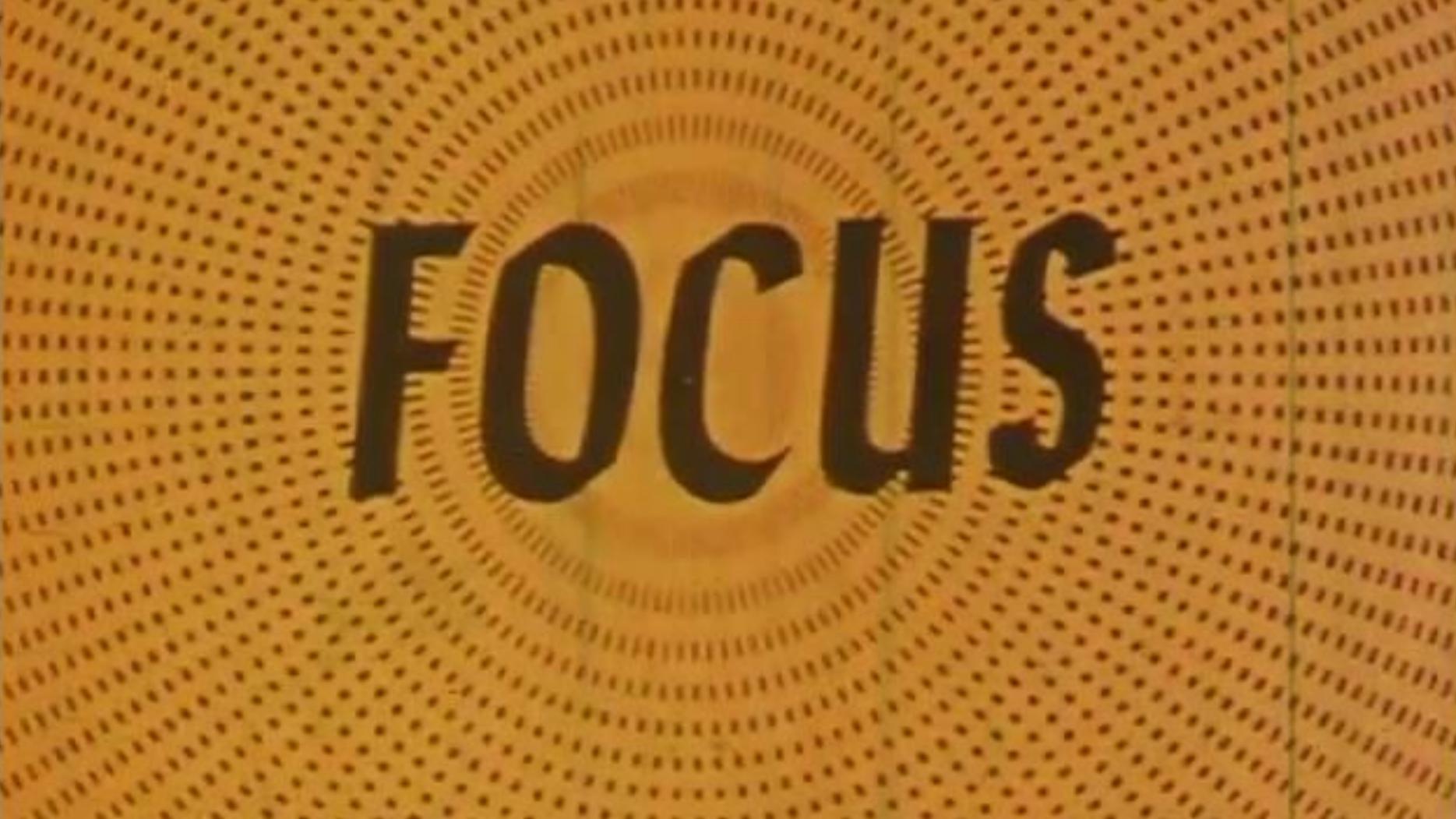


Robot Planning Meets Machine Learning

Tom Silver
Princeton University
Fall 2025



FOCUS

TYPE A SENTENCE

GOTHRU

PRECONDITION:

Near Door

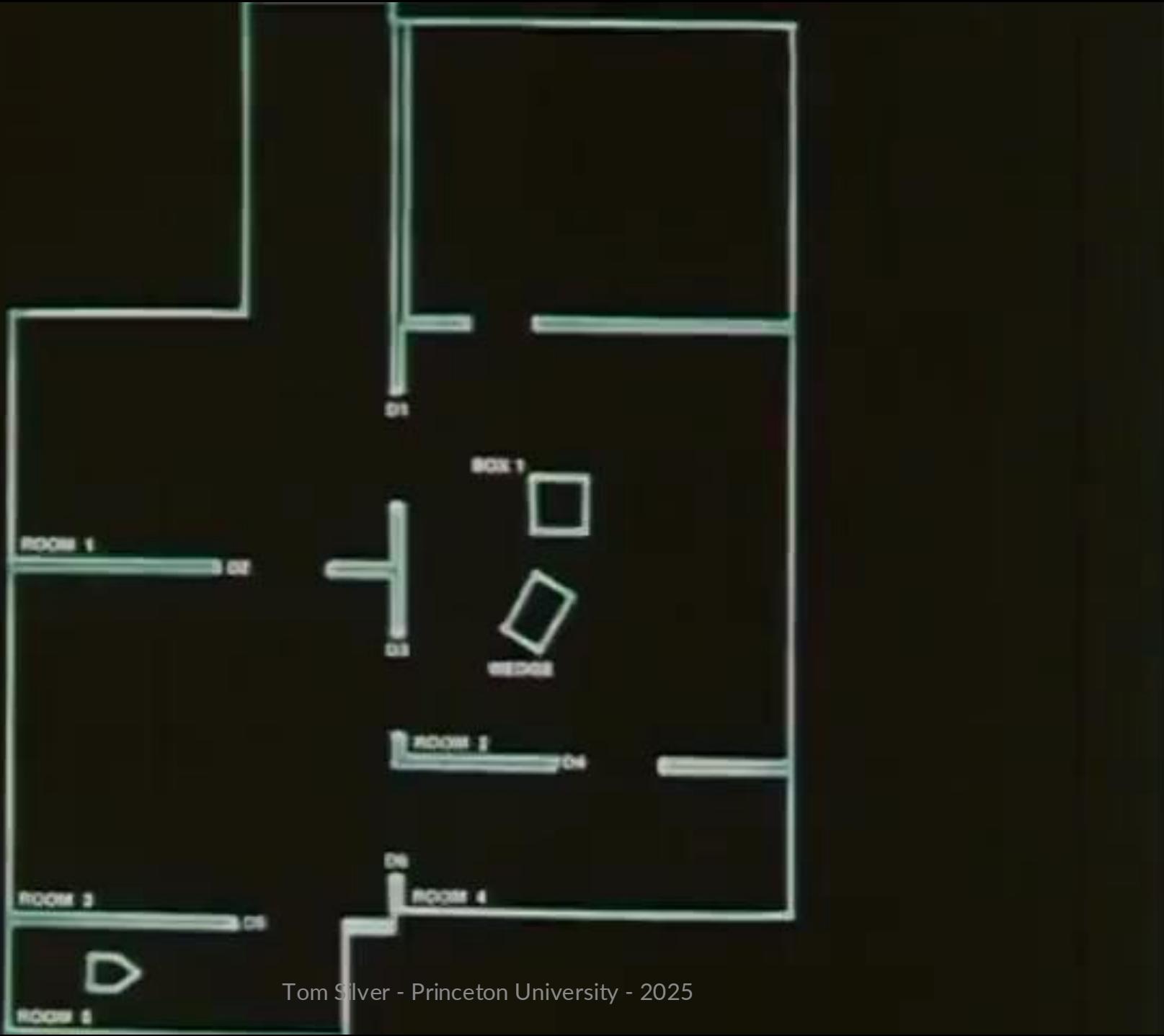
EFFECTS:

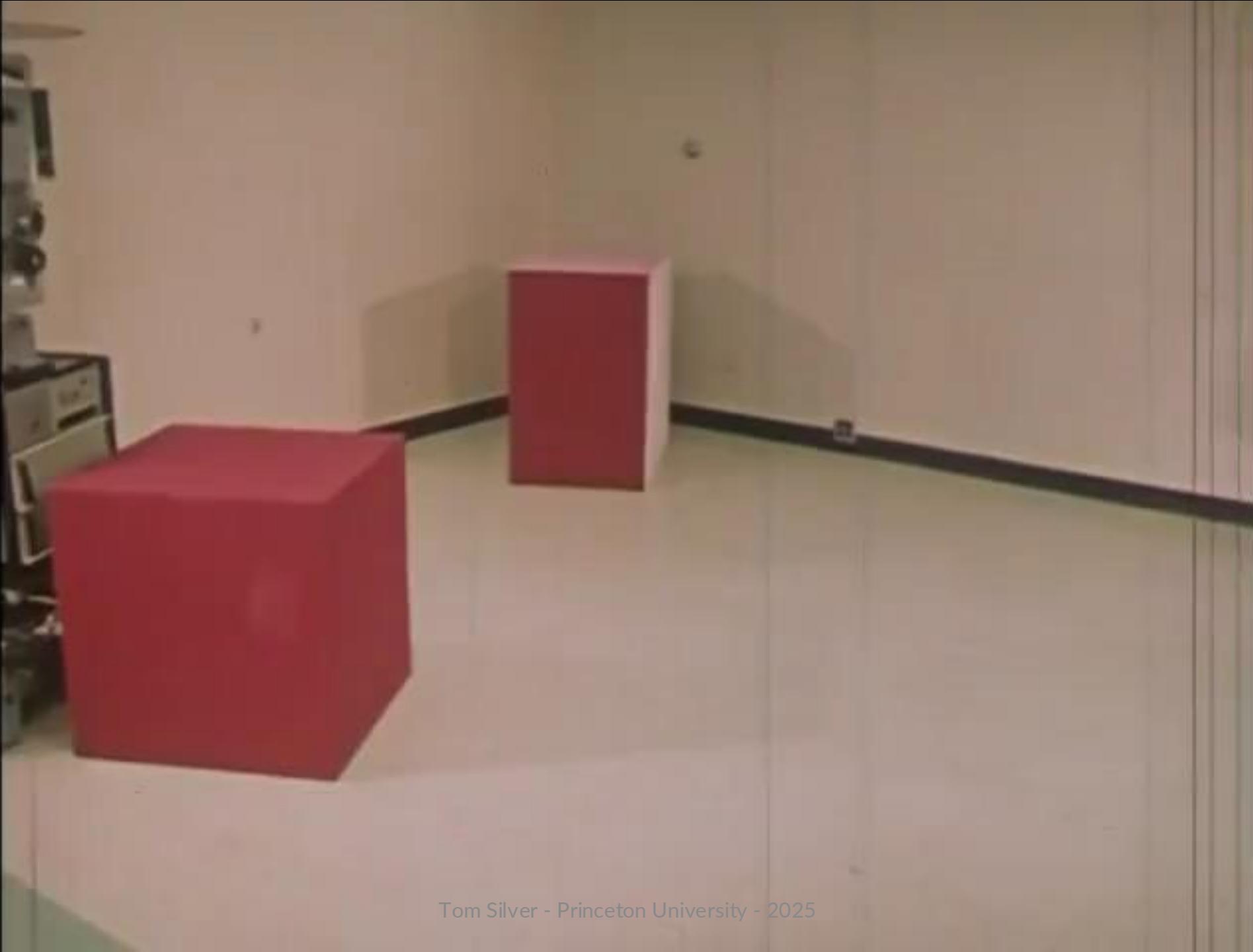
Will Be In Adjacent Room

START



GOAL





GOTO ()

GOTHRU ()

GOTO ()

GOTHRU ()

BLOCK (,)

That was 1972

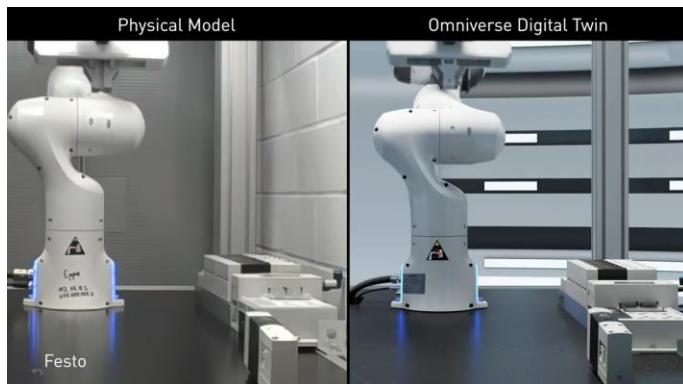
What's new?



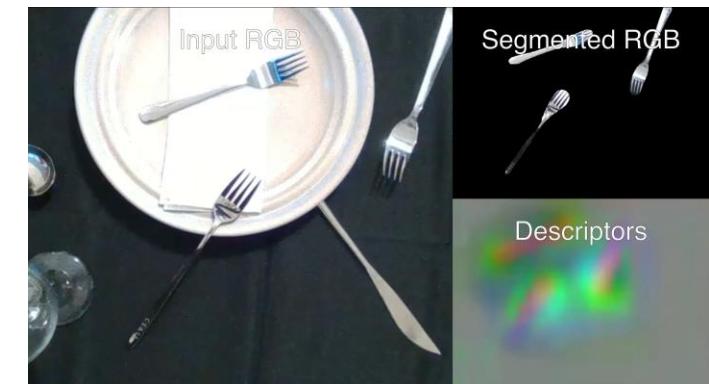
Hardware is better



Control is better



Simulation is better



Perception is better

[1] <https://openai.com/blog/learning-dexterity> [2] <https://www.bostondynamics.com/resources/blog/leaps-bounds-and-backflips>
[3] <https://developer.nvidia.com/isaac-sim> [4] <https://yenchenlin.me/nerf-supervision/>

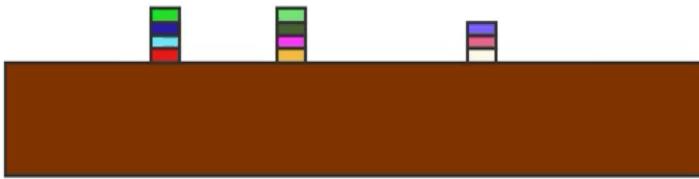
That was 1972

What's new?

Is planning better?

On one hand: yes, of course

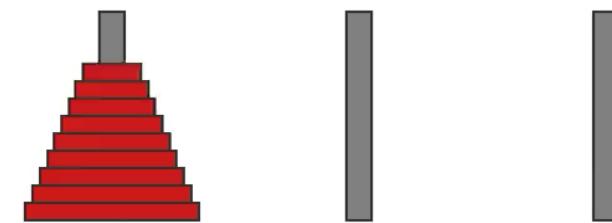
Planning is Better: Task Planning



Blocks World
Plan length: 28
Planning time: 0.12 s



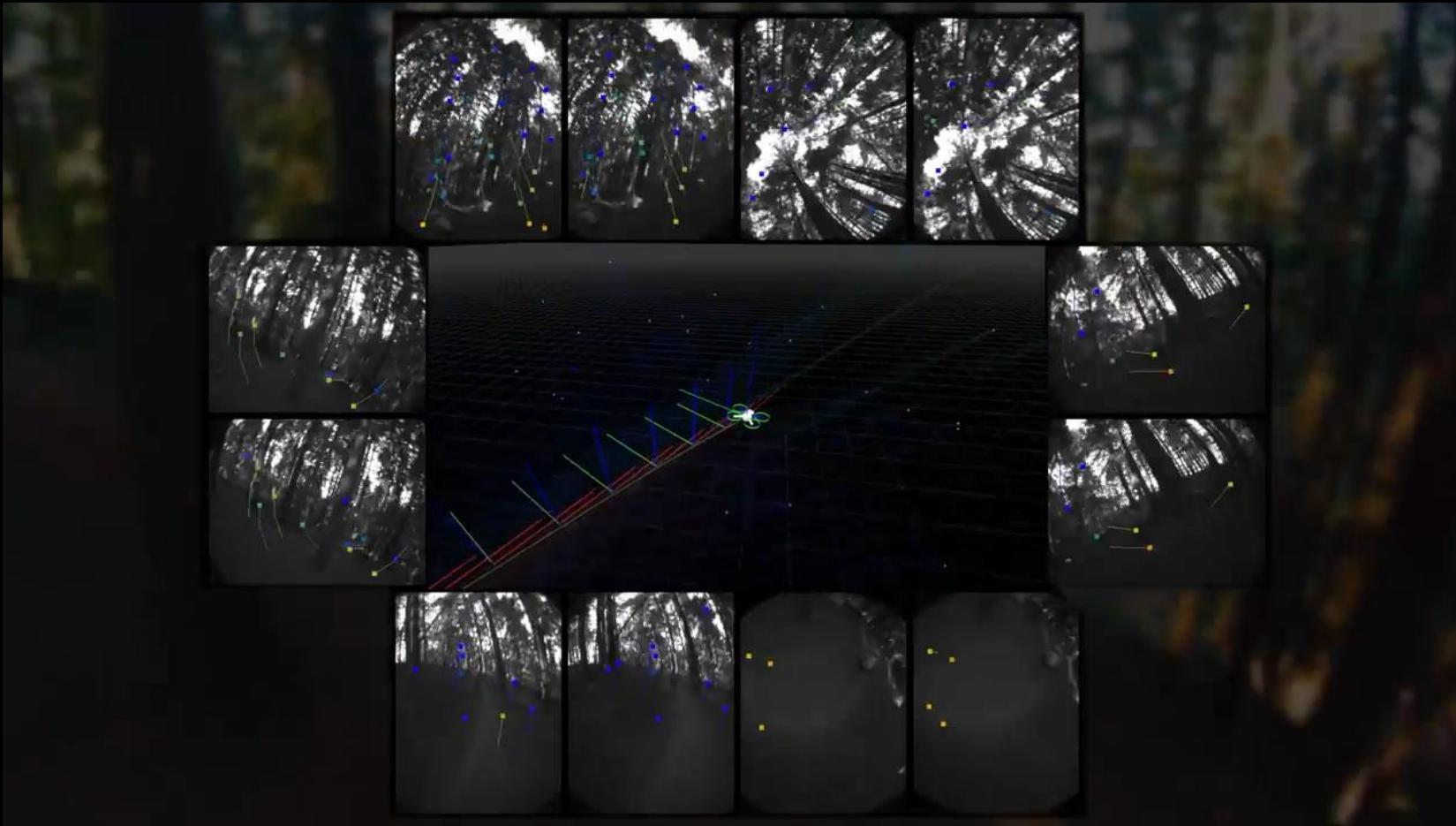
Sokoban
Plan length: 167
Planning time: 0.25 s



Hanoi
Plan length: 579
Planning time: 0.22 s

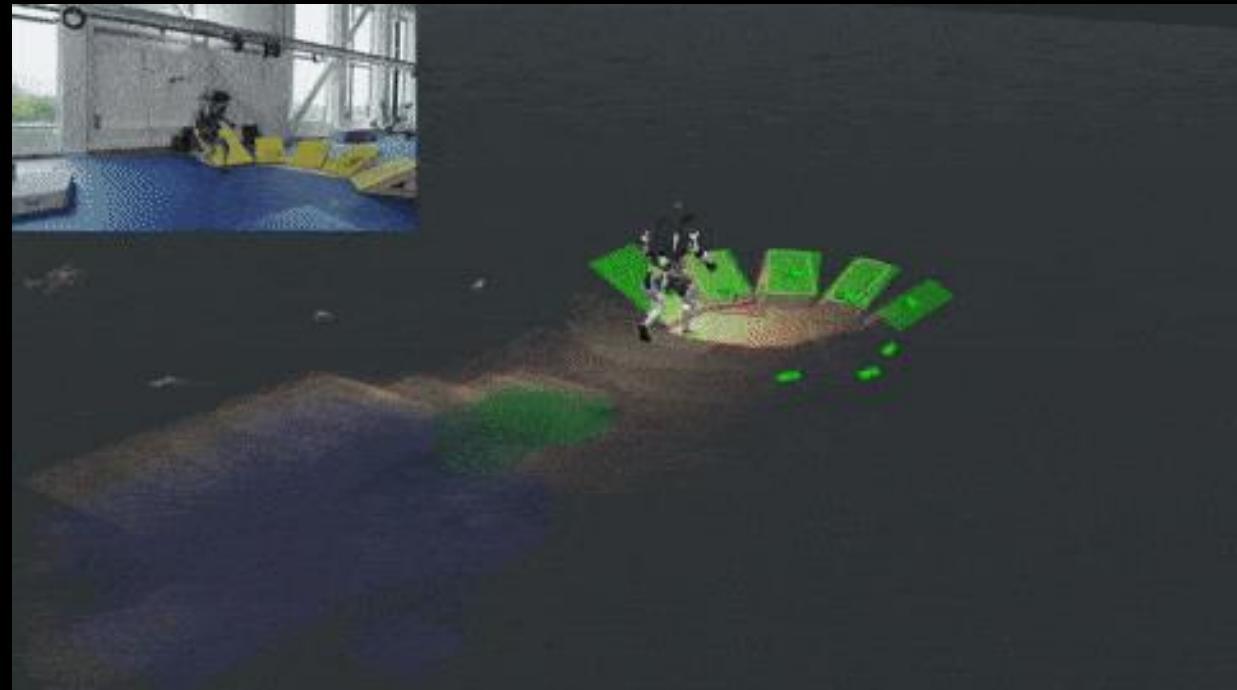
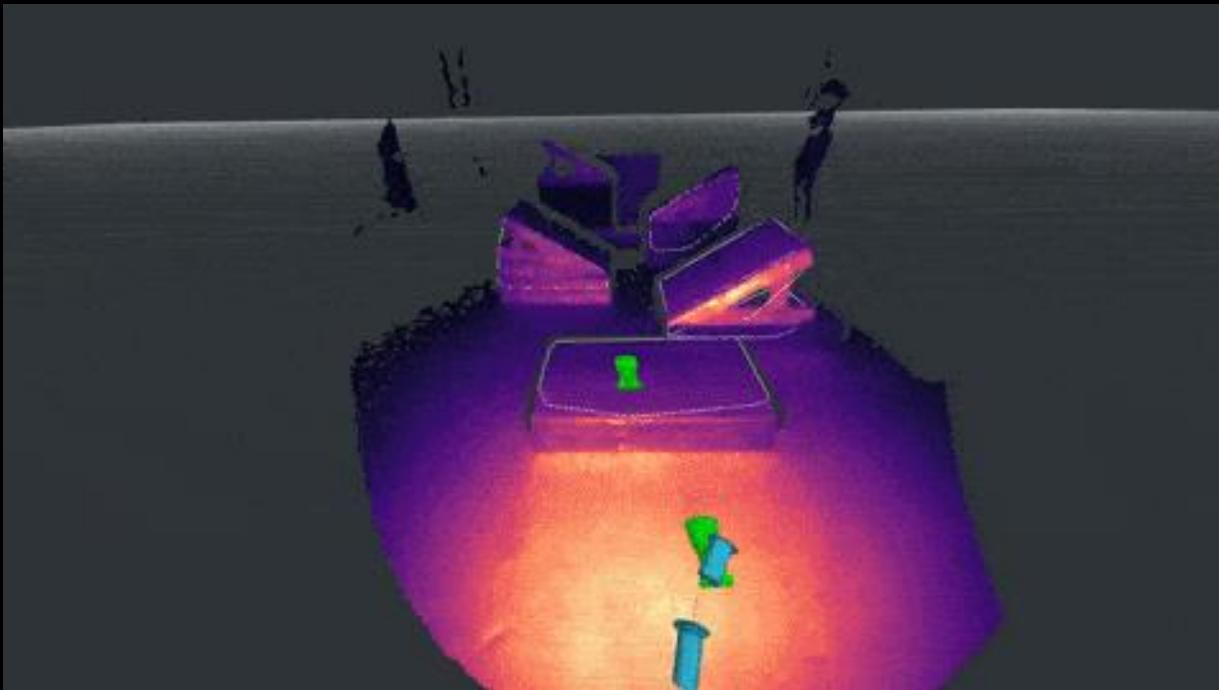
Planning with Fast Downward (<https://www.fast-downward.org>)
Rendering and simulation with PDDLGym (<https://github.com/tomsilver/pddlgym>)

Planning is Better: Motion Planning



<https://www.skydio.com/skydio-autonomy>

Planning is Better: Trajectory Optimization



<https://bostondynamics.com/blog/flipping-the-script-with-atlas/>

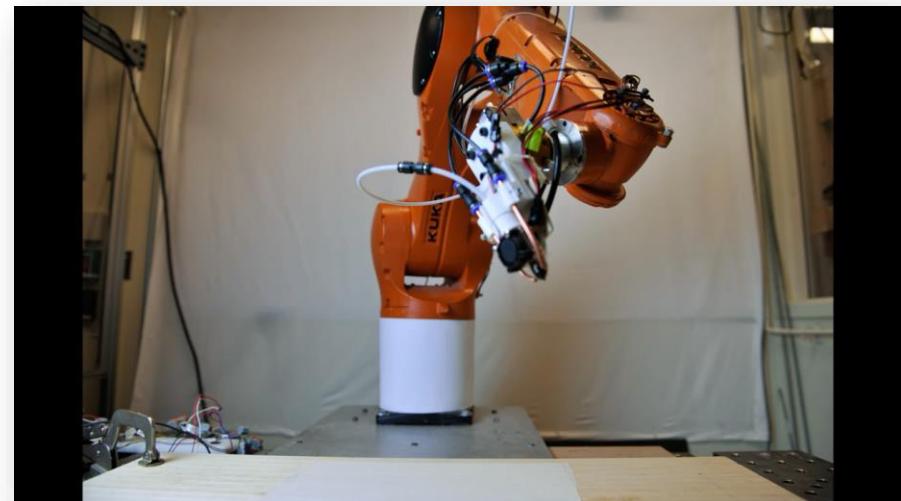
Planning is Better: Integrated TAMP

Setting a dinner table



(Srivastava et al. 2014)

3D printing



(Garrett et al. 2020)

"Integrated Task and Motion Planning." Caelan Reed Garrett, Rohan Chitnis, Rachel Holladay, Beomjoon Kim, Tom Silver, Leslie Pack Kaelbling, and Tomás Lozano-Pérez. ARCRAS 2021.

That was 1972

What's new?

Is planning better?

On one hand: yes, of course

On the other hand...

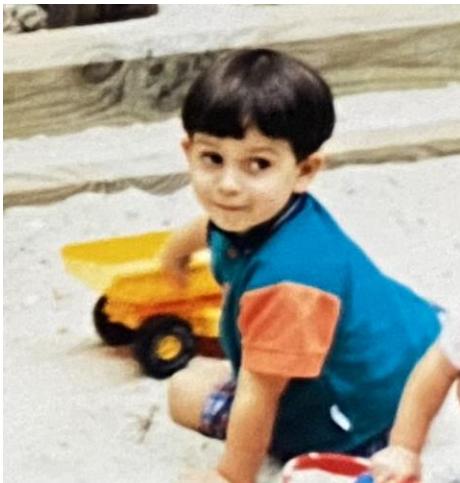
Our robots are still quite “Shakey”

Course thesis:

To create intelligent general-purpose robots, we need planning *and* learning, and they need each other.

About Me

Born and
raised in
Bergen
County, NJ



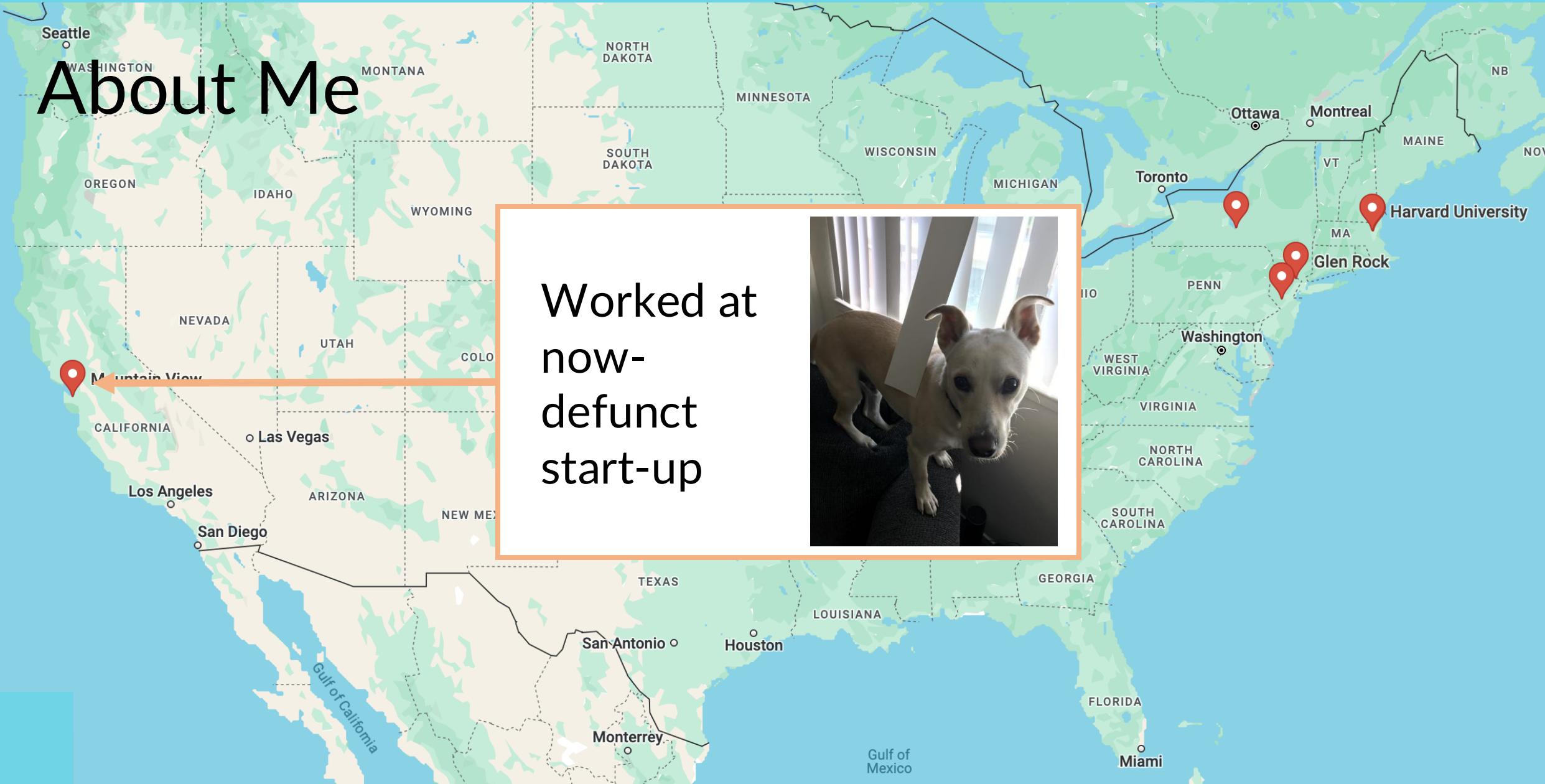
About Me

College at
Harvard



About Me

Worked at
now-
defunct
start-up



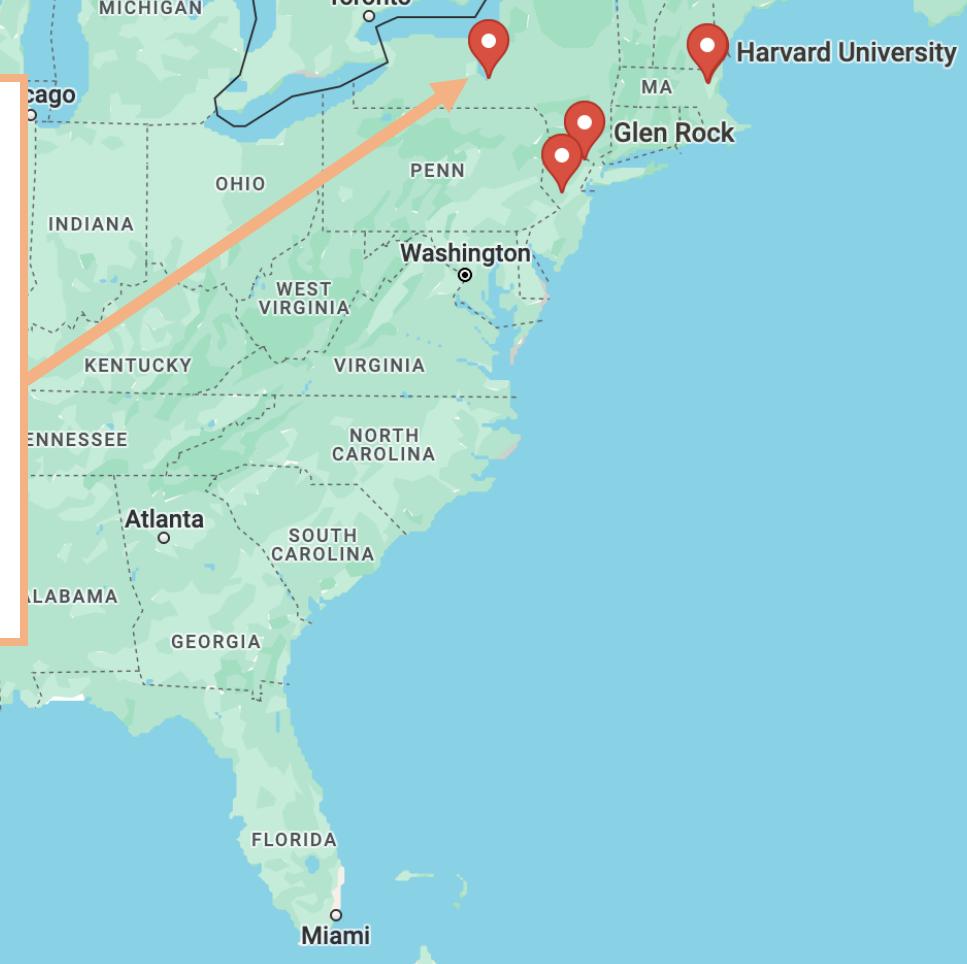
About Me

Grad
school
at MIT



About Me

Postdoc
at Cornell



About Me

Started at
Princeton
Fall 2025





Hey Spot, put
away the tools!

BostonDynamics

35

113

robot chefs, robot lab assistants, robot house cleaners, robot beekeepers, robot toileting assistants, robot tailors, robot grocery unpackers, robot dog walkers, robot dog companions, robot bathing assistants, robot search and rescue dogs, robot traffic controllers, robot social companions, robot snowplows, robot gardeners, robot baristas, robot beach cleaners, robot construction workers, robot dressing assistants, robot forest rangers, robot personal hygiene assistants, robot barbers, robot house movers, robot personal shoppers, robot home security guards, robot appliance fixers, robot firefighters, robot medication monitors, robot recycling sorters, robot surgical tool managers, robot memory assistants, robot berry pickers, robot locksmiths...



Robot Factory



Deployment 1



Deployment 2



Deployment 3



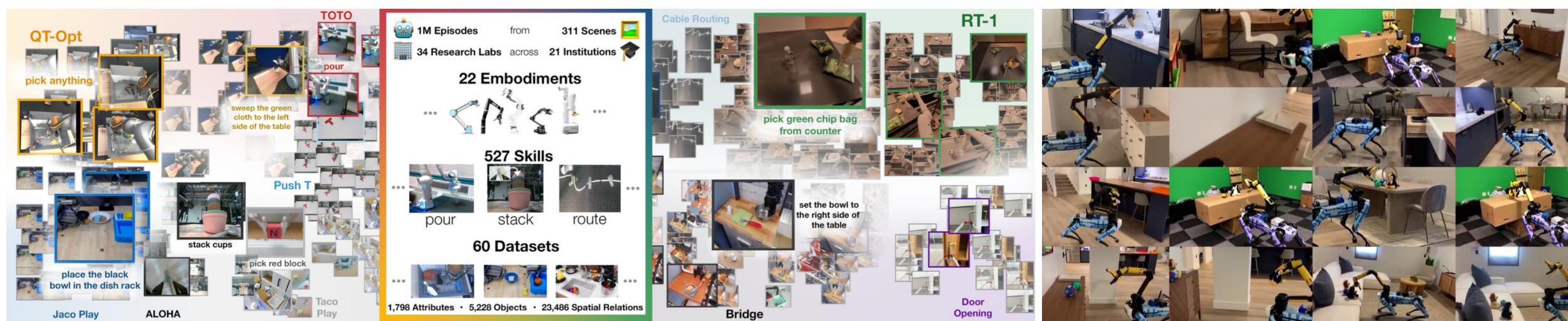
Deployment 4

...



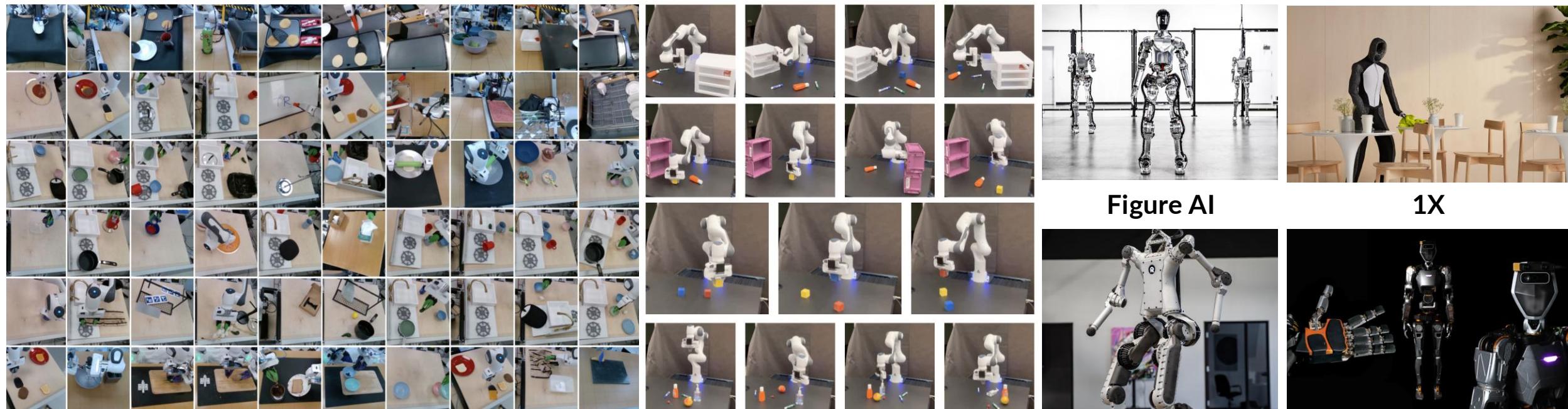
Robot Factory

**Robots that are good in general
General-purpose programming
Pretraining foundation models**



Google (RT-X, Open X-Eembodiment)

Meta (Ego 4D, Adaptive Skill Coordination)



Toyota Research Institute (Diffusion Policies)

NVIDIA (RVT)

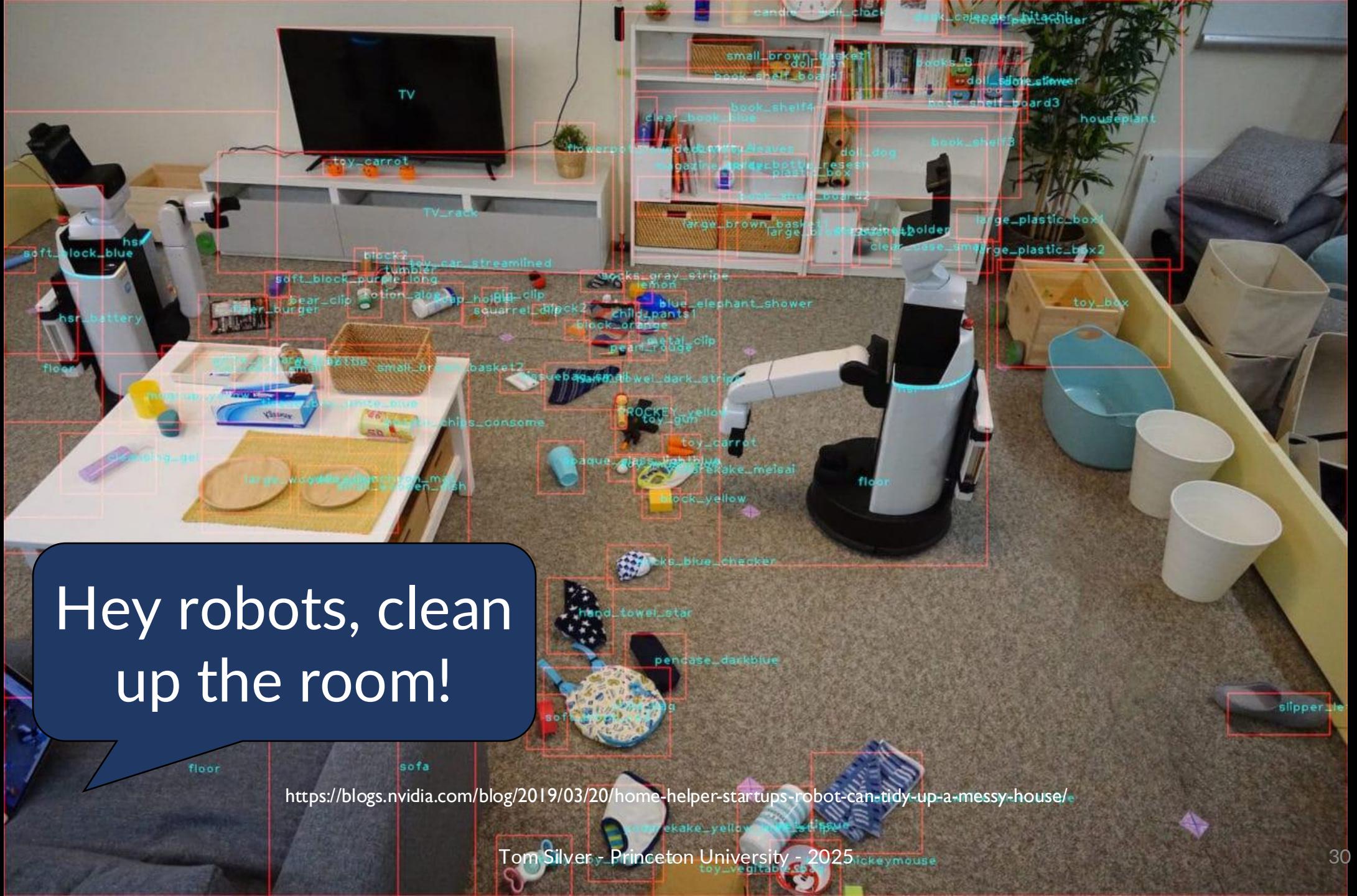
Apptronik

Sanctuary AI



Deployment

Robots that become **domain experts**
Learning to specialize
Planning & reasoning in the moment



Hey robots, clean
up the room!

<https://blogs.nvidia.com/blog/2019/03/20/home-helper-startups-robot-can-tidy-up-a-messy-house/>

Deployed Robots Must be Efficient and Effective

- ⌚ **Time efficient:** no philosopher robots
- 📊 **Data efficient:** learn a lot from a little
- 👤 🏫 **Human efficient:** our time is valuable
- ✓ **Effective:** solve hard tasks

AI Planning (Task and Motion Planning)

-  **Time efficient:** no philosopher robots
 - Slow in large problems
-  **Data efficient:** learn a lot from a little
 - No learning
-  **Human efficient:** our time is valuable
 - Need domain-specific models
-  **Effective:** solve hard tasks
 - Powerful solvers



(Srivastava et al. 2014)

(Model-Free) Reinforcement Learning

- ⌚ **Time efficient:** no philosopher robots

Fast to evaluate policy

- 📊 **Data efficient:** learn a lot from a little

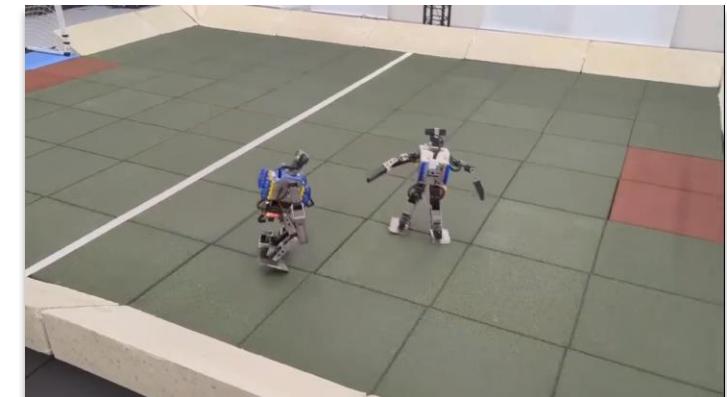
Notoriously data-hungry

- 👤 🏫 **Human efficient:** our time is valuable

Generally applicable

- ✓ **Effective:** solve hard tasks

Narrow, short horizon



(OP3 Soccer Team, DeepMind, 2023)

Planning with Large Language Models

- ⌚ **Time efficient:** no philosopher robots

Constant time

- 📊 **Data efficient:** learn a lot from a little

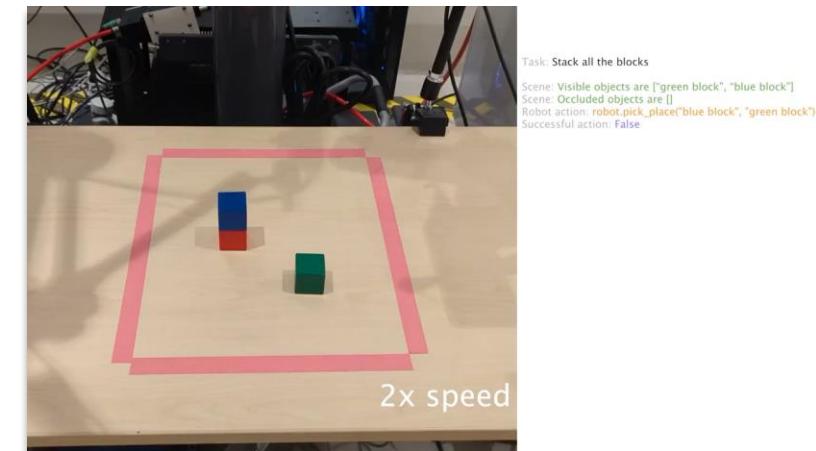
Few-shot prompting

- 👤 🏫 **Human efficient:** our time is valuable

Prompt engineering, validation

- ✓ **Effective:** solve hard tasks

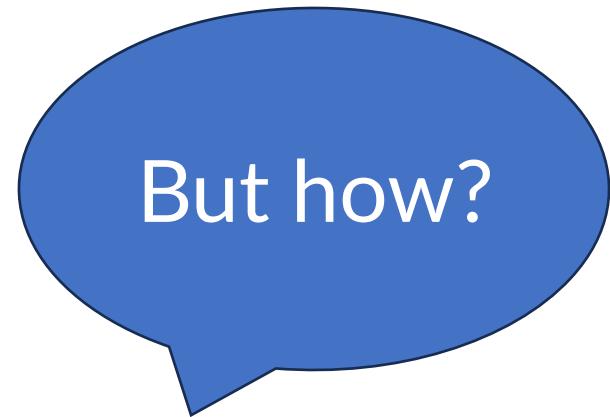
Emphasis on *hard*



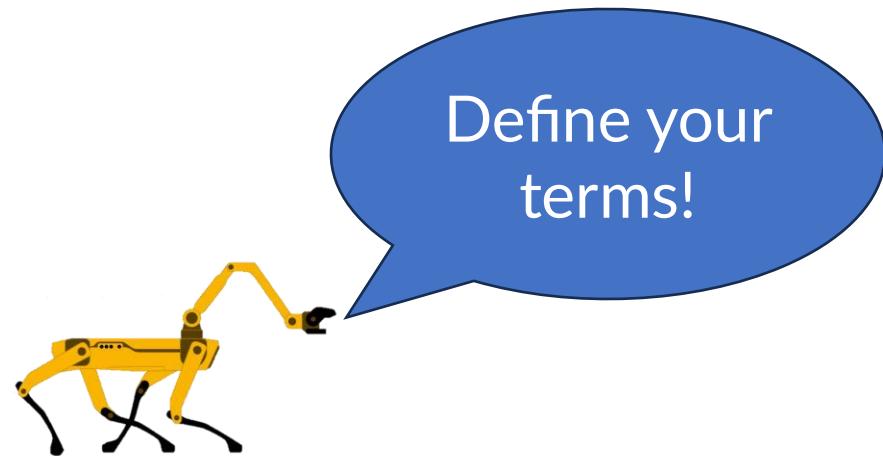
(Huang et al., 2023)

This Course: Learning + Planning

-  **Time efficient:** no philosopher robots
Learning to plan quickly
-  **Data efficient:** learn a lot from a little
Learning with structure
-  **Human efficient:** our time is valuable
Learning domain-specific models
-  **Effective:** solve hard tasks
Powerful solvers



Robot Planning Meets Machine Learning



Robot: [Definition]



Oh, I'm
a robot!



Robot: an agent that exists in our world and can sense, reason, and act.

Based on “The Robotics Primer” by Maja J Matarić (2007).



Planning: [Definition]



(SRI 1972)



(Srivastava et al. 2014)



(Boston Dynamics 2020)

Planning: explicit reasoning about future execution.

Based on “Robot Planning” by Drew McDermott (1992).



(SRI 1972)



(Srivastava et al. 2014)



(Boston Dynamics 2020)

Machine learning: [Definition]

NETFLIX

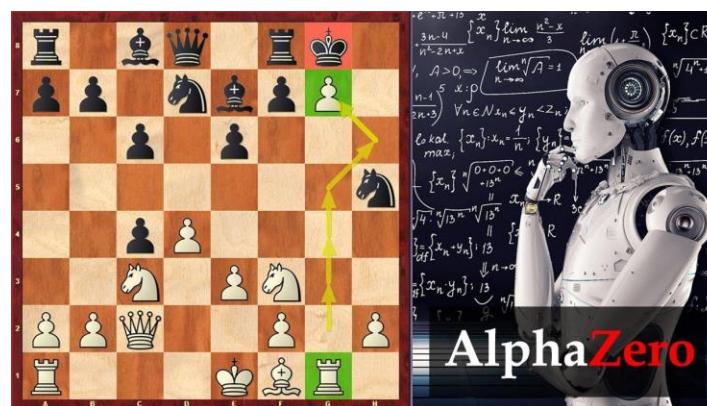
Netflix Prize

Home Rules Leaderboard Register Update Submit Download

Leaderboard

Display top 40 leaders.

Rank	Team Name	Best Score	% Improvement	Last Submit Time
-	No Grand Prize candidates yet	-	-	-
Grand Prize - RMSE <= 0.8563				
1	PragmaticTheory	0.8584	9.78	2009-06-16 01:04:47
2	Bellkor in BigChaos	0.8590	9.71	2009-05-13 08:14:09
3	Grand Prize Team	0.8593	9.68	2009-06-12 08:20:24
4	Deno	0.8604	0.68	2009-04-22 06:57:02

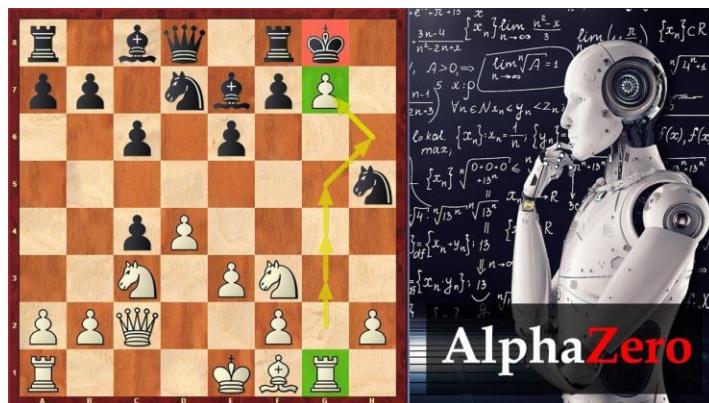


Machine learning: the automated detection of meaningful patterns in data.

Based on “Understanding Machine Learning” by Shai Shalev-Shwartz and Shai Ben-David (2014).

The screenshot shows the Netflix Prize Leaderboard page. At the top, it says "NETFLIX" and "Netflix Prize". Below that is a navigation bar with links: Home, Rules, Leaderboard, Register, Update, Submit, and Download. A yellow banner below the navigation bar says "Leaderboard". Underneath is a table titled "Leaderboard" with columns: Rank, Team Name, Best Score, % Improvement, and Last Submit Time. The table shows the top four teams:

Rank	Team Name	Best Score	% Improvement	Last Submit Time
1	PragmaticTheory	0.8584	9.78	2009-06-16 01:04:47
2	Bellkor in BigChaos	0.8590	9.71	2009-05-13 08:14:09
3	Grand Prize Team	0.8593	9.68	2009-06-12 08:20:24
4	Deno	0.8604	0.68	2009-04-22 06:57:02



Key Questions for the Course

What learning and planning should happen in the *factory* vs. *wild*?



Robot Factory

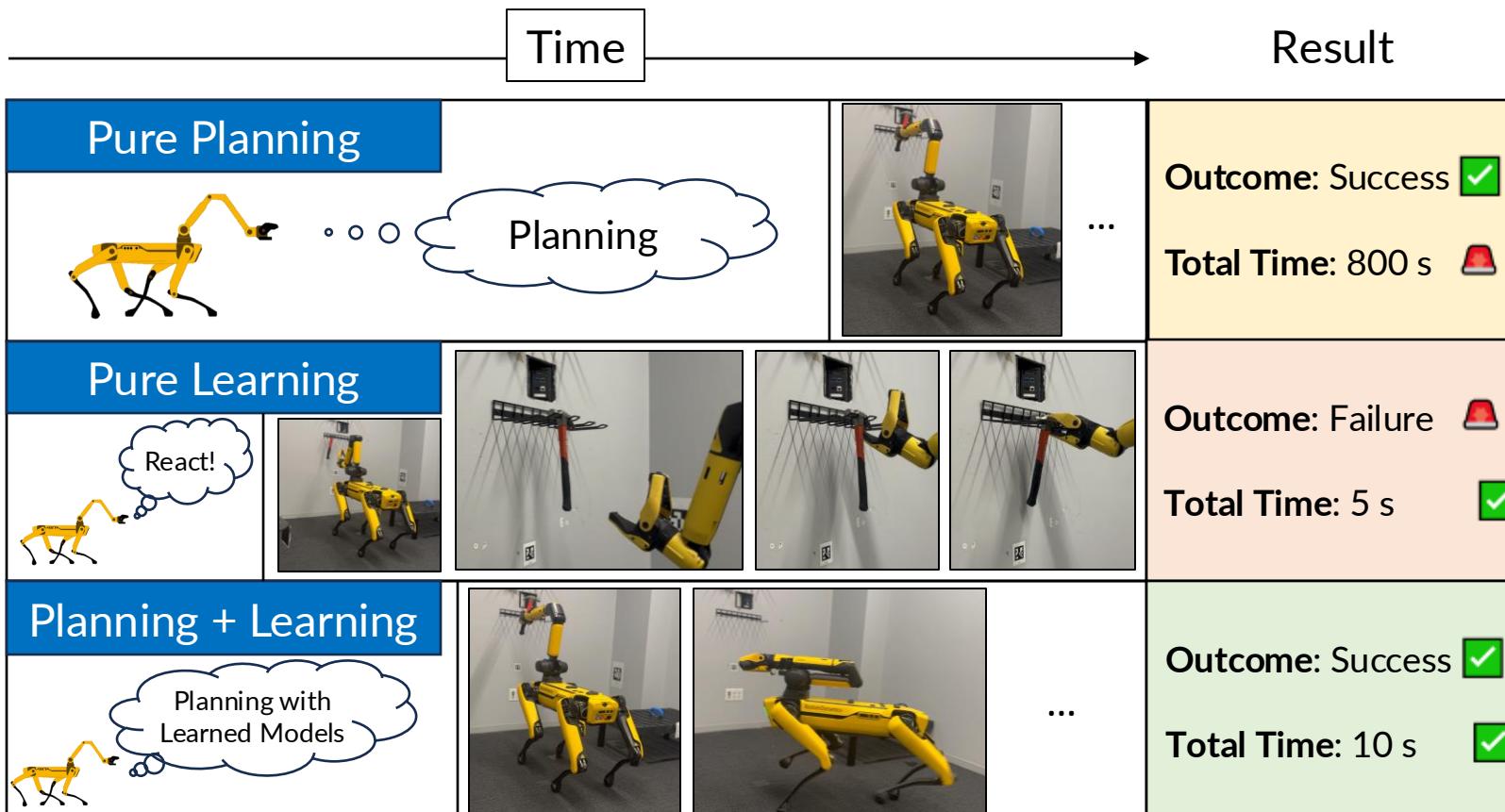


Deployment

Key Questions for the Course

Where on the learning-planning spectrum should robots be?

A Human Gives the Robot a Task



Bring me the hammer!

Key Questions for the Course

How should we taxonomize learning-for-planning methods?

Supervised learning

Unsupervised learning

Online learning

Offline learning

Analytic learning

Synthetic learning

Eureka learning

Planning through practice

...

Key Questions for the Course

What objectives should we use to train and evaluate?

-  **Time efficiency:** wall-clock time
 -  **Data efficient:** number of samples
 -  **Human efficient:** number of queries
 -  **Effective:** task objective complete
- ...

Key Questions for the Course

**To what extent are learning and planning
necessary for general-purpose robotics?**

Course Logistics

Course Structure

Part 1: Pure Planning

Lectures by me

Problem sets

Part 2: Planning + Learning

Paper presentations by you

Final projects

<u>Total Output</u>	
4 problem sets	20%
1 paper presentation	15%
Paper reviews	15%
1 final project	40%
In-class participation	10%

Course Website:

<https://rpmmml.github.io/>

All materials will be posted on this website

All announcements will be through Piazza

All submissions will be through GradeScope

Calendar

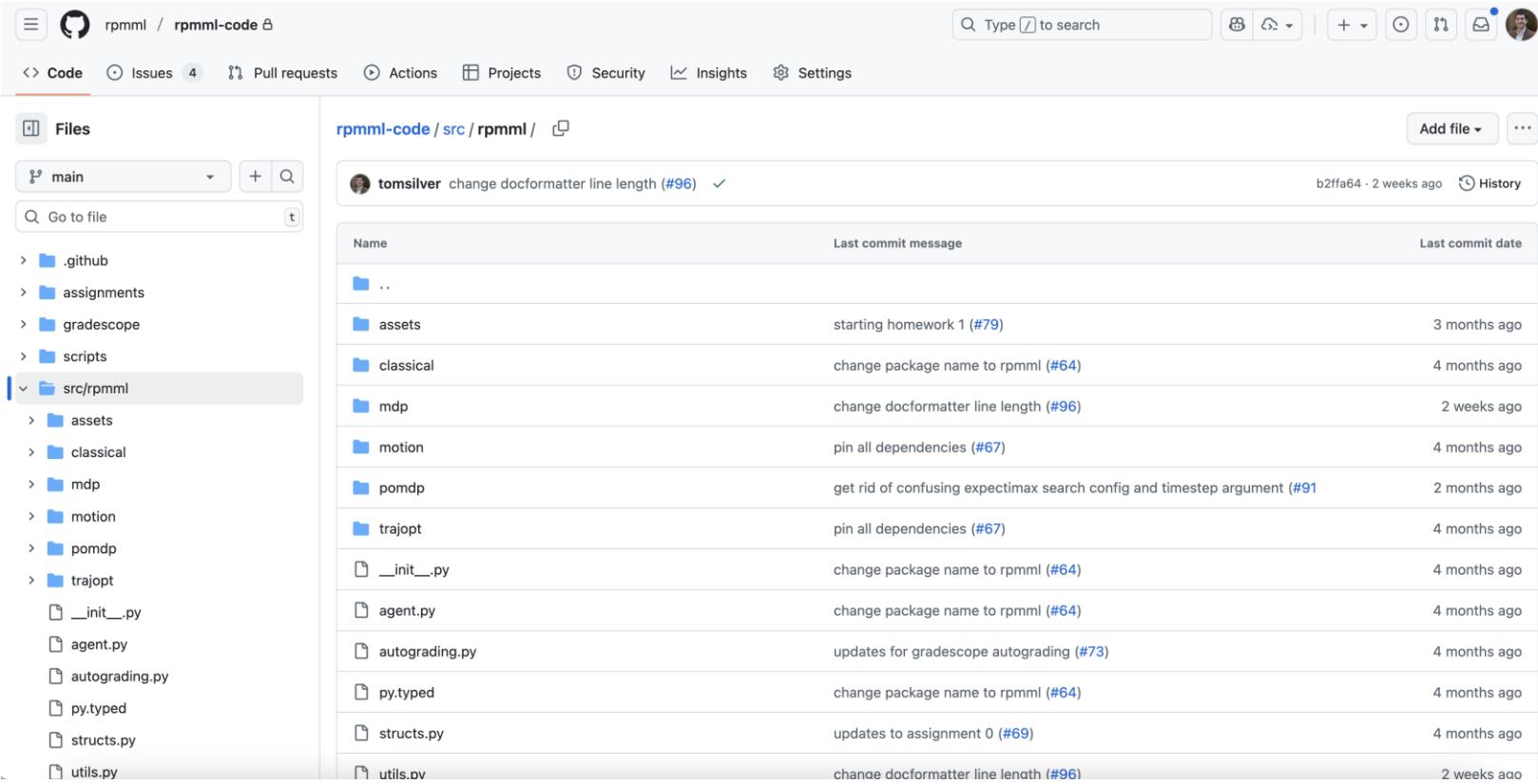
Subject to change.

Planning Foundations

Sep 2:	LECTURE	Intro	Slides
Sep 4:	LECTURE	Offline Planning in MDPs	Slides
Sep 8:	HW	HW0 Due	HW0
Sep 9:	LECTURE	Online Planning in MDPs	Slides
Sep 11:	LECTURE	Monte Carlo Methods	Slides
Sep 15:	HW	HW1 Due	HW1
Sep 16:	LECTURE	Partial Observability	Slides
Sep 18:	LECTURE	Planning and RL	Slides
Sep 22:	HW	HW2 Due	HW2
Sep 23:	LECTURE	Planning in Factored Spaces	Slides
Sep 25:	LECTURE	Motion Planning	Slides
Sep 29:	HW	HW3 Due	HW3
Sep 30:	LECTURE	Trajectory Optimization	Slides
Oct 2:	LECTURE	Hierarchy and Abstraction	Slides
Oct 6:	PROJECT	Final Project Proposal Due	Guidelines
Oct 7:	LECTURE	Guest Lecture (TBD)	Slides

HW0 due soon!

Course Code Repository



The screenshot shows a GitHub repository interface for the project `rpmmml / rpmmml-code`. The main navigation bar includes links for Code, Issues (4), Pull requests, Actions, Projects, Security, Insights, and Settings. The search bar at the top right contains the placeholder "Type to search". Below the navigation, there are icons for creating a new file, adding a file, and more.

The left sidebar displays the repository's file structure under the `rpmmml-code / src / rpmmml /` path. The `src/rpmmml` folder is currently selected. The files listed include `__init__.py`, `agent.py`, `autograding.py`, `py.typed`, `structs.py`, `utils.py`, `assets`, `classical`, `mdp`, `motion`, `pomdp`, `trajopt`, and `utils.pv`.

The right side of the interface shows a detailed list of commits for the `src/rpmmml` directory. The commits are ordered by date, with the most recent at the top:

Name	Last commit message	Last commit date
..		
assets	starting homework 1 (#79)	3 months ago
classical	change package name to rpmmml (#64)	4 months ago
mdp	change docformatter line length (#96)	2 weeks ago
motion	pin all dependencies (#67)	4 months ago
pomdp	get rid of confusing expectimax search config and timestep argument (#91)	2 months ago
trajopt	pin all dependencies (#67)	4 months ago
__init__.py	change package name to rpmmml (#64)	4 months ago
agent.py	change package name to rpmmml (#64)	4 months ago
autograding.py	updates for gradescopes autograding (#73)	4 months ago
py.typed	change package name to rpmmml (#64)	4 months ago
structs.py	updates to assignment 0 (#69)	4 months ago
utils.pv	change docformatter line length (#96)	2 weeks ago

Used for homework and (optionally) final projects



TA:
Alessio Amaolo

Email:
alessioamaolo@princeton.edu

Everything is New!



**Thank You For
Your Patience**

A large, stylized text message in red, bubbly font. The words "Thank You For" are on top, and "Your Patience" is on the bottom. The text is set against a yellow circular background.

With Remaining Class Time:

https://rpmmml.github.io/homework_instructions/

And sign up for Piazza & GradeScope