Introduction to Intelligent Home Service Robots and RoboCup @Home Competition

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Neumorph Center
Research Center for Neuromorphic AI Hardware, Kyushu Institute of Technology

Kyutech
Kyushu Institute of Technology

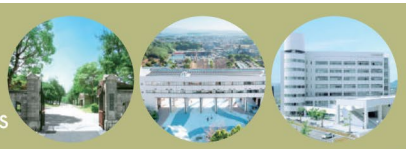
Tamukoh Lab.
A Brain-Like Computer System Lab.

Search Hibikino-Musashi@Home on WEB, YouTube, Facebook

Kyushu Institute of Technology (Kyutech)

Founded 115 years ago

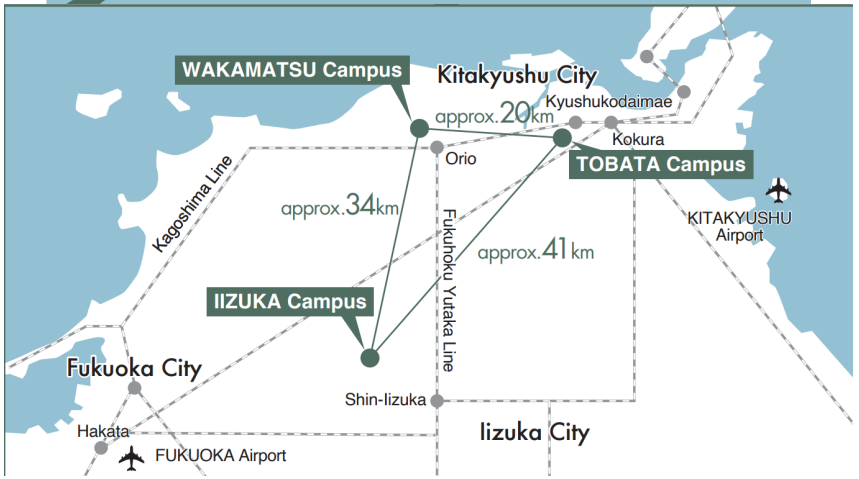
Tobata campus
Iizuka campus
Wakamatsu campus



3 Campuses

5,595 The number of students

4,066undergraduate students
1,309 master's students
220 doctoral students



国立大学法人
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Results of Robot Competitions

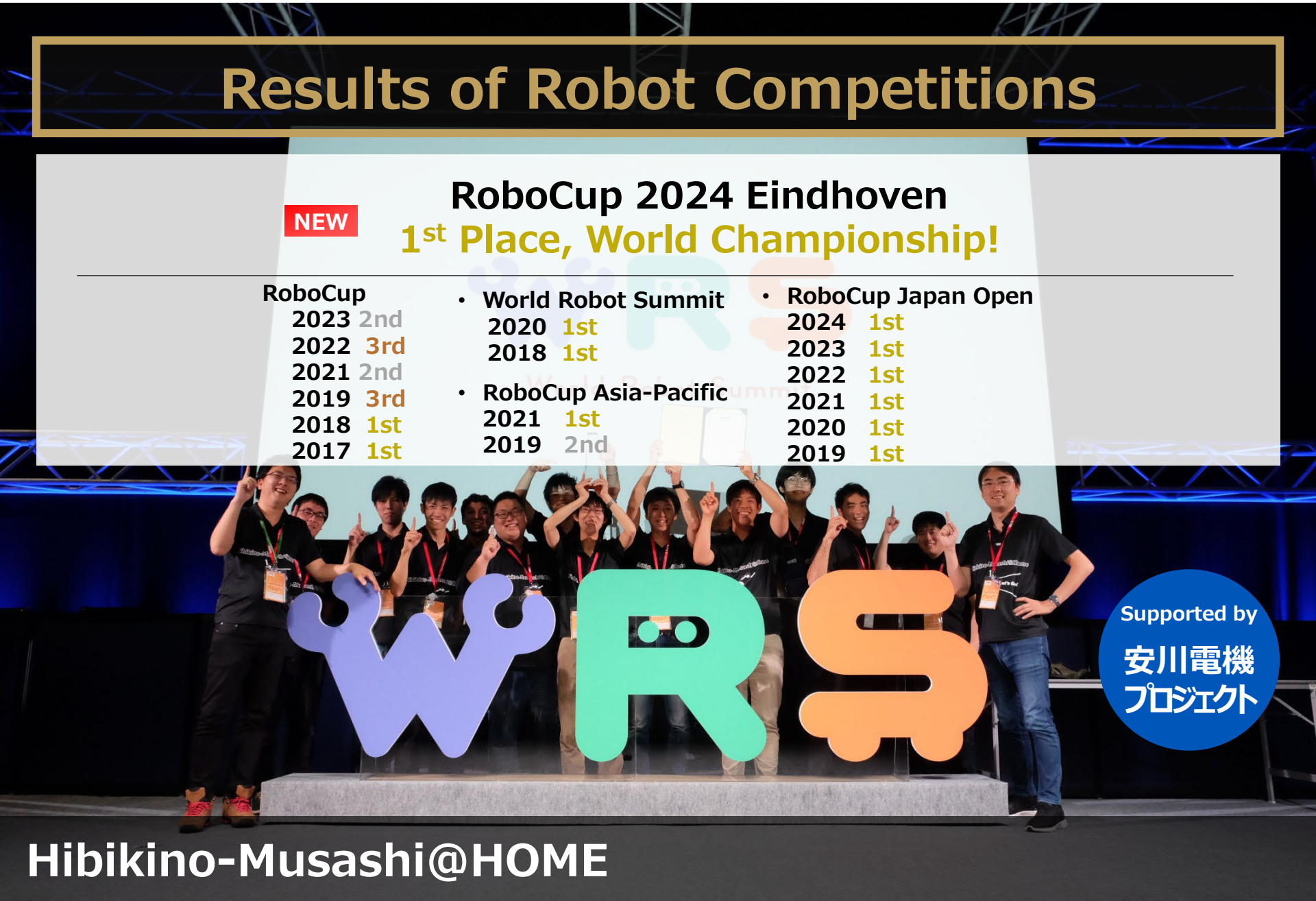
NEW

RoboCup 2024 Eindhoven
1st Place, World Championship!

RoboCup
- 2023 2nd
- 2022 3rd
- 2021 2nd
- 2019 3rd
- 2018 1st
- 2017 1st

- **World Robot Summit**
  - 2020 1st
  - 2018 1st
- **RoboCup Asia-Pacific**
  - 2021 1st
  - 2019 2nd

- **RoboCup Japan Open**
  - 2024 1st
  - 2023 1st
  - 2022 1st
  - 2021 1st
  - 2020 1st
  - 2019 1st



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プロジェクト

Hibikino-Musashi@HOME

World Robot Summit 2020 Final (Sept. 2021)

https://youtu.be/ElUb8bfSC34?t=5096

Left：UTokyo

Right：Kyutech

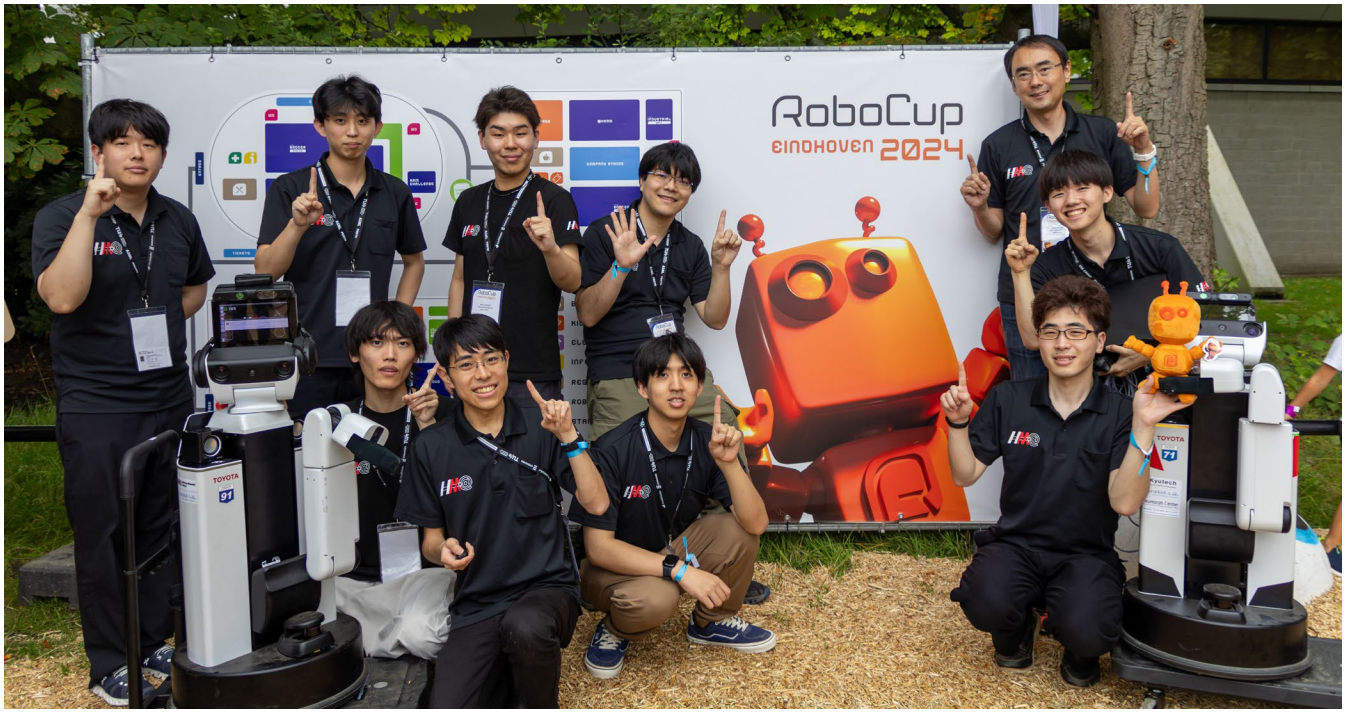
RoboCup2024 Eindhoven

- The premier championship for robotics
- The **27th** competition (since 1997)
- 5 categories, 27 competitions
  - Soccer, **@Home**, Rescue, Industrial, Junior
- Goal: winning against the human world champion football with robots **in 2050**

RoboCup@Home 2024 Eindhoven

Hibikino-Musashi@Home

@Home DSPL 1st Place



Hibikino-Musashi@Home is a **student project team** to develop home service robots that co-exist with humans.

32 members (6 labs from Kyutech, 2 labs from Univ. of Kitakyushu).
9 members joined the competition.

Competitions

Competition Days

DSPL: Domestic Standard Platform League

Team uses Toyota Human Support Robot (HSR)

Qualification（Paper）

Team description paper・Video・Web site

Stage I: Benchmark tests

Max score: 1000, time limit: 5min， 5 tasks

Stage II: Tests based on story

Top 6 teams in Stage I
Max score: 2000, time limit: 10， 4 tasks

Finals: Demonstrations

Top 3 teams in Stage II
Team shows their robot performance in their own way.

RoboCup 2024 @Home DSPL Results

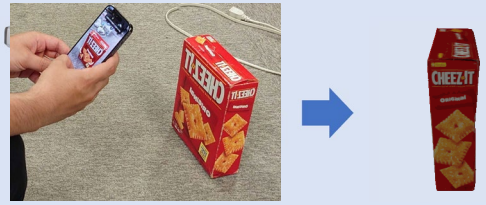
	Team	Stage I	Stage II	Final
1	Hibikino-Musashi@Home Kyutech & The Univ. of Kitakyushu, Japan	2554.09	5314.09	9,033.95
2	eR@sers Tamagawa Univ., Japan	1383.86	3808.86	6,252.88
3	Tidyboy-DSPL Seoul National Univ. & Pusan National Univ., Republic of Korea	1857.17	3552.17	5,091.44
4	TRAIL The Univ. of Tokyo, Japan	1017.5	2972.5	
5	Tech United Eindhoven Eindhoven Univ. of Technology, The Netherlands	1392.39	2922.39	
6	UT Austin Villa@Home The Univ. of Texas at Austin, USA	1377.67	2232.67	
7	SUTURO-VaB Univ. of Bremen & Univ. of Vienna, Germany & Austria	935.43		
8	RoboCanes-VISAGE Univ. of Miami, USA	800.87		
9	rUNSWeep UNSW Sydney, Australia	60.95		

Object Recognition with Deep Learning

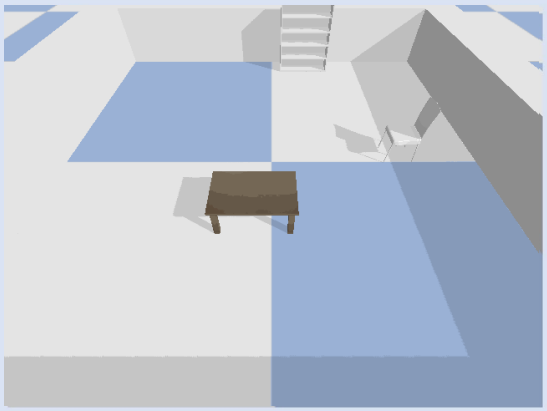
Automatic Generation of Training Datasets

Completely eliminate manual annotation tasks and automatically construct big data.

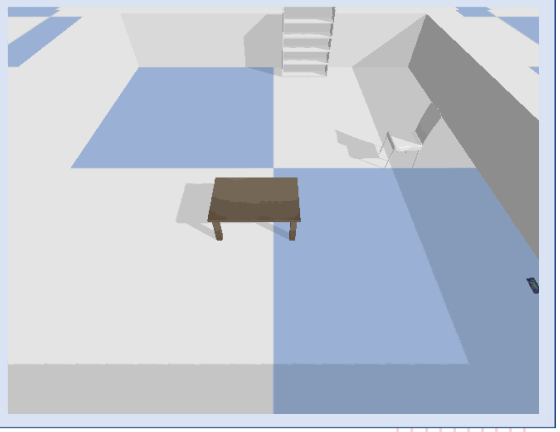
1. 3D Model Scanning



2. Environment Setup



3. Object Generation



Automatic Data Generation
&
YOLO Transfer Learning

Capable of constructing robot vision in <u>one day</u>

* J. Redmon et al., CVPR2016

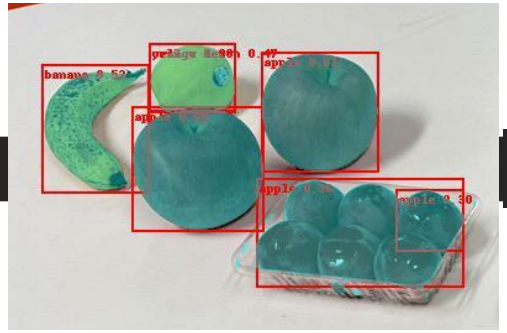
Recognition Model Tunable with Language

Zero-Shot Object Segmentation (Grounding DINO* + Nano SAM†**)

† Segment Anything Model

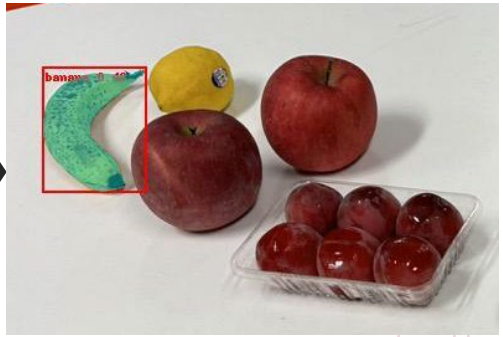
Recognize various objects by specifying a "prompt."

Input (RGB image)



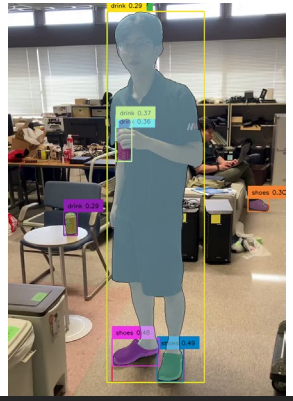
Default Output

Banana

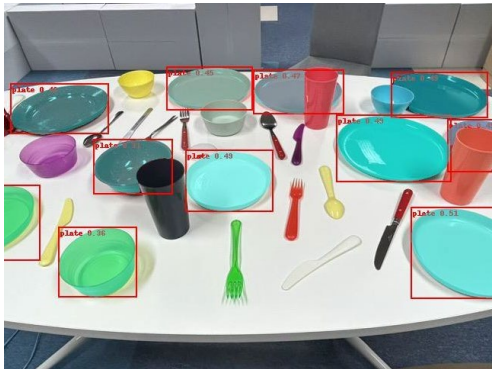


Specify "Banana"

Adjust the prompt to respond to various items



"Human"



"Plate"

"Shoes"

* https://github.com/IDEA-Research/GroundingDINO

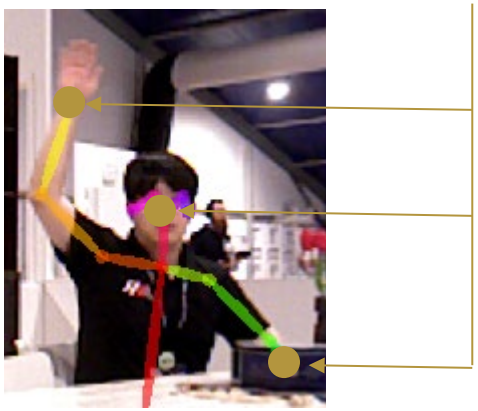
** https://github.com/NVIDIA-AI-IOT/nanosam

Human Recognition

Human Detection + Action Recognition

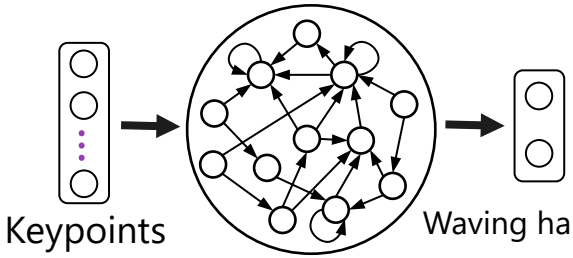
OpenPose* + Reservoir Computing**

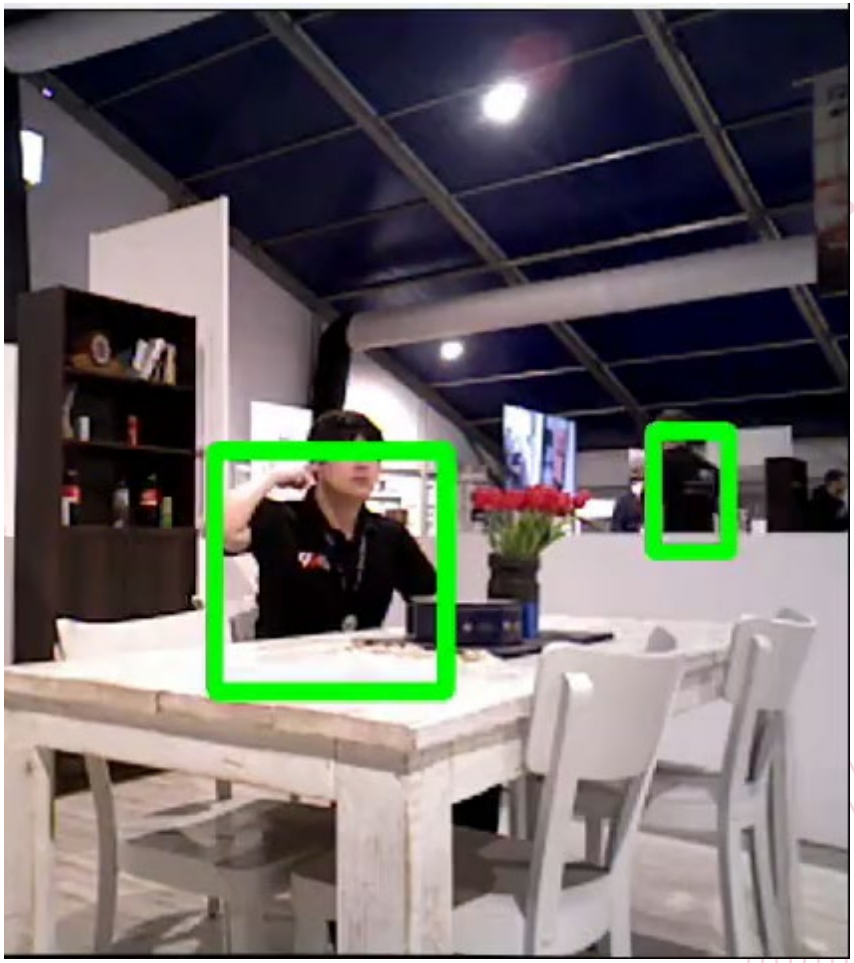
OpenPose： Keypoint extraction



Reservoir computing：

Processes time series data / Low training cost





*Z. Cao *et al.*, IEEE Transactions on Pattern Analysis and Machine Intelligence, 2021.
**M. Lukoservicius *et al.*, Computer Science Review, 2009.

Navigation System

Dynamic Obstacle Detection Using Point Clouds

After detecting obstacles, a safe path is generated

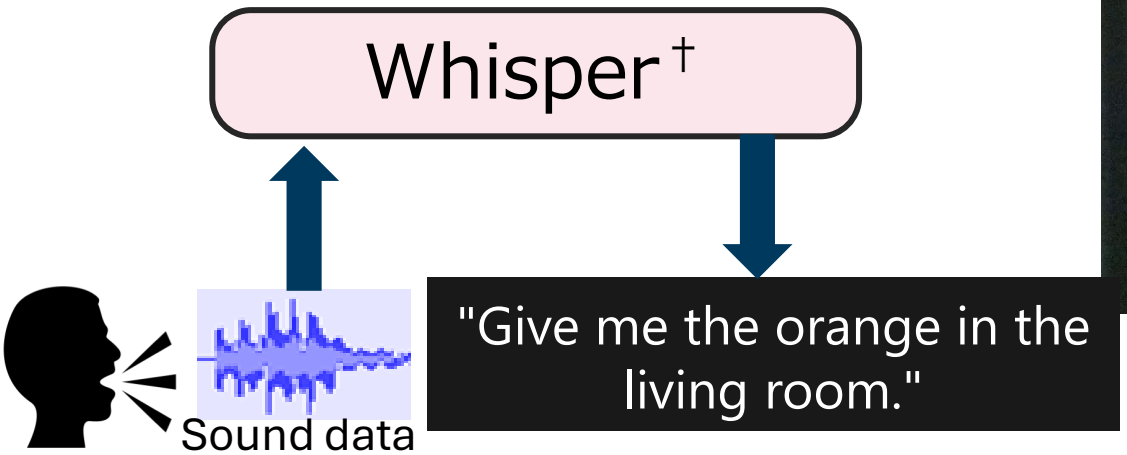
* https://github.com/ARTenshi/robot_navigation, M. Negrete et al., SPIIRAS Proceedings, 2018.

Real-Time Speech Recognition

Converting Recognized Speech Content to Text

Whisper*

- ✓ High-precision speech recognition using **large-scale language models**
- ✓ Real-time recognition of multiple languages



†Large Language Model

Speech Recognition Example

* A. Radford et al., PMLR 2023

Large Language Model (GPT-4o*)

Action Planning Using Large Language Models

Description:

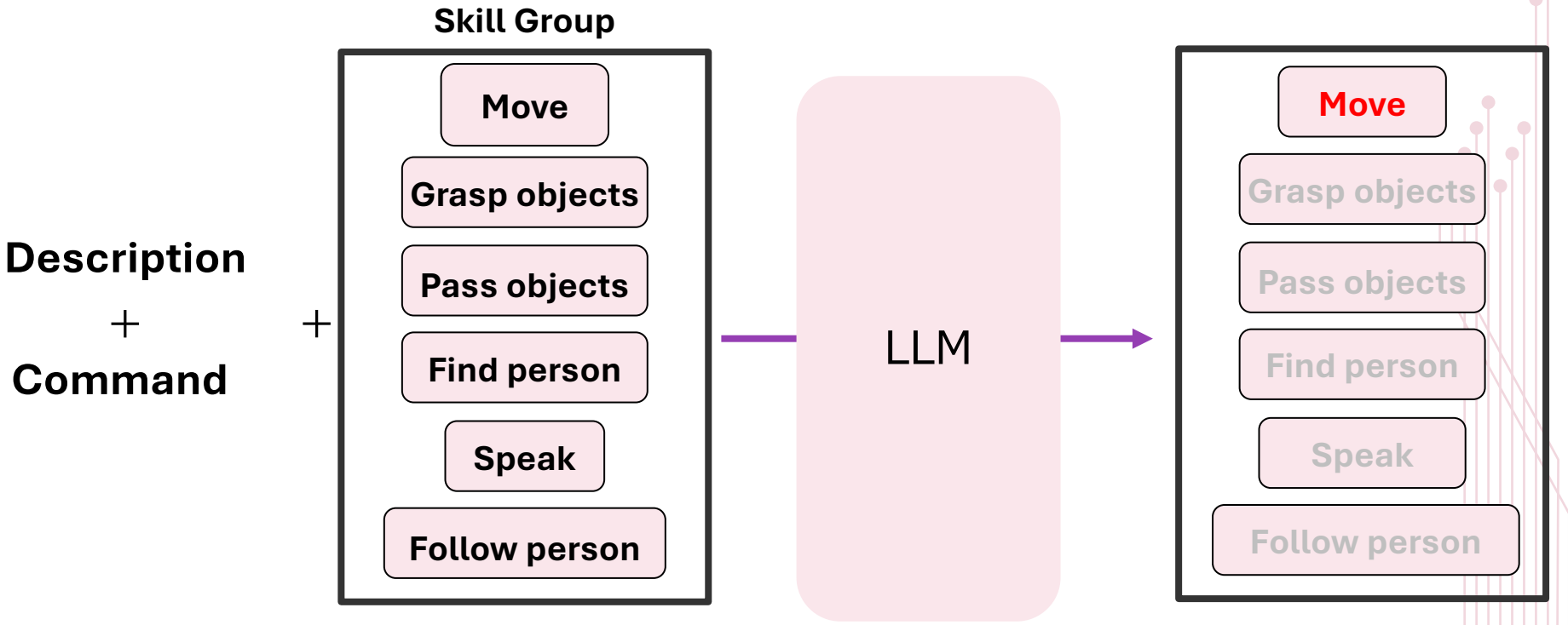
Provided initially to the robot, includes information about the robot's role, status, and environment

Command:

Desired actions for the robot to perform

Skill Group:

List of actions the robot can execute

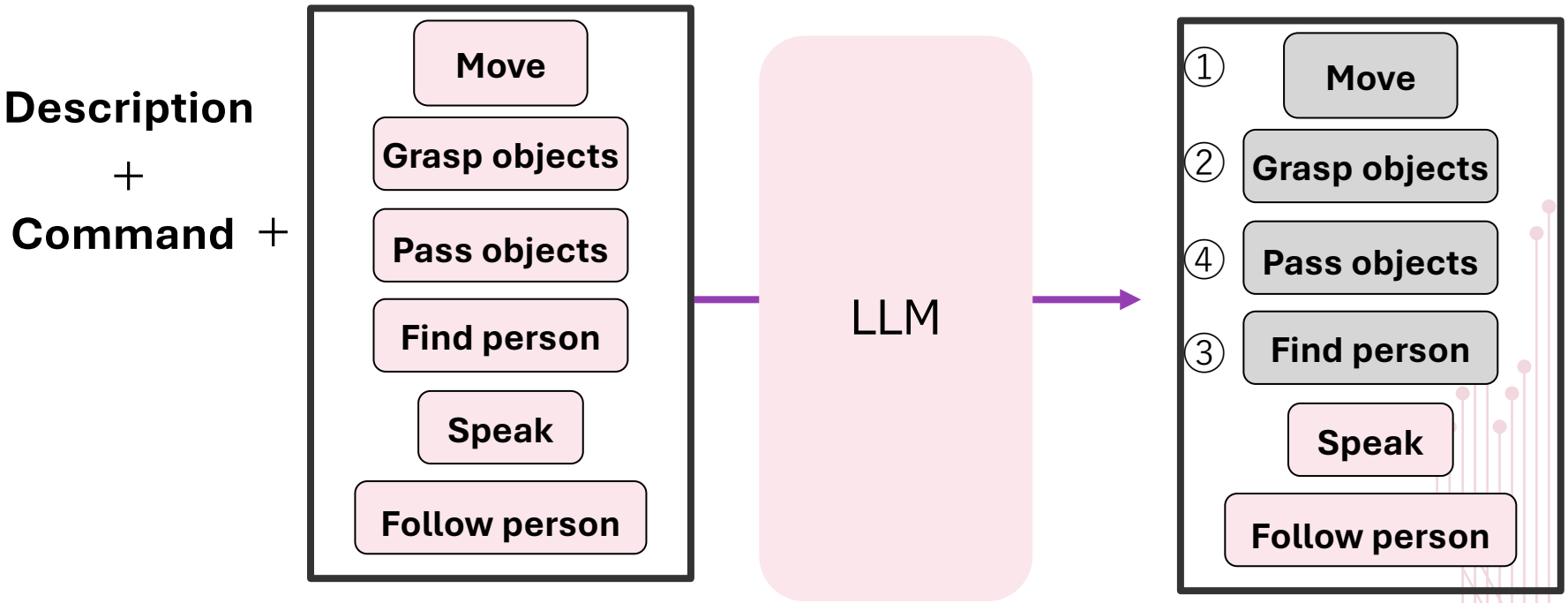


* https://openai.com/index/hello-gpt-4o

Large Language Model (GPT-4o*)

Action Planning Using Large Language Models

Command Example: "Get the orange from the living room"



Generated Action Plan

①**Move** to the living room
②Recognize and **grasp** the orange
③**Find** the indicated person
④**Pass** the orange

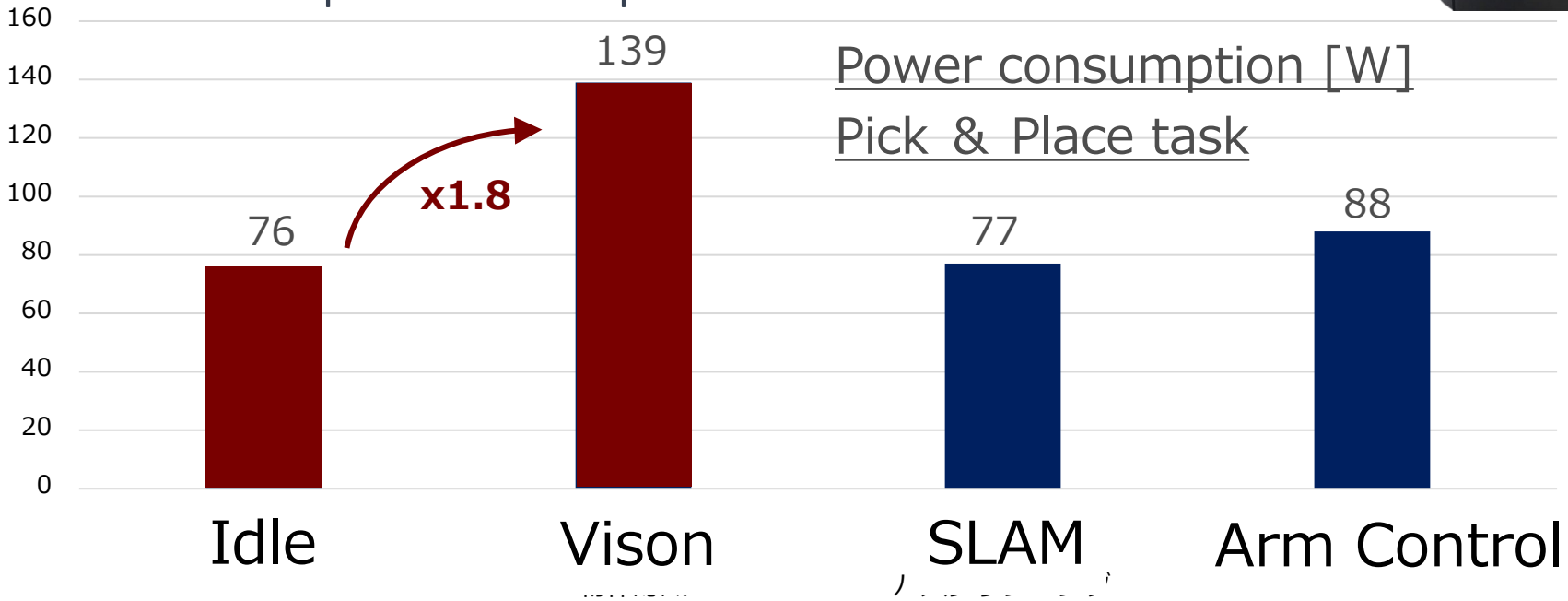
RC24 Hibikino Digest

Power consumption of home service robots

- The Power Consumption Challenge of Artificial Intelligence

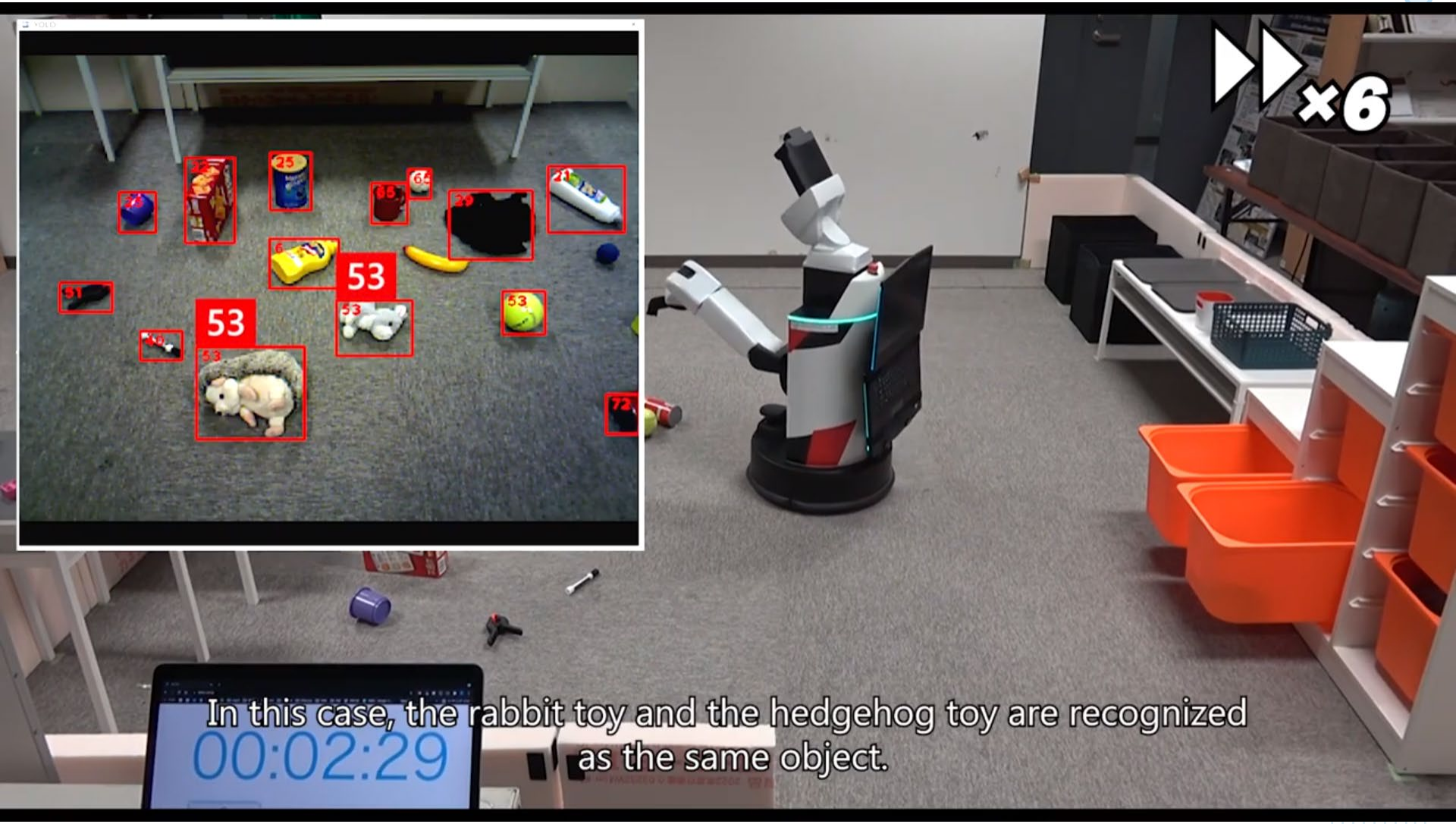
✓ **Year 2050:** 80% of server power consumption attributed to AI tasks, a 10,000-fold increase compared to the present.*

✓ The urgent need for technological innovations to achieve a 1/1,000 reduction in power consumption for AI tasks.



Exploring the Feasibility of Overall Power Savings in Robot Systems

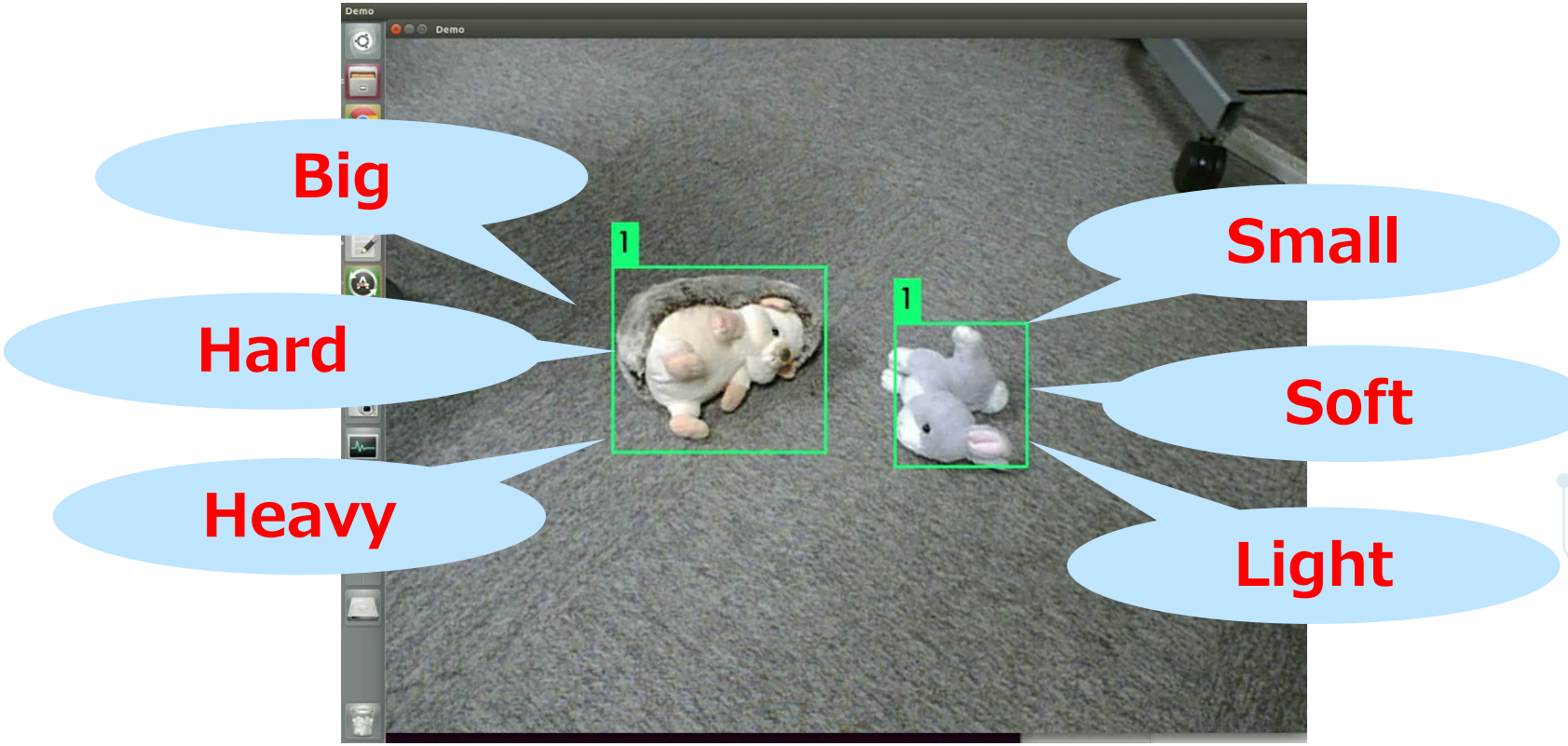
Limitations of DNN-based Robot Vision



Misrecognized a hedgehog and a rabbit. DNN debugging is impossible.

Object Recognition by Tactile Information

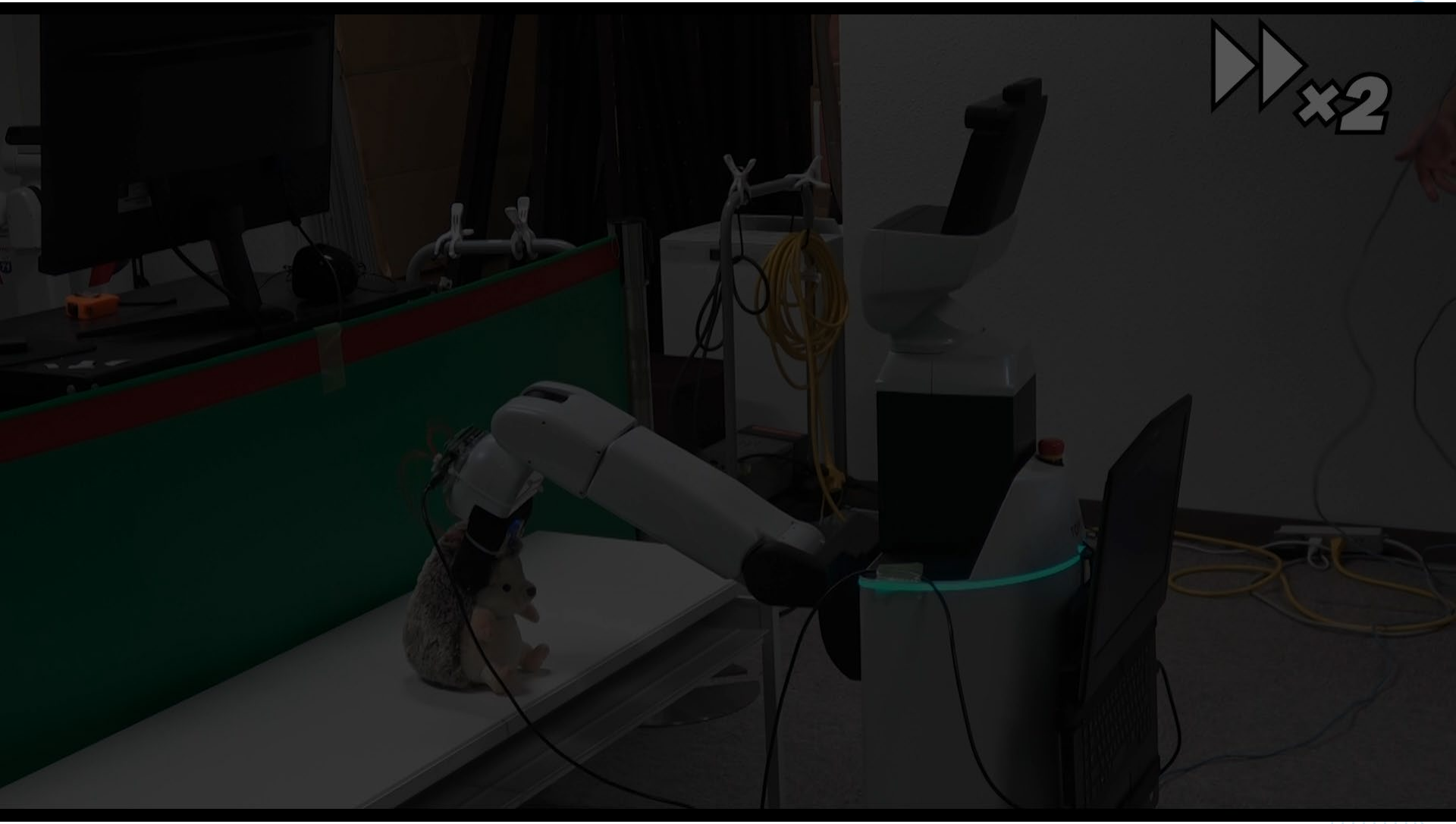
- Size, weight and hardness



Tactile information can be used for object recognition

Demonstrations

https://youtu.be/rItLyhqoc0A



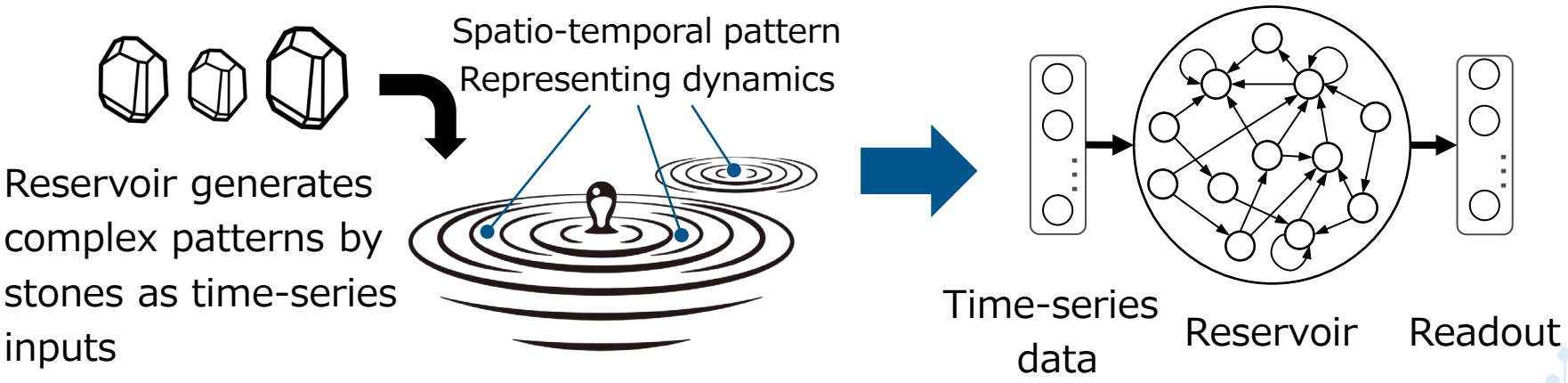
Results of RoboCup JapanOpen 2020 Proposed method

Vision only (42%, 5/12) Vision and Tactile (75%, 9/12)

RoboCup Worldwide 2021, Best Open Demonstration Award

Reservoir Computing: Introduction

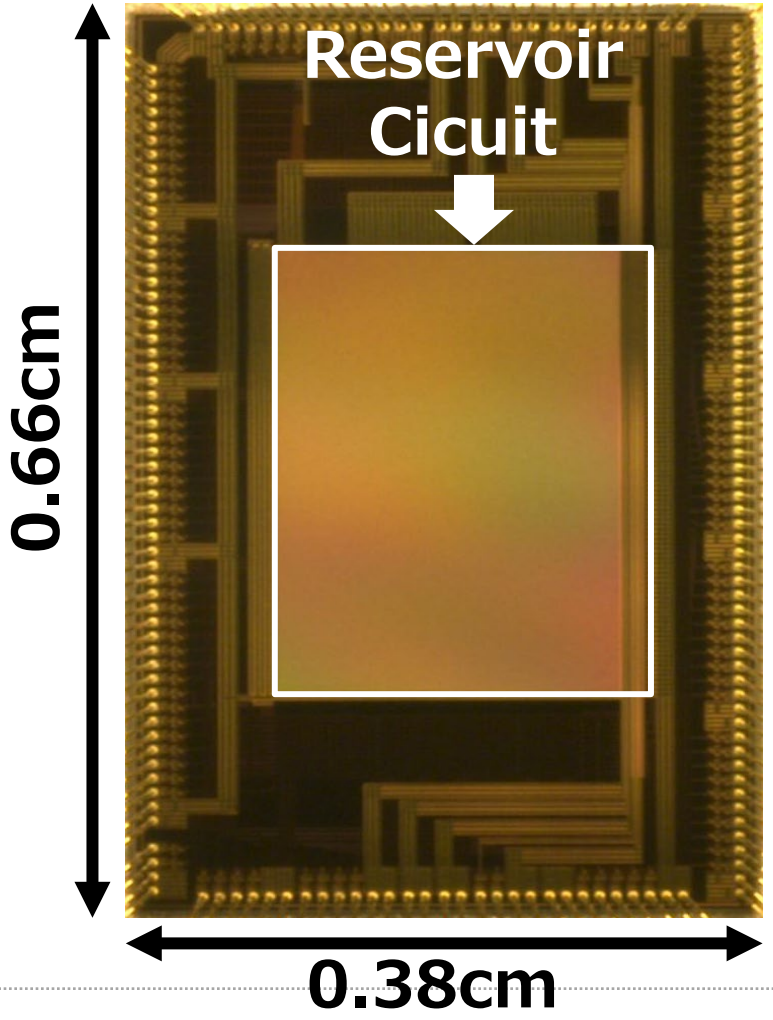
- A simple and light-weight recurrent neural network



- Comparable performance with DNNs in time-series data processing and recognition tasks
- “Physical Reservoirs”: Active exploration of diverse dynamics in various materials as a reservoir layer
  - ✓ Materials can be used for AI computation directly

Ultra low power reservoir chip

We propose a hardware-friendly reservoir model[1] and its VLSI implementation[2]



✓ **Only 177μW**

1/60,000

Commercial GPU[3]
Power consumption : 10W

[1] M.Yamaguchi et al., IJCNN, 2019
[2] Y. Katori, H. Tamukoh, T. Morie,
IEEE/INNS IJCNN 2017 Best paper award

[3] NVIDIA, https://www.nvidia.com/ja-jp/autonomous-machines/embedded-systems/jetson-agx-xavier/

RoboCup2021: The best research award!

RoboCup
WORLDWIDE 2021

CERTIFICATE OF AWARD

RoboCup @Home

Best Open Challenge Award

First Place

Hibikino-Musashi@Home

Kyushu Institute of Technology

RoboCup

Peter Stone

Peter Stone
President of RoboCup Federation
General Chair of RoboCup 2021

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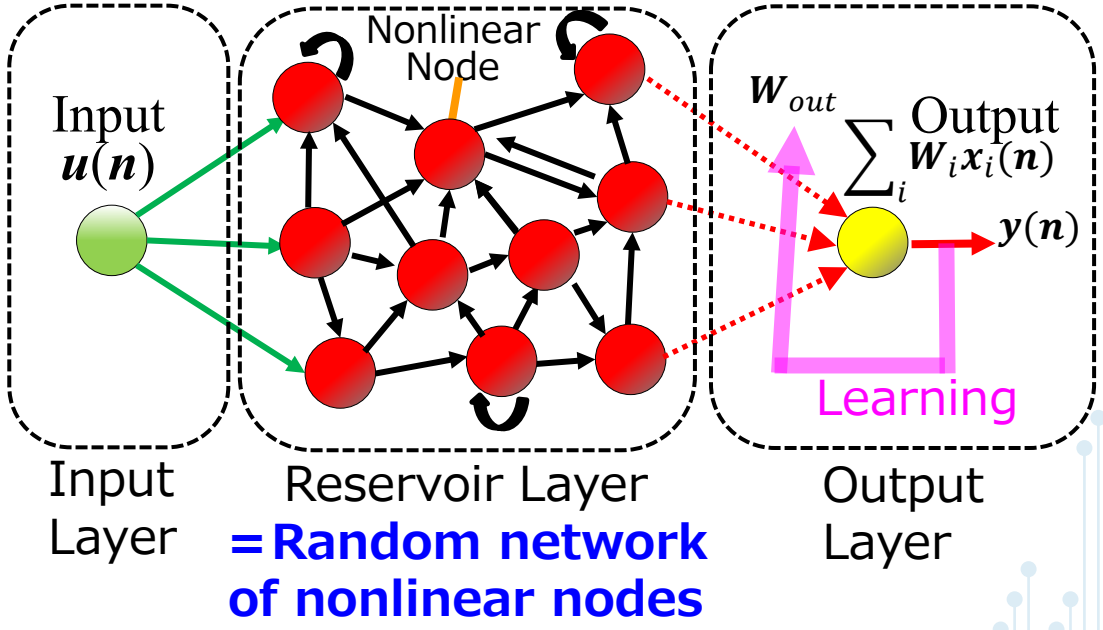
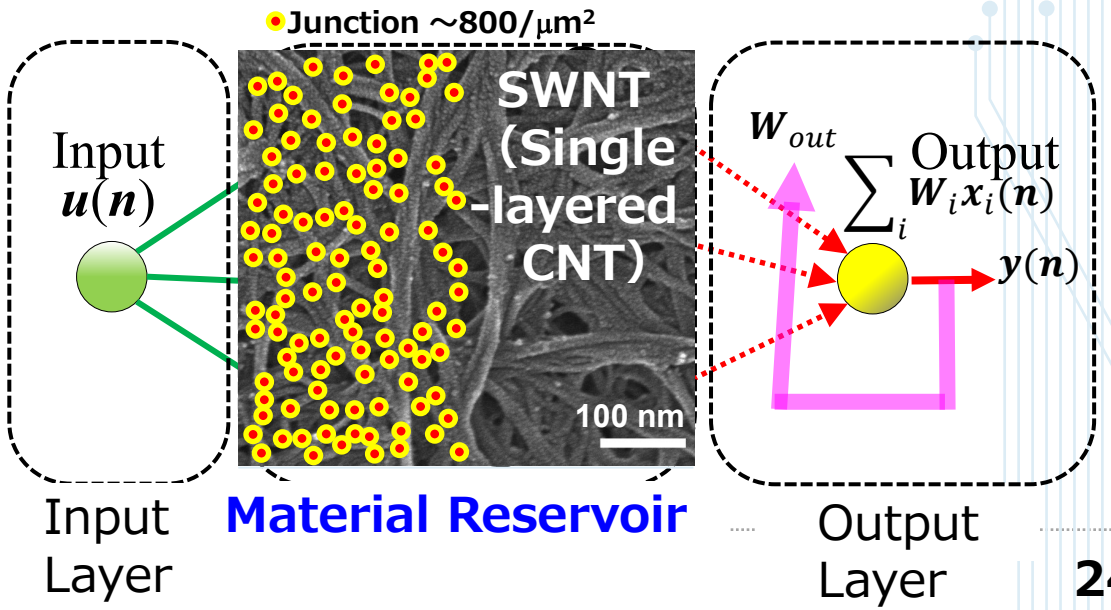
Material Reservoir and Its Potential

- A Paradigm Shift: Physically Integrated Nano-Material Reservoirs
  - ✓ Random networks
  - ✓ Chemical dynamics
  - ✓ Good Scalability and Simplified Processes
  - ✓ Found Fundamentals of Material Intelligence
- Emerging Phase in Robotics
  - ✓ Computational models
  - ✓ System integration
  - ✓ Energy Efficiency Impact



＝Random network of nonlinear nodes

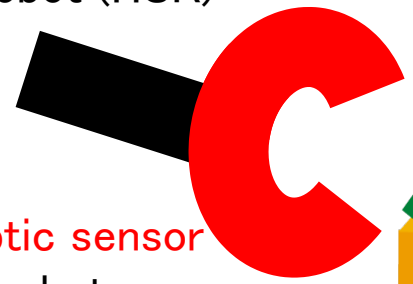


Potentials of Physical Reservoir Devices

SWNT/Porphyrin-POM

TOYOTA Human Support Robot (HSR)

Haptic sensor on robot arm

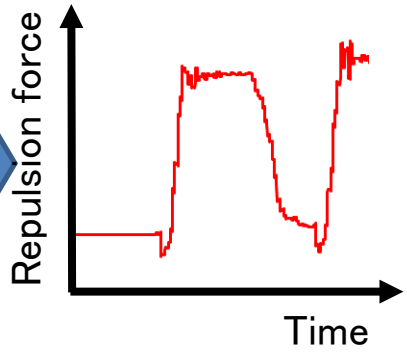


Stuffed doll

Block

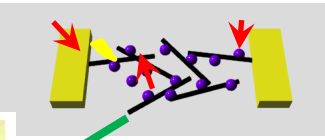
PET bottle

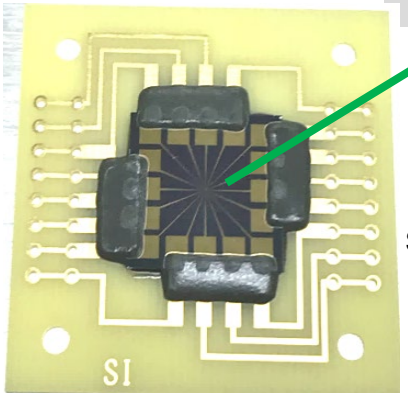
Sensing data was obtained as time series data.



Sensing data was applied as input signal.

Reservoir device





Generate many output signals to pick up featured value.

Weight was fixed by trained data.

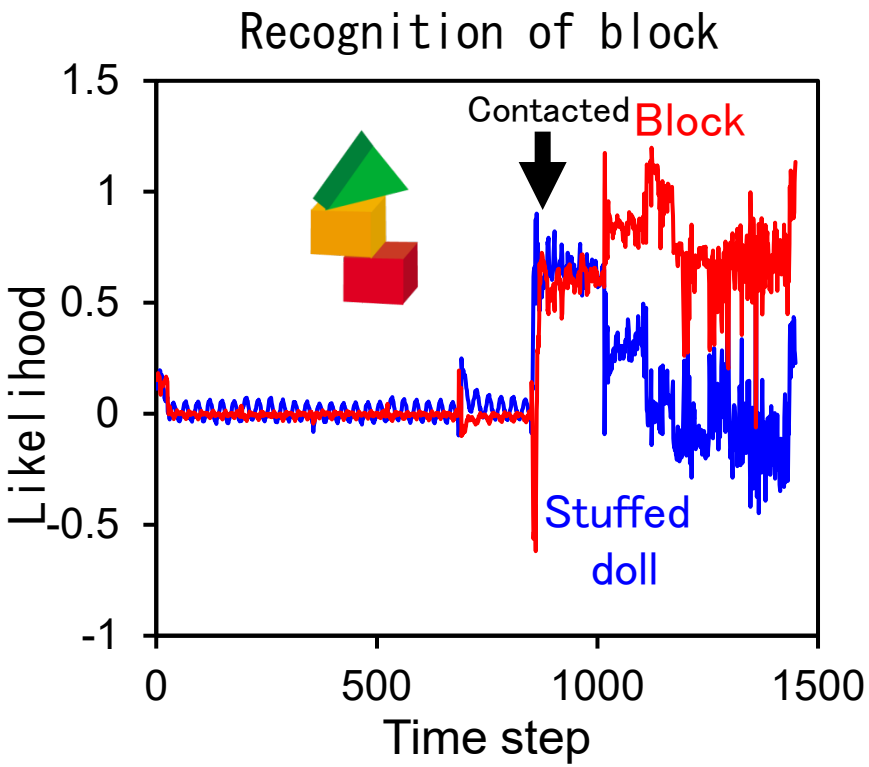
Recognize!

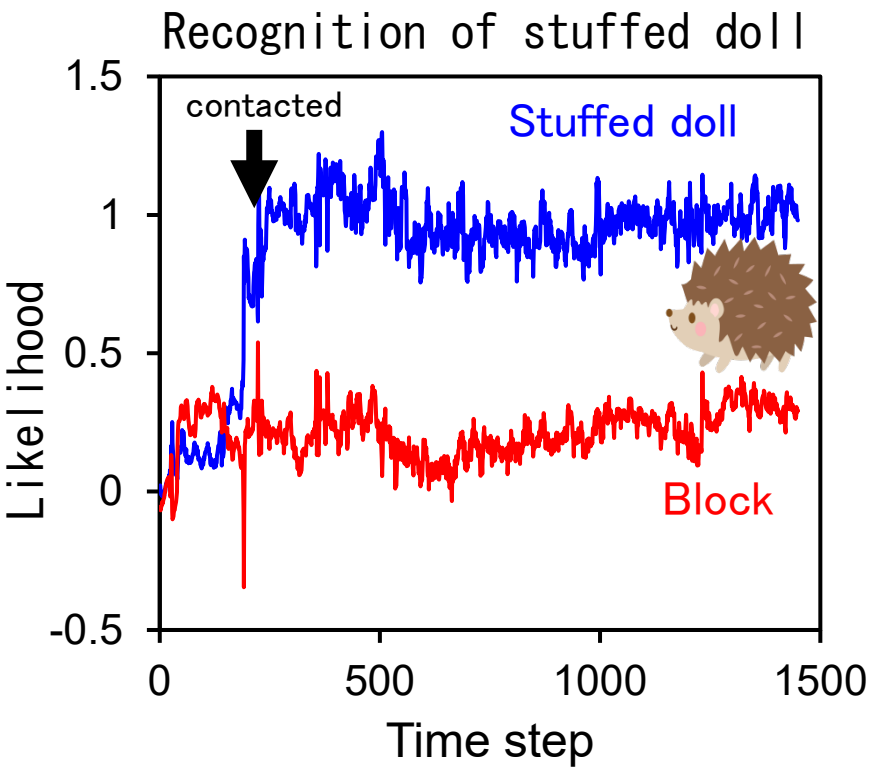
Winner of Robocup world series

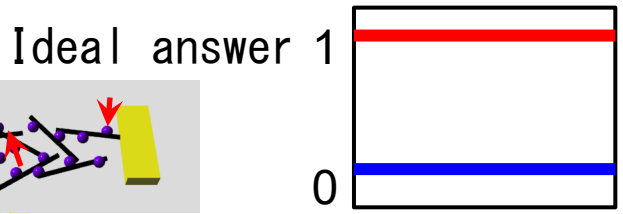
Prof. H. Tanaka
Collaboration work with Nano materials, Robotics, and Artificial Intelligence

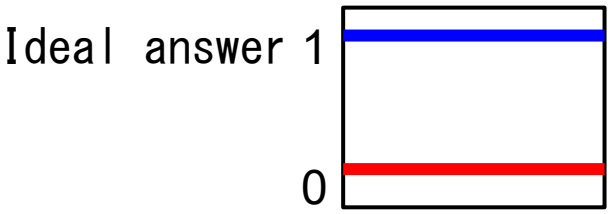
D. Banerjee, H. Tamukoh, J. Gimzewski, H. Tanaka et al., Adv. Intell. Syst., 4, 2100145 (2022).

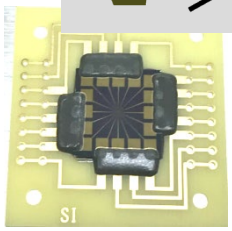
Physical reservoir could be implemented to TOYOTA HSR











Test data was generated by grabbing the stuffs 5 times and learned the sensing data. (Output electrodes 9, reservoir CNT/POM)

Two stuffs, stuffed doll and block, could be distinguished by physical reservoir!!

D. Banerjee, H. Tamukoh, J. Gimzewski, H. Tanaka et al., **Adv. Intell. Syst.** 4, 2100145 (2022).

Conclusions

- DNN-based Robot Vision
  - ✓ We won five times world championships in RoboCup and WRS using powerful DNN-based robot vision
  - ✓ High-power consumption
- Reservoir computing
  - ✓ Object recognition by tactile information
  - ✓ Ultra low-power CMOS implementation
- Material reservoirs have high potential for AI systems
  - ✓ Confirmed its fundamentals and potentials
  - ✓ Emerging Phase in Robotics

Acknowledgements

- This research is collaborative work with Professor Hirofumi Tanaka, other colleagues, my laboratory students and Hibikino-Musashi@Home members.

Hibikino-Musashi@Home （HMA）members

RoboCup 2023 Bordeaux

Thank you!

ご清聴ありがとうございました。

http://www.brain.kyutech.ac.jp/~tamukoh/