



New activities/challenges of fundamental research in Bay Area.

August. 2023

NTT Research, Inc.

<https://ntt-research.com>



NTT Research, Inc. at glance

Established: Apr. 2019

Shareholder: 100% subsidiary of NTT Holdings Company

Our mission:

- Focus on Basic Research related Quantum Computing, Cryptography, Block chain & Medical Informatics
- Grow NTT brands by original technologies in Worldwide

Number of Members: Jul. 2023:

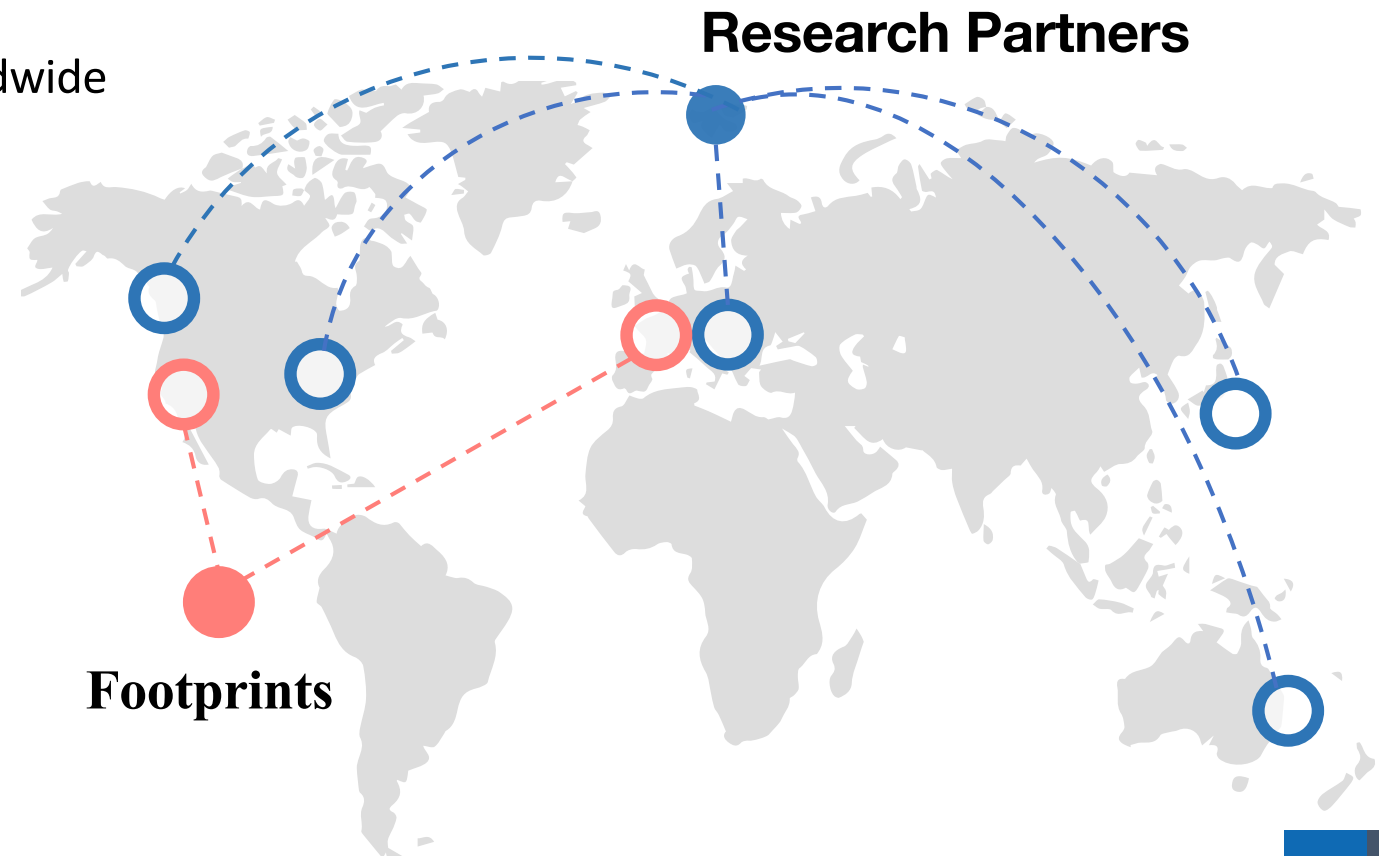
- Researchers 48
- 44 has Ph.D. degree 2 has M.D.

Footprints:

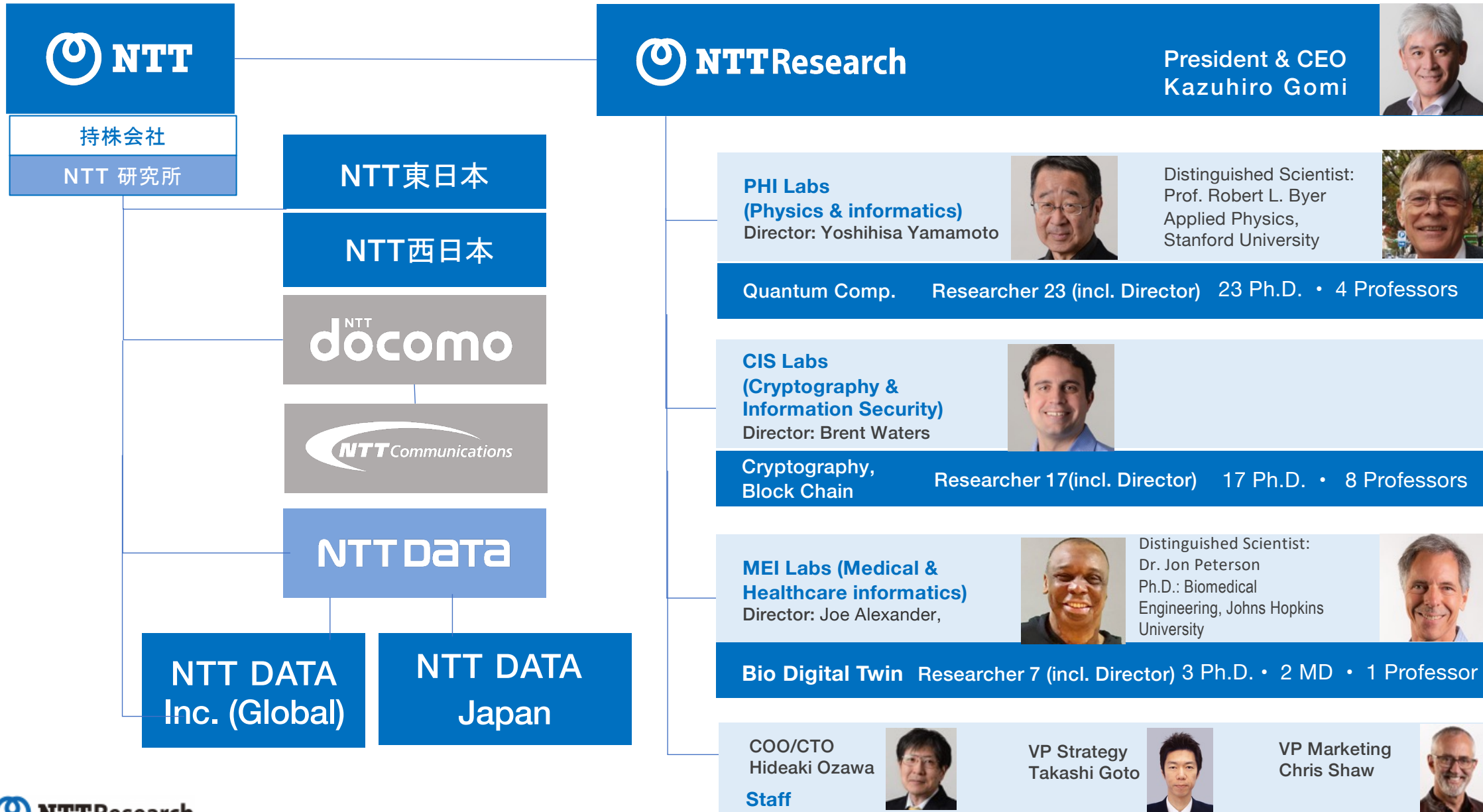
- Headquarters: Sunnyvale, CA, U.S.A
- Branch: Munich, Germany

Research Partners:

- Universities: 11 US, 1 Canada, 1 Germany, 1 Australia, 1 Japan
- 2 National Research Center (US, Japan)



Position of NTT Research, Inc.



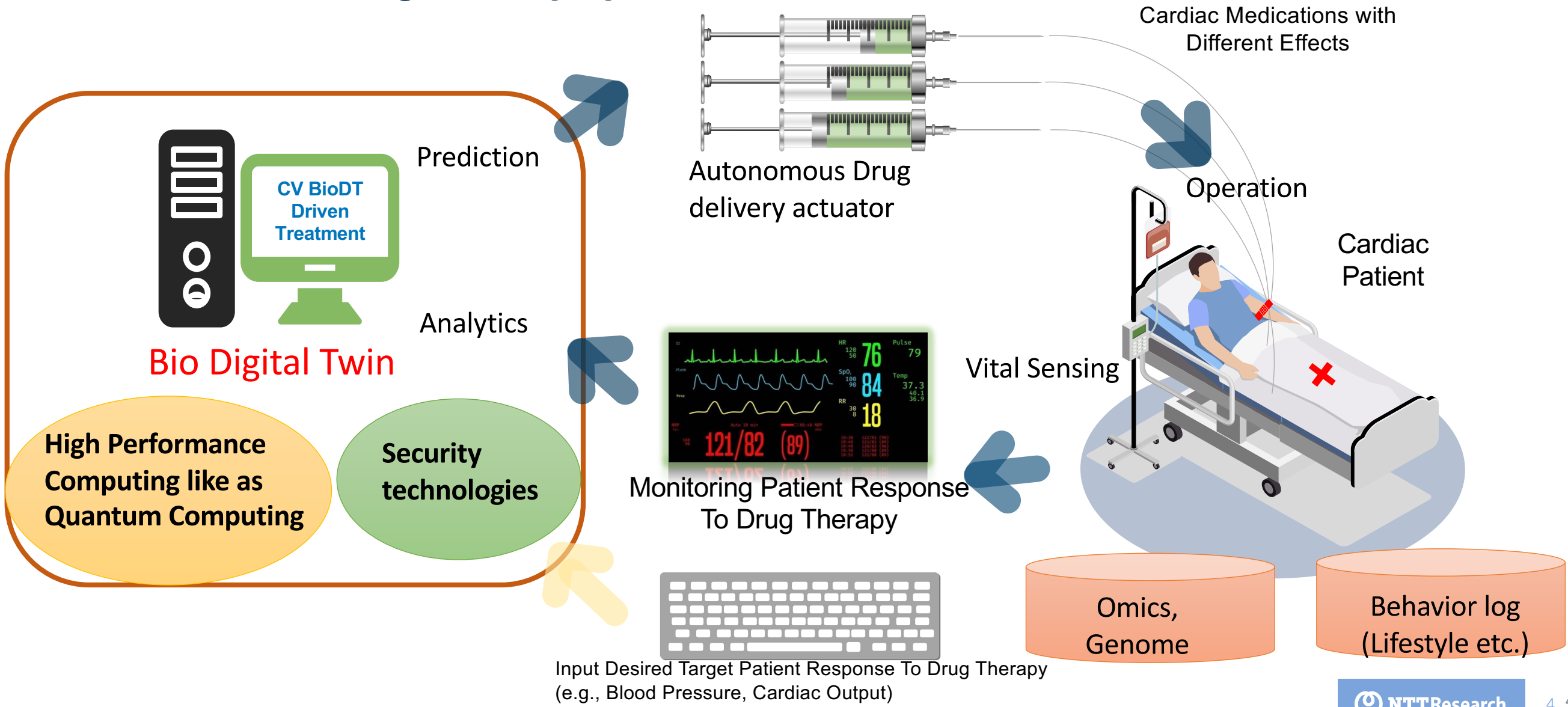
MEI Lab – Bio Digital Twin

- A bio digital twin is ultimately a virtual representation (an electronic replica) of an individual



Towards closed loop therapeutic system

Cardiovascular Drug Delivery System



Otto: Cardiovascular Bio Digital Twin (CV BDT)

- The prototype of CV BDT was developed based on hemodynamic model (Otto) which models blood circulation and simulation scenario of the response of the system to treatment such as medication.
- In Otto, the mechanism of the circulator is represented by an electrical circuit model. In terms of the relationship between blood vessels and the heart, the heart is a pump or a battery that pushes out electrical current in electrical circuitry, and blood vessels are electrical wires in electrical circuitry. In addition, factors such as whether a blood vessel is hardened due to arteriosclerosis or whether there is a narrow place in the blood vessel due to plaque accumulation are represented by the resistance value. So far, we have built computer simulated model based on the Bayesian Network that can simulate parameters representing individual circulatory differences and changes in conditions that occur during treatment such as medication for acute heart failure or myocardial infarction.
- In the future, we will add simulation functions for organs related to circulatory organs, such as the autonomic nerve, which plays an important role in keeping blood pressure constant, and the kidney (which regulates blood flow), and then verify the effectiveness of the bio-digital twin by animal experiments.

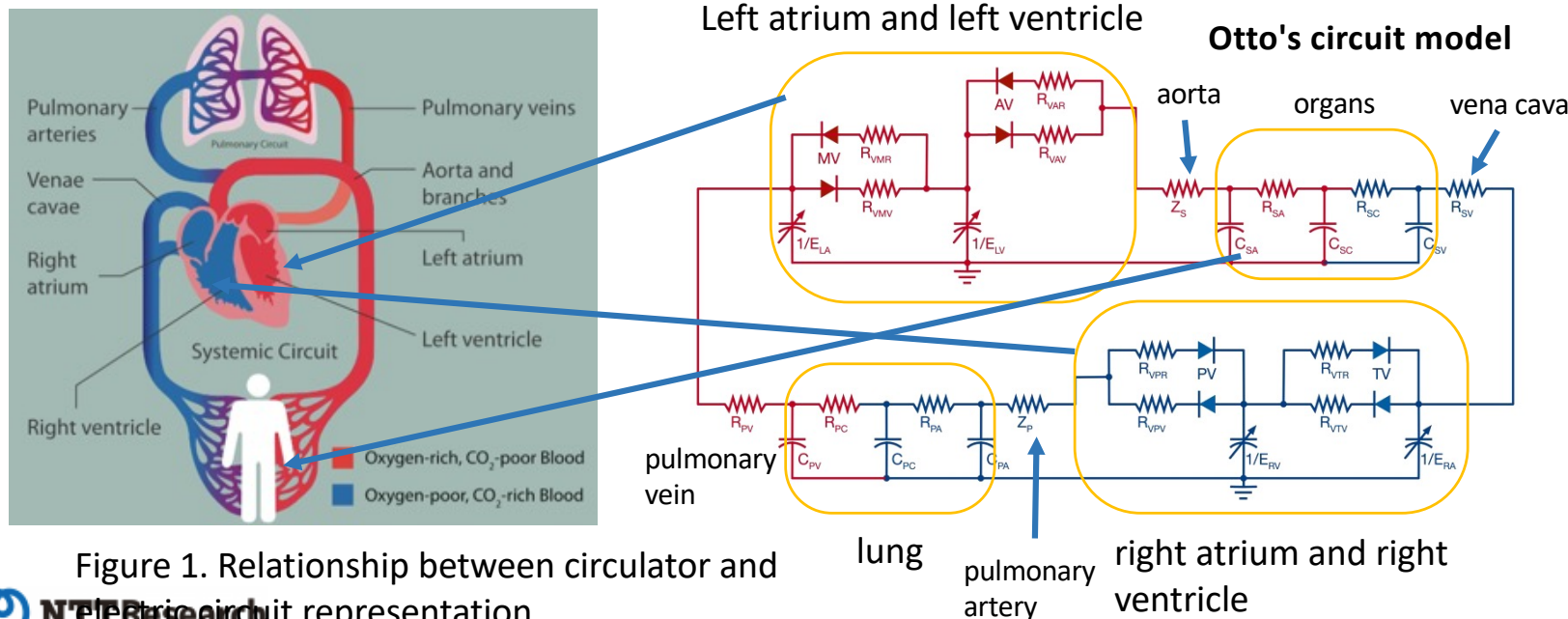
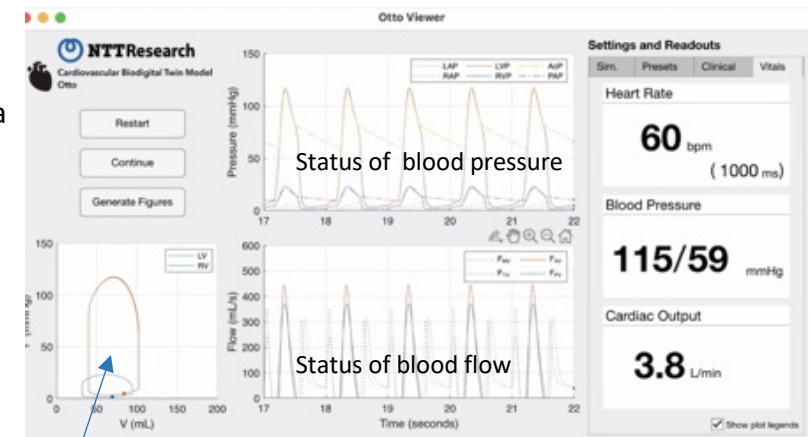


Figure 1. Relationship between circulator and its representation



state of heart movement

Figure 2. Simulation Results



A method for optimizing the infusion of drugs for acute heart failure

- This study aims to automate drug treatment for acute heart failure by using simulation methods to select the most appropriate combination of drugs and to develop a method that can deliver the most appropriate dose of medication to conventional physicians based on their experience and guidelines.
- The goal of treatment is to normalize the overall circulation of blood by simultaneously achieving multiple goals, such as whether the patient's blood pressure is within a certain level and whether the heart is pushing blood below the lower limit.
- It is now possible to construct a model called the Drug Library, which expresses how the effects of drugs contribute to the resistance and capacitor values of the Bio Digital Twin, and simulate the medication situation with the CV Bio Digital Twin.
- The combination and dosage of drugs were optimized for 5600 patients including 3 patient conditions (Figure 1-II, III, IV Conditions). The combination of drugs selected met the treatment guidelines, and the dosage of each drug could be determined in detail (Fig. 2). The system also supports the physician's decision to switch to a different treatment plan early to pre-identify patients who cannot be treated with drugs by simulation. Based on this result, we will conduct animal experiments to verify whether the proposed method is effective for treatment.

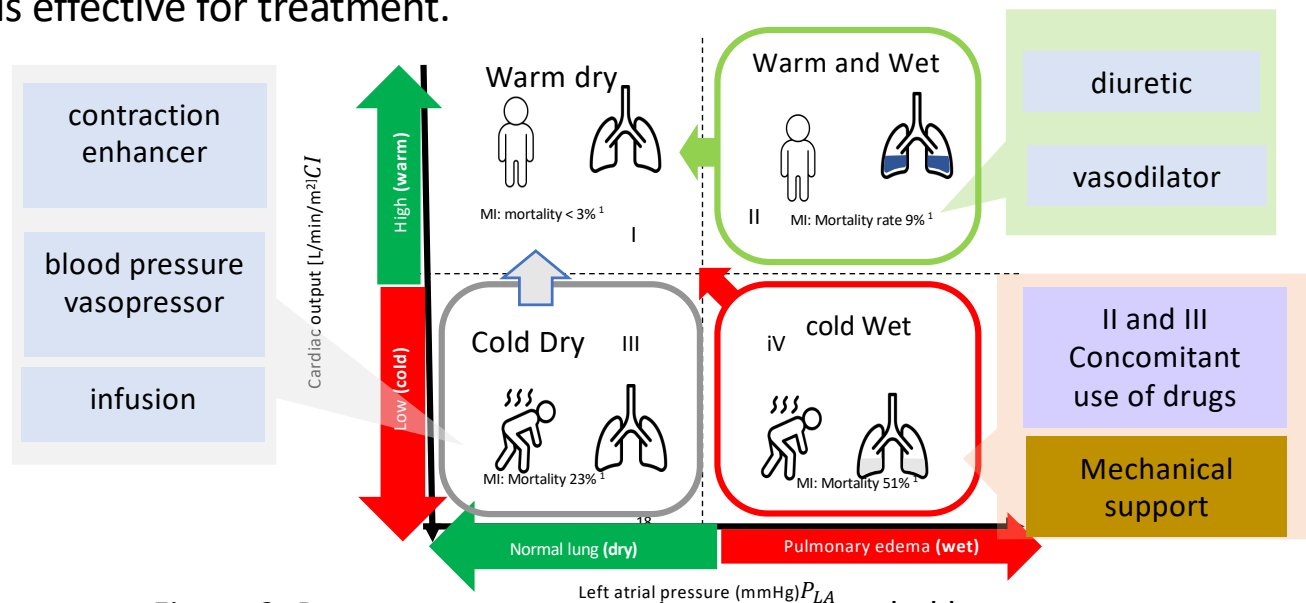


Figure 2. Drug treatment strategies recommended by

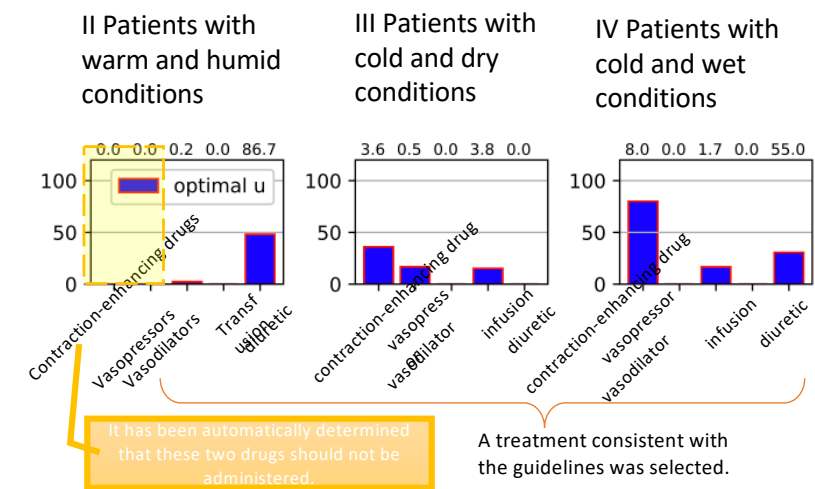
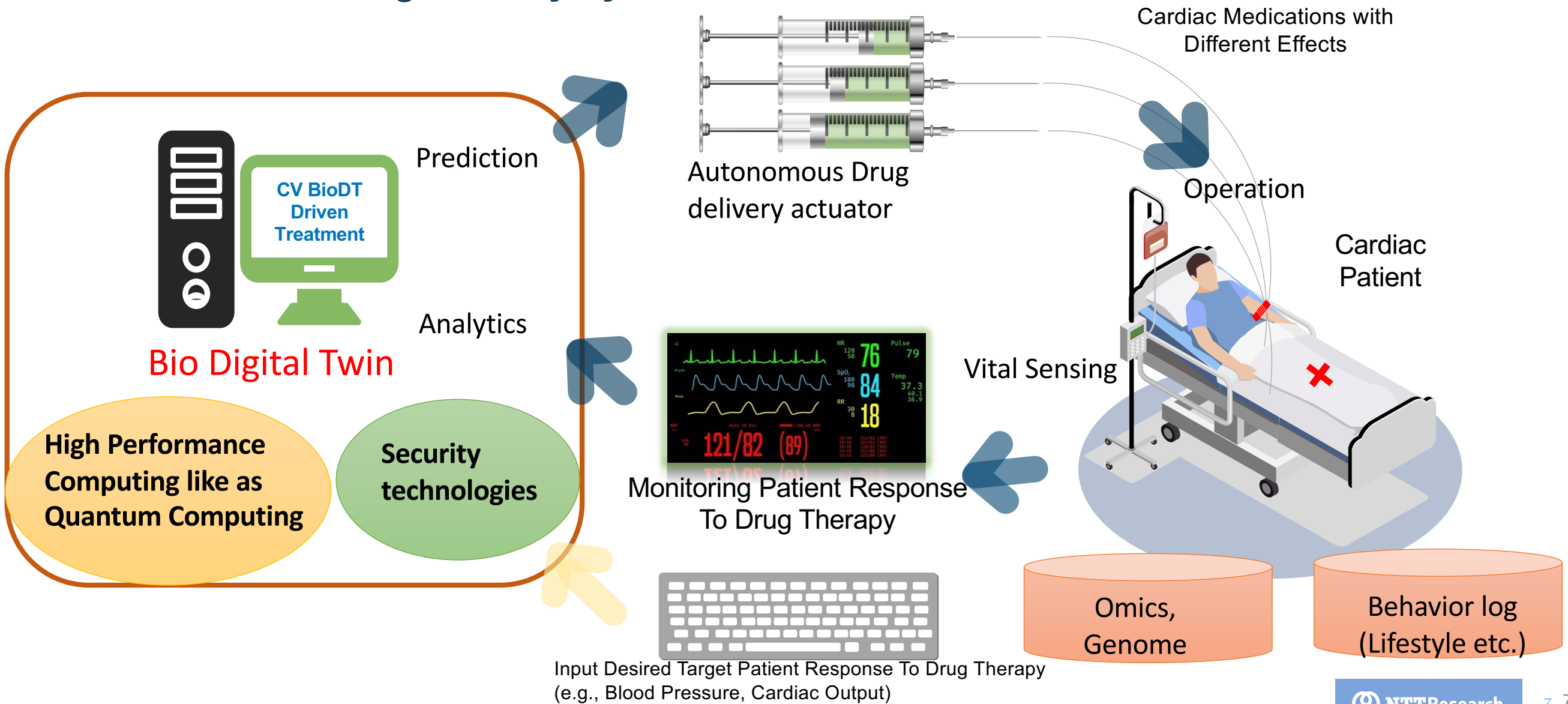


Figure 3. Results of the calculation of the medication to minimize the total dose

Towards closed loop therapeutic system

Cardiovascular Drug Delivery System



Overview of Quantum Computing Research

MaxSAT, Drug discovery, Sparse Coding
(Combinatorial Optimization Problem)

Brain or Artificial Intelligence research
(Machine Learning)

Target applications

Algorithm/Computing methods for Ising
machine etc.

Analog Computing mechanism

Algorithm/mechanism

Optical computing platform

MVM by optical computing etc.









Device Research

TFLN based silicon photonics

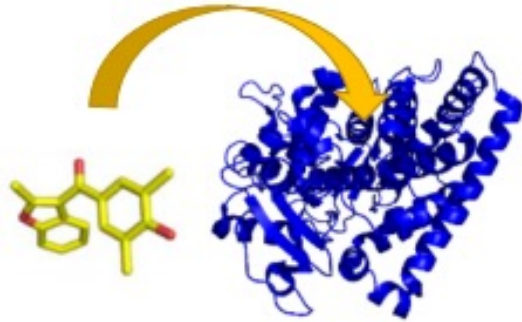
Theory of Coherent Ising Machine

Quantum Computing

- PHI Labs. tackle to develop Annealing based quantum computer using Quantum behavior of photon.
- Annealing of Quantum behavior can be simulated on current digital computing technology. We tackle to develop implementation of CIM on FPGA/GPU as CyberCIM

	Annealing - Coherent Ising Machine -		Quantum Gate
Approach	Quantum inspired digital implementation	Quantum behavior	Quantum gate
Applications	Combinatorial optimization		General purpose
Organization	 	  	  
Merit	Reliability by stable hardware	Robust against noise and gate error	Transparent physics and established theoretical limit
Demerit	Resource hanging	Complicated physics; theoretical limit unknown	Sensitive to noise and gate errors
Time to Commercial	Shortly in a few years	Shorter than Quantum Gate implementation	Still very long

Combinatorial Optimization and Machine Learning



Structure Based Virtual Screening (SBVS) for discovery of

- Lead optimization (drug discovery)
- Peptide drug
- Biocatalyst



<https://ja.wikipedia.org/wiki>

Sparse estimate in compressed sensing for

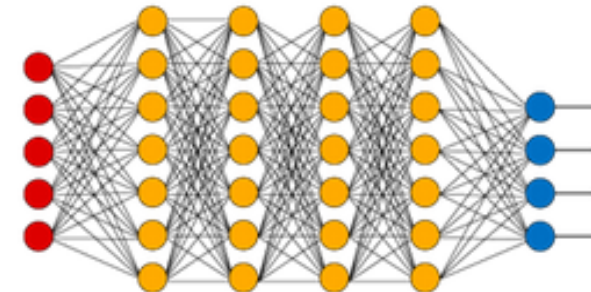
- Astronomy
- Magnetic Resonance Imaging (MRI)
- Computed Tomography (CT)



<https://ja.storyblocks.com/stock-image/smart-city-and-wireless-communication-network-abstract-image-visual-internet-of-things-mono-blue-tone--roiwpowej044z2ev>

Resource optimization in

- Wireless communication
- Logistics
- Scheduling
- Portfolio management



<https://iartificial.net/redes-neuronales-desde-cero-i-introduccion/>

● Input Layer ● Hidden Layer ● Output Layer

Learning and synaptic pruning in deep neural network for

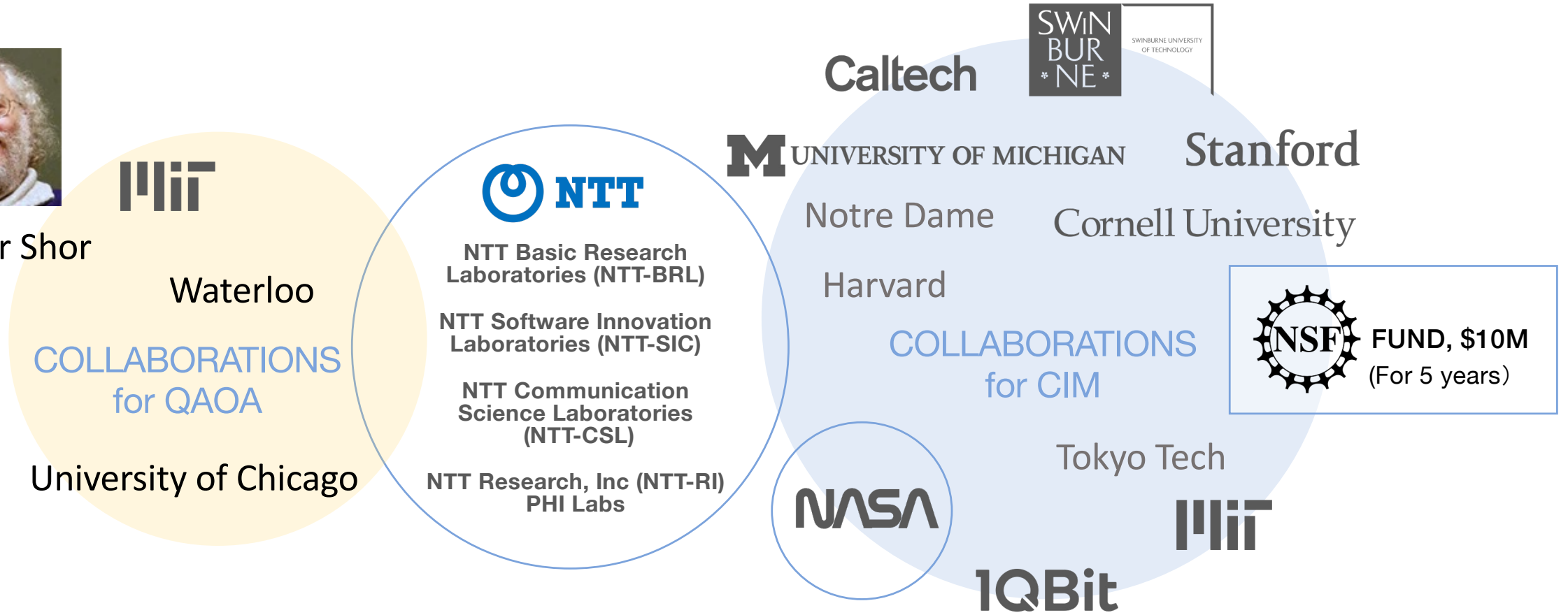
- Voice and image recognition
- Self-driving cars
- Healthcare, Finance

Research area and team

- Research of QAOA(Quantum Approximate Optimization Algorithm) is added as new topic. QAOA is an algorithm for combinatorial optimization to use Gate typed Quantum Computer. This is a theoretical research.
- One of collaborator is Prof. Peter Shor at MIT who is well known as the Shor Algorithm for integer factorization
- Notre Dame University and Tokyo Tech joined to the collaboration team for CIM

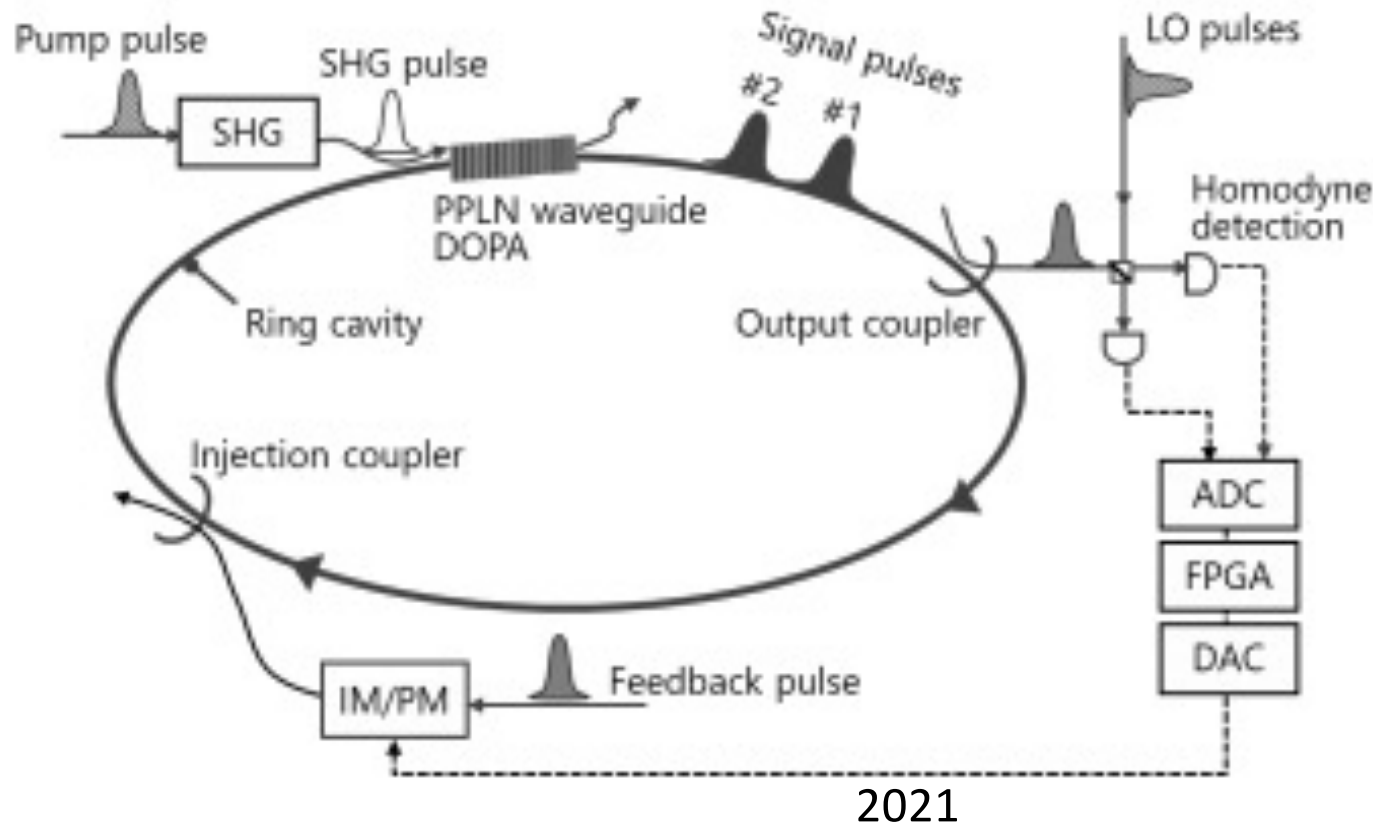


Prof. Peter Shor

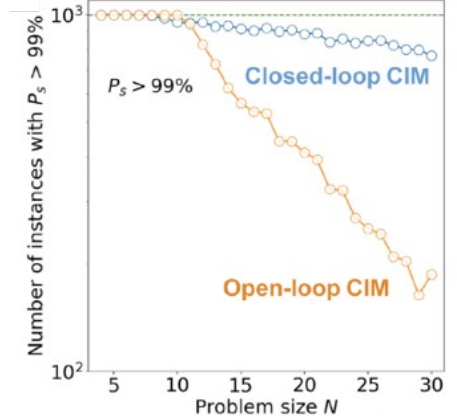
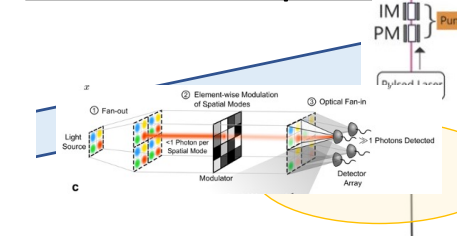


CIM Research direction

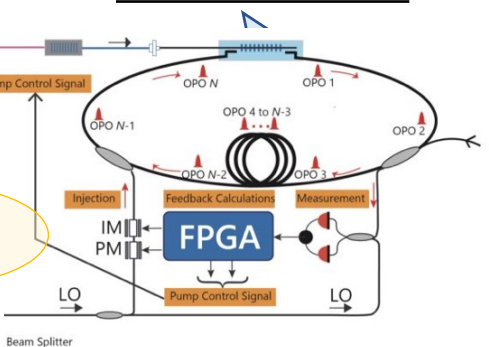
1. Theoretical research : Understanding performance limitation of Coherent Ising Machine
2. Hardware improvements: More spins, stable machine.
3. Explore practical applications:



Optical based vector matrix multiplier



All Optical Architecture

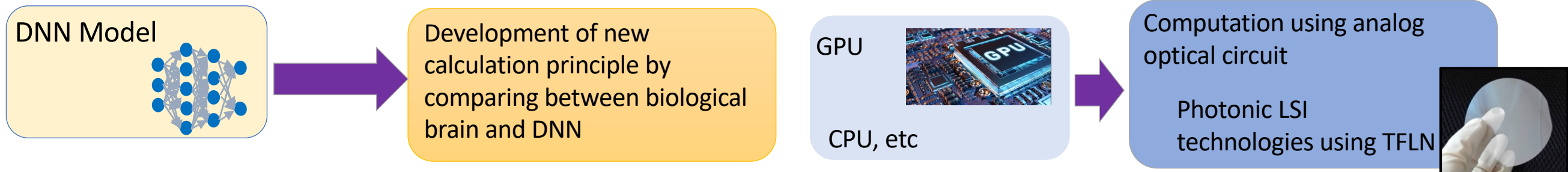


TFLN based optical memory or processing unit

2025-2030

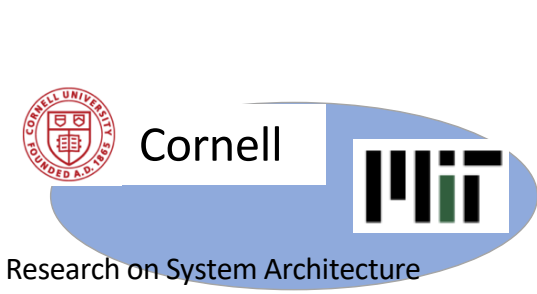
Artificial Intelligence Research in NTT Research

- In the course of research aimed at realizing CIM, technologies applicable to artificial intelligence are emerging.
 - 1) Increase the reliability of current AI that is too complex to explain its behavior (make AI Trusted)
 - 2) Achieve drastic energy savings for digital circuit-based DNNs (Deep Neural Networks) that consume enormous amounts of electricity
- Each research topic has been published in the world's top journals such as Nature/Science.



- ❖ In the biological brain, it is known that roles are divided by parts, and that there are certain rules in the learning process. By applying these characteristics of the biological brain to learning by AI, we are developing a research field called "the physics of knowledge" that guides the rules of learning.
- ❖ While modern AI greatly improves performance by learning with a huge amount of data, it cannot be ruled out that a behavior different from the original intention may occur. In addition, when such a wrong behavior occurs, there is no means to efficiently repair the wrong behavior. Therefore, the aim is to **realize a safe and secure AI** by understanding which stage and method of learning can suppress or repair the unintended behavior by utilizing knowledge of psychology.

- It is estimated that ChatGPT requires more than 10 MW of power to run 20 (1GWh in One time when learning). DNN (**Physical Neural Network**), which is based on analog technology, is a way to keep performance as an artificial intelligence and bring energy requirements closer to the human brain. The PHI Institute has confirmed its basic operation and is studying a scaling strategy.
- By replacing the product sum operation, which accounts for most of the AI power consumption, with an optical circuit, a drastic reduction in power consumption can be realized. Advancing this direction, we are conducting research aimed at replacing GPUs with **optical LSI**-based systems. Specifically, we aim to realize optical LSI manufacturing technology using TFLN(Thin Film Lithium Niobate) as a material.



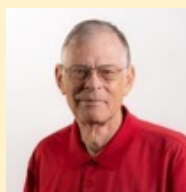
PHI Labs Researchers



Myoung-Gyun Suh
Senior Scientist
Ph.D. : Caltech



Satoshi Kako
Deputy Director of
PHI Lab.
Ph.D. : Univ of Tokyo
Faculty: Assist Prof of U-Tokyo



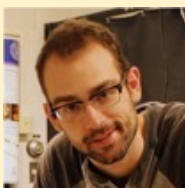
Robert Byer
Distinguished Scientist.
Ph.D. : Stanford Univ.



Michael D. Fraser
Group Head
Ph.D. : The Australian
National University(AU)



Ryan Hamerly
Group Head
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Logan Wright
Research Scientist
Ph.D. : Cornell Univ.



Yoshihisa Yamamoto
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Ph.D. : Univ of Tokyo
Faculty: Prof. of Stanford Univ.



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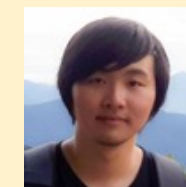
Timothee Leleu
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Faculty : Assoc. Prof. of U-Tokyo



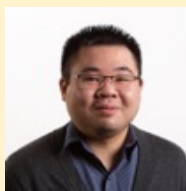
Hideanori Tanaka
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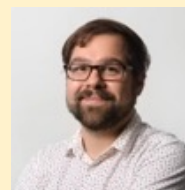
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Edwin Ng
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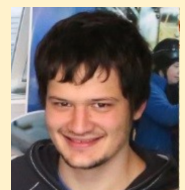
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**Gautam Reddy
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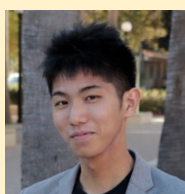
Sina Zeytinoglu
Post-Doctoral Fellow
Ph.D. : ETH



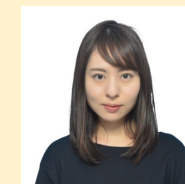
Sho Sugiura
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Yoshitaka Inui
Research Scientist
Ph.D. : Kyoto Univ.



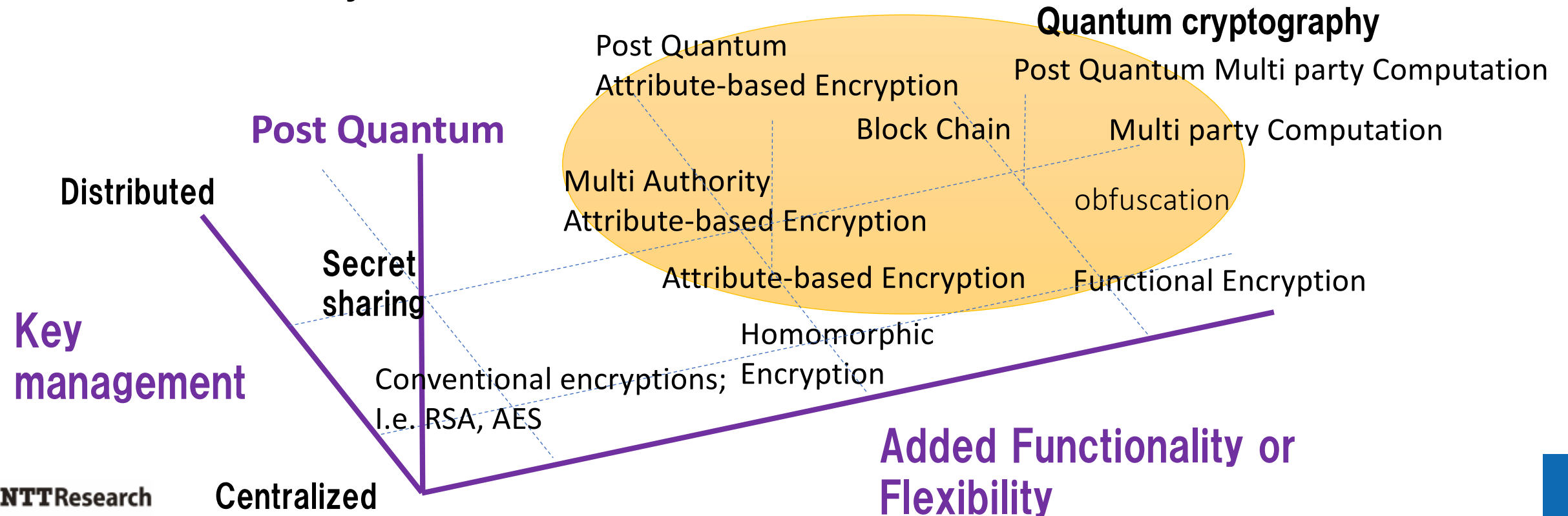
Ryotatsu Yanagimoto
Post-Doctoral Fellow
Ph.D. : Stanford Univ.



Maya Okawa
Research Scientist
Ph.D.: Kyoto Univ.

CIS Lab: Research Direction

- CIS Labs. tackle to develop algorithm of advanced cryptography for below 3 criteria
 1. Conventional encryption can provide one cipher key and one decipher key. CIS Labs tackle to develop more flexible theory of Cryptography. Such as, multiple type of decipher key for purpose of using encrypted data, or statical functions without decipher operation
 2. Decentralized key management or Distributed encryption data storage
 3. Post Quantum cryptography. It is not only measures for conventional cryptography in Quantum computing era. We tackle brand-new theory of cryptography using Quantum information like as Quantum money too



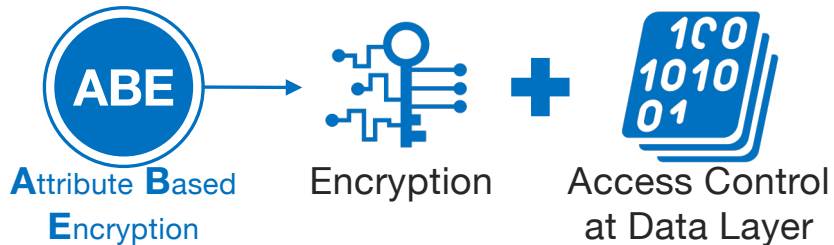
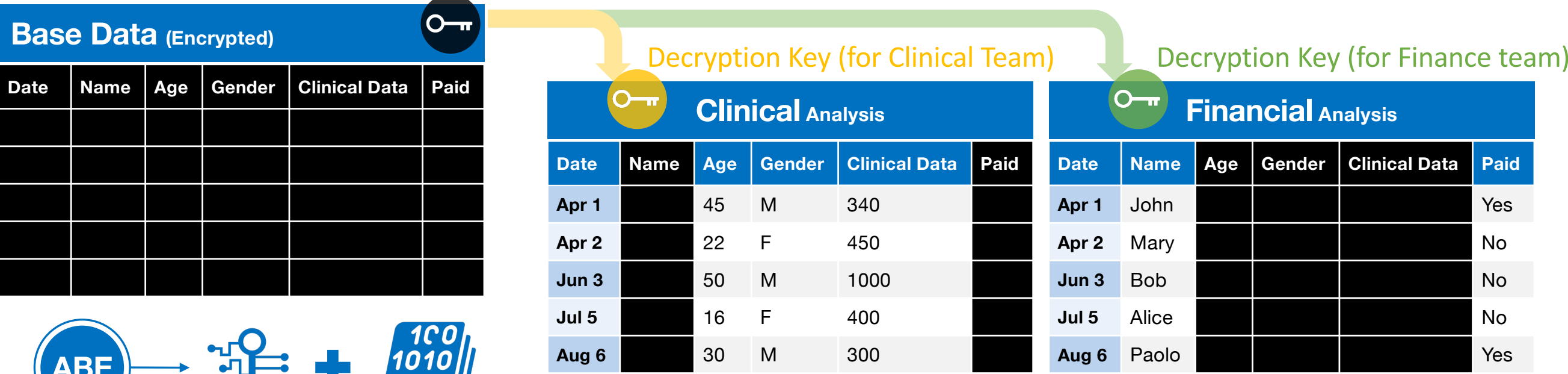
Attribute-based Encryption (ABE): Business development

What is ABE: Invented by Brent Waters several years ago. This technology realizes “Access control at Data Layer”, which is commonly required in IOT implementations. NTT Research Inc. recognizes this technology as byproduct of our R&D, which is ready for market implementation.

IP ownership: NTT Research Inc. now owns key 5 patents, and related software libraries. NTT OpCo can use all of them.

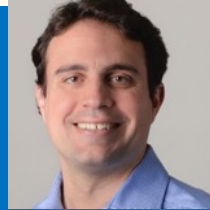
Current status:

- Demo system created (with the help from NTT Data Italy) to start business based discussions.
- To be first implemented at the smart-university project in NSW (Australia) led by NTT Ltd. in Australia.



CIS Lab: = World leading crypto team

Brent Waters



- Simons Investigators Award 2019 from Simon Foundation
- IACR Test-of-Time Award 2020 from IACR
- Best Paper Award on Crypto 2020 from IACR
- Best Paper Award on Crypto 2022 from IACR
- IACR Test-of-Time Award 2023 from IACR

Mark Zhandry



- Best Paper Award on EuroCrypt 2019 from IACR
- Best Paper Award on AsiaCrypt 2022 from IACR

Daniel Wichs



- Best Paper Award on STOC 2023 from ACM

Number of publications at the top international crypto conferences

Organization	Crypto 2023	EuroCrypt 2023	Crypto 2022	EuroCrypt 2022
NTT CIS Lab (NTT Total)	14(15)	14 (17)	17(22)	9(12)
Berkeley	10	4	4	3
Cornell	3	4	1	1
UCLA	6	2	3	6
CNRS	5	9	2	3
Microsoft	4	2	4	0
IBM	5	3	3	4
Google	4	4	1	3

CIS Lab researchers

Brent Waters

DIRECTOR

Ph.D.: Princeton Univ.

Faculty: Professor at
University of Texas at Austin



Daniel Wicks

SENIOR SCIENTIST

Ph.D.: New York Univ.

Faculty: Assoc. Prof. at
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Vipul Goyal

SENIOR SCIENTIST

Ph.D.: UCLA

Faculty: Assoc. Prof. at
Carnegie Mellon Univ.



Go Yamamoto

SENIOR SCIENTIST

Ph.D.: Univ. of Tokyo



Hoeteck Wee

SENIOR SCIENTIST

Ph.D.: UC Berkeley

CNRS Senior Researcher at
ENS, Paris



Sanjam Garg

SENIOR SCIENTIST

Ph.D.: UCLA

Faculty: Assoc. Prof. at
UC Berkeley



Elette Boyle

SENIOR SCIENTIST

Ph.D.: MIT

Faculty: Assoc. Prof. at
Reichman Univ., Israel

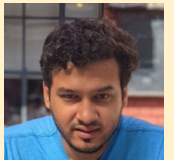


Arka Choudhuri

Post-Doctoral Fellow

Ph.D.: Johns Hopkins

Univ.



Mark Zhandry

SENIOR SCIENTIST

Ph.D.: Stanford Univ.

Faculty: Assist. Prof. at
Princeton University



Ilan Komargodski

SCIENTIST

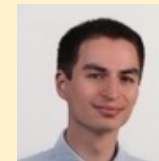
Ph.D.: The Weizmann
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Justin Holmgren

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Thyagarajan

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Chen-Da Liu Zhang

POSTDOCTORAL FELLOW

Ph.D.: ETH



Summer Internship program

- NTT Research, Inc. conducts internships mainly for doctoral students.
- More than 30 students from PHI and CIS laboratories participated in the summer internship program in 2023. (Mainly students from graduate schools in the United States)
- We welcome interns who can participate for five or six months, not only during the summer vacation.
- We are planning to hold interns in 2024, so we look forward to receiving applications from talented students.
- We will open the site of intership program for FY2024 at end of Jan. 2024.
- Recruitment Overview: Practical training at PHI Laboratory (quantum computer: Coherent Ising Machine research)
- Eligibility: Graduate student in Physics, Computer Science, Applied Mathematics, Electrical Engineering, or related technical field.
- Location: In principle, Sunnyvale. Depending on the theme of the training, the training may be conducted at a joint research center in the U.S.
- Treatment:
 - Salary provided for the duration of the internship period in accordance based on our company policy
 - Reimbursement provided for round-trip economy class tickets from Japan to US
 - Housing allowance will be subsidized base on our company policy
- Application: Please access to the site below on Feb.

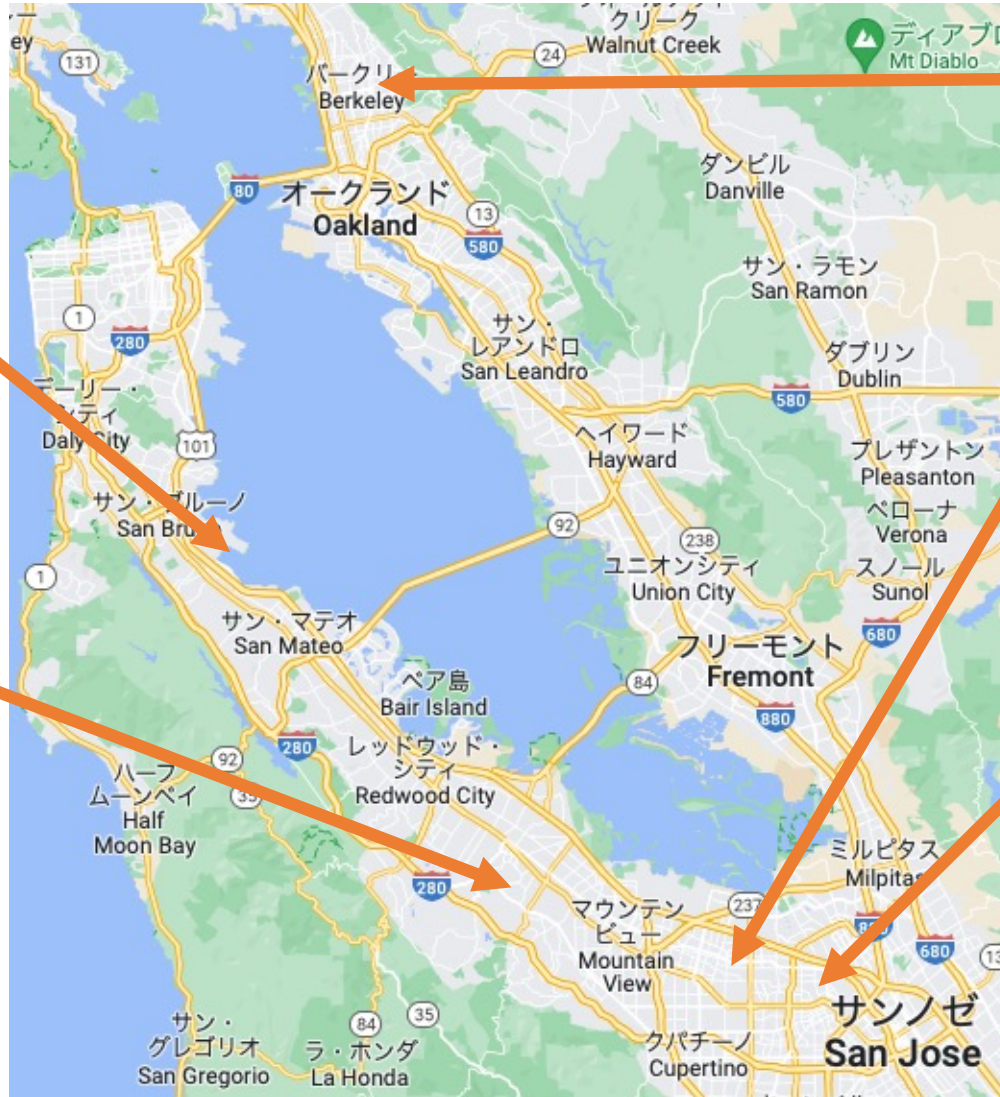
<https://careers.ntt-research.com/phi>

Areas of internship program at the PHI Lab.

Examples of themes	Research overview	Location
Research on brain science and artificial brain (AI)	Research that uses the superior properties of biological brains for artificial intelligence such as DNNs	Sunnyvale, Boston(Harvard)
Applications for Ising machines	Exploring applications suitable for CIM, developing algorithms for quantum computers	Sunnyvale
Quantum Inspired Machine (Simulator)	Simulator for solving combinatorial optimization problems at high speed on a digital computer	Sunnyvale
CIM hardware technology (Optical Technology)	Research on optical technologies to improve CIM / Research on optical circuit technology using TFLN	Sunnyvale, Los Angels(Caltech), Ithaca(Cornell), Boston(MIT)
Quantum theory in CIM	Research on the theory inherent in NTT's quantum computer CIM	Sunnyvale
Theoretical research of Quantum Computer	Theoretical Study of Gate Quantum Computer and Annealing Quantum Computer	Sunnyvale, Boston(MIT)

NTT One Vision Center

- NTT Group global R&D Campus: NTT Research, Docomo Innovations
- NTT Group West Cost campus : NTT DATA, NTT Docomo, NTT Ltd., NTT-AT



San Francisco International Airport

NTT One Vision Center

Stanford University

San Jose Airport



 <https://www.ntt-research.com>

 <https://www.linkedin.com/company/ntt-research>