Schedule

Start	End	Section	Speaker
13:00	13:45	Overview of Embodied AI	Zhiwei Jia (video)
13:45	14:30	The Basic Frameworks and techniques for Embodied AI	Fanbo Xiang (in person)
14:30	15:15	Design Choices in Embodied AI Environments	Jiayuan Gu (video)
15:15	15:30	Break	
15:30	16:15	Experience and Practices to Debug Simulators	Fanbo Xiang (in person)
16:15	16:35	Real World Robotics and Sim2Real	Rui Chen (video)
16:35	17:00	Embodied AI Tasks in ManiSkill and Visual Learning Challenges	Fanbo Xiang (in person)

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SFU SIMON FRASER UNIVERSITY

Building and Working in Environments for Embodied AI

CVPR 2022 Tutorial


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Overview of Embodied AI: Simulators, Datasets and Tasks

Building and Working in Environments for Embodied AI (part I)

CVPR 2022 Tutorial

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Overview

This part of the tutorial is intended to give an introduction of Embodied AI

- What is Embodied AI and why Embodied AI?
- Why studying Embodied AI in virtual environments?
- What are the key factors of building environments?
- Roadmap for other parts of the tutorial

Outline

- Background
  - Why embodiment in AI and What is Embodied AI?
- What are the Key Factors in the Environments?
  - Simulators
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Example: Penalty Kick

You have to learn by doing!

Image source: https://www.thesoccerstore.co.uk/blog/football-goals/best-kids-garden-football-goals/

Embodiment Hypothesis:

"intelligence ***emerges*** in the interaction of an agent with an environment and as a result of sensorimotor activity"

The Development of Embodied Cognition: Six Lessons from Babies

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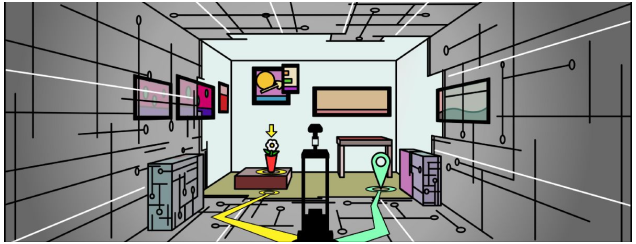
Abstract The embodiment hypothesis is the idea that intelligence emerges in the interaction of an agent with an environment and as a result of sensorimotor activity. We offer six lessons for *developing* embodied intelligent agents suggested by research in developmental psychology. We argue that starting as a baby grounded in a physical, social, and linguistic world is crucial to the development of the flexible and inventive intelligence that characterizes humankind.

Keywords
Development, cognition, language, embodiment, motor control

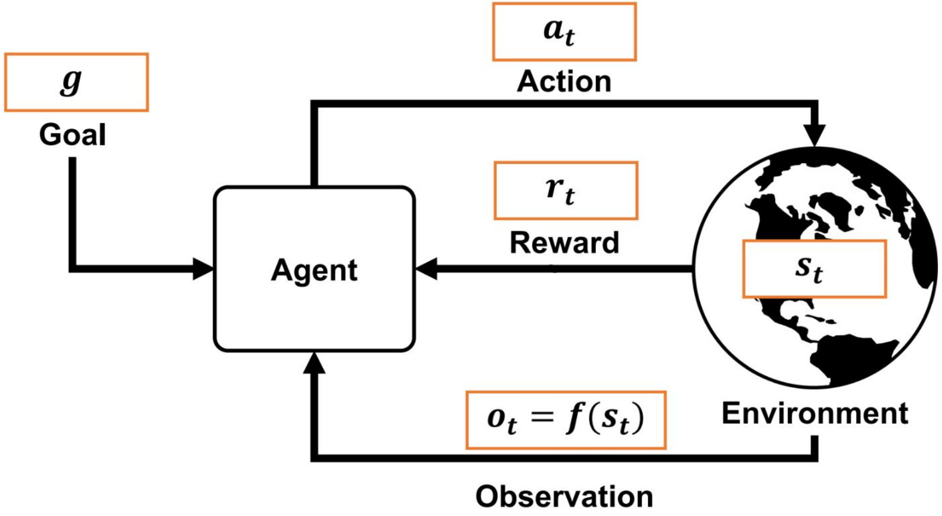
What is Embodied AI?

- Concretely, the study of intelligent agents to solve tasks by
  - **seeing** (usually in an egocentric view)
  - **talking** (via texts or audios)
  - **reasoning** (understand the surroundings and plan)
  - **acting** (through motor controls or high-level actions).
- An interdisciplinary field
  - Embodied AI Workshop @ CVPR 20/21/22



How to Model Agents, Environments & Tasks?

Usually via a Markov Decision Process (MDP)



Slide Credit: Stefan Lee

How to model the intelligent agents, the environment and the tasks?

- Usually via partially-observed Markov decision process

  S, O, A: State, Observation and Action space

  $p(s)$ the observation distribution

  T the dynamics, $\mathcal{R}$ the reward

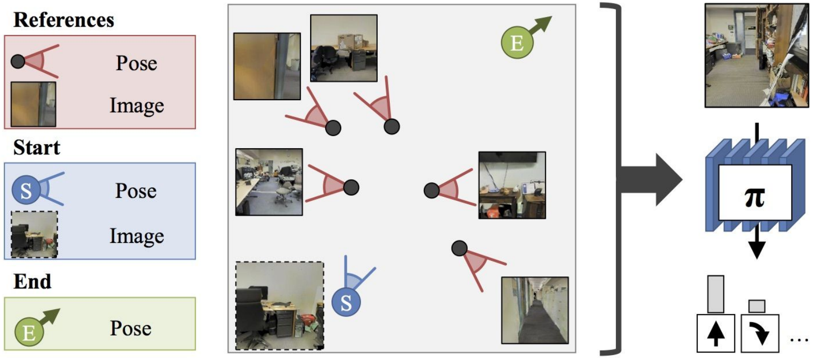
  ρ_0 the initial state distribution

  γ the discount factor

  H the finite horizon

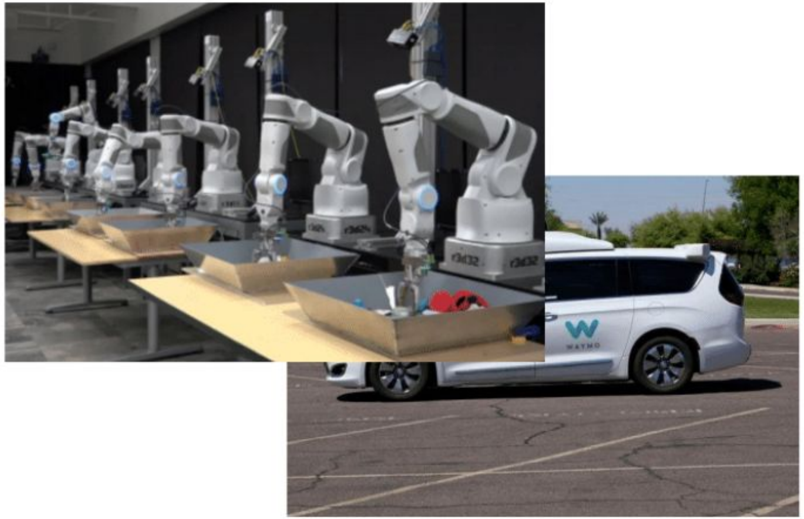
$$\pi^* = \arg\max_{\pi} \mathbb{E}_{\tau\sim\pi} \sum_{t=0}^{H} \gamma^t r_t$$

$$(\mathcal{S}, \mathcal{O}, \mathcal{A}, p(s), T, \mathcal{R}, \rho_0, \gamma, H)$$



Many Embodied AI Work Starts from Virtual Environments. Why?

- Learning in real world: dangerous and expensive
- Learning in virtual environment: safe and scalable



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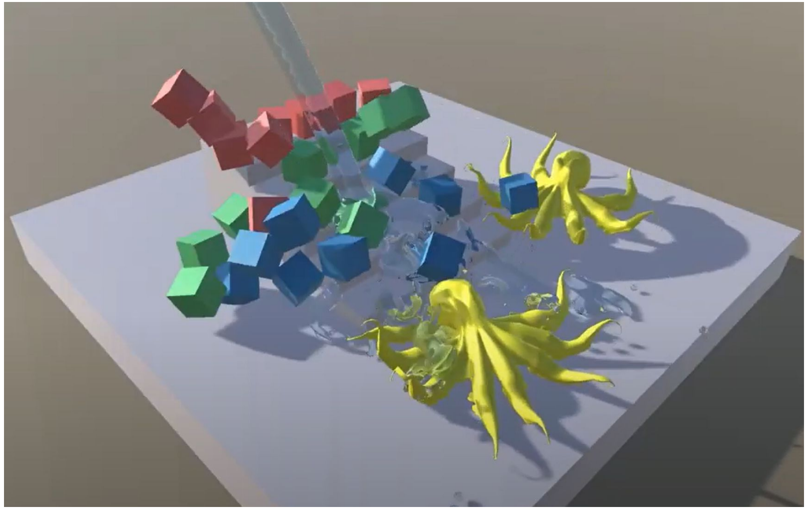
What is a Simulator?

- Simulator = **Physics Simulation** + **Sensory Signal Rendering**
- Simulation provides the mathematical model of the dynamics
- Rendering provides observations of the robot and its surroundings



Source: Nvidia FleX

What to Consider When Choosing a Simulator?

- Rendering
- Physics
- Speed
- Objects types and properties
- Action modeling
- Human interface

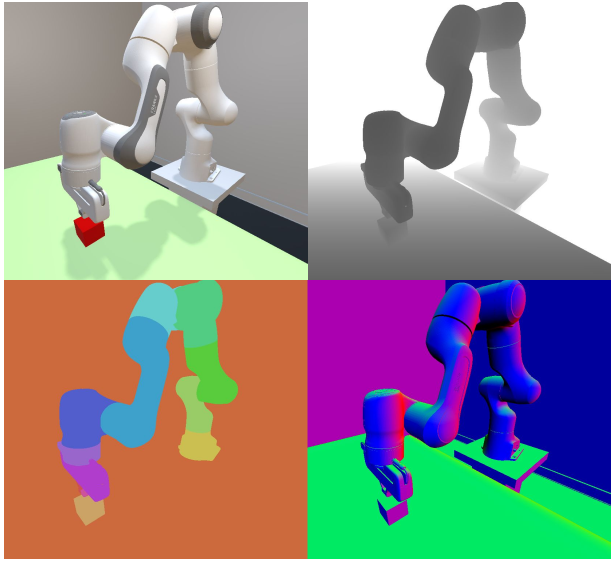
Rendering in Simulators

- What type of sensory signals are supported?

Rendering in Simulators

Common sensory signals

- RGB, depth, surface normal
- Instance/semantic segmentation
- Optical flow, scene flow

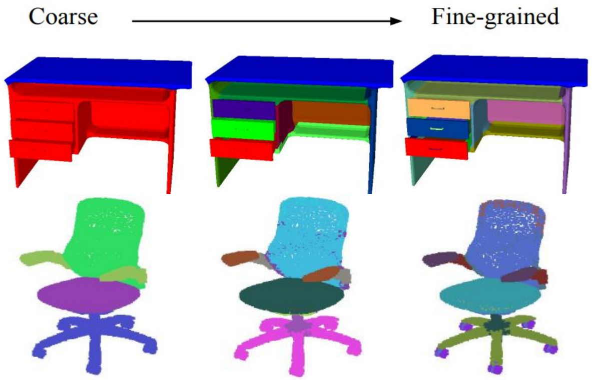


ManiSkill 2022: rgb, depth, semantic segmentation, normal

Rendering in Simulators

Uncommon sensory signals

- Part-level segmentation
  - Help to understand dynamics of articulated objects.
- Acoustic signals
  - Help to understand mass, texture, collision, etc.

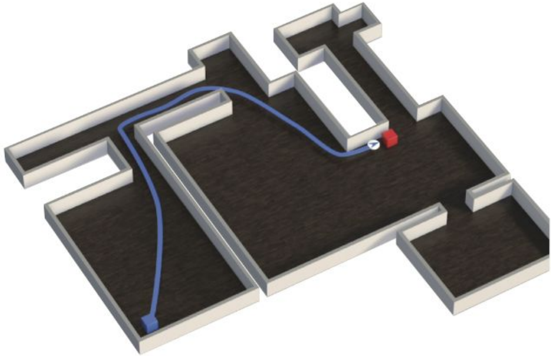


PartNet

ThreeDWorld

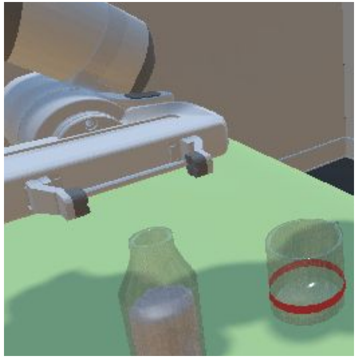
Physics

- Physical vs. non-physical simulation
  - No-physics, rigid-body, articulated body, fluid and soft-body
- Different tasks require different granularity level of physics



Partial Physics
(Figure from DD-PPO, for Visual Navigation)

Full physics
(ManiSkill 2021)



Full physics
(ManiSkill 2022)

Speed of Simulators

- Number of interaction steps per second affects what kind of training approaches are viable for solving tasks in the simulators.
    - **Imitation Learning?**
        - Slow simulators can be used. Only need to evaluate policies.
    - **Model-free RL?**
        - Need very fast simulators. Agents practices many times to learn.
    - **Model-based RL?**
        - Relatively fast simulator can be used. Agents use an internal world model to reduce dependency on interactions.

Speed of Simulators

Deciding factors of speed

- Speed of underlying engines
- Environment complexity
    - Geometry complexity
    - Interaction complexity
    - Rendering complexity

Objects Types and Properties

By kinematic structure:

- Rigid-body objects
- Articulated objects
- Soft-body objects

ManiSkill 2021

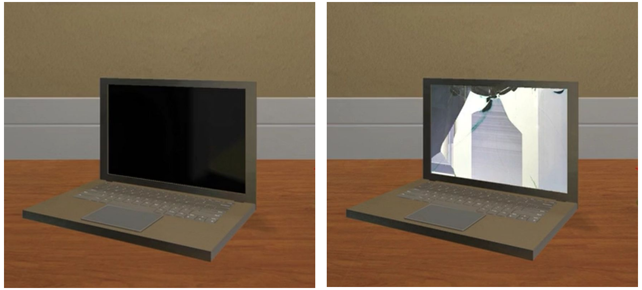
ManiSkill 2022

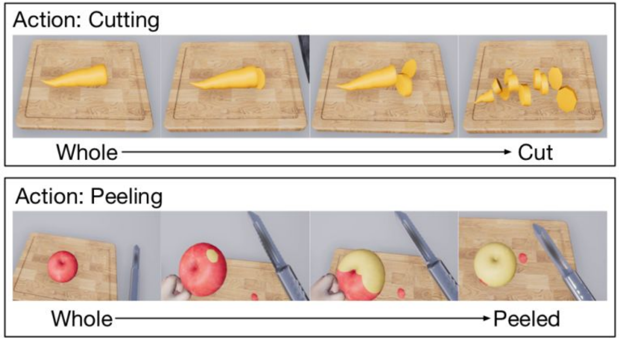
Objects Types and Properties

Other actionable properties

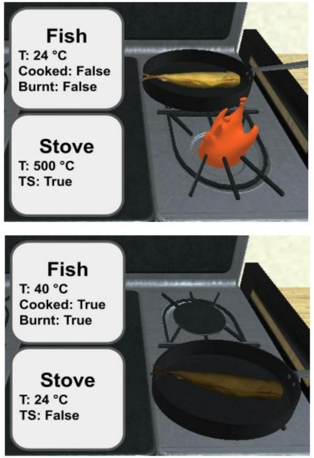
- AI2-THOR: cooled, broken, sliced, etc.
- iGibson 2.0: heated, cooked, etc.
- VRKitchen: cut, peeled, juiced, etc.

…


“Broken” from AI2-THOR



“Peeling” and “Cutting” from VRKitchen



“Cooked” and “heated” from iGibson 2.0

Action Modeling

What actions are supported? It depends on

- Types of **physics simulation** (introduced before)
- Types and properties of **objects** (introduced before)
- Types of **robots** (introduced next)

Actions can be classified as

- Low-level, high-level, somewhere in between, etc.

Action Modeling

Robot models to use

For example:

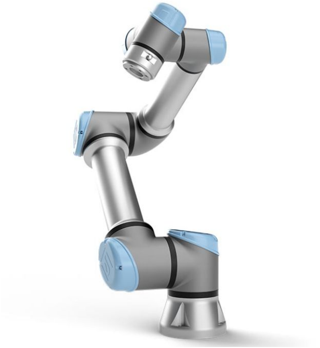
- Fetch
- Franka
- Kuka
- UR
- More at https://robots.ros.org/

Common concern: versatility vs. realisticity

Fetch

Franka

Kuka



UR

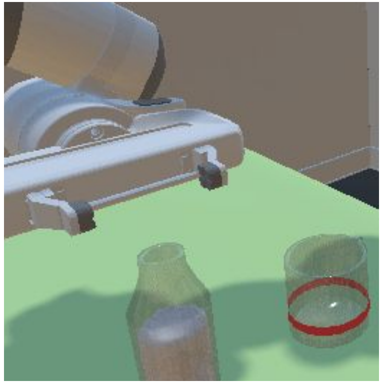
Action Modeling

Low-level vs. High-level Actions

- **Low-level** actions (e.g., motor controls)
  - Necessary for actual robot deployment to the real world
- **High-level** actions (e.g., [Action] [TargetObjA] [TargetObjB])
  - Good for long-horizon tasks, skill chaining, task planning, etc.
- Somewhere **in between**

High-level (iTHOR)

In between (ManipulaTHOR)

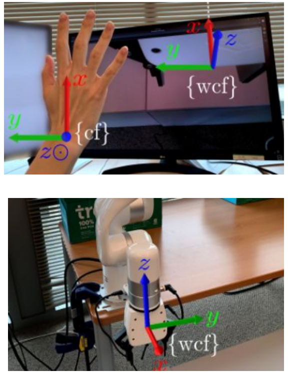


Low-level (ManiSkill 2022 in July)

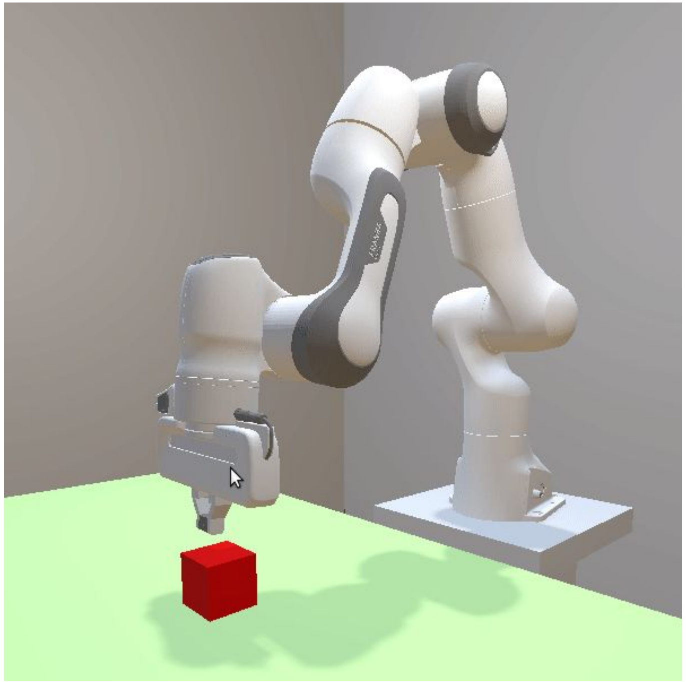
Human Interface

- Mouse & keyboard
- Virtual reality (VR)
- Vision-based Teleoperation

VRKitchen



“Single RGB-D Camera Teleoperation for General Robotic Manipulation”



SAPIEN

Outline

- Background
    - What is Embodied AI and why Embodied AI?
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What are Assets?

In simulation, we load data structures stored as files to

- **specify each object** by its properties;
- **define a scene** by the arrangement of objects;
- **represent demonstrations** with trajectories or human instructions;

  …

We call these data structures as assets.

Object Asset

Geometry and kinematic structure

- Mesh, revolute vs. prismatic joint, etc.

Optical material properties

- Reflection model, texture, etc.

Dynamical material properties

- Friction, mass properties (density, inertia), elasticity & plasticity, etc.

Other properties

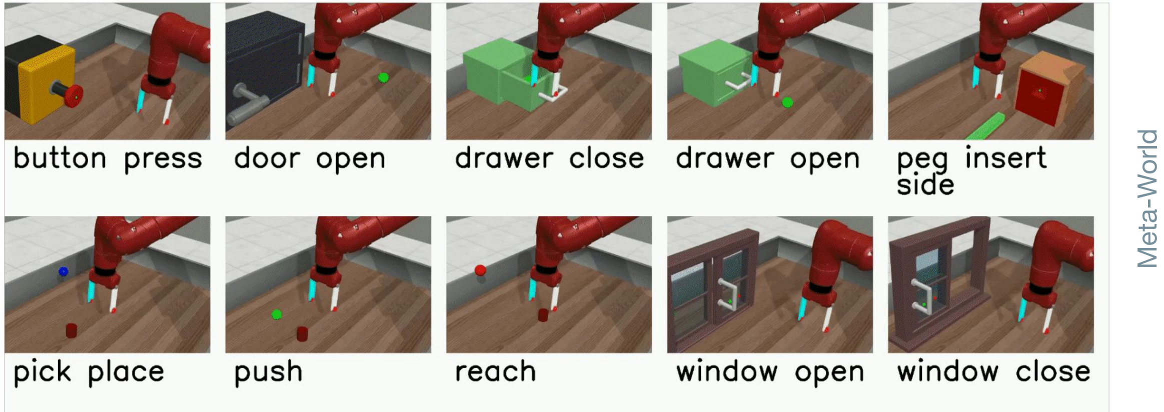
- Acoustics, thermodynamics, etc.

Object Asset Example 1: Grasping Assets

- YCB
- EGAD!

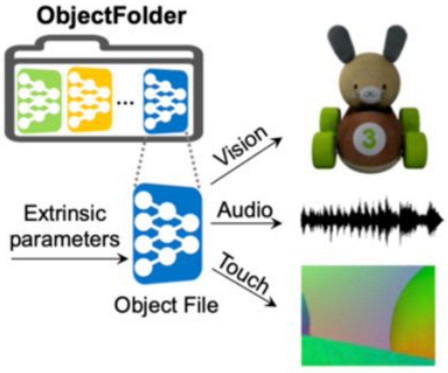
Object Asset Example 2: General Manipulation Skill Assets

- PartNet-Mobility
- DoorGym
- Objects from iTHOR
- Meta-World



Object Asset Example 3: Multisensory Object Assets

- ObjectFolder
- ThreeDWorld



ObjectFolder

ThreeDWorld

Scene Assets

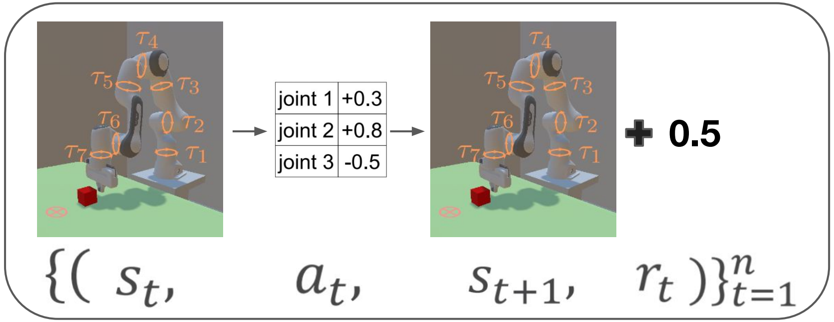
- Static
  - E.g, Habitat-Matterport 3D Dataset
- Interactable
  - E.g., iTHOR scenes

iTHOR

Habitat-Matterport 3D

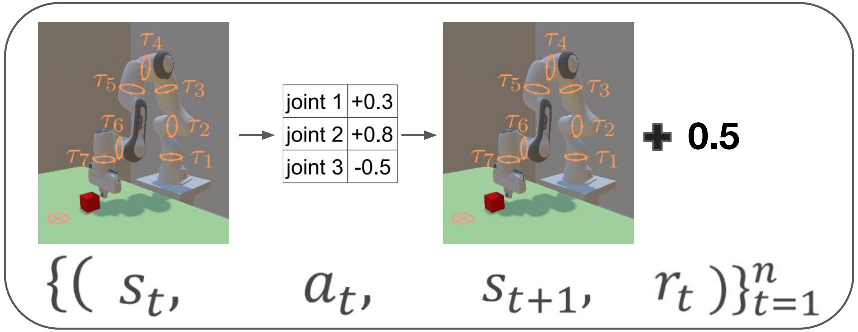
Demonstration Assets

State (ManiSkill)



Video (HOI4D)

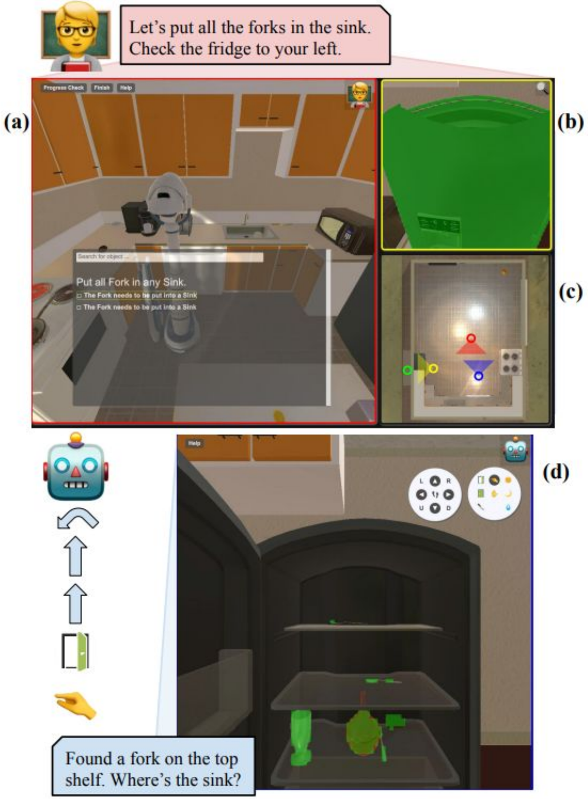
Language (ALFRED)



τ_4
τ_5
τ_3
τ_6
τ_2
τ_7
τ_1
joint 1 +0.3
joint 2 +0.8
joint 3 -0.5
+ 0.5
$\{(s_t, \quad a_t, \quad s_{t+1}, \quad r_t)\}_{t=1}^{n}$

Language-oriented Datasets & Assets

- Language also as outputs
  - Examples:
    - Embodied Question Answering
    - Vision-and-Dialogues Navigation
      - VLN + dialogues
    - Task-driven Embodied Agents that Chat
      - ALFRED + dialogues
  - Cons:
    - Even harder to train online as dialogue generation is an open question.



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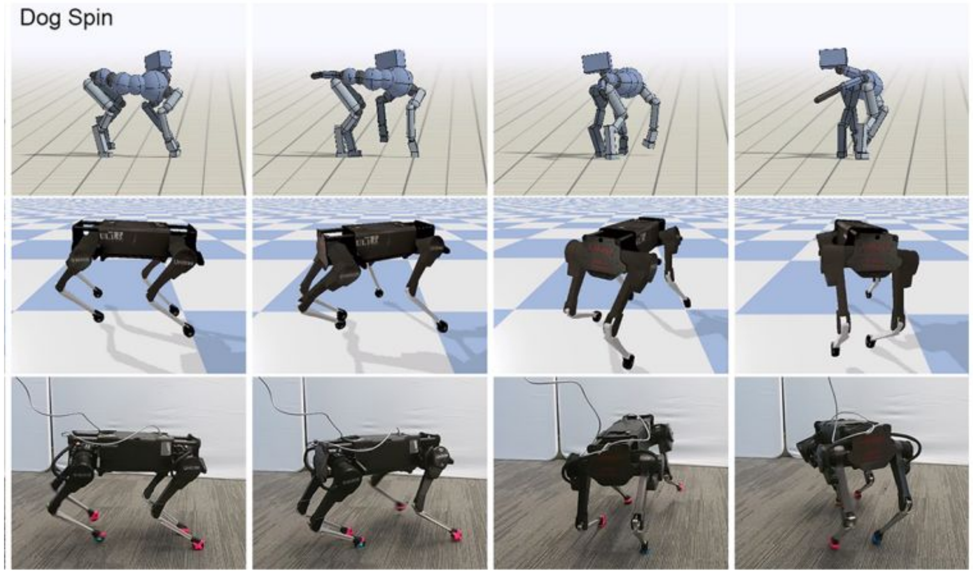
Example Tasks in Embodied AI

- Locomotion
- Visual navigation
- Object manipulation
- Rearrangement

Example of Locomotion - Legged Robot Control

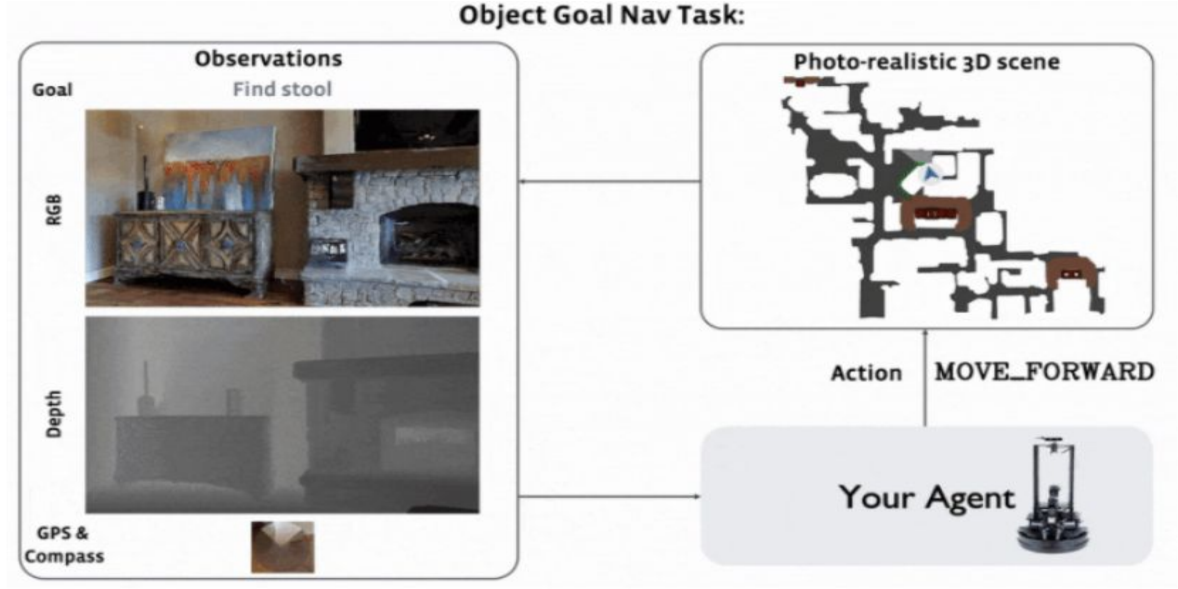
- Control a robot dog to perform a series of actions



"Learning Agile Robotic Locomotion Skills by Imitating Animals"

Example of Visual Navigation (VN) - Object Goal Navigation

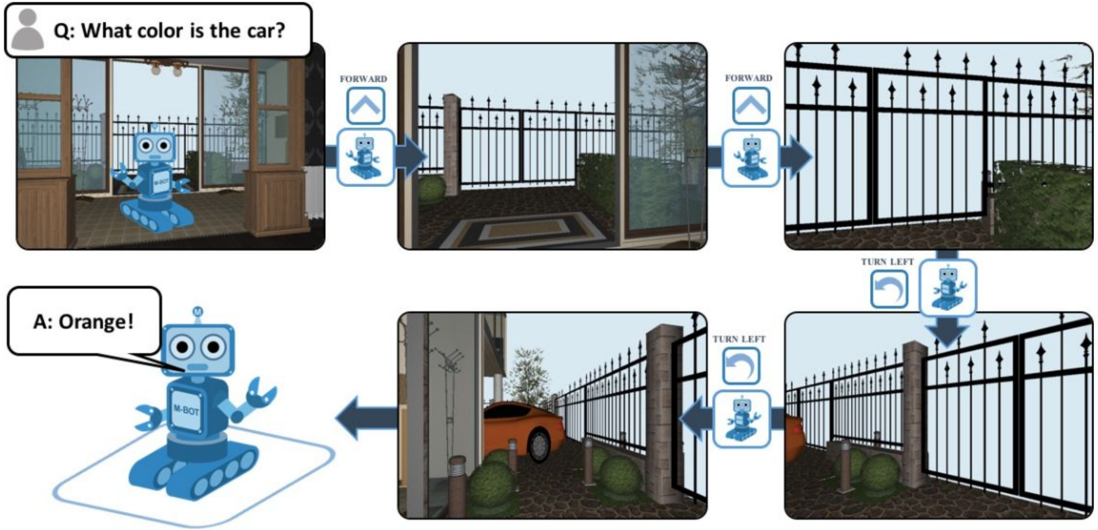
- Specify an object category and ask the agent to find it



From Habitat 1.0

Example of VN with Language - Embodied Question Answering

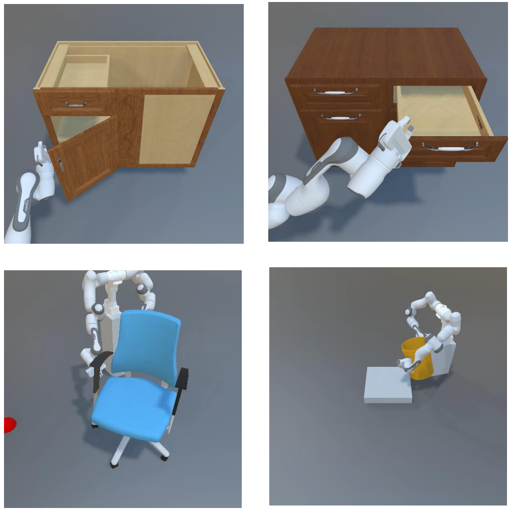
- Ask an agent to answer a question which requires it to navigate in the scene



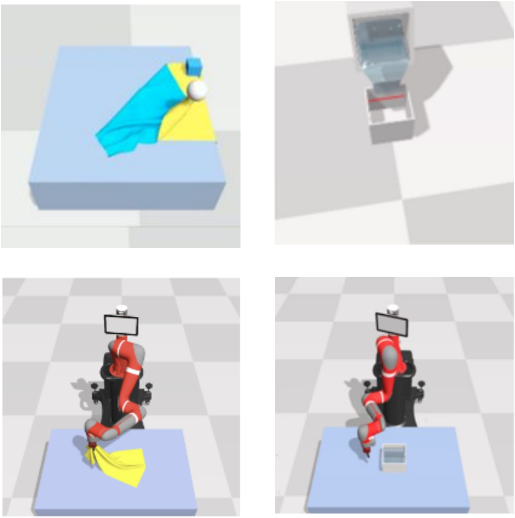
From https://embodiedqa.org/

Examples of Object Manipulation - ManiSkill and SoftGym

- Rigid/articulated object manipulation example - ManiSkill
- Soft-body manipulation example - SoftGym



ManiSkill 2021
(Note: ManiSkill 2022 will add softbody simulation tasks)



SoftGym

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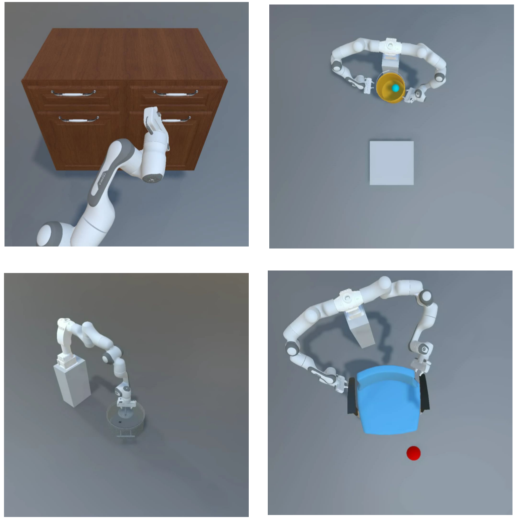
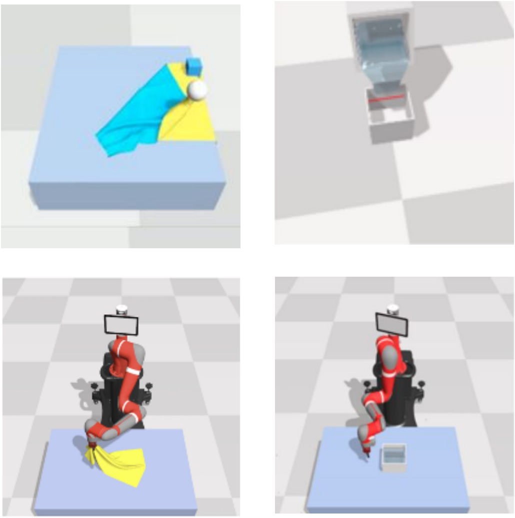


ManiSkill



SoftGym

Example of Object Manipulation with Language - ALFRED

- Ask the agent to perform object manipulations by high-level or step-by-step language instructions

Example of Rearrangement - AI2-THOR Rearrangement Challenge

- Ask the agent to bring poses of the objects to a specified configuration

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- **Part II: The Basic Frameworks and Techniques for Embodied AI**
  - Problem formulation, basics to RL/planning/control/simulation, environment construction example
- **Part III: Design Choices in Modern Embodied AI Environments**
  - Design factors, case studies by popular embodied AI frameworks
- **Part IV: Experiences and Practices to Debug Simulators**
  - Common issues, simulation debugging, environment optimization
- **Part V: Real Robot and Sim-to-Real**
  - Causes of domain gaps, techniques and tips to address sim-to-real gap
- **Part VI: Embodied AI Tasks in ManiSkill and Visual Learning Challenges**
  - Summary of ManiSkill 2021, preview of ManiSkill 2022