SymSkill:


Symbol and Skill Co-Invention for Data-Efficient and Real-Time Long-Horizon Manipulation

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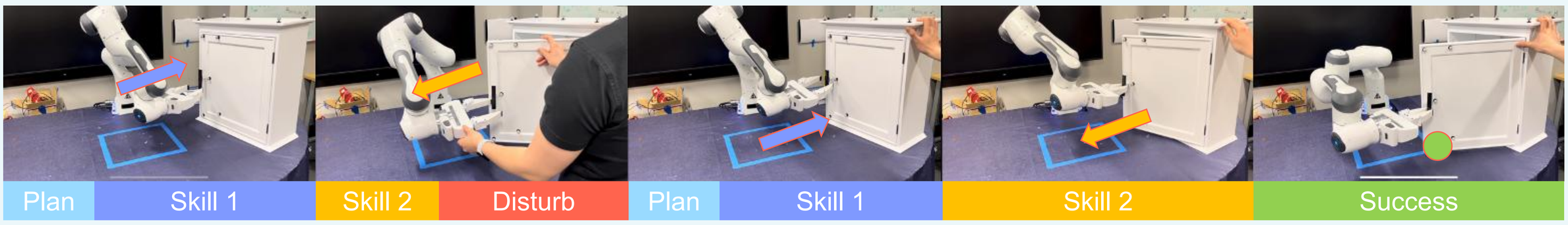
SymSkill performs long-horizon task by recomposing learned Predicates, Operators and Skills from just 5 min of play data

Real-time Skill & Symbol Failure Recovery

Guaranteed to be complete* and stable**
**symbolic planning is a complete planner **skill is stable wrt single attractor*

Reuseable Symbols & Skills for new task



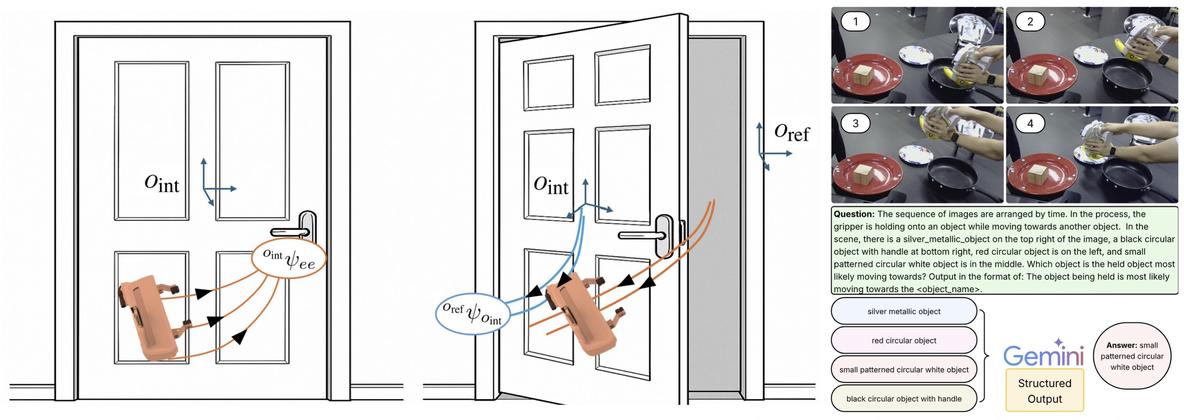
Operators Learned from Play Data

$$\text{add} = \bigcap(s_1 \setminus s_0),\ \text{del} = \bigcap(s_0 \setminus s_1),\ \text{eff} = \{\text{add}, \text{del}\} \qquad \text{maintain} = \bigcap_{t(s_0)\le t<t(s_1)} \mathbf{x}(t) \qquad \text{pre} = \bigcap s_0$$

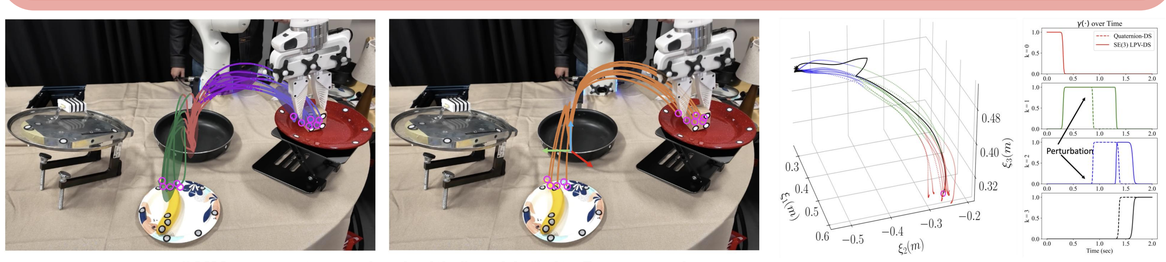
Operators	Human-Interpretable Summary	Preconditions	Effects	Maintain Conditions
Op7	Pick lid *from* cabinet	GripperOpen, Lid-in-cabinet	Gripper-in-lid, ¬Lid-in-cabinet, ¬GripperOpen	Lid-in-cabinet, GripperOpen
Op11	Pick lid *from* cookware	GripperOpen, Lid-in-cookware	Gripper-in-lid, ¬Lid-in-cookware, ¬GripperOpen	Lid-in-cookware, GripperOpen
Op1	Place lid → cabinet	Gripper-in-lid	Lid-in-cabinet, ¬Gripper-in-lid, GripperOpen	Gripper-in-lid
Op8	Place lid → cookware	Gripper-in-lid	Lid-in-cookware, ¬Gripper-in-lid, GripperOpen	Gripper-in-lid
Op9	Pick thing *from* drawer	GripperOpen, Thing-in-container, Thing-in-drawer	Gripper-in-thing, ¬Thing-in-drawer, ¬GripperOpen	Thing-in-container, Thing-in-drawer, GripperOpen
Op5	Pick thing *from* cookware	GripperOpen, Lid-in-cabinet, Thing-in-cookware	Gripper-in-thing, ¬Thing-in-cookware, ¬GripperOpen	Thing-in-cookware, Lid-in-cabinet, GripperOpen
Op10	Pick thing *from* container	GripperOpen, Thing-in-container	Gripper-in-thing, ¬Thing-in-container, ¬GripperOpen	Thing-in-container, GripperOpen
Op4	Place thing → drawer	Gripper-in-thing, Thing-in-cookware	Thing-in-drawer, ¬Gripper-in-thing, GripperOpen	Gripper-in-thing, Thing-in-cookware
Op3	Place thing → cookware	Gripper-in-thing, Lid-in-cabinet	Thing-in-cookware, ¬Gripper-in-thing, GripperOpen	Gripper-in-thing, Lid-in-cabinet
Op6	Place thing → container	Gripper-in-thing	Thing-in-container, ¬Gripper-in-thing, GripperOpen	Gripper-in-thing

R. Chitnis, T. Silver, J. B. Tenenbaum, T. Lozano-Perez, and L. P.Kaelbling, "Learning neuro-symbolic relational transition models forbilevel planning," in 2022 IEEE/RSJ International Conference onIntelligent Robots and Systems (IROS). IEEE, 2022, pp. 4166–4173.

Predicates Naturally Emerge when motion stops



Skills are stable SE(3) LPV-DS Policies in relative frame (requiring 5 demos)



GMM parameters solved with Semidefinite Programming

$$\dot{x} = \sum_{k=1}^{K} \gamma_k(x)\mathbf{A}_k\,(x - x^*) \qquad (\hat{\mathbf{q}}_{att})^{des} = \sum_{k=1}^{K} \gamma_k(\mathbf{q})\mathbf{A}_k \log_{\mathbf{q}_{att}} \mathbf{q}$$

$$\Theta_\gamma = \{\pi_k, \mu_k, \mathbf{\Sigma}_k\}_{k=1}^{K} \qquad \Theta_\gamma = \{\pi_k, \tilde{\mu}_k, \tilde{\mathbf{\Sigma}}_k\}_{k=1}^{K}$$

S. Sun and N. Figueroa, "SE(3) Linear Parameter Varying Dynamical Systems for Globally Asymptotically Stable End-Effector Control," *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Abu Dhabi, United Arab Emirates, 2024, pp. 5152-5159, doi: 10.1109/IROS58592.2024.10801844.

Complete Pipeline

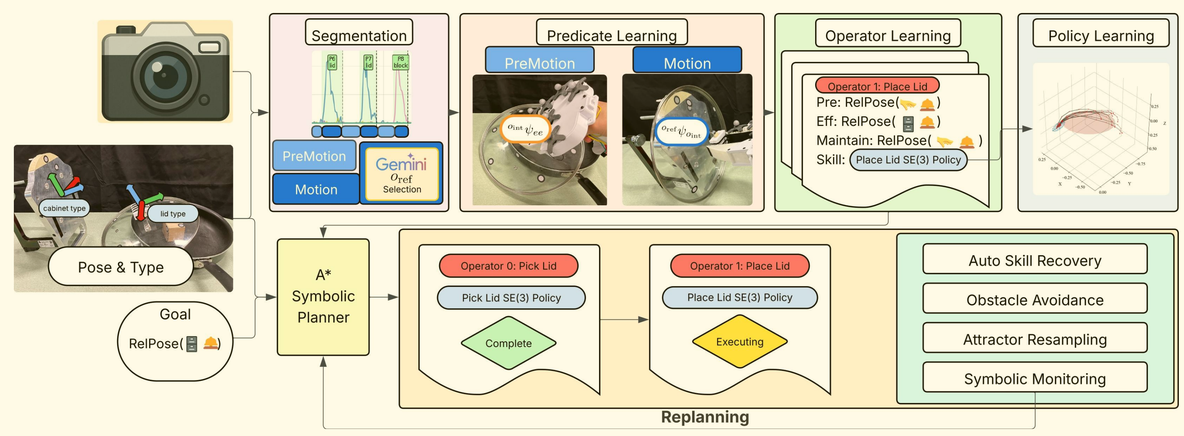


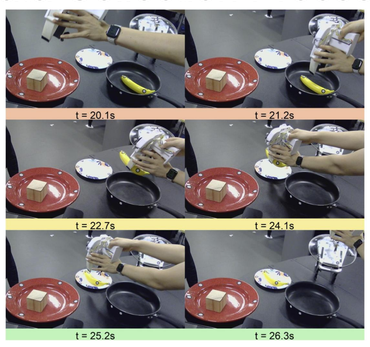
TABLE II: RoboCasa simulation result on 10 trials per task

Task Success Rate %	Proposed	Proposed w/o Monitoring	Proposed w/ DP
OpenSingleDoor	**100**	100	0
CloseSingleDoor	**100**	80	0
PnPCounterToCab	**80**	70	0
PnPCabToCounter	**100**	40	0
PnPStoveToCounter	**70**	30	0
PnPCounterToStove	**20**	0	0
OpenDrawer	**100**	100	0
CloseDrawer	**70**	50	40
TurnOnStove	**100**	100	0
TurnOffStove	**80**	30	0
TurnOnSinkFaucet	**100**	100	0
TurnOffSinkFaucet	**100**	90	0
Average	**85.0**	**65.0**	**3.3**

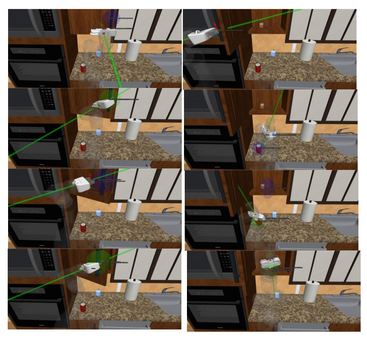
TABLE I: Comparison of predicate and skill learning methods.

Approach	Predicates	Skills	# of Demos	Planning Time
SymSkill (Ours)	Relative Pose Cluster (Start/End Motion)	SE(3) LPV-DS [12]	1-10	<100ms
NSIL [5]	Relative Pose Cluster (Low Relative Velocity)	MLP BC	200	<100ms
LAMP [4]	Relational Critical Regions	Motion Planning (MP)	200	> 50 s
NOD-TAMP [16]	NDF Features	Optimization + MP	1-10	> 50 s

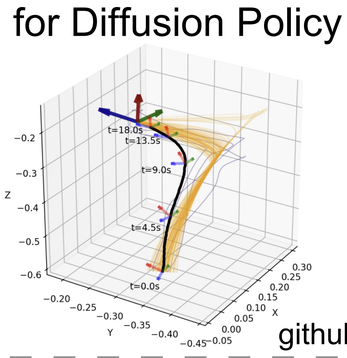
Data Collection Process



Robocasa Multitask



Data Augmentation for Diffusion Policy



Previous work

Physical Correction as LLM Interface

Human Robot Comanipulation

github.com/shaoyifei96/Symskill/