Learning to Rearrange with Physics-Inspired Risk Awareness

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Risk Aware Decision Making Workshop at RSS 2022

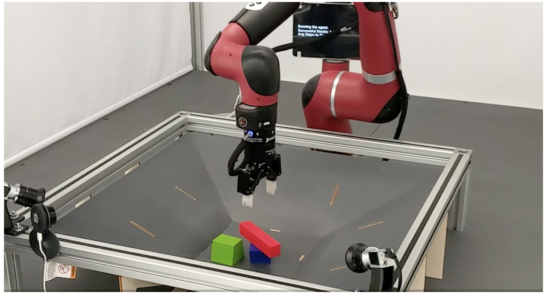
UCSD

Risks in Physical Interactions

- Real-world applications require a robot operating in the physical world with awareness of potential risks besides accomplishing the task.
- A large part of risky behaviors arises from the physical process of robot interacting with objects.

Locomotion on slippery ground

Pushing a heavy box



Stacking blocks into a tower

Credit: Legged Robotics at ETH Zürich, 2019
Adobe Stock image by CYCLONE
Beyond Pick-and-Place: Tackling Robotic Stacking of Diverse Shapes, Lee, Devin et al., 2021

Physics-Inspired Risk Quantification

- Model the risk in terms of **physical cost** over the trajectories in rearrangement tasks.
  - The amount of **virtual physical work** the agent spends on pushing an object
  - **Step physical cost** c(t)
    - Normalize over all steps so far

$$c(t) = \frac{E(t) - E_{min}(t)}{E_{max}(t) - E_{min}(t)}$$

  - **Episode physical cost** c(τ)
    - Normalize over all successful episodes so far

$$c(\tau) = \frac{E(\tau) - E_{min}(\tau)}{E_{max}(\tau) - E_{min}(\tau)}$$

- Incorporate physical cost into the reward functions of RL formulation

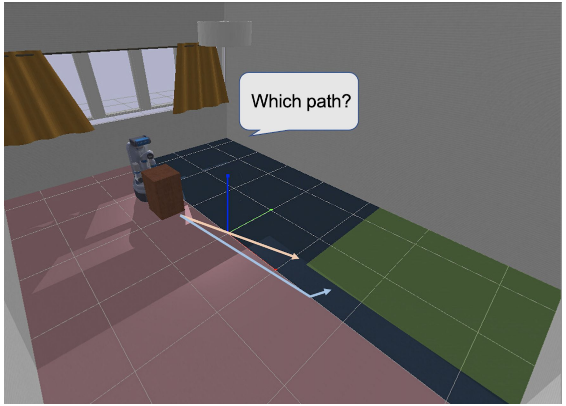
Physics-Aware Indoor Rearrangement Tasks

- 3D simulated environments
  - Physics engine: Pybullet
  - Renderer: iGibson
  - Classroom scenes: OpenRooms dataset
  - Fetch robot
    - Two-wheel
    - Fixed torso and arm
- State space
  - 3D positions and orientations of robot and the interactive objects
- Action space
  - Four discrete actions: move forward, stop, turn left, turn right
  - Parameterized by wheel velocity

Variable Friction Pushing Tasks

- Two-band floor with different friction coefficients
- The agent aims to push the box to the target region across a floor along the most physically efficient trajectory without collisions with obstacles.

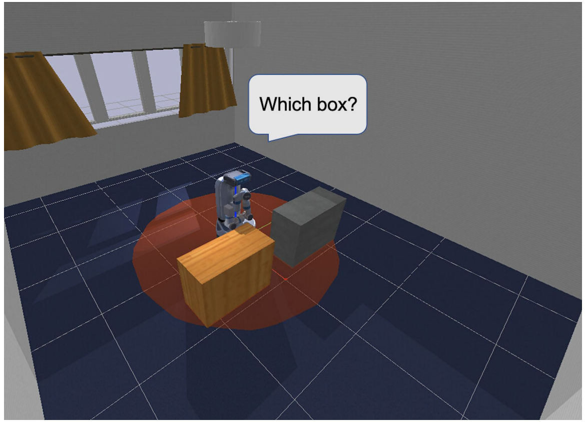
$$r(\mathbf{s}_t, \mathbf{a}_t) = \begin{cases} 10 & \text{succeed} \\ -10 & \text{agent collides with obstacles (e.g. walls)} \\ -0.5 \cdot \boxed{c(t)} & \text{agent pushes box} \\ -1 & \text{otherwise} \end{cases}$$



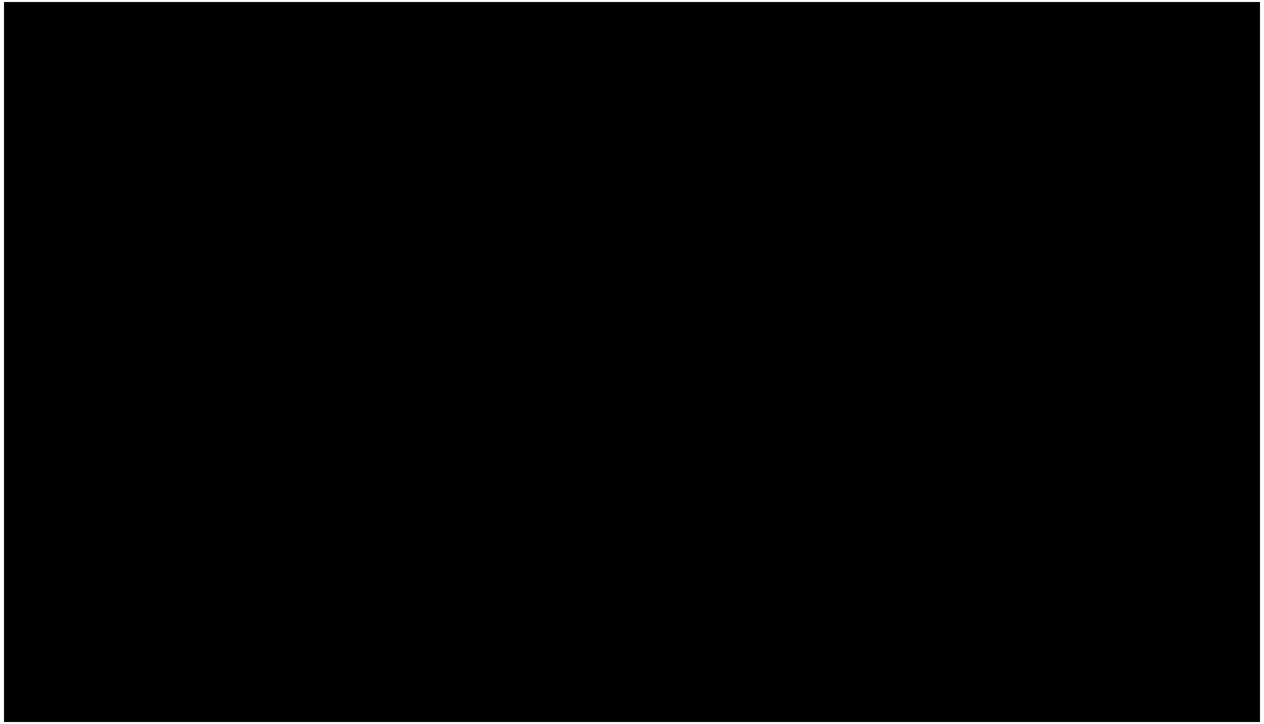
Variable Mass Pushing Tasks

- Two boxes have the same geometry, but different weights.
- The agent aims to push at least one box outside the circle without collisions with obstacles in minimum physical efforts.

$$r(\mathbf{s}_t, \mathbf{a}_t) = \begin{cases} 100 \cdot (1 - \boxed{c(\tau)}) & \text{succeed} \\ -10 & \text{agent collides with obstacles (e.g. walls)} \\ 0 & \text{otherwise} \end{cases}$$



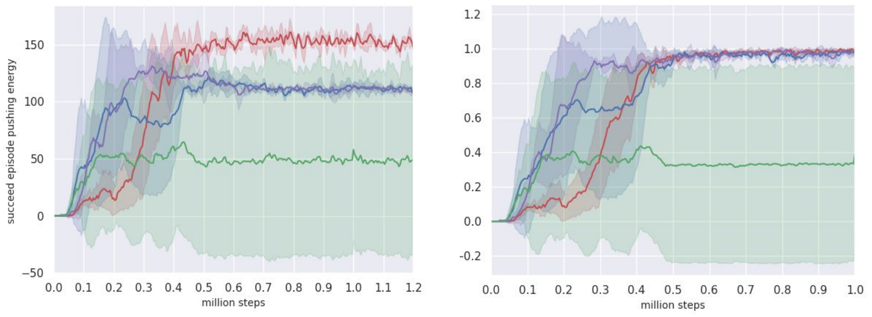
Results



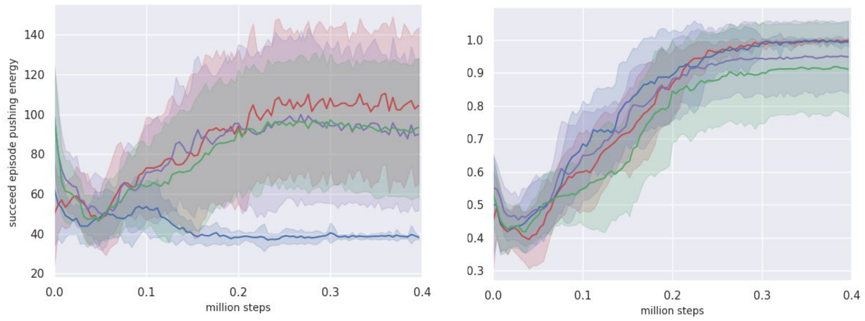
Results

- The policies learned with our physics-inspired reward function
  - Successful and physically efficient
  - Reflect the agent’s awareness of mass and friction
  - Perform better than other design strategies

Ours
No energy
Robot energy normalized by running bounds
Pushing energy normalized by fixed bounds



Variable friction pushing task



Variable mass pushing task

Future Work

- Extend the method to vision-based RL
  - To correlate the object appearance with physical properties
  - To generalize the risk-aware policies to unseen layouts
- Learn the physical risk in small pushing, lifting and locomotion trials and inject the priors to downstream tasks