Nonprehensile Manipulation of Multi-Link Hinges

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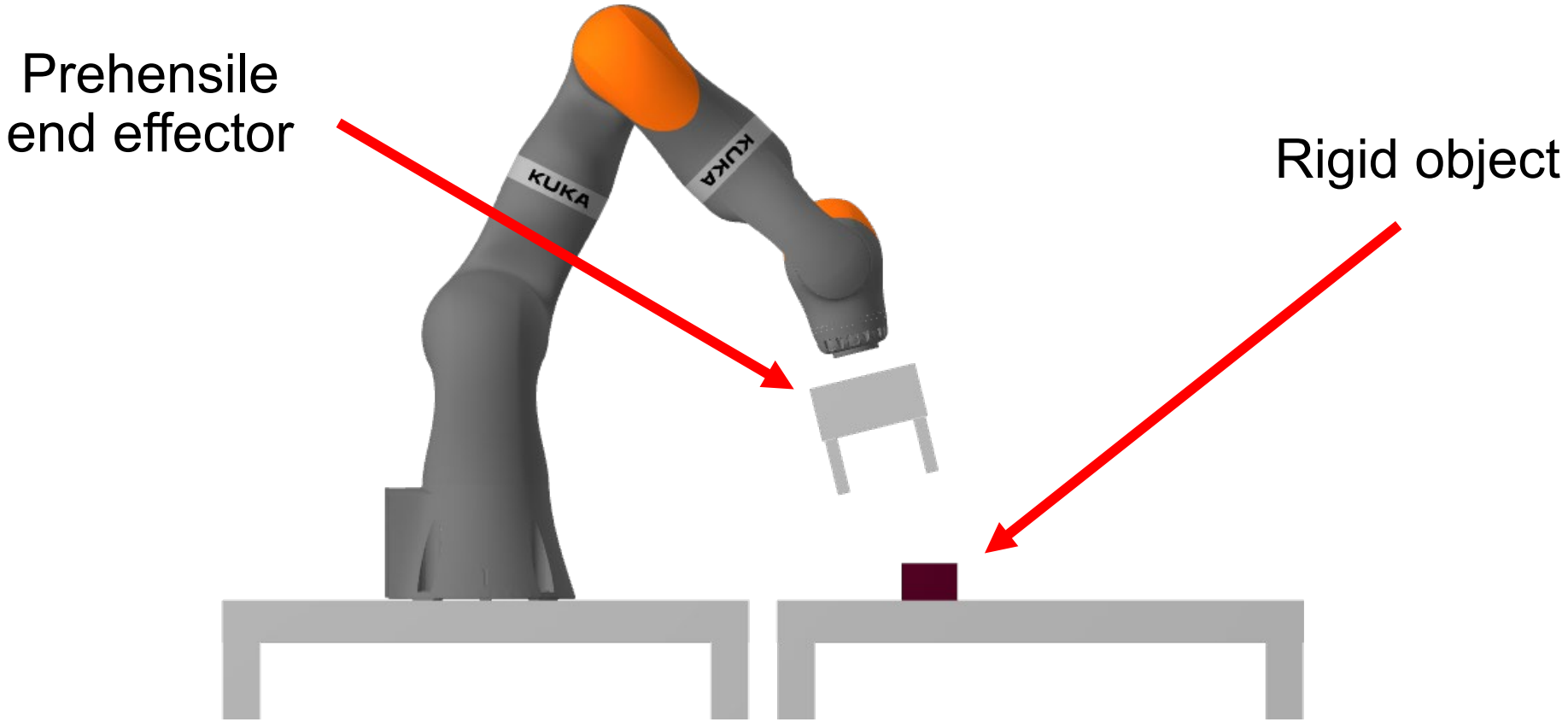
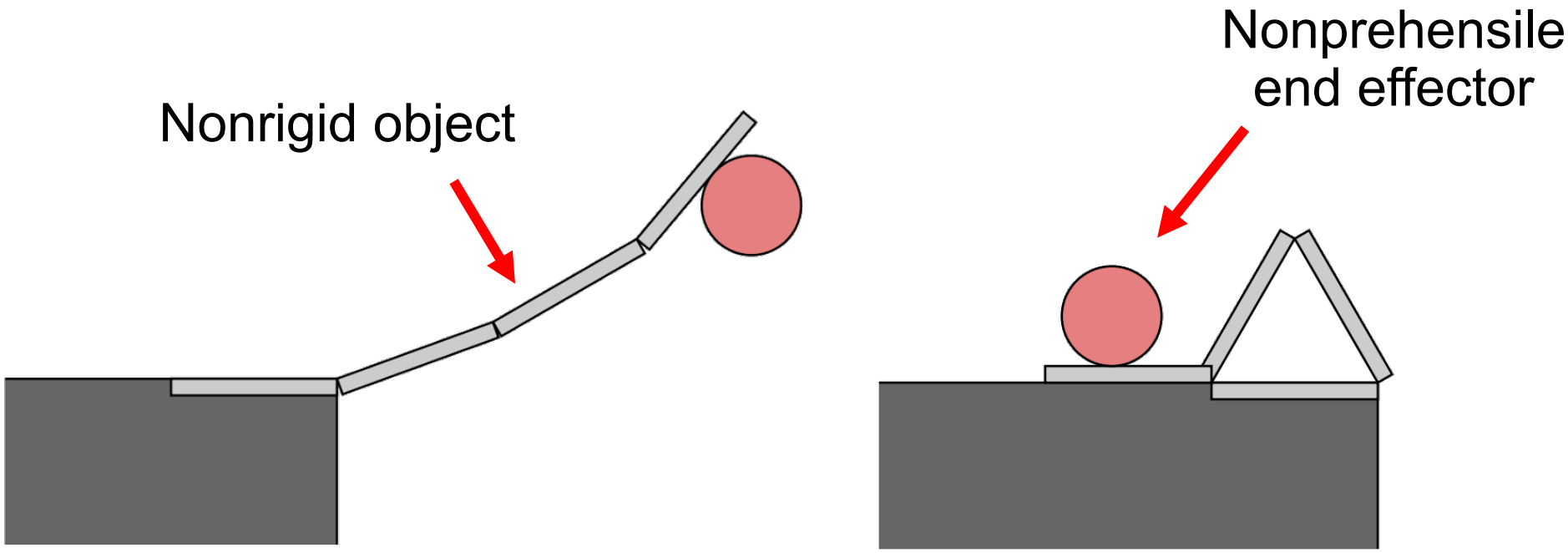
Common manipulation assumptions



Russ Tedrake. *Robot Manipulation: Perception, Planning, and Control (Course Notes for MIT 6.800).* Downloaded on 5/20/22 from http://manipulation.csail.mit.edu/

Multi-link hinge manipulation



In progress

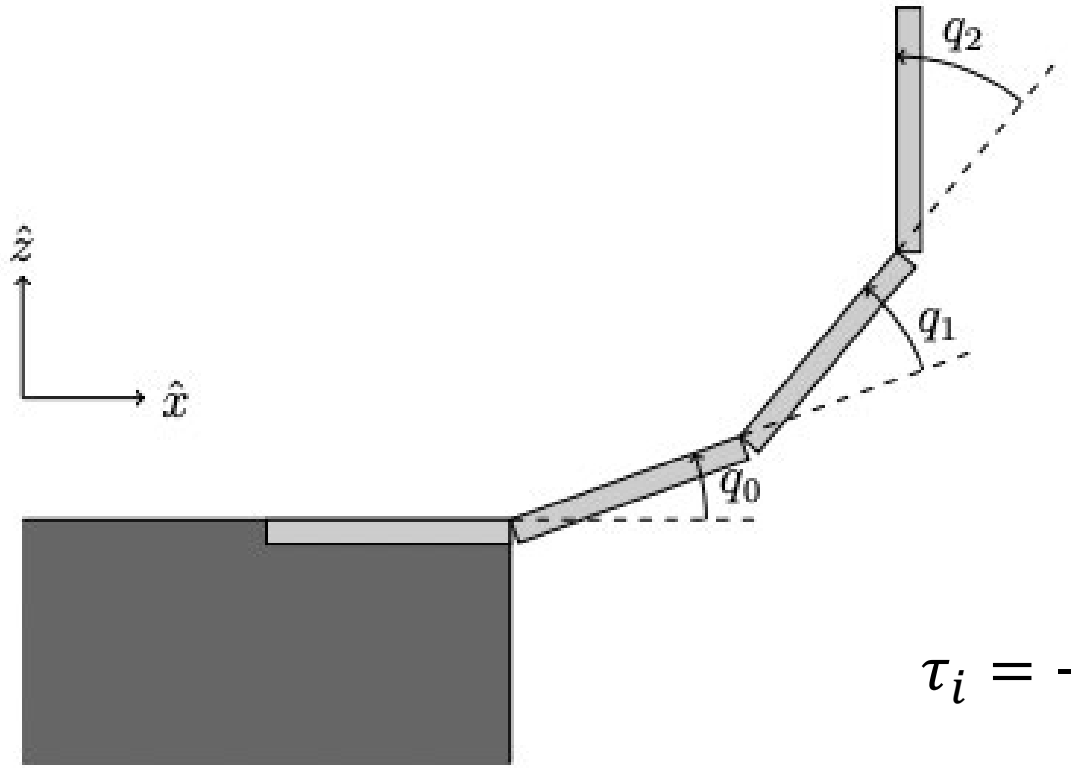
Folded state

Other high level goals: robustness, investigate feedback types

Object modeling

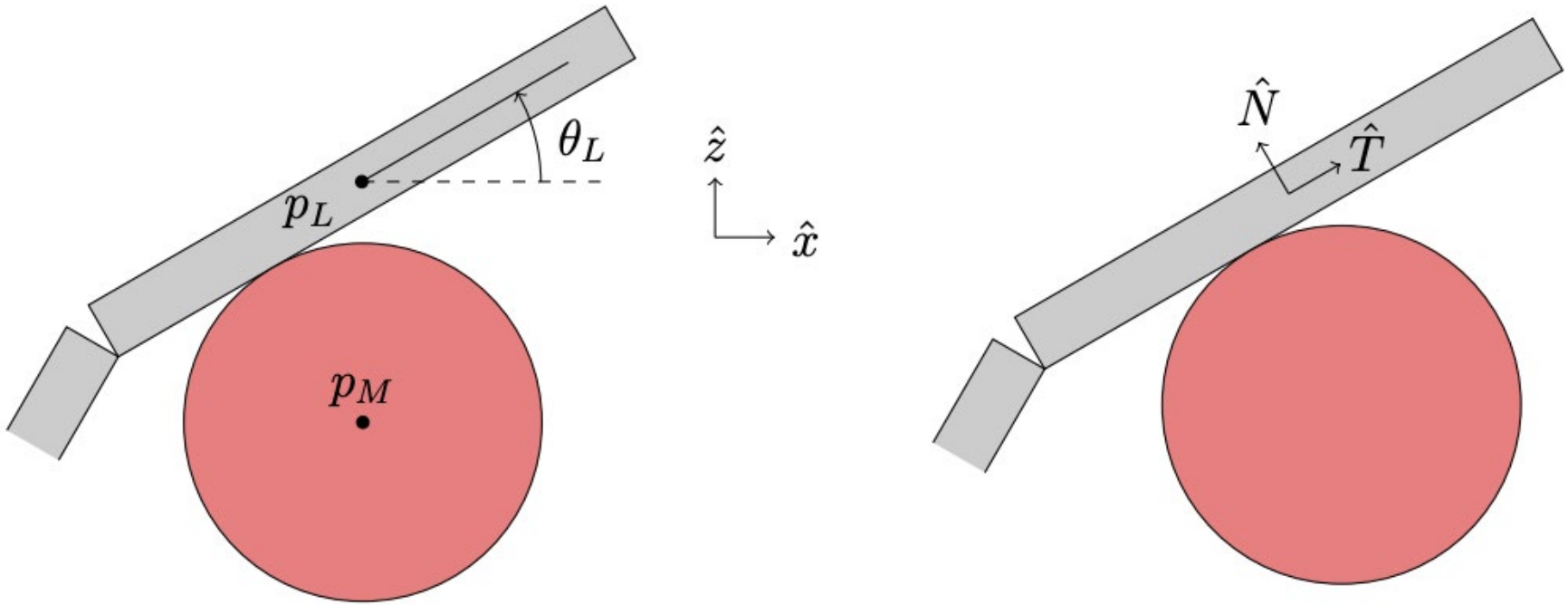
+ Problem definition

Full hinge model



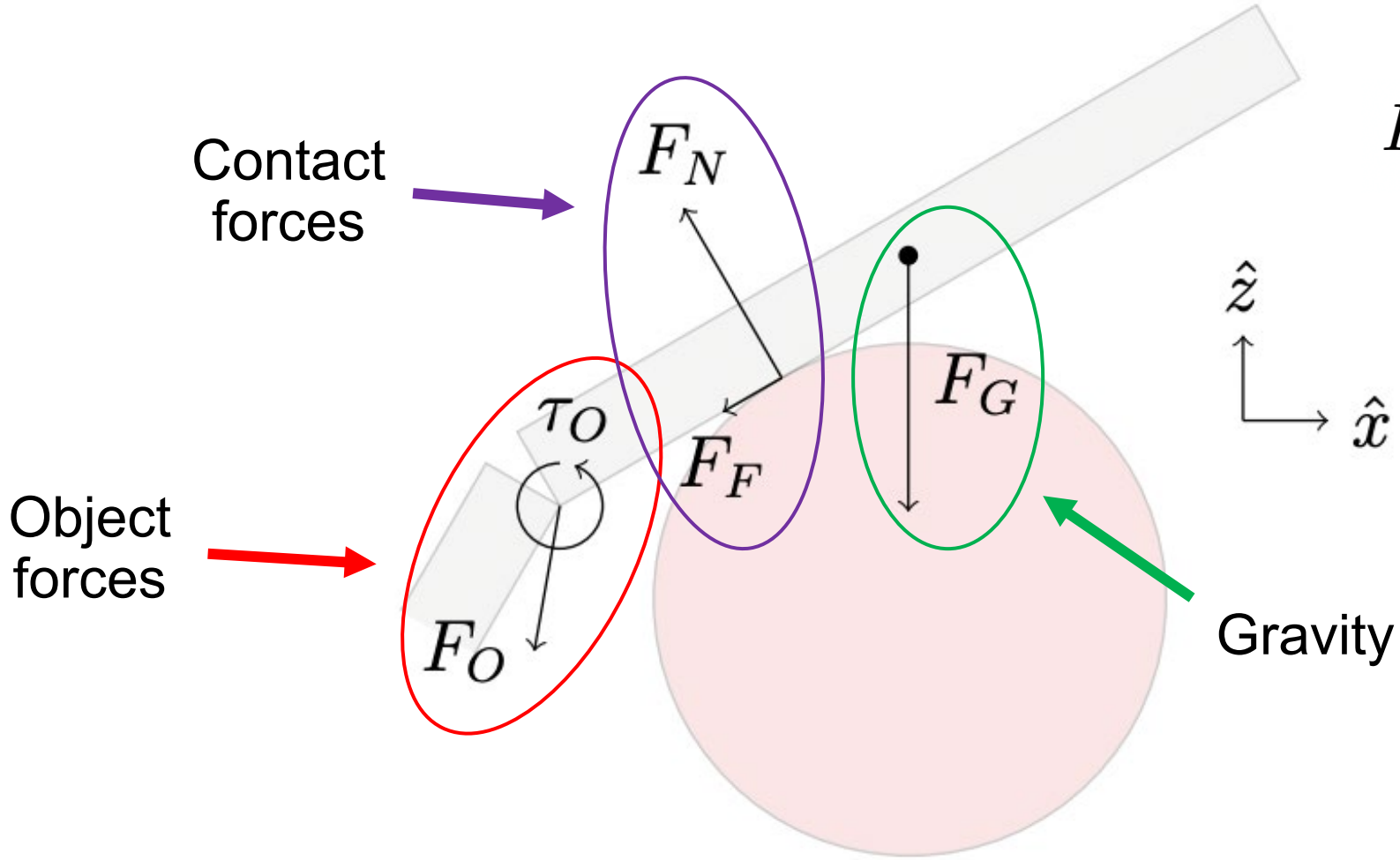
$$\tau_i = -kq_i - dq_i$$

Last link model: kinematic definitions



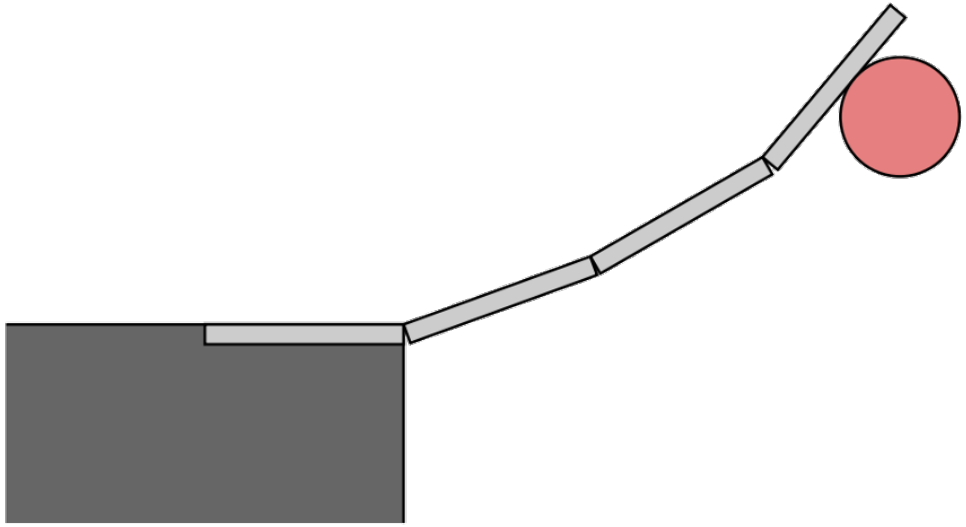
Last link model: dynamics

$$m_L a_L = F_N + F_G + F_O + F_F$$

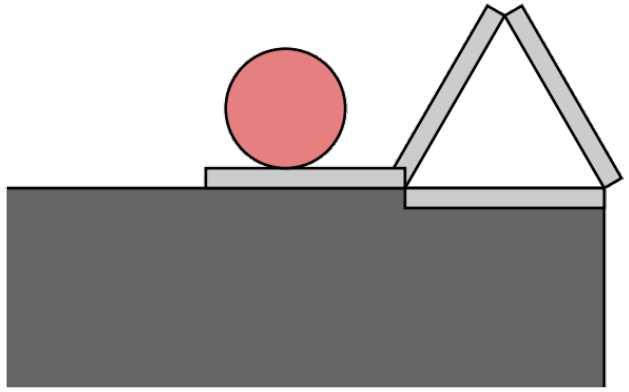


Task definition

Recall:

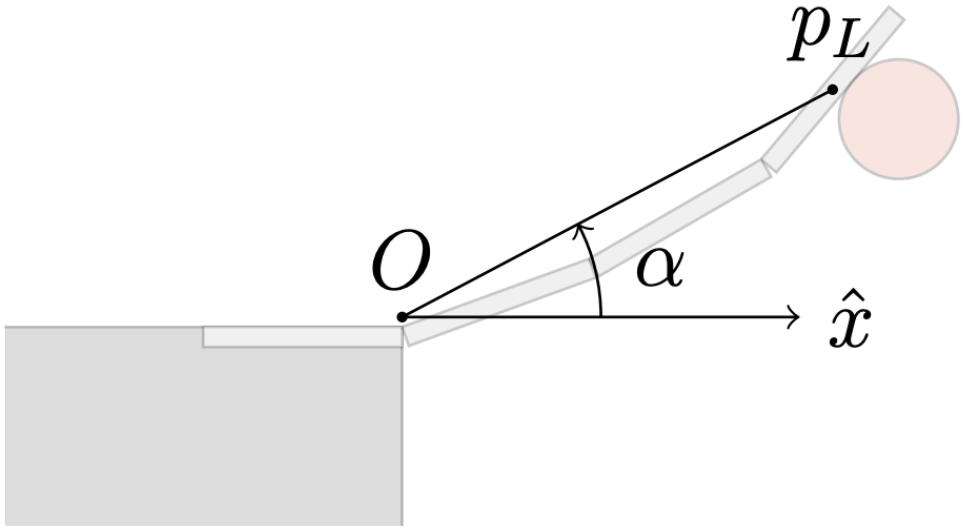


In progress



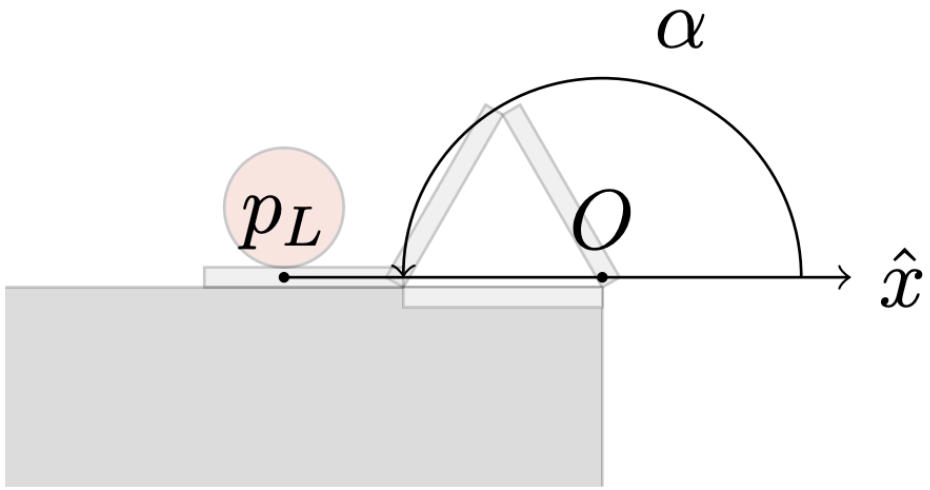
Folded state

Task definition



$(\mathrm{a})\ \alpha \approx \pi/6$

In progress

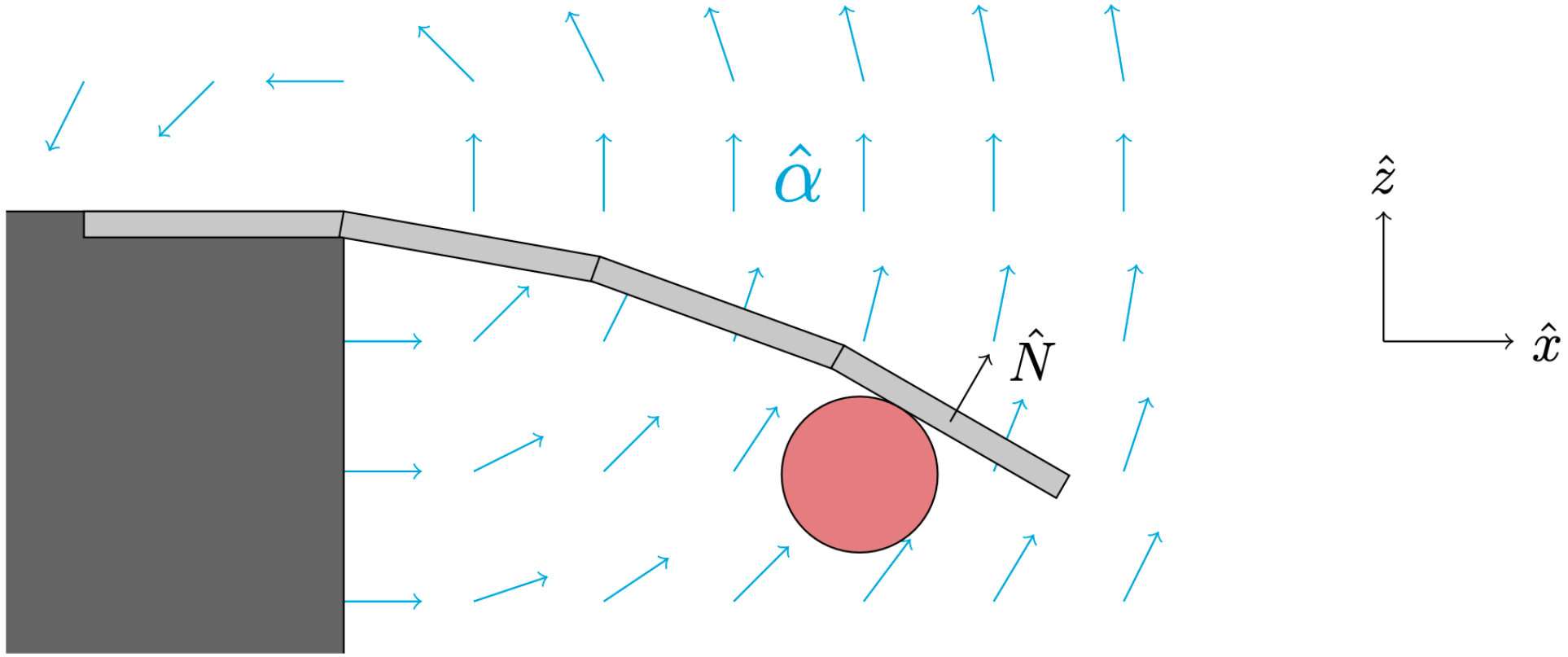


$(\mathrm{c})\ \alpha = \pi$

Folded state

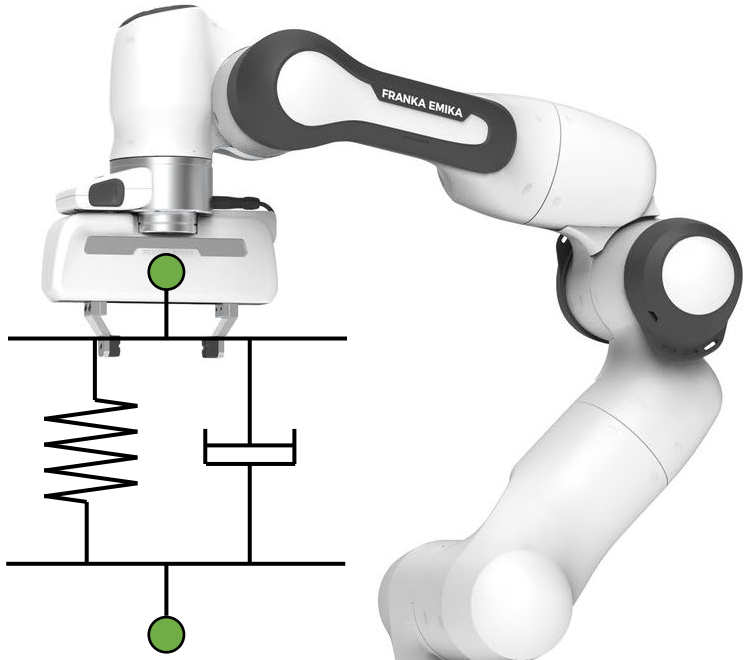
Control strategies

Key design assumption: $\hat{N} \cdot \hat{\alpha} > 0$



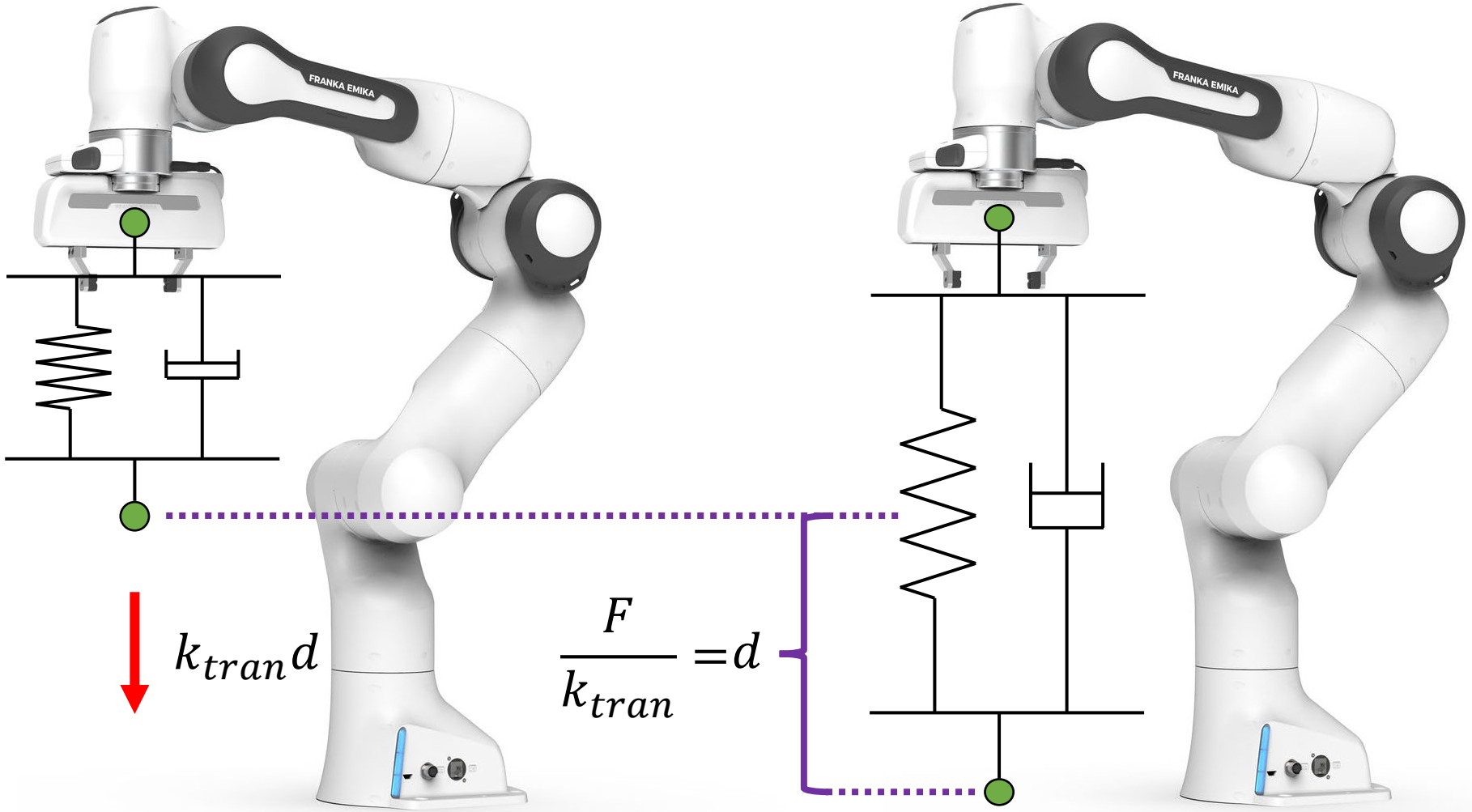
Controller goal: move in $\hat{N}$ direction, maintain contact in $\hat{T}$ direction

Impedance control



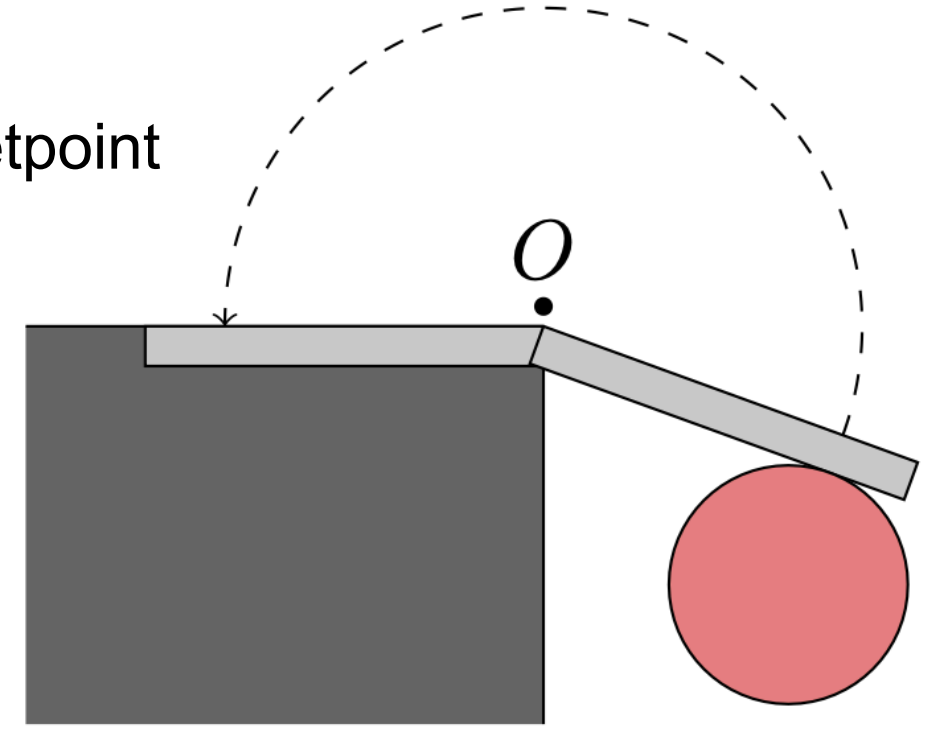
$$M\ddot{X} + D(\dot{X} - \dot{X}_0) + K(X - X_0) = F_{ext}$$

Impedance control



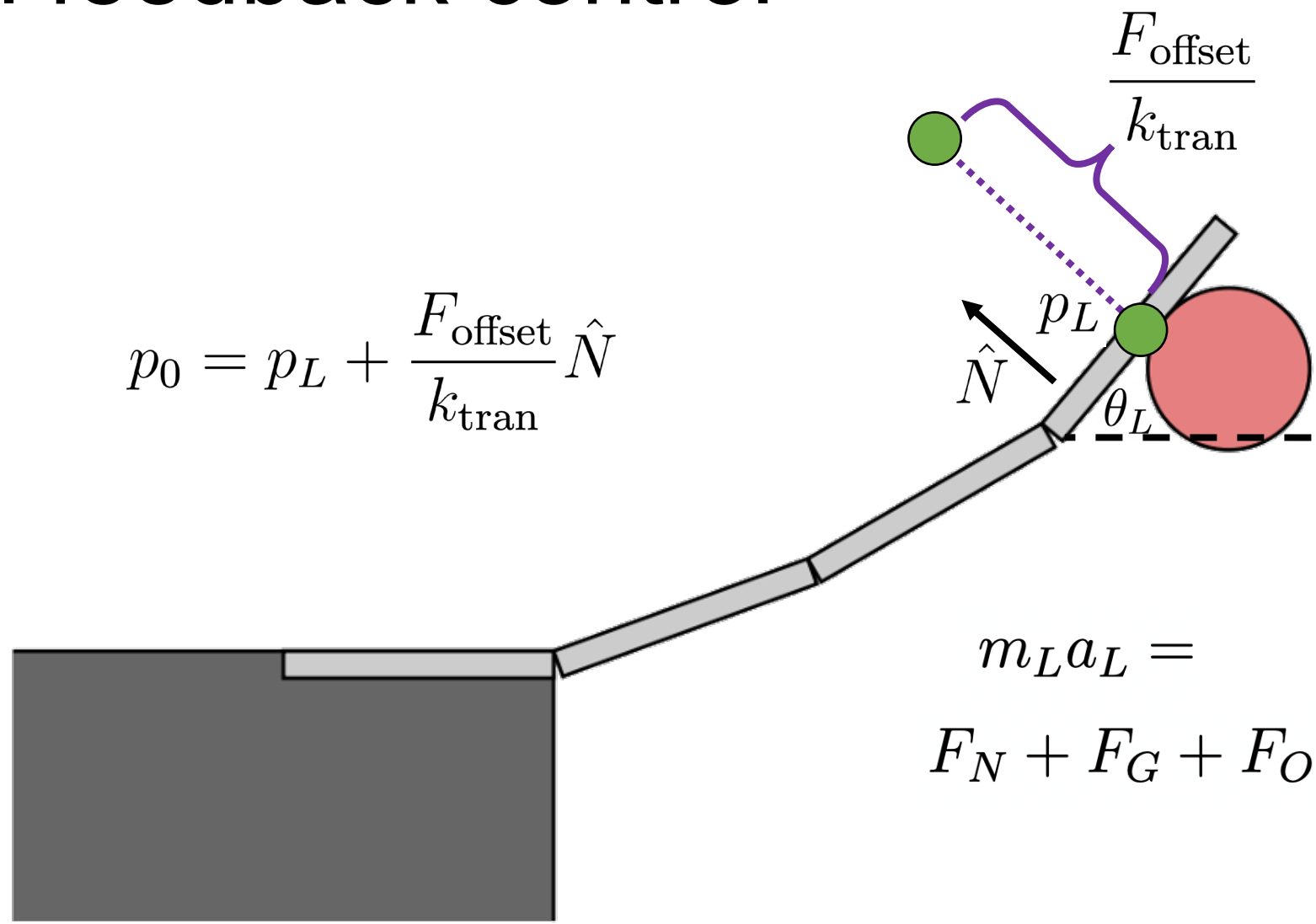
Open loop trajectory

p_0 = translational setpoint



Visual feedback control

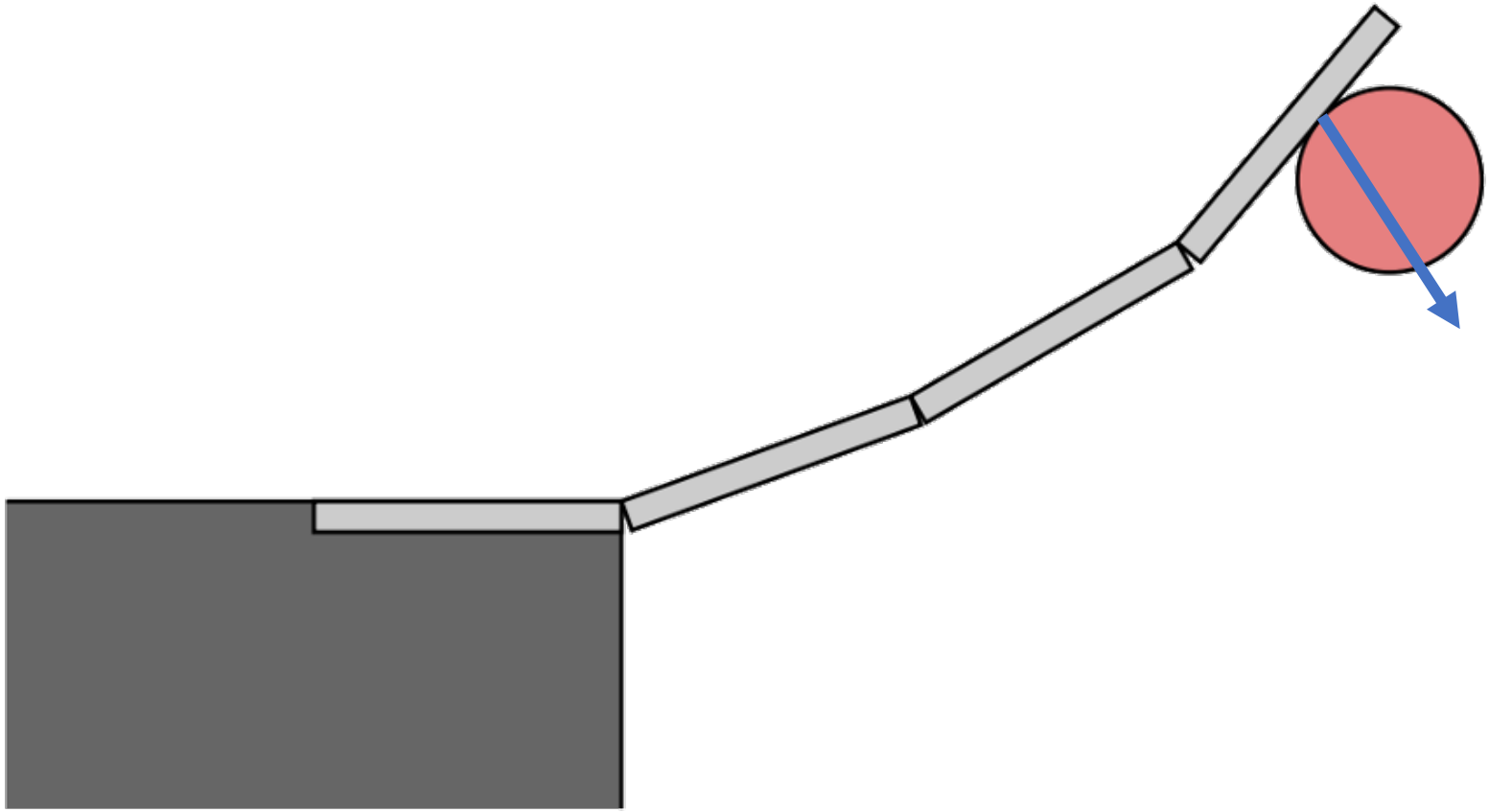
$$p_0 = p_L + \frac{F_{\text{offset}}}{k_{\text{tran}}} \hat{N}$$



$$m_L a_L =$$

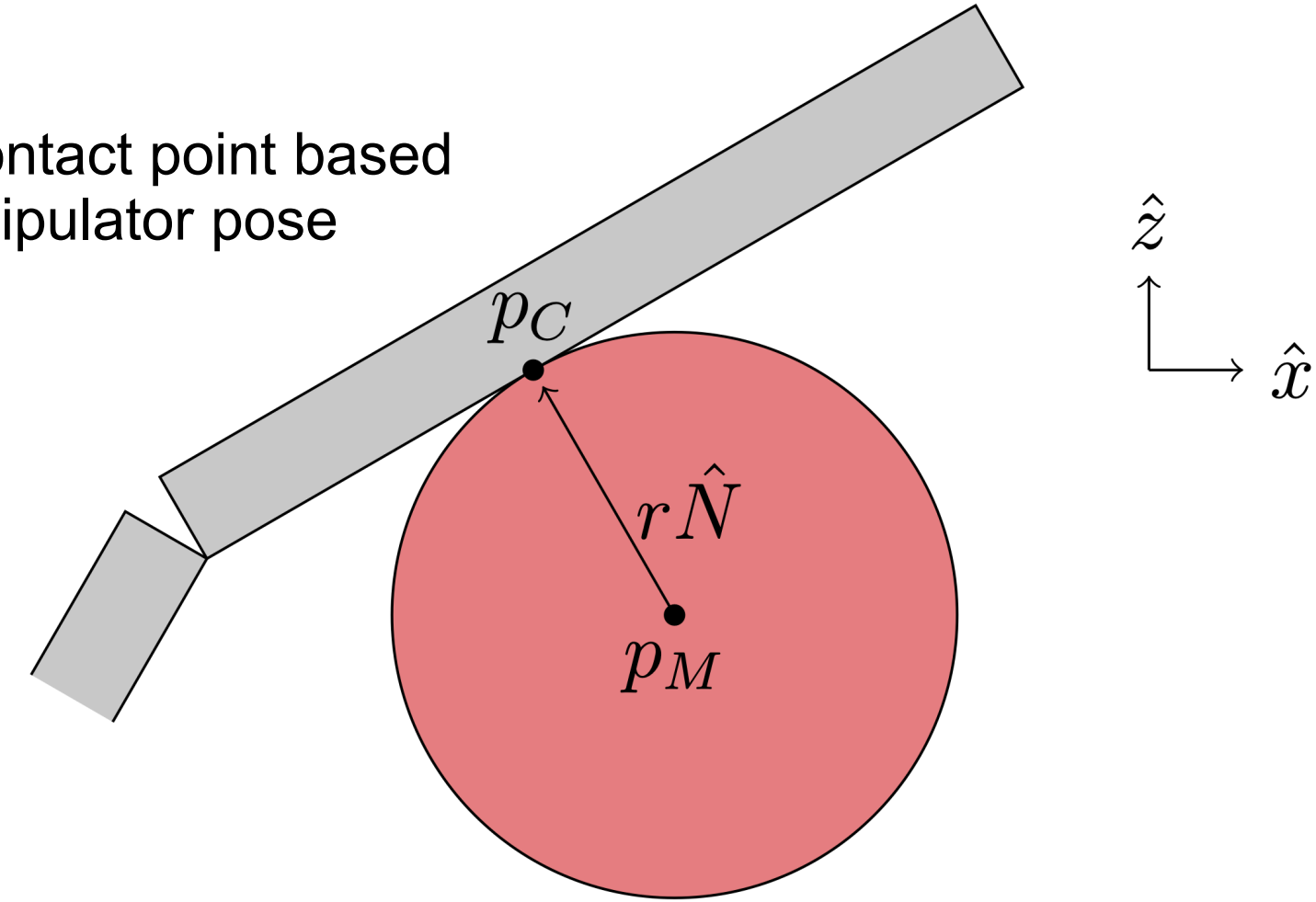
$$F_N + F_G + F_O + F_F$$

Force feedback control



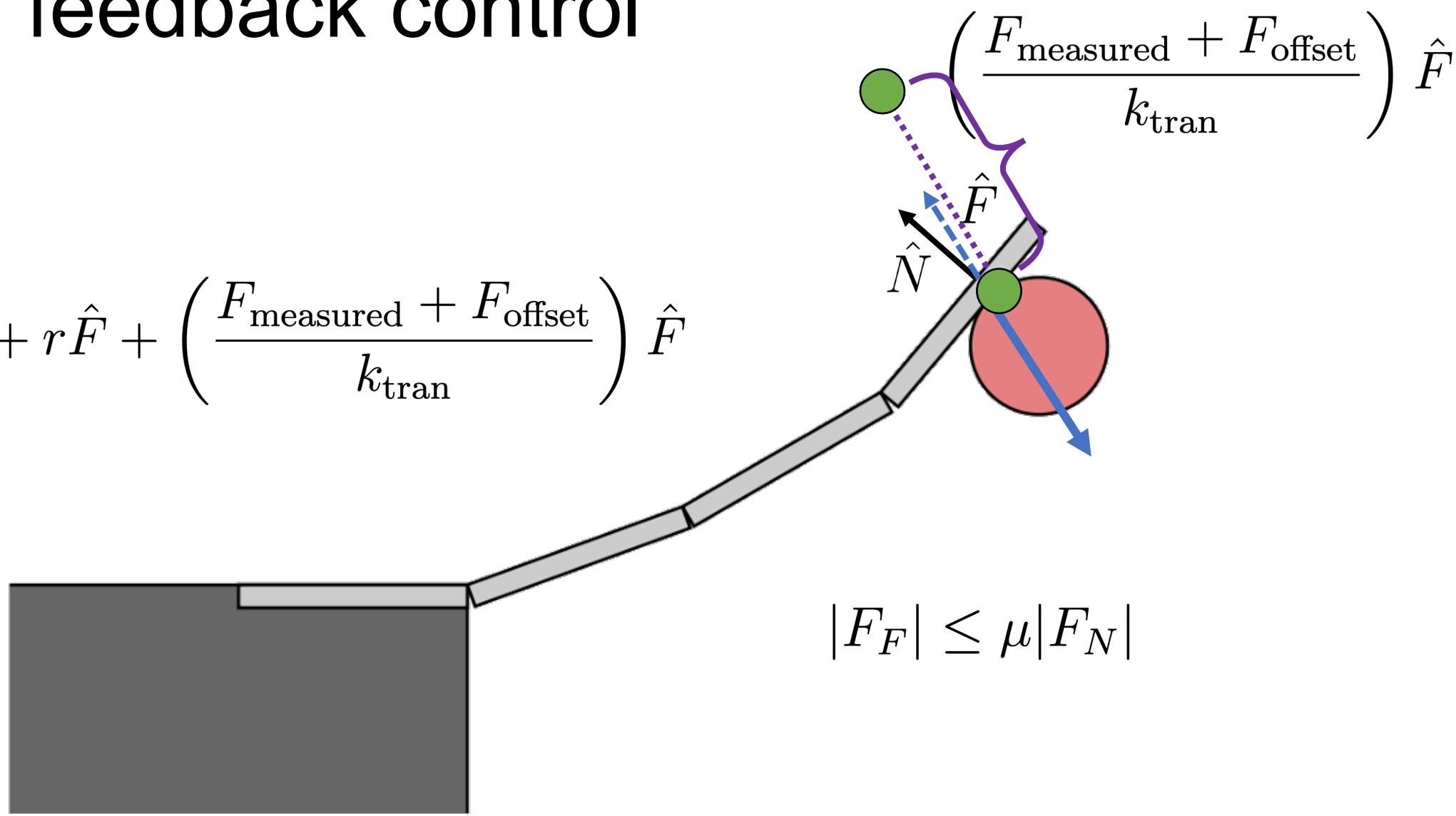
Force feedback control

We can get contact point based off $\widehat{N}$ and manipulator pose



Force feedback control

$$p_0 = p_M + r\hat{F} + \left(\frac{F_{\text{measured}} + F_{\text{offset}}}{k_{\text{tran}}}\right)\hat{F}$$



$$|F_F| \leq \mu |F_N|$$

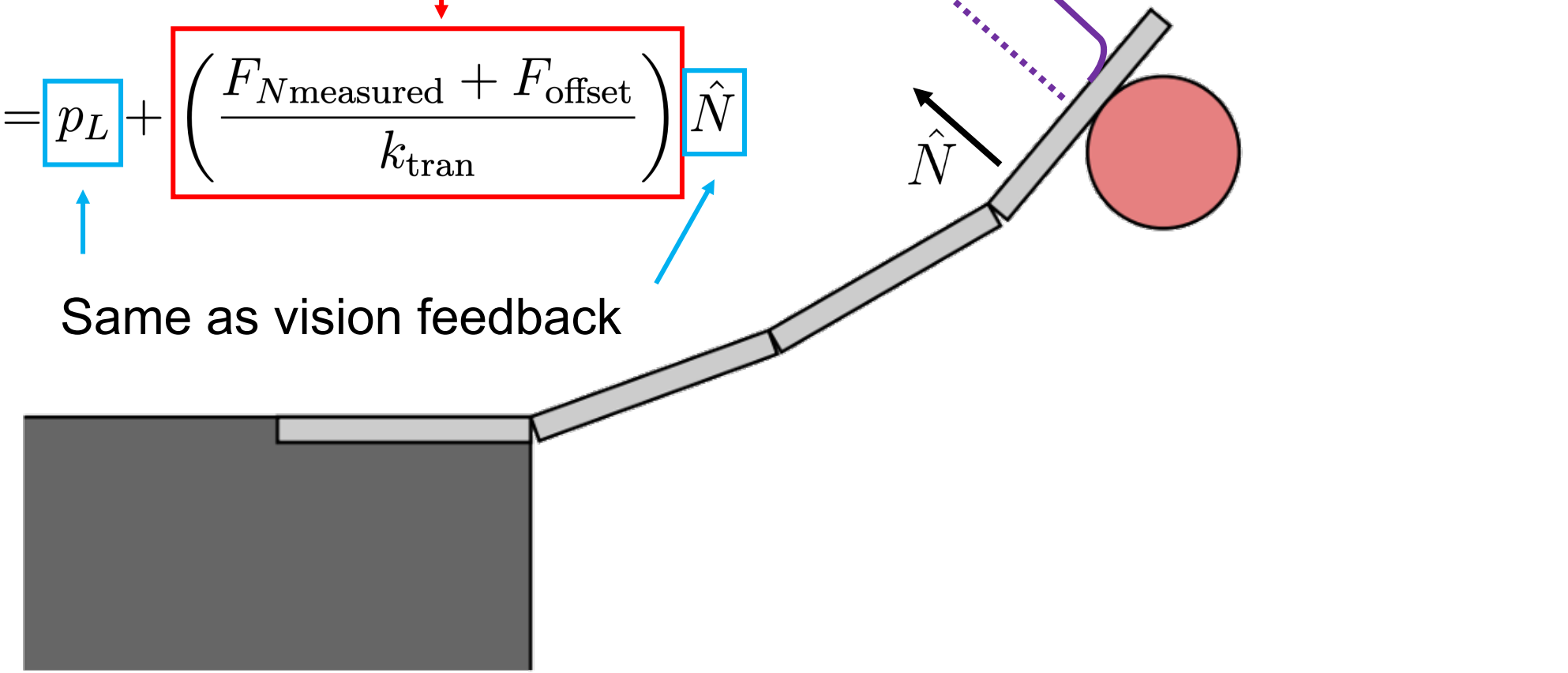
Visual and force feedback

$$\left(\frac{F_{N\text{measured}} + F_{\text{offset}}}{k_{\text{tran}}}\right)\hat{N}$$

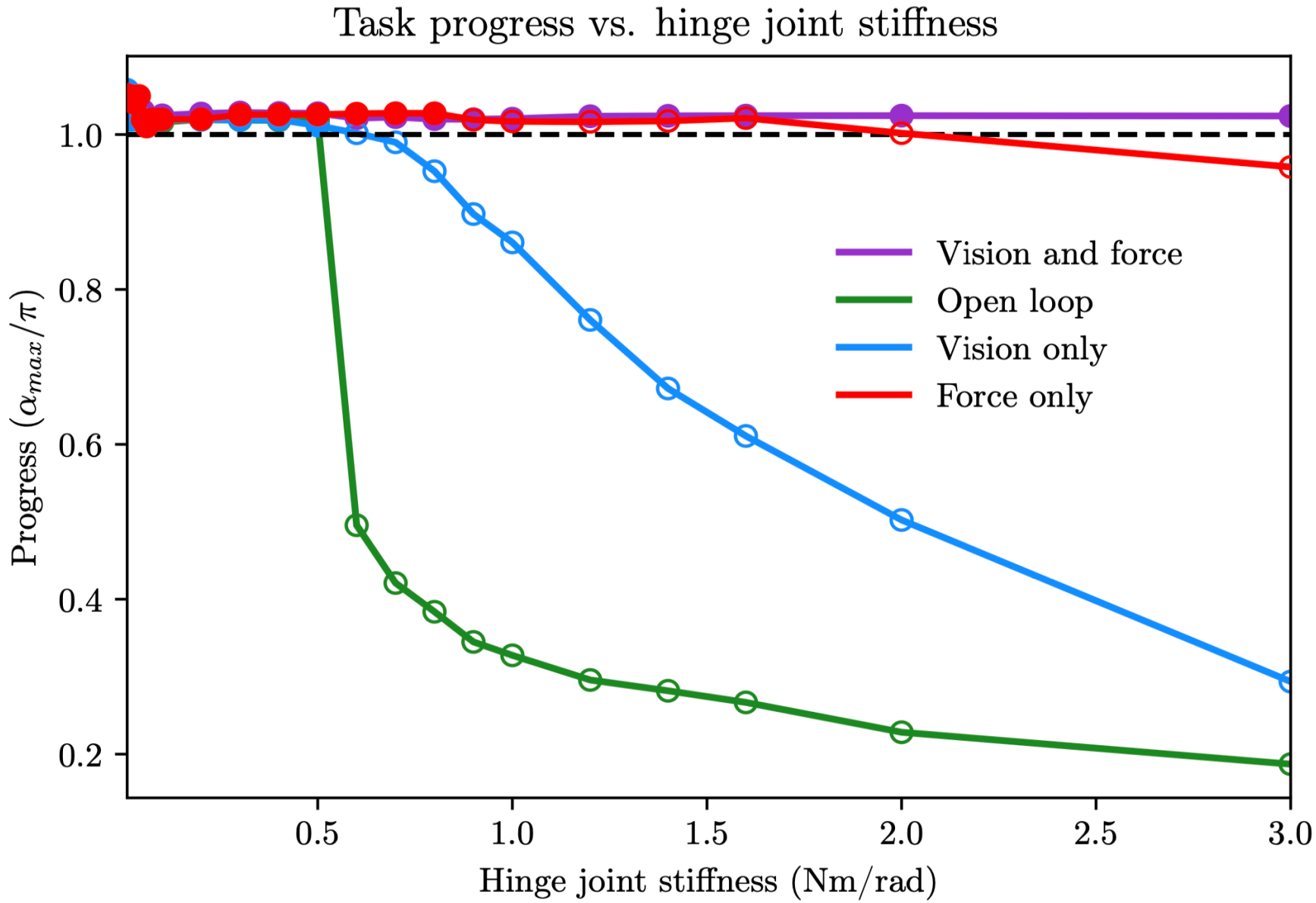
Same as force feedback

$$p_0 = p_L + \left(\frac{F_{N\text{measured}} + F_{\text{offset}}}{k_{\text{tran}}}\right)\hat{N}$$

Same as vision feedback

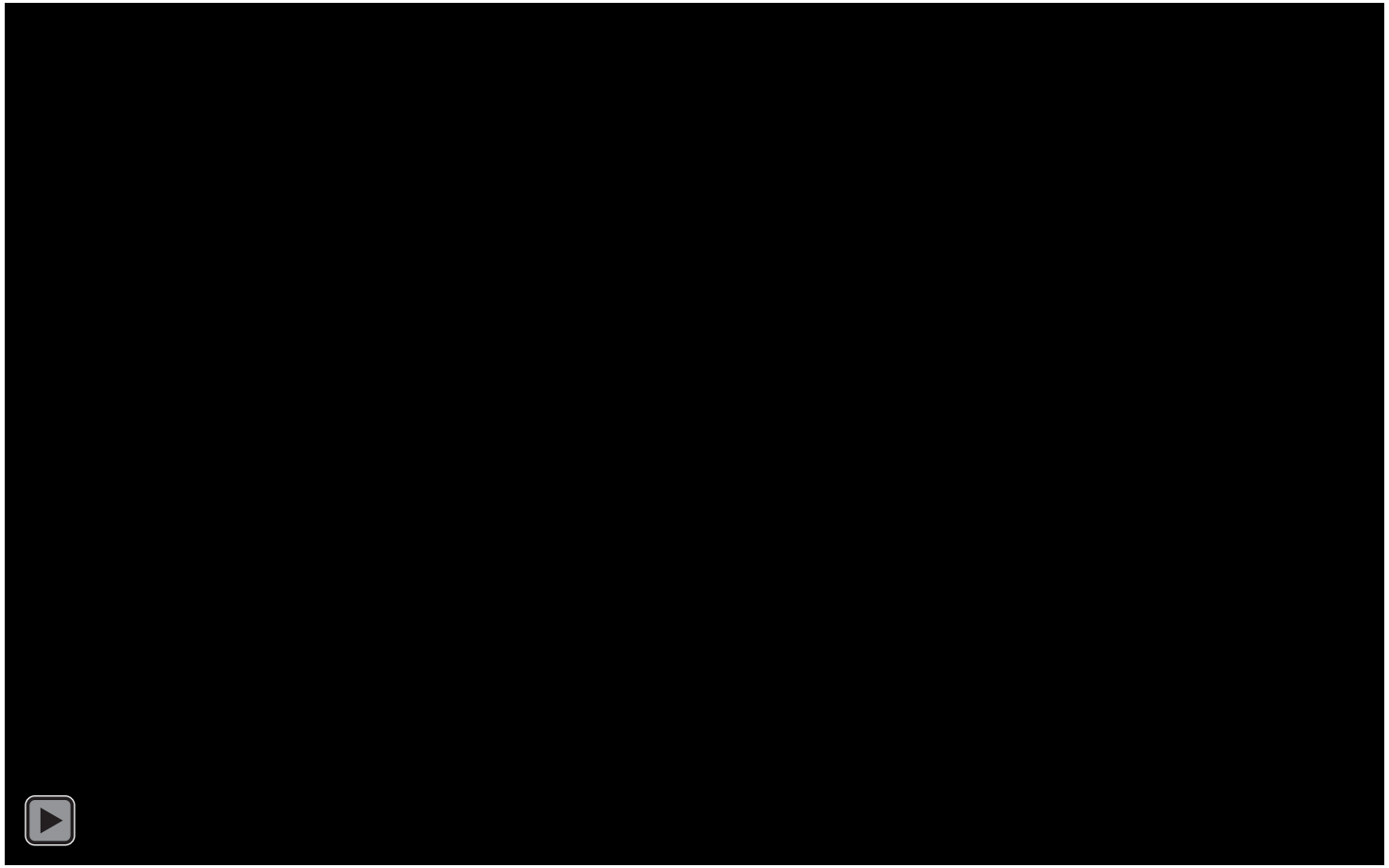


Experiments

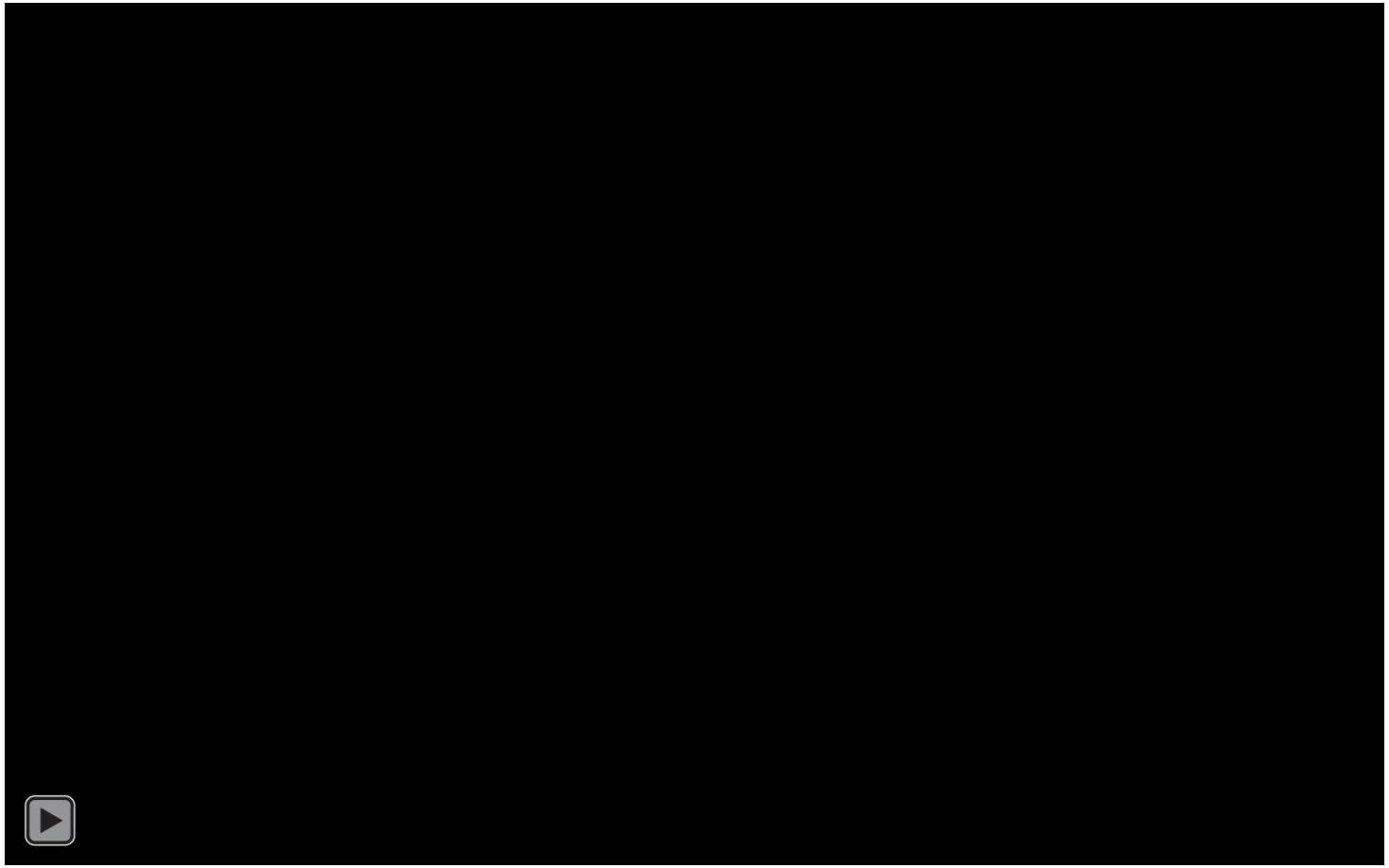

Task progress vs. hinge joint stiffness
Progress (α_{max}/π)
1.0
0.8
0.6
0.4
0.2
0.5
1.0
1.5
2.0
2.5
3.0
Hinge joint stiffness (Nm/rad)
Vision and force
Open loop
Vision only
Force only

$$\tau_i = -kq_i - dq_i$$

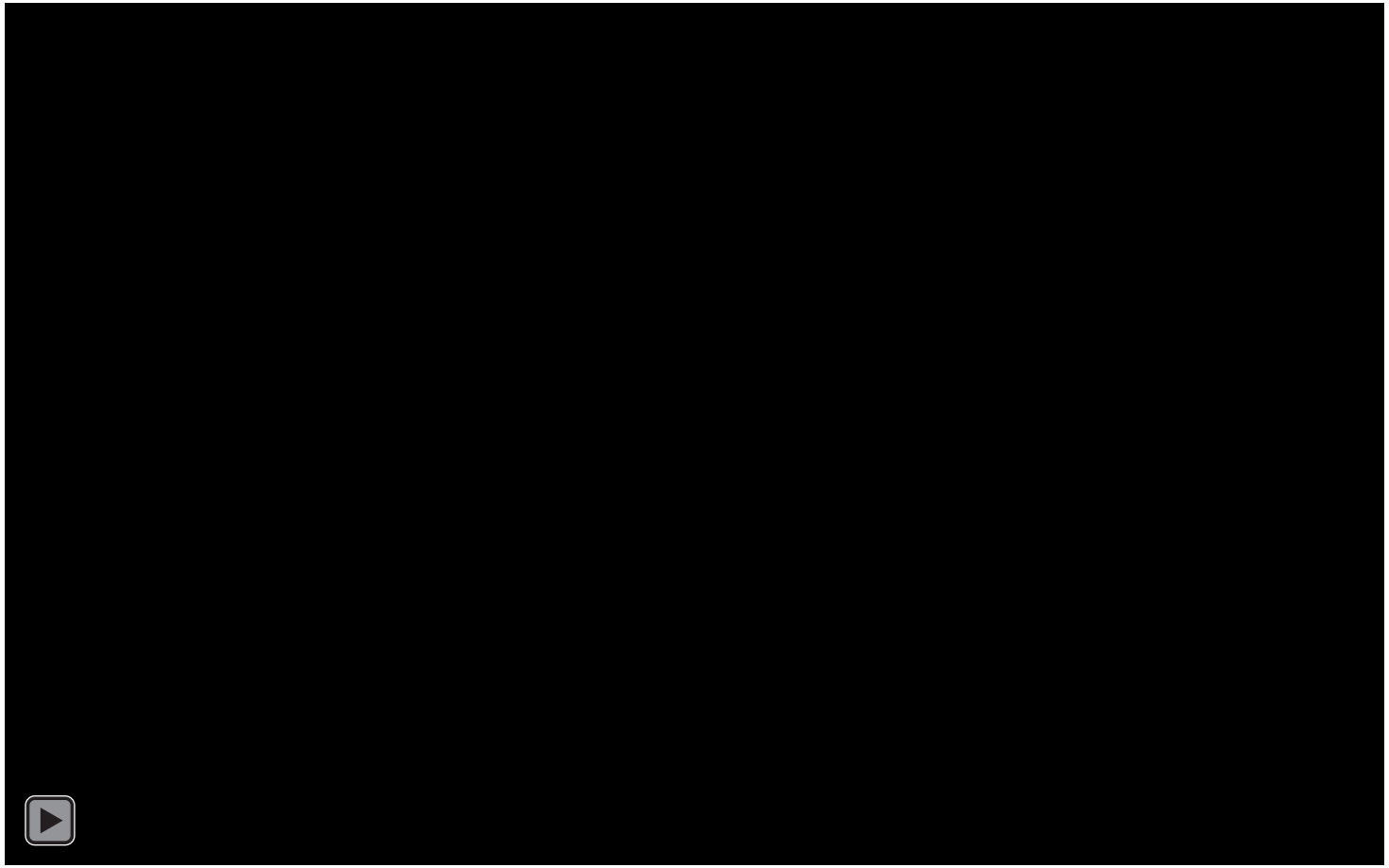
Success with vision and force feedback



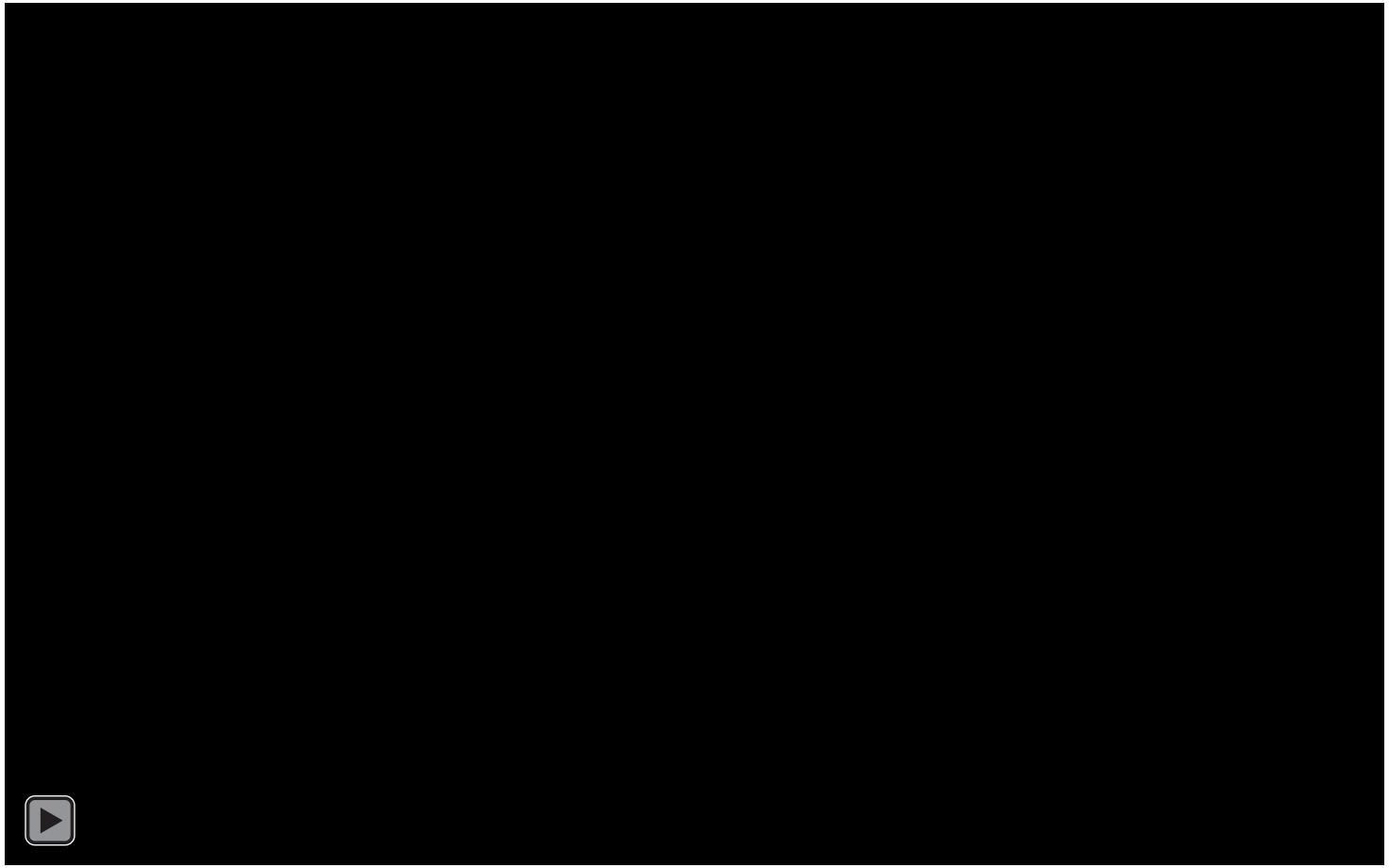
Failure with visual feedback

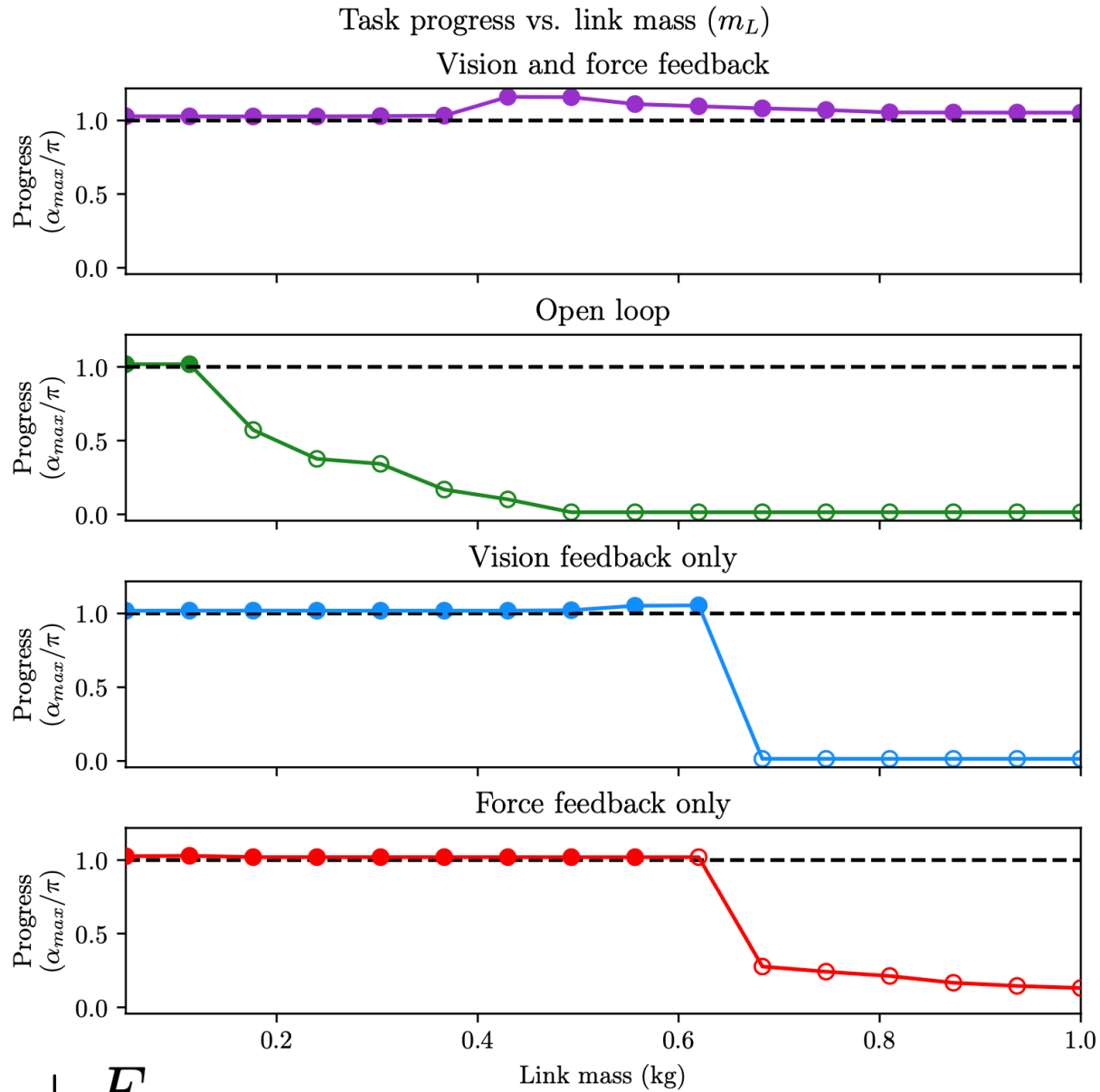


Failure with force feedback



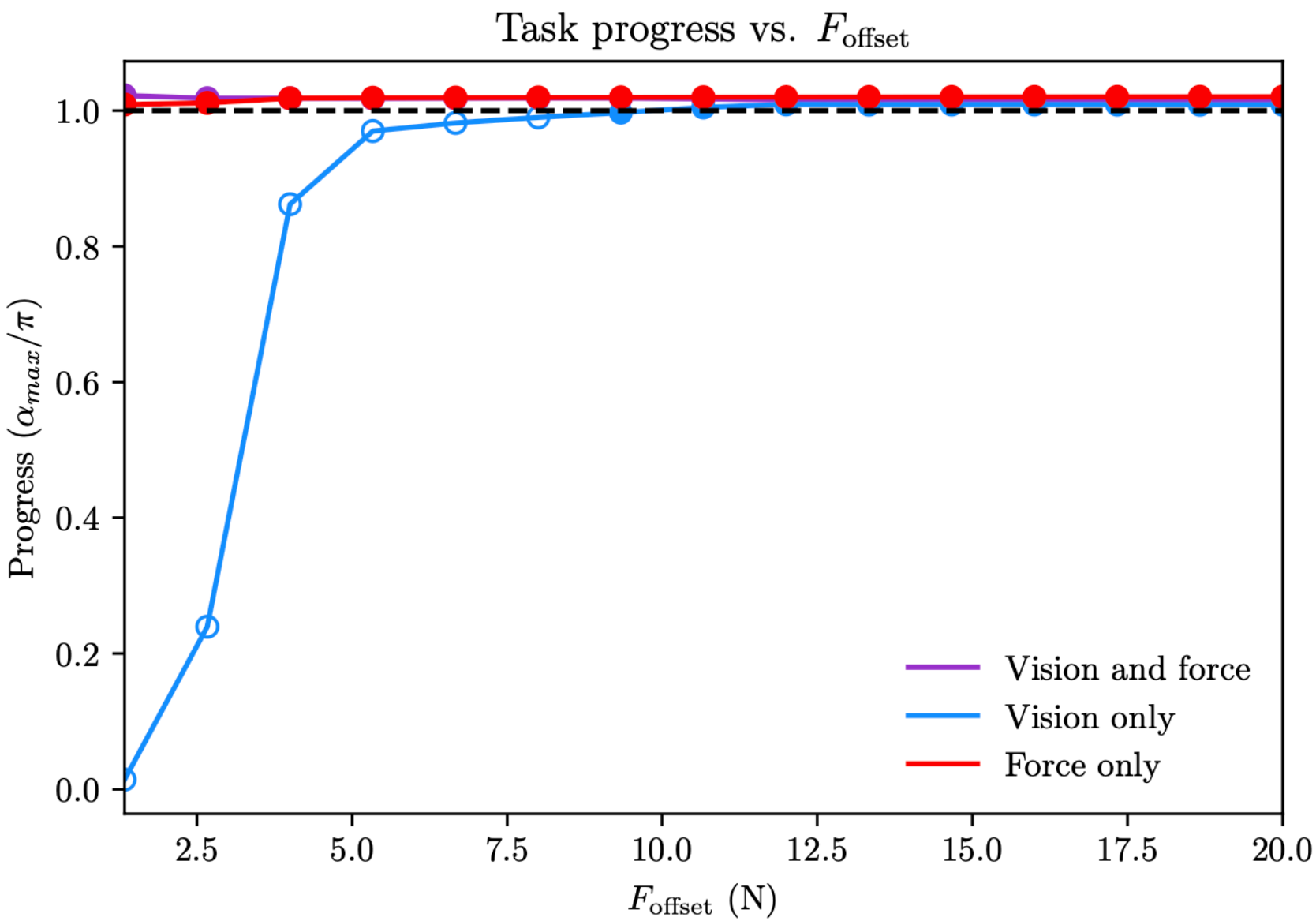
Failure with open loop trajectory





$$m_L a_L =$$

$$F_N + F_G + F_O + F_F$$


Task progress vs. F_{offset}
Progress (α_{max}/π)
1.0
0.8
0.6
0.4
0.2
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
F_{offset} (N)
Vision and force
Vision only
Force only

Future directions

- Improve normal control with vision feedback
  - Estimate normal forces based on vision
  - Use PI controller
- Improve contact control with force feedback
  - Improve estimates of $\widehat{N}$ direction by taking into account when we break contact
- Further real robot testing

Questions?