Pathway to Generalist Robots: Scaling Law, Data Flywheel, and Humanlike Embodiment

Yuke Zhu

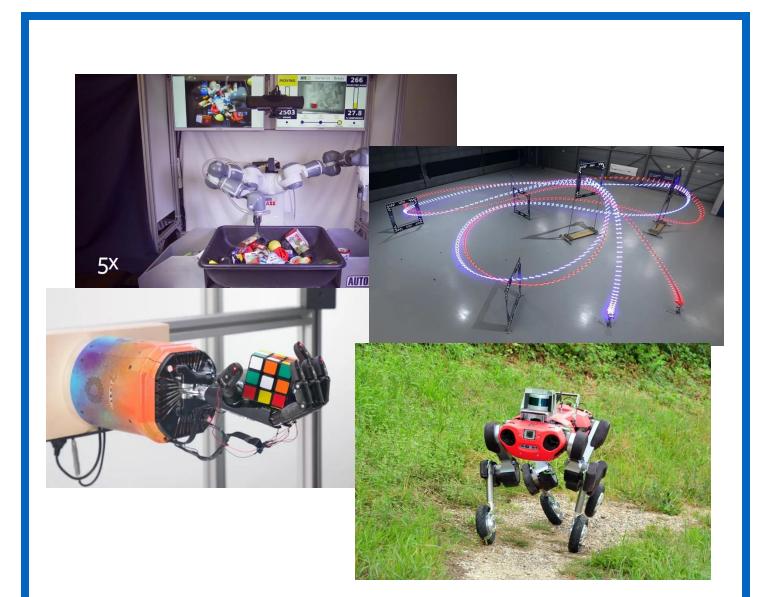
November 8th, 2023



UT Robot Perception & Learning Lab

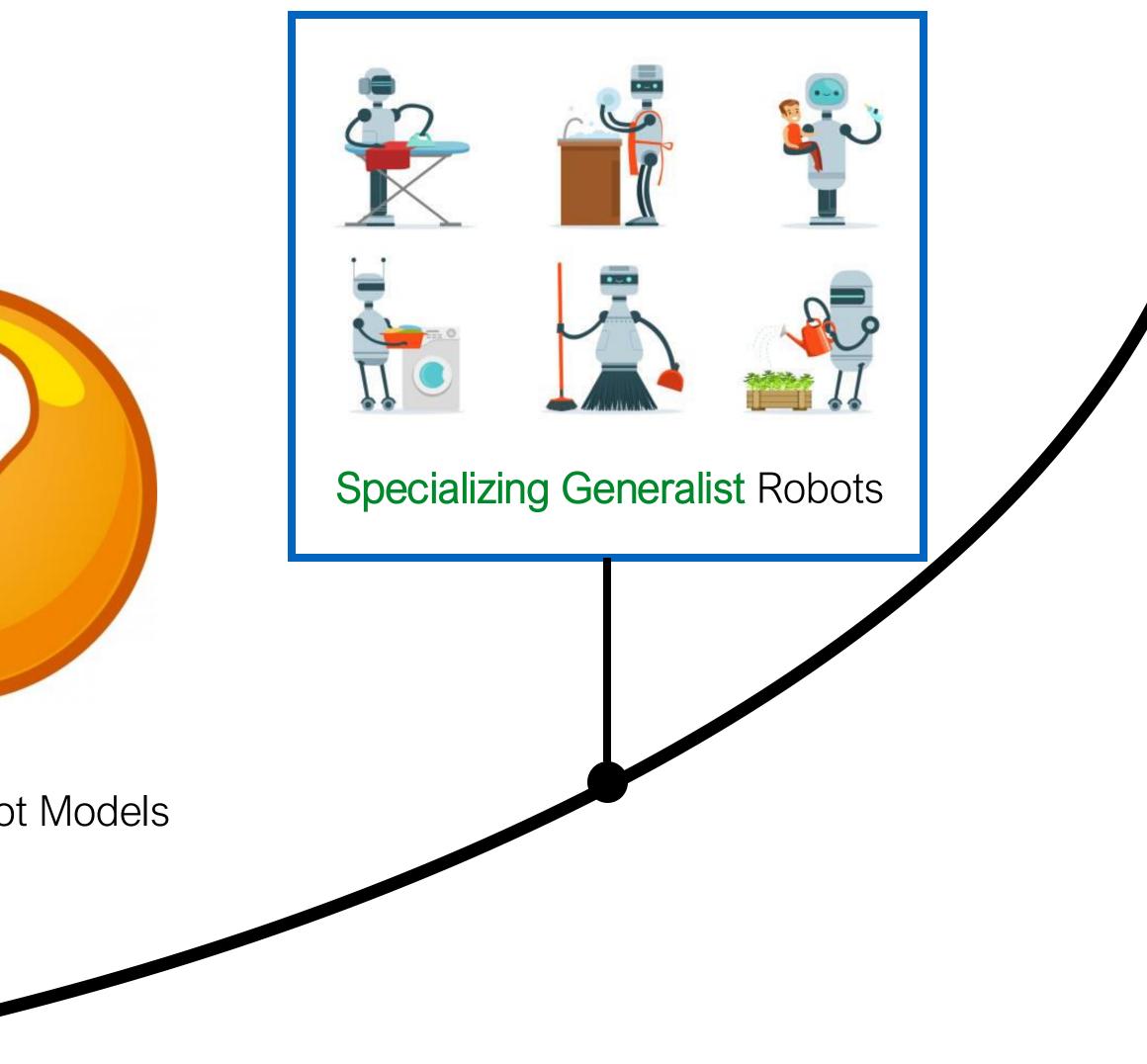




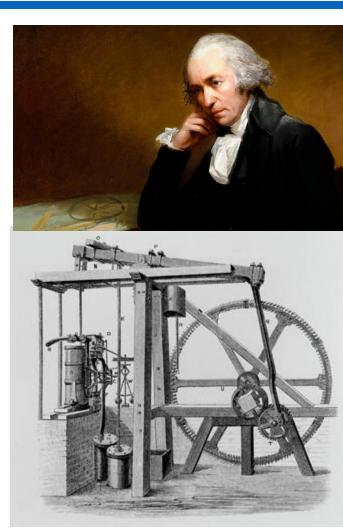


Generalist Robot Models

Specialist Robots





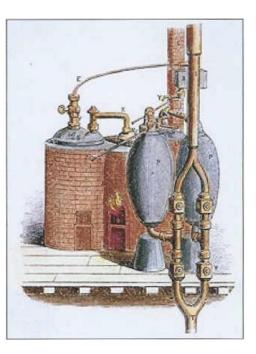


Watt's Steam Engine (James Watt, 1764)





Aeolipile (Heron of
Alexandria, 10–70 AD)Rudimentary Steam
Turbine (Taqi al-Din, 1551)Savery Steam Pump
(Thomas Savery, 1698)





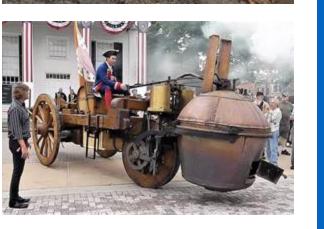
Internal Combustion Engine



Steam Turbine

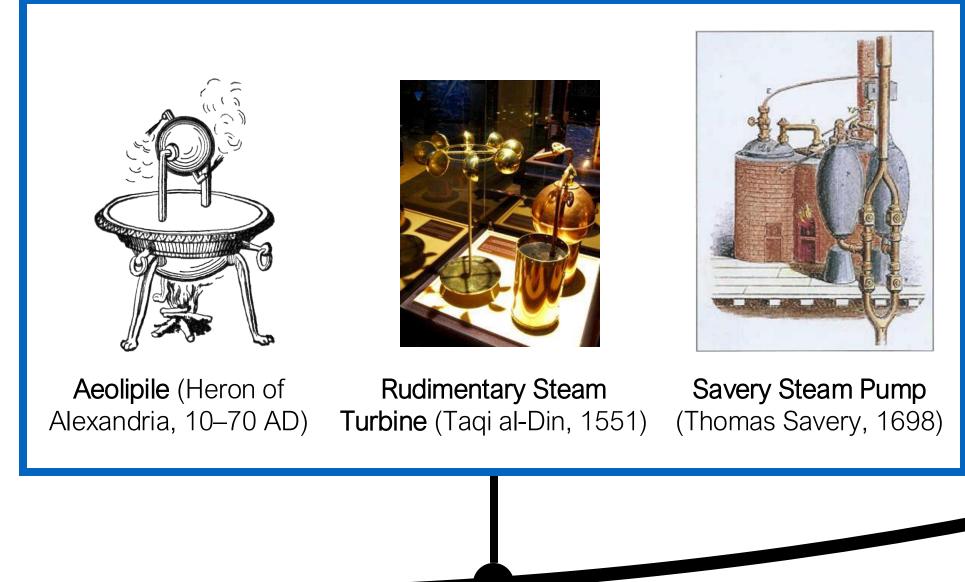






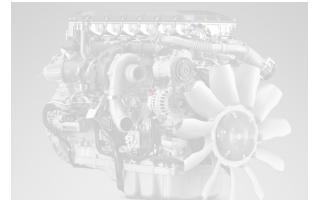


Specialist technology working in limited conditions





Watt's Steam Engine (James Watt, 1764)



Internal Combustion Engine



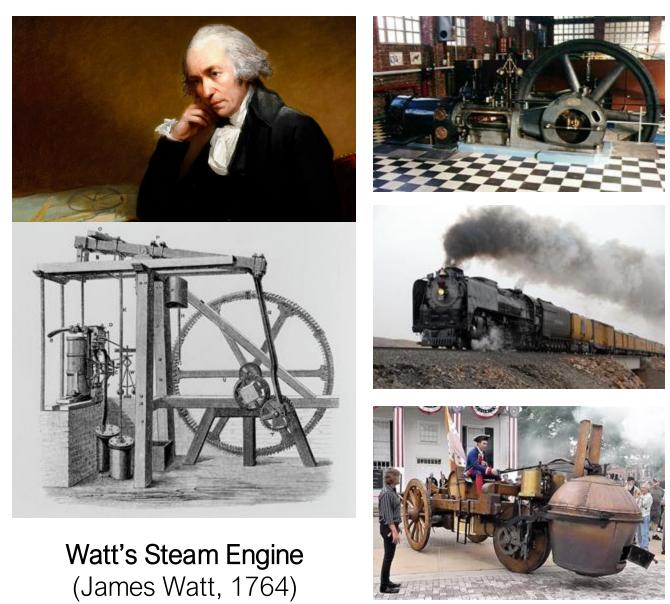
Steam Turbine



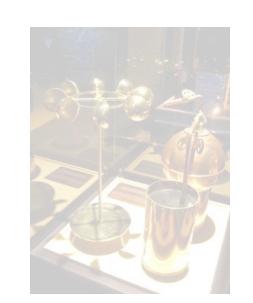




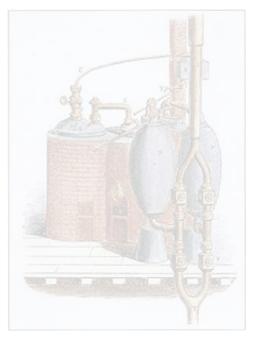
Generalist technology leading to widespread adoption

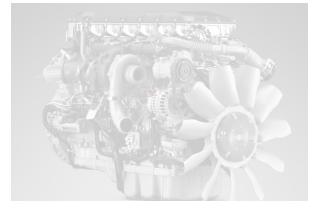






Aeolipile (Heron ofRudimentary SteamSavery Steam Pump Alexandria, 10–70 AD) **Turbine** (Taqi al-Din, 1551) (Thomas Savery, 1698)





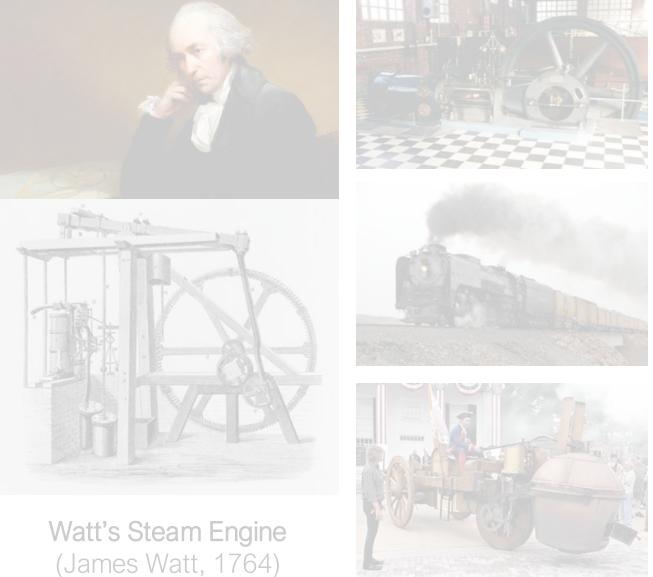
Internal Combustion Engine



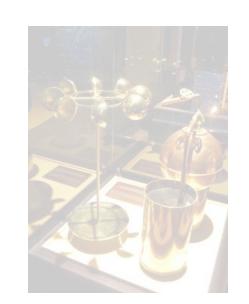
Steam Turbine



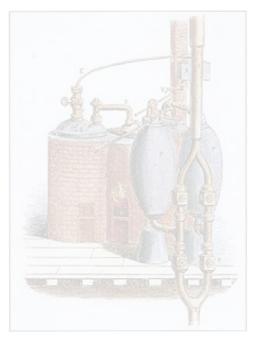
Further specialization for various problem domains







Aeolipile (Heron ofRudimentary SteamSavery Steam Pump Alexandria, 10–70 AD) **Turbine** (Taqi al-Din, 1551) (Thomas Savery, 1698)



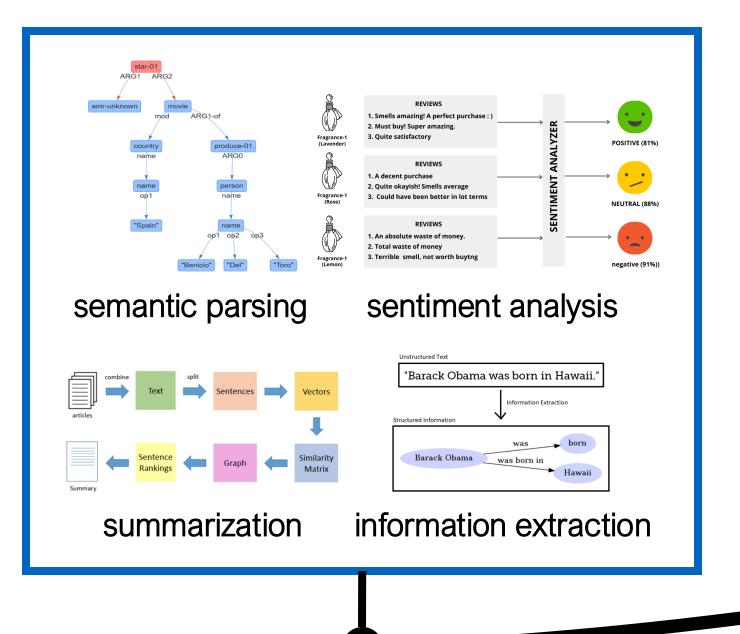


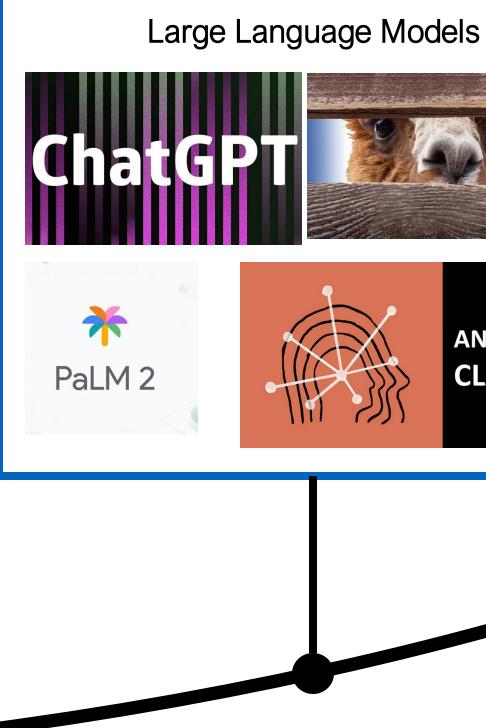
Internal Combustion Engine

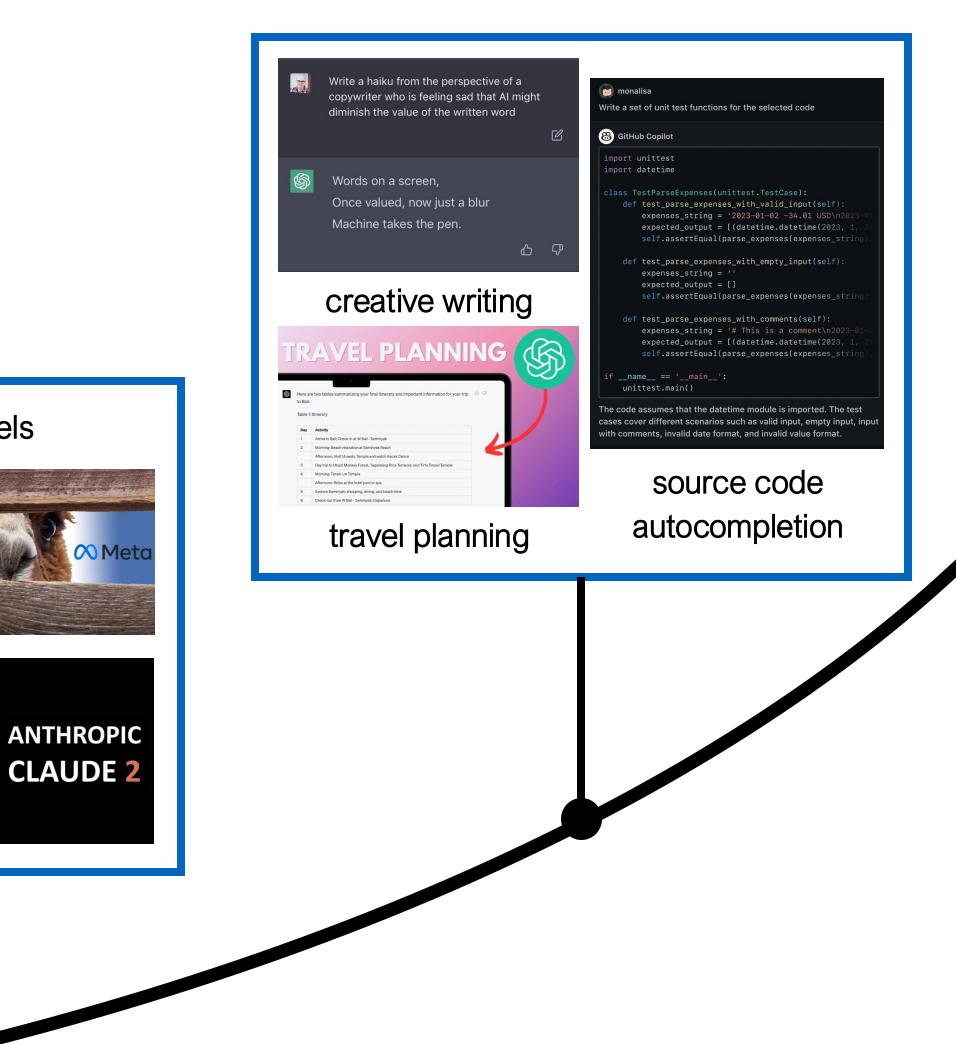


Steam Turbine



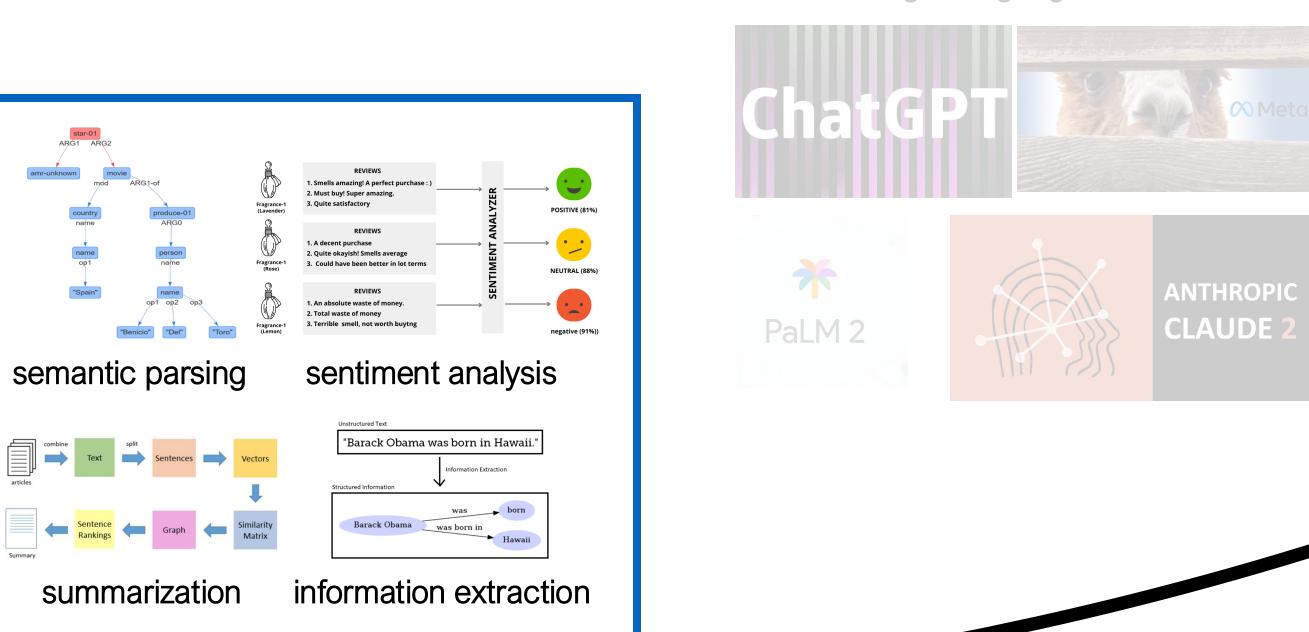


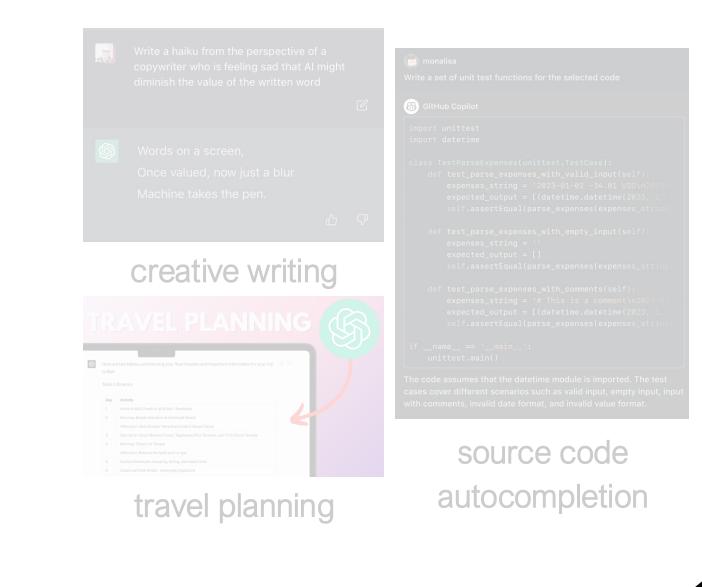






Large Language Models

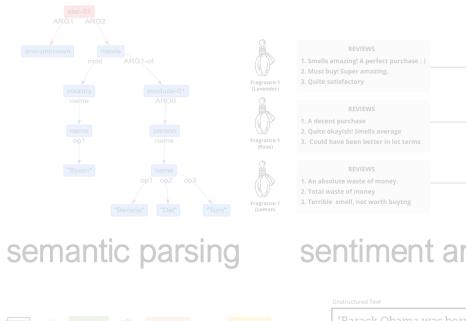


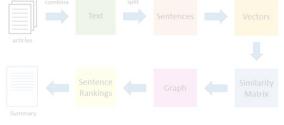












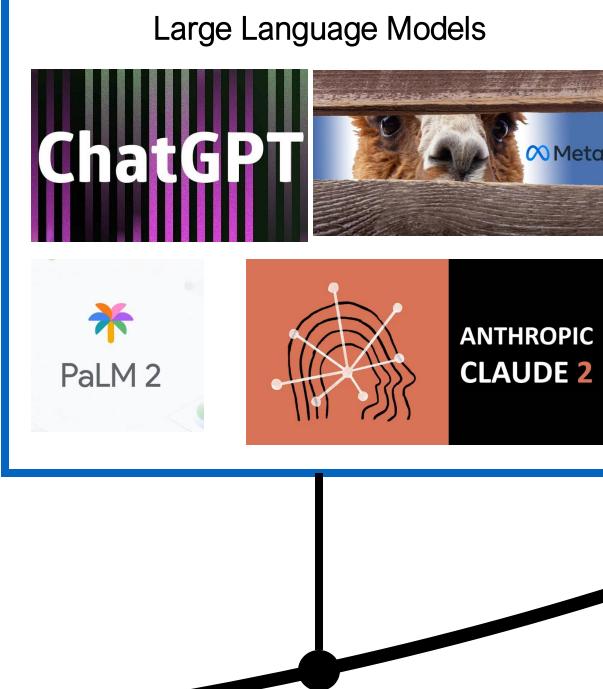
summarization

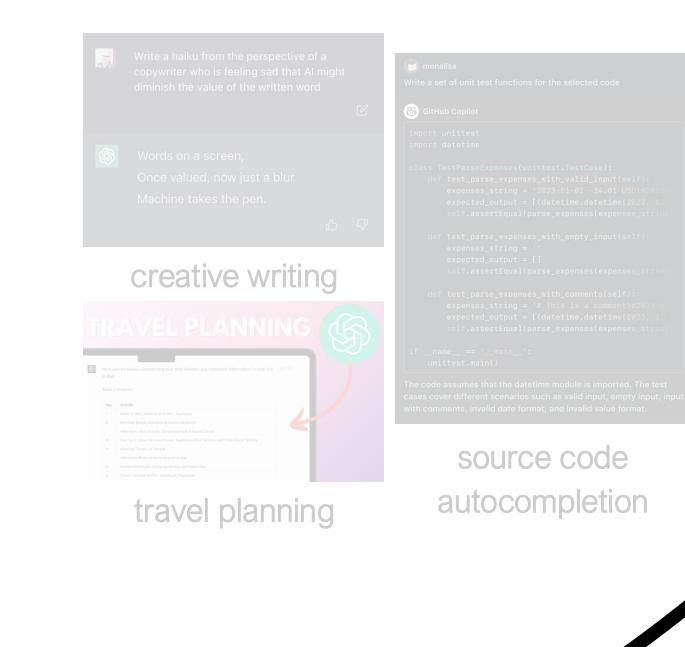
REVIEWS 1. Smells amazing! A perfect purchase :) 2. Must buy! Super amazing. 3. Quite satisfactory	LYZER	POSITIVE (81%)
REVIEWS 1. A decent purchase 2. Quite okayish! Smells average 3. Could have been better in lot terms	timent ana	NEUTRAL (88%)
REVIEWS 1. An absolute waste of money. 2. Total waste of money 3. Terrible smell, not worth buytng	SEN.	

sentiment analysis

Barack Oban	na was born in Hawaii.
tured Information	Information Extraction
	was born in

information extraction

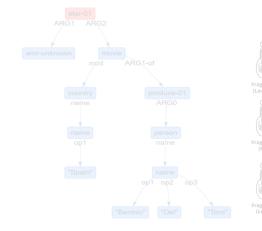




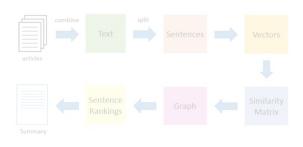


Large Language Models





semantic parsing



summarization

REVIEWS 1. Smells amazing! A perfect purchase :) 2. Must buy! Super amazing. 3. Quite satisfactory		OSITIVE (81%
REVIEWS 1. A decent purchase 2. Quite okayish! Smells average 3. Could have been better in lot terms		EUTRAL (88%
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sentiment analysis

Barack Oban	na was born in Hawaii."
	Information Extraction
	was born
Barack Obama	was born in

information extraction





Recipe for Building Generalist Robot Models

Scaling Law

Powerful robot learning models that scale with data and compute



Data

Data Flywheel

New mechanism to collect massive training data



Algorithms

Generalist **Robot Model**



Hardware

Humanlike Embodiment

Humanoid robot platform for broad applications



Recipe for Building Generalist Robot Models

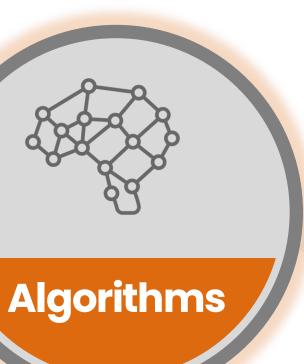
Scaling Law

Powerful robot learning models that scale with data and compute



New mechanism to collect massive training data

Data



Generalist **Robot Model**

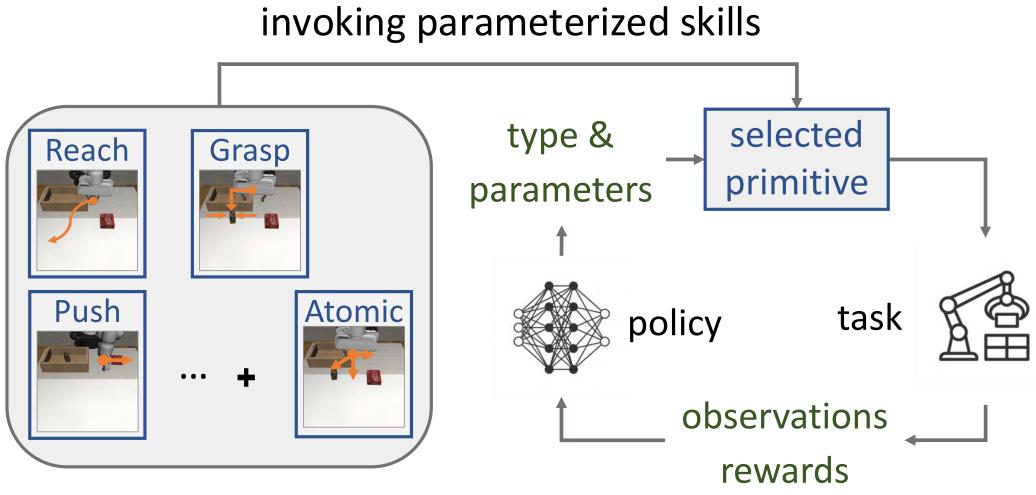


Hardware

Humanlike Embodiment

Humanoid robot platform for broad applications

Key Idea: Skills as APIs and Scaling Law



library of skill APIs

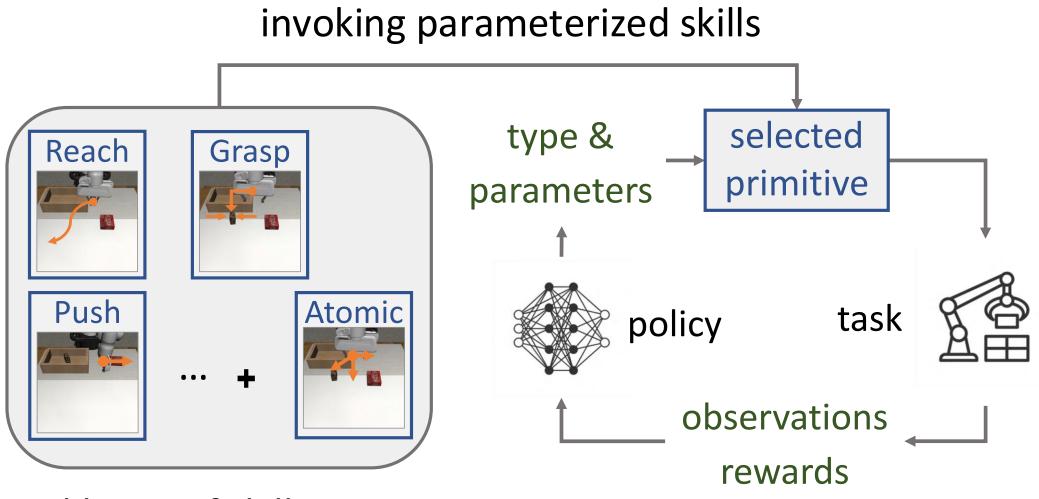
Skills as APIs

(Nasiriany et al. ICRA 2022)



Soroush Nasiriany

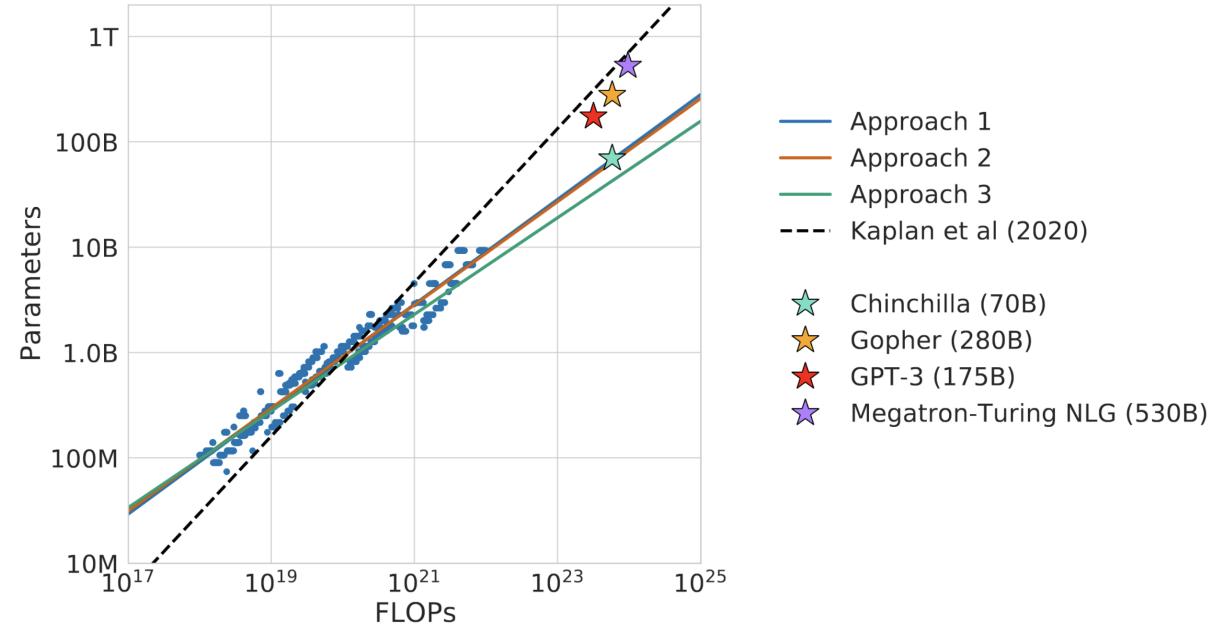
Key Idea: Skills as APIs and Scaling Law



library of skill APIs

Skills as APIs

(Nasiriany et al. ICRA 2022)



Scaling Law for Language Models

(Kaplan et al. 2020; Hoffmann et al. 2022)



Raw visual observation



Yifeng Zhu

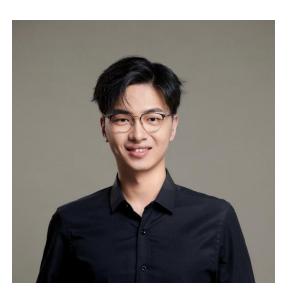






Raw visual observation

General object proposals

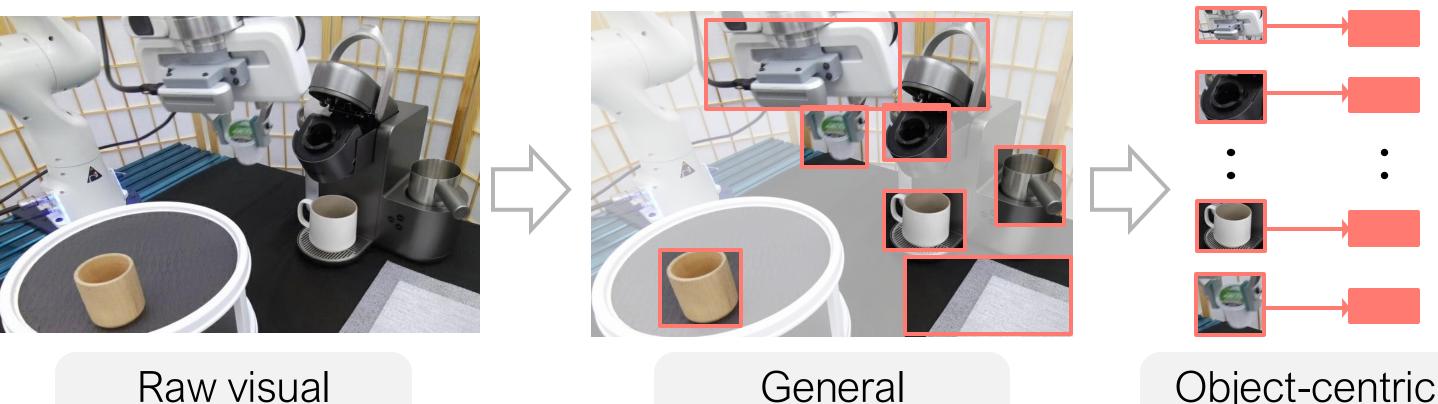


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Yifeng Zhu
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arge vision model trained on Internet-scale image datasets





object proposals

Raw visual observation

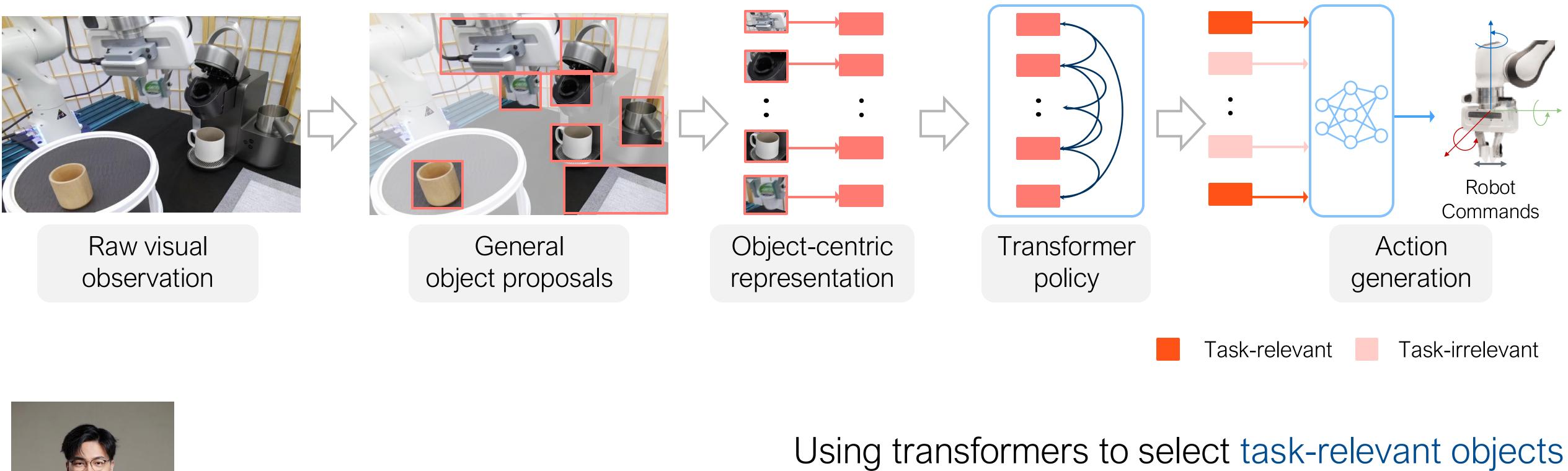


Yifeng Zhu

Object-centric representation

Encoding object visual appearances and their spatial locations







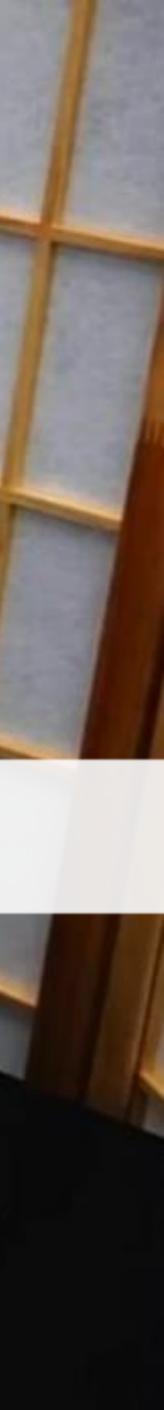
Yifeng Zhu

and reason about their relations



It learns to make coffee without additional 50 annotations on human demonstrations.

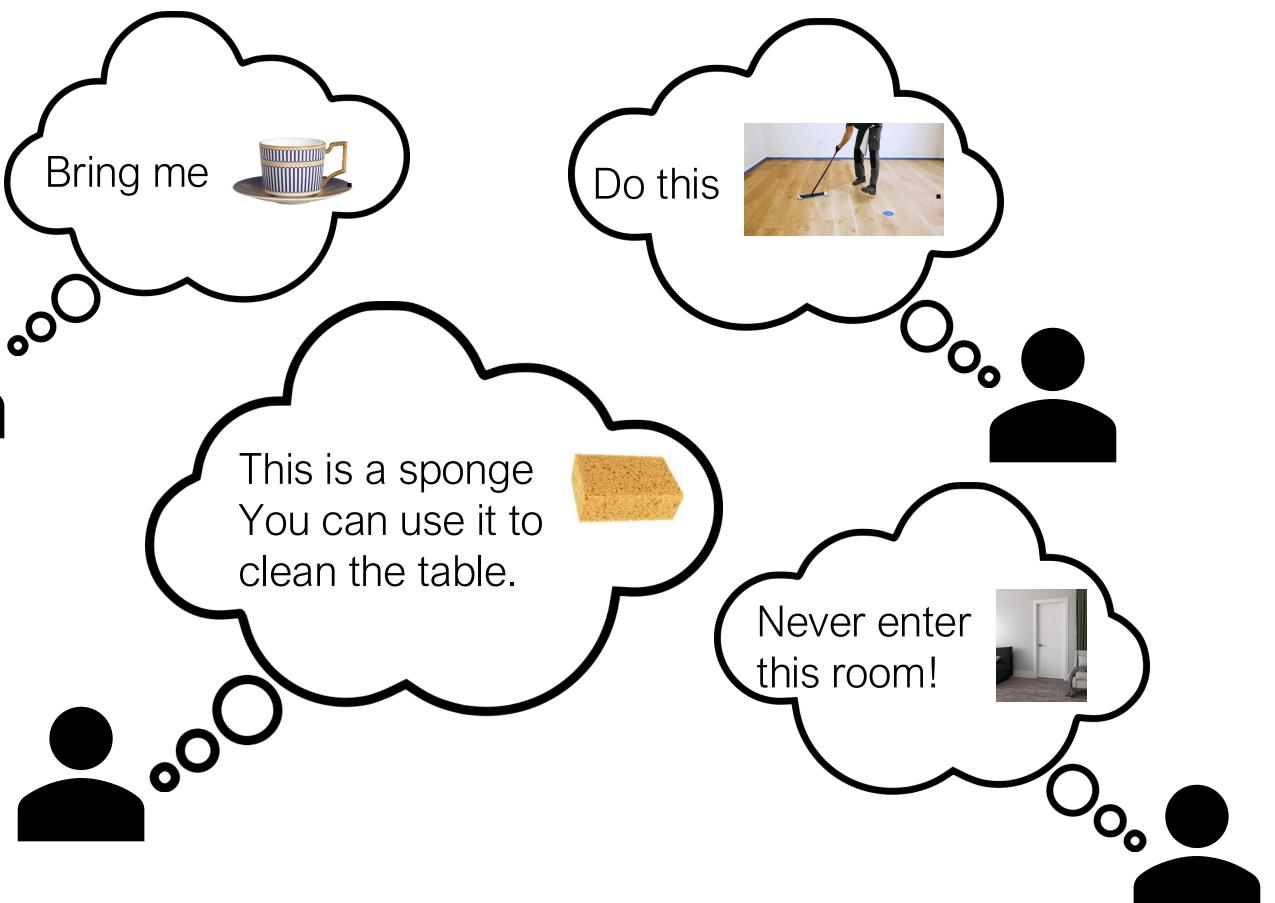
Policy Input



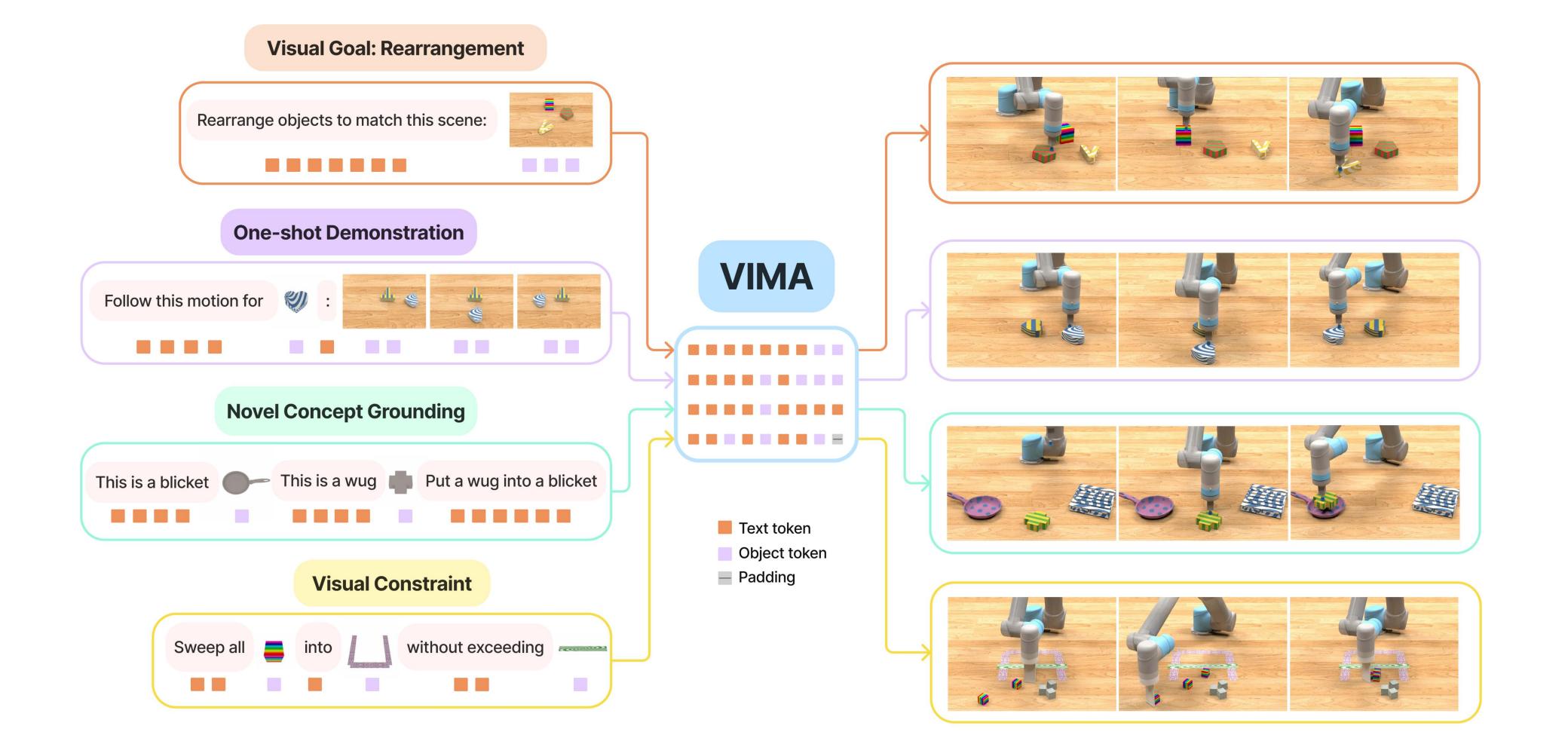
Massively Multi-Task Robot Learning for Model Scaling What if we can prompt a household robot to ... Recite the first law of robotics Input Prompt: Bring me Do this 0 ~0₀ .

Output: A robot may not injure a human being

[Credit: Jay Alammar]





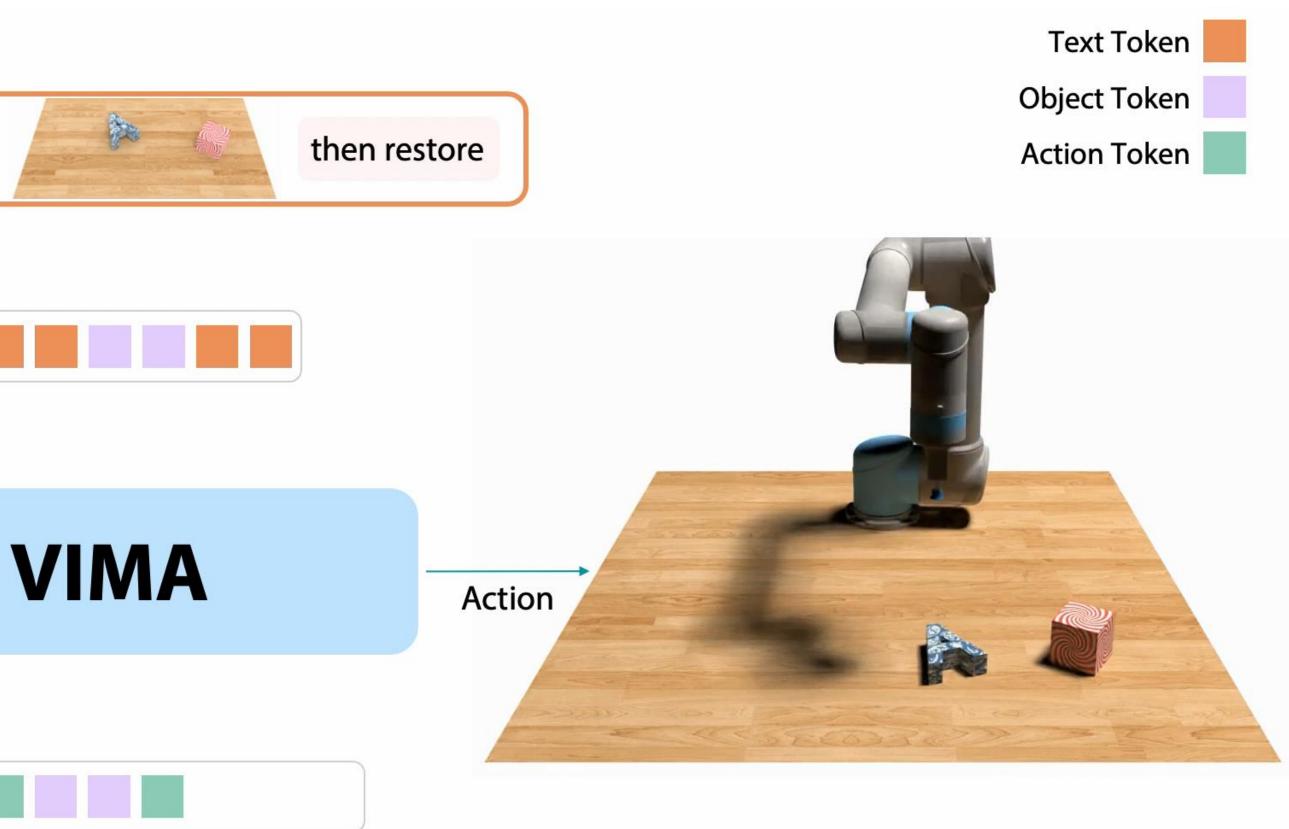


generalist robot agent for multi-task learning and zero-shot generalization

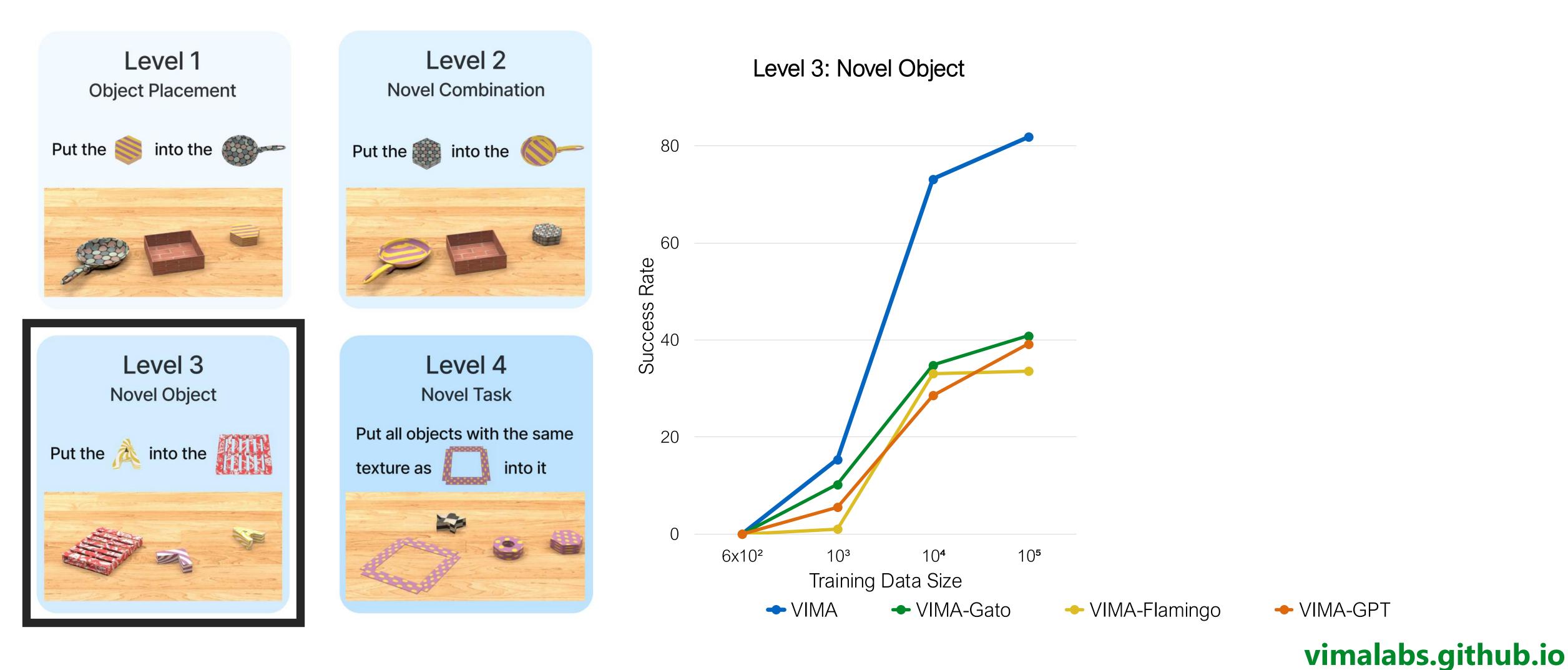
Massively Multi-Task Robot Learning for Model Scaling VIMA: Visuo-Motor Attention model

- Transformer **encoder-decoder**; ullet
- Encodes multimodal prompts lacksquarewith a frozen language model;
- **Object-centric** representations for visual observations
- Predicts skill APIs given the \bullet prompt and interaction history.

Rearrange to this
Prompt Tokens
History Tokens

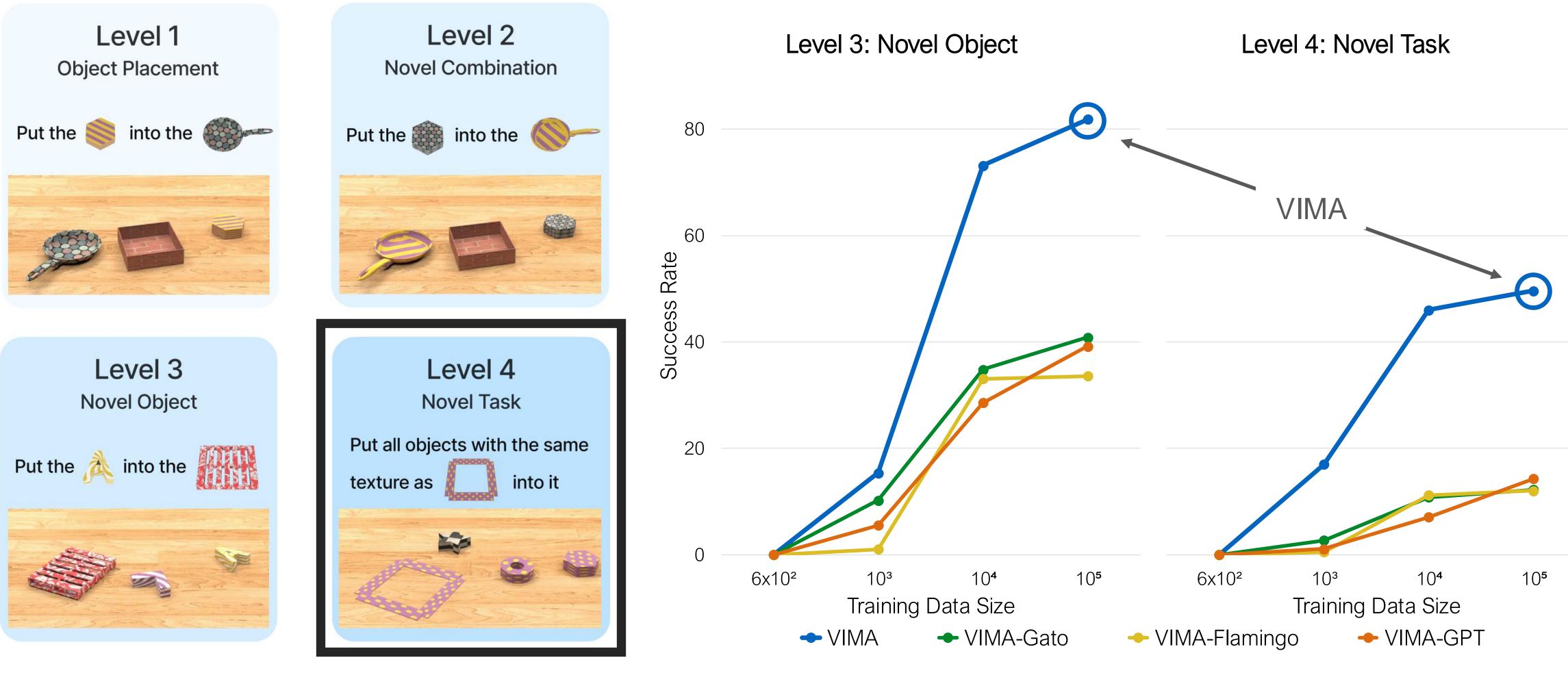


"VIMA: General Robot Manipulation with Multimodal Prompts." Jiang et al. ICML 2023



Data scalability from 0.1% to full dataset





Data scalability from 0.1% to full dataset

vimalabs.github.io









Rutav Shah

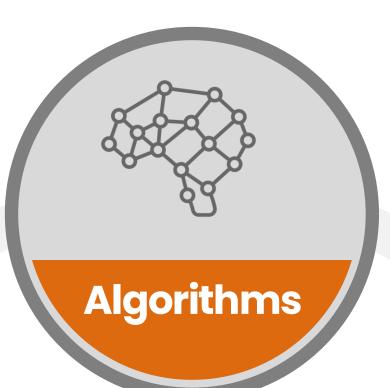
[Shah et al. CoRL 2023]

Recipe for Building Generalist Robot Models

Scaling Law

Powerful robot learning models that scale with data and compute

Data



Data Flywheel

New mechanism to collect massive training data

Generalist Robot Model



Hardware

Humanlike Embodiment

Humanoid robot platform for broad applications

Key Idea: Robot Learning Data Flywheel

How can we ensure trustworthy deployment?

Wider Deployments

More Capable

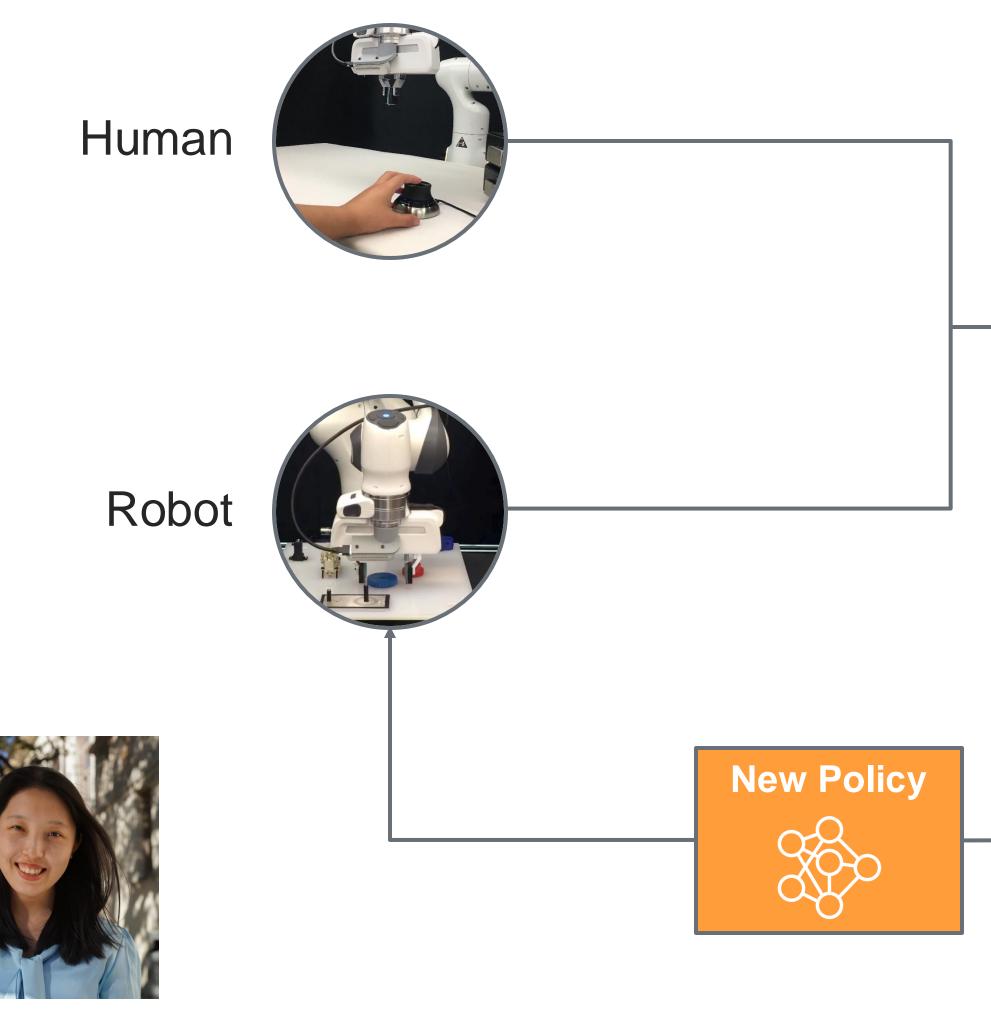
Robots

More Training Data

How can robots learn continually with more data?

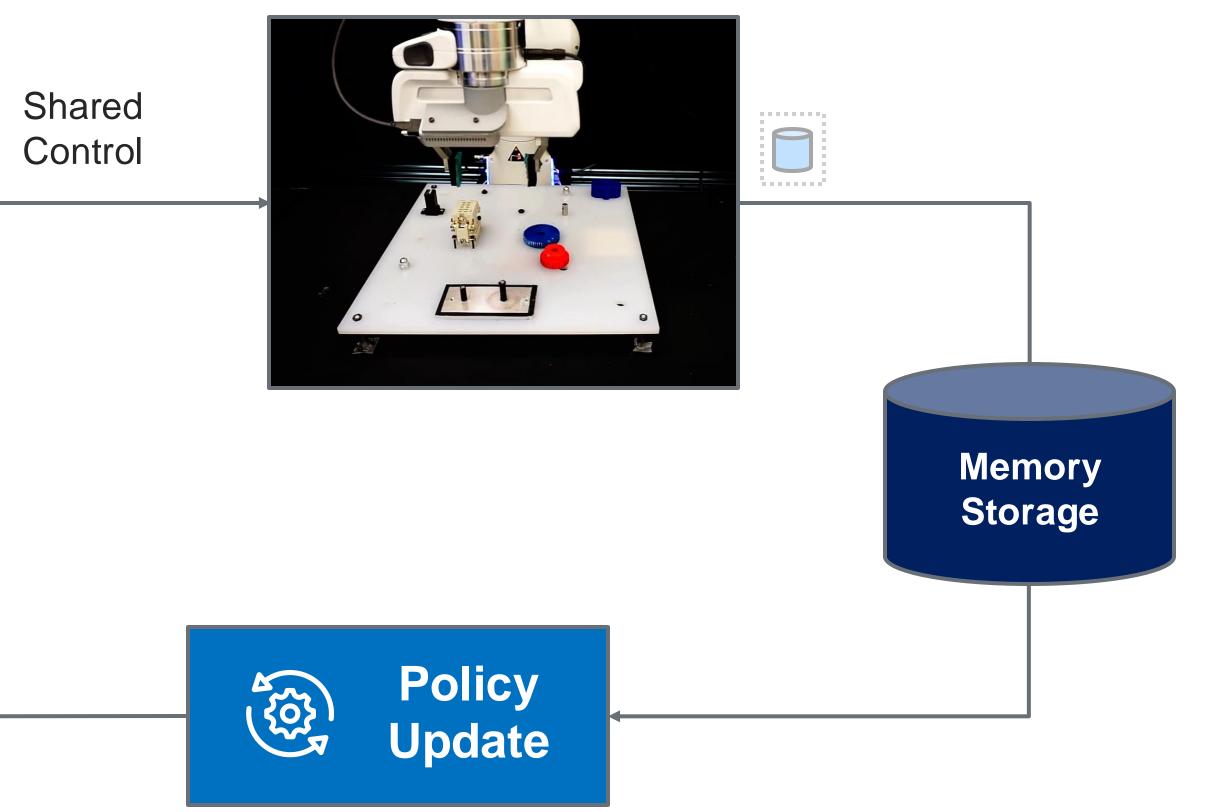
Better Models



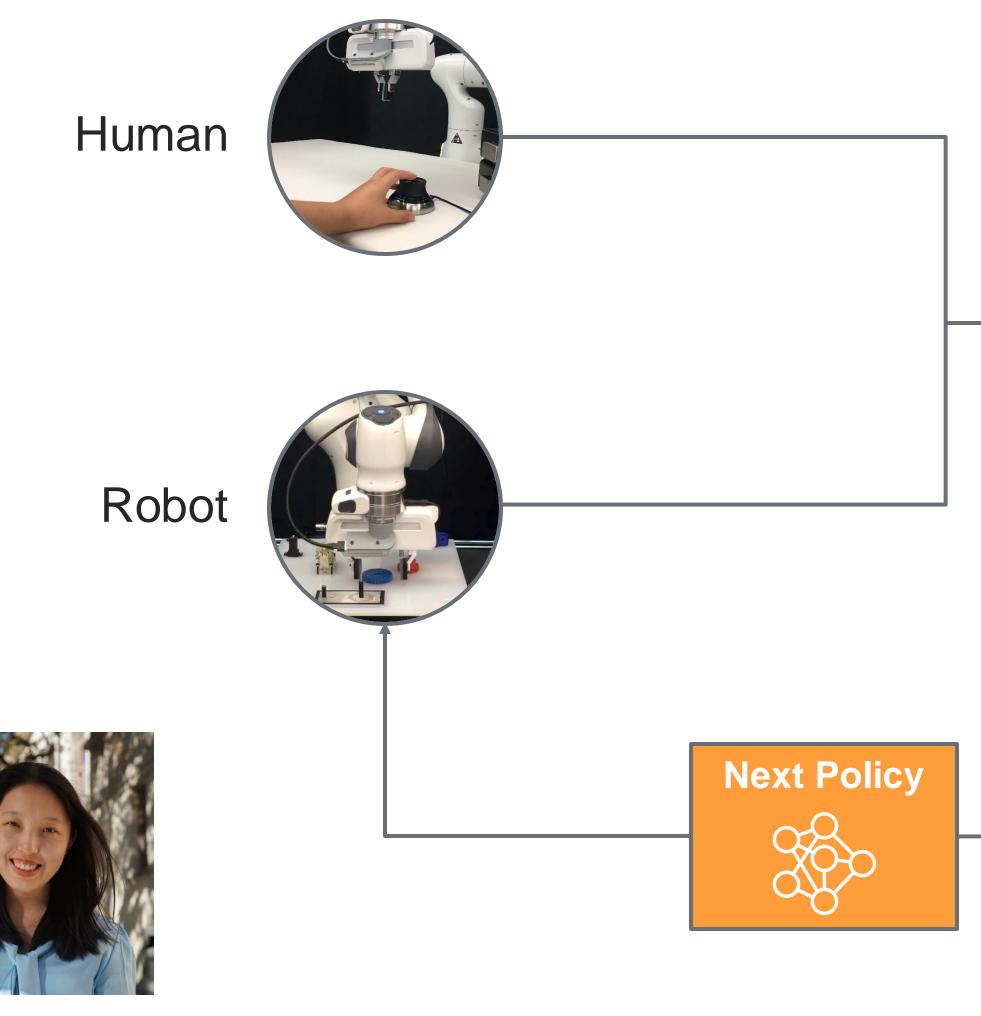


Huihan Liu

"Robot Learning on the Job: Human-in-the-Loop Autonomy and Learning During Deployment." (Sirius) Liu et al. RSS 2023

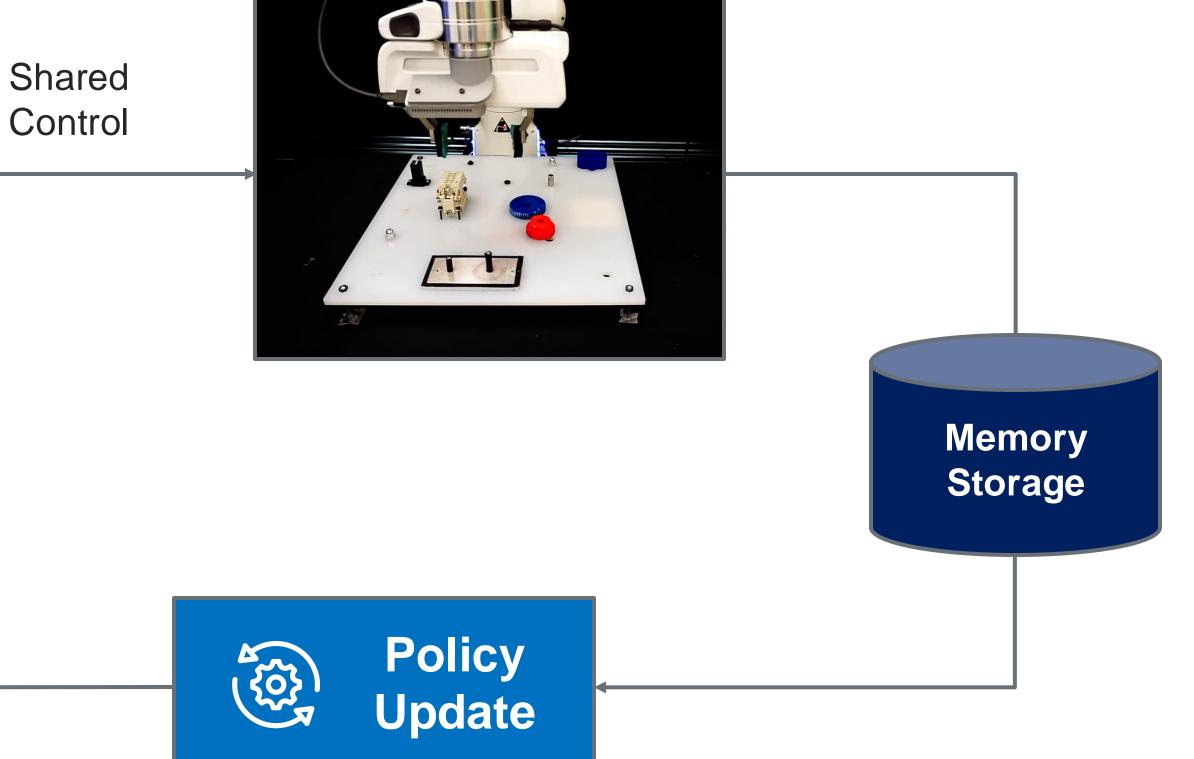




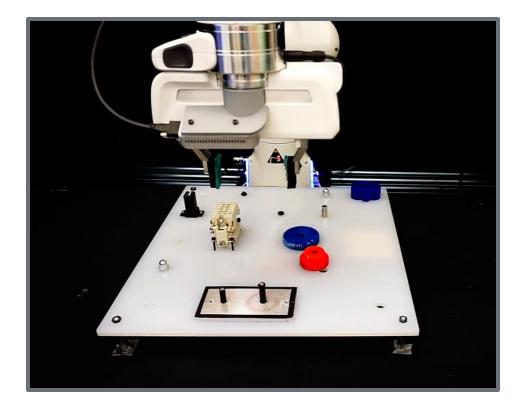


Huihan Liu

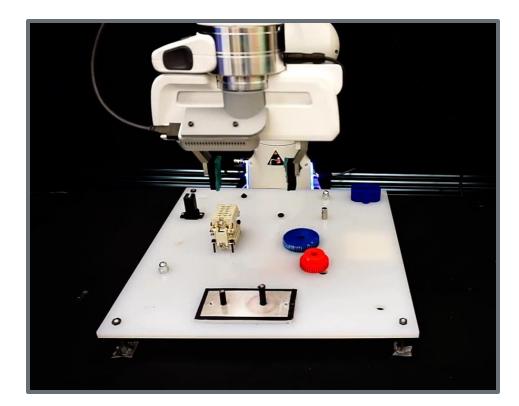
"Robot Learning on the Job: Human-in-the-Loop Autonomy and Learning During Deployment." (Sirius) Liu et al. RSS 2023



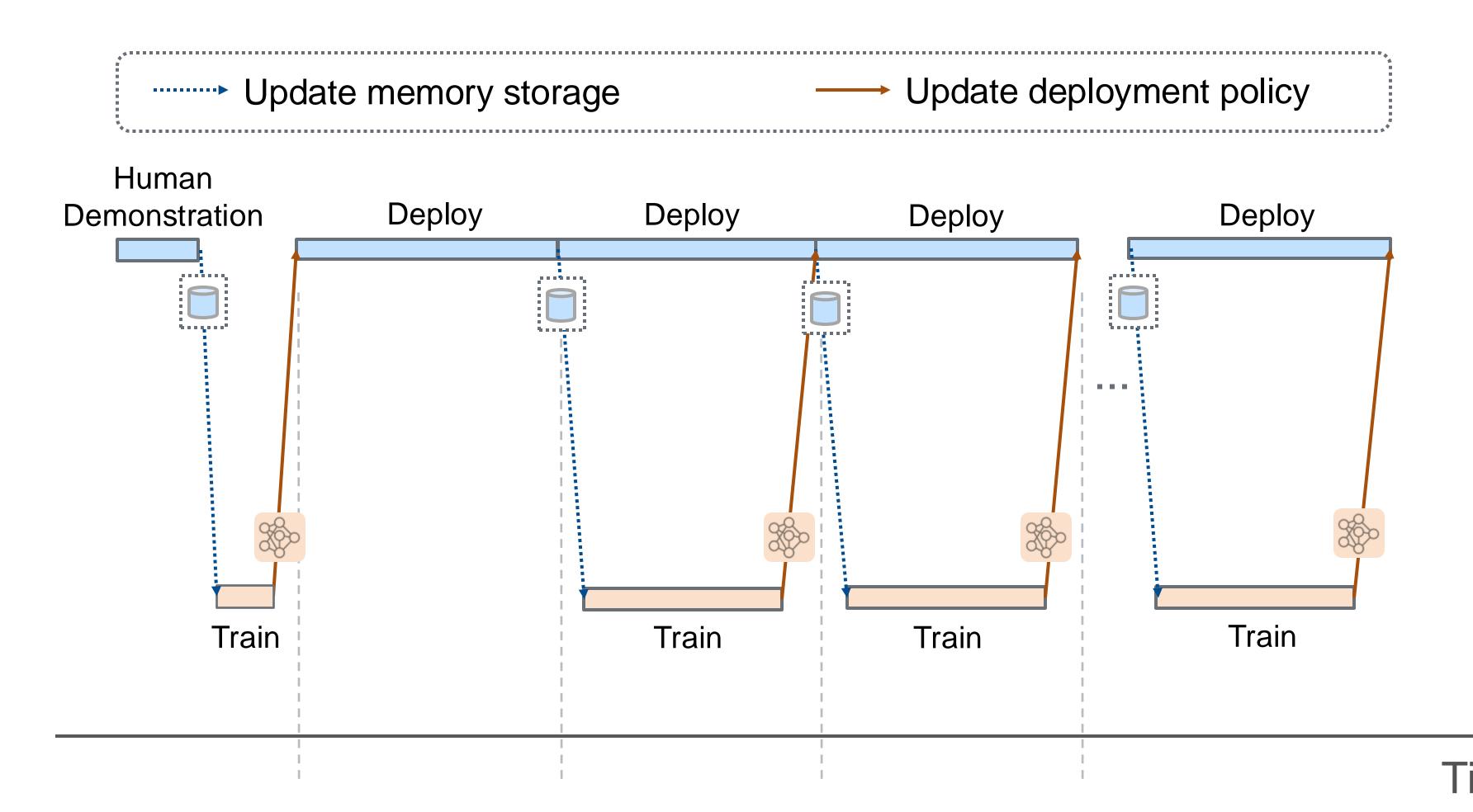














Human provides a intervention

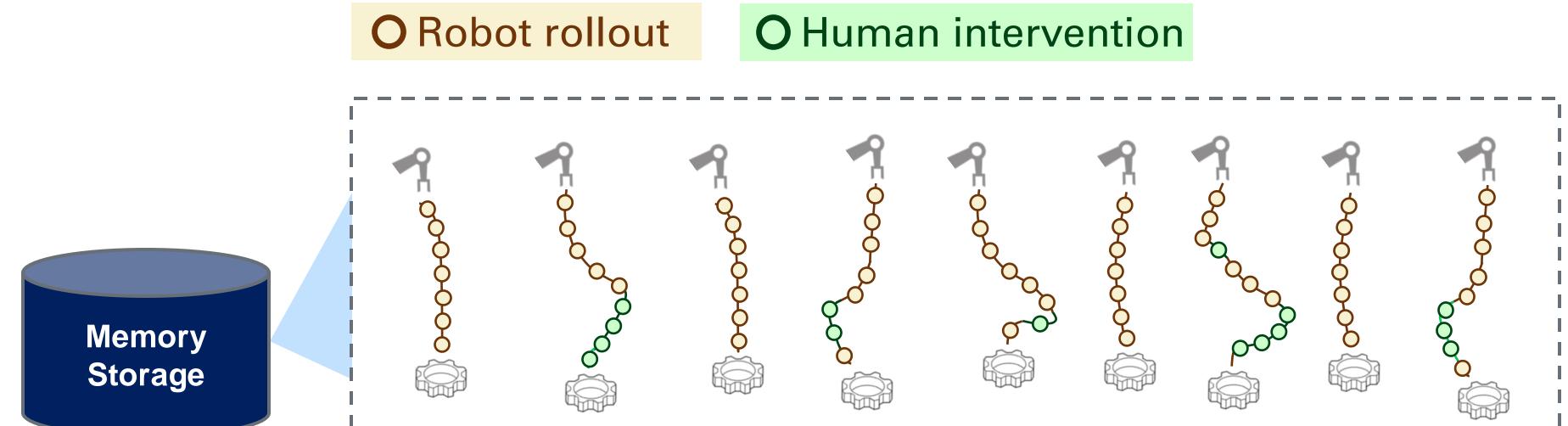
Robot takes control again

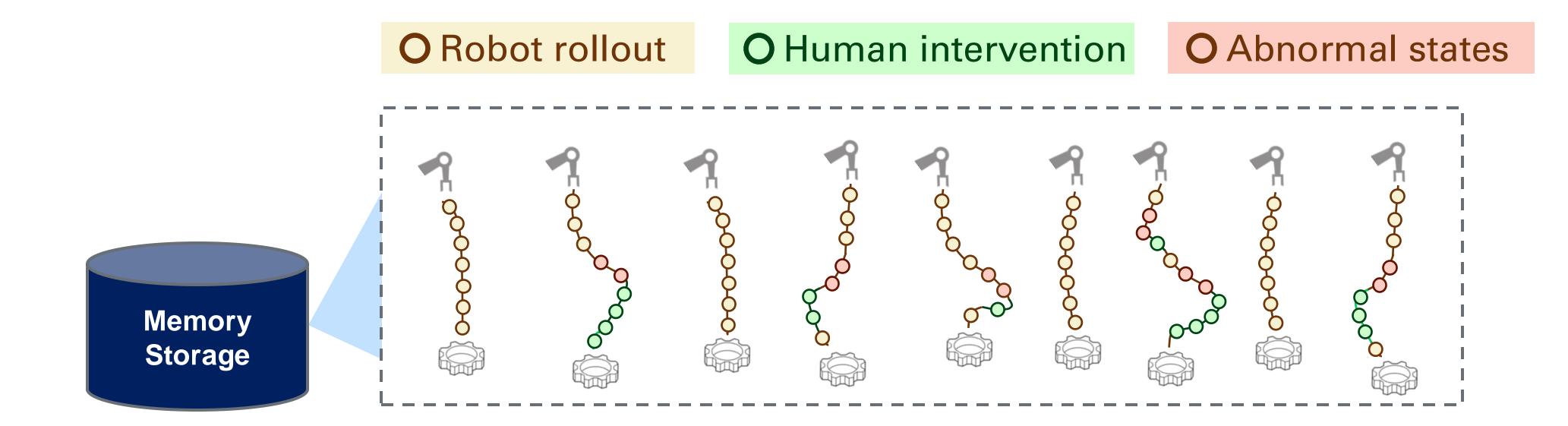
"Model-Based Runtime Monitoring with Interactive Imitation Learning." Liu et al. 2023

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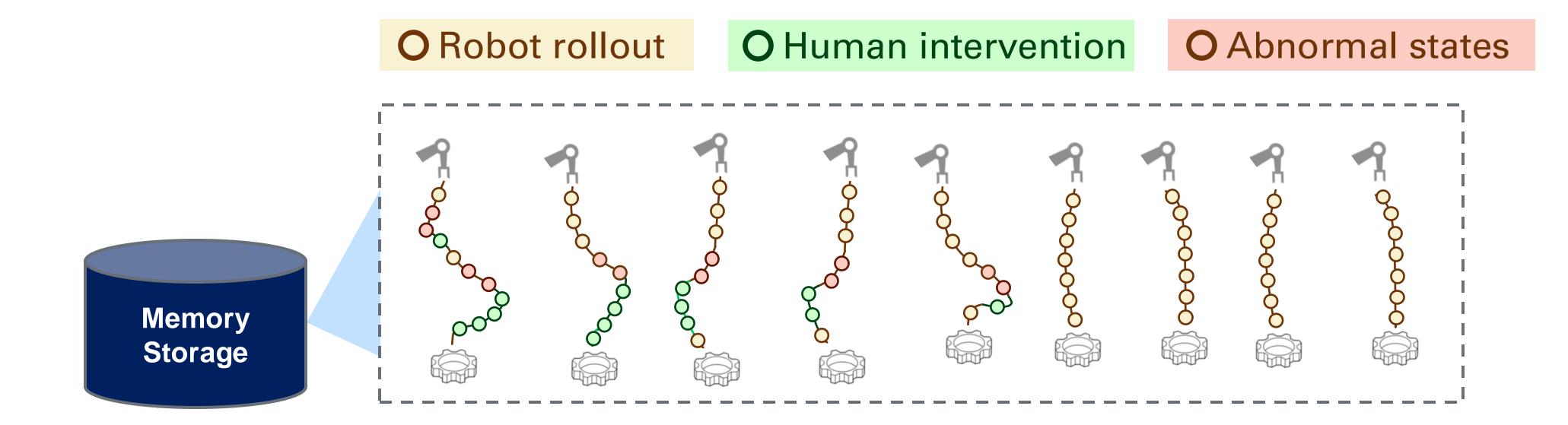
FRANKA



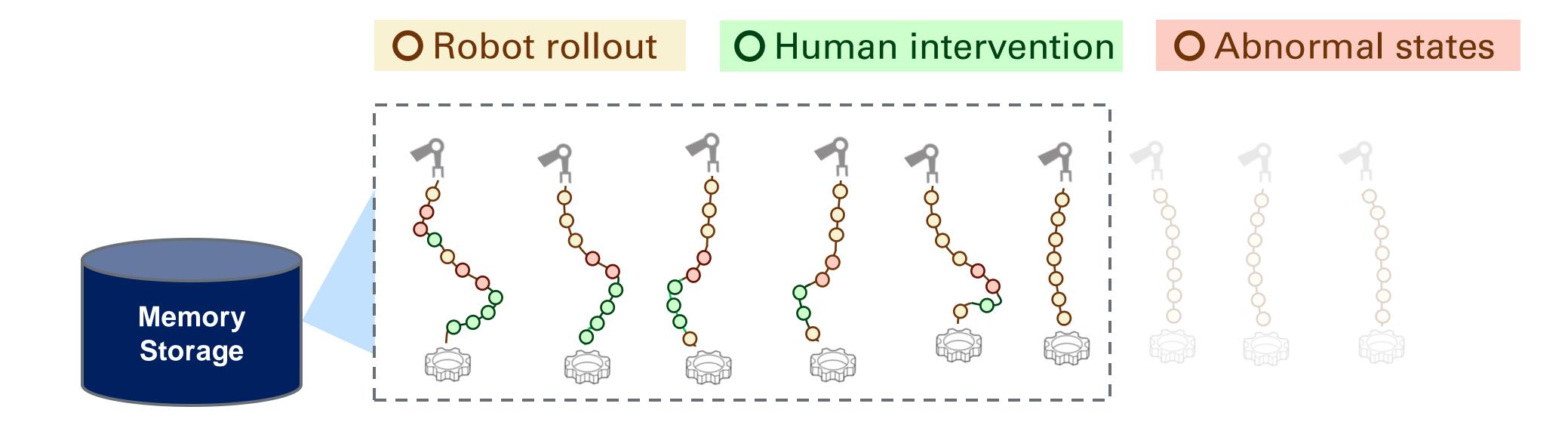




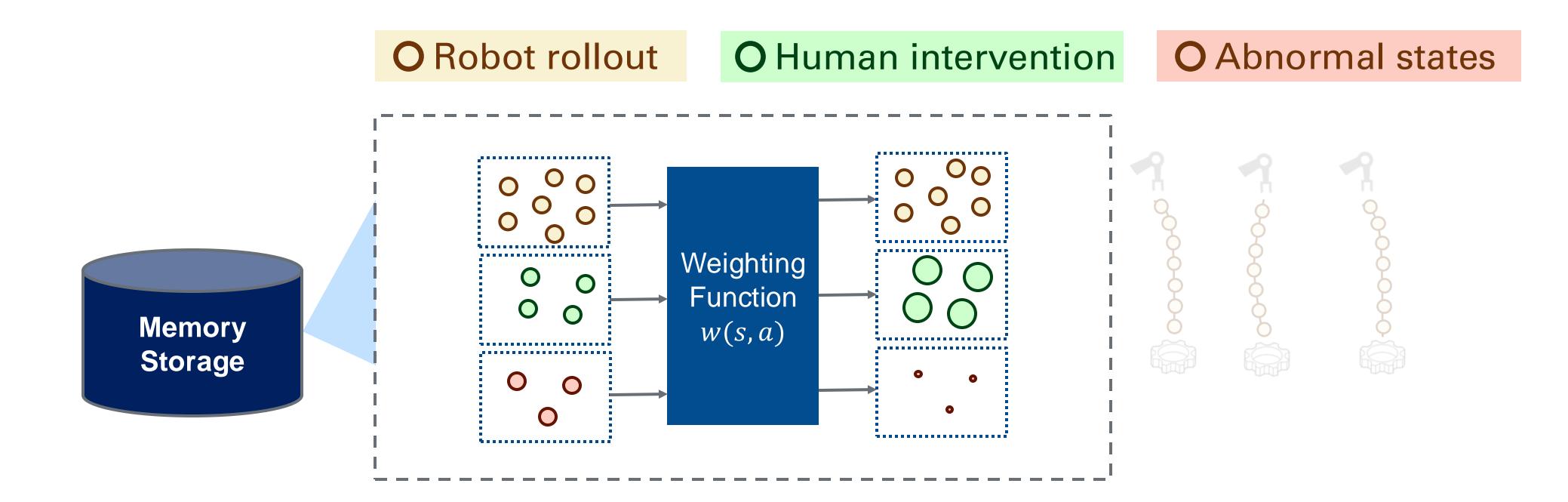
Relabel **abnormal states** before interventions



Sort by a **dataset curation** strategy

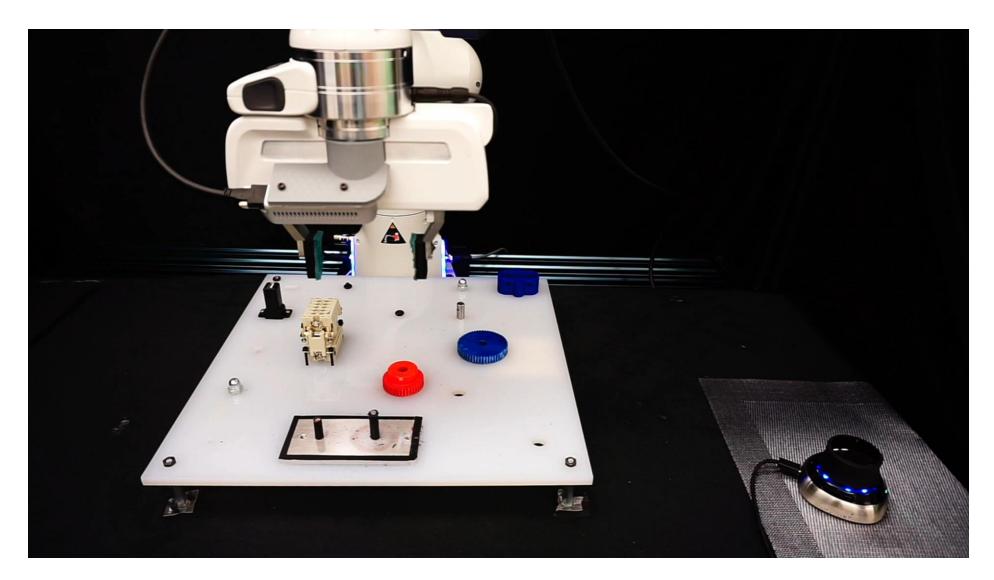


Reduce memory to a **fixed size**



Reweight samples for imitation learning

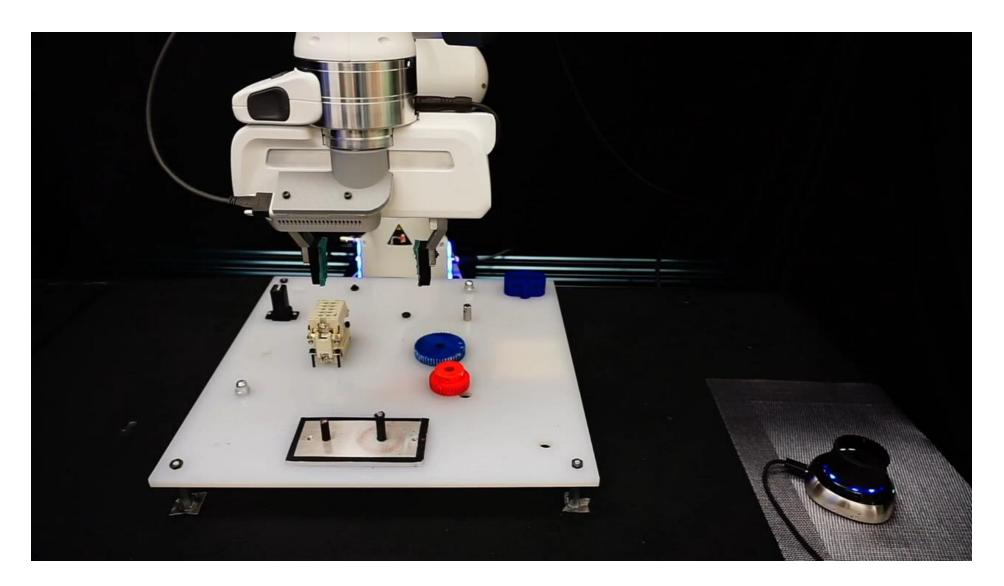
Round 1 Deployment



† Green masks indicate human intervention.

Intervention Distribution

Round 3 Deployment



Intervention Distribution

Recipe for Building Generalist Robot Models

Scaling Law

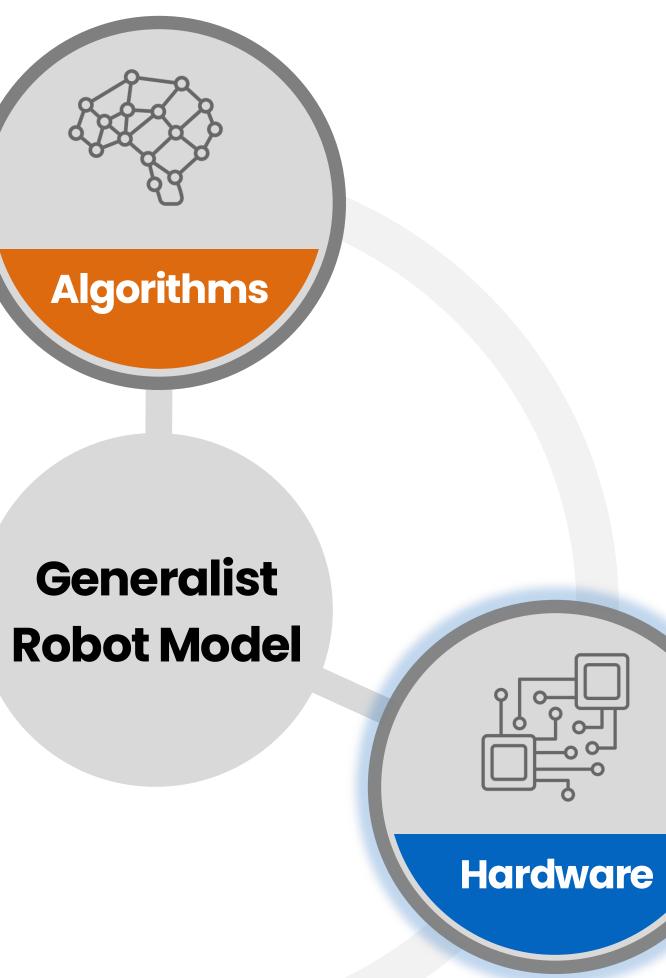
Powerful robot learning models that scale with data and compute



Data Flywheel

New mechanism to collect massive training data



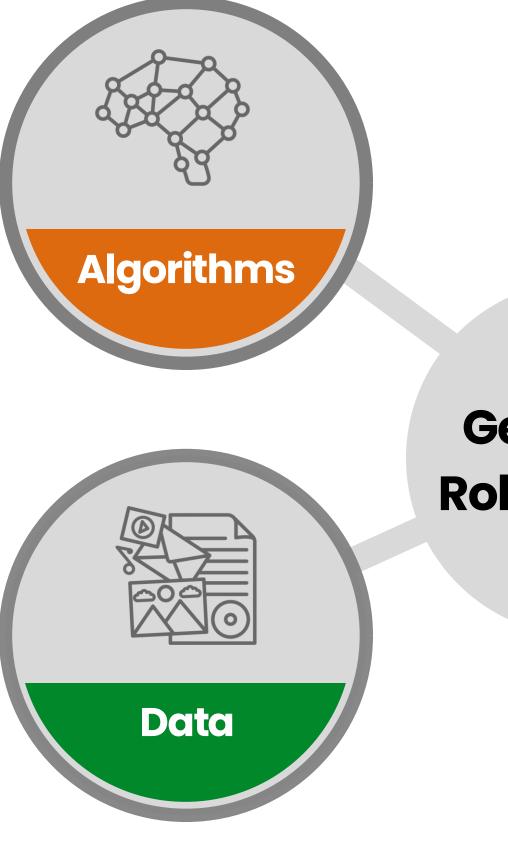


Humanlike Embodiment

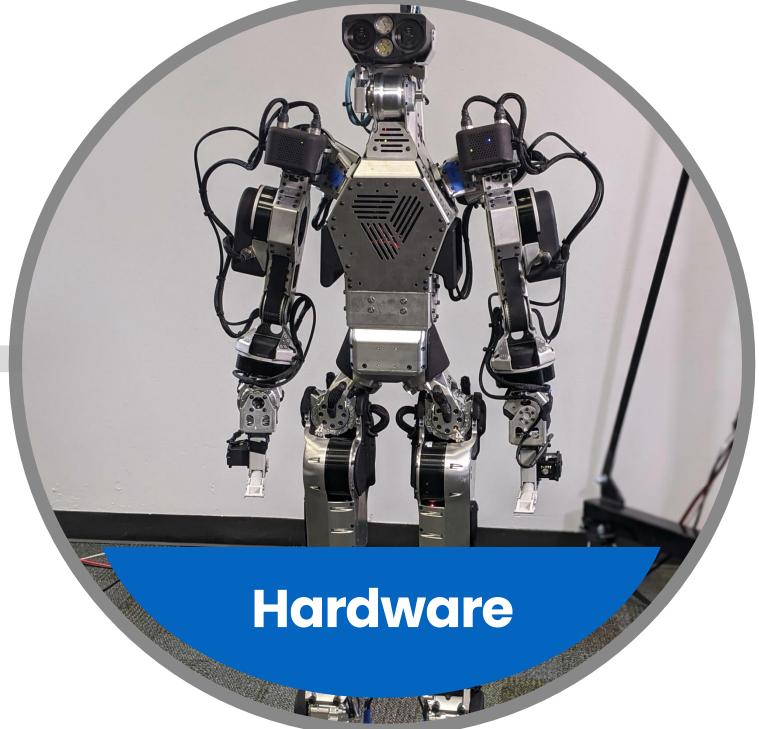
Humanoid robot platform for broad applications



Humanlike Embodiment: Generalist Humanoid Robot



Generalist **Robot Model**





Draco3 Humanoid

Team



Mingyo Seo

Luis Sentis

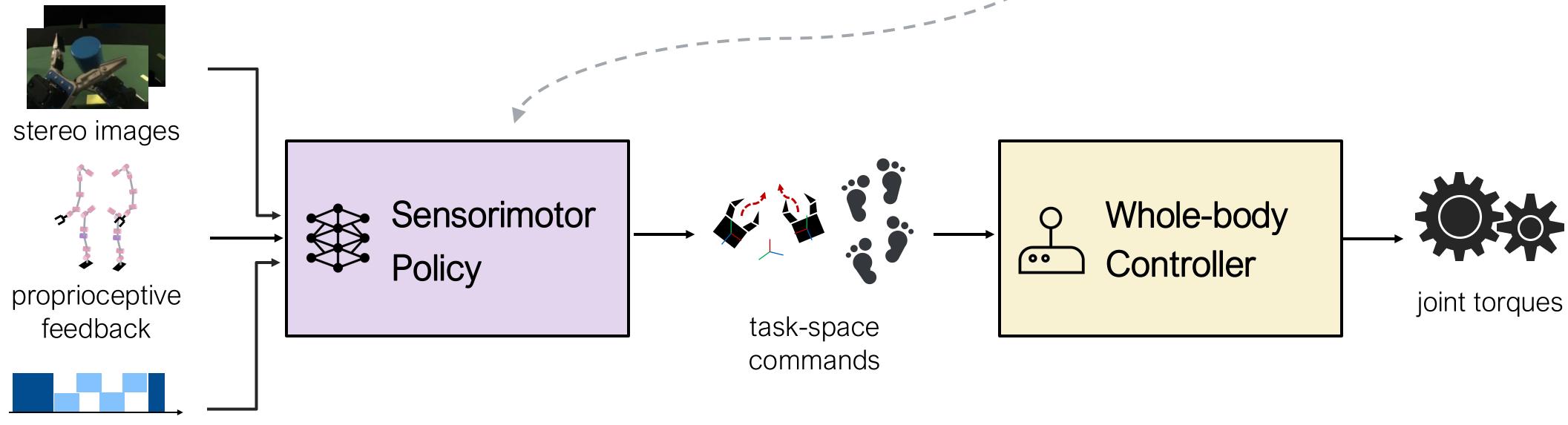




Humanlike Embodiment: Generalist Humanoid Robot



human teleoperation



state machine

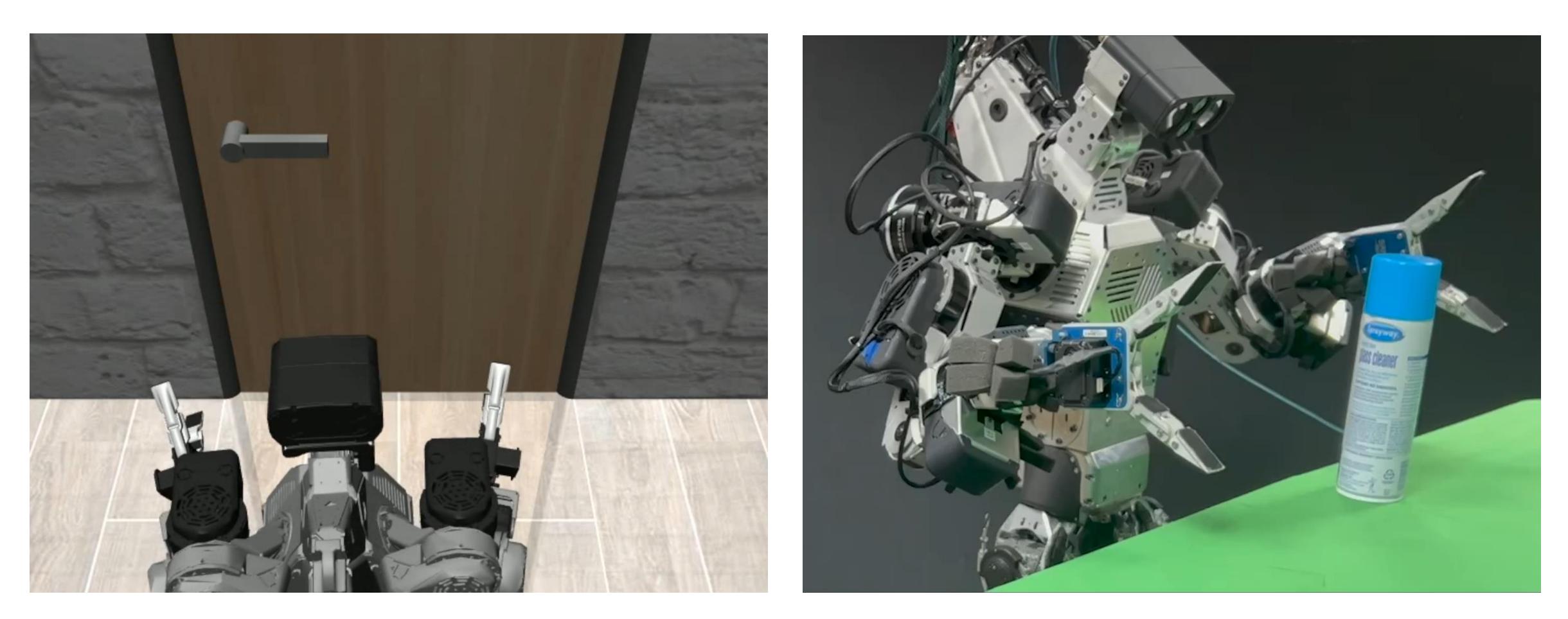
"Deep Imitation Learning for Humanoid Loco-manipulation through Human Teleoperation." Seo et al. Humanoids 2023



task demonstrations



Humanlike Embodiment: Generalist Humanoid Robot Policy deployments in simulation and real world



Loco-manipulation (sim): 92% success rate

Bimanual manipulation (real): 90% success rate

Pathway to Generalist Robots



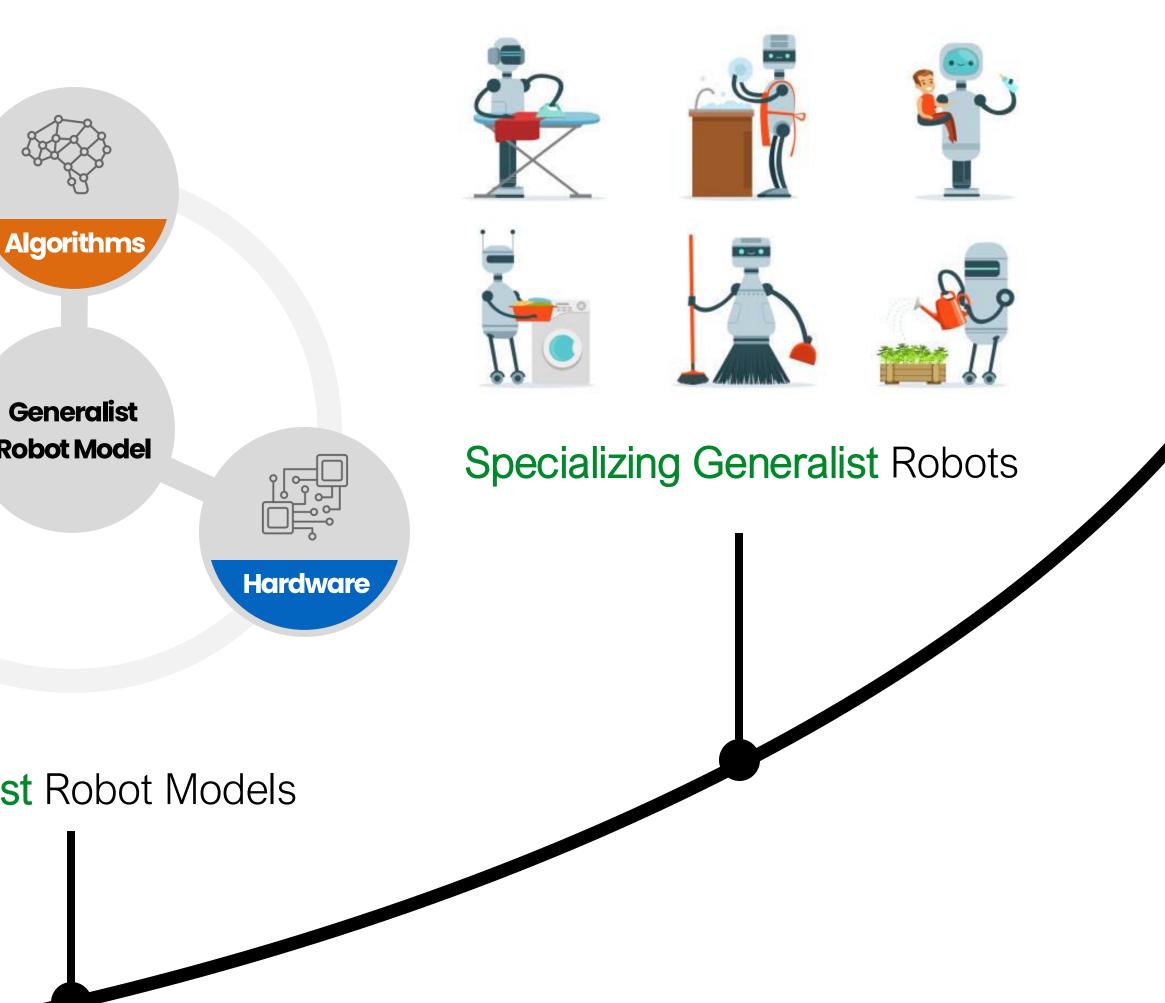


Generalist **Robot Model**

Generalist Robot Models

Data





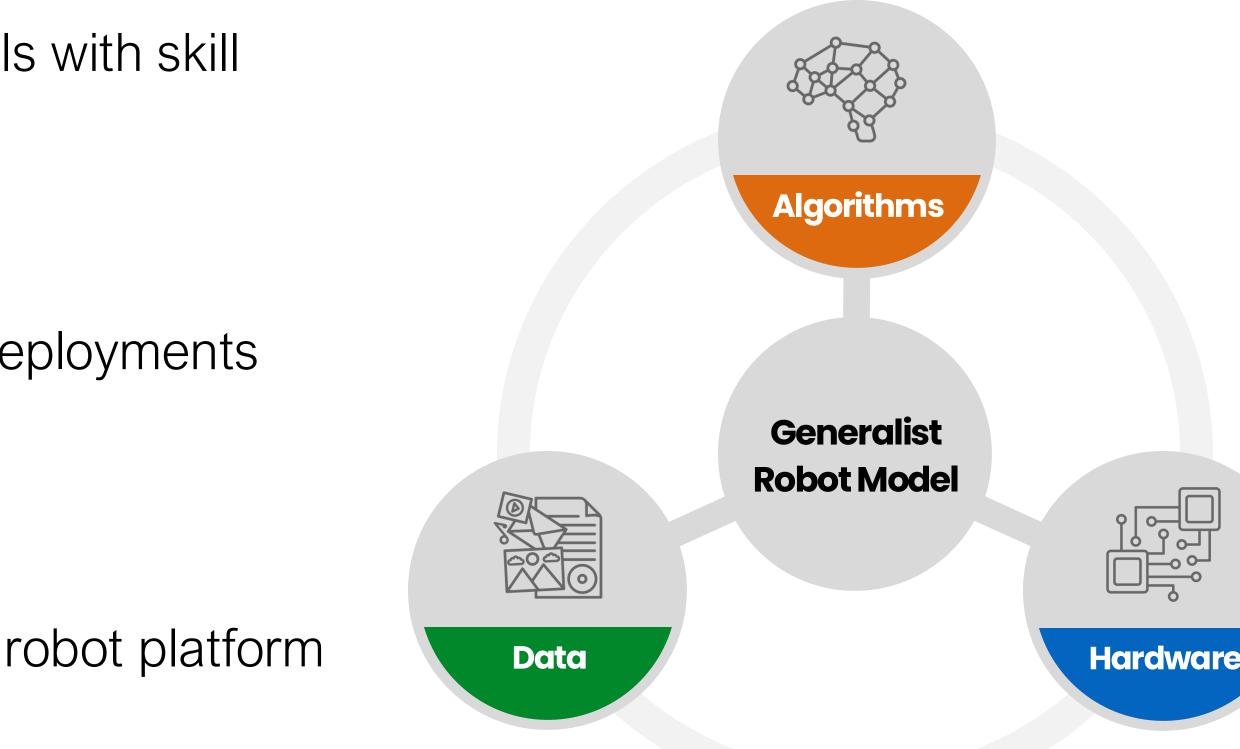


Pathway to Generalist Robots

- **Algorithms:** Scaling up robot learning models with skill \bullet APIs and massively multi-task training
- **Data:** Building a data flywheel in real-world deployments through human-in-the-loop robot autonomy
- Hardware: Humanoid robots as a generalist robot platform \bullet to develop human-level physical intelligence

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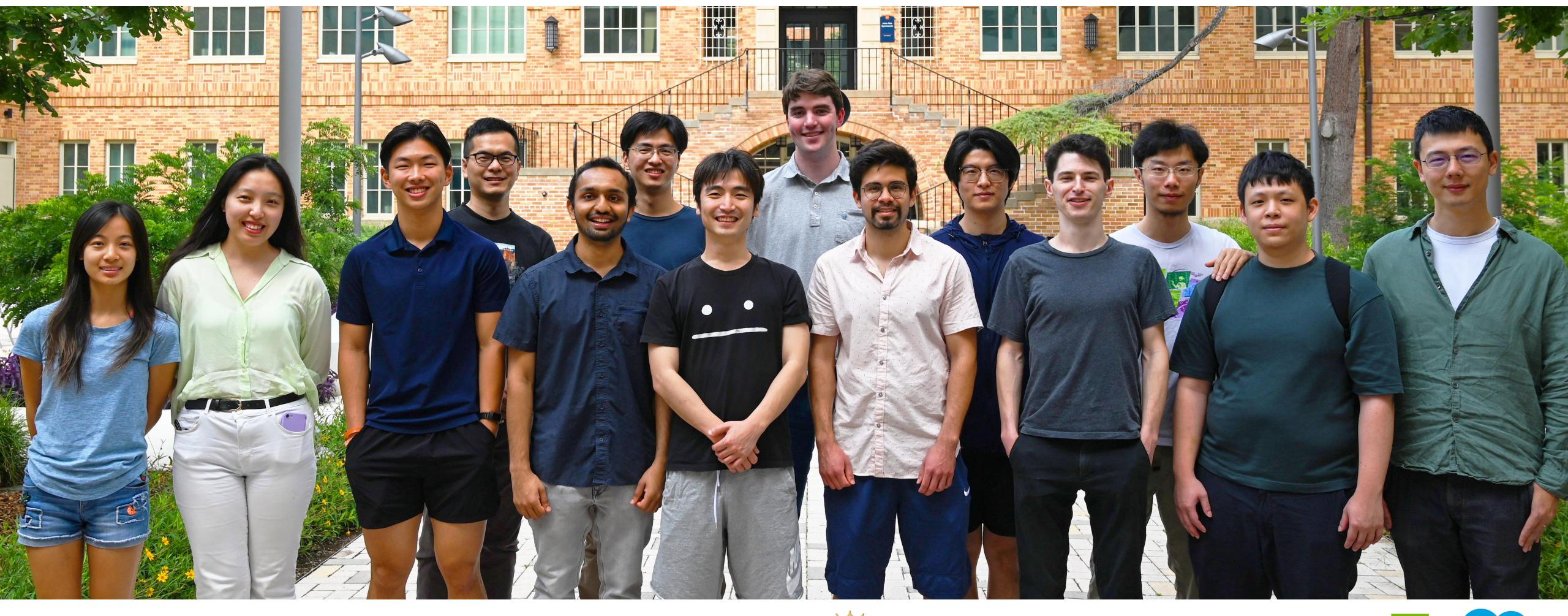






UT Robot Perception & Learning Lab

Mission statement: building general-purpose robot autonomy in the wild



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Acknowledgement:







NVIDIA.