CZECH TECHNICAL UNIVERSITY IN PRAGUE

Vision Language Models in Robotics

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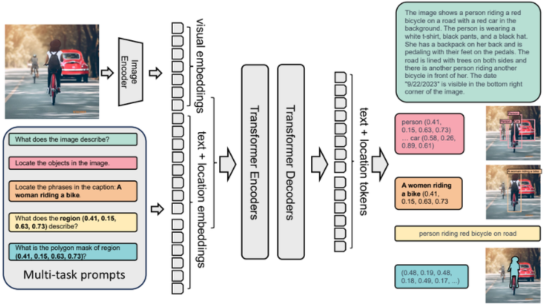
Motivation: Talking to Robots

- Traditional Pipeline:
  - Object Detector (bounding boxes)
  - Planner (geometry)
  - Controller (inverse dynamics)
- Problem: "Pick up the empty cup"
  - Detector needs the class "empty_cup"
  - Hard to generalize to new objects
- Solution: Vision Language Models (VLM)
  - Understand semantic concepts
  - Connect pixels to language directly

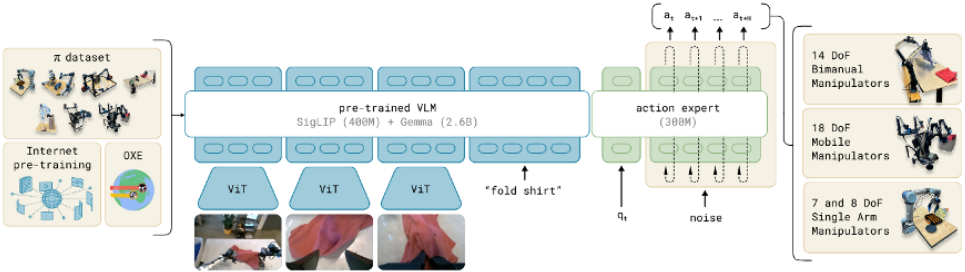
Vision-Language Models (VLM) - High Level

- **The Core Idea:** Giving Large Language Models "eyes".
  - **Input:** Image + Text - **Output:** Text reasoning
  - Trained on internet-scale data
- Why is this better than standard detectors?
  - Standard Detector: Output is "Box: Cup".
  - VLM: Output is "The cup is empty and close to the edge."
  - They understans **context** and **relationships** - crucial for robotics.

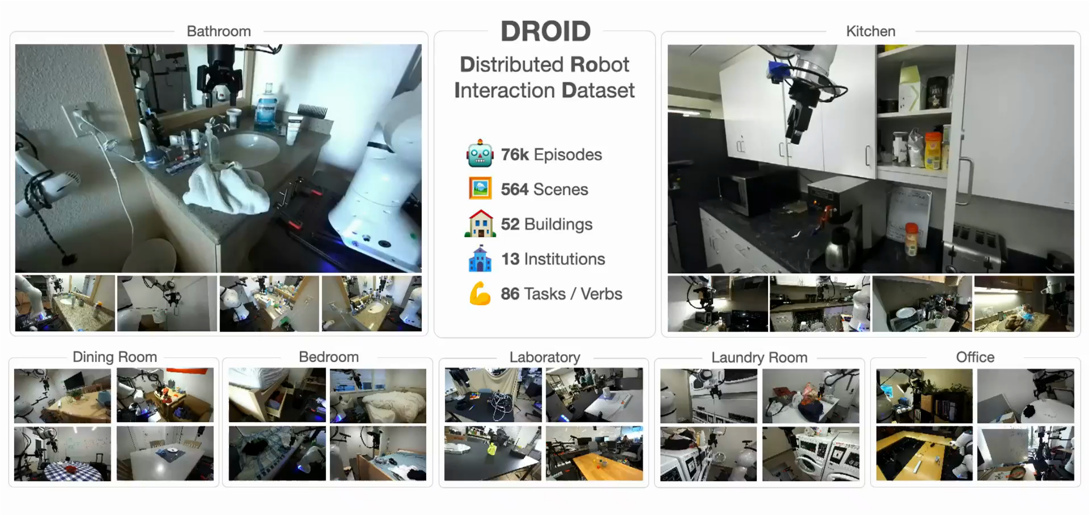


From VLM to VLA (Vision-Language-Action) model

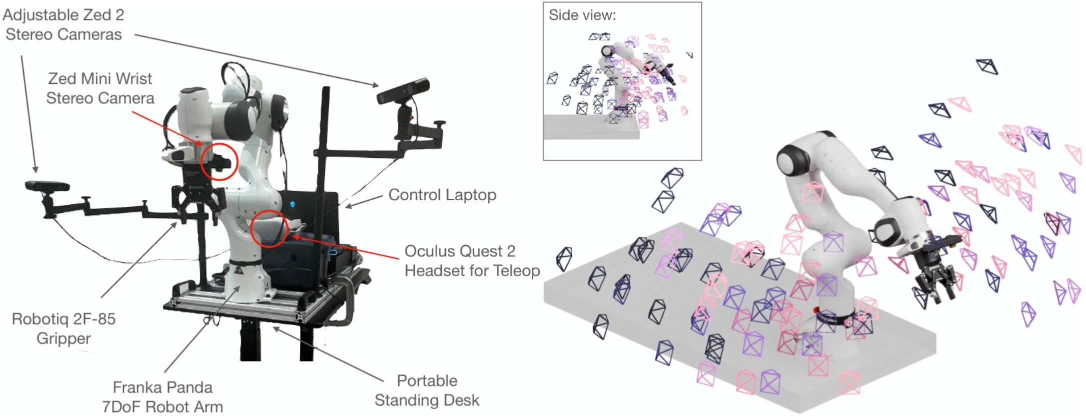
- Robots need to output **actions**, not just text
- π_0 architecture
  - 3 input images (from three cameras)
  - query text (task description)
  - robot configuration q
  - outputs a horizon of robot actions



We need data for training - DROID



DROID



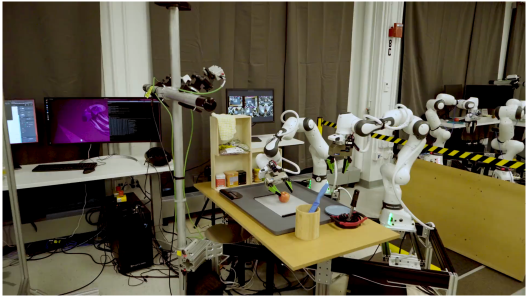
Adjustable Zed 2
Stereo Cameras
Zed Mini Wrist
Stereo Camera
Control Laptop
Oculus Quest 2
Headset for Teleop
Robotiq 2F-85
Gripper
Franka Panda
7DoF Robot Arm
Portable
Standing Desk
Side view:

How it works after training

Put the apple into the pot and close the lid.

Put chips into the bowl.

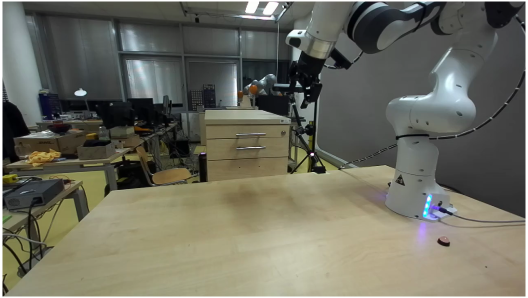
Examples from other platforms - impressive results



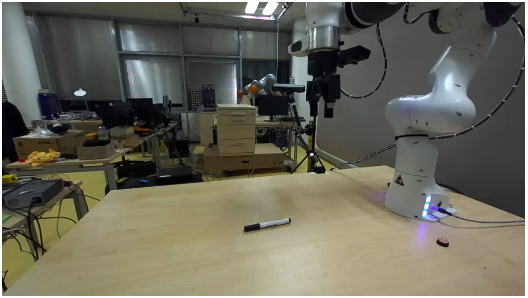
Slice the apple.

Take the laundry out of the washing machine.

Reality check

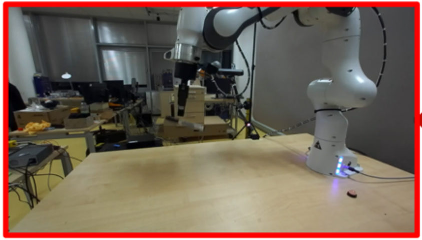


Open the top drawer.



Rotate the marker.

So where are we actually?

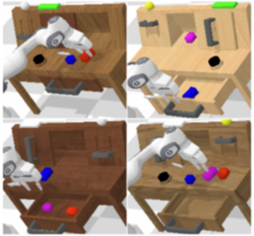


?

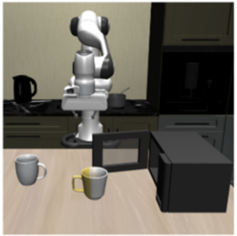
Evaluating Vision-Language-Action Models

- VLAs can handle deformable objects or sliding apples
- They still fail on some simple tasks
- Key questions about their performance remain:
  - What are the failure modes?
  - How well do VLAs understand human language instructions?
  - Can VLAs generalize across diverse objects, scenes and tasks?
- Problem: real-world evaluation is very expensive...

Solution: Simulated benchmarks

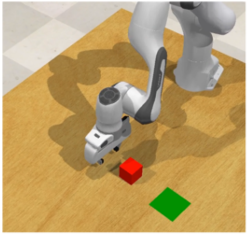


CALVIN [1]



LIBERO [2]

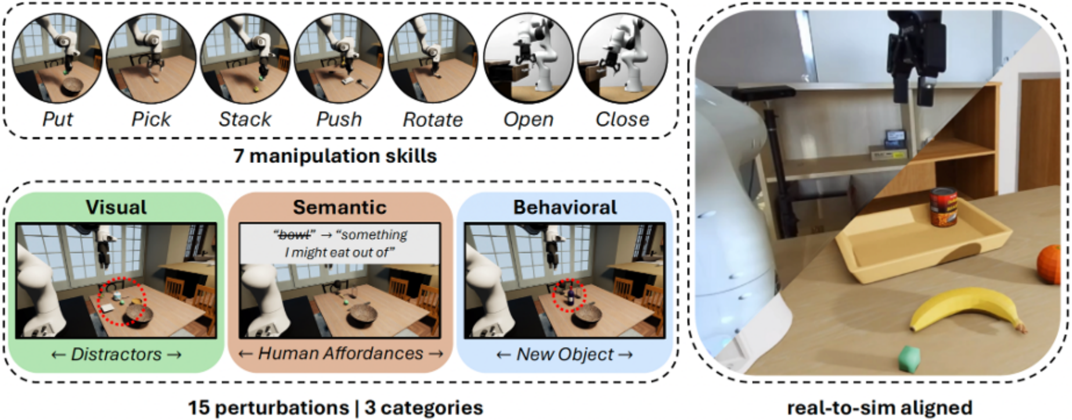
VLABench [3]



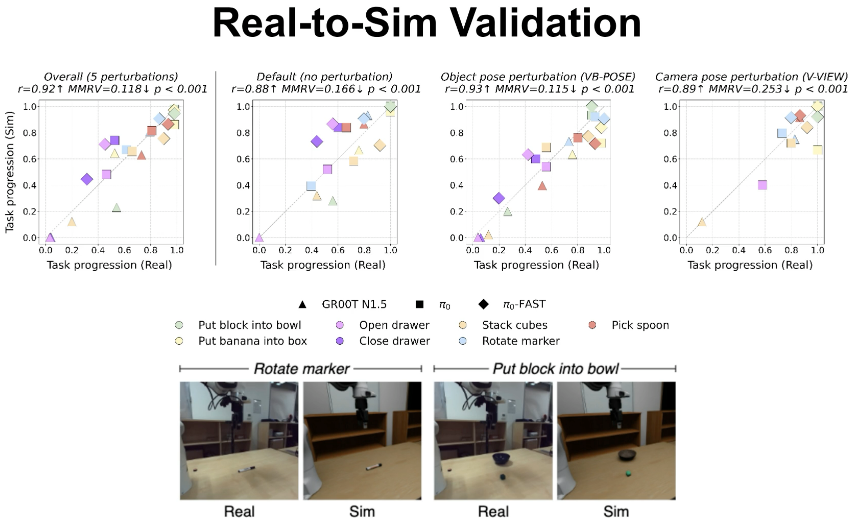
COLOSSEUM [4]

- Can we trust the results?
- Real-world performance of VLAs does not correspond to simulated performance
  - Visual gap
  - Control gap

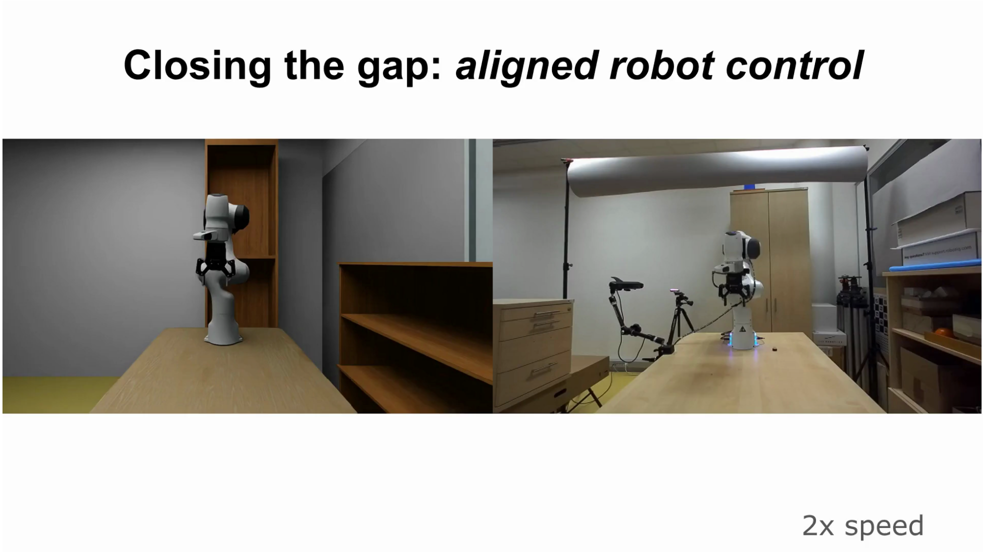
REALM: a real-to-sim validated generalization benchmark



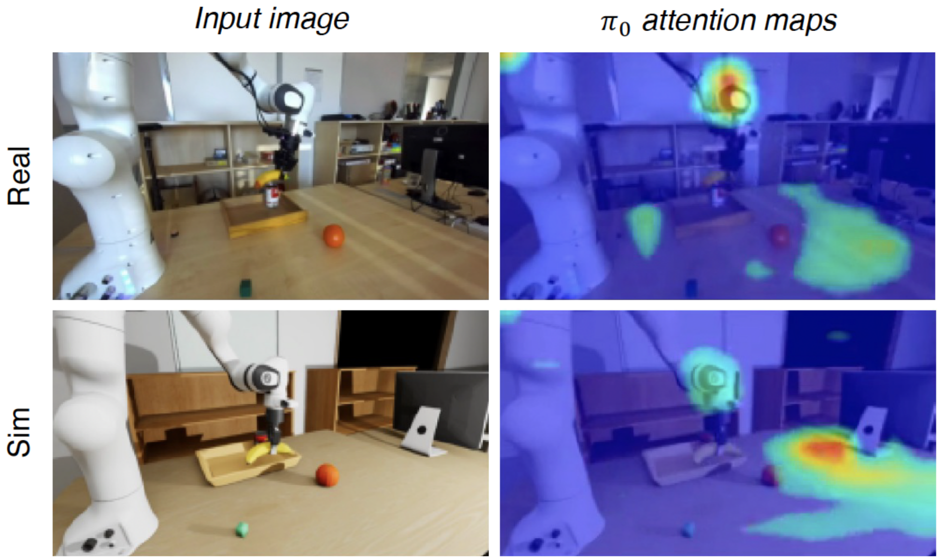
Real-to-sim validation



Control alignment



Visual validation

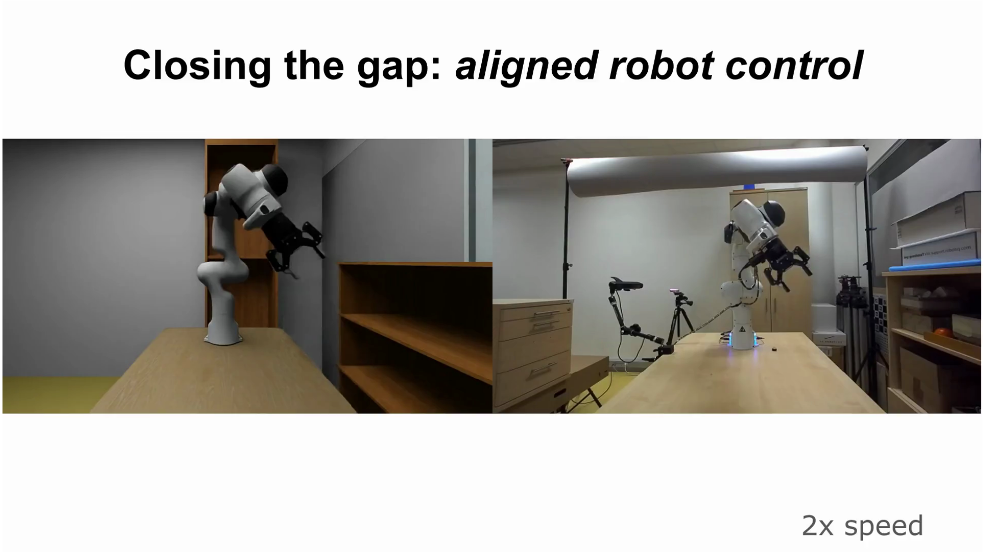


REALM benchmark

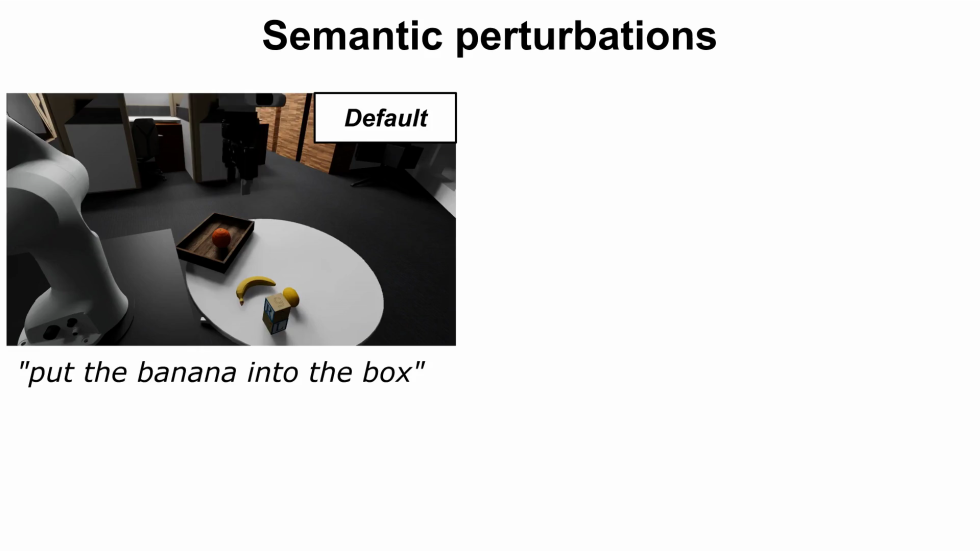
- We have a trusted simulator - 800 rollouts in the real world compared to simulation.
- We can build generalization benchmark via perturbations.
  - Visual perturbations
  - Semantic perturbations
  - Behavioral perturbations

Perturbation	Description & Implementation
Default	Testing a skill under no specific perturbations.
	Visual
V-AUG	Randomize *blur* and *contrast*.
V-SC	Randomly spawn *new distractors* in the scene.
V-VIEW	Random shifts to external *camera pose*.
V-LIGHT	Randomize illumination *color* and *intensity*.
	Semantic
S-PROP	Reference objects based on their properties.
S-LANG	Reference similar verbs and remove articles.
S-MO	Reference spatial relationships in the scene.
S-AFF	Reference human needs and use cases.
S-INT	Reference facts about the world that typically require knowledge from Internet-scale text data.
	Behavioral
B-HOBJ	Randomize manipulated object *mass*.
	Visual+Behavioral
VB-POSE	Randomize manipulated *object pose*.
VB-MOBJ	Randomize object *size* and *shape*.
	Semantic+Behavioral
SB-NOUN	Reference *another known object in the scene*.
SB-VRB	Change the *tested skill* for another compatible one.
	Visual+Semantic+Behavioral
VSB-NOBJ	Sample a *new unseen manipulated object*.

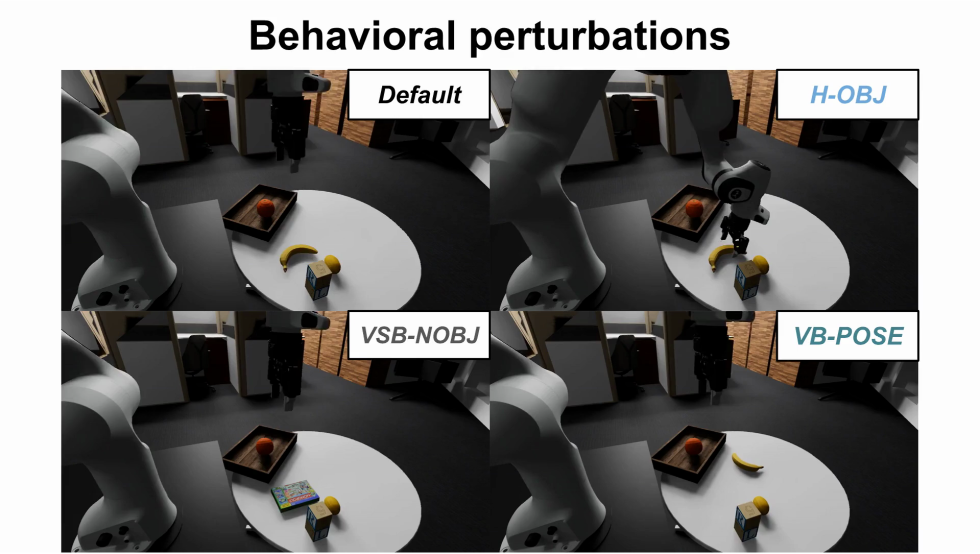
Visual perturbations



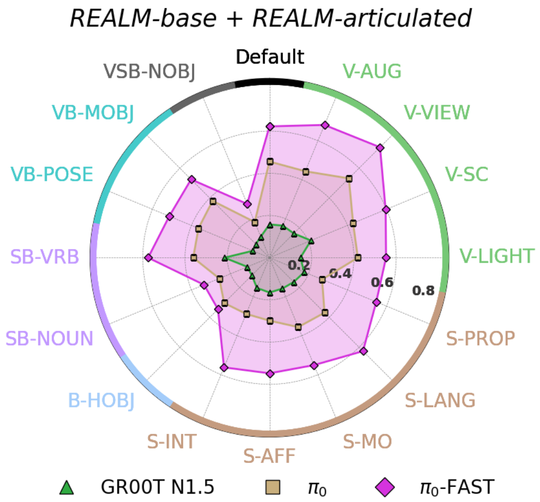
Semantic perturbations



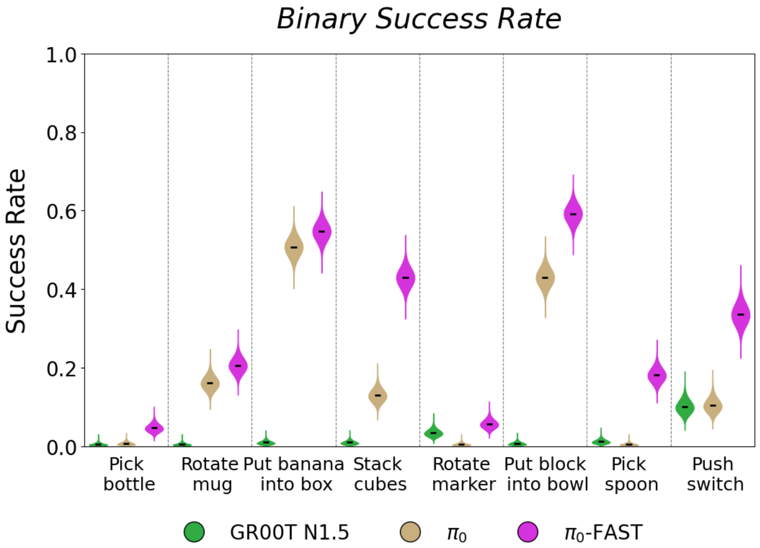
Behavioral perturbations



Performance of VLAs



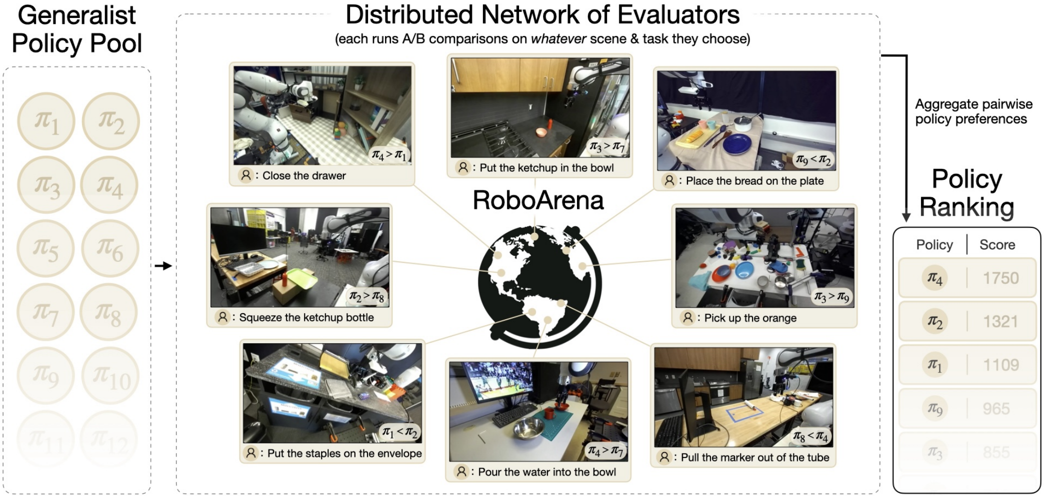
Performance of VLAs



Takeaways for VLAs

- High-fidelity simulation with aligned robot control can serve as a valuable **proxy** for real-world performance
- Noticeable drop in performance under semantic perturbations
- High sensitivity to camera view
- All skills are short-horizon
  - Put something into something
  - Wipe a board
- Reliability and robustness have not yet been achieved - we need more data

RoboArena

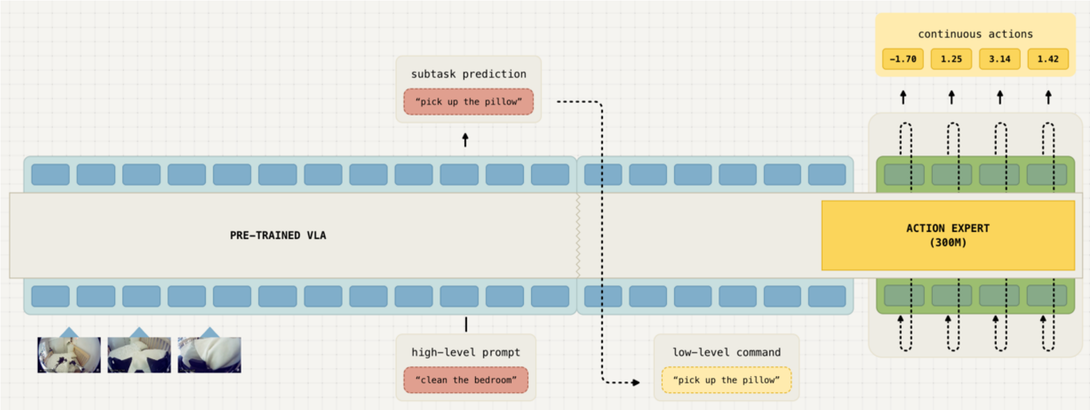


Generalist Policy Pool
π_1 π_2 π_3 π_4 π_5 π_6 π_7 π_8 π_9 π_{10} π_{11} π_{12}
Distributed Network of Evaluators
(each runs A/B comparisons on *whatever* scene & task they choose)
$\pi_4 > \pi_1$
: Close the drawer
$\pi_3 > \pi_7$
: Put the ketchup in the bowl
$\pi_9 < \pi_2$
: Place the bread on the plate
RoboArena
$\pi_2 > \pi_8$
: Squeeze the ketchup bottle
$\pi_3 > \pi_9$
: Pick up the orange
$\pi_1 < \pi_2$
: Put the staples on the envelope
$\pi_4 > \pi_7$
: Pour the water into the bowl
$\pi_8 < \pi_4$
: Pull the marker out of the tube
Aggregate pairwise policy preferences
Policy Ranking
Policy | Score
π_4 1750
π_2 1321
π_1 1109
π_9 965
π_3 855

RoboArena Leaderboard

Rank	Policy	Score	SD	# A/B Evals	Open Source
1	pi05_droid	1867	29.1	490	
2	pi0_fast_droid	1819	27.9	654	
3	paligemma_fast_specialist_droid	1806	28.8	873	✓
4	paligemma_vq_droid	1780	30.3	680	✓
5	paligemma_fast_droid	1744	31.5	882	✓
6	paligemma_diffusion_droid	1652	43.8	678	✓
7	dam	1238	219.3	60	✓
8	pi0_droid	887	32	939	
9	paligemma_binning_droid	707	28.7	566	✓

Hierarchical reasoning - π 0.5



Conclusion

- VLAs can revolutionize robotics
  - Active research area
  - Needs data
- To remember
  - what is VLA
  - difference between simulated and real-world evaluations
- Topics not covered
  - Other modalities for VLA
  - Chain of thought reasoning for VLA
  - Safety issues
- Do you want to contribute to VLM/VLA research?

Exam

- CIIRC: B670
- Written (2h):
  - Theoretical questions
  - Computation with transformations
  - Kinematics of open kinematic chains
- Oral exam (10 minutes)