Tac-Man: Tactile-Informed Prior-Free Manipulation of Articulated Objects

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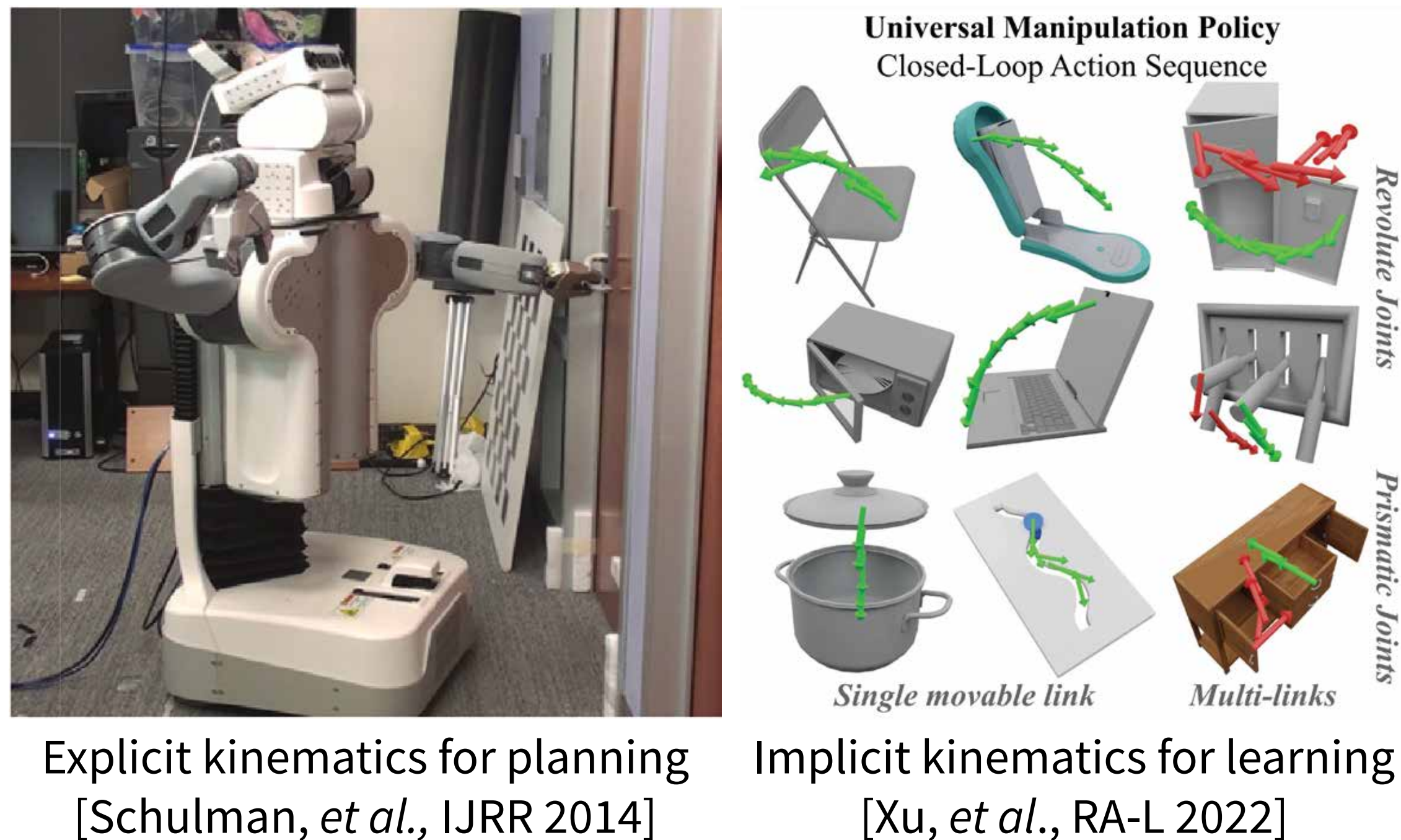
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Paper   Project page   Video

Efficient version   With vision

Are **kinematic priors** necessary for manipulating an articulated object?

Explicit kinematics for planning [Schulman, *et al.,* IJRR 2014]

Universal Manipulation Policy
Closed-Loop Action Sequence

Implicit kinematics for learning [Xu, *et al.*, RA-L 2022]

Revolute Joints   *Prismatic Joints*

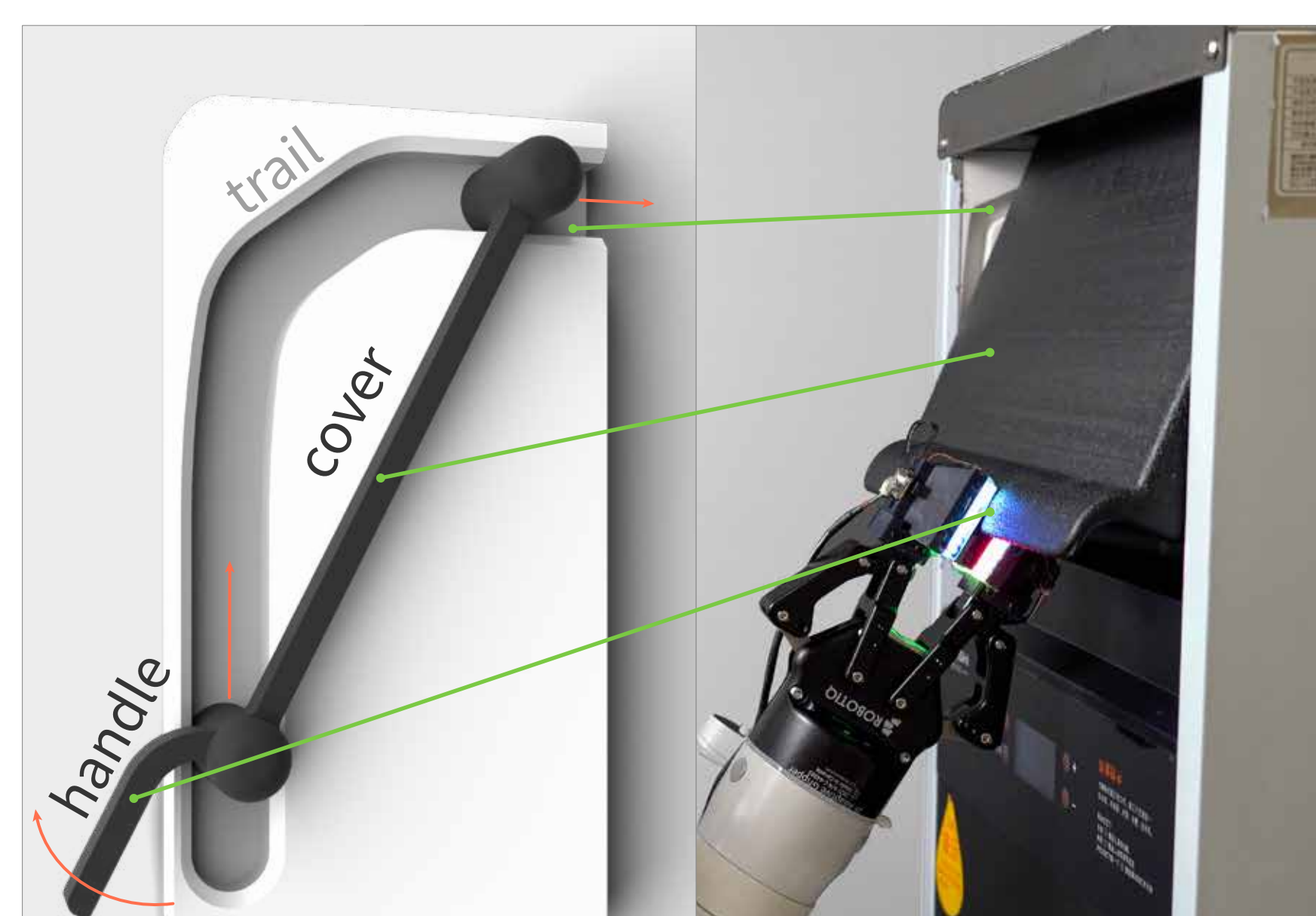*Single movable link*   *Multi-links*

## Although effective, these priors can be difficult to obtain precisely.

These priors can be **ambiguous**.
Different mechanism can share the same appearance.

Off-axis door
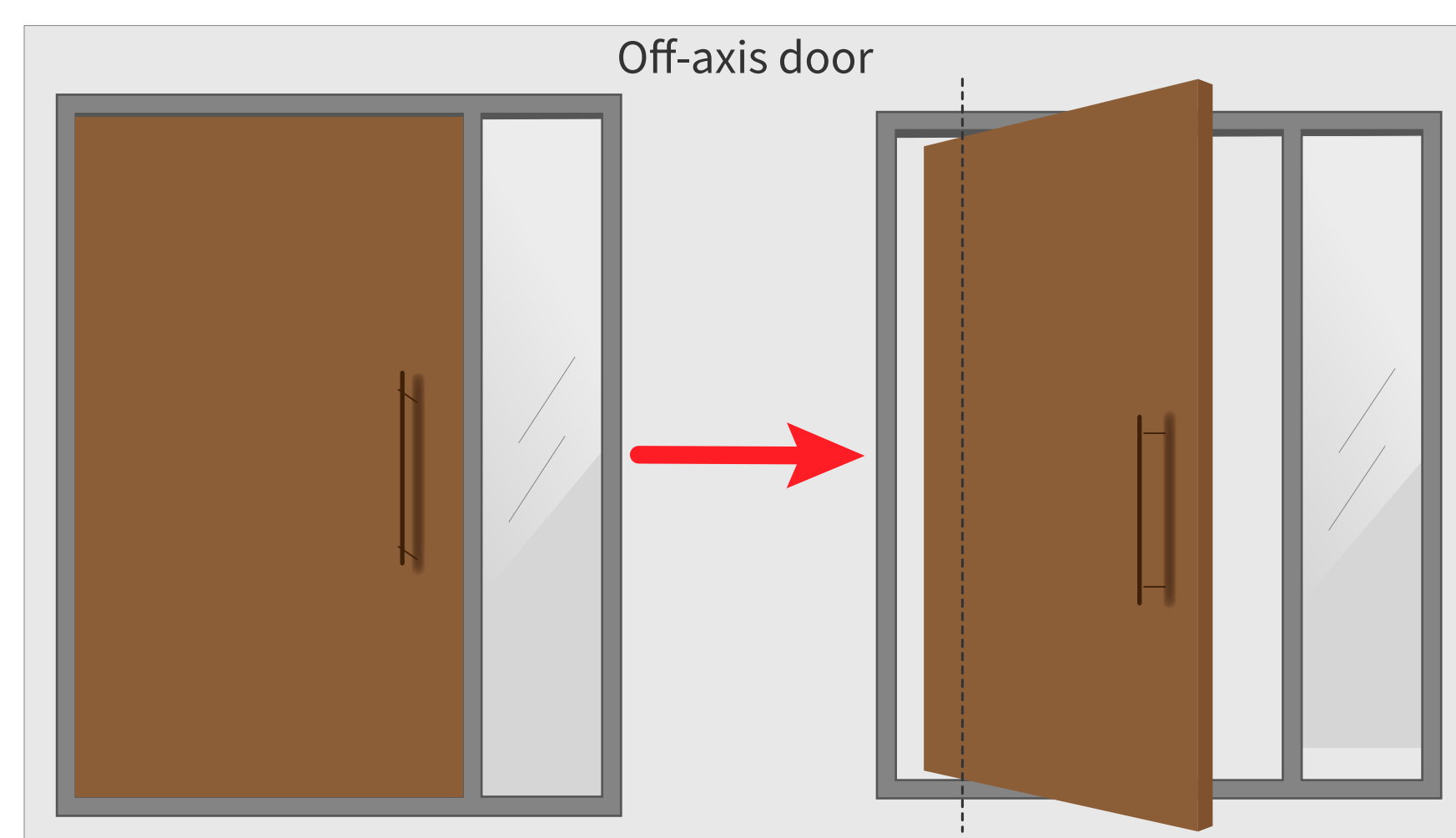
These priors can be **imperfect**.
Even with the correct articulation type, parameter estimation is prone to errors.


trail   cover   handle

These priors can be **unknown**.
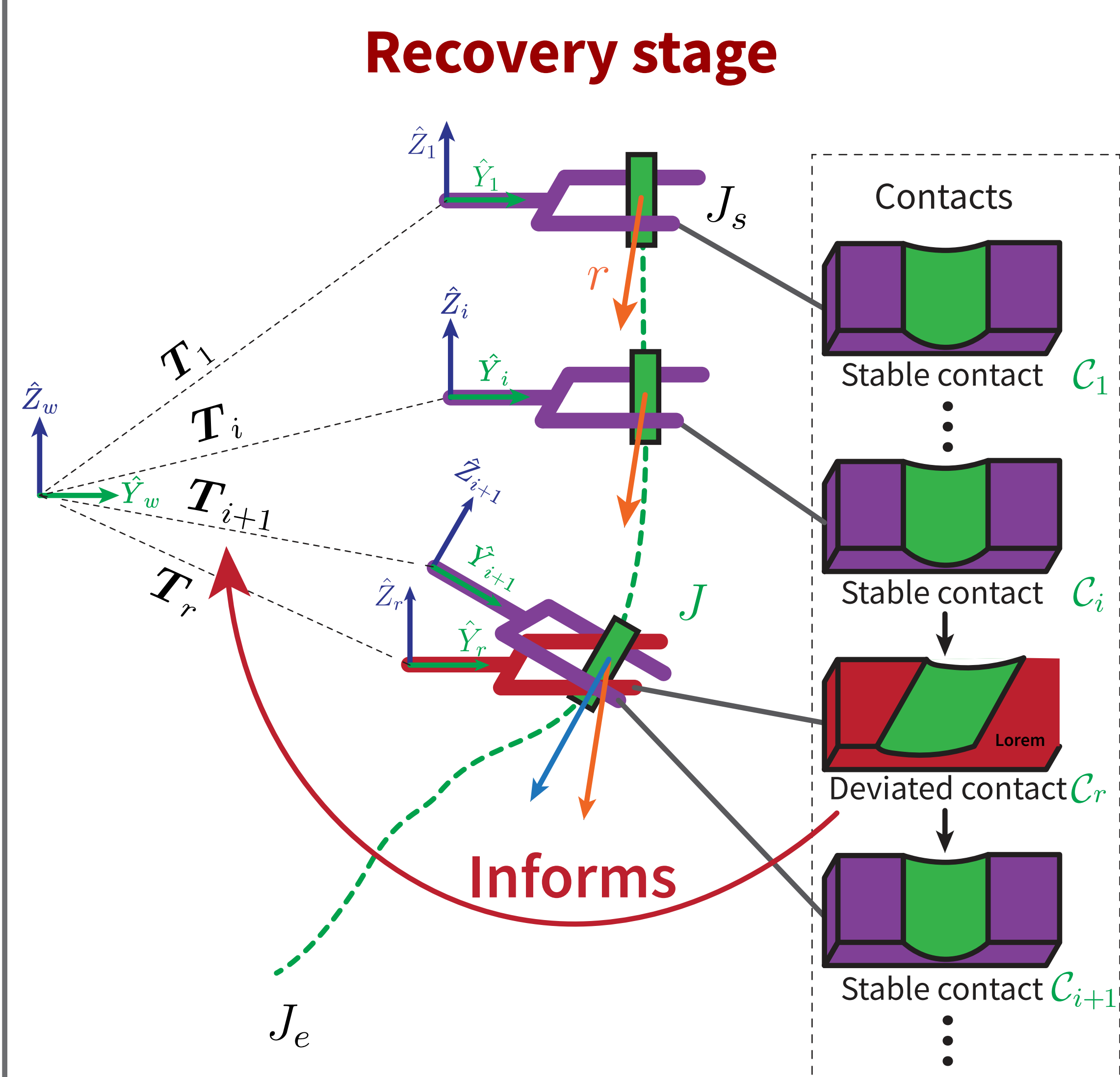Some complex screw motions are hard to model and to capture in datasets.

Push   Push
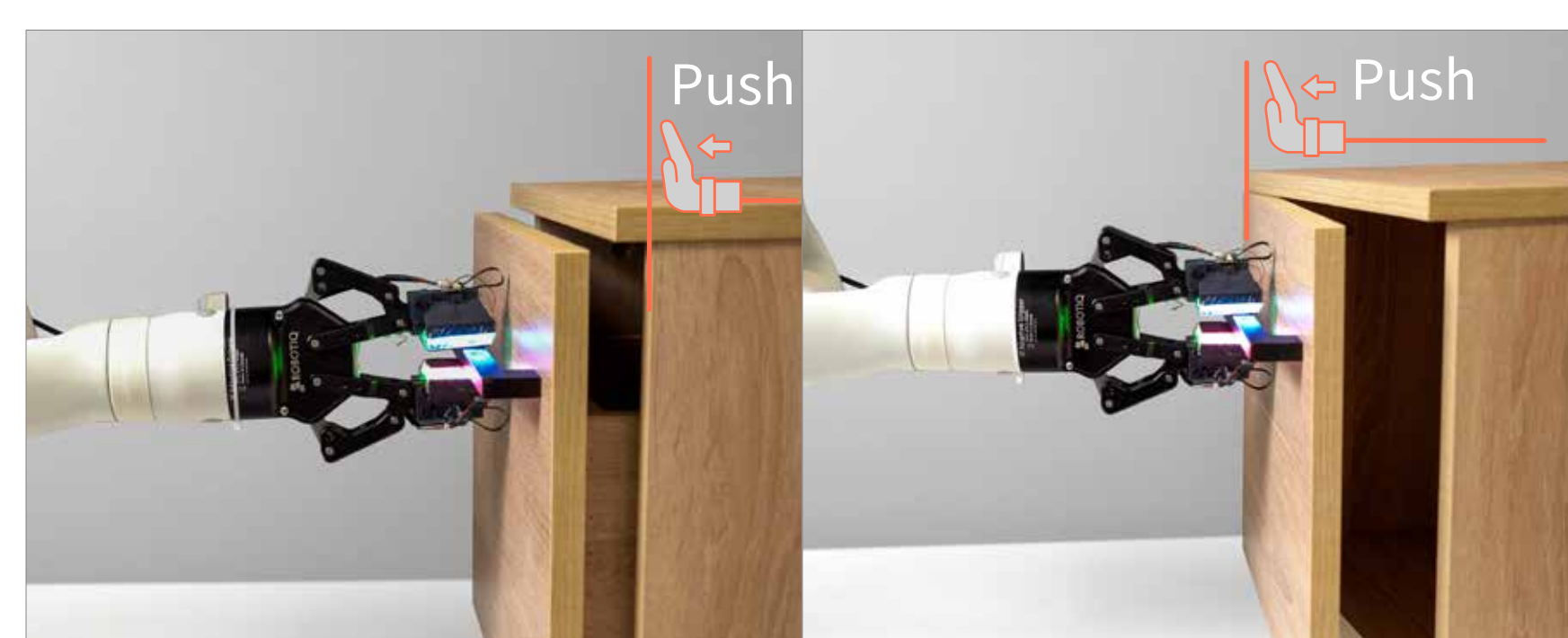
These priors can be **obsolescent**.
Perturbations can render the priors unsuitable for the current scenario.

Contact regulation is all you need!
A two-stage tactile-informed policy:

Execution stage

J_s

Contacts

r

Stable contact $\mathcal{C}_1$

Stable contact $\mathcal{C}_i$

J

J_e
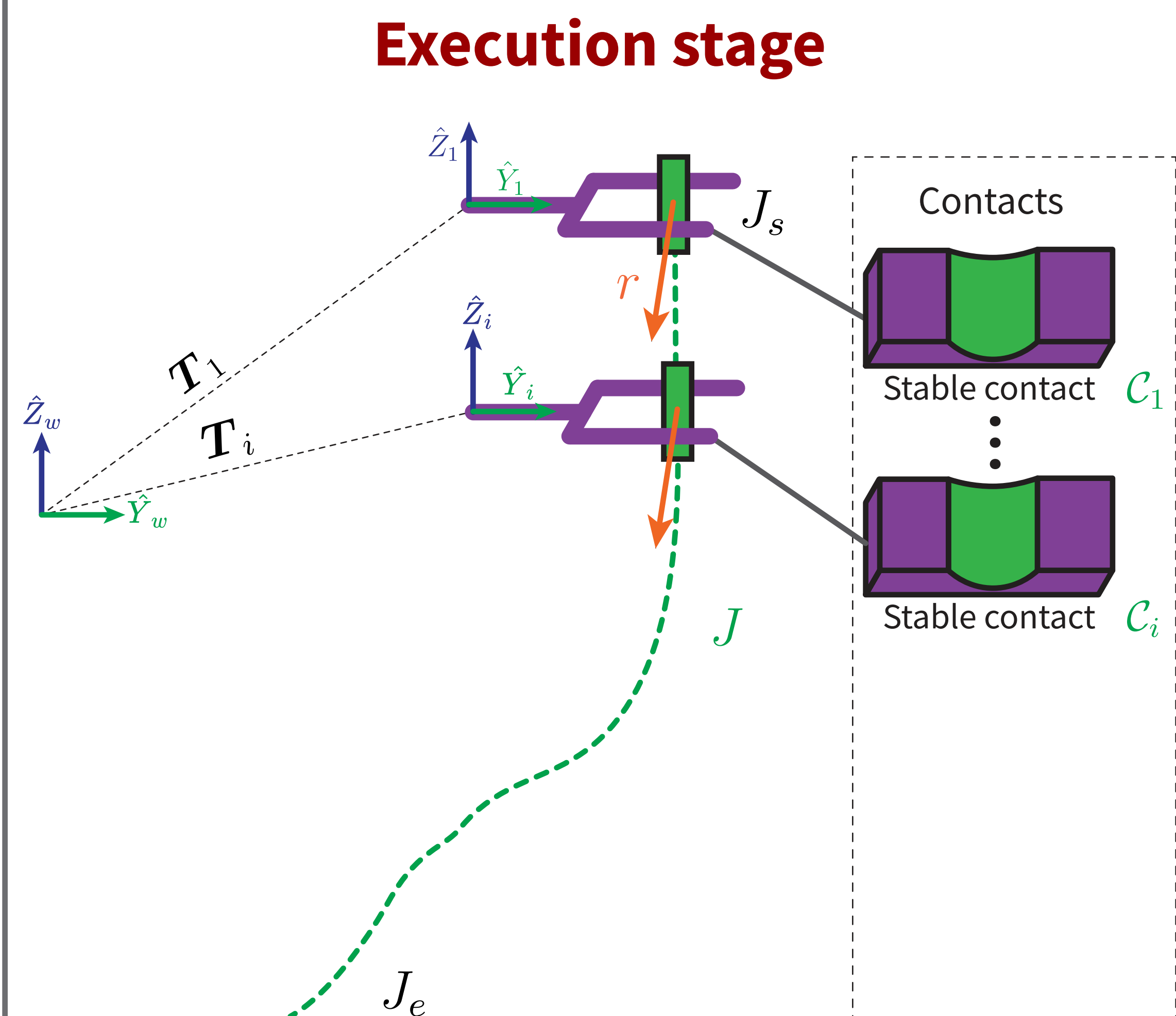
For any articulation J, execute along a preliminary direction r when the contact $\mathcal{C}_i$ is **stable**:

$$\underset{t}{\text{maximize}} \quad t$$

subject to
$$f_e(f_c(\boldsymbol{T}_i \boldsymbol{T}_r^i, J), \mathcal{C}_0) \leq \boldsymbol{e}, \text{ Material strength}$$
$$f_s(f_c(\boldsymbol{T}_i \boldsymbol{T}_r^i, J), \mathcal{C}_0) \leq s, \text{ Non-slip}$$
$$f_d(f_c(\boldsymbol{T}_i \boldsymbol{T}_r^i, J), \mathcal{C}_1) \leq d. \text{ Contact deviation}$$

Stable contact constraint

Recovery stage

J_s

Contacts

r

Stable contact $\mathcal{C}_1$

Stable contact $\mathcal{C}_i$

Deviated contact $\mathcal{C}_r$

Stable contact $\mathcal{C}_{i+1}$

J

J_e

Informs

Until the contact violates the stable contact constraint, the contact deviation informs the necessary adjustments to reestablish stable contact:
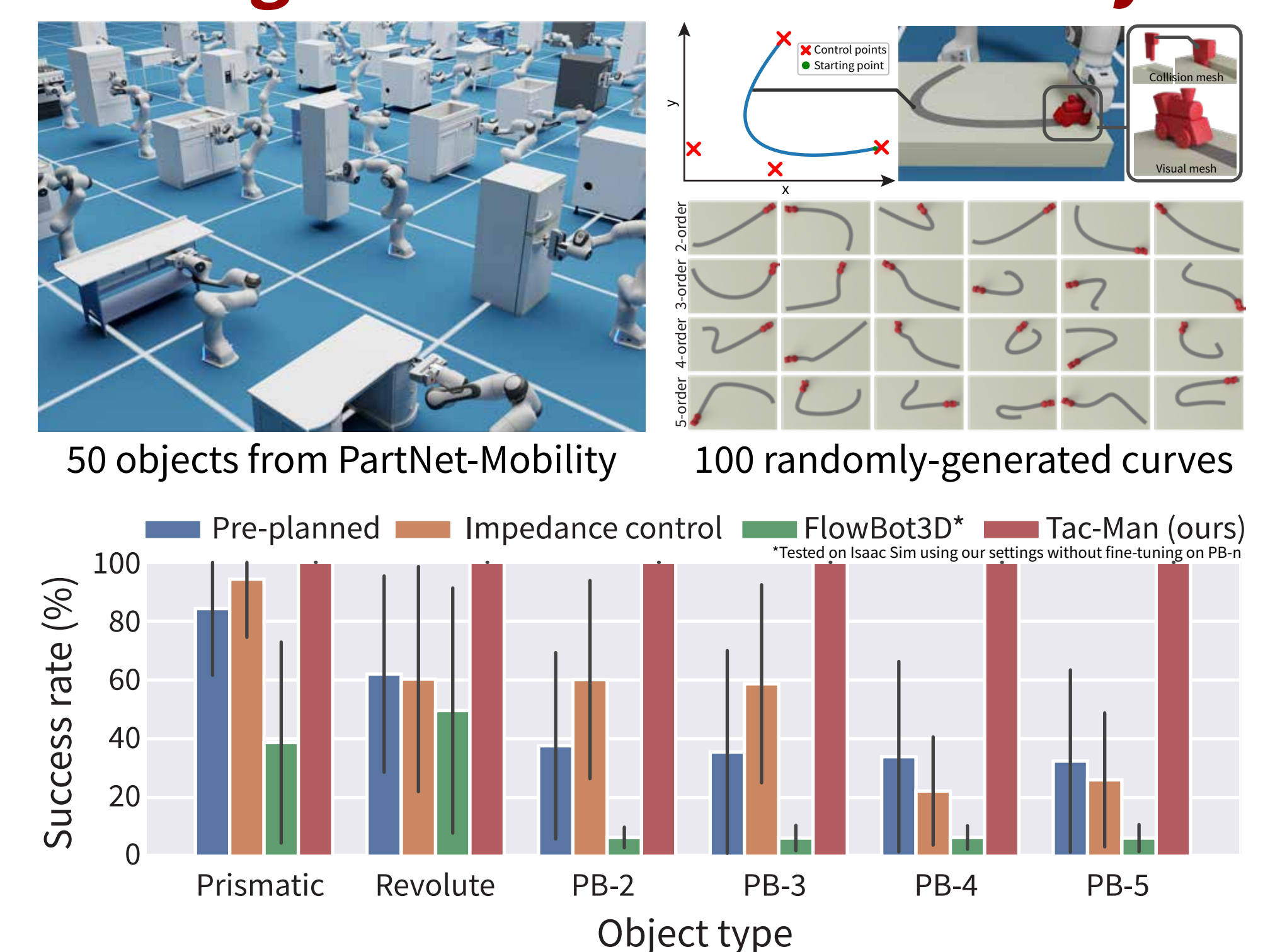
$$\boldsymbol{T}_{i+1}^r = \underset{\boldsymbol{T}_{i+1}^r \in SE(3)}{\arg\min} \sum_{(\boldsymbol{u},\boldsymbol{v}) \in \mathcal{K}_{1r}} \|\boldsymbol{T}_{i+1}^r \boldsymbol{u} - \boldsymbol{v}\|_2$$

$$\mathcal{K}_{1r} = \{(\boldsymbol{u},\boldsymbol{v}) \mid \boldsymbol{u} \in \mathcal{C}_1, \boldsymbol{v} \in \mathcal{C}_r\}$$
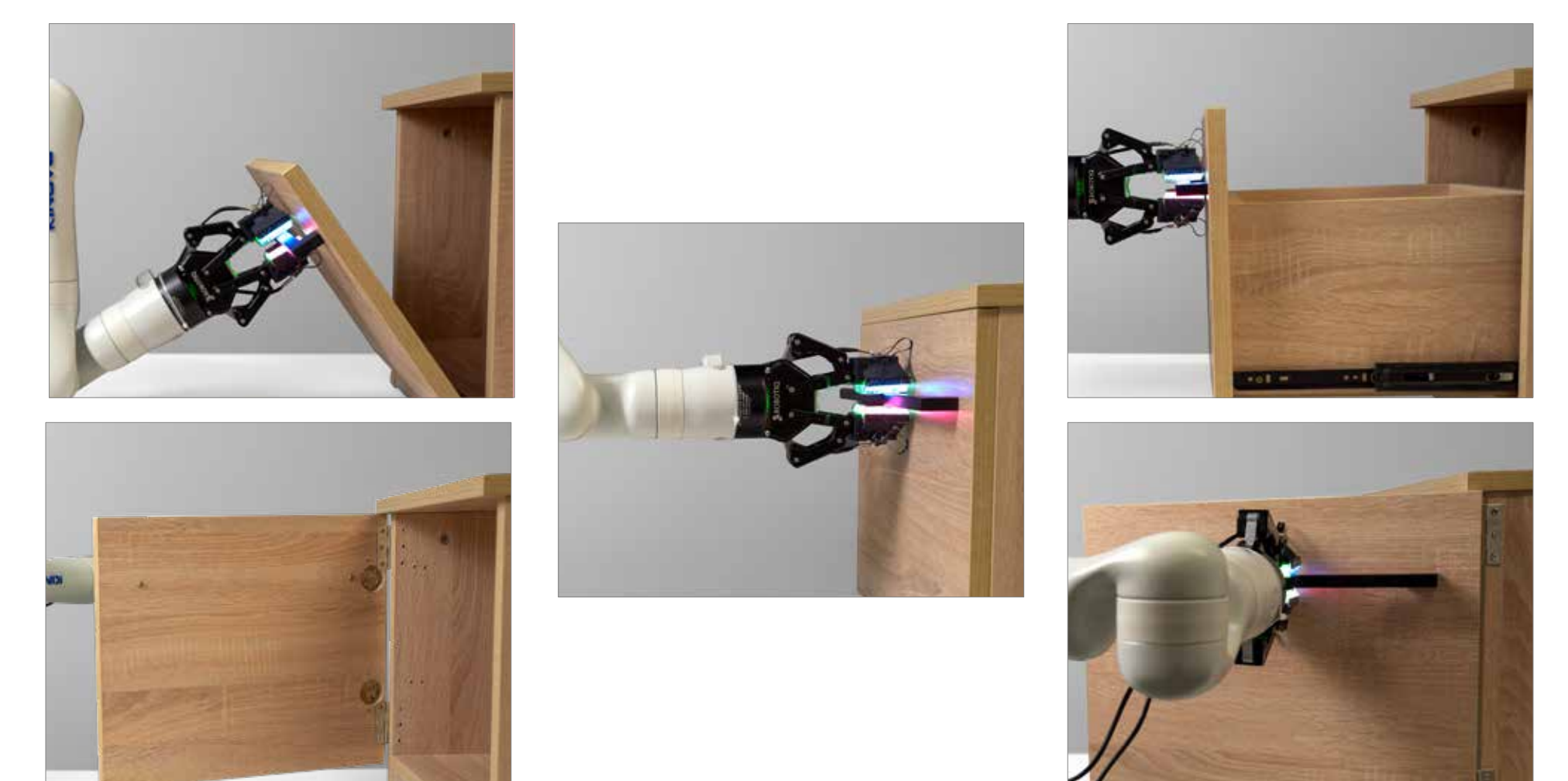
Through the iterative process, the manipulation can be completed.

Near-perfect results:

Large-scale simulation study

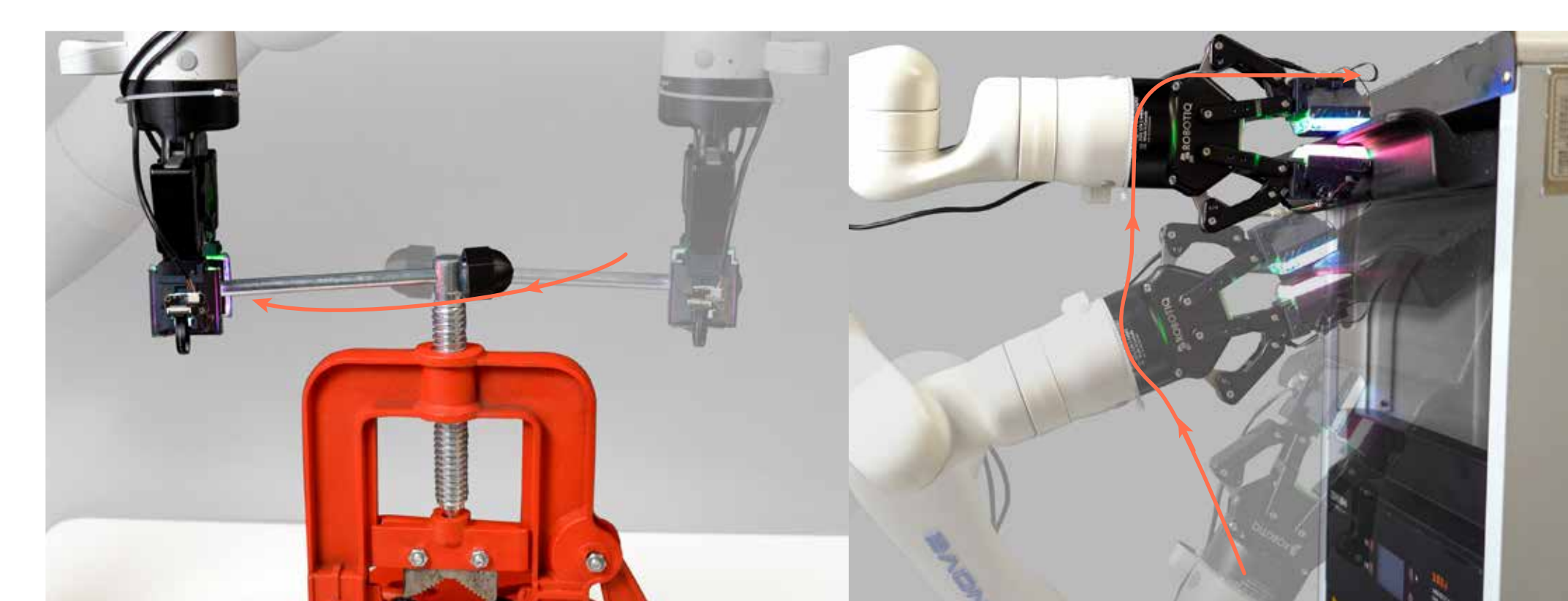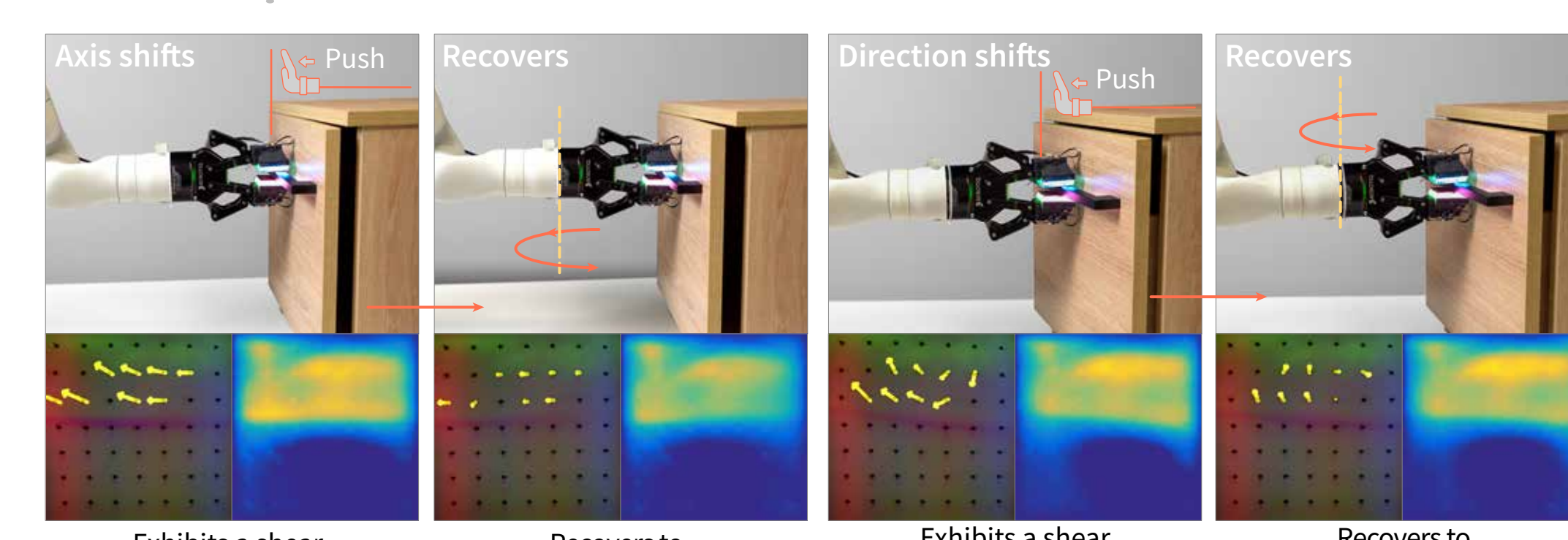50 objects from PartNet-Mobility   100 randomly-generated curves

Success rate (%)

Pre-planned   Impedance control   FlowBot3D*   Tac-Man (ours)

*Tested on Isaac Sim using our settings without fine-tuning on PB-n

Prismatic   Revolute   PB-2   PB-3   PB-4   PB-5

Object type

Real-world validations

Manipulation under **ambiguous priors**

Contact deviation   Fail!   Fail!

Deviation increases   Deviation further increases   Contact breaks   Contact breaks

Contact deviation   Success!

Exhibits a deviation   Recovers to stable contact   Contact remains stable   Contact remains stable
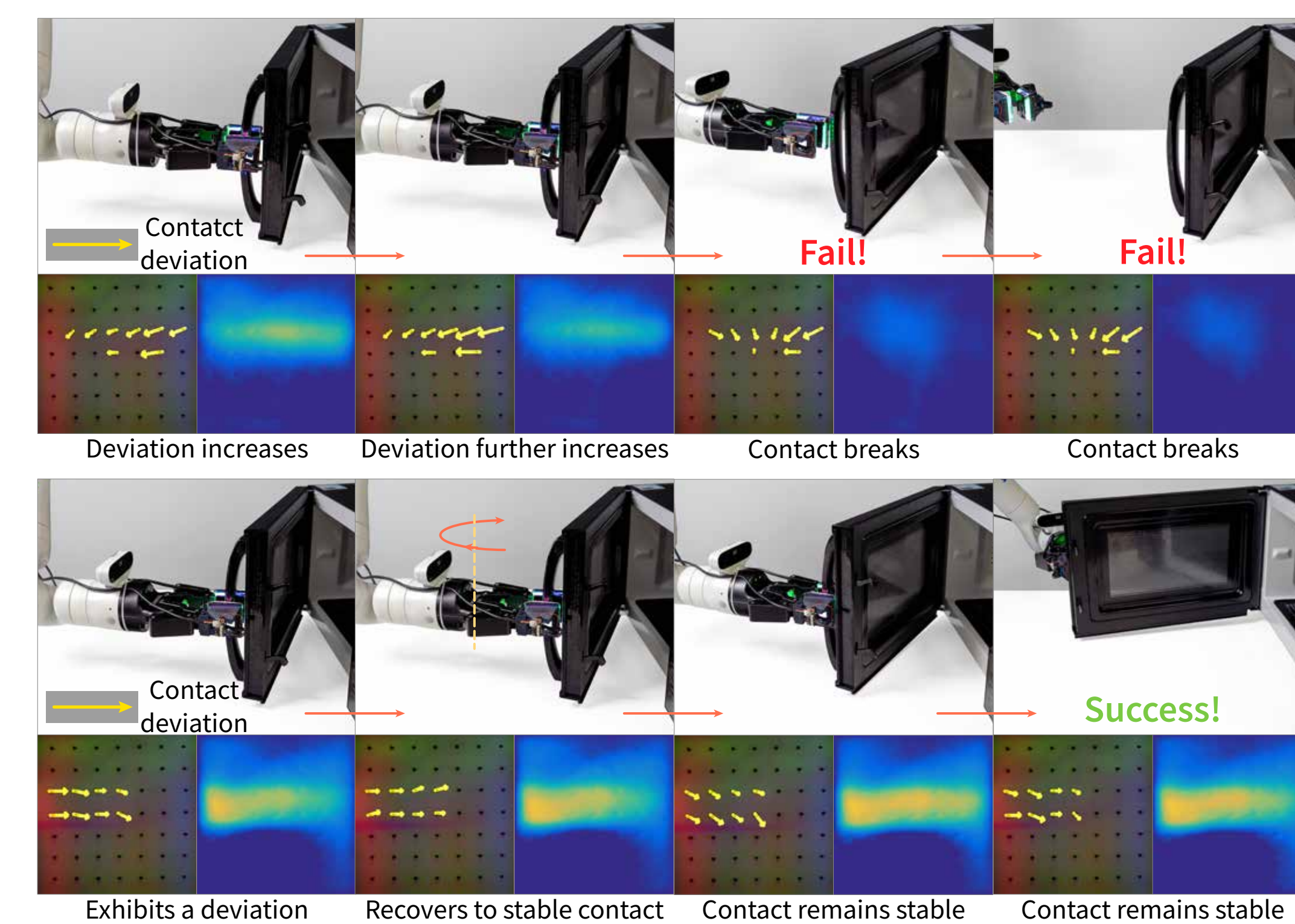
Manipulation under **imperfect priors**

Manipulation under **unknown priors**

Axis shifts   Push   Recovers   Direction shifts   Push   Recovers

Exhibits a shear clockwise deviation   Recovers to stable contact   Exhibits a shear clockwise deviation   Recovers to stable contact

Manipulation under **obsolescent priors**