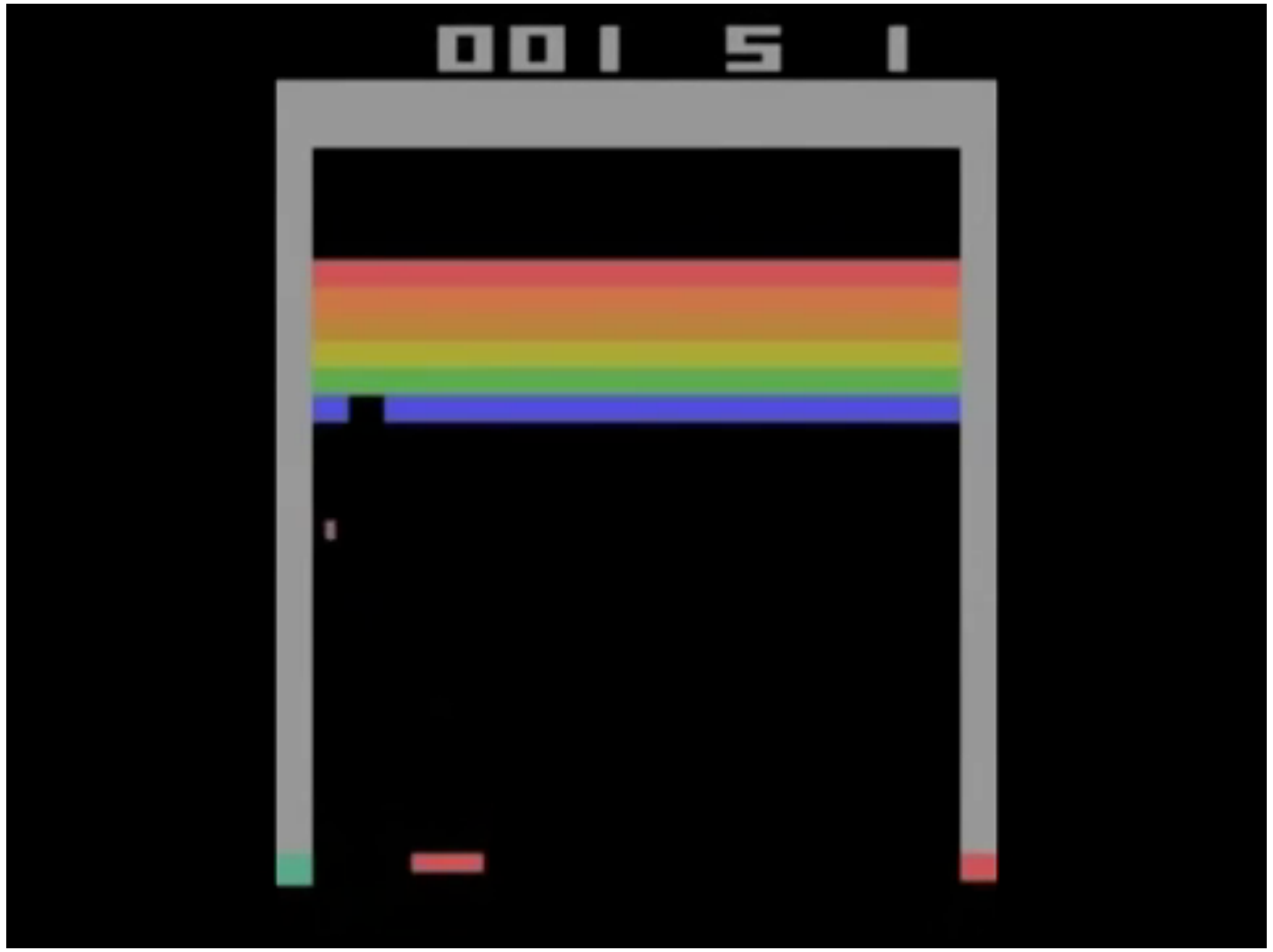
Advanced Model Learning

October 2, 2017

Chelsea Finn

Previously: DQN with images



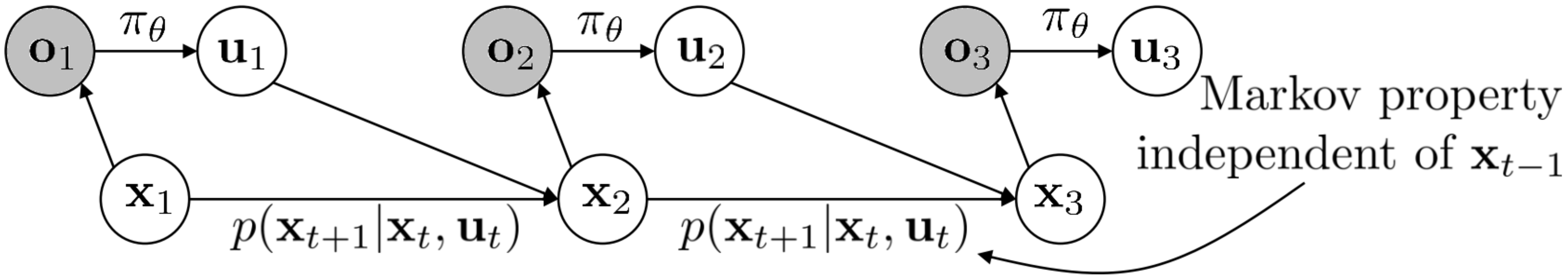
This lecture: Can we use model-based methods with images?

Recap: Model-based RL

model-based reinforcement learning version 1.0:

1. run base policy $\pi_0(\mathbf{u}_t|\mathbf{x}_t)$ (e.g., random policy) to collect $\mathcal{D} = \{(\mathbf{x}, \mathbf{u}, \mathbf{x}')_i\}$
2. learn dynamics model $f(\mathbf{x}, \mathbf{u})$ to minimize $\sum_i \|f(\mathbf{x}_i, \mathbf{u}_i) - \mathbf{x}'_i\|^2$
3. backpropagate through $f(\mathbf{x}, \mathbf{u})$ to choose actions (e.g. using iLQR)
4. execute those actions and add the resulting data $\{(\mathbf{x}, \mathbf{u}, \mathbf{x}')_j\}$ to $\mathcal{D}$

What about POMDPs?



Outline

1. Models in latent space
2. Models directly in image space
3. Inverse models
4. Predict alternative quantities

Note: This is an active area of research.

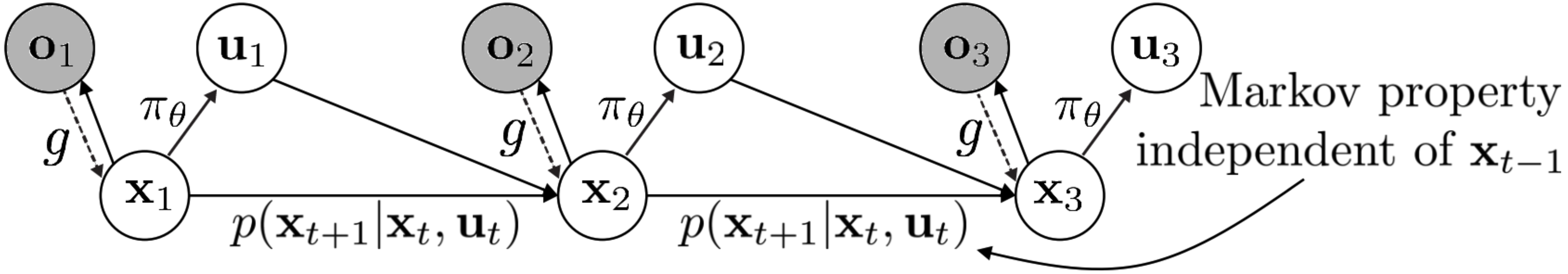
Outline

1. **Models in latent space**
2. Models directly in image space
3. Inverse models
4. Predict alternative quantities

Learning in Latent Space

Key idea: learn embedding $g(\mathbf{o}_t)$, then learn in latent space

(model-based or model-free)



What do we want g to be?

It depends on the method — we'll see.

Learning in Latent Space

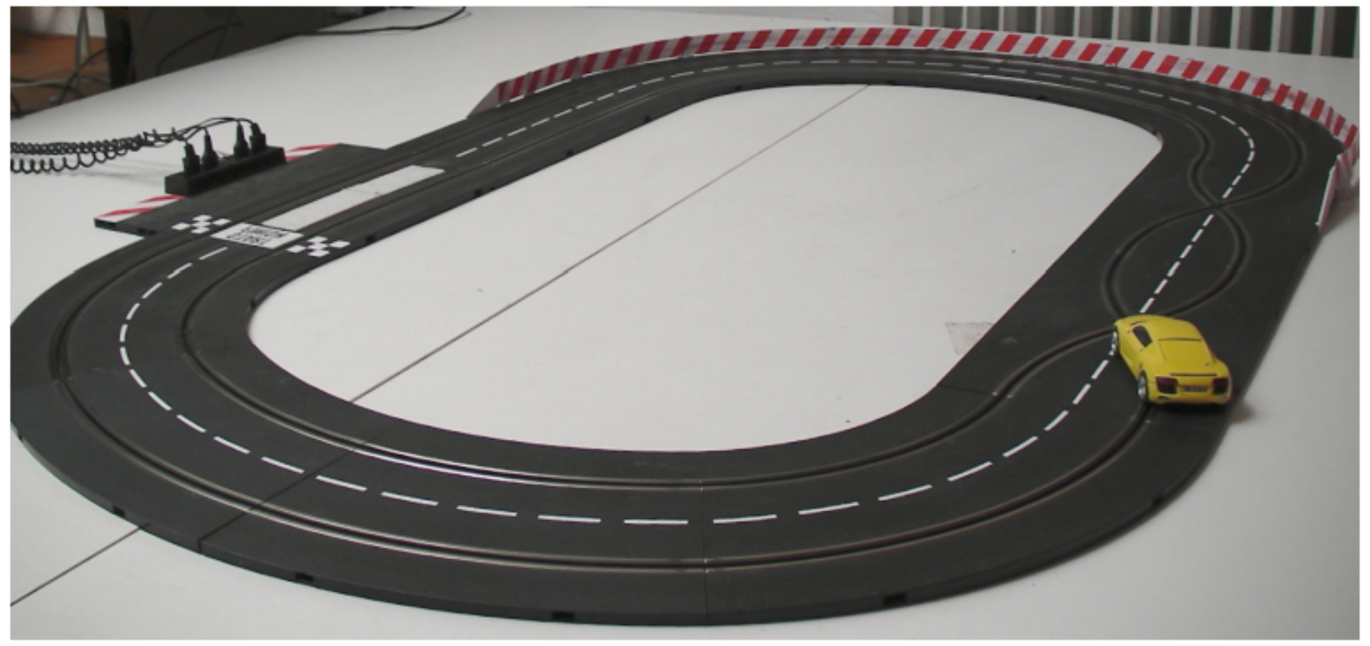
Key idea: learn embedding $g(\mathbf{o}_t) = \mathbf{x}_t$, then learn in latent space

(model-based or **model-free**)

Autonomous reinforcement learning on raw visual input data in a real world application

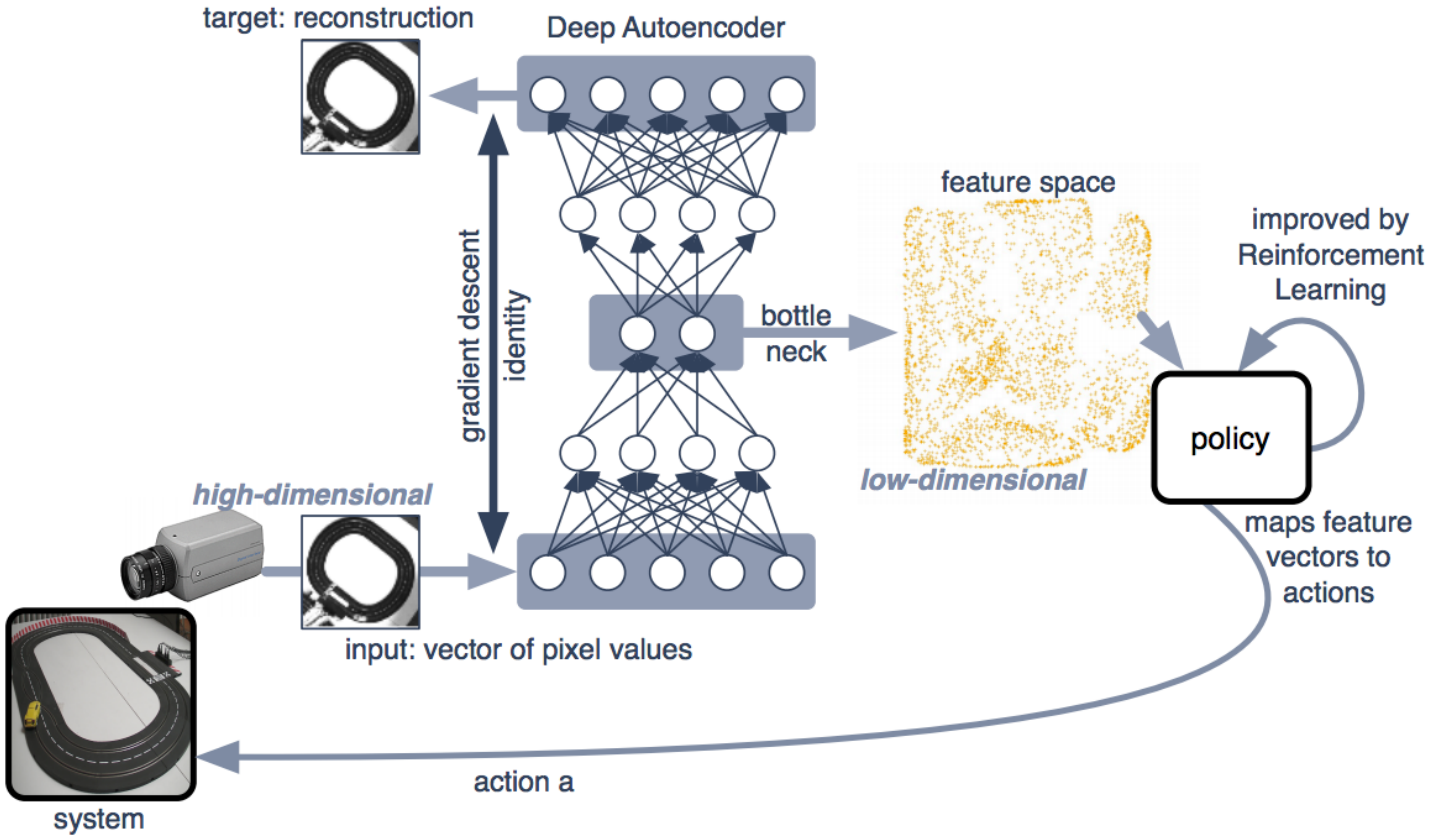
Sascha Lange, Martin Riedmiller
Department of Computer Science
Albert-Ludwigs-Universität Freiburg

Arne Voigtländer
Shoogee GmbH & Co. KG
Krögerweg 16a



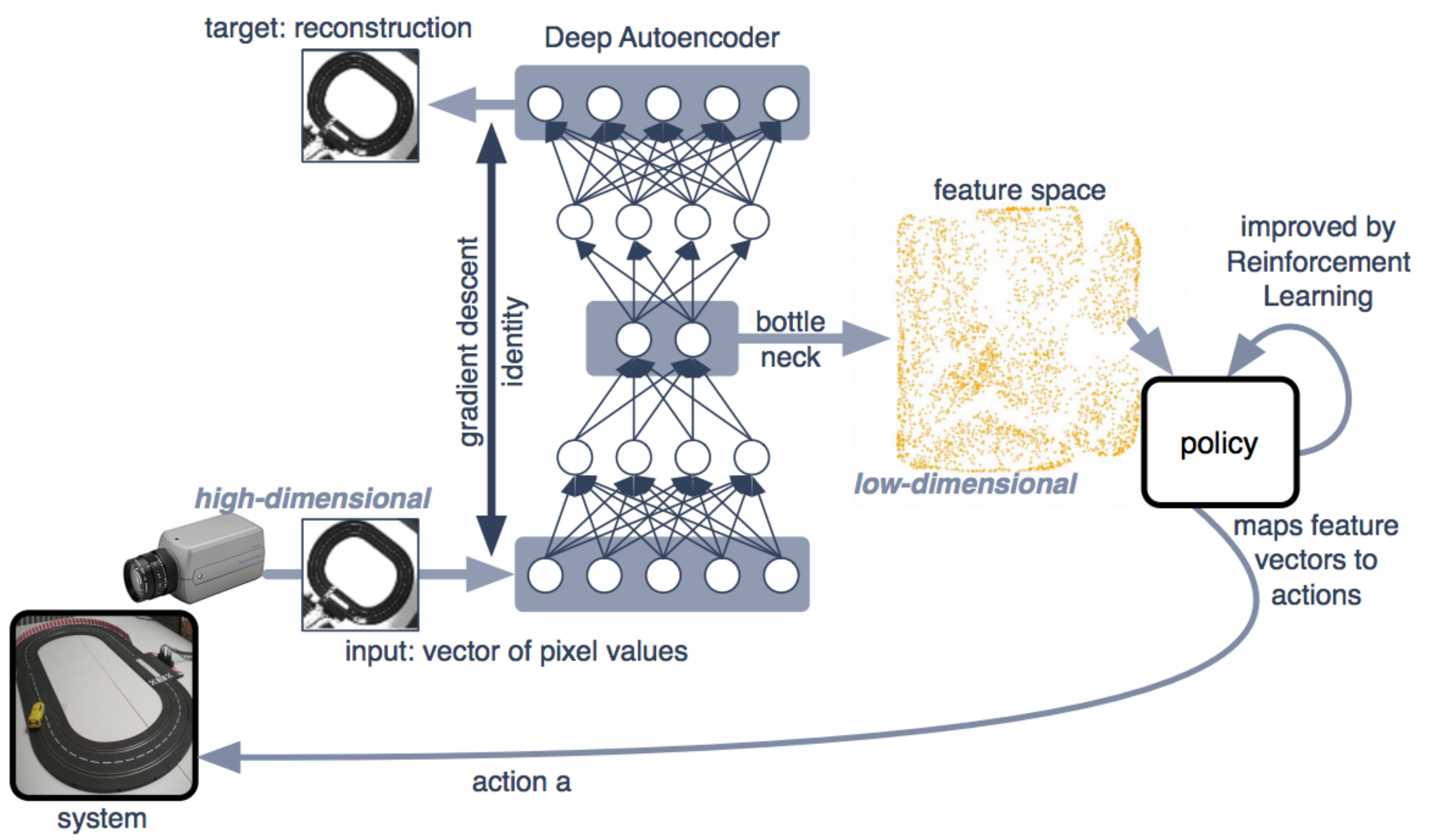
controlling a slot-car

1. collect data with exploratory policy
2. learn **low-dimensional** embedding of image (how?)
3. run q-learning with function approximation with embedding



embedding is **low-dimensional** and summarizes the image

1. collect data with exploratory policy
2. learn **low-dimensional** embedding of image (how?)
3. run q-learning with function approximation with embedding



Pros:

+ Learn visual skill very efficiently

Cons:

- Autoencoder might not recover the right representation
- Not necessarily suitable for model-based methods

Learning in Latent Space

Key idea: learn embedding $g(\mathbf{o}_t) = \mathbf{x}_t$, then learn in latent space

(**model-based** or model-free)

Deep Spatial Autoencoders for Visuomotor Learning

Chelsea Finn, Xin Yu Tan, Yan Duan, Trevor Darrell, Sergey Levine, Pieter Abbeel

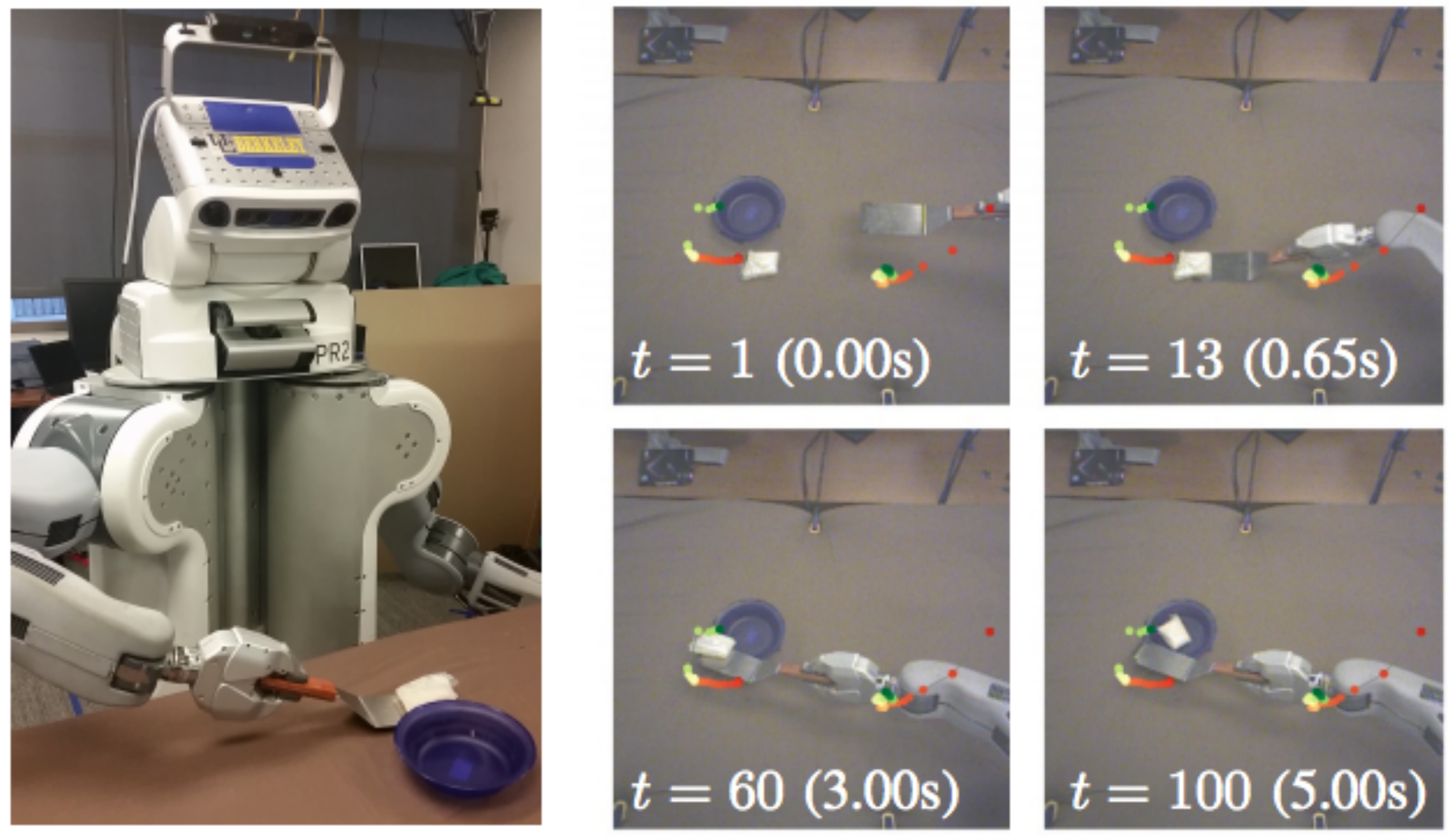
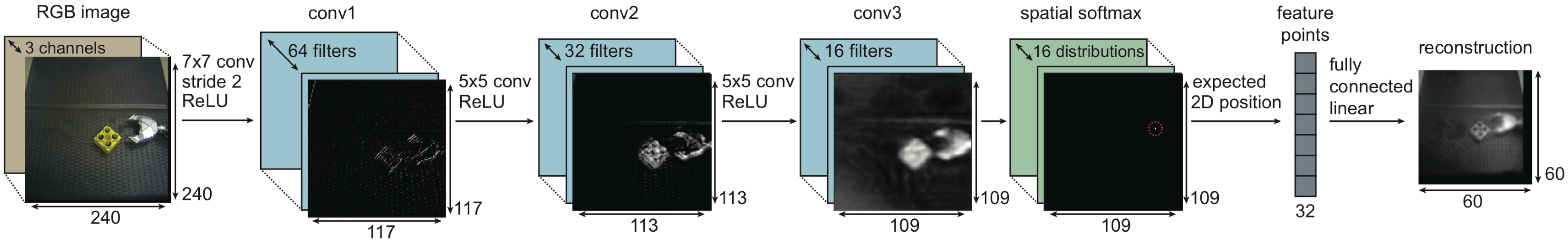
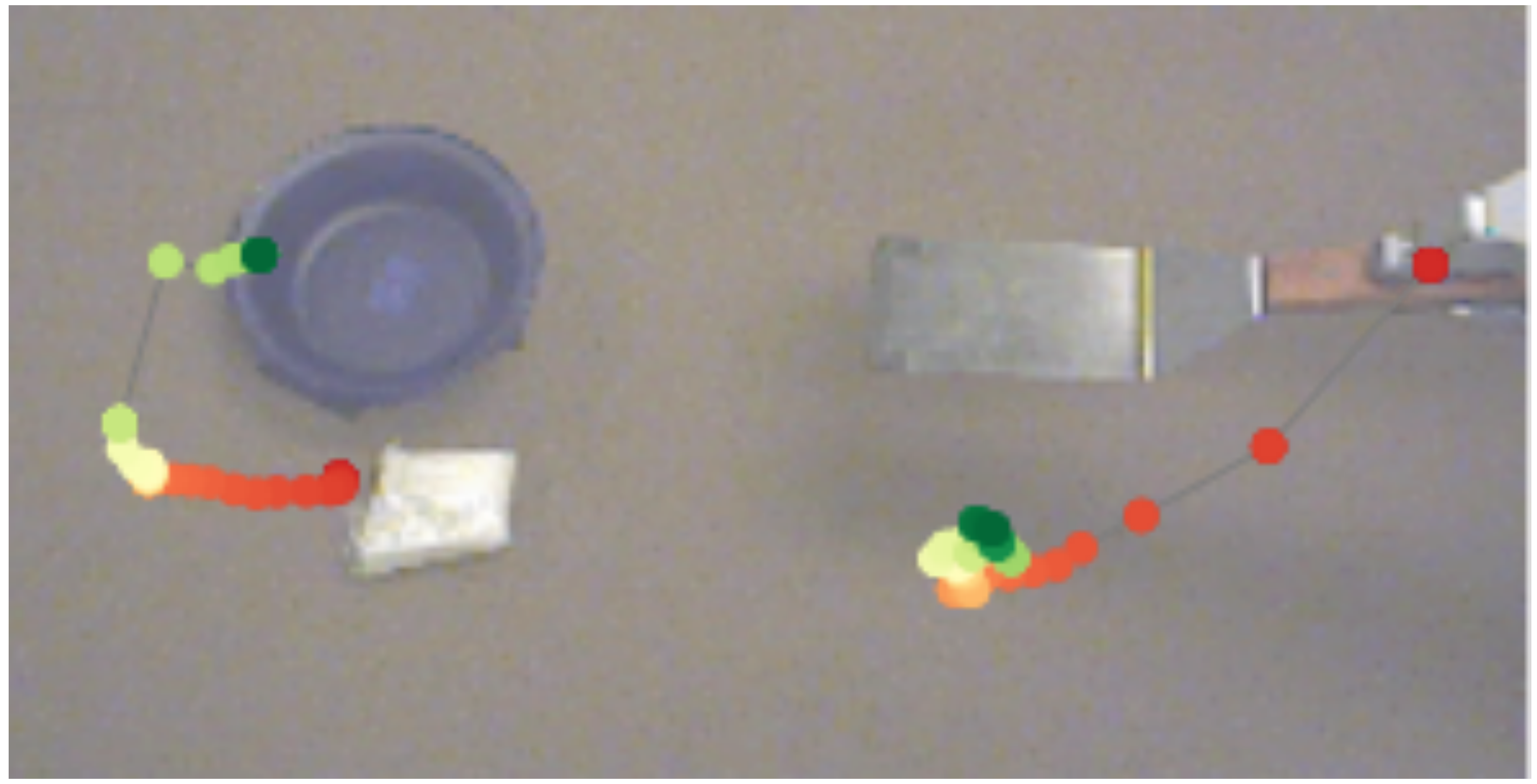


Fig. 1: PR2 learning to scoop a bag of rice into a bowl with a spatula (left) using a learned visual state representation (right).

1. collect data with exploratory policy
2. learn **smooth, structured** embedding of image
3. learn local-linear model with embedding
4. run iLQG to learn to reach image of goal & goal gripper pose

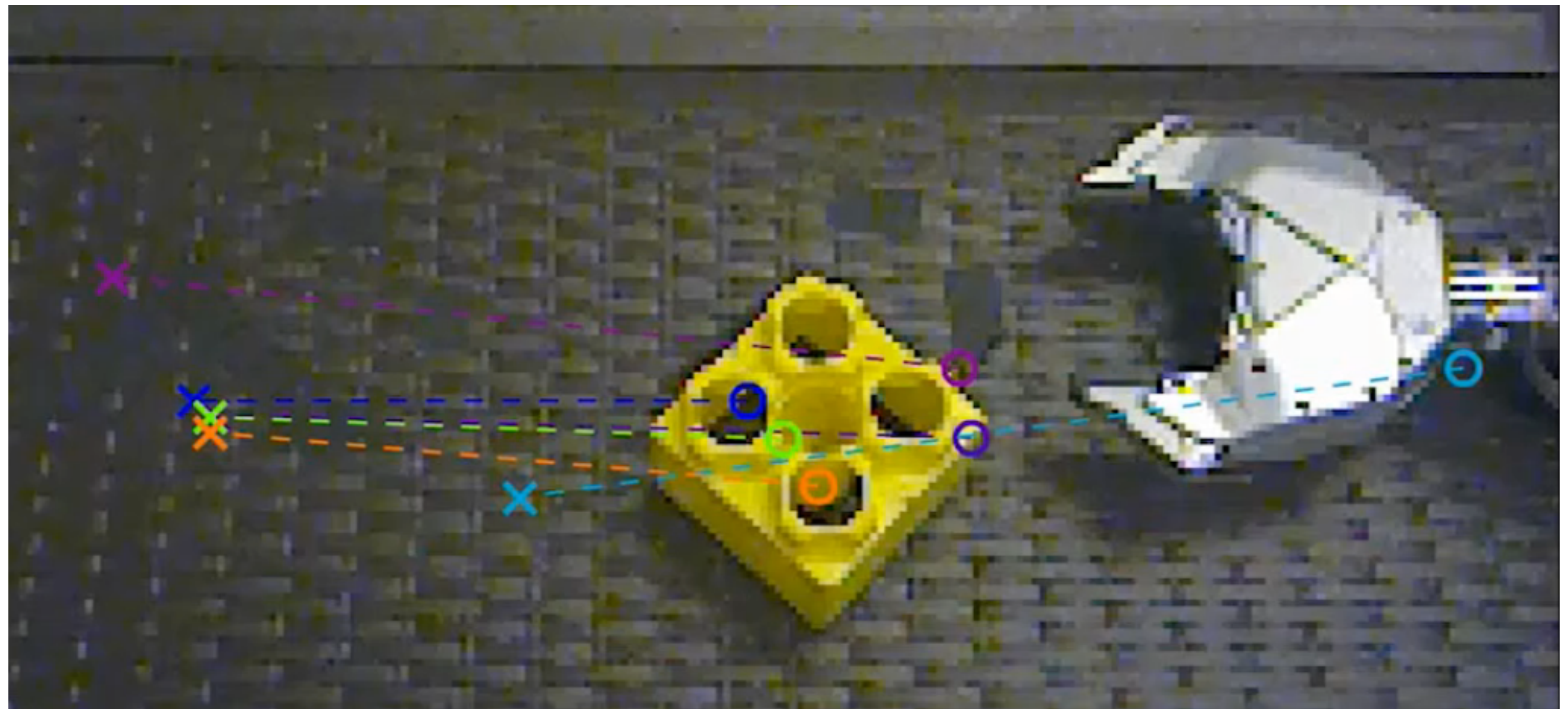


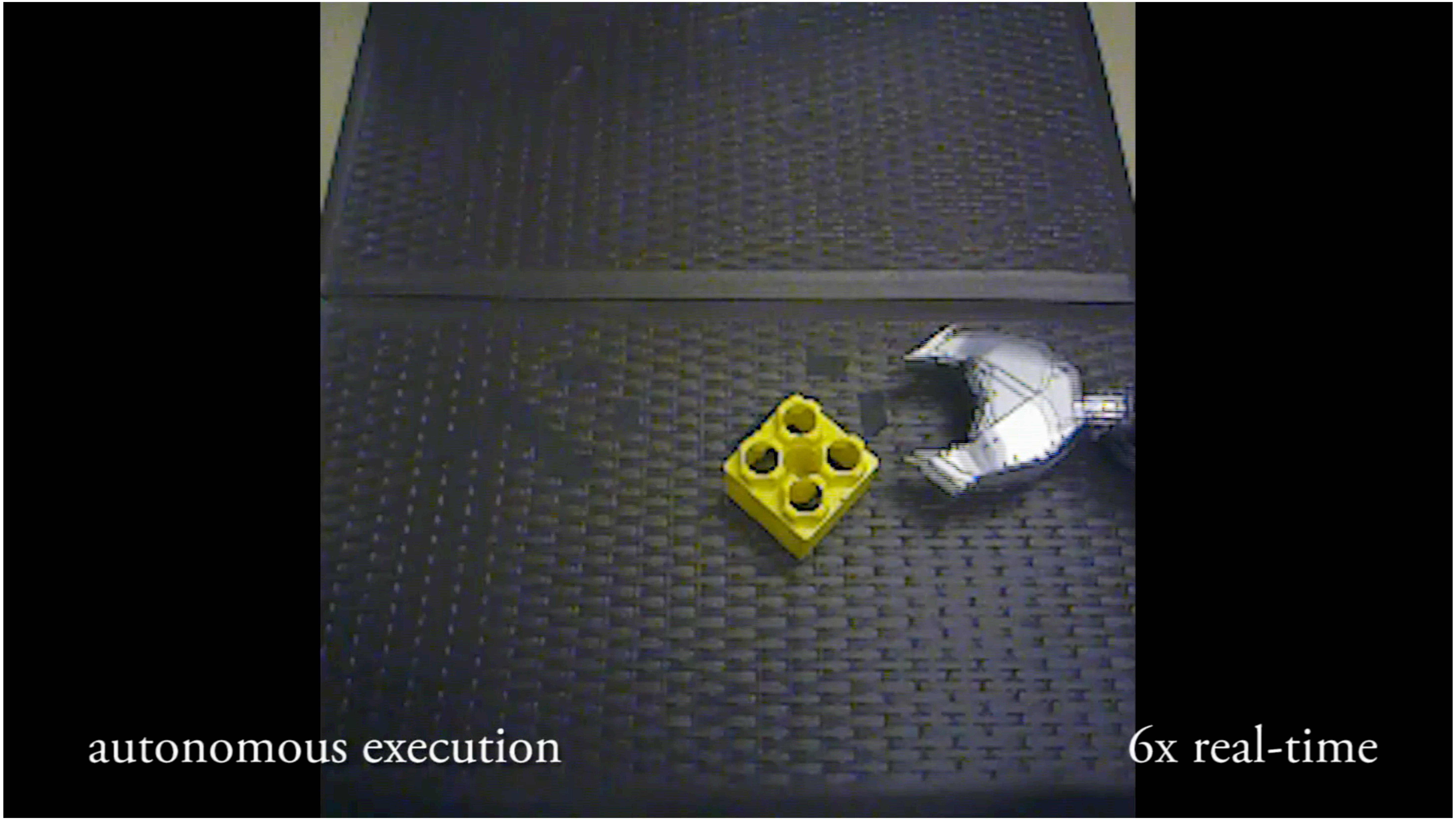


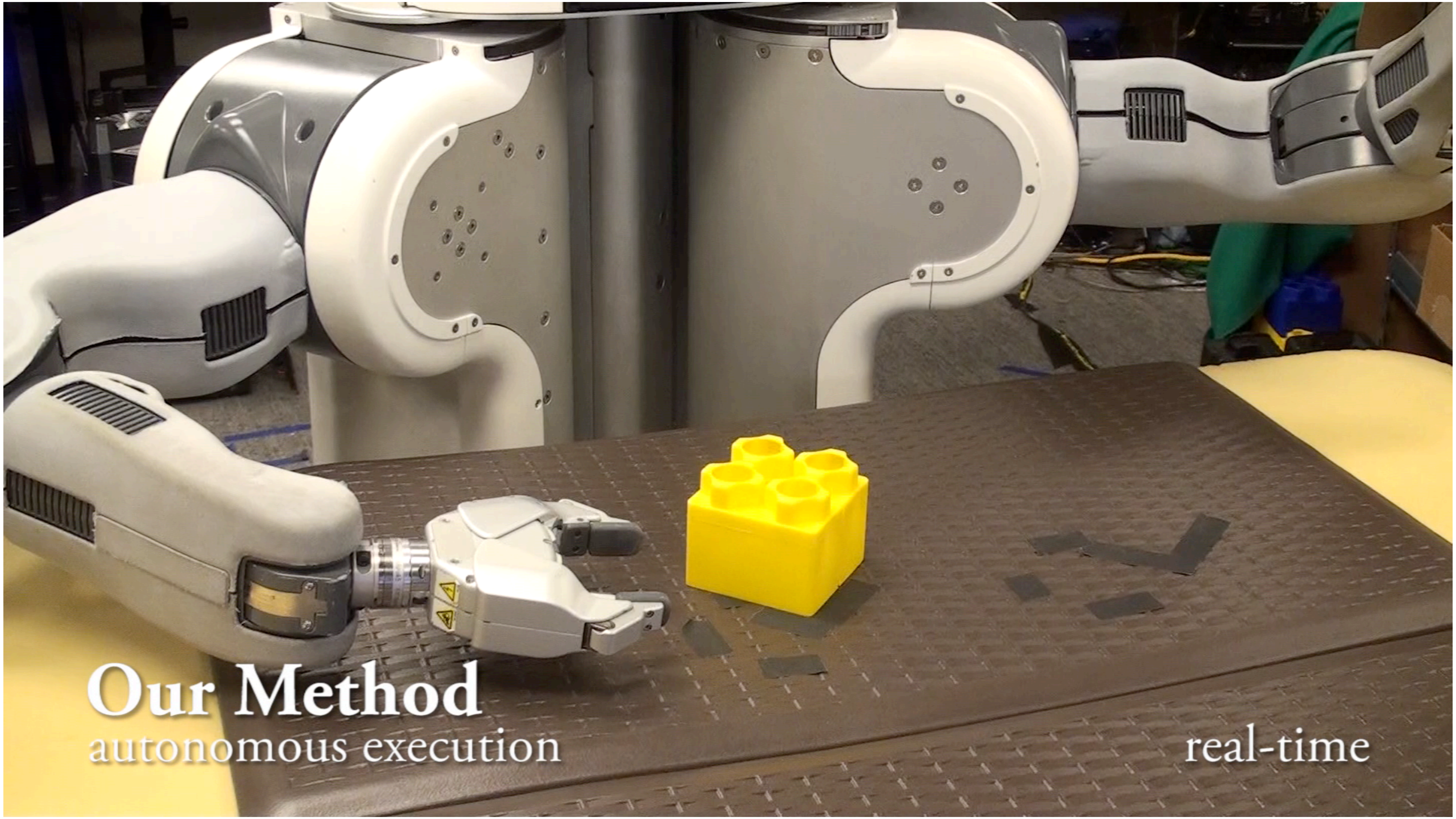
embedding is **smooth and structured**

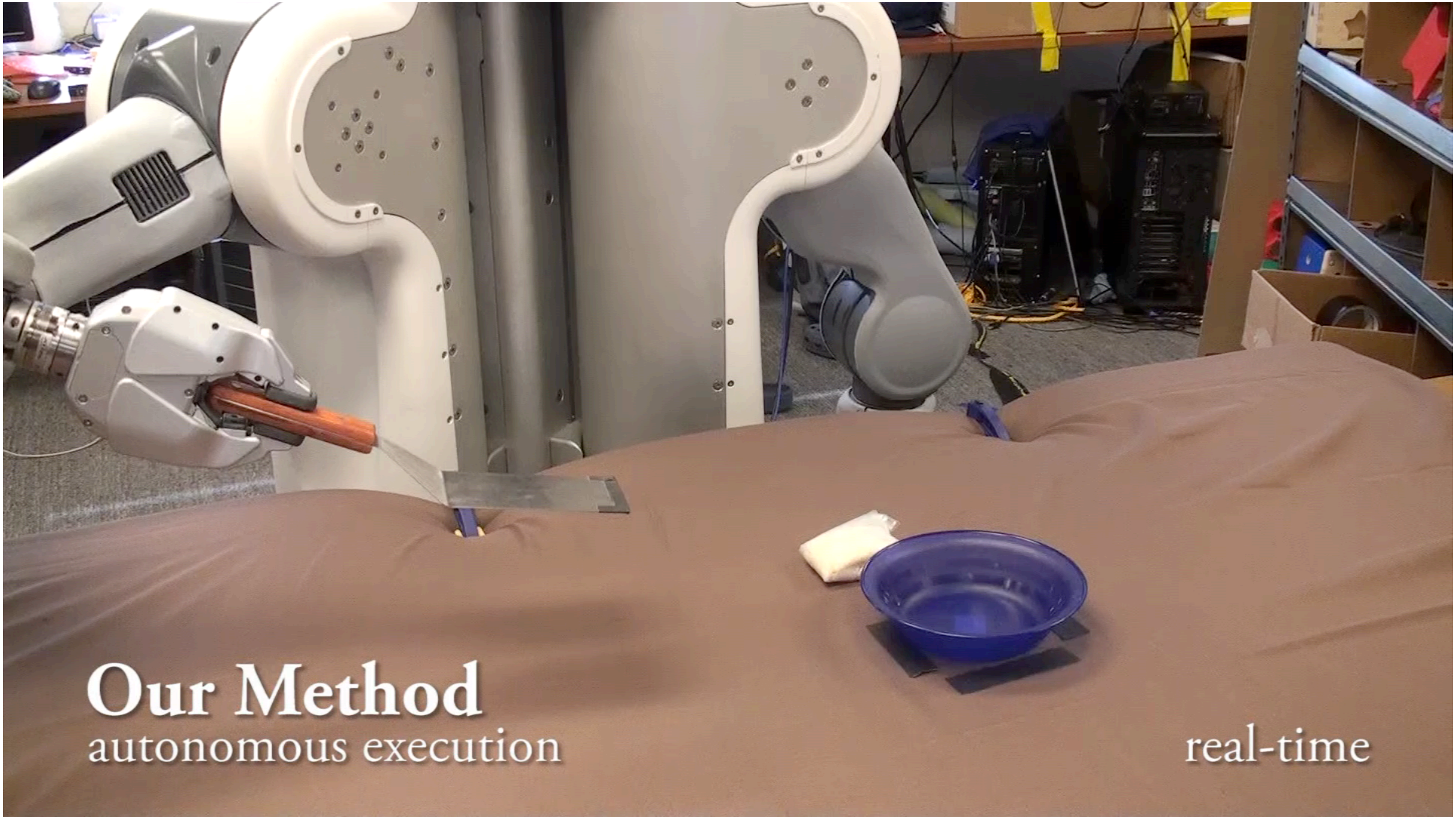
1. collect data with exploratory policy
2. learn **smooth, structured** embedding of image
3. learn local-linear model with embedding
4. run iLQG to learn to reach **image of goal** & goal gripper pose

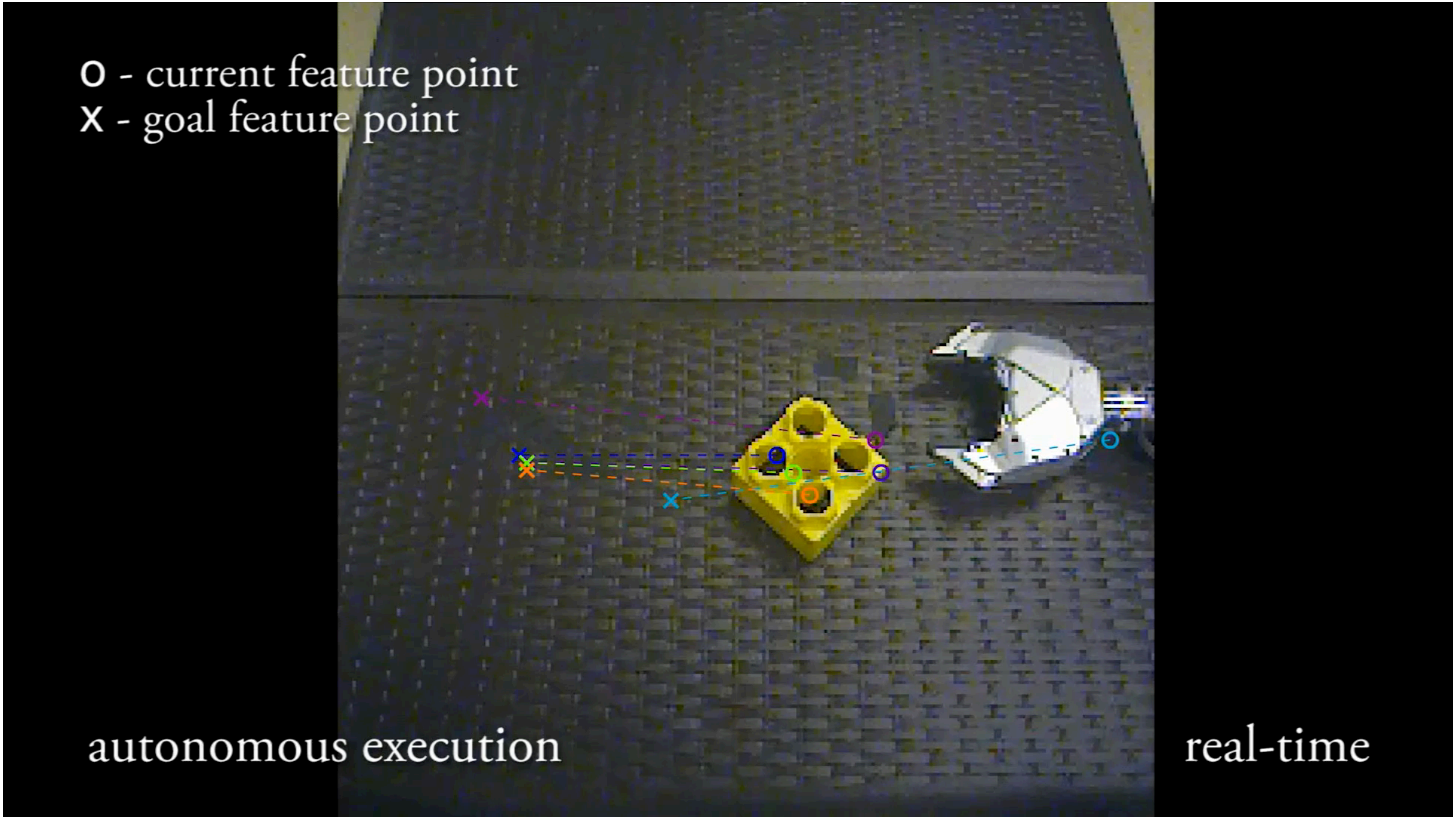
Because we aren't using states, we need a reward.




autonomous execution
6x real-time

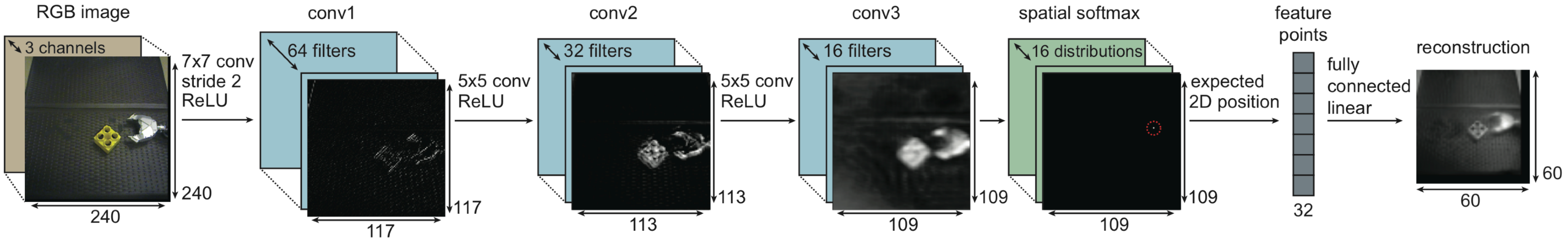

Our Method
autonomous execution
real-time


Our Method
autonomous execution
real-time



125 trials = 11 min of robot time (per task)

1. collect data with exploratory policy
2. learn **smooth, structured** embedding of image
3. learn local-linear model with embedding
4. run iLQG to learn to reach image of goal & goal gripper pose



Pros:

+ Learn complex visual skill very efficiently

+ Structured representation enables effective learning

Cons:

- Autoencoder might not recover the right representation

Learning in Latent Space

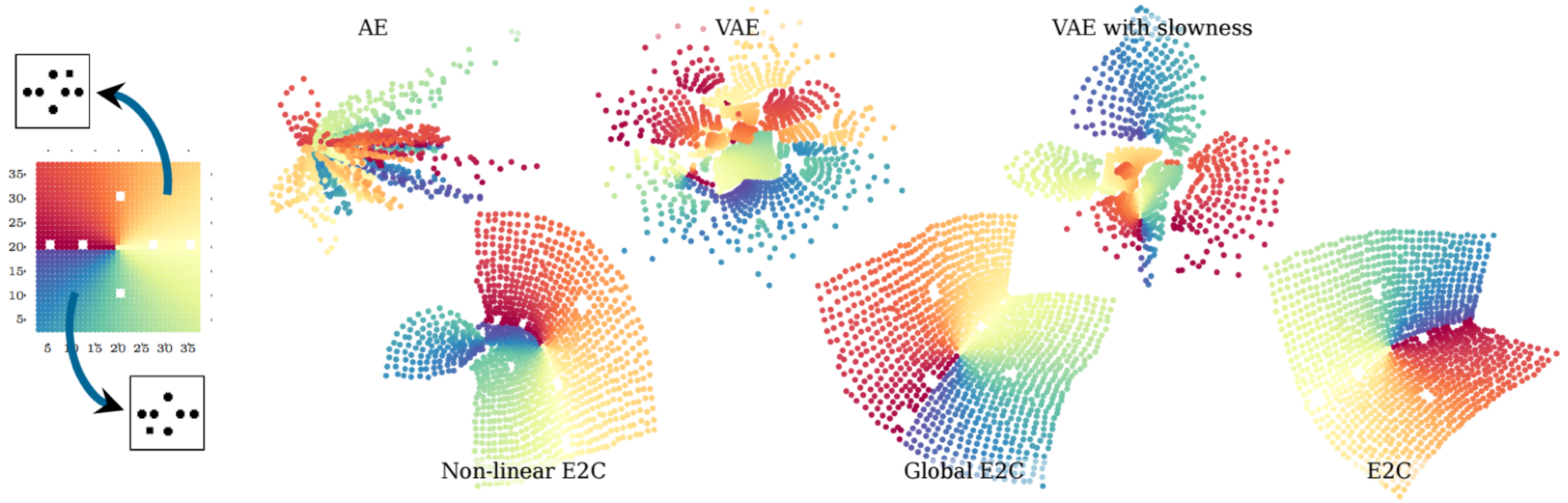
Key idea: learn embedding $g(\mathbf{o}_t) = \mathbf{x}_t$, then learn in latent space

(**model-based** or model-free)

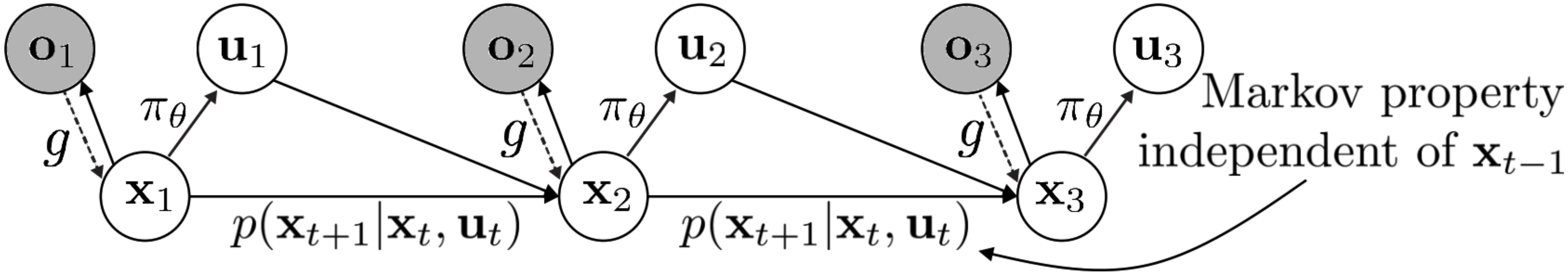
Embed to Control: A Locally Linear Latent Dynamics Model for Control from Raw Images

Manuel Watter* **Jost Tobias Springenberg***
Joschka Boedecker
University of Freiburg, Germany
{watterm, springj, jboedeck}@cs.uni-freiburg.de

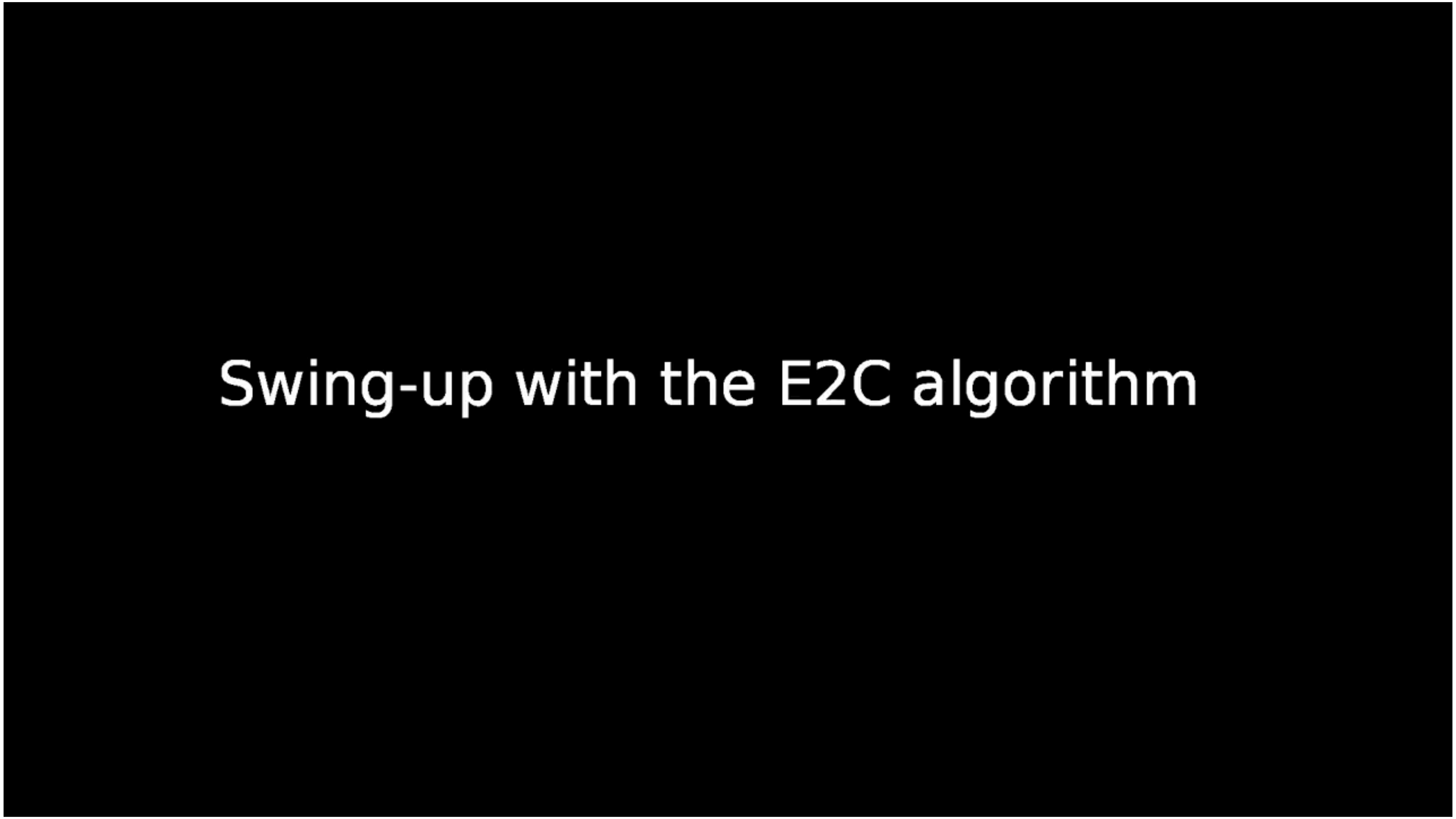
Martin Riedmiller
Google DeepMind
London, UK
riedmiller@google.com



1. collect data
2. learn embedding of image & dynamics model (**jointly**)
3. run iLQG to learn to reach image of goal



embedding that can be **modeled**



~300 trials = ~25 min of robot time (per task)

Thought exercise:
Why reconstruct the image?
Why not just learn embedding and model on embedding?

Outline

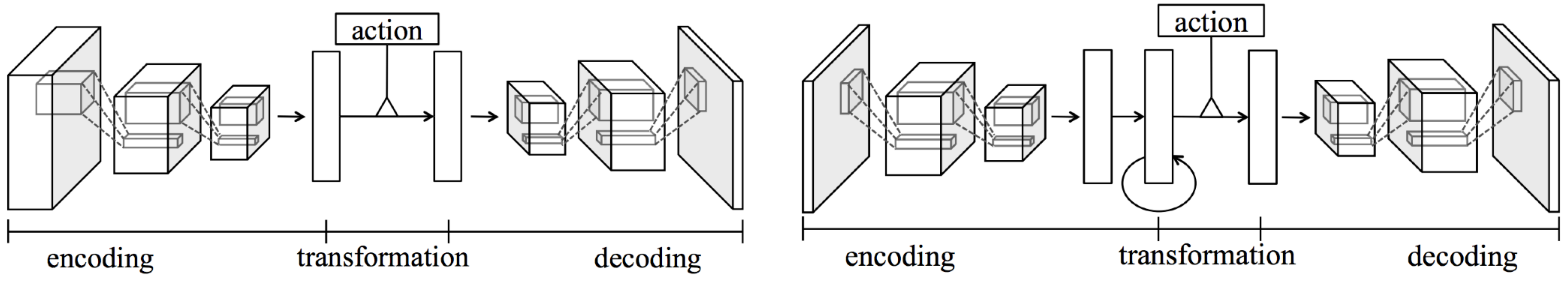
1. Models in latent space
2. **Models directly in image space**
3. Inverse models
4. Predict alternative quantities

Models with Images

Action-conditioned video prediction $f(\mathbf{o}_t, \mathbf{u}_t) = \mathbf{o}_{t+1}$

Action-Conditional Video Prediction using Deep Networks in Atari Games

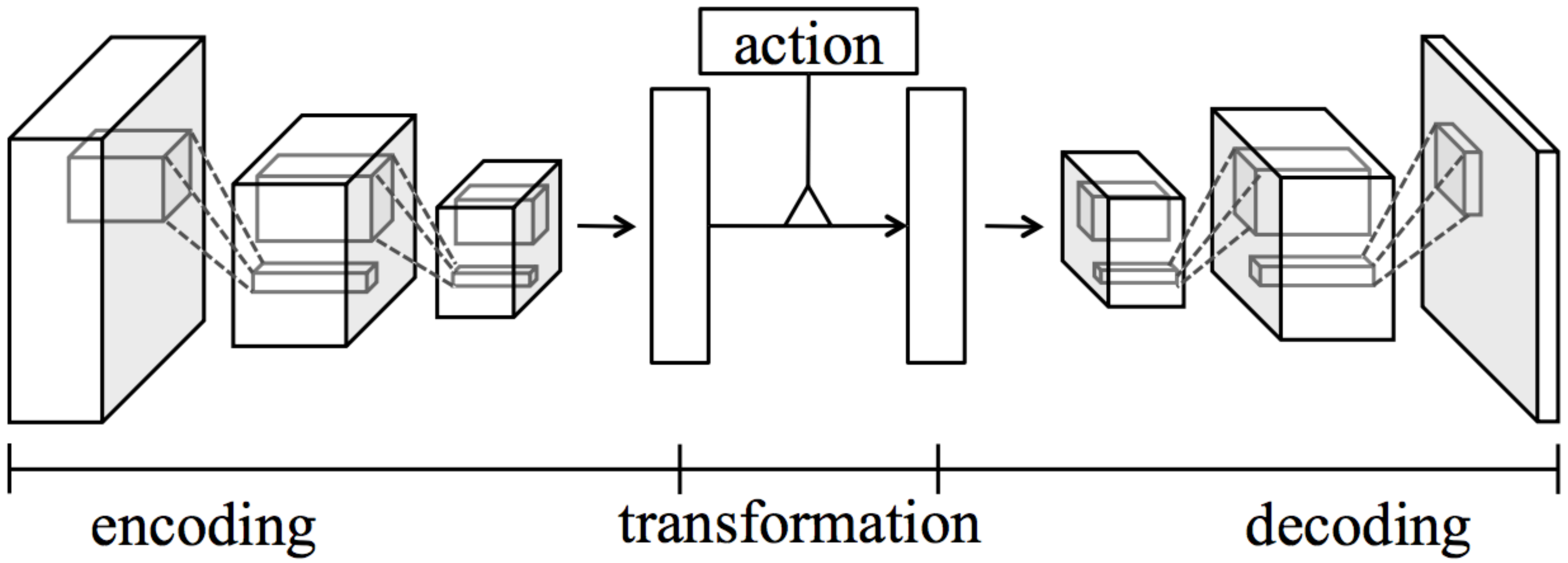
Junhyuk Oh **Xiaoxiao Guo** **Honglak Lee** **Richard Lewis** **Satinder Singh**
University of Michigan, Ann Arbor, MI 48109, USA



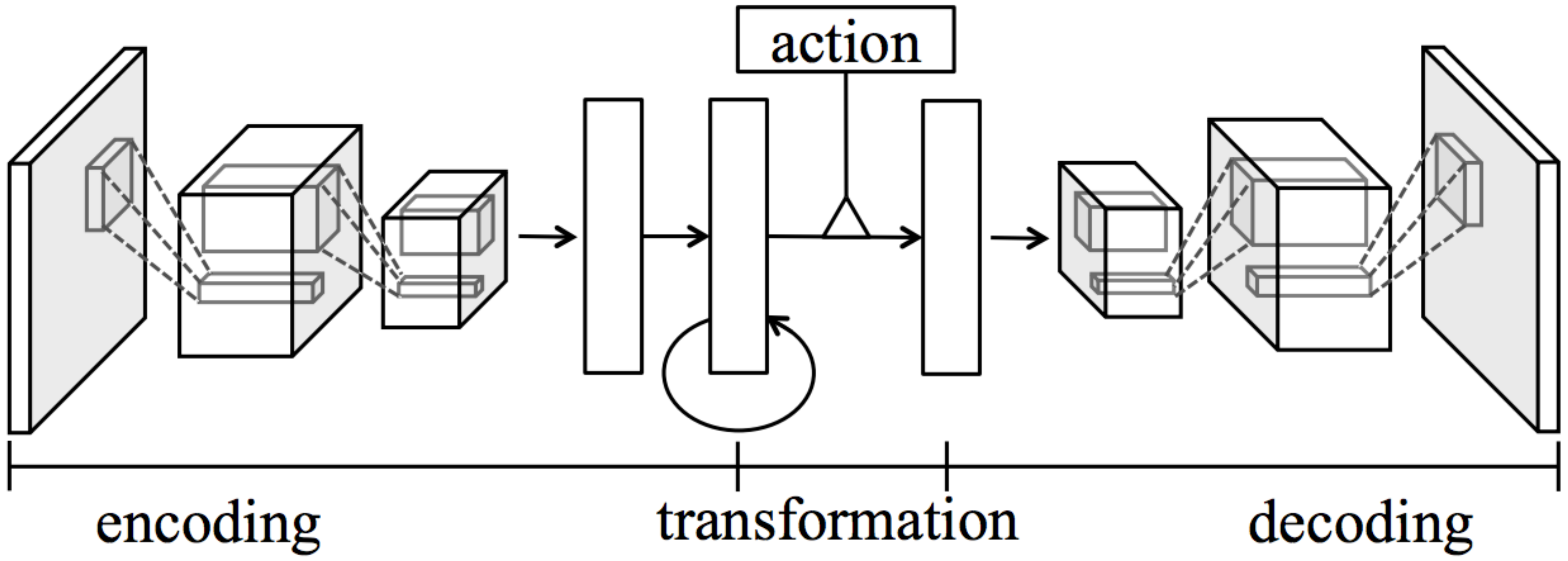
(a) Feedforward encoding (b) Recurrent encoding

Models with Images

Action-conditioned video prediction $f(\mathbf{o}_t, \mathbf{u}_t) = \mathbf{o}_{t+1}$



(a) Feedforward encoding



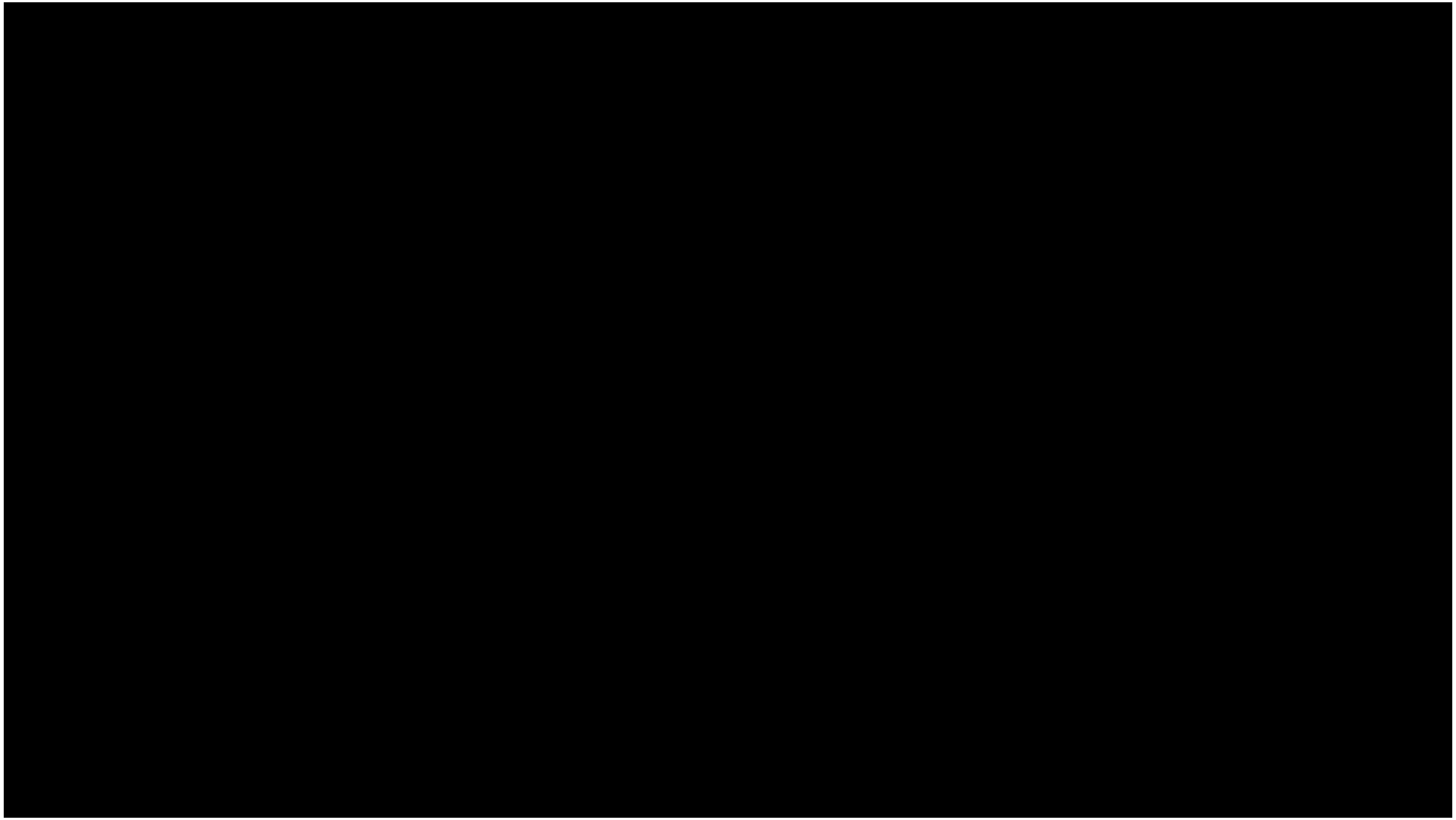
(b) Recurrent encoding

Key components:

multi-step prediction $f(\mathbf{o}_t, \mathbf{u}_{t:T-1}) = \mathbf{o}_{t+1:T}$

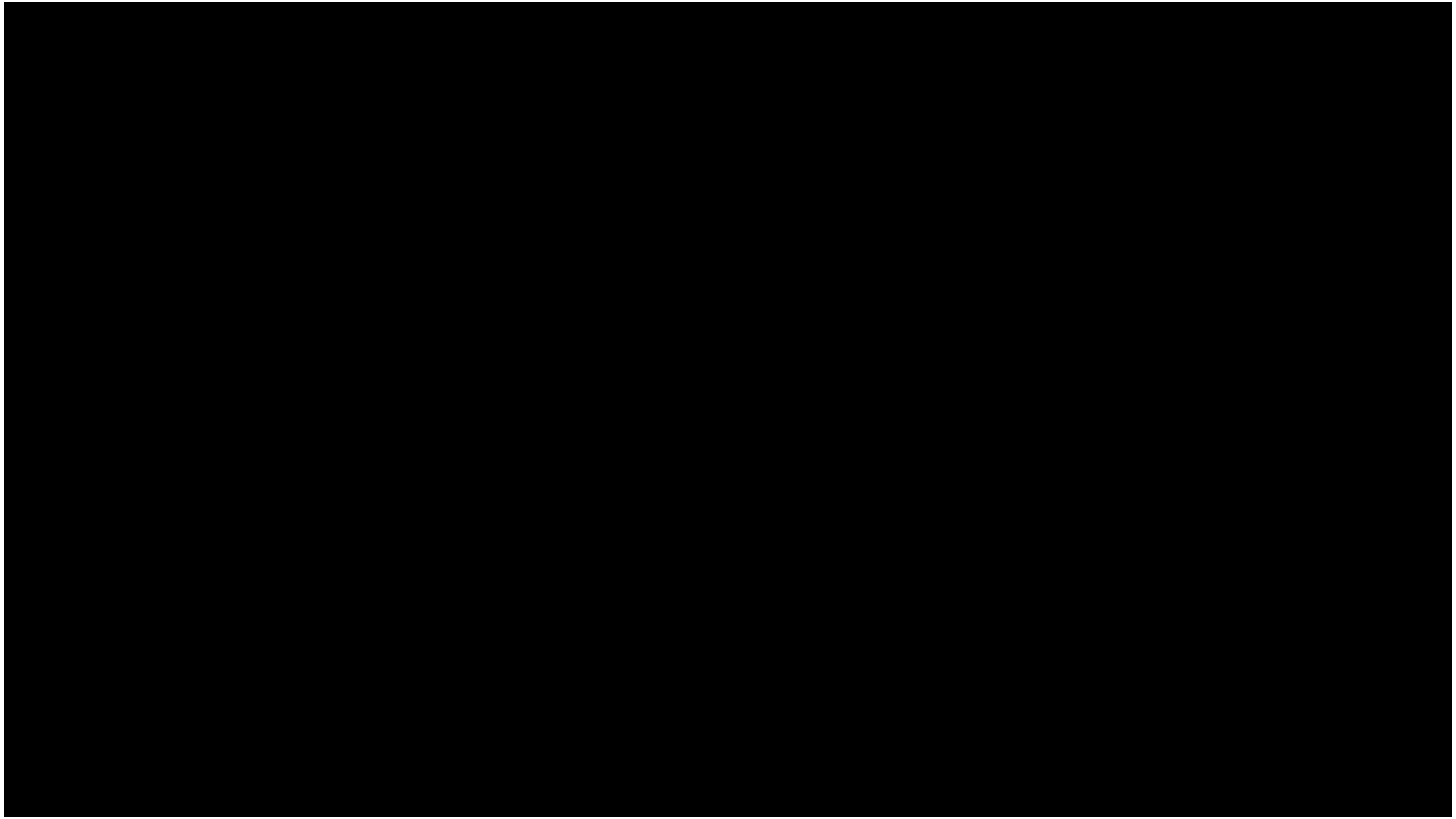
curriculum learning and/or scheduled sampling

Does it work? Yes!



can make 100-step predictions

Does it work? Maybe not.



fails to model a critical part of the game

Does it work?

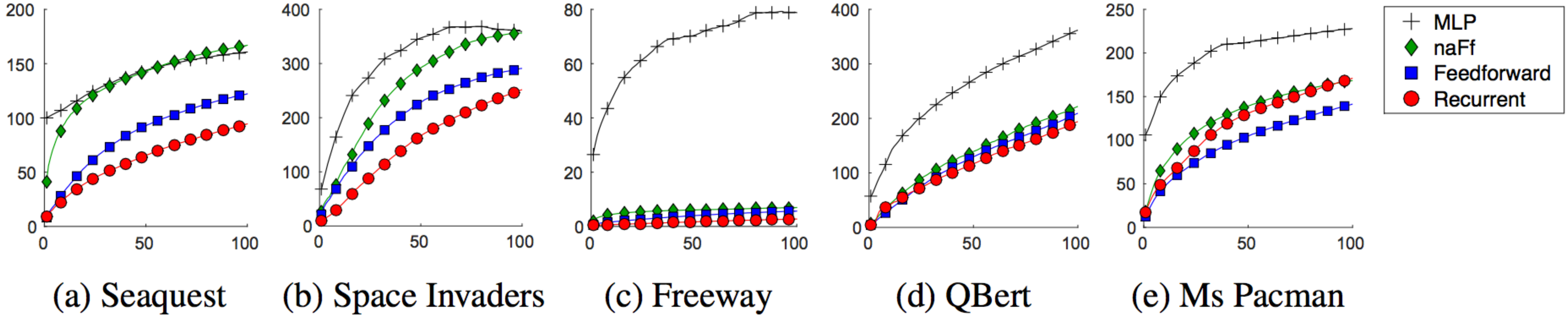
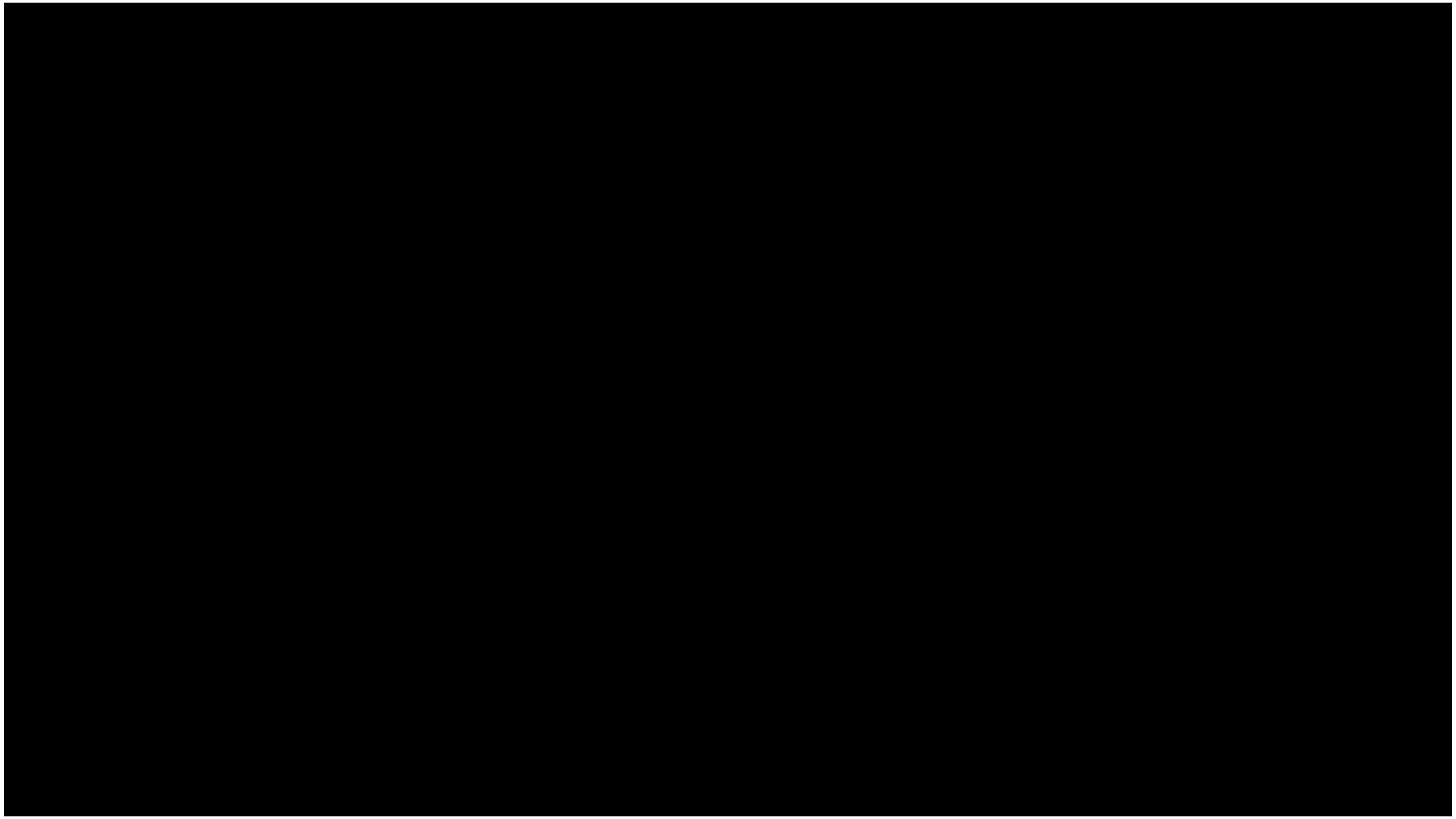


Figure 3: Mean squared error over 100-step predictions

Is it useful?

Using model for informed exploration



Using model for informed exploration:

1. Store most recent d frames
2. For every valid action, predict 1 frame ahead
3. Take action corresponding to future frame least like the previous d frames

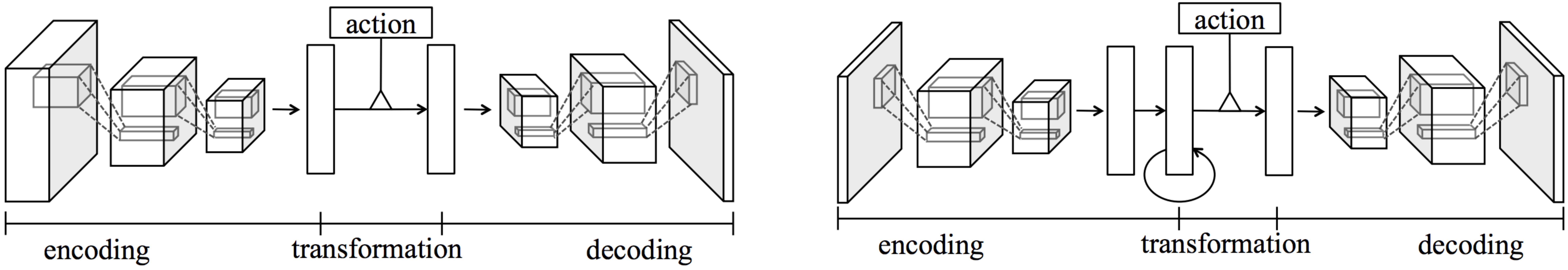
Use Gaussian kernel similarity metric on images:

$$n_D(\mathbf{x}^{(a)}) = \sum_{i=1}^{d} k(\mathbf{x}^{(a)}, \mathbf{x}^{(i)}); \quad k(\mathbf{x}, \mathbf{y}) = \exp(-\sum_j \min(\max((x_j - y_j)^2 - \delta, 0), 1)/\sigma)$$

***caveat:** prediction model was trained with data from DQN agent

more on exploration later in this course!

Action-conditioned video prediction $f(\mathbf{o}_t, \mathbf{u}_t) = \mathbf{o}_{t+1}$



(a) Feedforward encoding

(b) Recurrent encoding

Pros:

+ Stability through multi-step prediction
+ Useful for control

Cons:

- Synthetic images are easier to generate
- Not immediately clear how to plan with it

What about real images?

Unsupervised Learning for Physical Interaction through Video Prediction

Chelsea Finn[*]
UC Berkeley

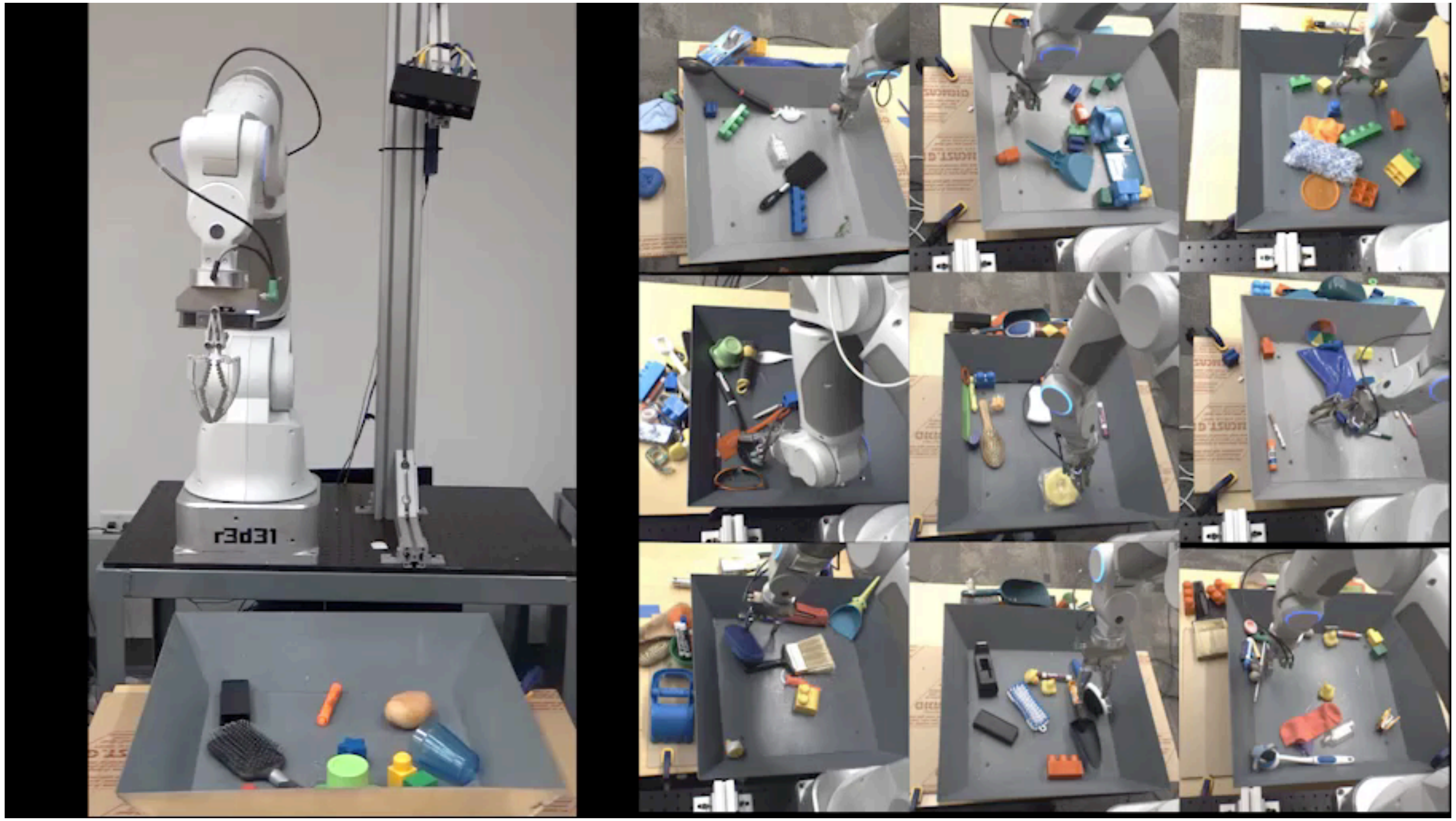
Ian Goodfellow
OpenAI

Sergey Levine
Google Brain

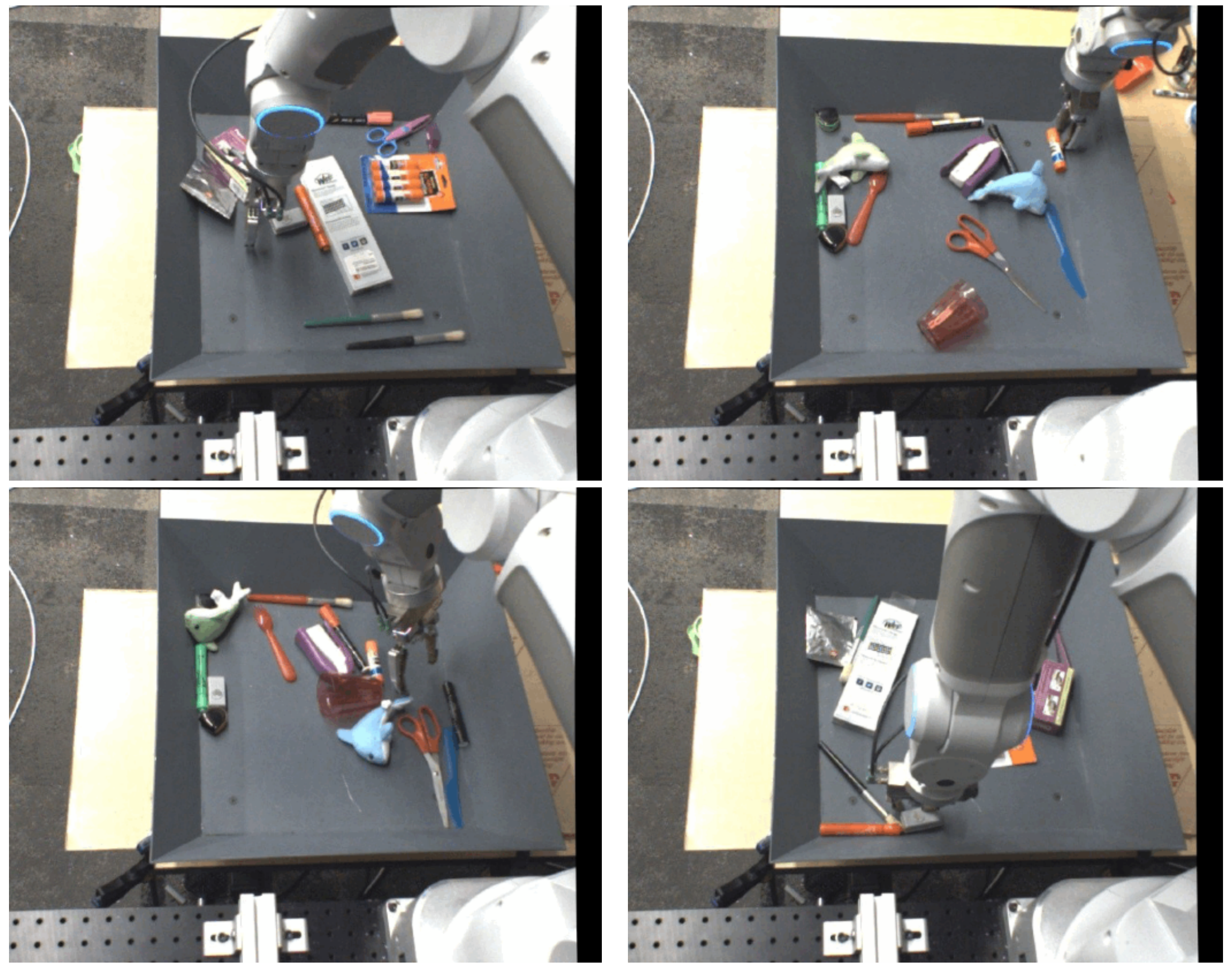
Deep Visual Foresight for Planning Robot Motion

Chelsea Finn[1,2] and Sergey Levine[1,2]

Data collection - 50k sequences (1M+ frames)



test set with
novel objects



data publicly available for download **sites.google.com/site/brainrobotdata**

Train 8-step predictive model

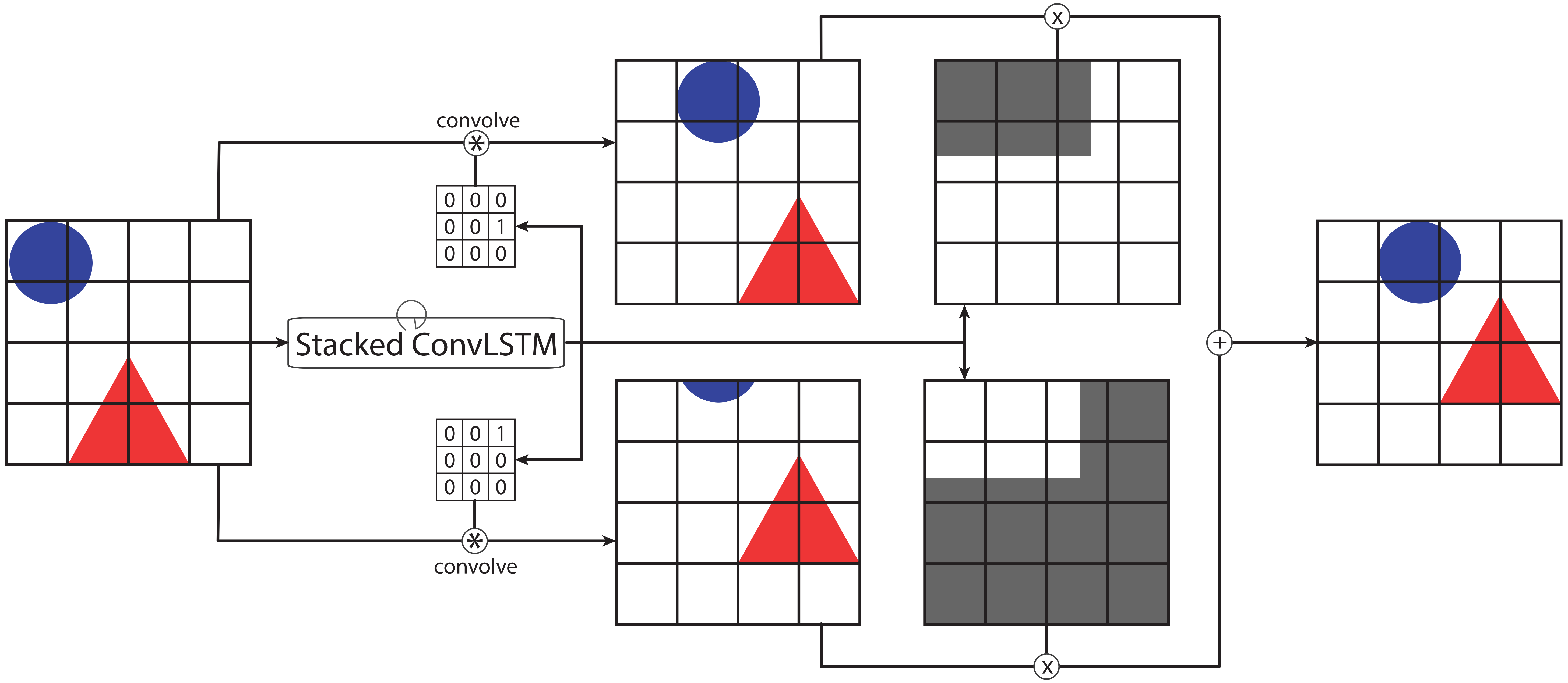
Atari recurrent model

evaluate on held-out objects

— > doesn’t have capacity to represent real images.

Train predictive model

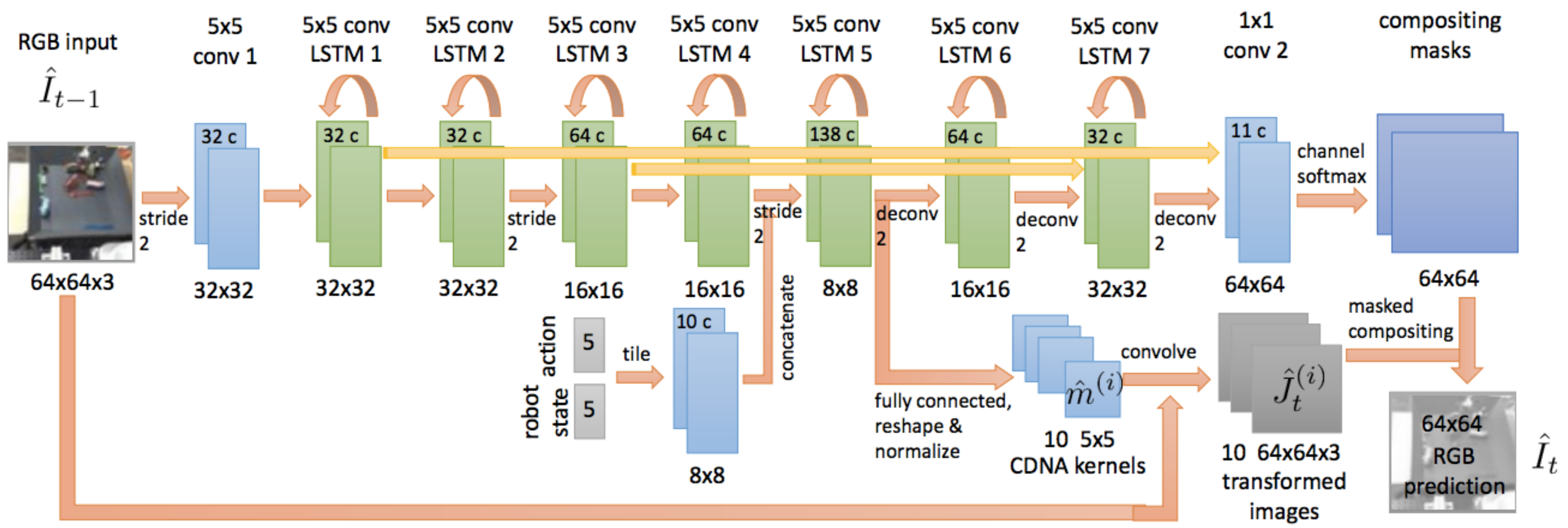
action-conditioned multi-frame video prediction
via **flow prediction**



- feed back model's predictions for multi-frame prediction
- trained with l_2 loss

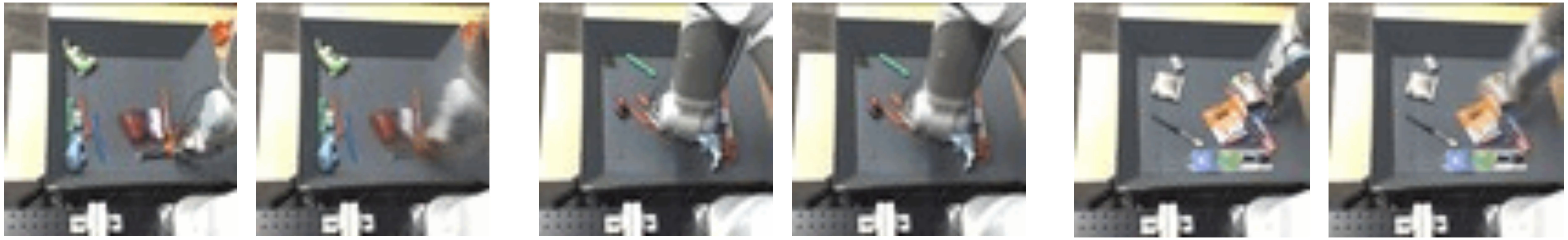
Train predictive model

convolutional LSTMs



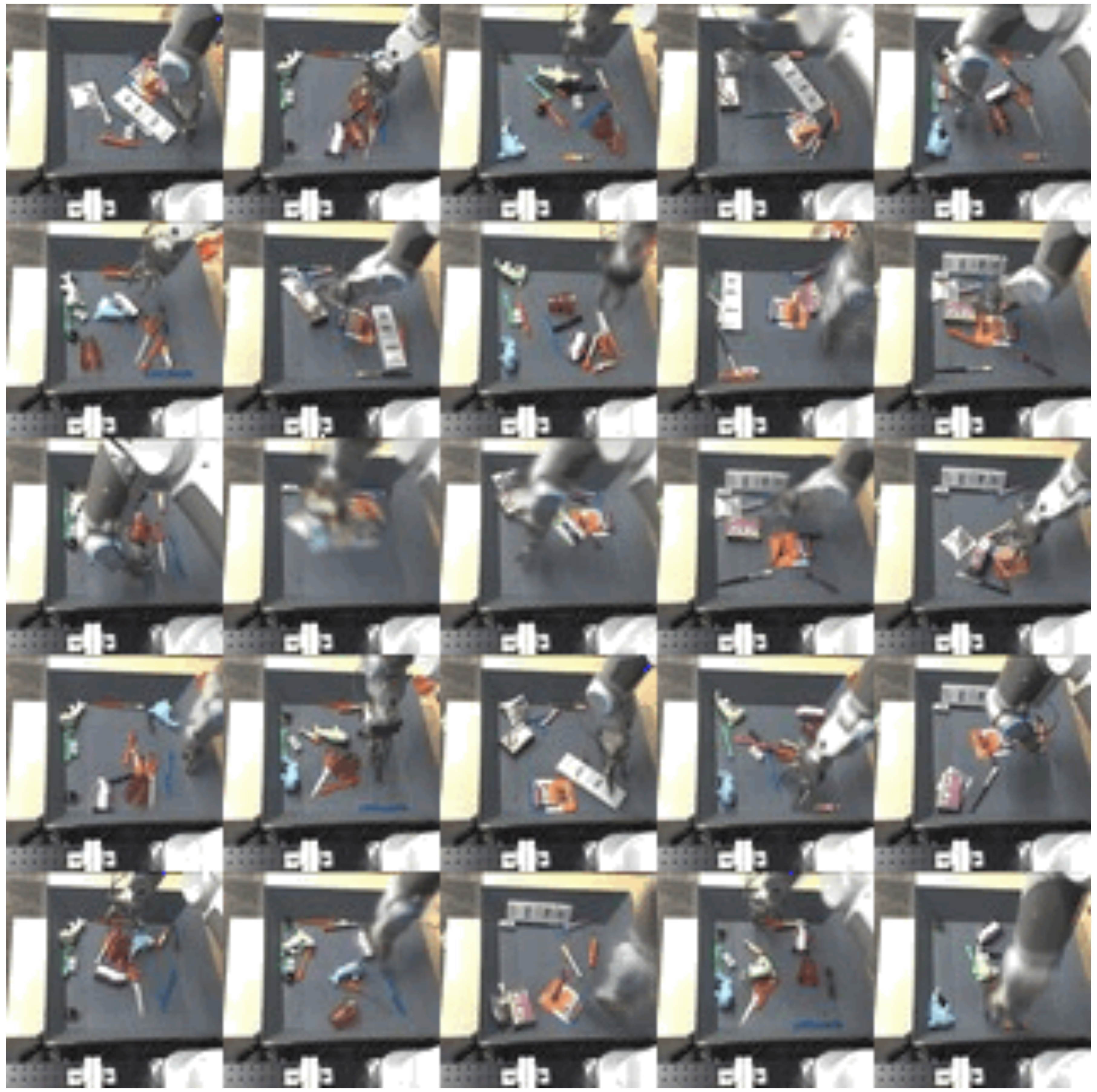
action-conditioned **stochastic flow prediction**

evaluate on held-out objects

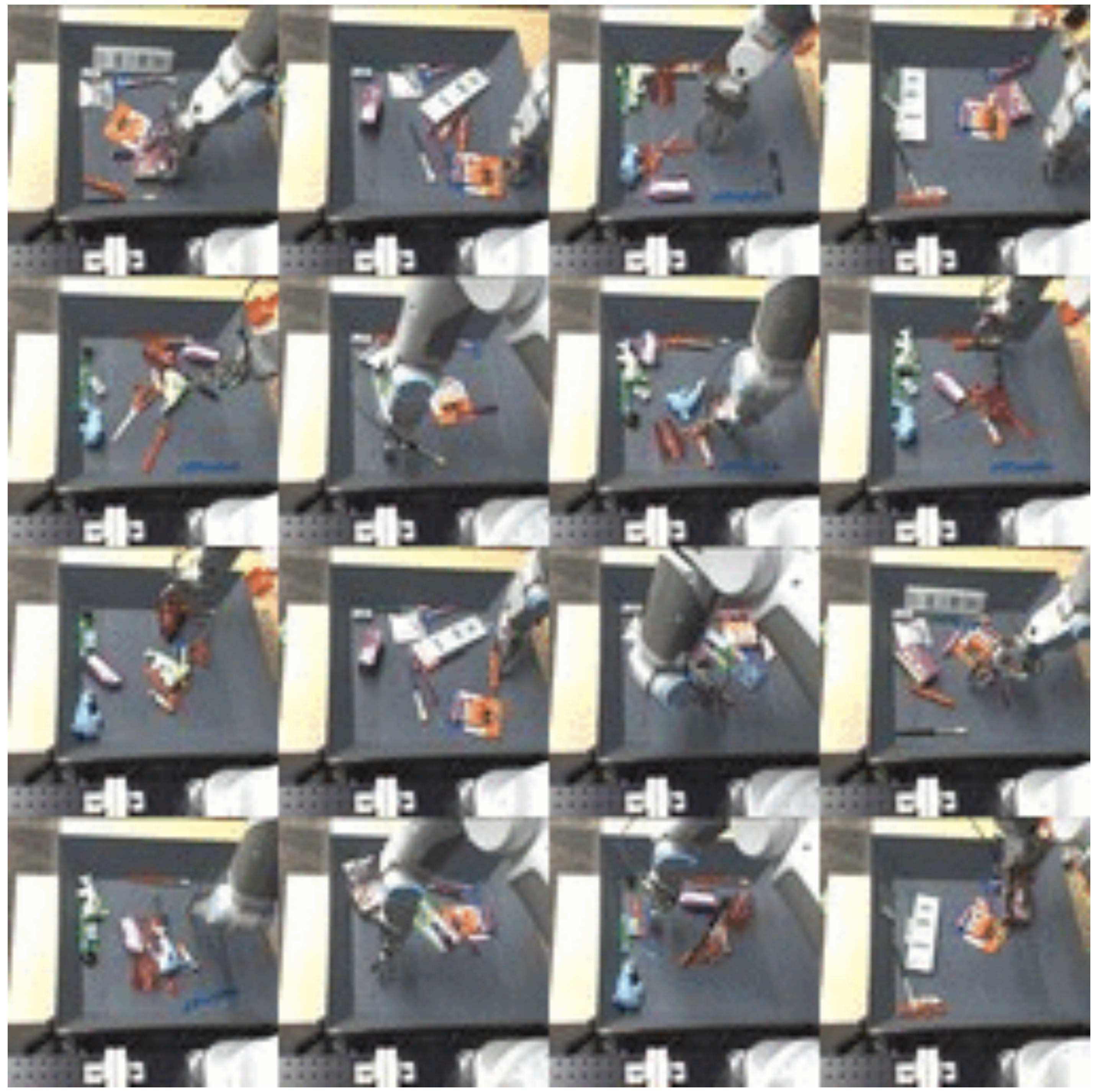


Train predictive model

Finn et al., '16



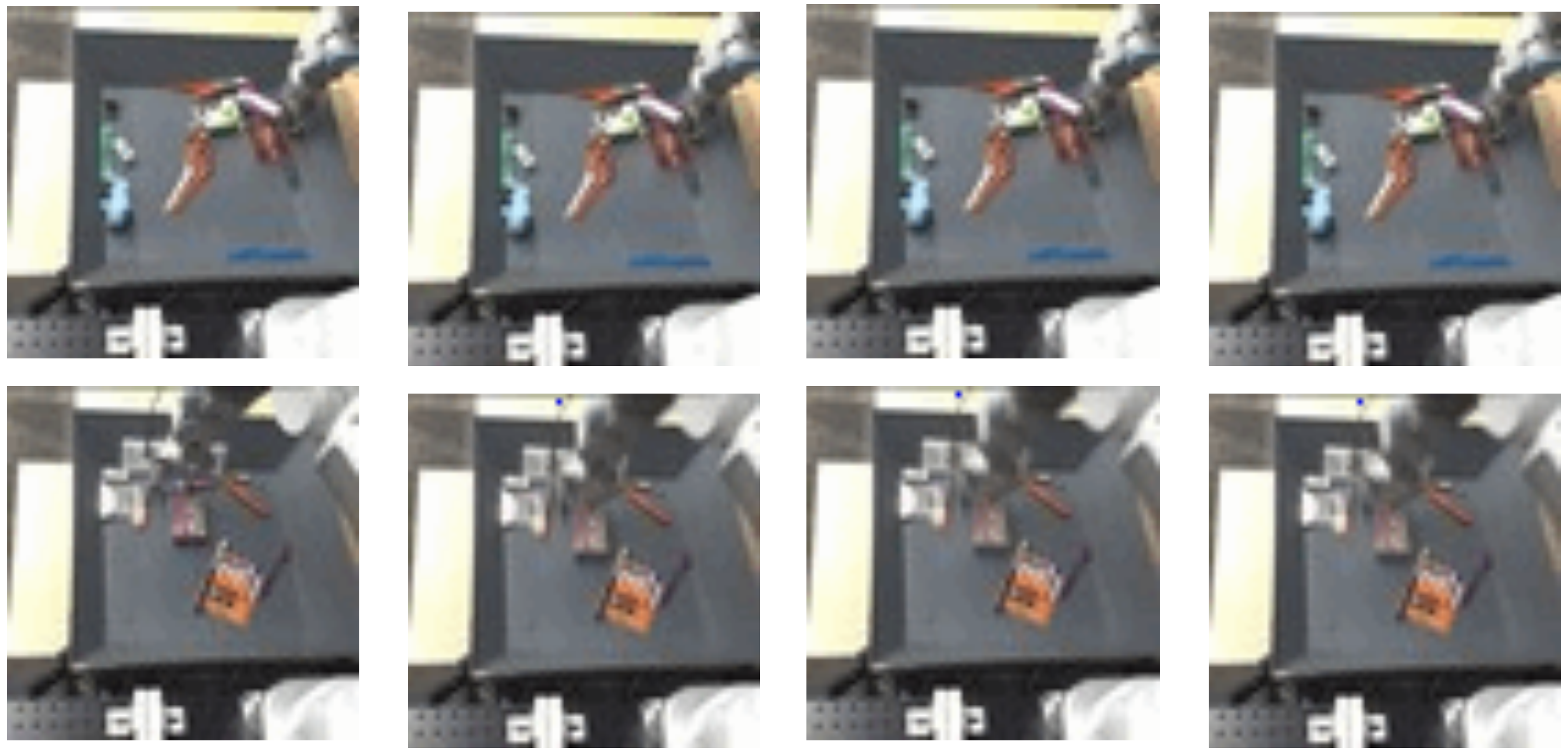
Kalchbrenner et al., '16



Are these predictions good? accurate? useful?

What is prediction good for?

action magnitude: 0x 0.5x 1x 1.5x

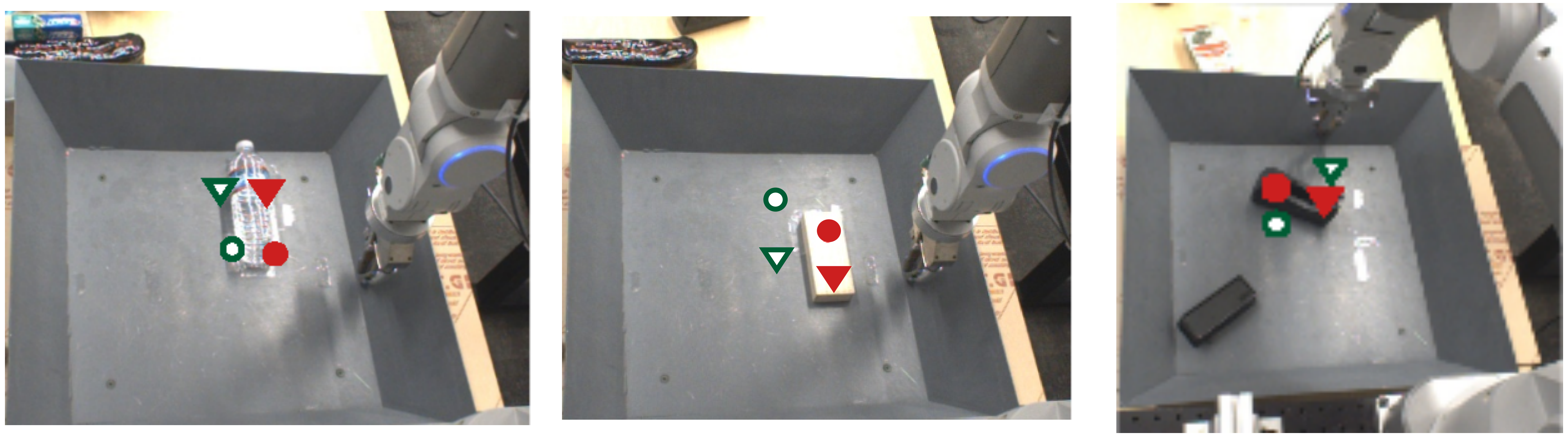


Planning with Visual Foresight (MPC)

1. Sample N potential action sequences
2. Predict the future for each action sequence
3. Pick best future & execute corresponding action
4. Repeat 1-3 to replan in real time

Which future is the best one?

Specify goal by selecting where pixels should move.



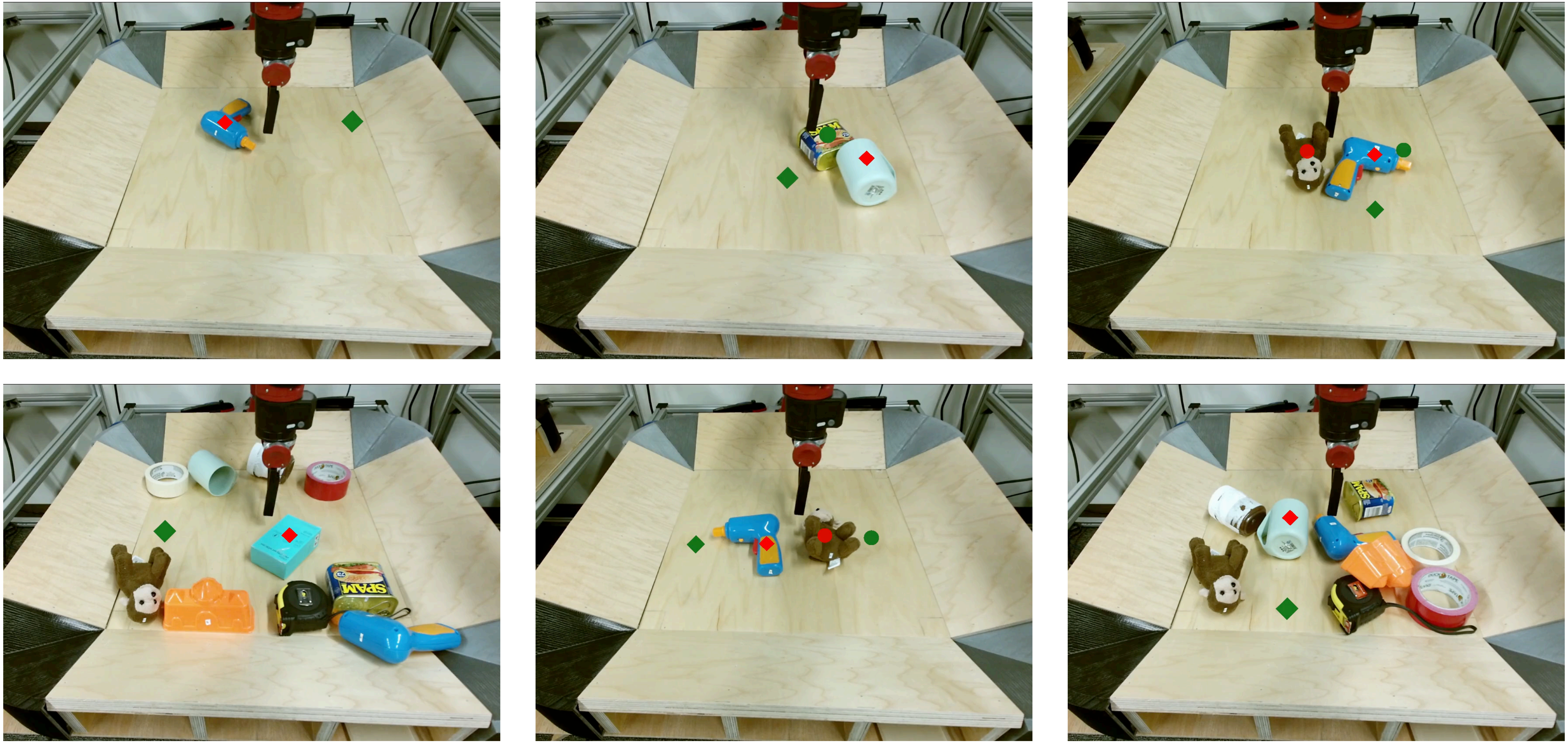
Select future with maximal probability of pixels reaching their respective goals.

How it works

<2 days of *unsupervised* robot time

Only human involvement: programming initial motions and providing objects to play with.

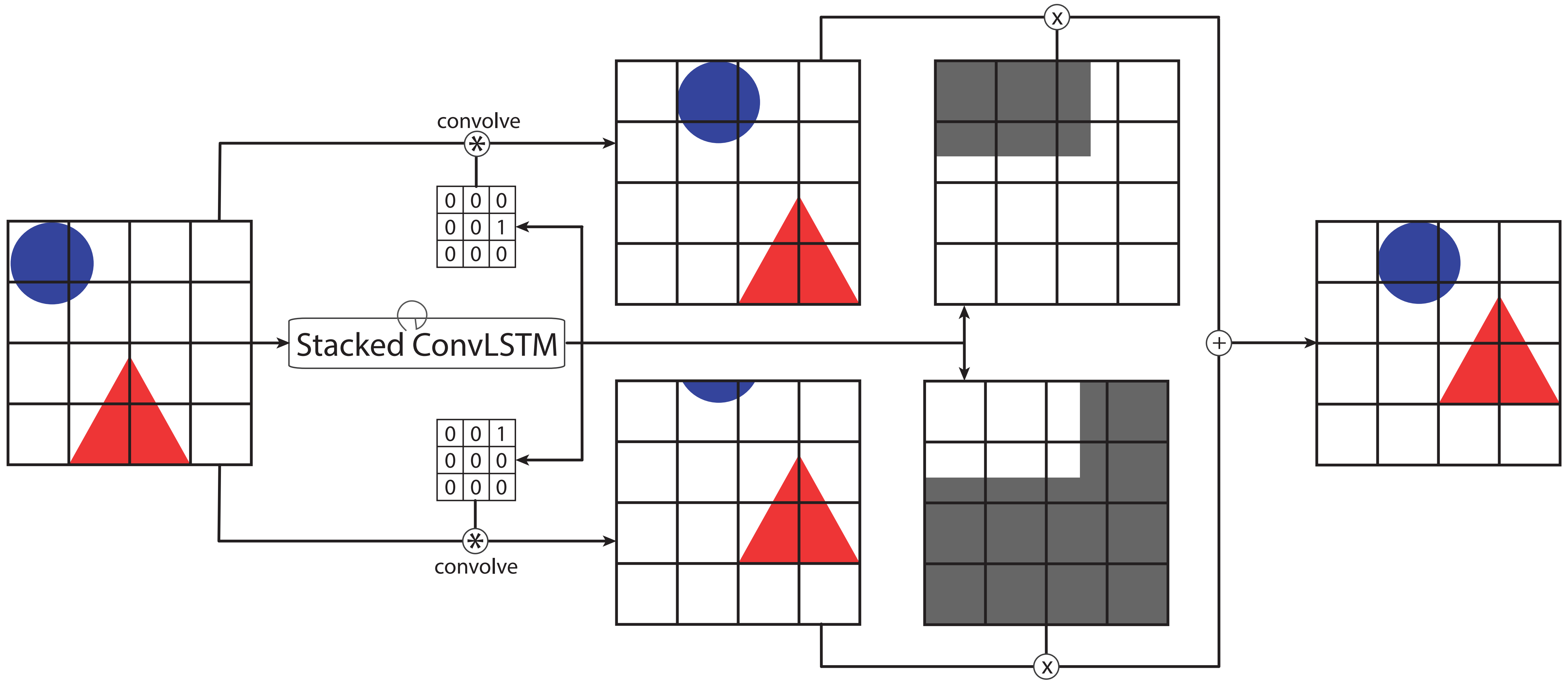
Modeling directly in observation space



model can be reused for different tasks

Ebert et al. '17

action-conditioned multi-frame video prediction via **flow prediction**



Pros:

+ Real images
+ Very limited human involvement (self-supervised)
+ More efficient than single-task model-free learning

Cons:

- Despite real images, limited background variability
- Can't [yet] handle as complex skills as model-free methods
- Compute intensive at test-time

Outline

1. Models in latent space
2. Models directly in image space
3. **Inverse models**
4. Predict alternative quantities

Inverse Models

Thought exercise revisited:
Why reconstruct the image?

Learn embedding via inverse model $f(\mathbf{o}_t, \mathbf{o}_{t+1}) = \mathbf{u}_t$

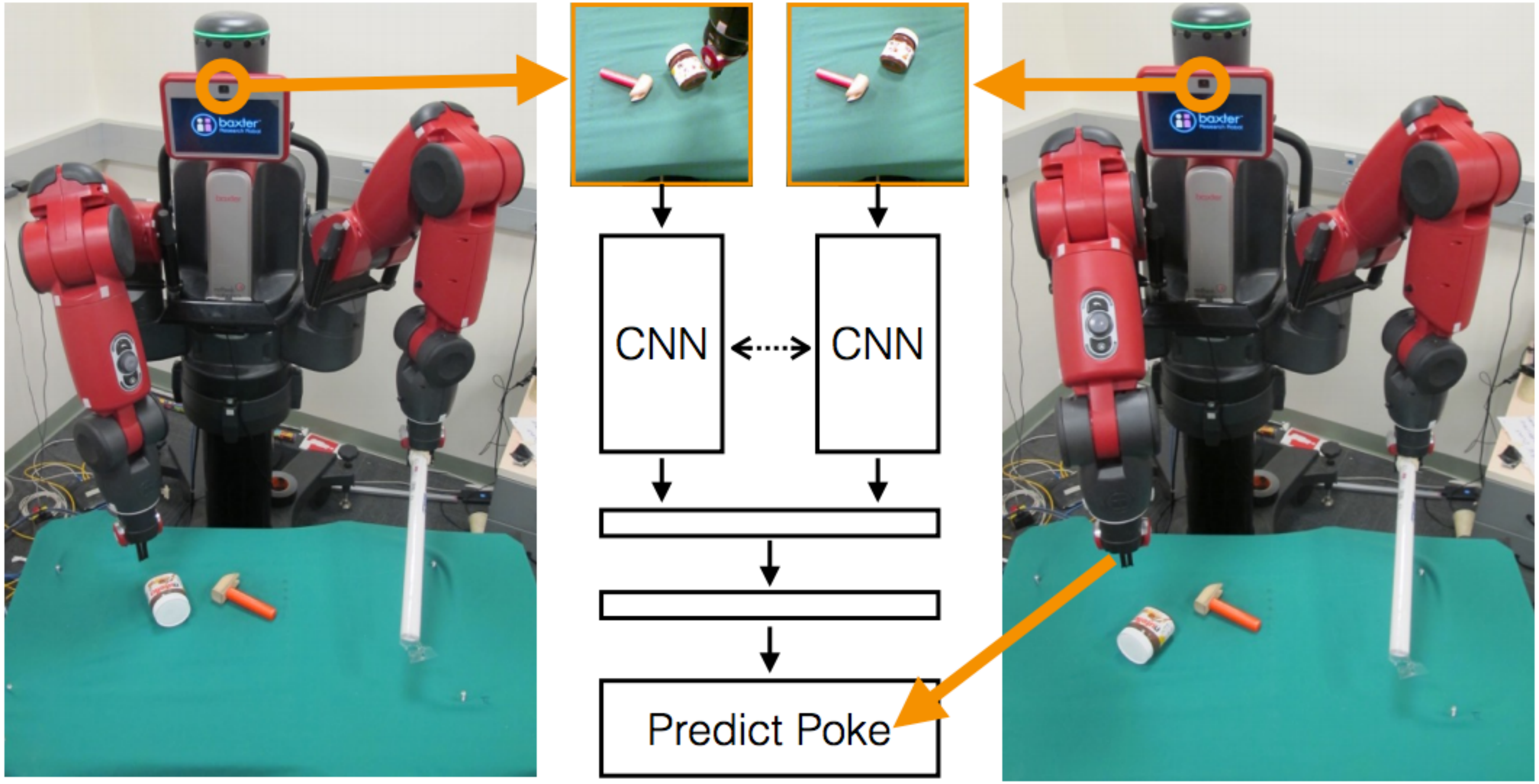
Inverse Models

Learn embedding via inverse model $f(\mathbf{o}_t, \mathbf{o}_{t+1}) = \mathbf{u}_t$

Learning to Poke by Poking: Experiential Learning of Intuitive Physics

Pulkit Agrawal* **Ashvin Nair*** **Pieter Abbeel** **Jitendra Malik** **Sergey Levine**
Berkeley Artificial Intelligence Research Laboratory (BAIR)
University of California Berkeley

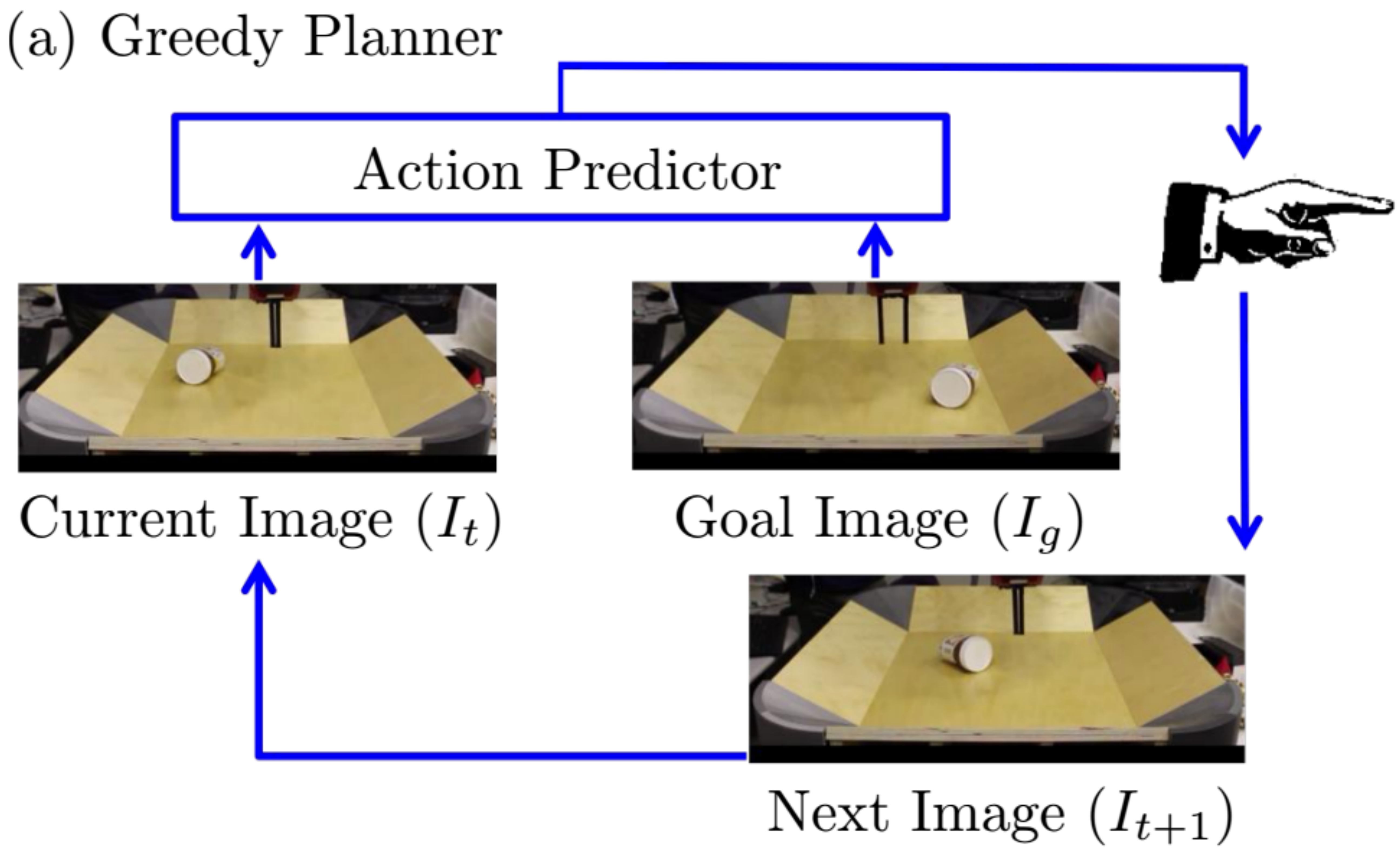
Learn embedding via inverse model $f(\mathbf{o}_t, \mathbf{o}_{t+1}) = \mathbf{u}_t$

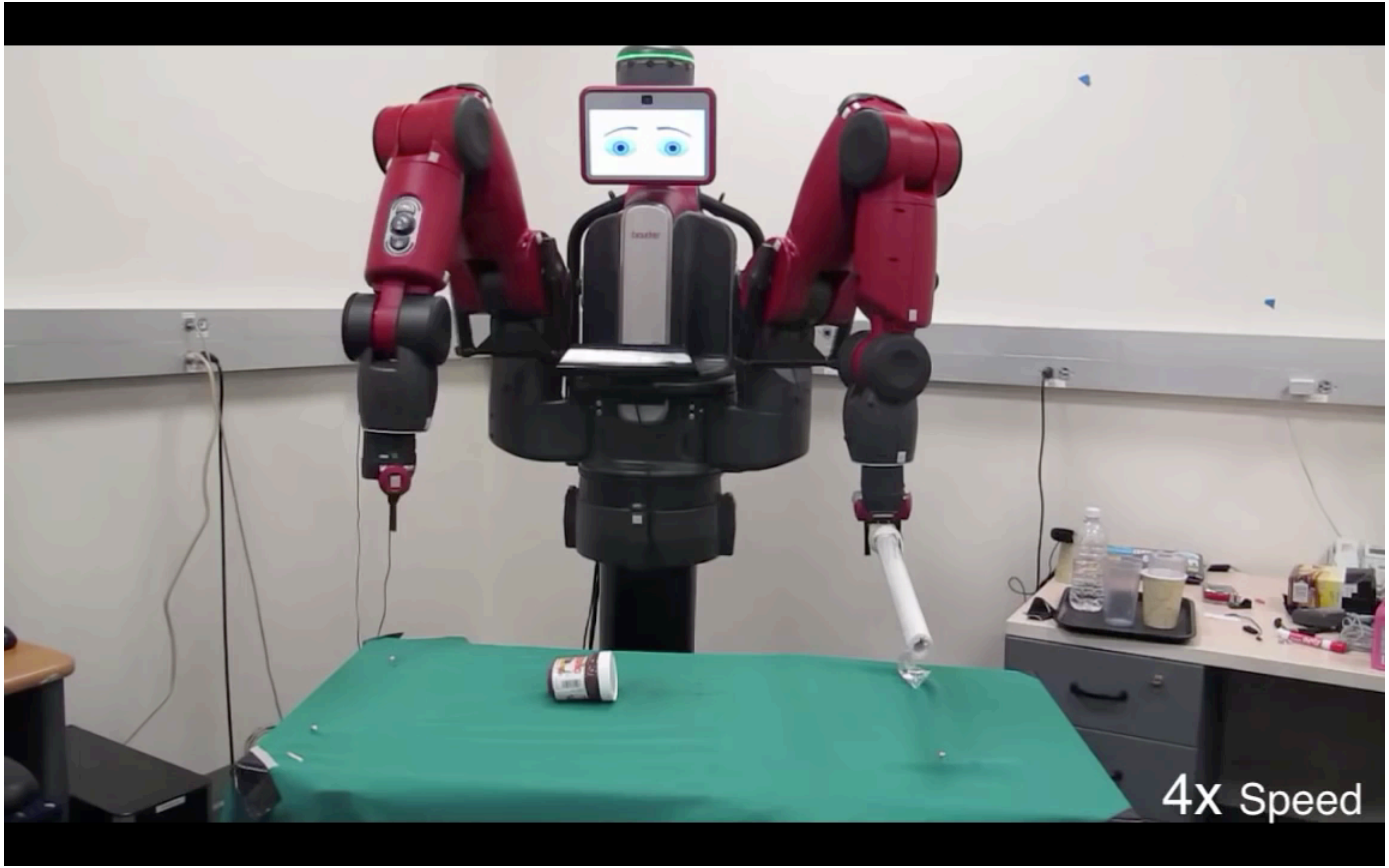


regularize embedding with forward model

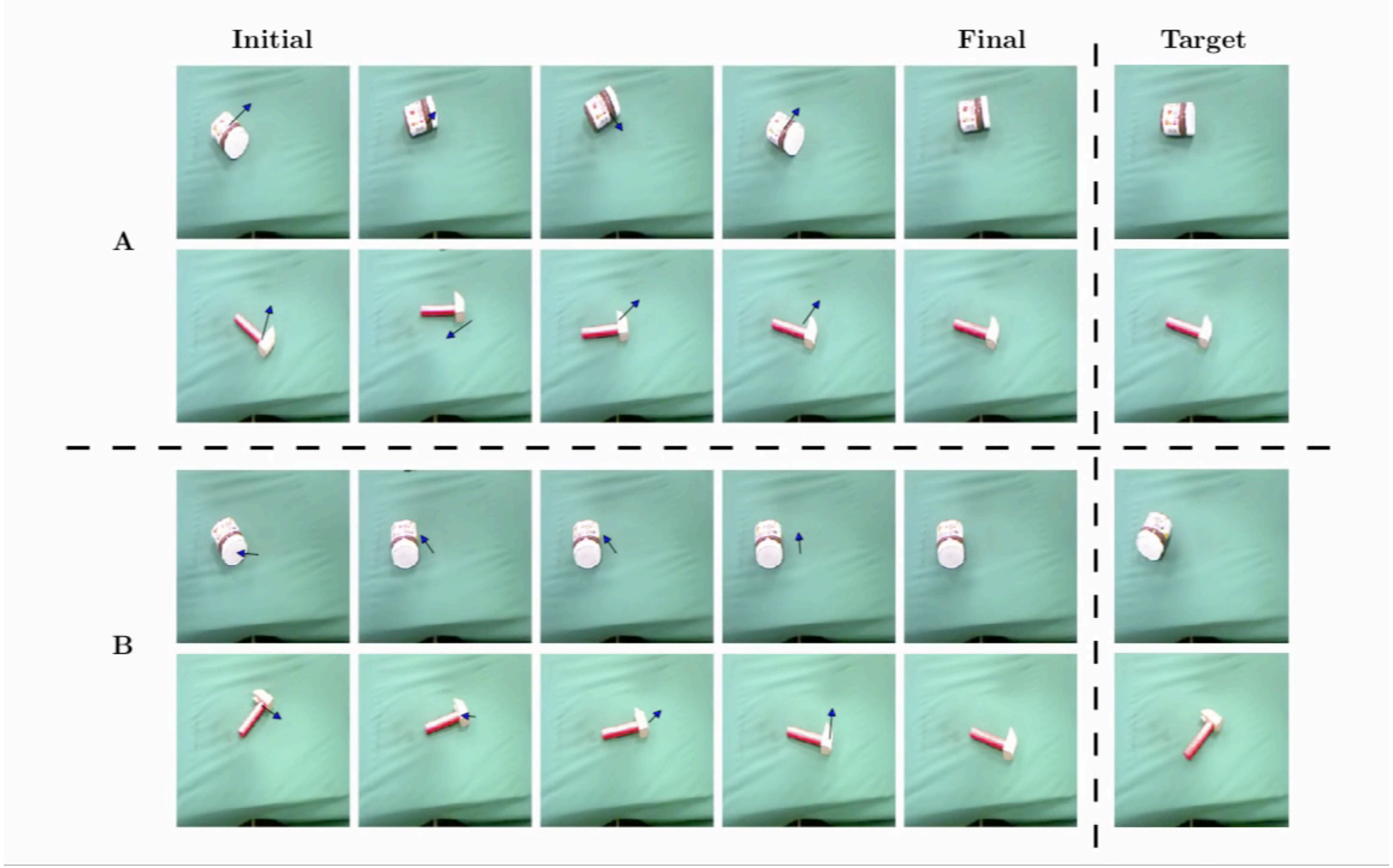
Learn embedding via inverse model $f(\mathbf{o}_t, \mathbf{o}_{t+1}) = \mathbf{u}_t$

Greedily plan with inverse model and image of goal

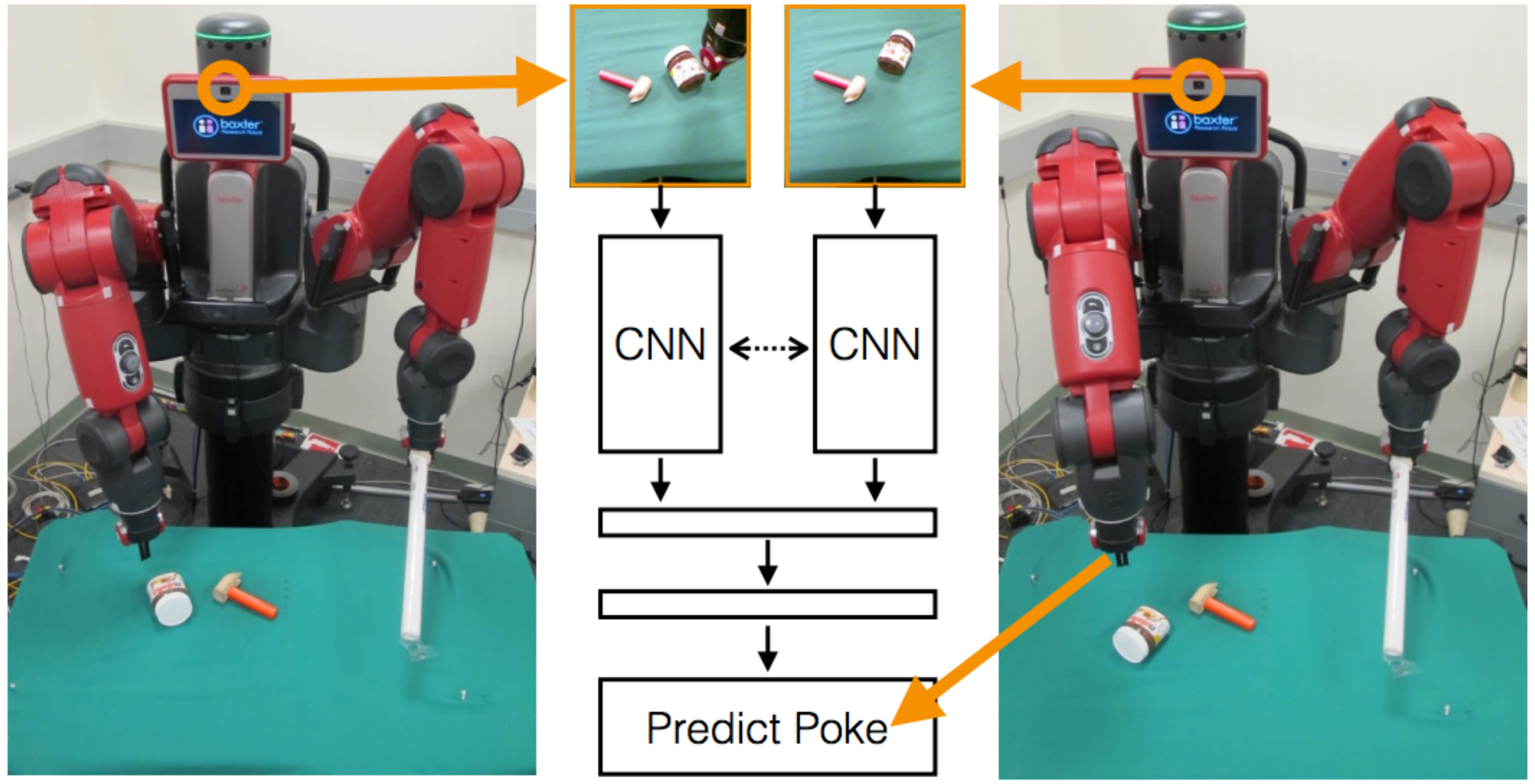



4x Speed

Qualitative Results



Learn embedding via inverse model $f(\mathbf{o}_t, \mathbf{o}_{t+1}) = \mathbf{u}_t$



Pros:

+ Very limited human involvement (self-supervised)
+ Don't have to reconstruct image

Cons:

- Can't plan with inverse model
- Inverse model objective just cares about action

Outline

1. Models in latent space
2. Models directly in image space
3. Inverse models
4. **Predict alternative quantities**

Predict alternative quantities

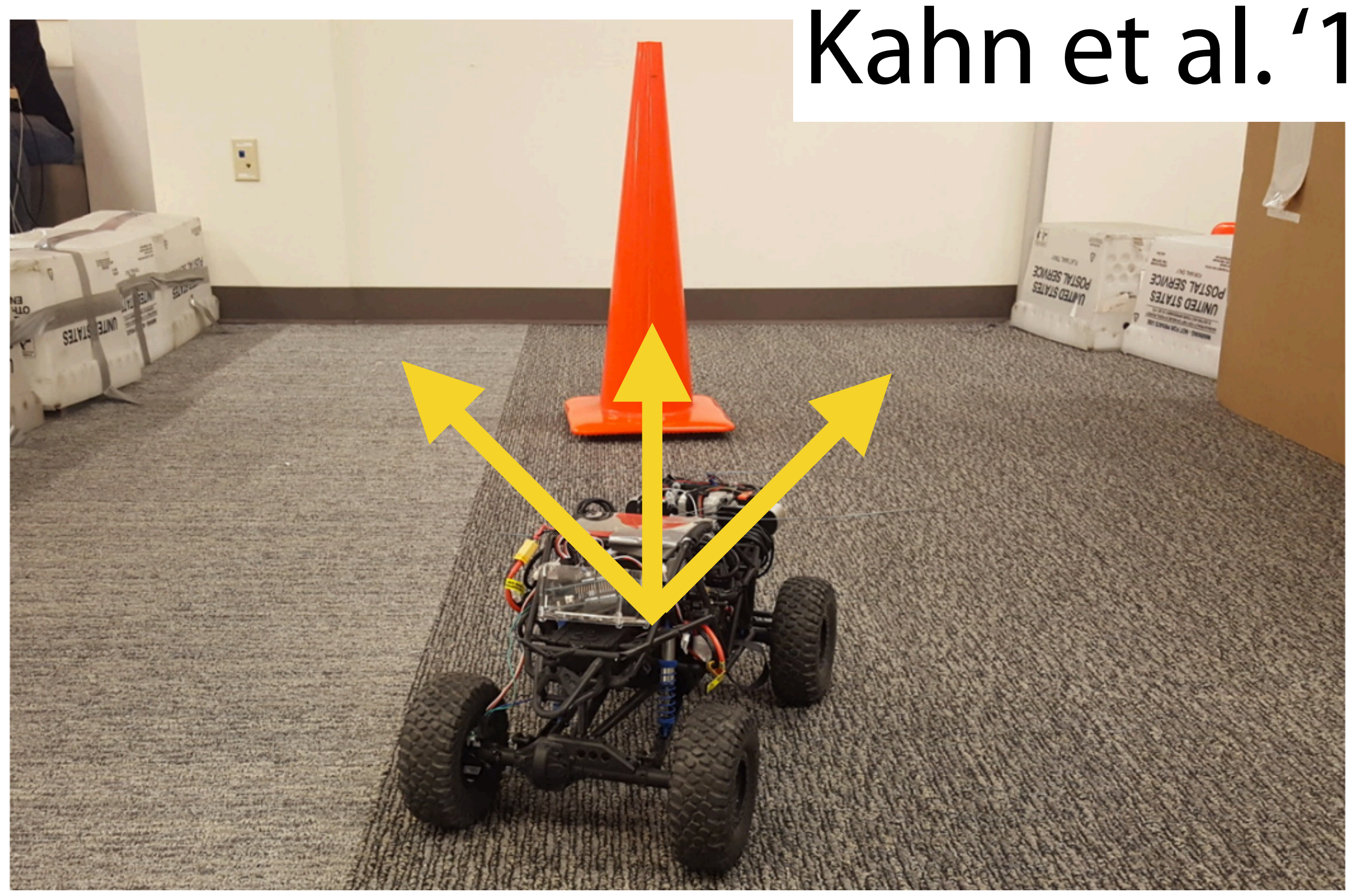
If I take a set of actions:

Pinto et al. '16

Will I successfully grasp?

Will I collide?

Kahn et al. '17



Dosovitskiy & Koltun '17

What will health/damage/etc. be?

Pros:

+ Only predict task-relevant quantities!

Cons:

- Need to manually pick quantities, must be able to directly observe them

Advanced Model Learning Takeaways

- Learning the **right** features is important

- Need to think about reward/objective when using models of observations

Next week: Learning rewards from demonstrations

Model-Based vs. Model-Free Learning

Models:

+ Easy to collect data in a scalable way (self-supervised)
+ Possibility to transfer across tasks
+ Typically require a smaller quantity of supervised data
- Models don't optimize for task performance
- Sometimes harder to learn than a policy
- Often need assumptions to learn complex skills (continuity, resets)

Model-Free:

+ Makes little assumptions beyond a reward function
+ Effective for learning complex policies
- Require a lot of experience (slower)
- Not transferable across tasks

Ultimately we will want both!