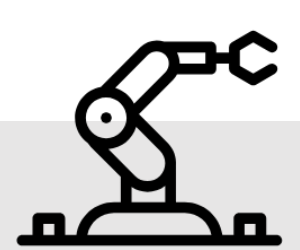# DexGarmentLab
Dexterous Garment Manipulation Environment with Generalizable Policy

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Project Page

MOTIVATION

🦾 ENVIRONMENT
Dexterous hands can handle garments with diverse deformables effortlessly, but relavant simulation environment is absent.
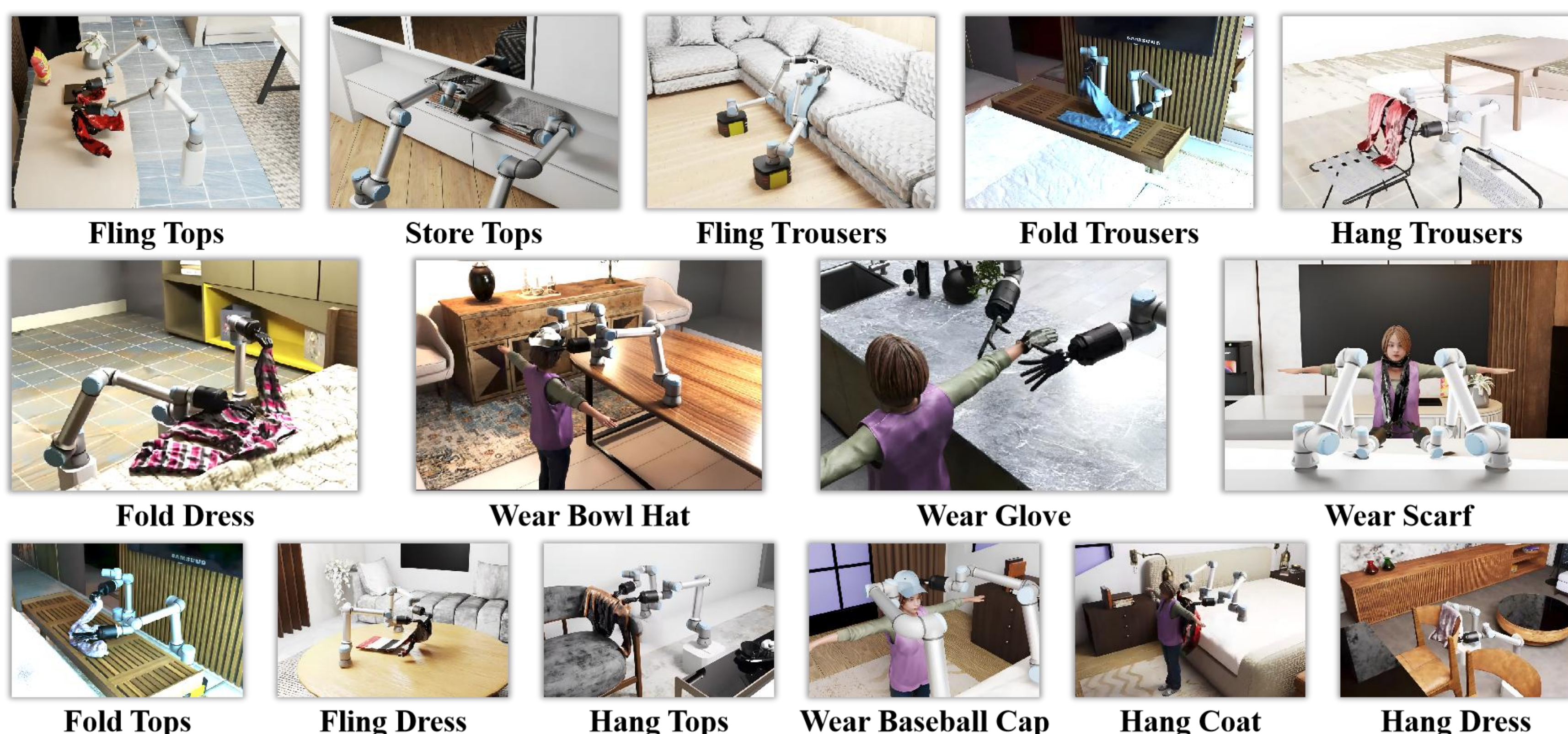
🗄 DATA
Data required for garment manipulation is much larger, but teleoperation-based data collection is both time and labor costly.
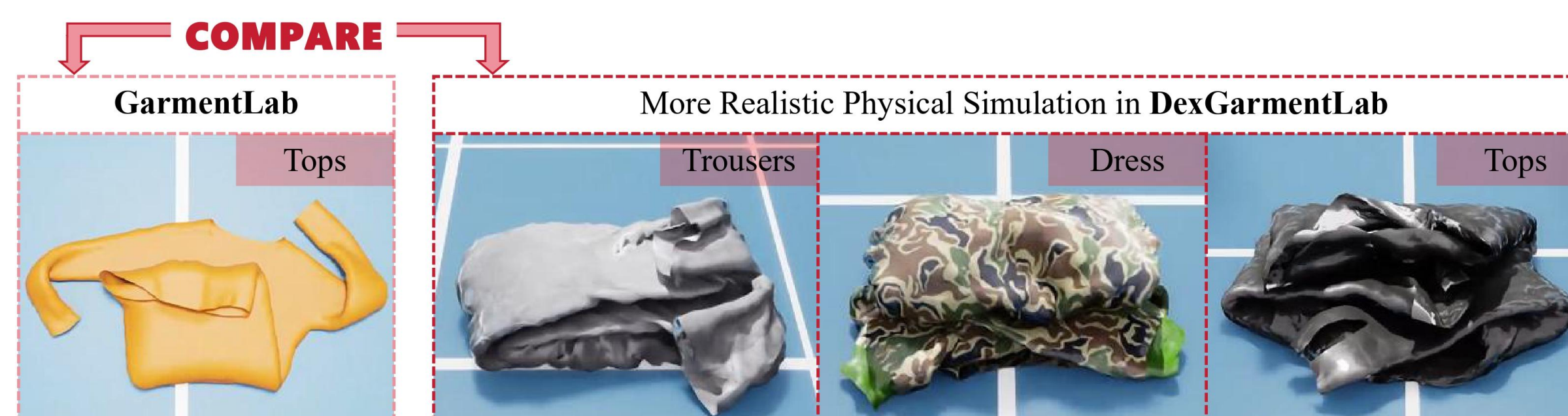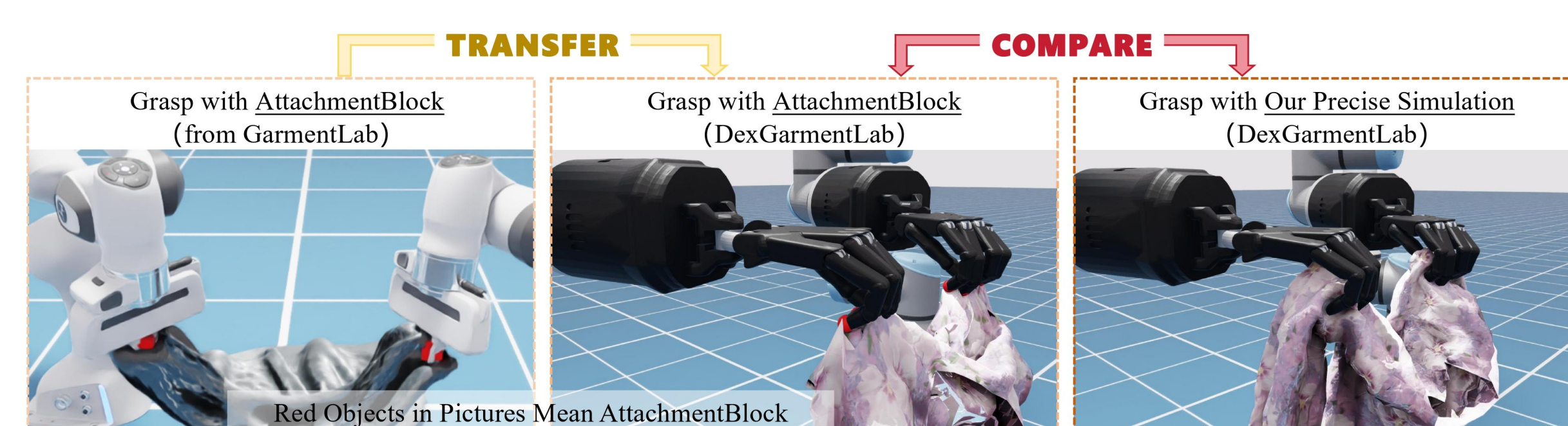
⚛ POLICY
The shapes and styles of garments are diverse, which makes current policy generalize poorly across category-level garments.

SIMULATION ENVIRONMENT

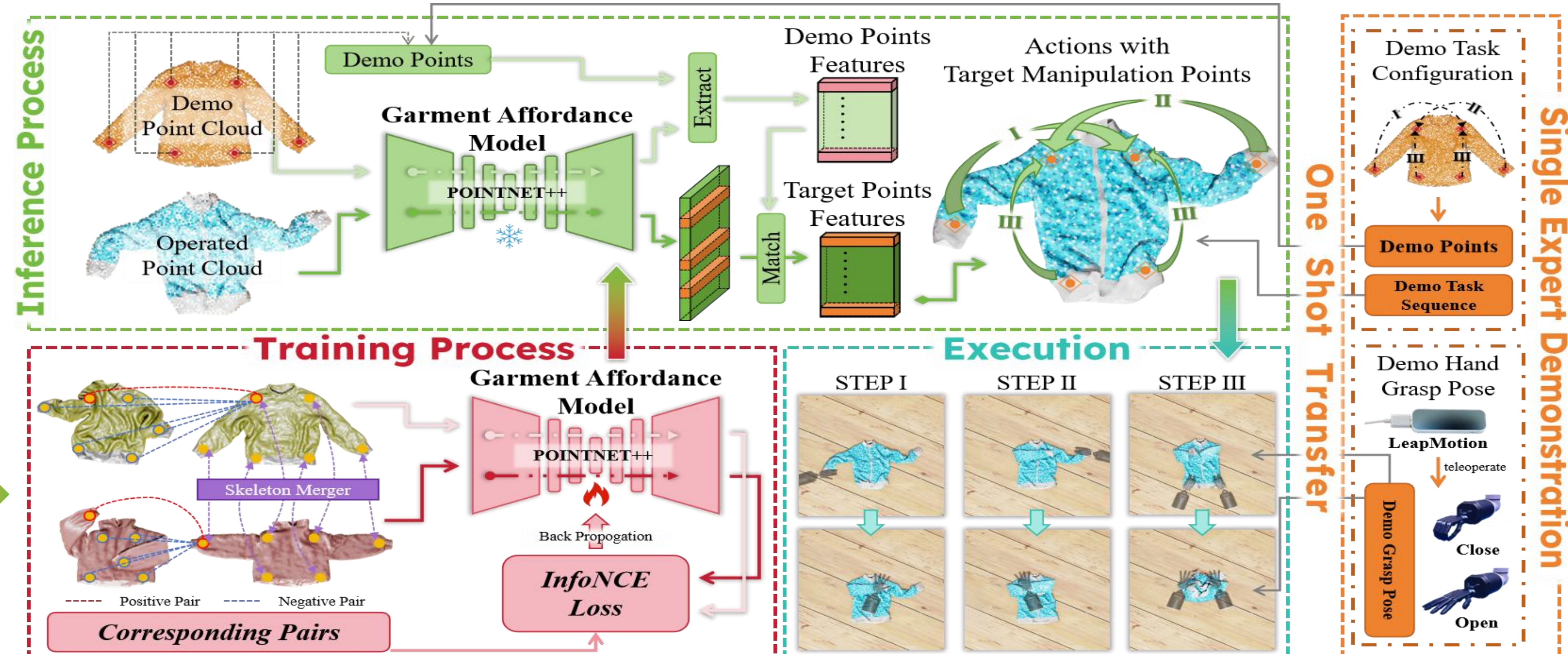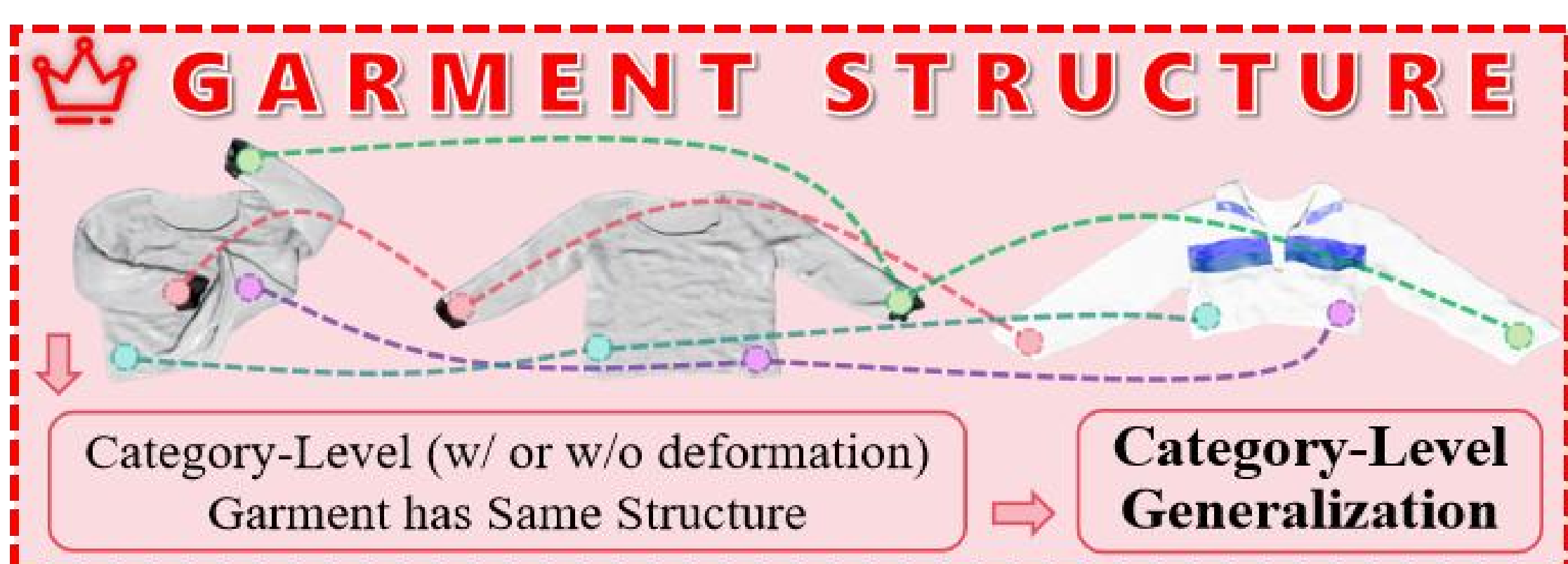15 Task Scenes   2500+ Garments   **Better** Simulation Performance

Task scenes: Fling Tops, Store Tops, Fling Trousers, Fold Trousers, Hang Trousers, Fold Dress, Wear Bowl Hat, Wear Glove, Wear Scarf, Fold Tops, Fling Dress, Hang Tops, Wear Baseball Cap, Hang Coat, Hang Dress

More nature interactions between dexterous hands and garment

TRANSFER: Grasp with AttachmentBlock (from GarmentLab) — Grasp with AttachmentBlock (DexGarmentLab) — COMPARE — Grasp with Our Precise Simulation (DexGarmentLab)

Red Objects in Pictures Mean AttachmentBlock

COMPARE: GarmentLab — More Realistic Physical Simulation in DexGarmentLab (Trousers, Dress, Tops)
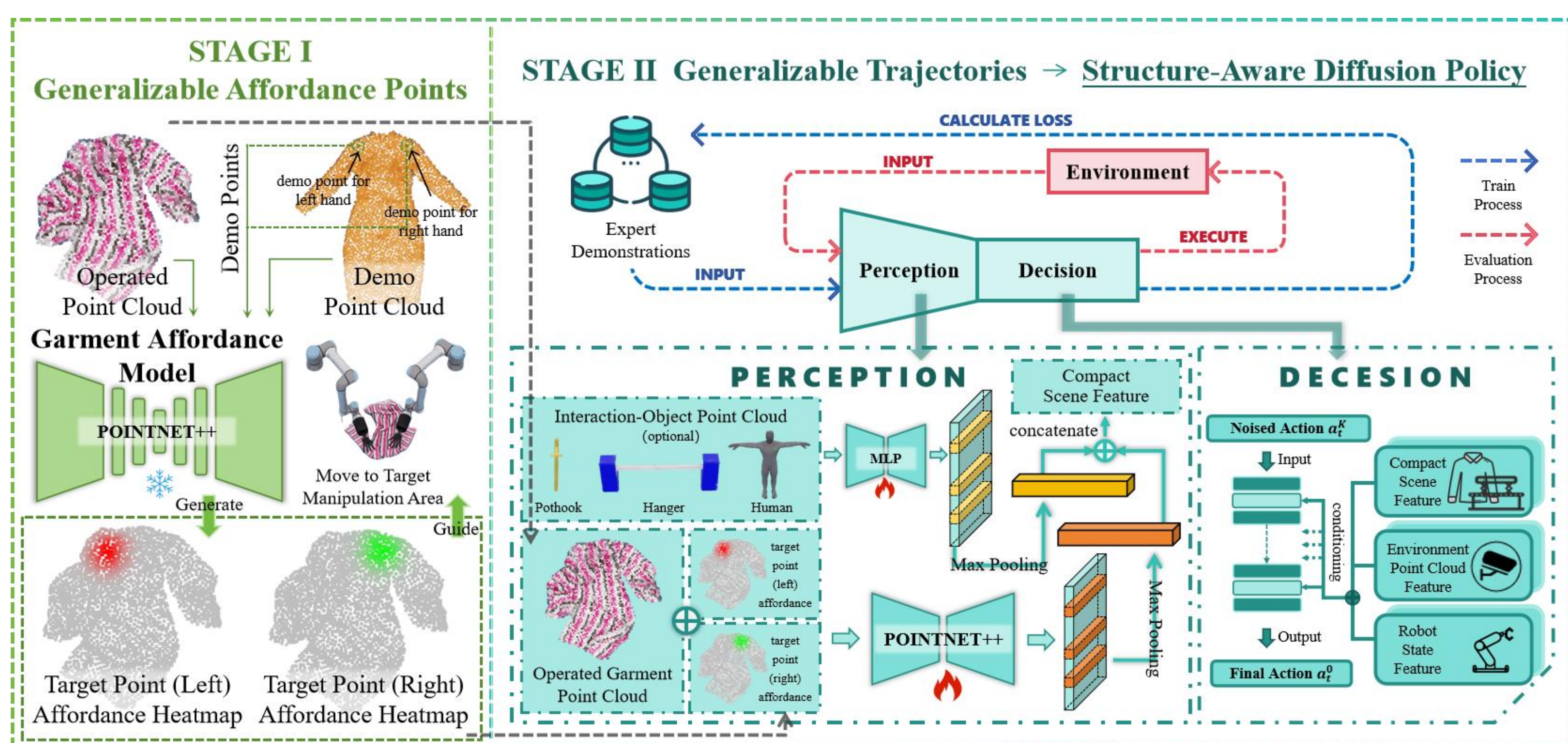
folded garments can stably **maintain their folded states**

AUTOMATED DATA COLLECTION

- Given demo points in demo garment, we can get target points in target garment **because of same structure of category-level garment**.
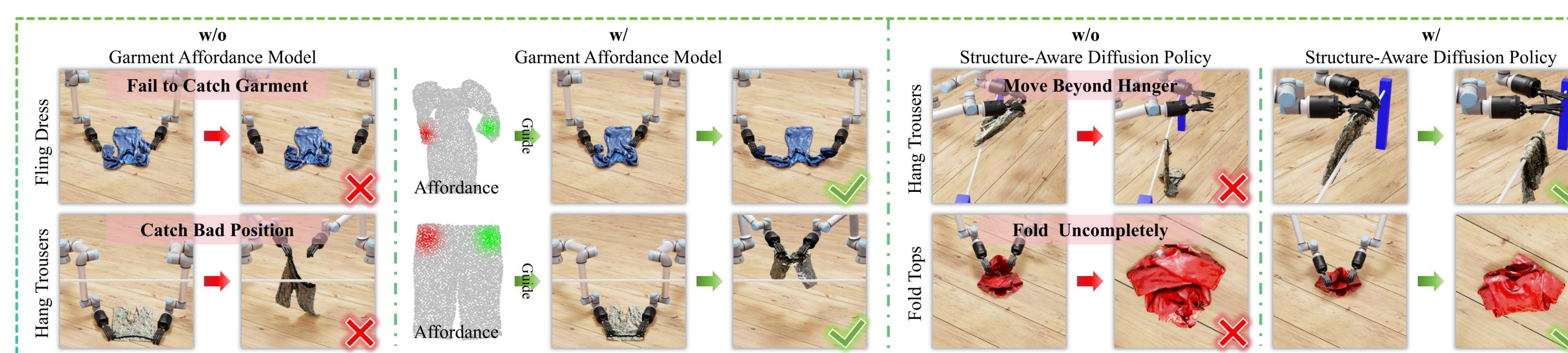- With single expert demonstration, robot can automatically finish task on new garment.

👑 GARMENT STRUCTURE

Category-Level (w/ or w/o deformation) Garment has Same Structure → **Category-Level Generalization**

Inference Process: Demo Point Cloud / Operated Point Cloud → Garment Affordance Model POINTNET++ → Extract → Demo Points Features / Target Points Features → Match → Demo Points Features / Actions with Target Manipulation Points

Training Process: Skeleton Merger → Garment Affordance Model POINTNET++ → Back Propogation → InfoNCE Loss
Corresponding Pairs — Positive Pair / Negative Pair

Execution: STEP I, STEP II, STEP III

One Shot Transfer — **Single Expert Demonstration**: Demo Task Configuration → Demo Points / Demo Task Sequence; Demo Hand Grasp Pose → LeapMotion → teleoperate → Demo Grasp Pose (Close / Open)

GENERALIZABLE POLICY

STAGE I Generalizable Affordance Points

Operated Point Cloud / Demo Point Cloud → Garment Affordance Model POINTNET++ → Generate → Move to Target Manipulation Area; Guide → Target Point (Left) Affordance Heatmap / Target Point (Right) Affordance Heatmap

STAGE II Generalizable Trajectories → Structure-Aware Diffusion Policy

Expert Demonstrations → INPUT → Perception / Decision → Environment → CALCULATE LOSS; Train Process / Evaluation Process / EXECUTE

PERCEPTION: Interaction-Object Point Cloud (optional) (Pothook, Hanger, Human) → MLP; Operated Garment Point Cloud → POINTNET++ → Max Pooling → Compact Scene Feature

DECISION: Noised Action a_i^k → Compact Scene Feature / Environment Point Cloud Feature / Robot State Feature → Max Pooling → Output → Final Action a_i^0

Our generalizable policy (HALO) includes two components:
1. **Garment Affordance Model (GAM)**, which generate generalizable affordance points for robots to locate and move to target area.
2. **Structure-Aware Diffusion Policy (SADP)**, which can assist in adjust-ing the trajectories according to the garments' own shapes and structure, thereby better accomplishing the tasks
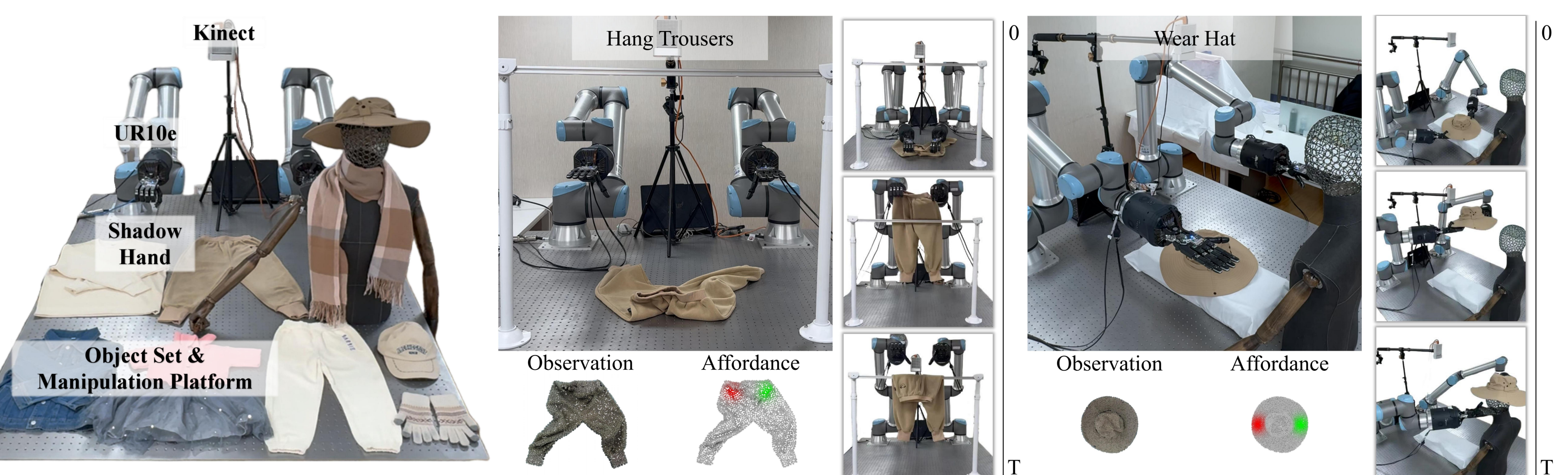
w/o Garment Affordance Model — Fail to Catch Garment / w/ Garment Affordance Model (Fling Dress, Hang Trousers)
w/o Structure-Aware Diffusion Policy — Move Beyond Hanger / Fold Uncompletely — w/ Structure-Aware Diffusion Policy (Hang Trousers, Fold Tops)

Without GAM: robots may fail to catch the right manipulation points.
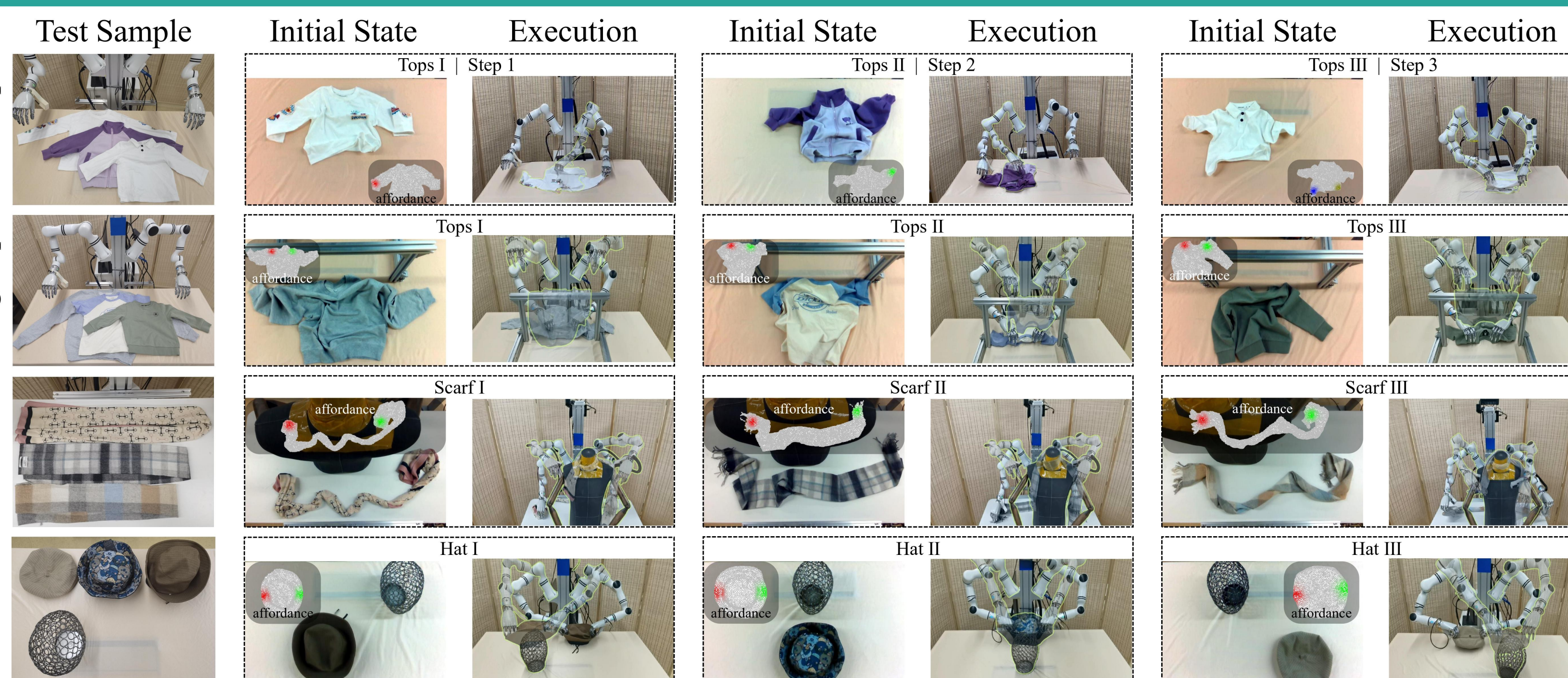**Without SADP:** robots may fail to adjust the trajectories based on garment shapes and structures.

Real-World Result

The test samples have different shapes, length, deformations while position of garments and interaction objects are variable. HALO can handle all the situations smoothly.

Kinect, UR10e, Shadow Hand, Object Set & Manipulation Platform

Hang Trousers / Wear Hat — Observation / Affordance

HALO Policy Sim2Real

Test Sample | Initial State | Execution
Fold Tops (Tops I / Step 1, Tops II / Step 2, Tops III / Step 3)
Hang Tops (Tops I, Tops II, Tops III)
Wear Scarf (Scarf I, Scarf II, Scarf III)
Wear Hat (Hat I, Hat II, Hat III)

GAM Sim2Real for Data Collection and HALO Training in Real World