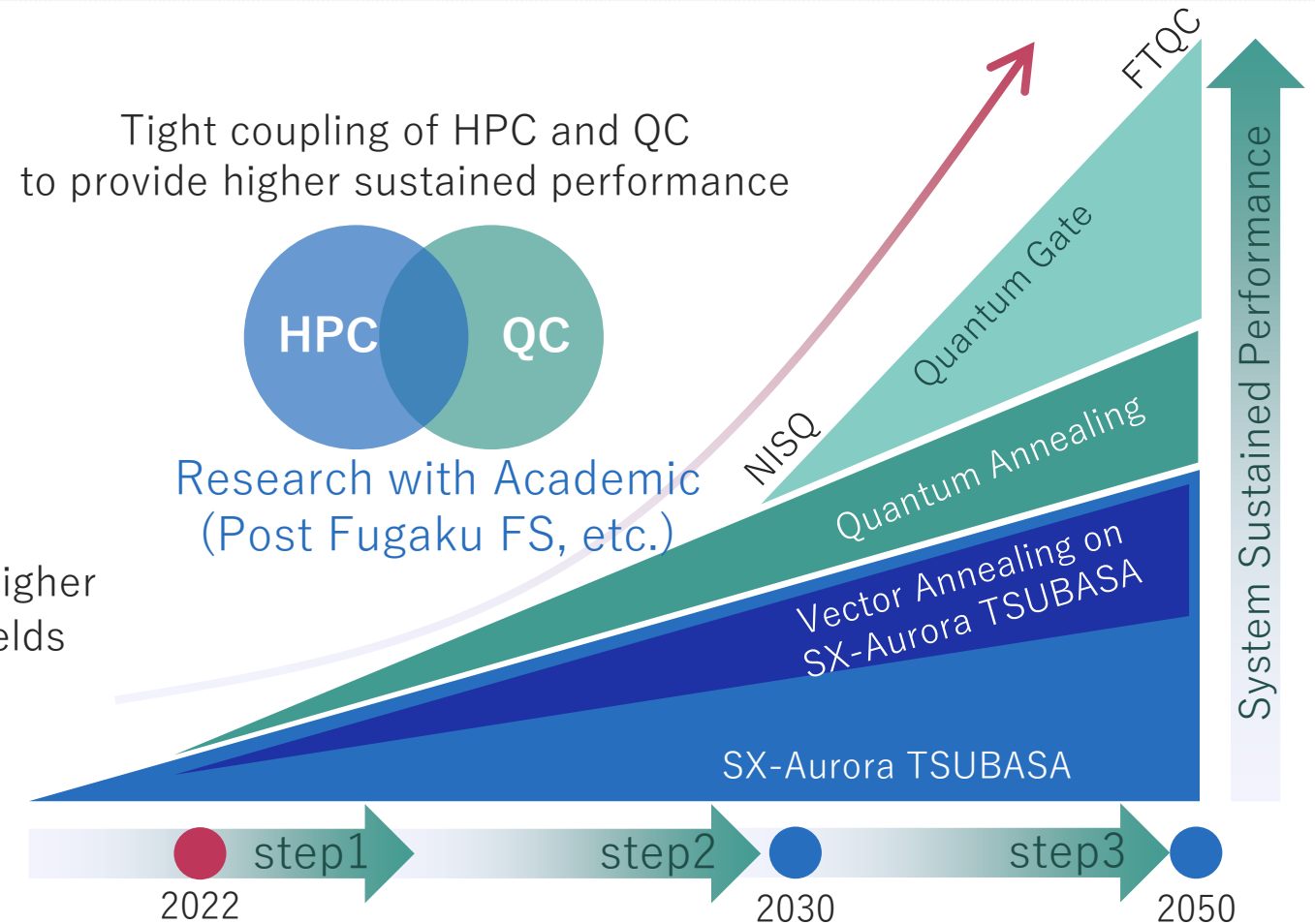 - ■ Vector Annealing on SX-Aurora TSUBASA
  - ■ Using Quantum Annealer to accelerate
- ◆ **Step2: HPC/QC Hybrid Computing**
  - ■ Tight coupled HPC/QC hybrid system to reach higher sustained performance in scientific/industrial fields
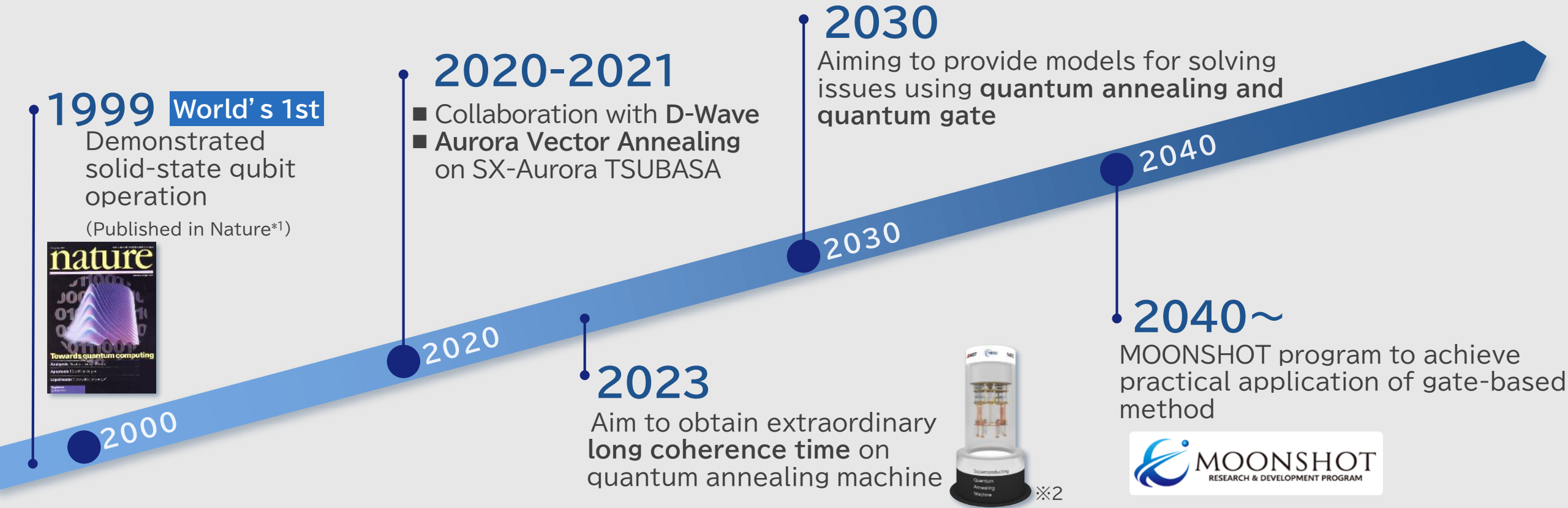- ◆ **Step3: Introducing "QC Gate" as new era**
  - ■ NISC type: Around 2030
  - ■ FTQC type: Around 2050

NISQ
Noisy Intermediate-Scale QC
FTQC
Fault Tolerant QC

Tight coupling of HPC and QC
to provide higher sustained performance

HPC   QC

Research with Academic
(Post Fugaku FS, etc.)

FTQC

Quantum Gate

NISQ

Quantum Annealing

Vector Annealing on SX-Aurora TSUBASA

SX-Aurora TSUBASA

System Sustained Performance

step1   step2   step3

2022   2030   2050

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NEC's Initiative in Quantum Computing

Since succeeding in the world's first demonstration of solid-state qubit operation, NEC has been working towards the social implementation of quantum computing.
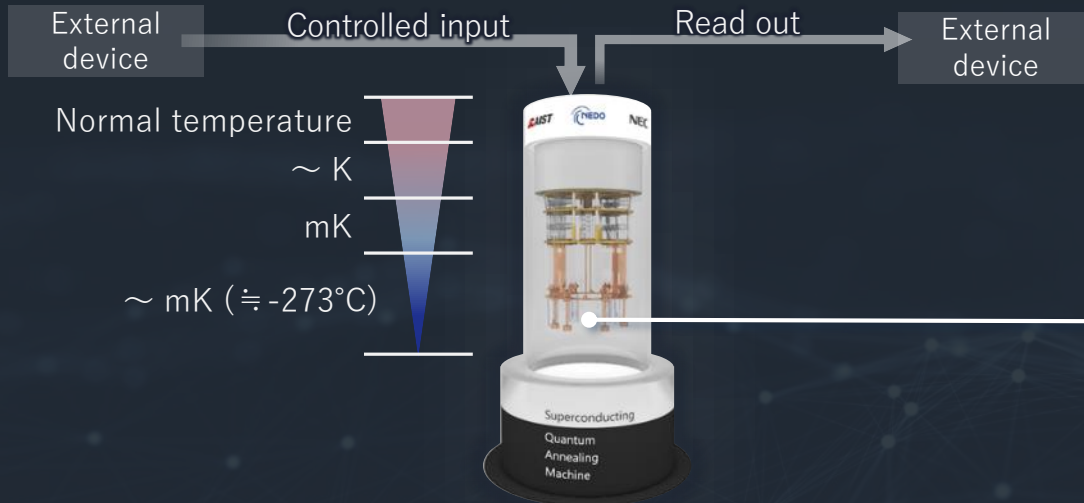
1999 `World's 1st`
Demonstrated solid-state qubit operation
(Published in Nature*1)

2020-2021
- Collaboration with **D-Wave**
- **Aurora Vector Annealing** on SX-Aurora TSUBASA

2030
Aiming to provide models for solving issues using **quantum annealing and quantum gate**

2023
Aim to obtain extraordinary **long coherence time** on quantum annealing machine ※2

2040~
MOONSHOT program to achieve practical application of gate-based method

2000
2020
2030
2040

*1: Y. Nakamura et al., Nature 398, 786 (1999)
*2; Based on results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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NEC is leading the development of quantum annealing devices to enable practical use of superconducting quantum annealing machine in 2023

Superconducting quantum annealing machine (mockup)

External device — Controlled input — Read out — External device

Normal temperature
~ K
mK
~ mK (≒ -273°C)

Superconducting Quantum Annealing Machine

* Based on results obtained from a project commissioned by
the New Energy and Industrial Technology Development Organization (NEDO).

Support	Participating organizations
NEDO	NEC (Deputy rep. facilities responsible for operationalization and practical application) AIST (Rep.), Tokyo Institute of Technology, Waseda Univ., Yokohama National Univ., and others

Quantum annealing device that NEC has been working on
(The heart part of the machine)

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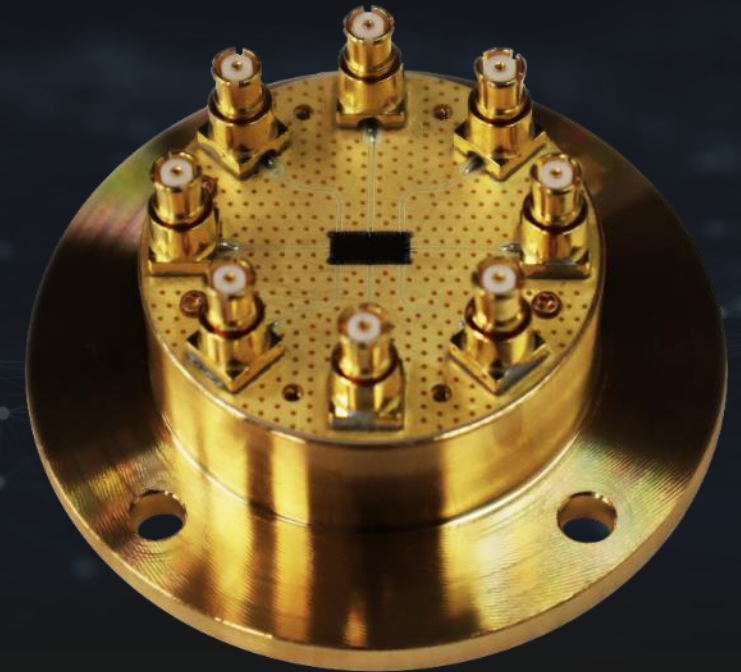
NEC Vector Annealing (VA) and D-Wave Leap

VA is ready for customers
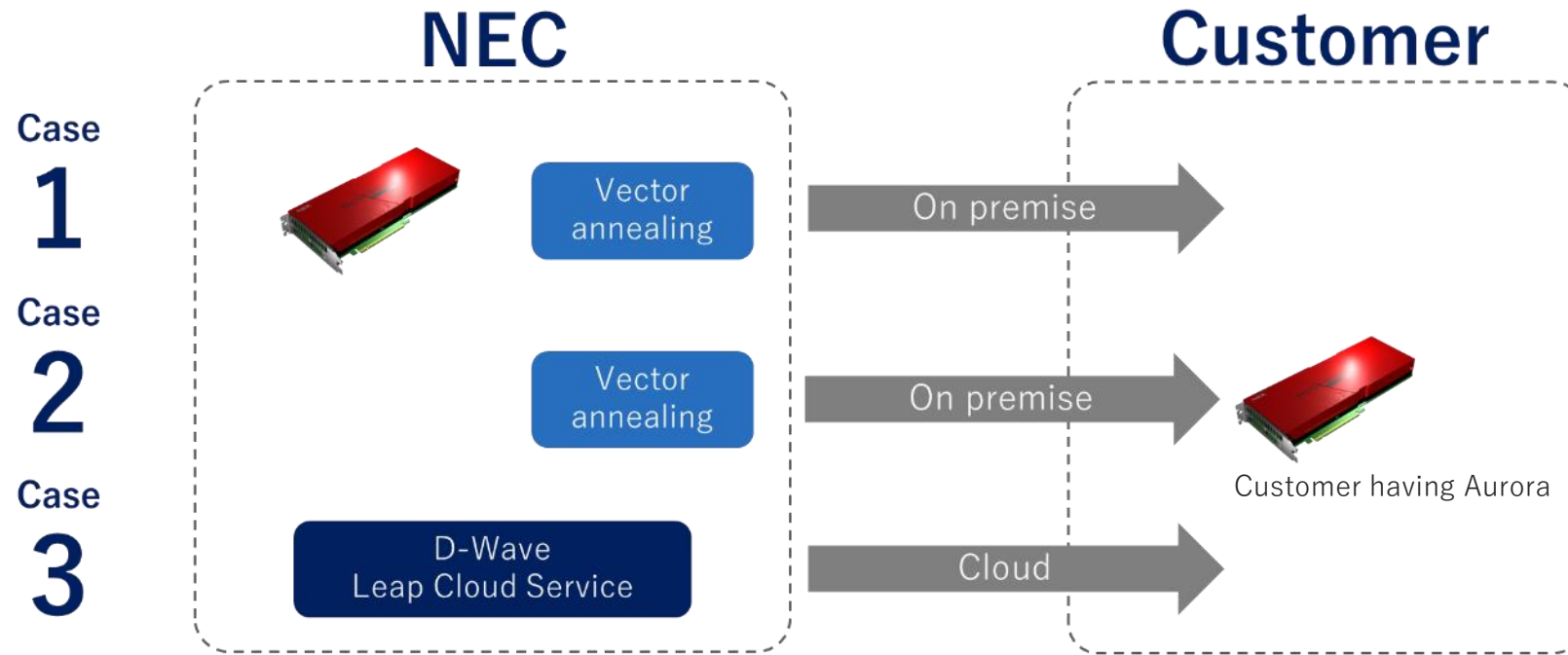
1: Providing Aurora platform and NEC VA application (on premise)
2: Providing NEC VA application to customer's Aurora (on premise)
3: Providing D-Wave Leap cloud service

VA test drive is available now!

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Vector Annealing on SX-Aurora TSUBASA

Expectation for Quantum Annealing
Faster solving combinatorial optimization problems than mathematical approaches

Combinatorial Optimization Problems:
To find a combination which provides max/min value of an evaluation function from huge number of combinations with satisfying constraints

Typical problems
- Travelling Salesman Problem
- Knapsack Problem
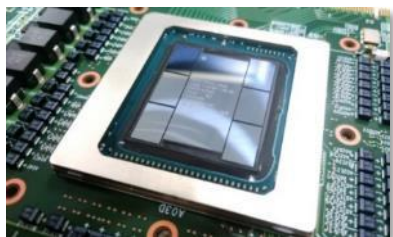- Job Shop Problem
- Work Shift Problem
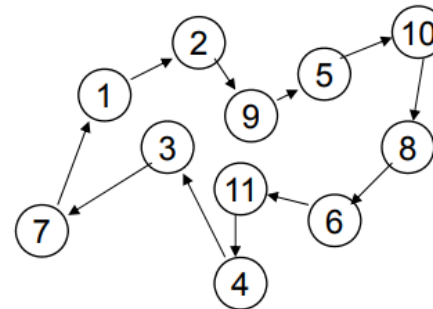
Travelling Salesman

Knapsack

Job Shop

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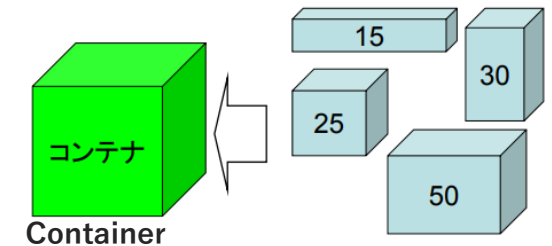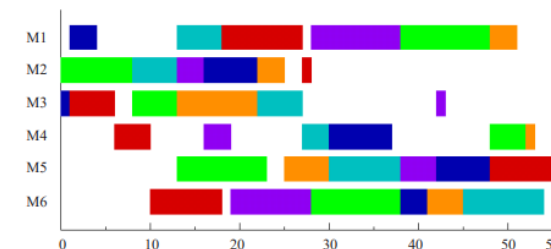
NEC Vector Annealing

6x Acceleration by the Vector Architecture

50x Acceleration by skipping constraint violations

Vector operation on VE
Energy calculation is matrix operation

Qij

SpinState

```
for(i=0; i<numSpins; i++)
    DeltaEnergy +=
        Qij[FlipSpin][i] x SpinState[i]
```

Effect from neighbor spin   0 or 1
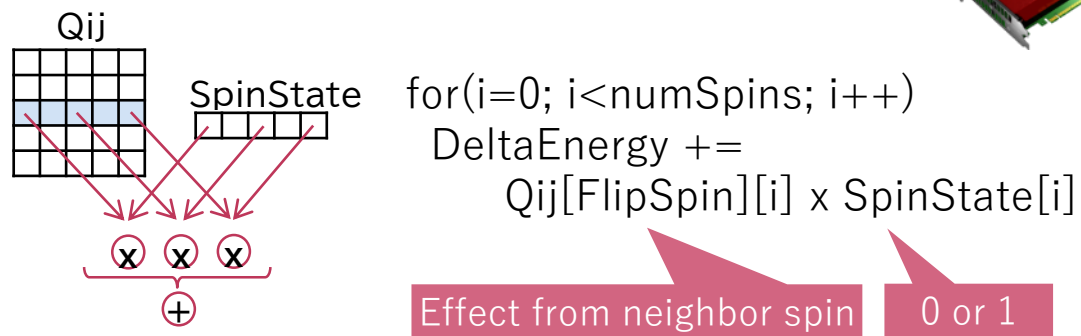
Full connect 100k bits/VE and high memory bandwidth

- 48GB memory capacity and 1.5TB/s memory bandwidth
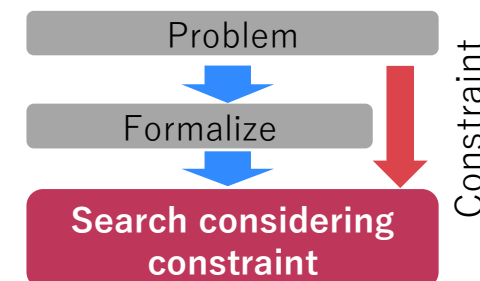- Multi card supports larger number of qbits $(100k\ qbits\ x\ n)^{1/2}$

Optimized algorithm for VE
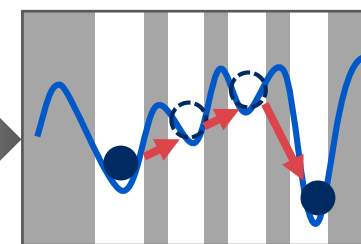### Avoiding Redundant Search

Existing search
Including constraint violations

better
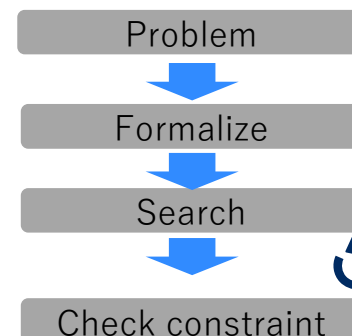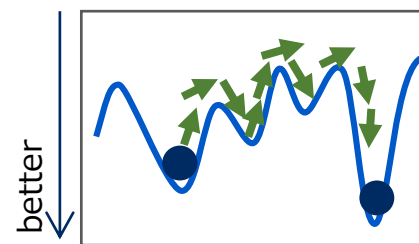
VA search
skip constraint violations

Problem → Formalize → Search → Check constraint

Violation →try again

Problem → Formalize → **Search considering constraint**

Constraint

computational complexity reduction

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Case Study

Solving Social Issues Using Quantum Computing

NEC is trying to apply QC technologies for practical use with partners

Development with Co-creation Partners
SMBC Group/ JRI / NEC Platforms / NEC Fielding etc.

Advertisement Infrastructure	Manufacturing	Traffic/Logistics	Financial	Material/Drug
• Matching/ Recommendation • Com. base station • Surveillance sensor	• Production plan • Parts ordering plan	• Crew shift • Delivery plan • Load placement	• Card fraud detection • Monte Carlo simulation • Risk calculation	• Screening • Experimental • parameter search

※研究中、顧客実証～実用に至るものが含まれています

Leap Quantum Cloud Service	NEC Vector Annealing Service

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Use Case: **Delivery Route and Schedule Optimization**
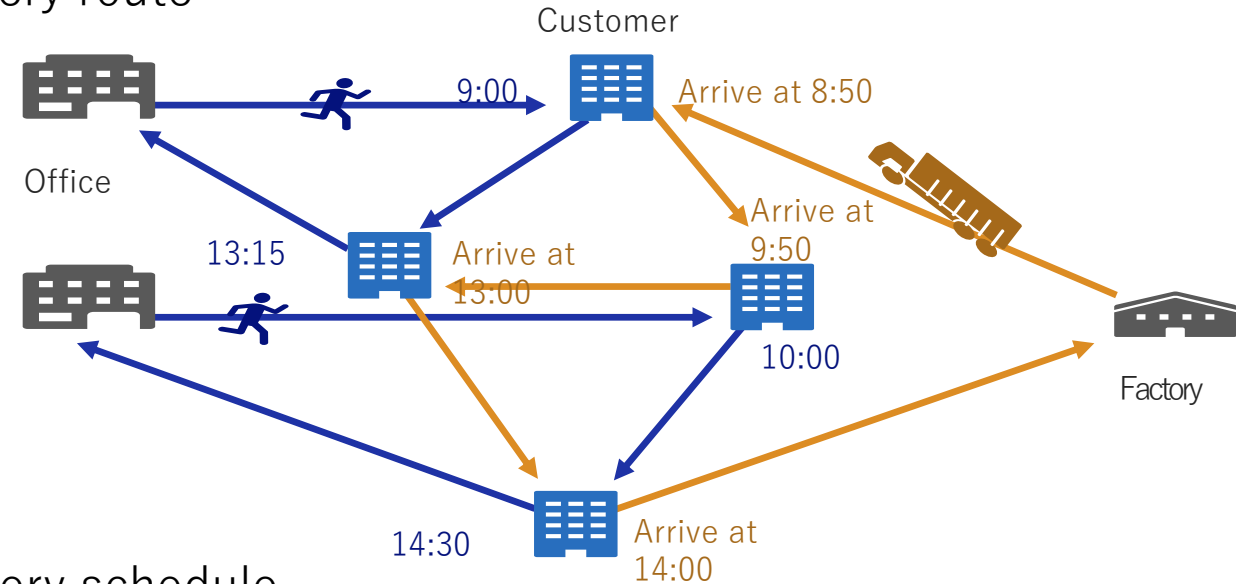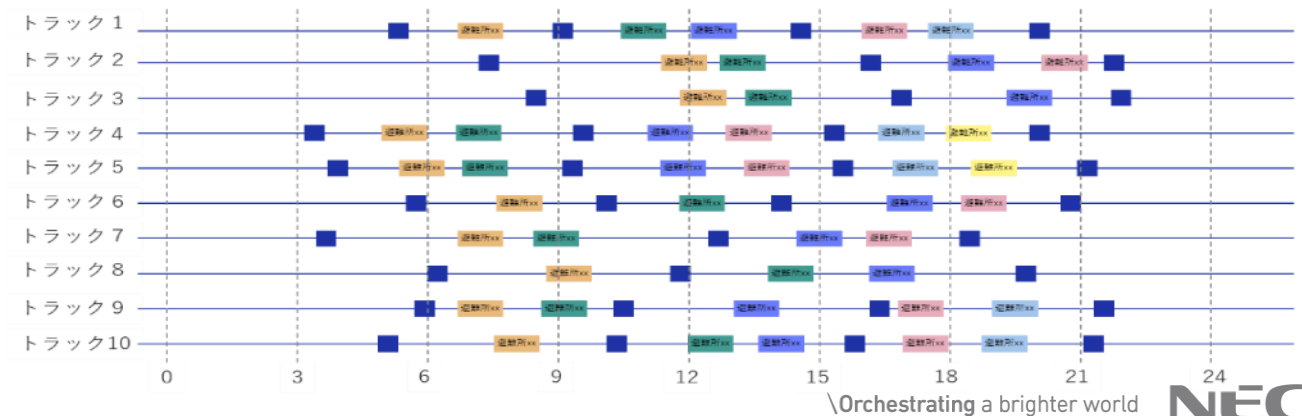## for reducing costs, time, energy, CO_2, etc.

delivery route

EX. **Delivery of parts and dispatch of Engineers**

- Parts are delivered by truck
- Engineers move by car/train
- Have to consider skills of each engineer

delivery schedule

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NEC Fielding（Maintenance Service）

Providing maintenance and repair services for corporations.
1st example of using VA for actual operation.

●ICT machines

●Medical equipment
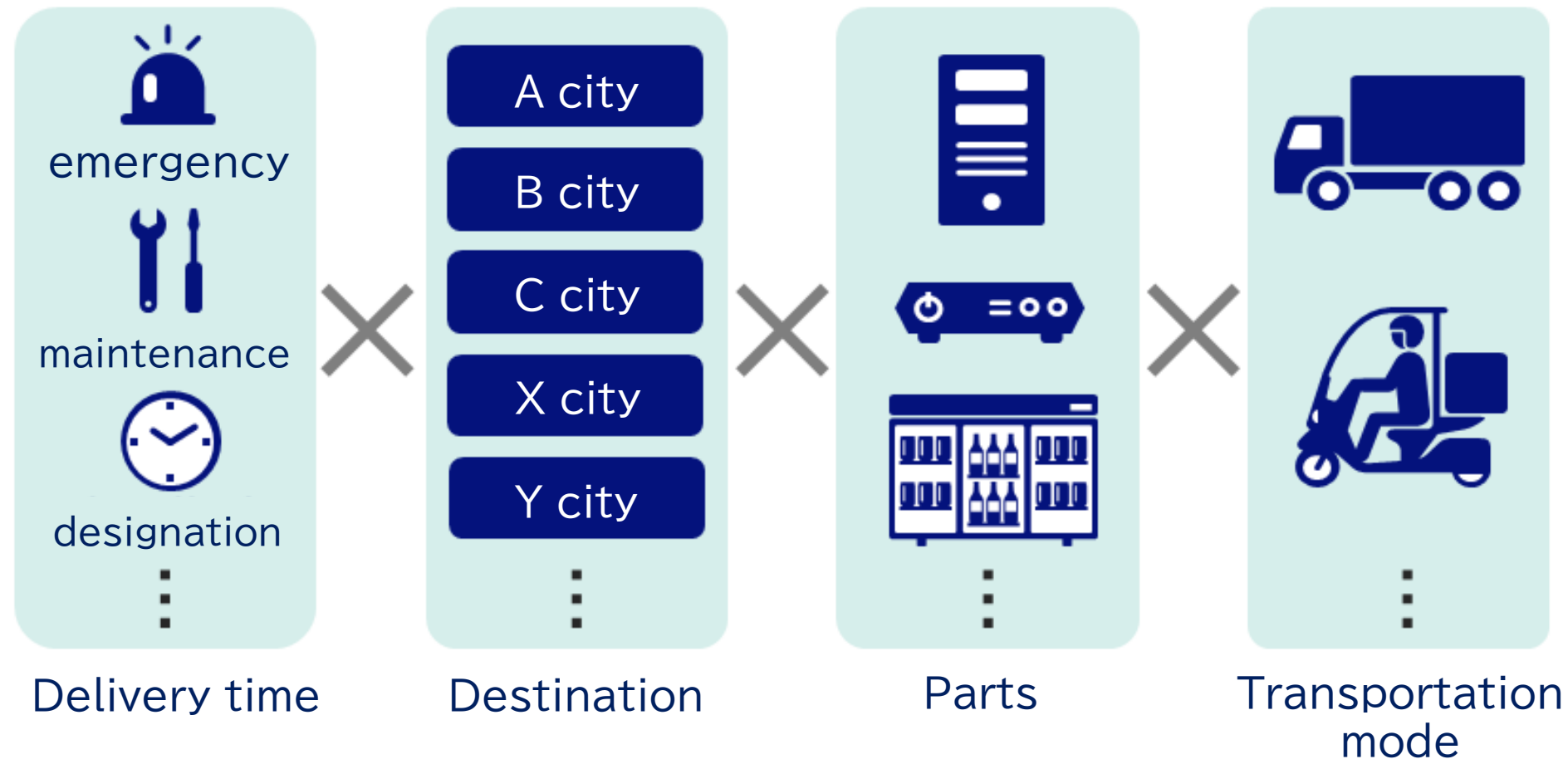
●Analysis equipment

●Robots

●Commercial washing machines

●Commercial refrigerators

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Delivery Optimization

Combinatorial optimization from huge combination

Delivery time × Destination × Parts × Transportation mode

emergency
maintenance
designation

A city
B city
C city
X city
Y city

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Logistics Problem to be Solved

Tokyo Parts Center
☐ Warehouse: 6,000m², 150k maintenance parts stock
☐ Delivering to several hundreds destinations in Tokyo by 40 cars

Region： Tokyo metropolitan area
Operation: 24h x 365days
Delivery Cars： 30 cars and 8 motor bikes
Employee： 43

Tokyo Parts Center

Parts Center

High   Low
Delivery Amount
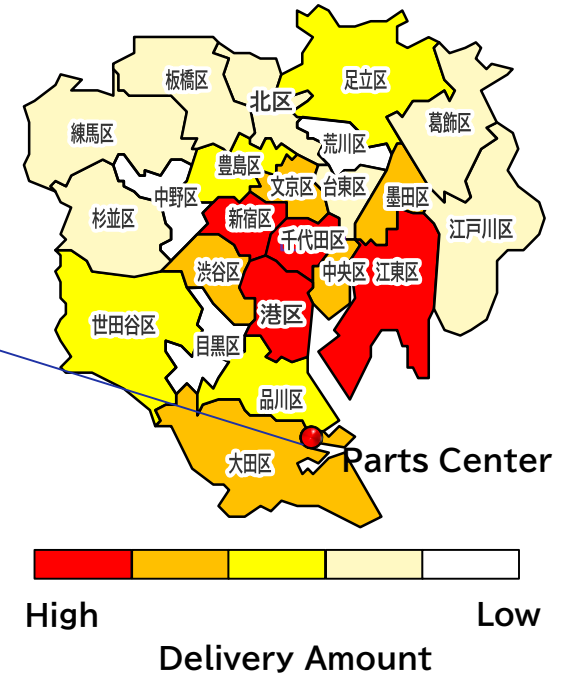
Delivery Operation
☐ Engineers move by public transport
☐ Arrival of engineer and each maintenance parts must be same timing
☐ Each car/bike brings some parts to deliver some destinations
☐ **Huge combination of delivery times, destinations, car/bike, parts**
☐ **Professional engineer made delivery plan every day**

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Actual Operation by VA as a 1ˢᵗ Step

Start applying VA optimization to delivery order the day before

Actual Operation from October

Delivery order the day before

input

Several 100s Order /day

Future Plan

Delivery order today & Emergency

30% cost reduction CO₂ reduction

Professional engineer optimization

120 min./day

● **Delivery Planning**
  ・Delivery time
  ・Traffic Jam
  ・Delivery area
  ・Parts count
  ・Parts weight
  ・Transportation mode

Maintenance at customer

Vector Annealing optimization

12 min./day

Oil Field Exploration as a Combinatorial Optimization Problem
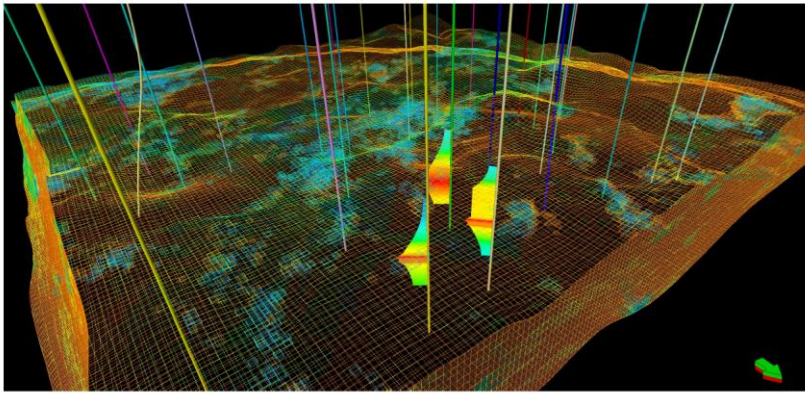
Subsurface modeling is only the beginning of oil field exploration.
Given a map of the distribution of oil and a limited number of resources to develop the field, energy companies must plan a drilling sequence that considers:

- The **value of placing** a well at a given location.
- The **cost of moving a drilling platform** from one location to another.
- The impact placement of a well has on neighboring locations
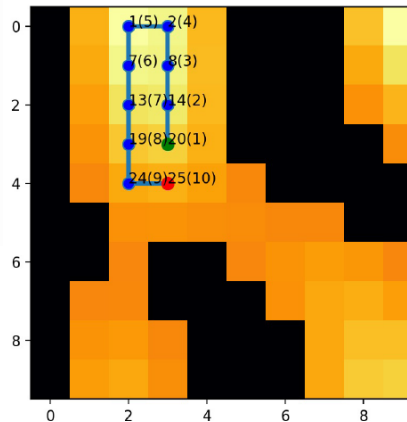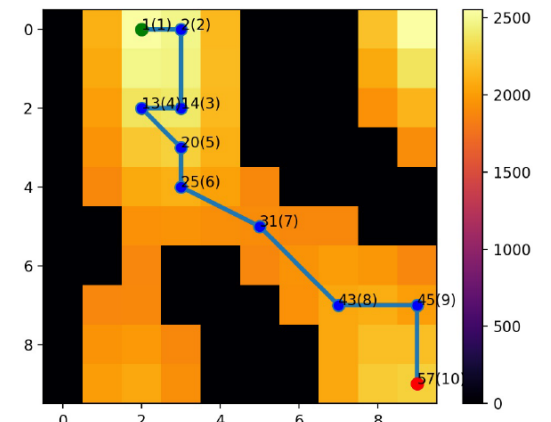 (**well interference**)

Value Only
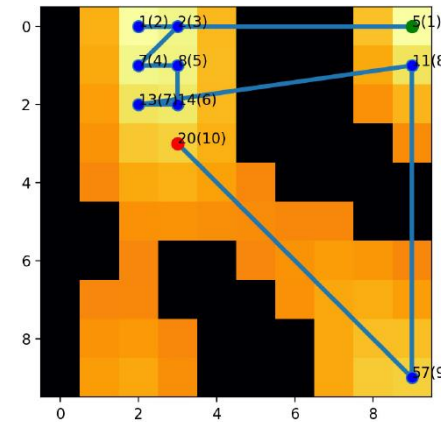
Trivial problem

Value and Moving Costs
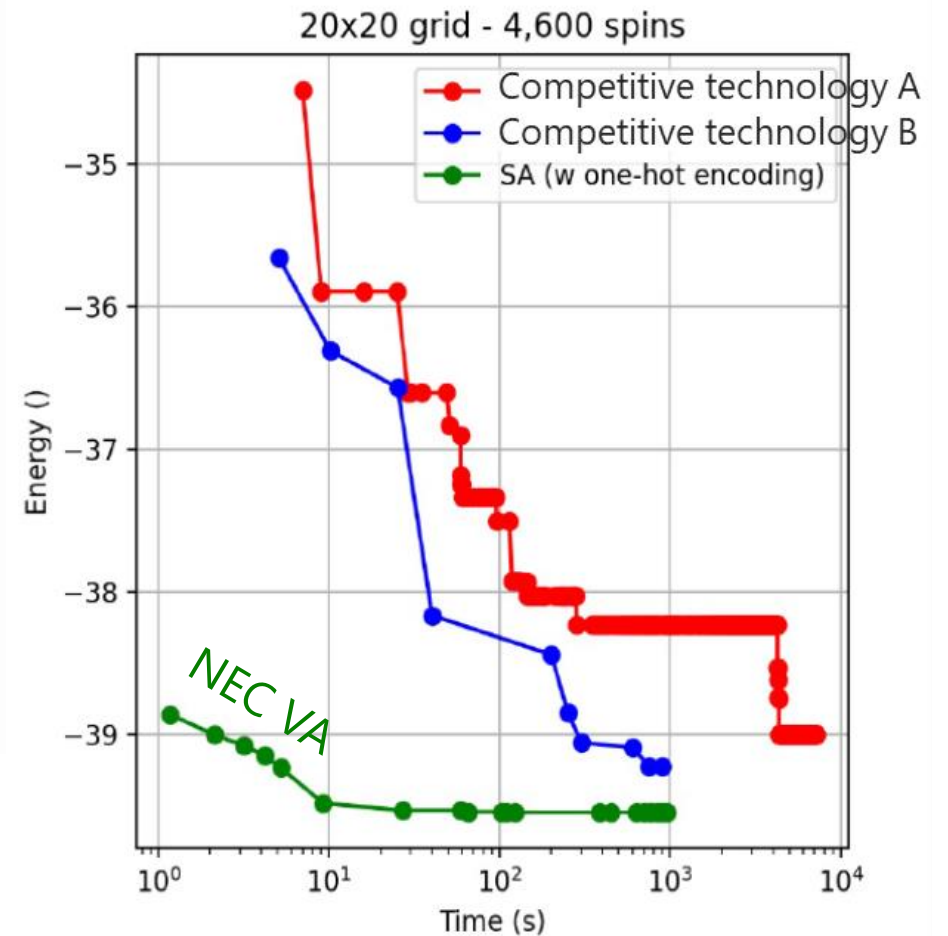
Value, Well Interference and Moving Costs

NP-Hard Problem

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Welling Plan Benchmark

◆ Completed **PoC with software company in US** focusing on energy resource exploration optimization problem.

◆ NEC VA with external constraints like one-hot encoding provided **best results** in comparison to other ISV SA software running on classical computers as well as accelerators.

20x20 grid - 4,600 spins

- Competitive technology A
- Competitive technology B
- SA (w one-hot encoding)

NEC VA

NEC achieved lowest energy with shortest time

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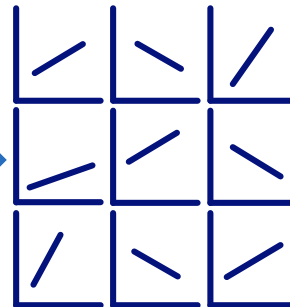# Toward advanced MI (Materials Informatics) key technology

- Predictive model creation by AI
  → Quantum computing solves the **inverse problem**
- Providing **multiple influential recipe** proposals

①Predictive model by AI

Explanatory variables   Characteristic value

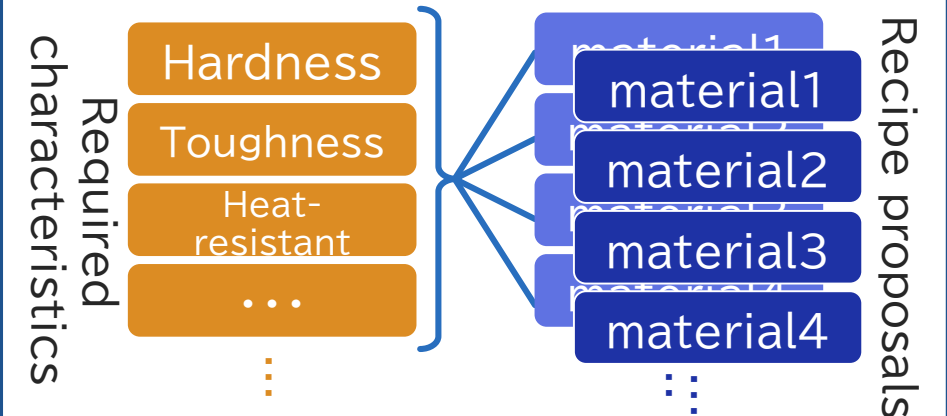| material1 | | Hardness |
material2		Toughness
material3		Heat-resistant
material4		...
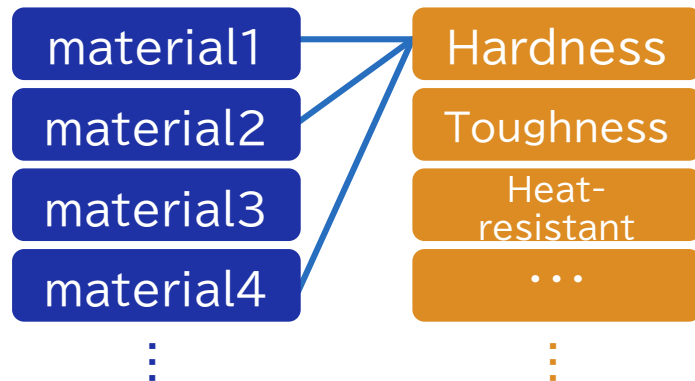
Create a predictive model of the impact of material type and quantity on product characteristics from past experimental data

②QC solves the inverse problem

Characteristic value   Explanatory variables

Required characteristics

Hardness		material1
Toughness		material2
Heat-resistant		material3
...		material4

Recipe proposals

Find the optimal combination of the amount of material that expresses the characteristic target value

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Real Time TSUNAMI Disaster Simulation & Real Time Proposing Optimal Evacuation Routes

"Next Generation Supercomputing Platform assisted by Quantum Annealing"
R&D with Tohoku University

earthquake	Tsunami simulation	Disaster simulation	Evacuation route

Supercomputing   Annealing
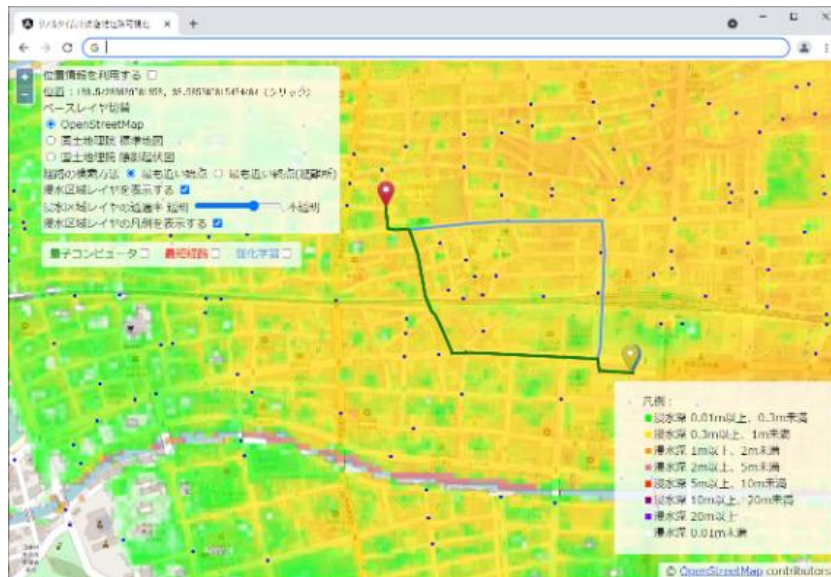
Evacuation Route (Annealing)

Tohoku University

Information Science
Prof. Kobayashi, Prof. Ozeki

Disaster Science
Prof. Koshimura
Associate Prof. Erick

Faculty of Science
Associate Prof. Ota

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