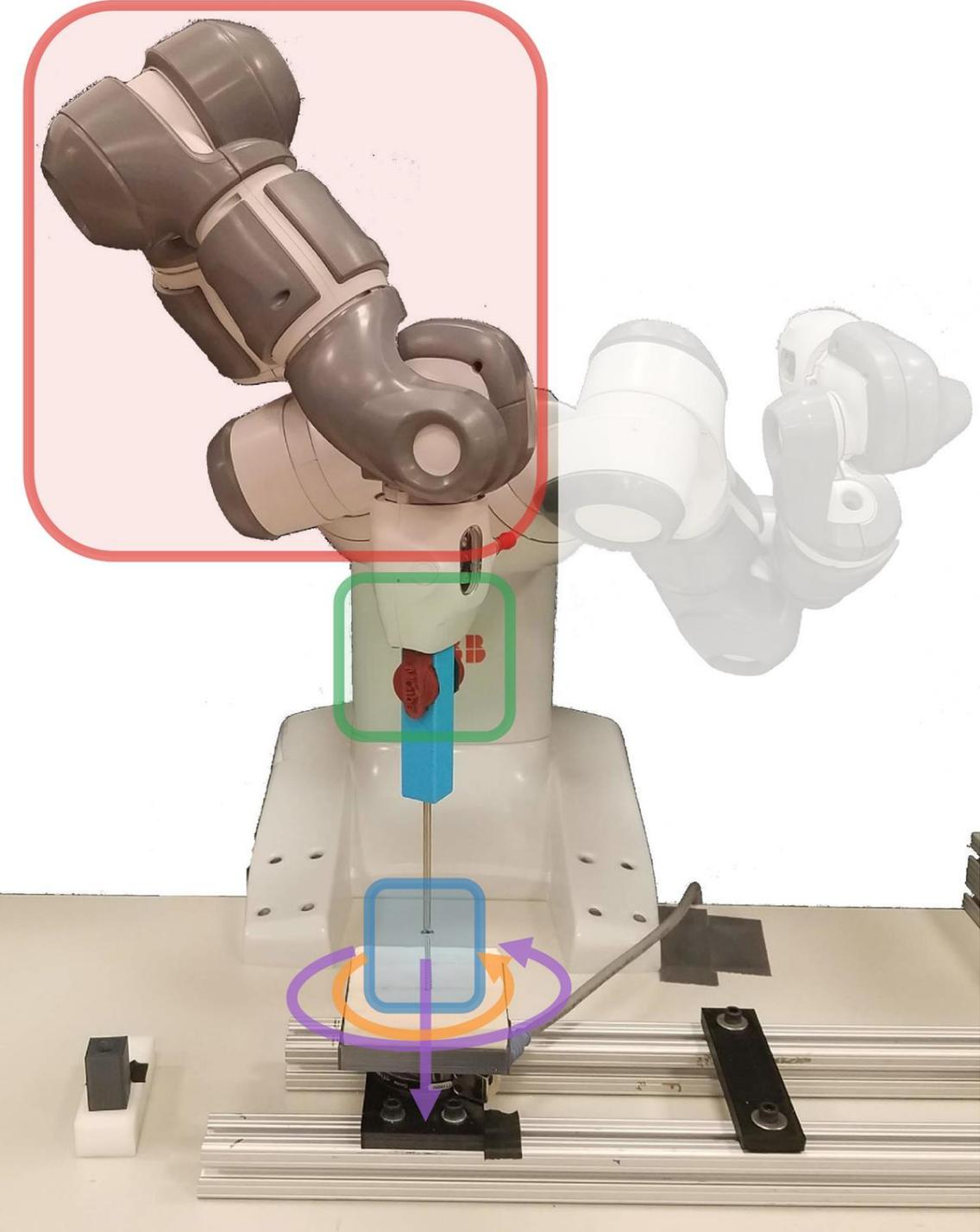


Force-and-Motion Constrained Planning for Tool Use

Rachel Holladay
Tomás Lozano-Pérez
Alberto Rodriguez

IROS 2019







Forceful Manipulation

A collage of four images showing hand tools in use. The top-left image shows a hammer with a wooden handle and a metal head. The top-right image shows a hand using a red-handled screwdriver to turn a screw in a metal surface. The bottom-left image shows a silver adjustable wrench with the number '374' engraved on it. The bottom-right image shows a hand using a large kitchen knife to cut an onion on a white cutting board, with other vegetables like cucumbers and tomatoes in the background.

Forceful Manipulation with Hand Tools

Animal Tool Use

Animal Tool Use

1. Extending reach

Animal Tool Use

1. Extending reach

Sinapov et al. `08, Tikhanoff et al. `13, Jain et al. `14, Elliott et al. `16, Xie et al. `19

Animal Tool Use

1. Extending reach

Sinapov et al. '08, Tikhanoff et al. '13, Jain et al. '14, Elliott et al. '16, Xie et al. '19

2. Amplifying mechanical force

Animal Tool Use

1. Extending reach

Sinapov et al. '08, Tikhanoff et al. '13, Jain et al. '14, Elliott et al. '16, Xie et al. '19

2. Amplifying mechanical force

Our Work

Animal Tool Use

1. Extending reach
2. Amplifying mechanical force
3. Control liquid flow

Sinapov et al. '08, Tikhanoff et al. '13, Jain et al. '14, Elliott et al. '16, Xie et al. '19

Our Work

Animal Tool Use

1. Extending reach

Sinapov et al. '08, Tikhanoff et al. '13, Jain et al. '14, Elliott et al. '16, Xie et al. '19

2. Amplifying mechanical force

Our Work

3. Control liquid flow

4. Enhance effectiveness of antagonistic displays

Animal Tool Use

1. Extending reach

Sinapov et al. `08, Tikhanoff et al. `13, Jain et al. `14, Elliott et al. `16, Xie et al. `19

2. Amplifying mechanical force

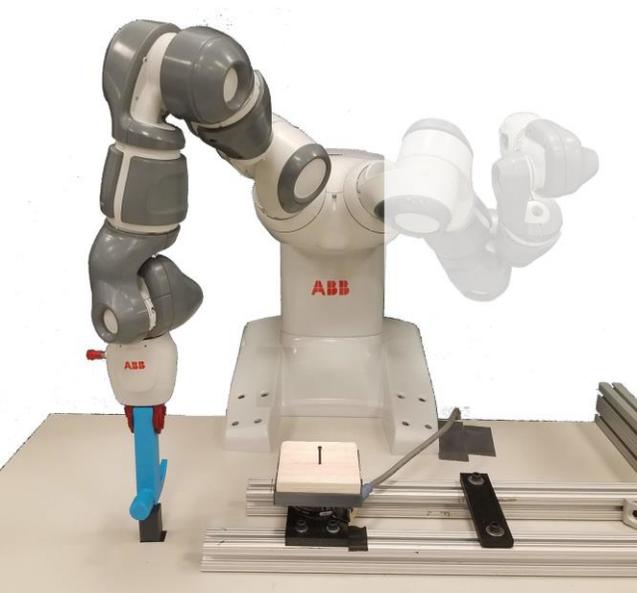
Our Work

3. Control liquid flow

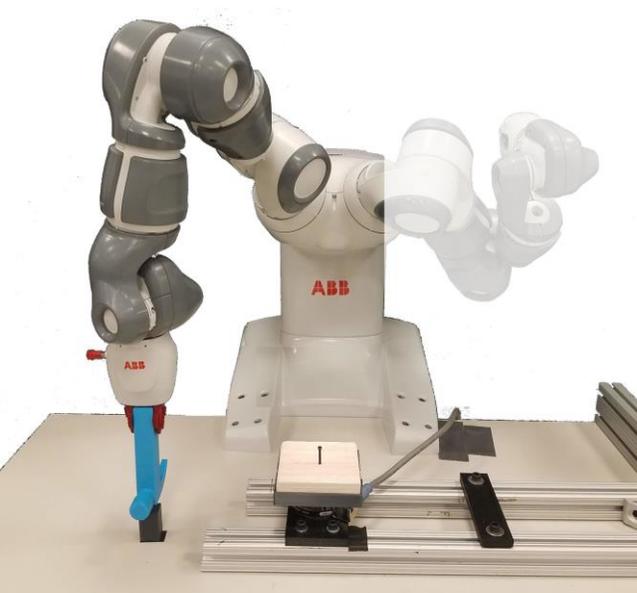
4. Enhance effectiveness of antagonistic displays

What does it mean to use a tool?

What does it mean to use a tool?

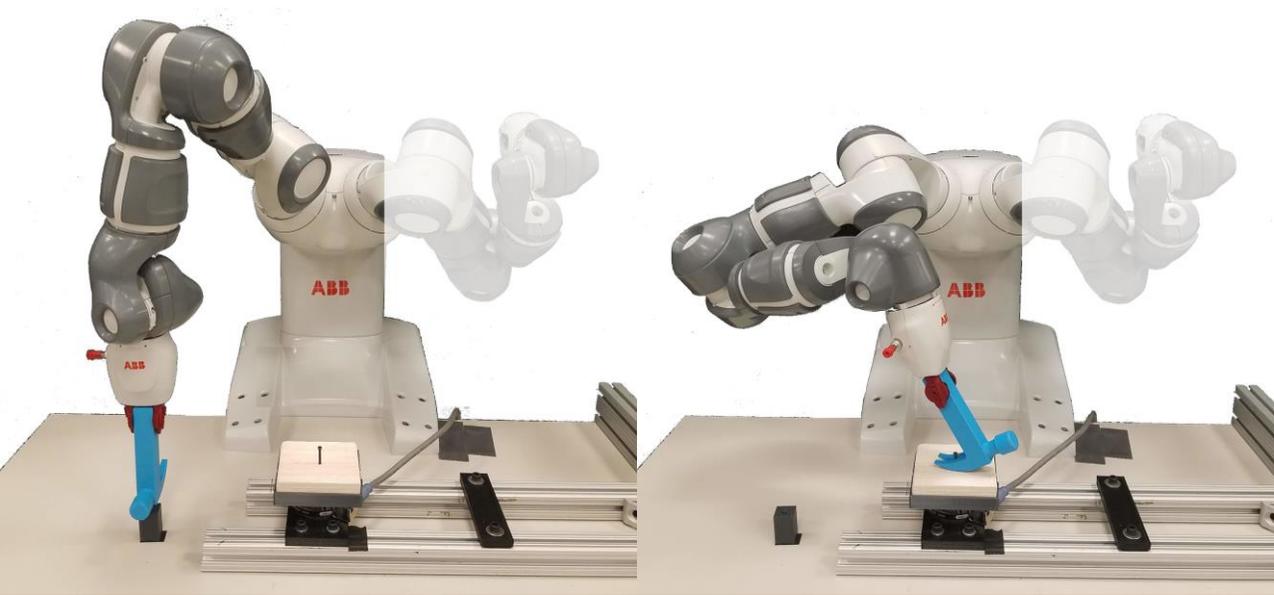


What does it mean to use a tool?



Grasp

What does it mean to use a tool?



Grasp

Engage

What does it mean to use a tool?

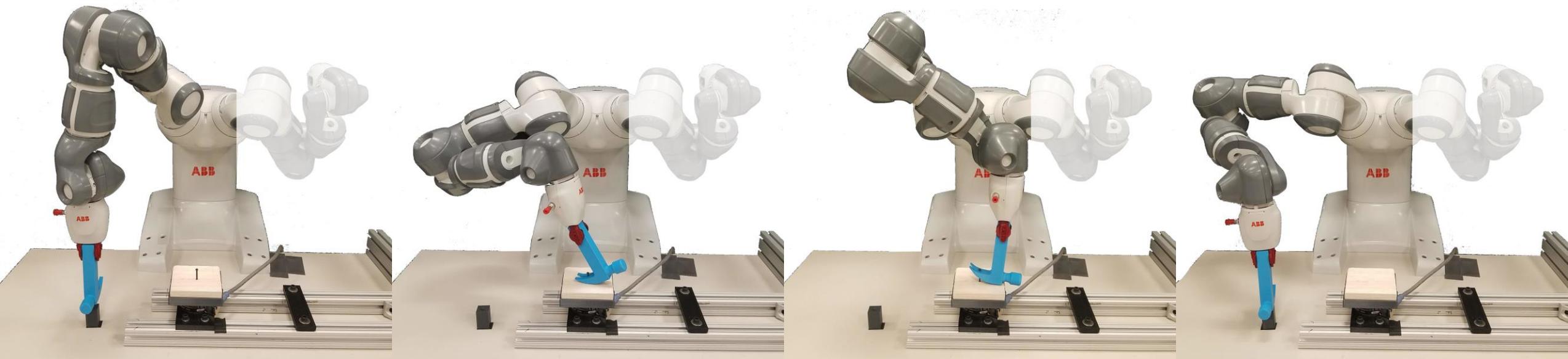


Grasp

Engage

Actuate

What does it mean to use a tool?



Grasp

Engage

Actuate

Place

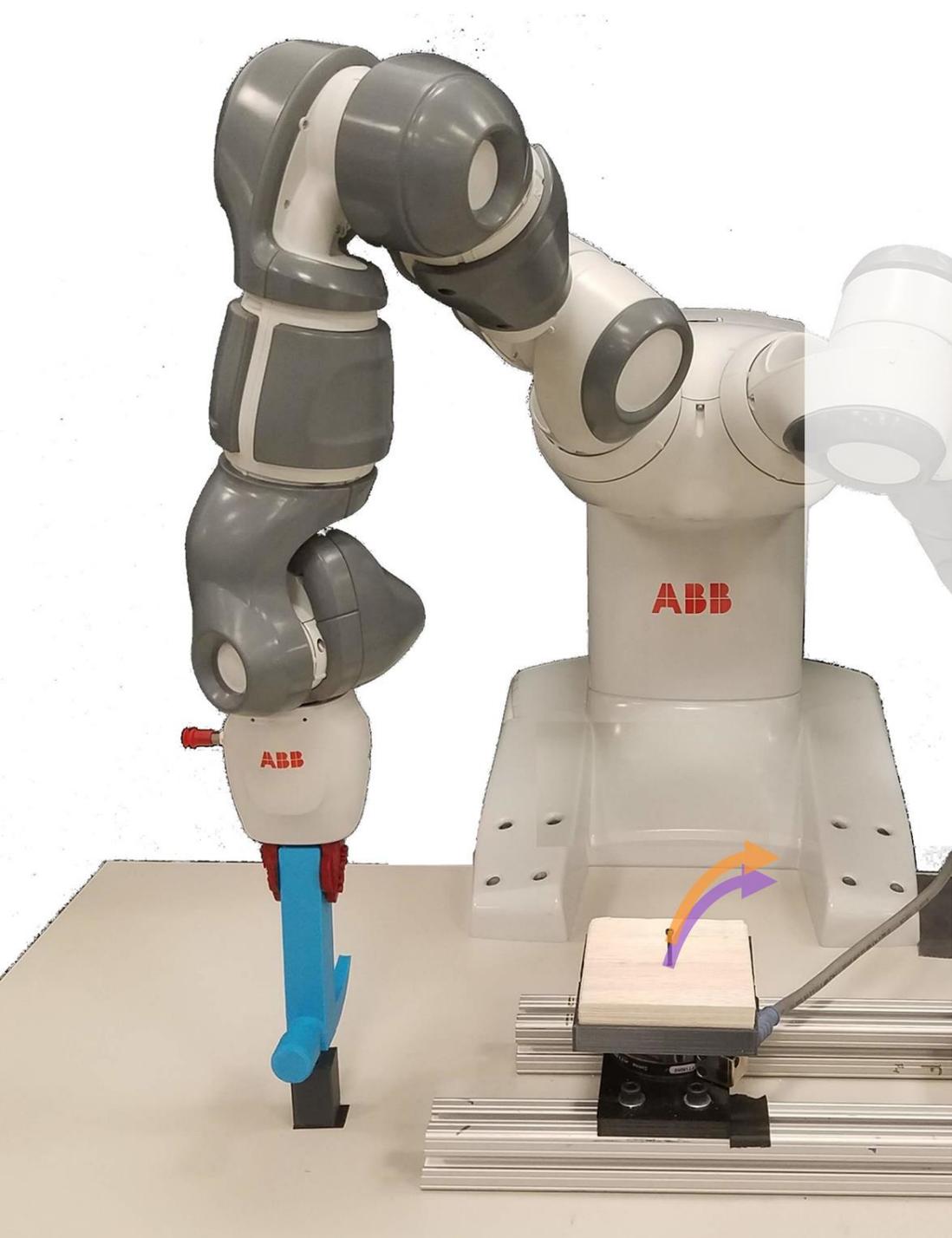
What choices does the robot need to make
at each stage?

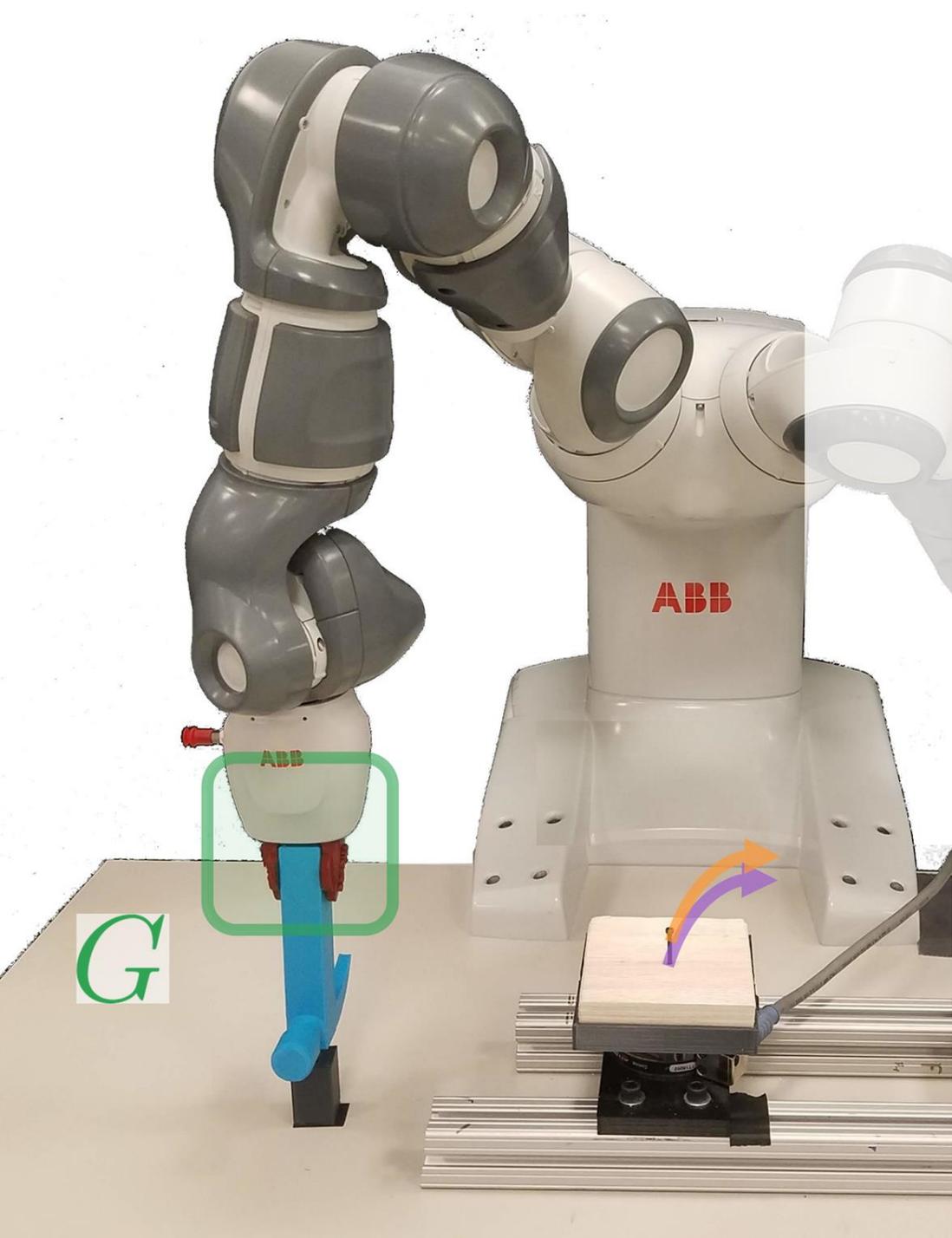
What choices does the robot need to make
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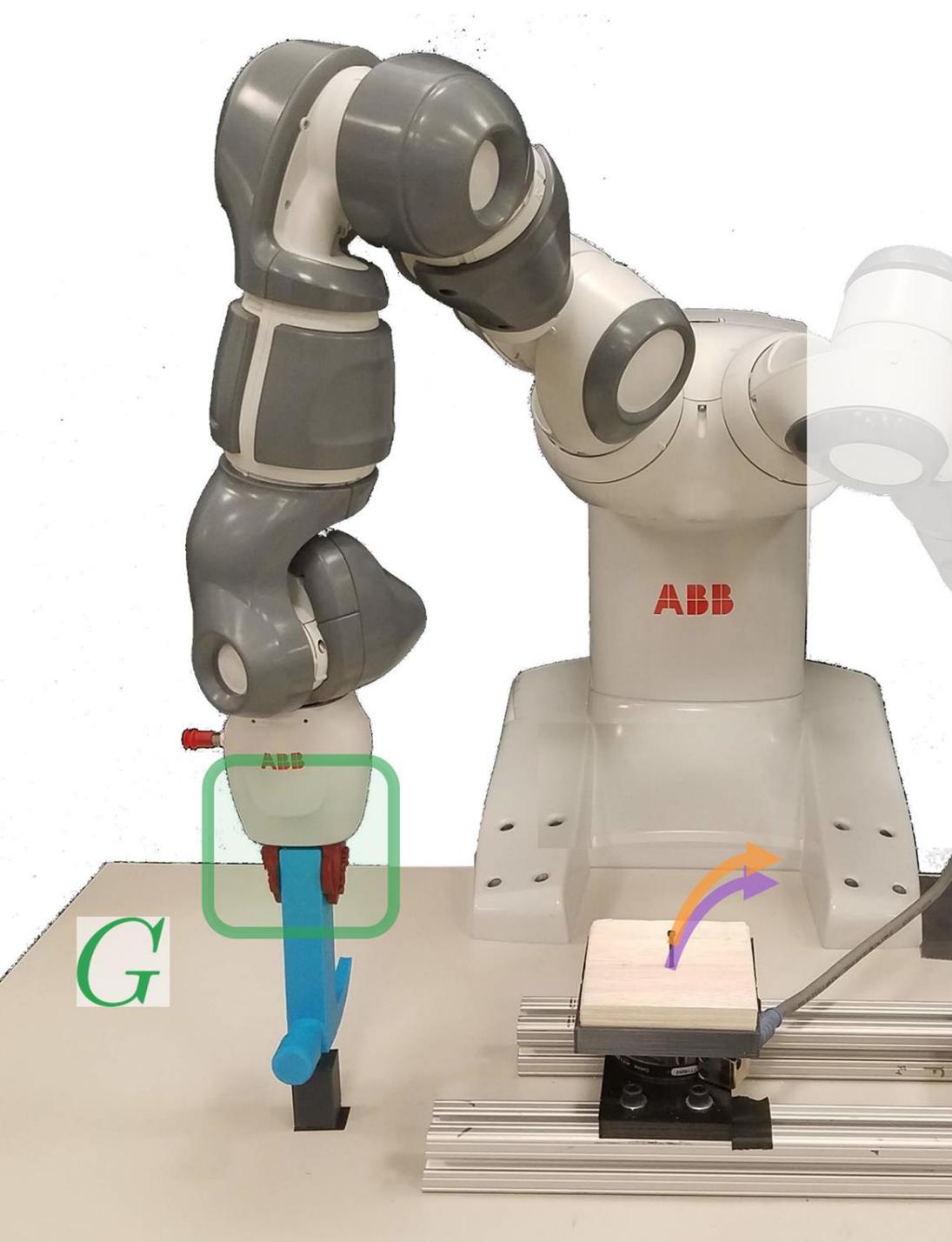
Decision Variables

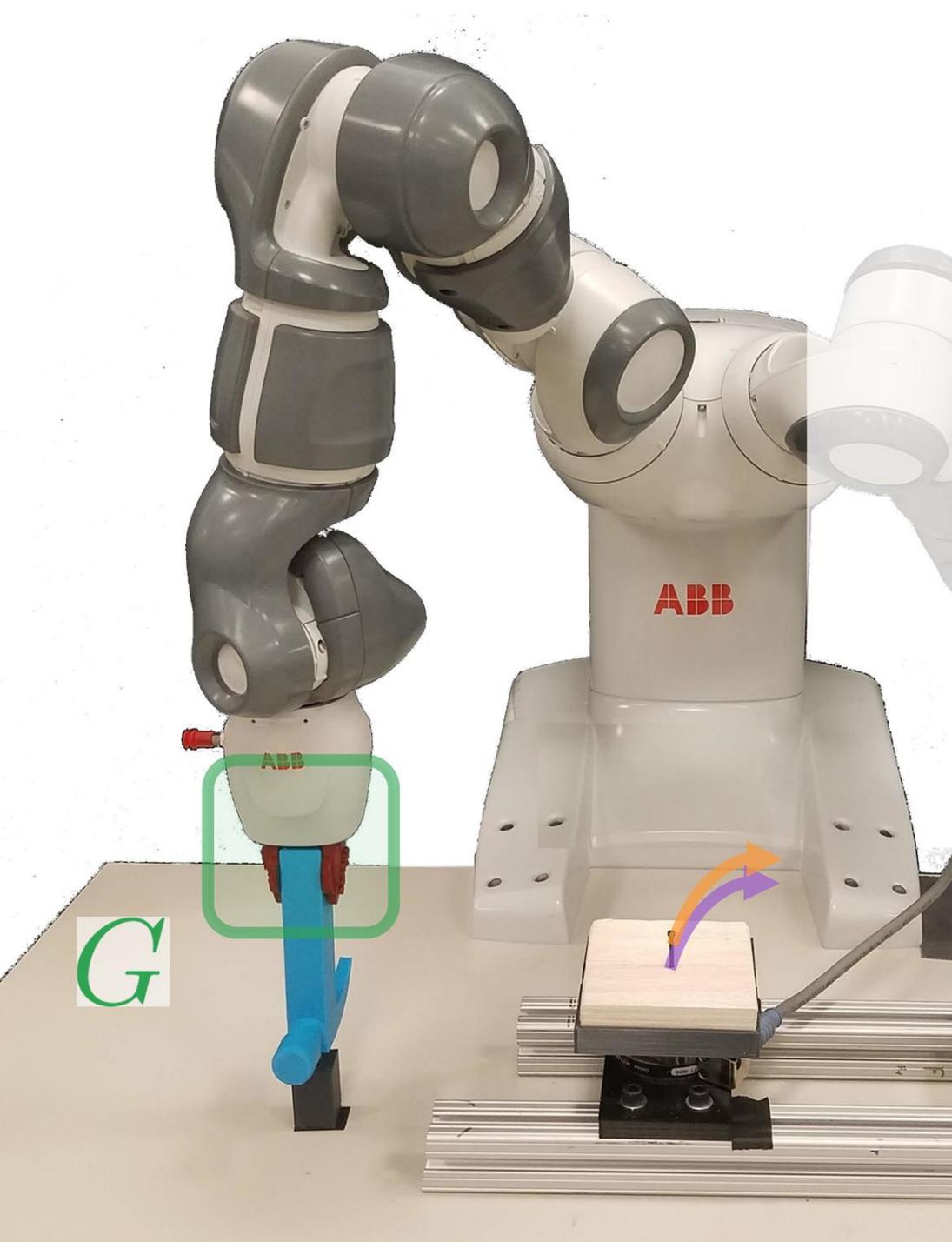
What choices does the robot need to make
at each stage?

Decision Variables and Constraints



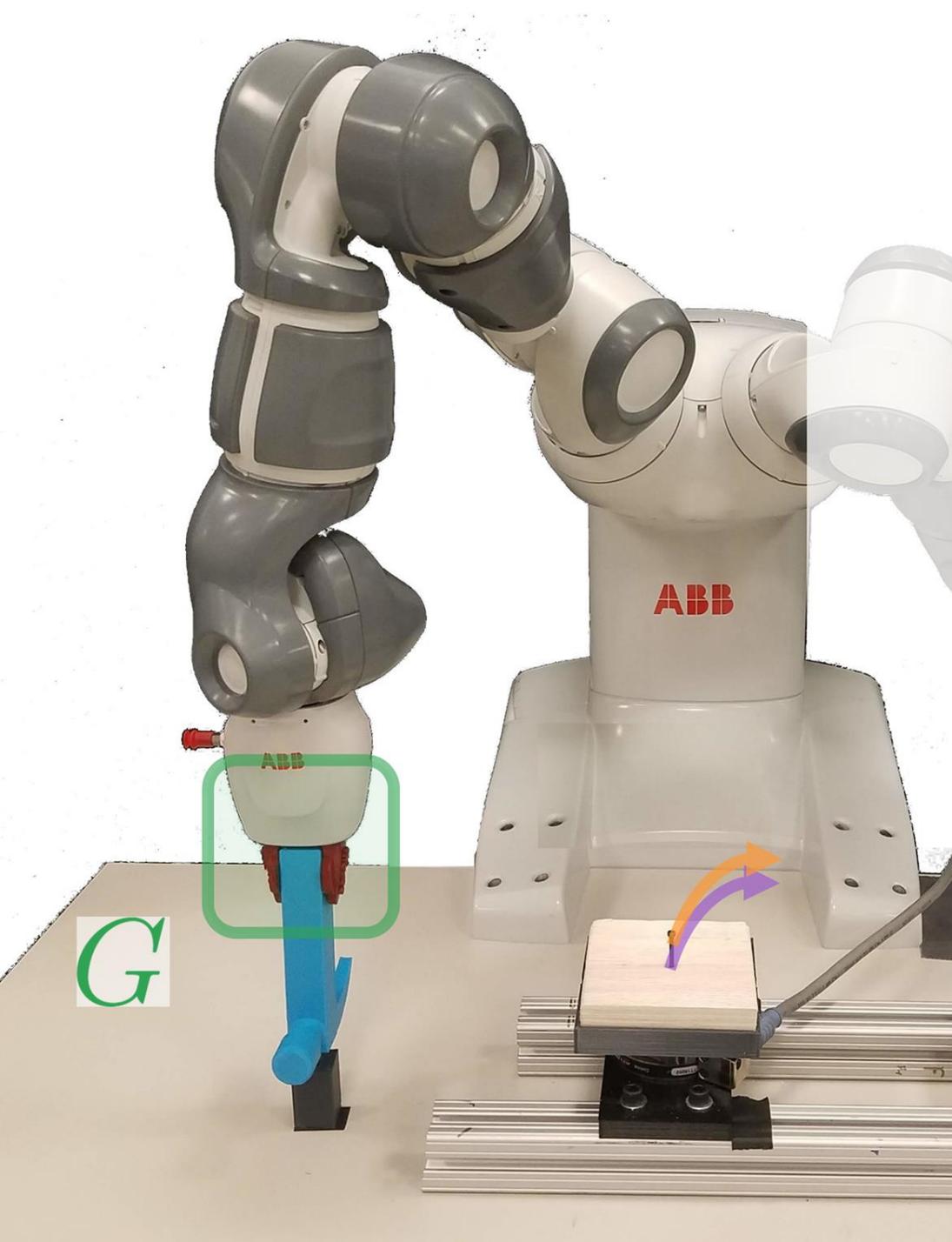






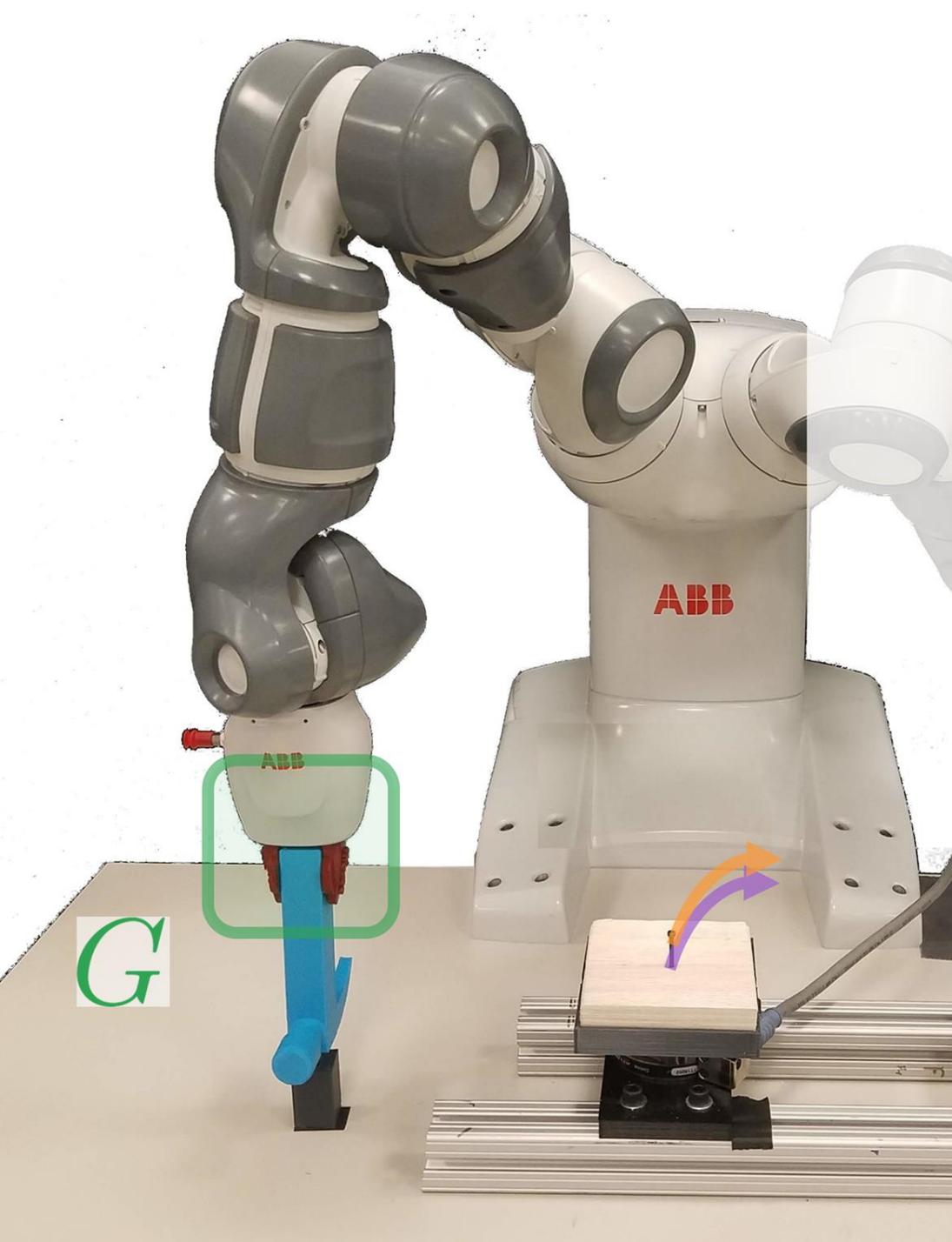
C-Free?





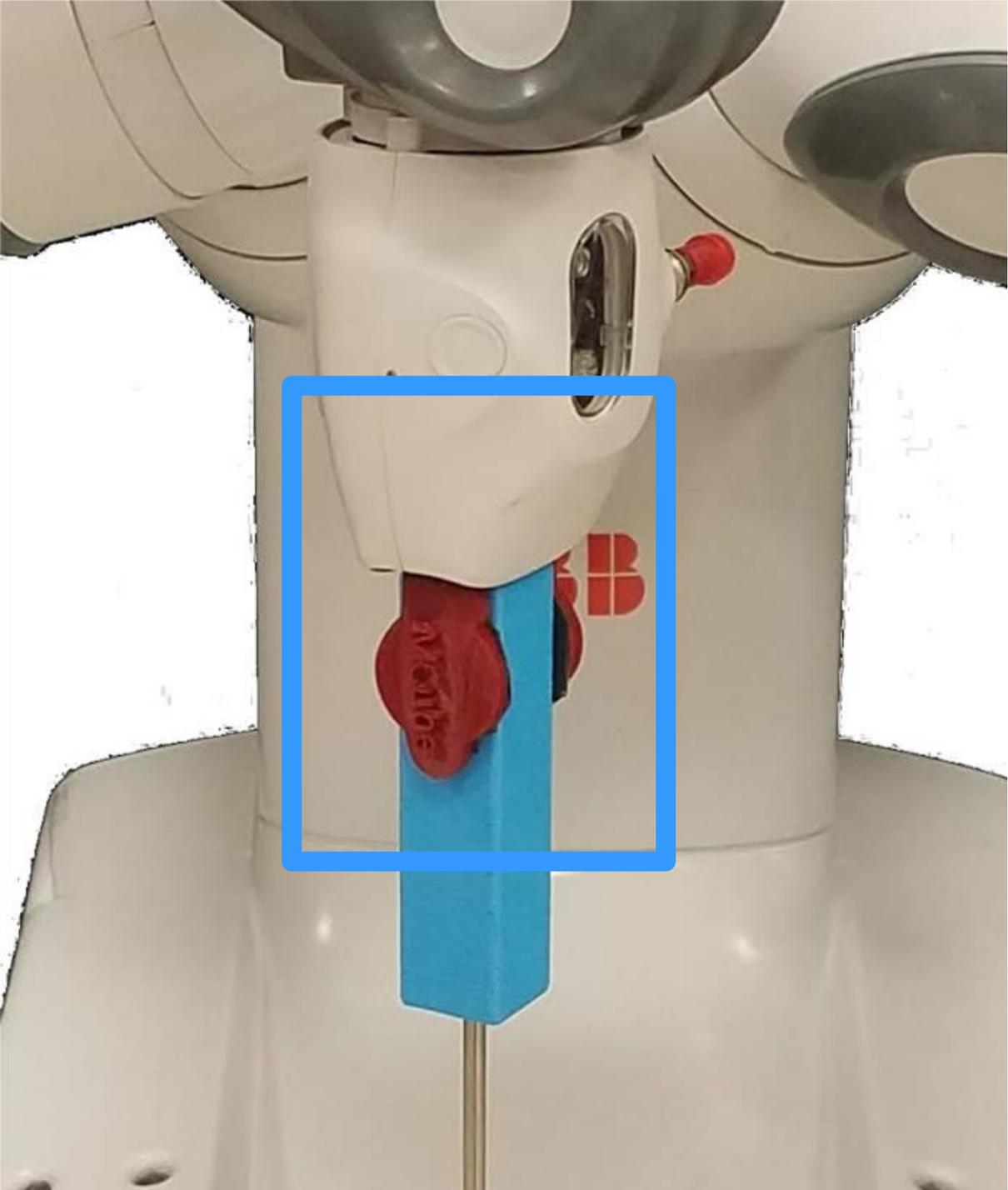
C-Free?
Reaches?



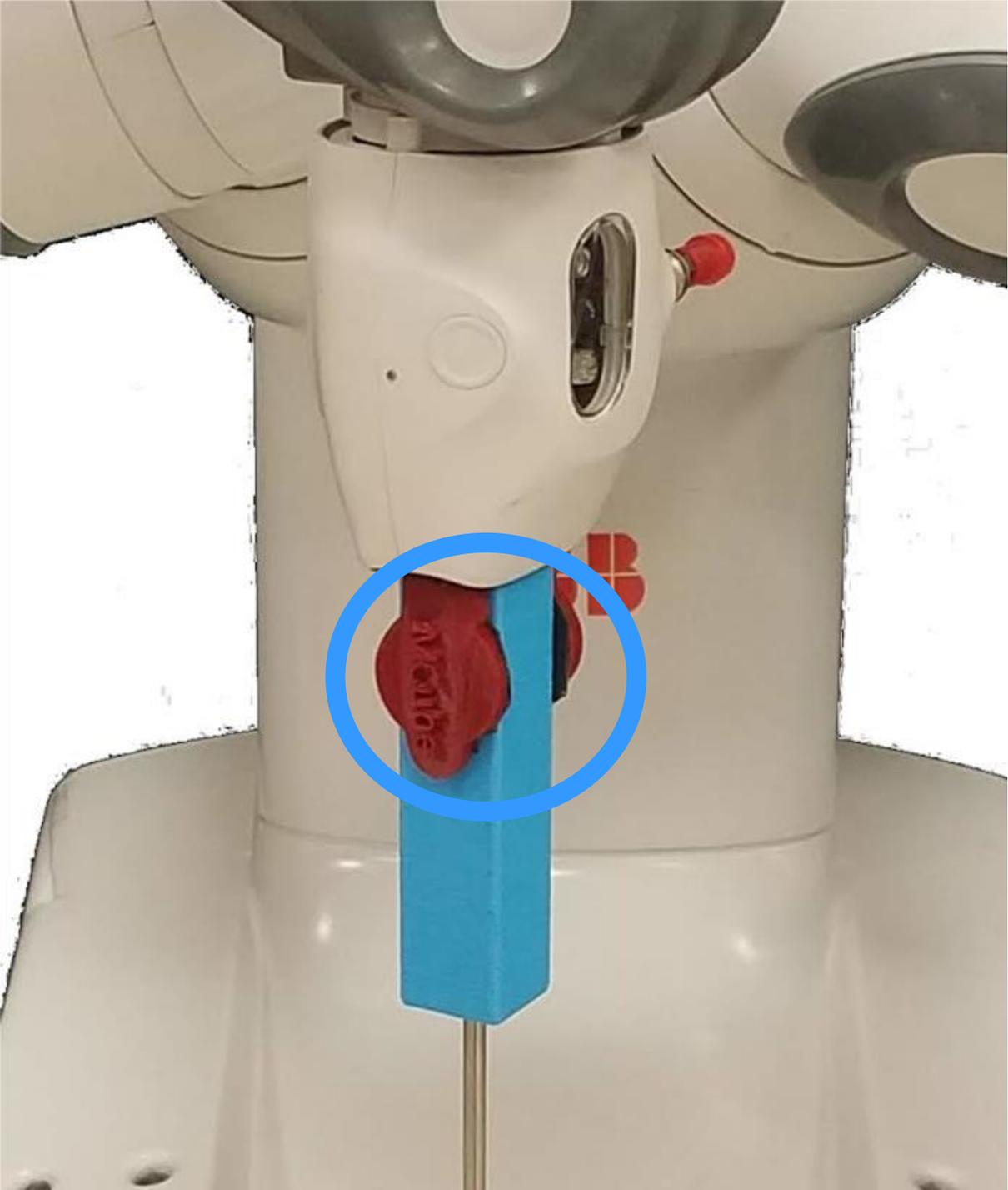


C-Free?
Reaches?
Stable?





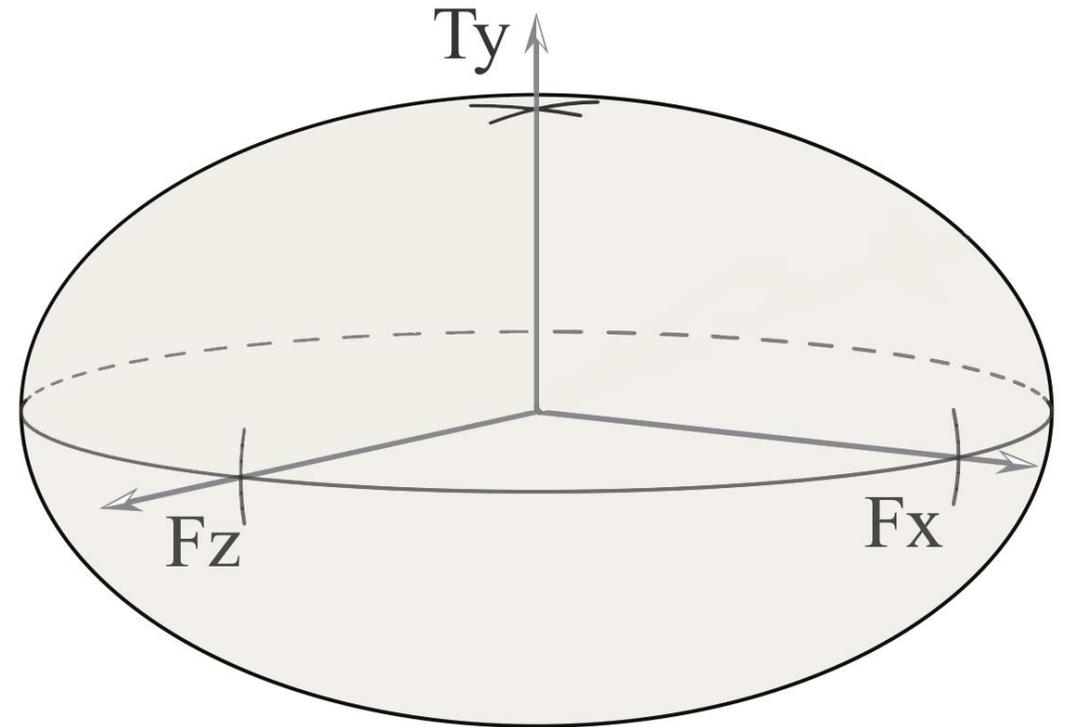
Frictional Joint

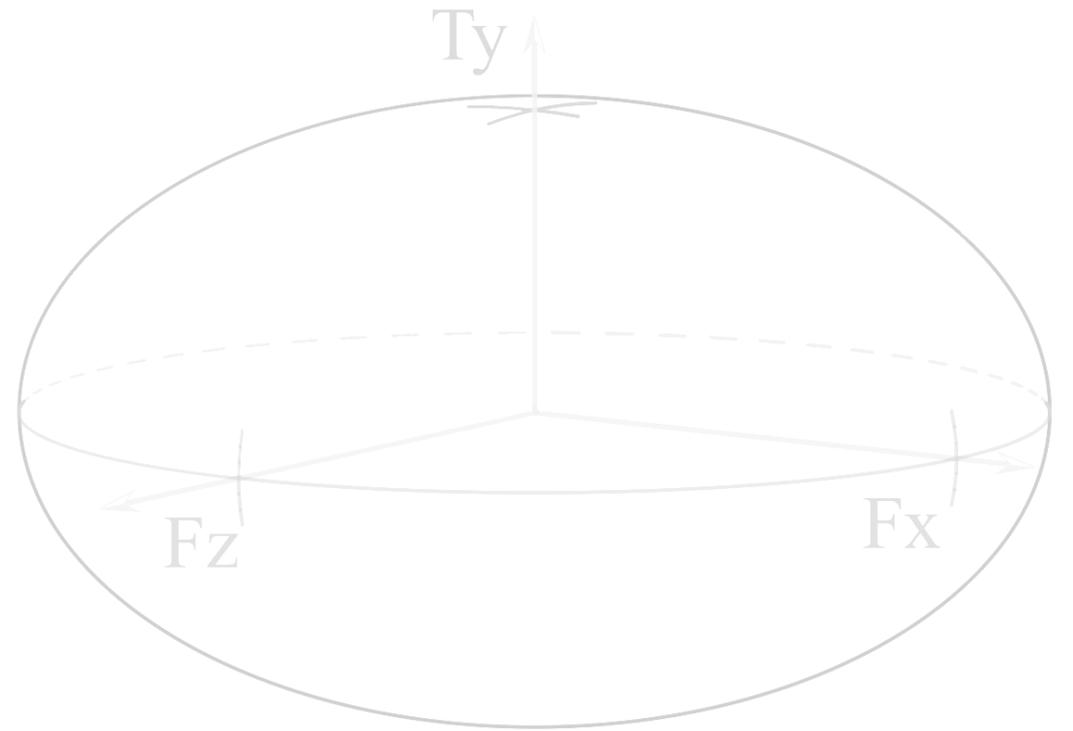
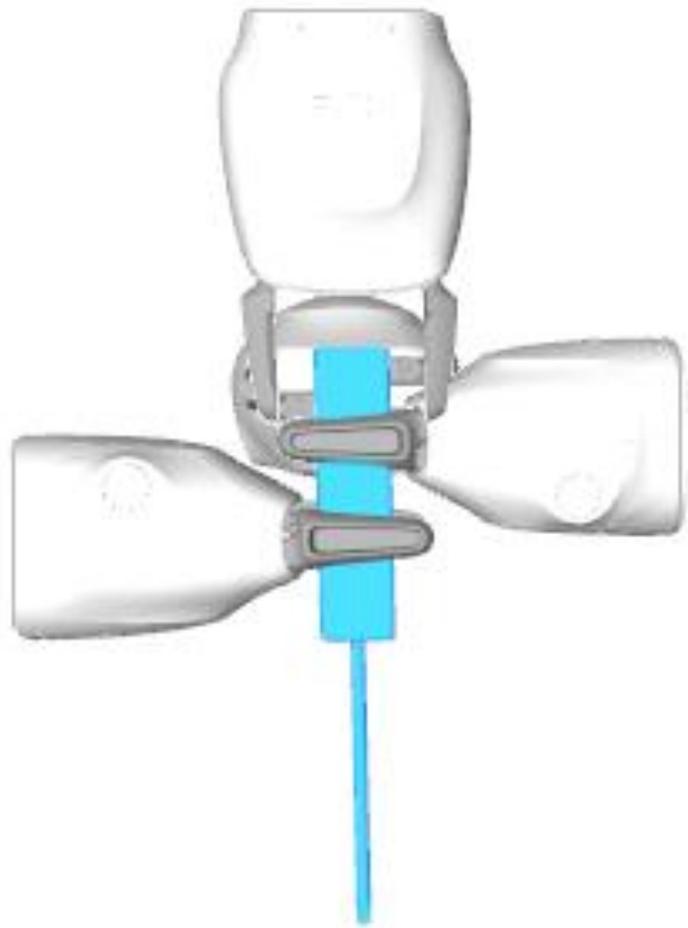


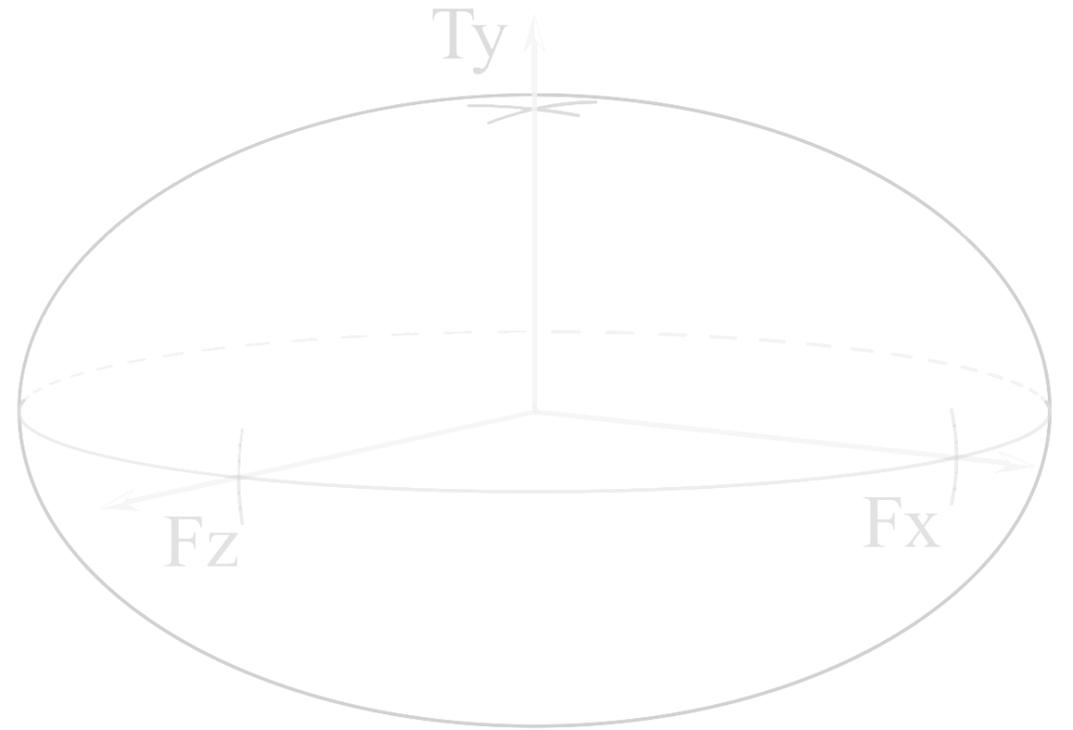
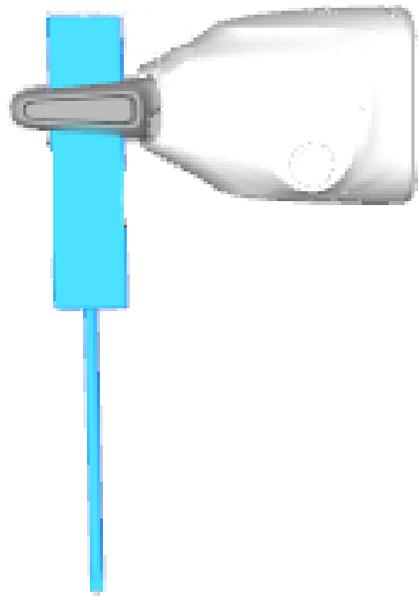
Planar Patch Contacts

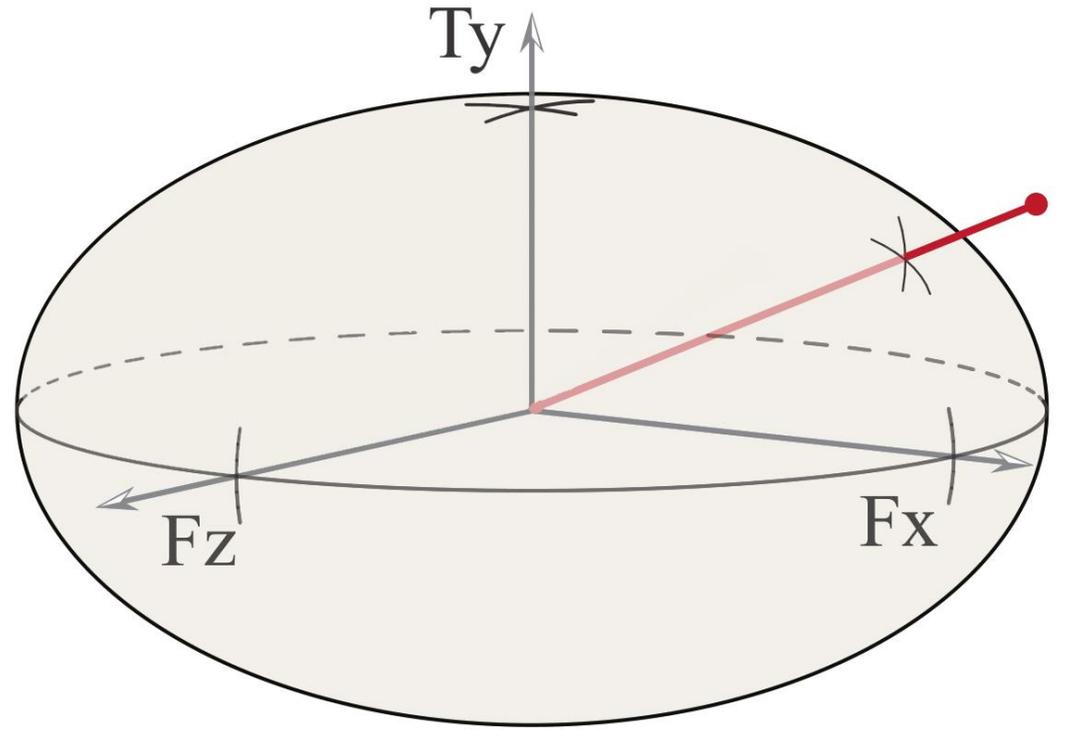
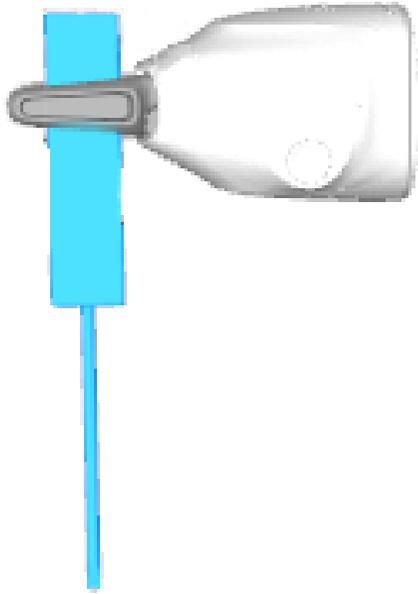
Limit Surface

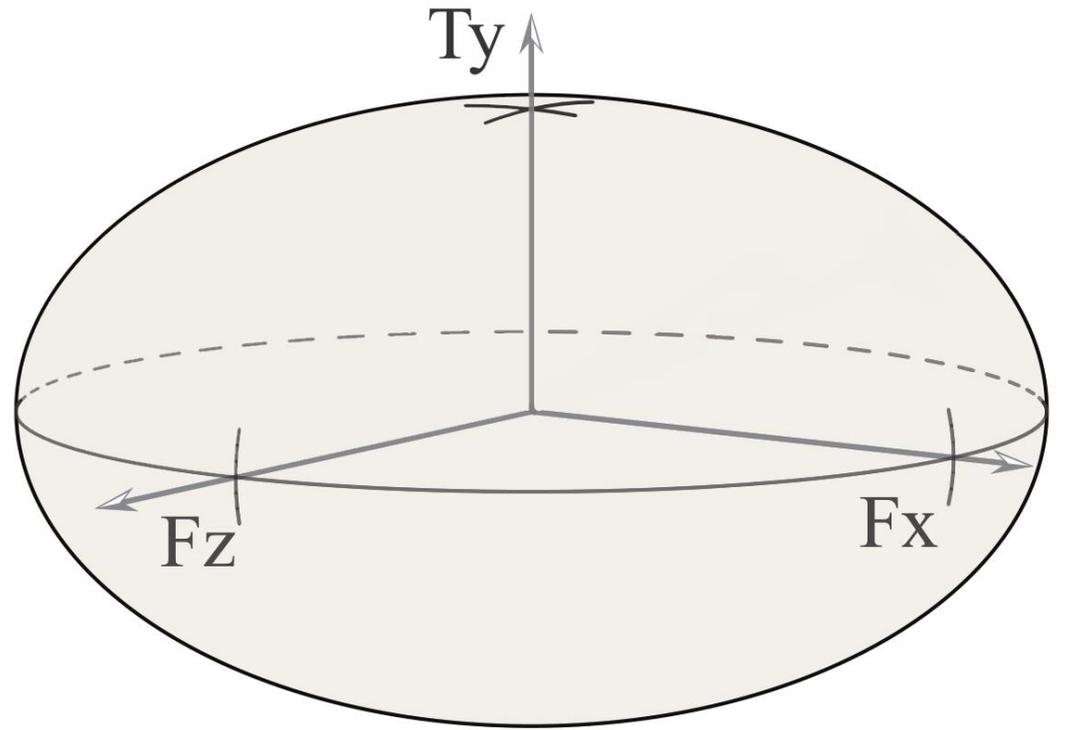
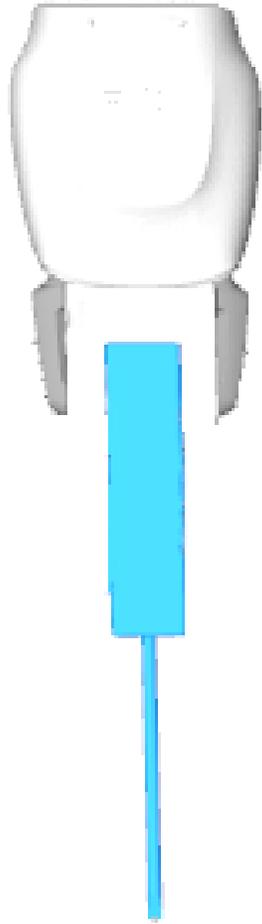
Limit Surface

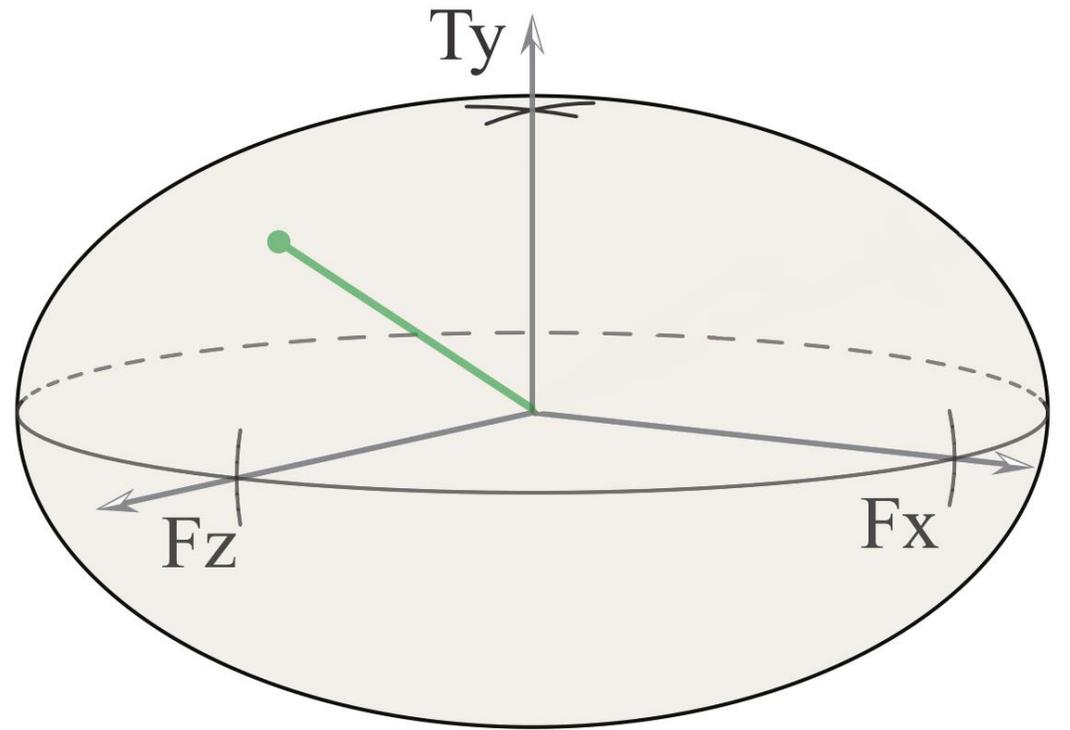
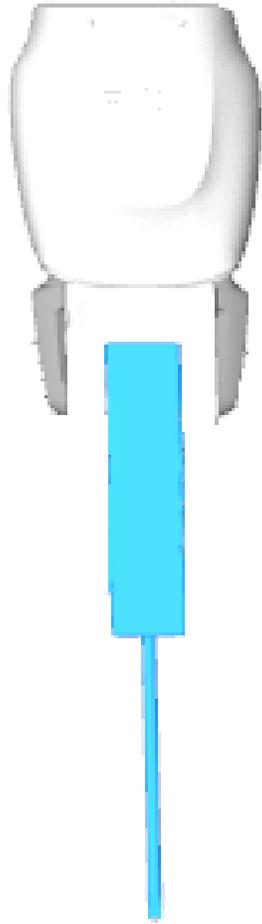


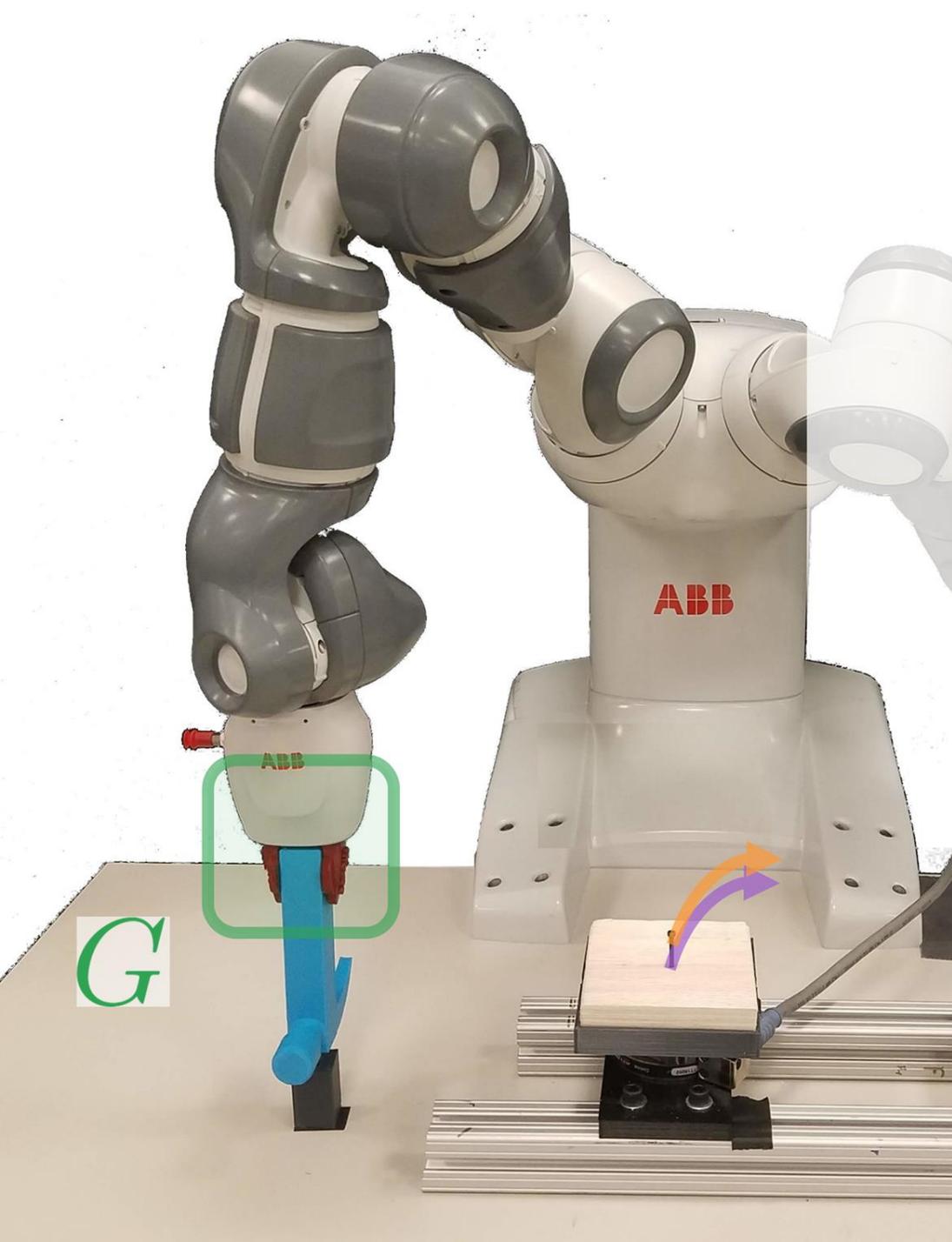






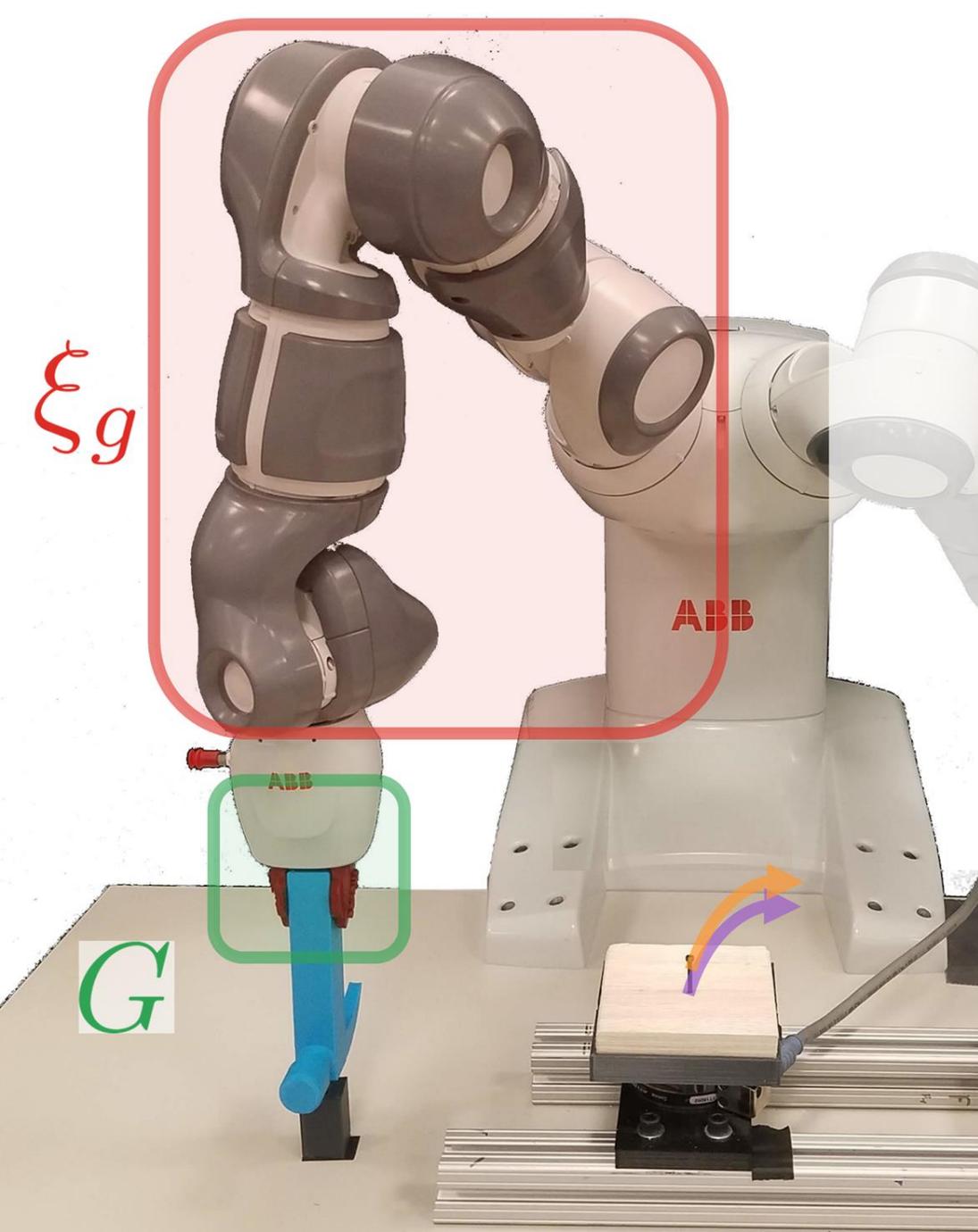






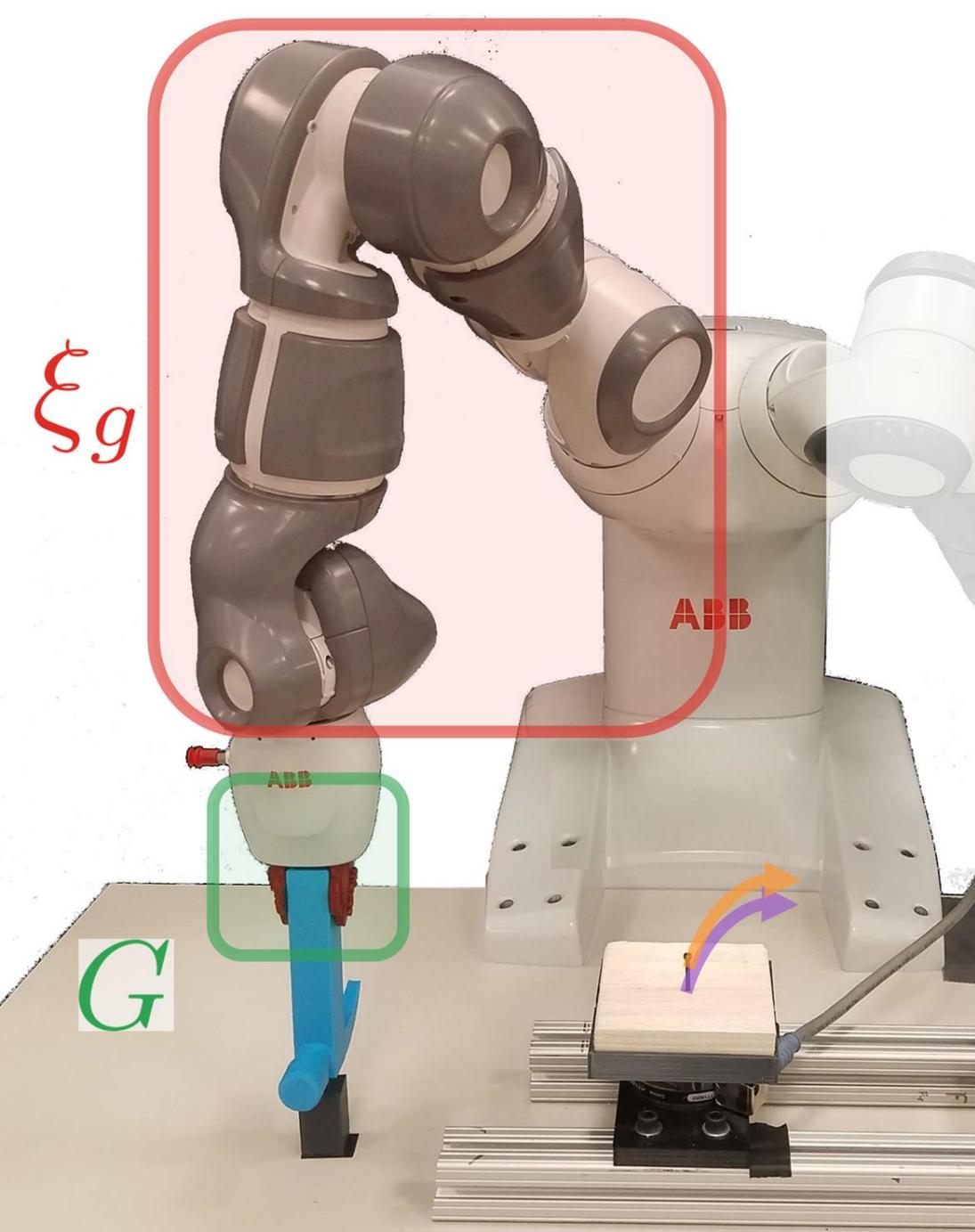
C-Free?
Reaches?
Stable?





C-Free?
Reaches?
Stable?

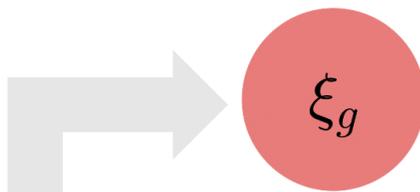


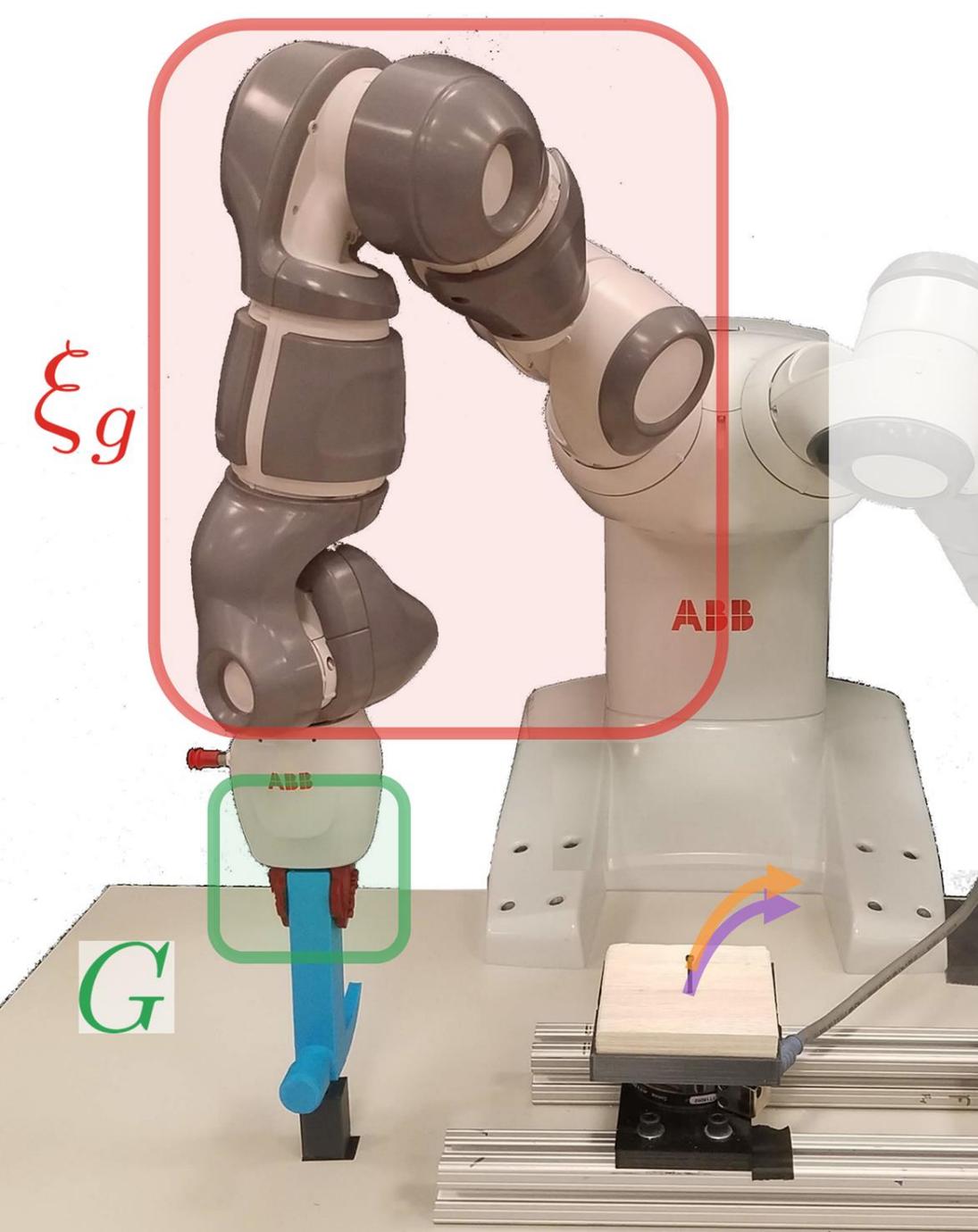


C-Free?
Reaches?
Stable?

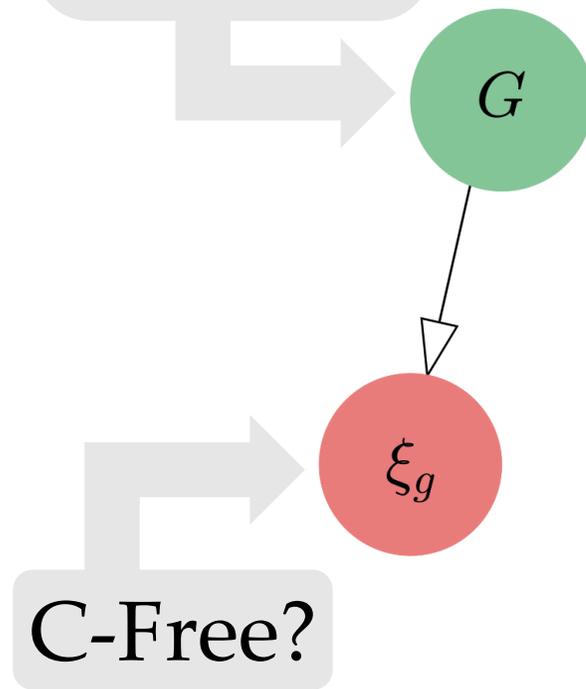


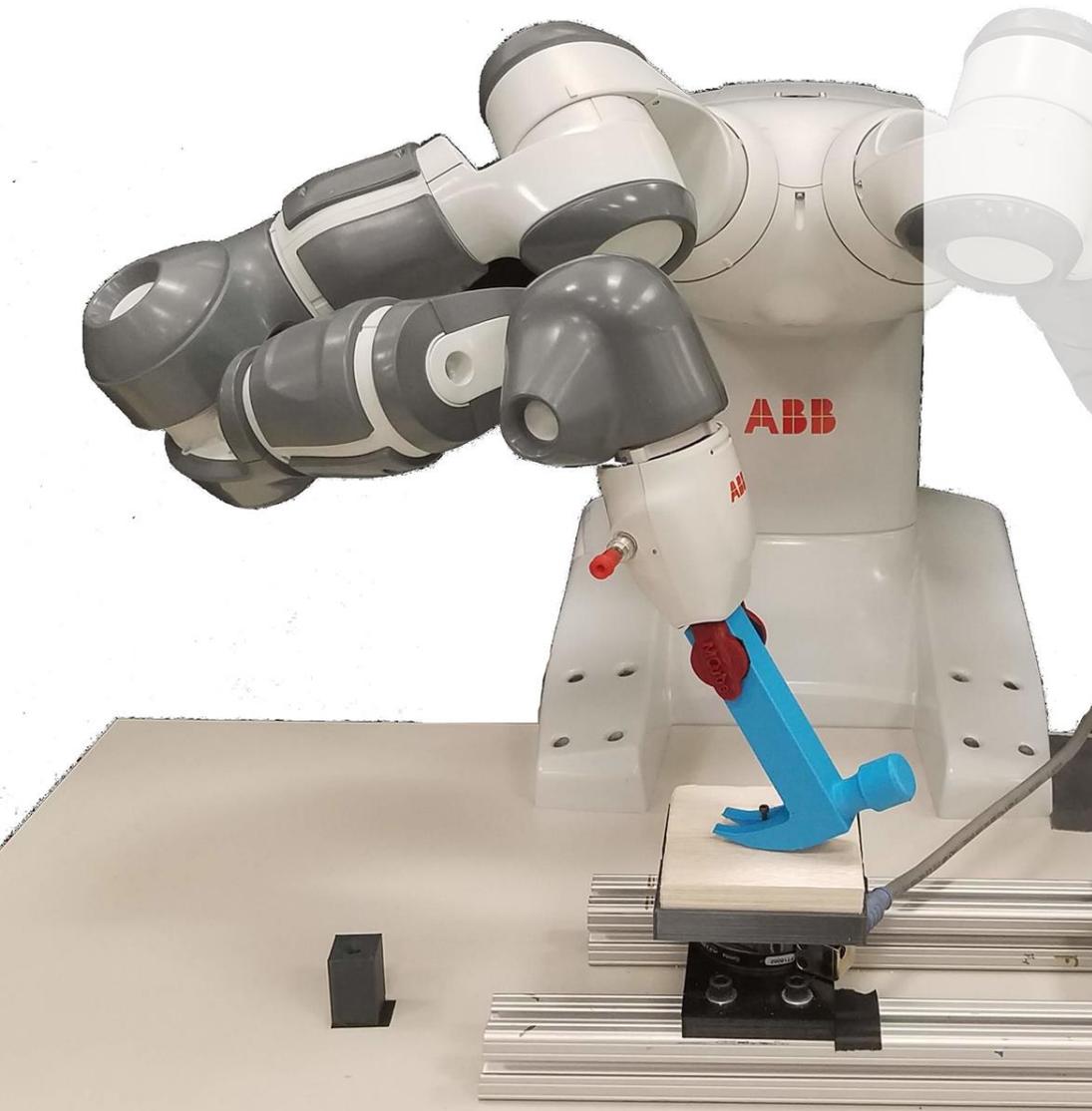
C-Free?



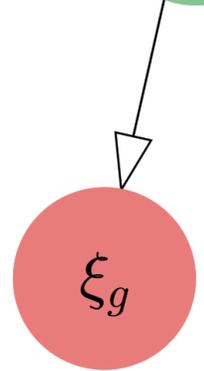


C-Free?
Reaches?
Stable?

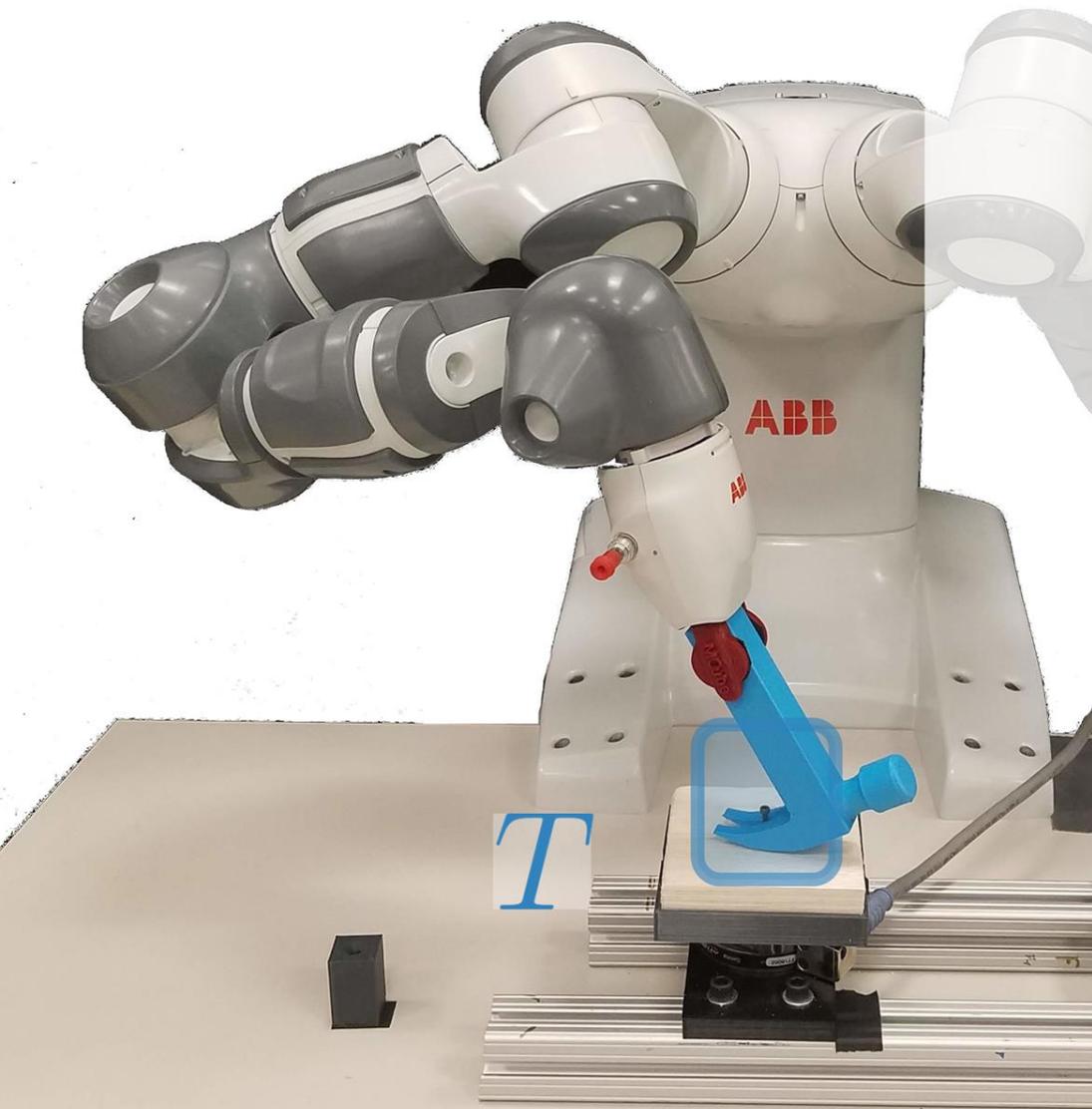




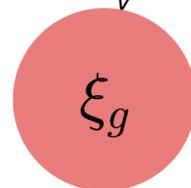
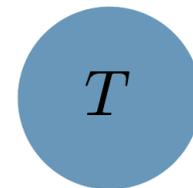
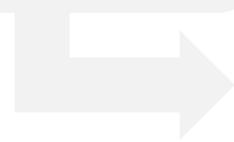
C-Free?
Reaches?
Stable?



C-Free?

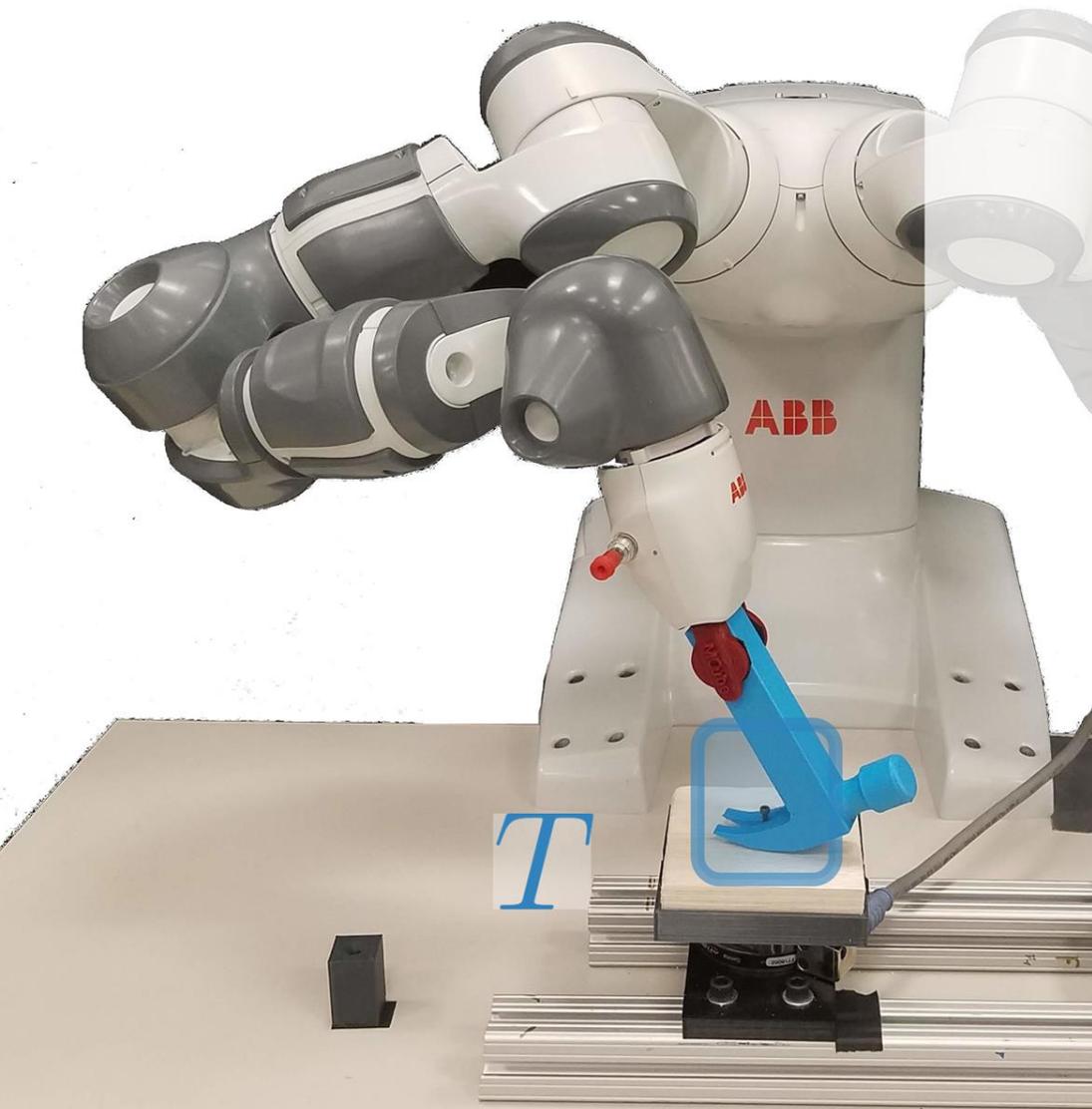


C-Free?
Reaches?
Stable?

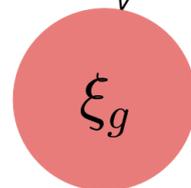


C-Free?



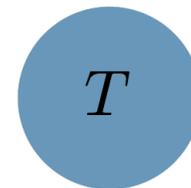


C-Free?
Reaches?
Stable?

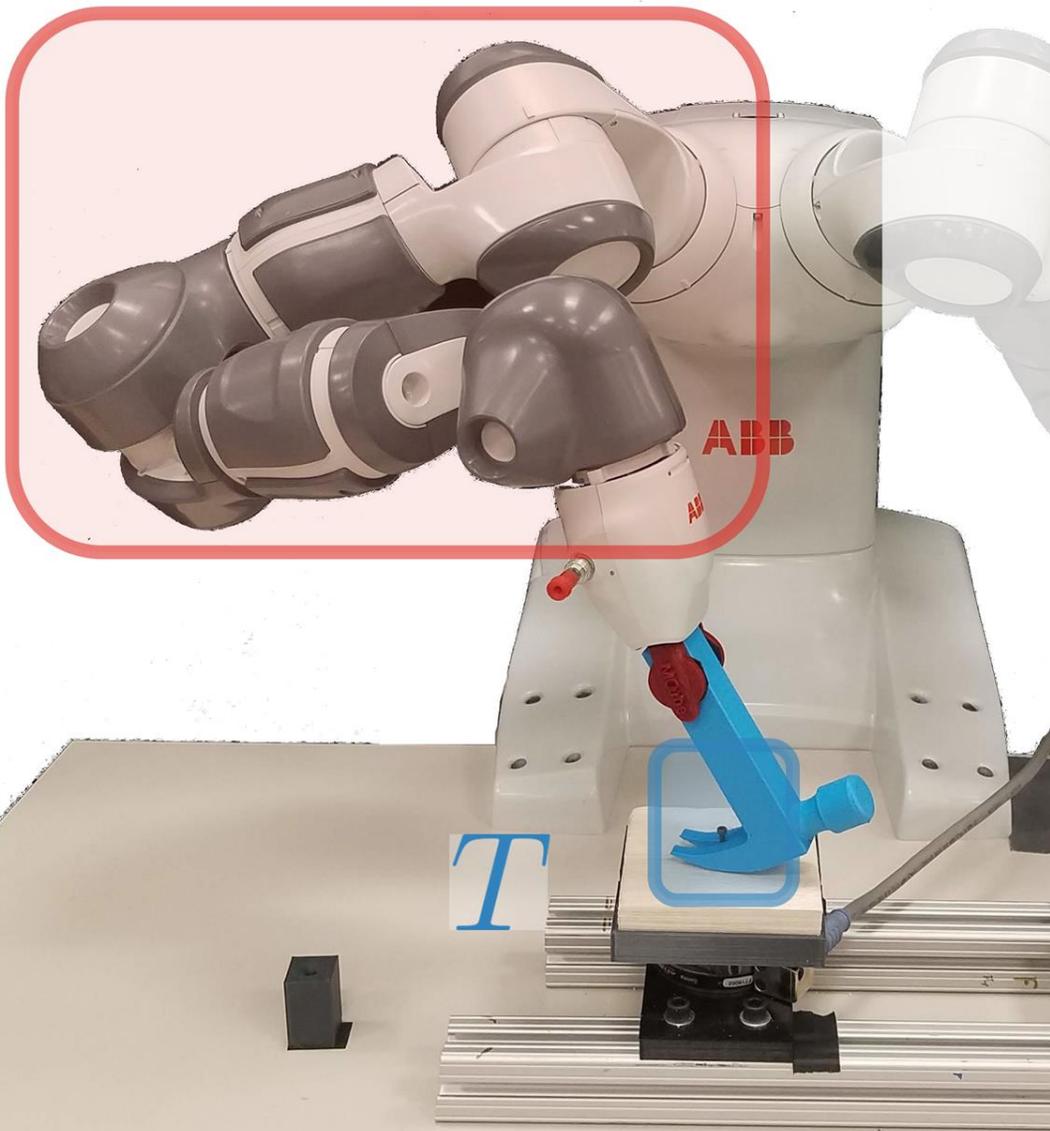


C-Free?

Reaches?



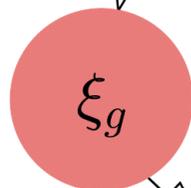
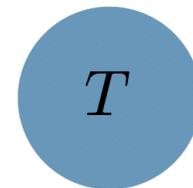
ξ_m



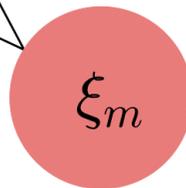
C-Free?
Reaches?
Stable?



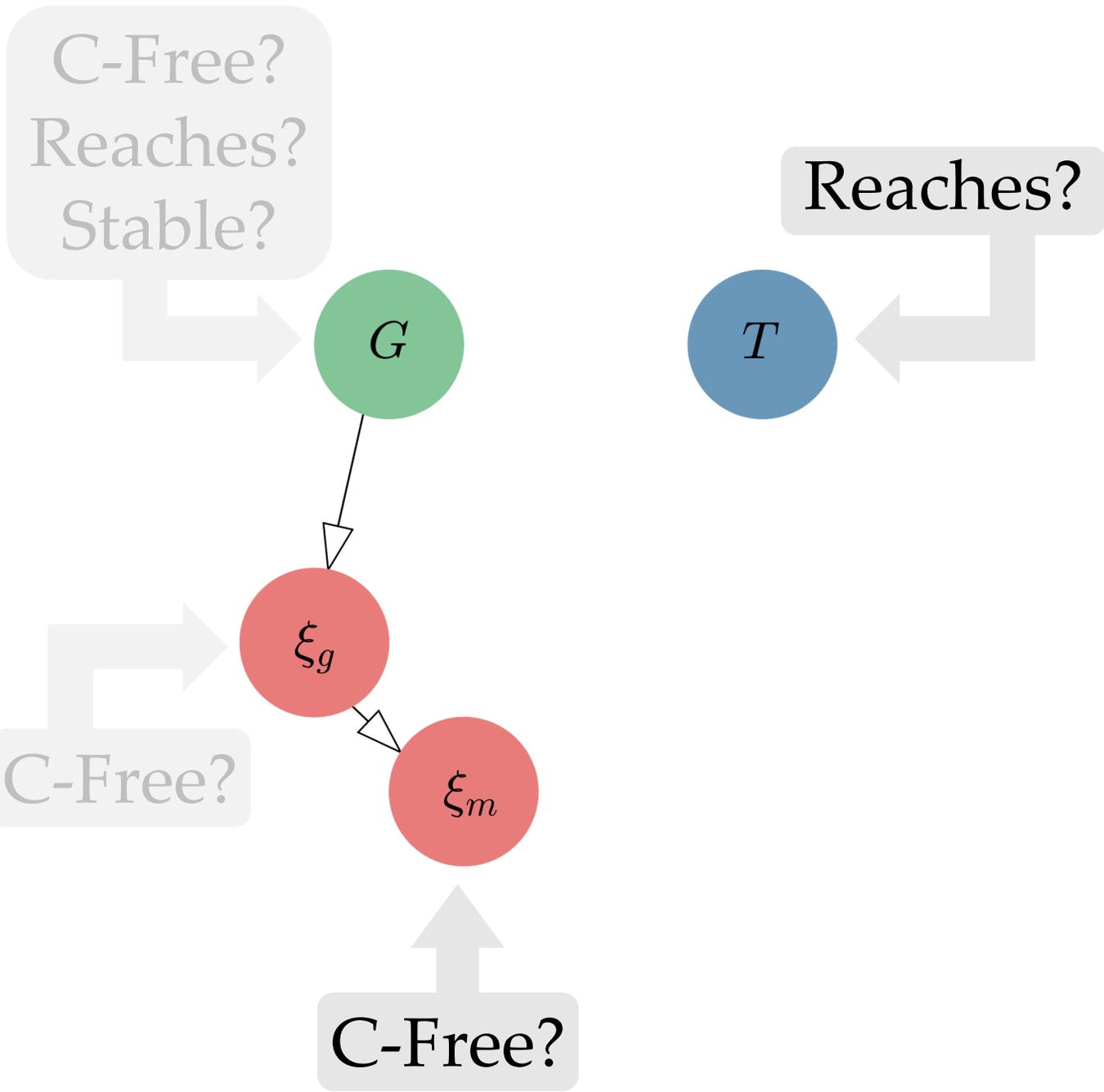
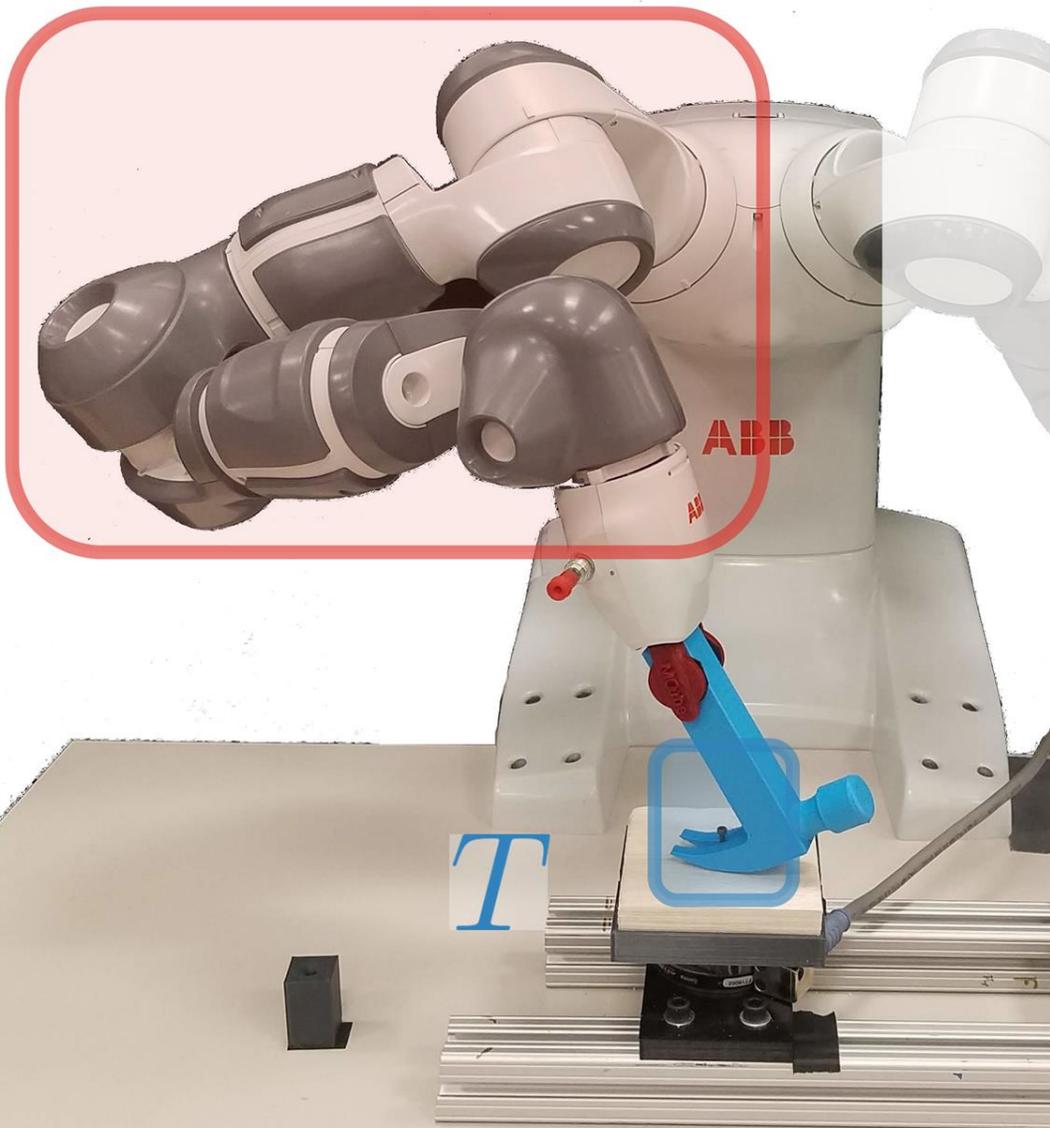
Reaches?

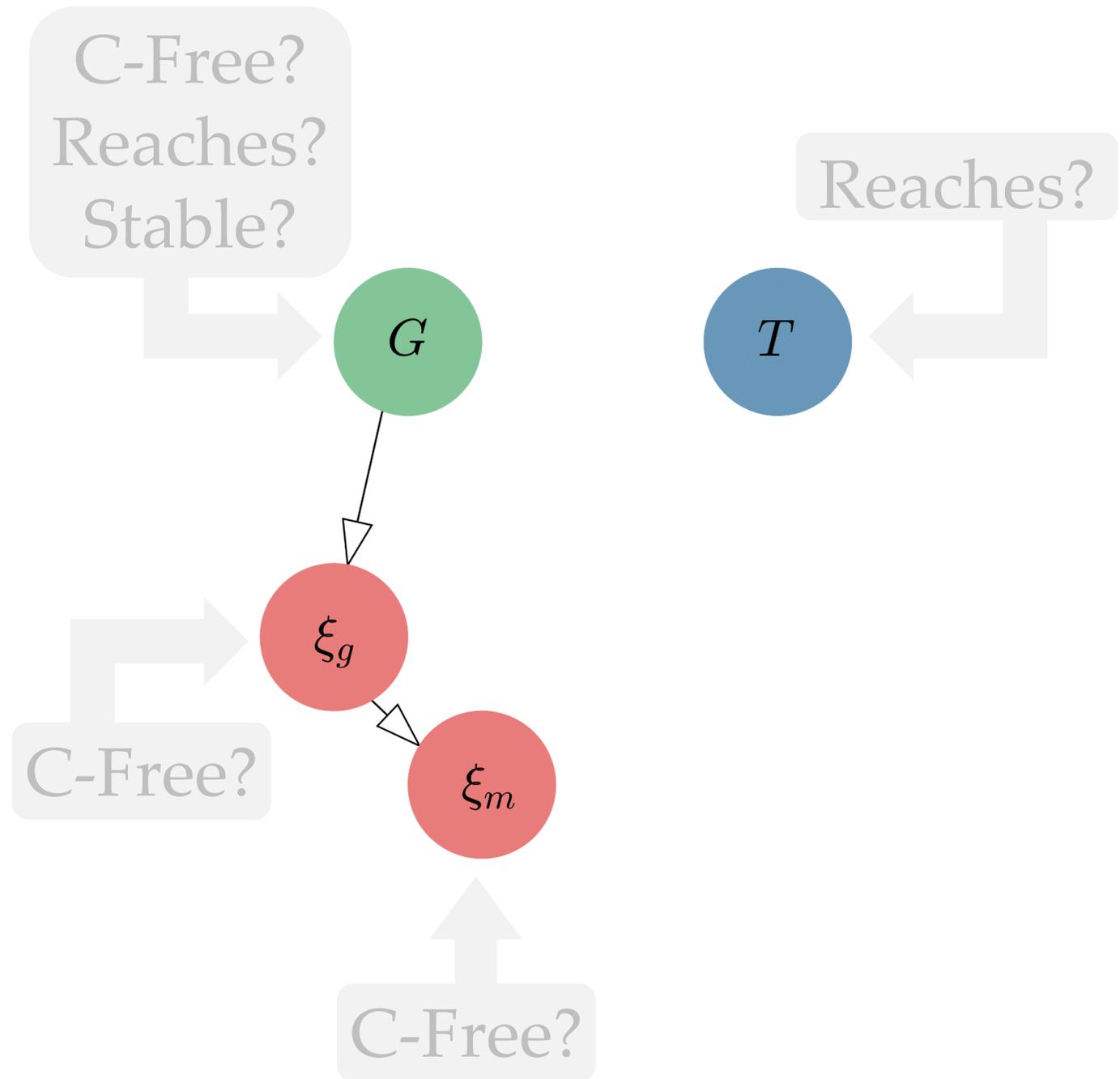
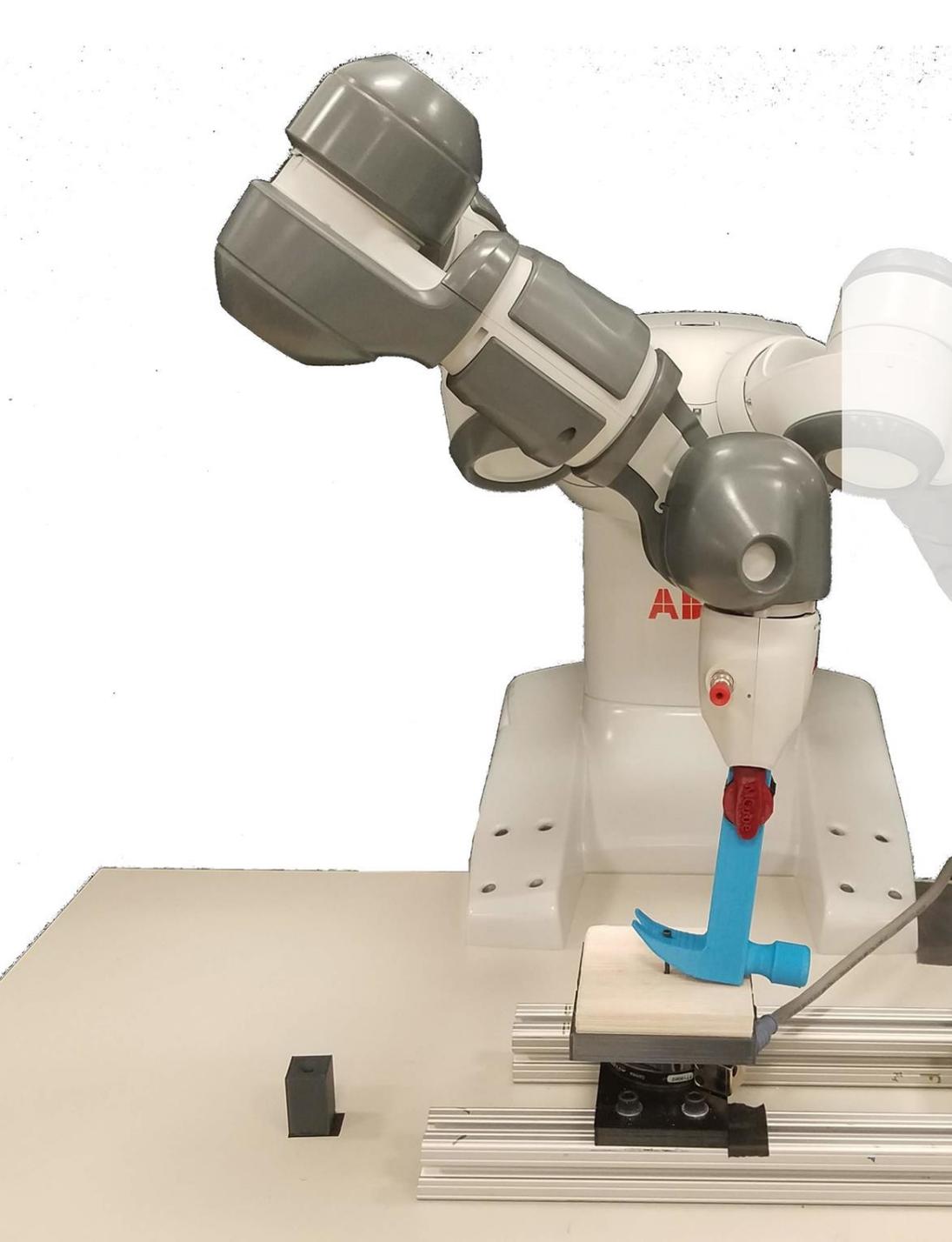


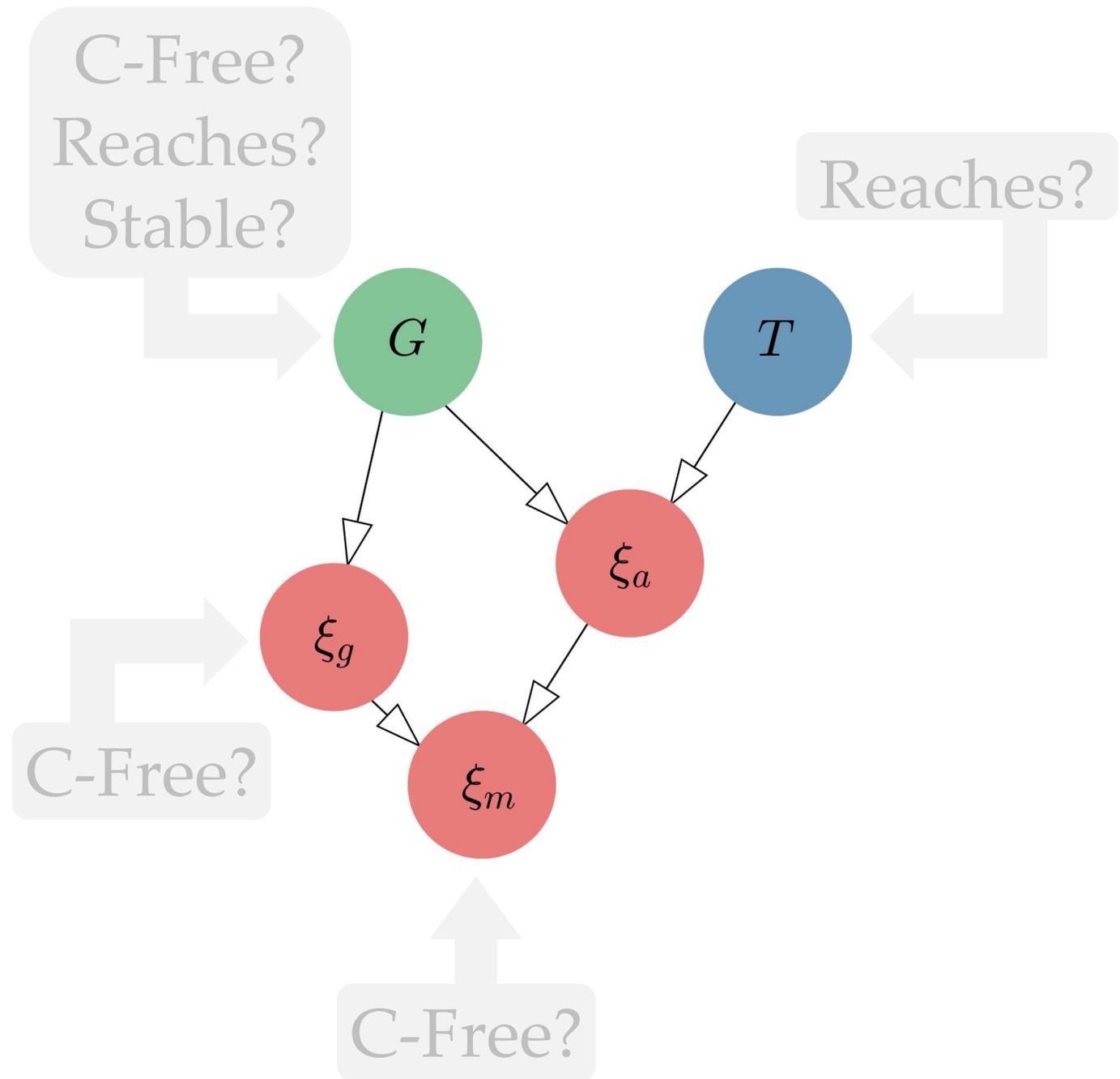
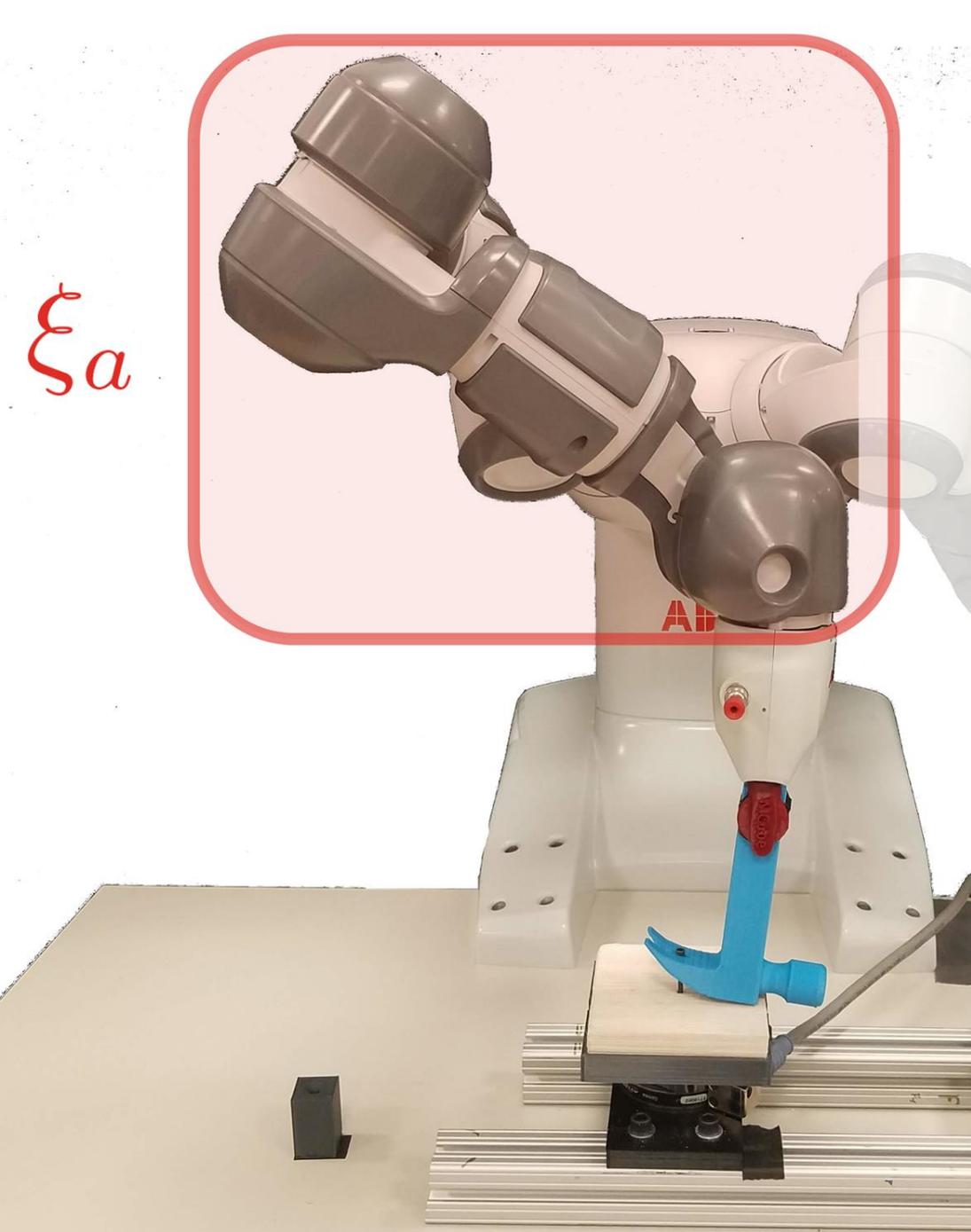
C-Free?

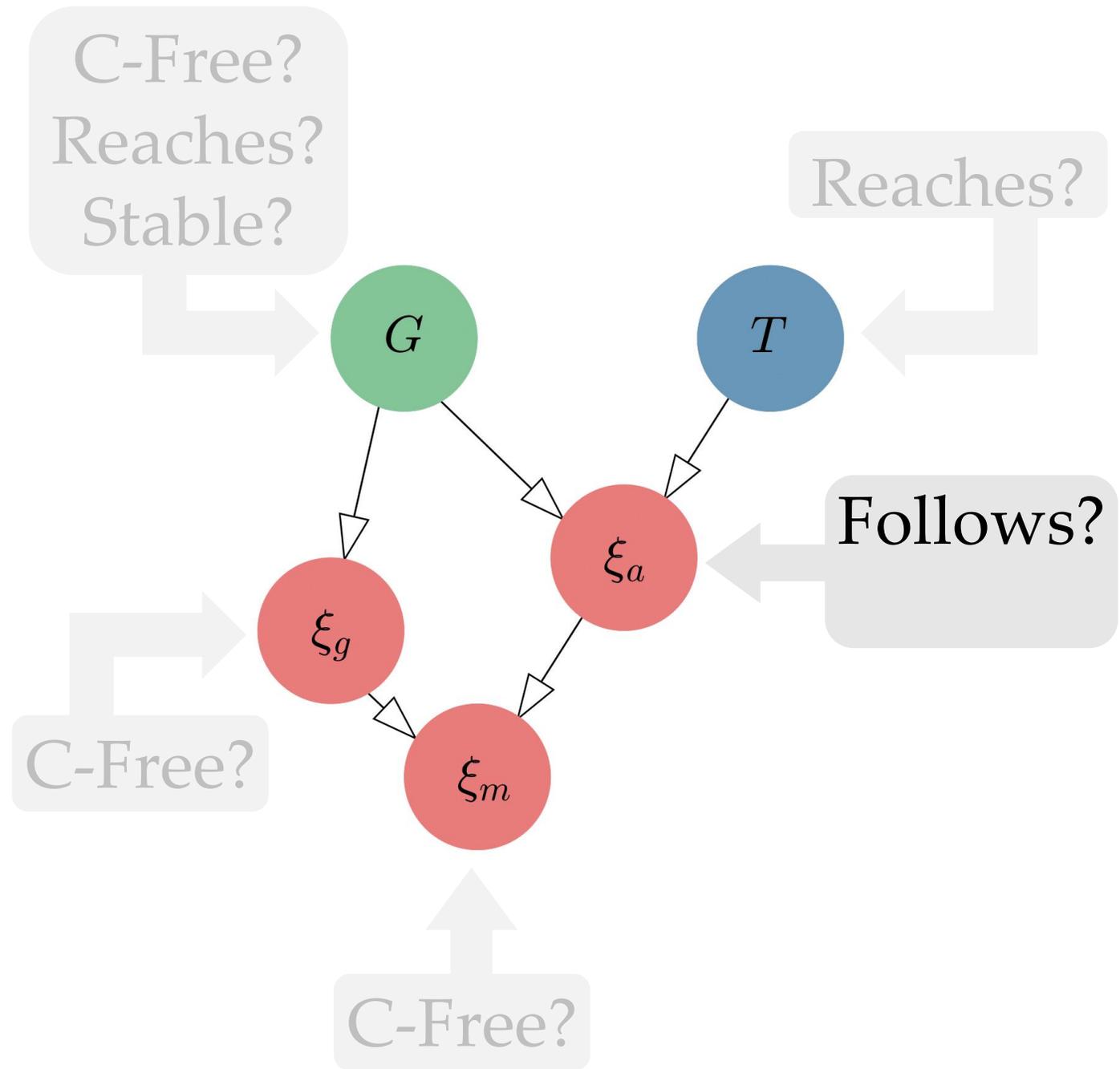
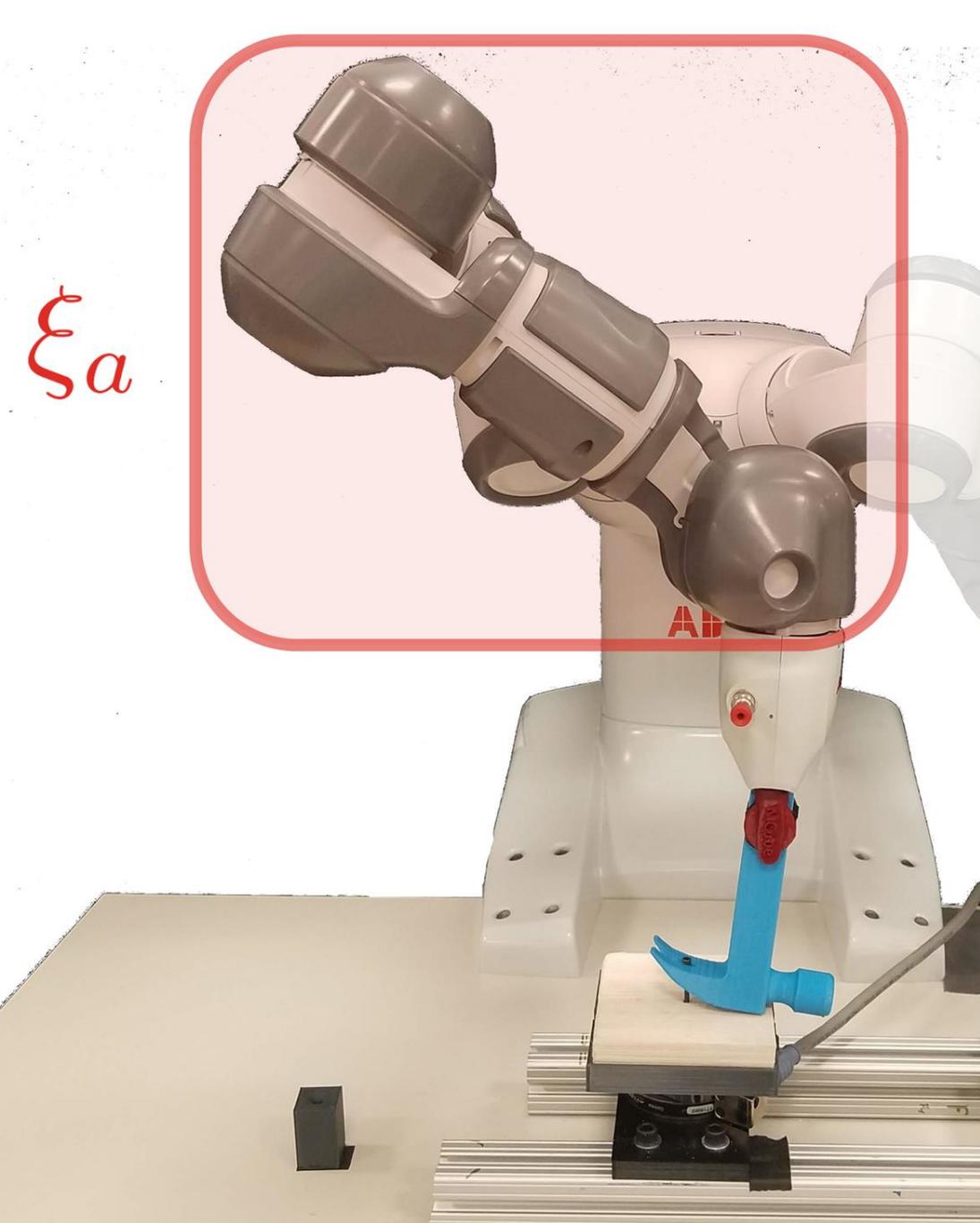


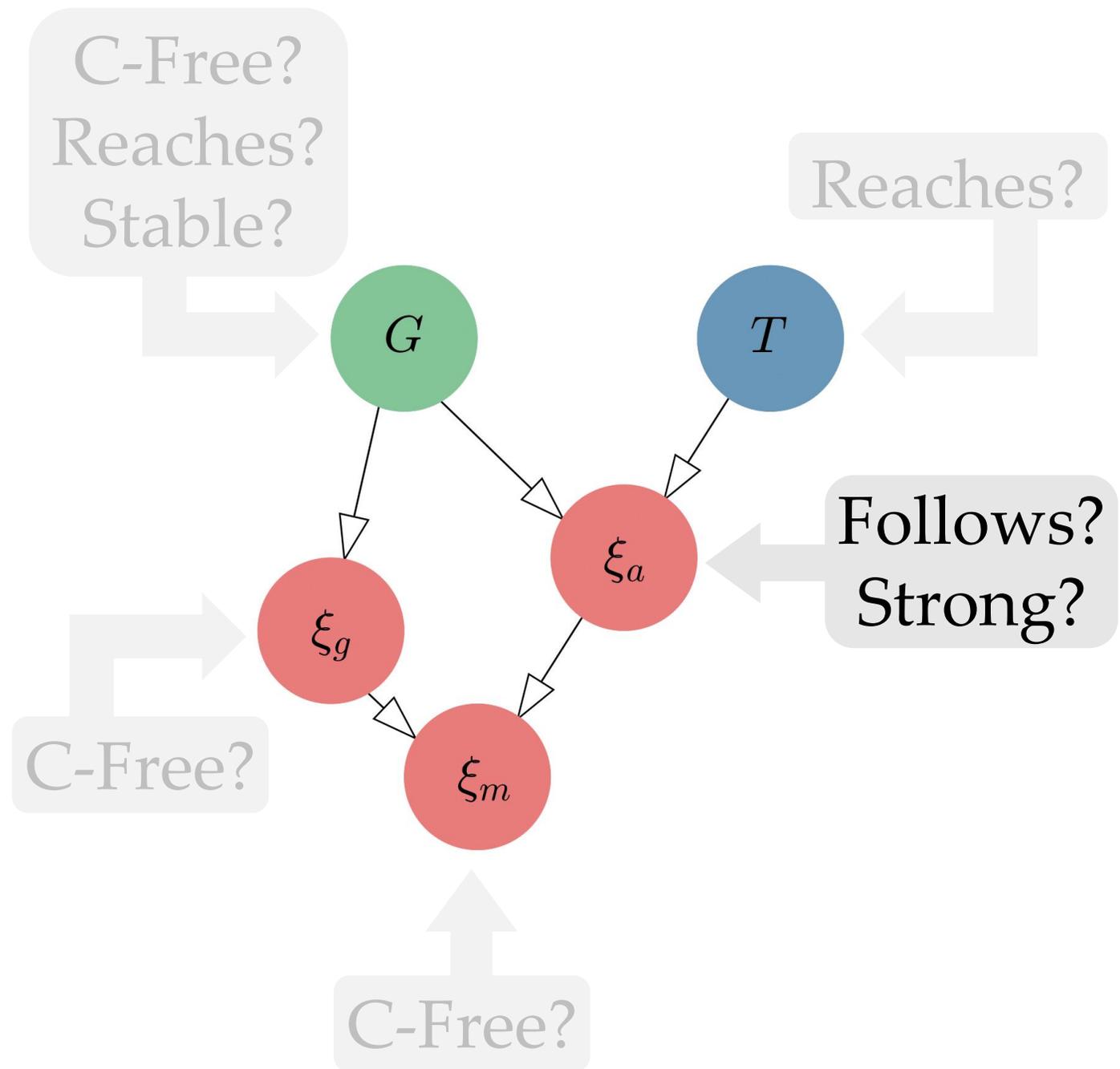
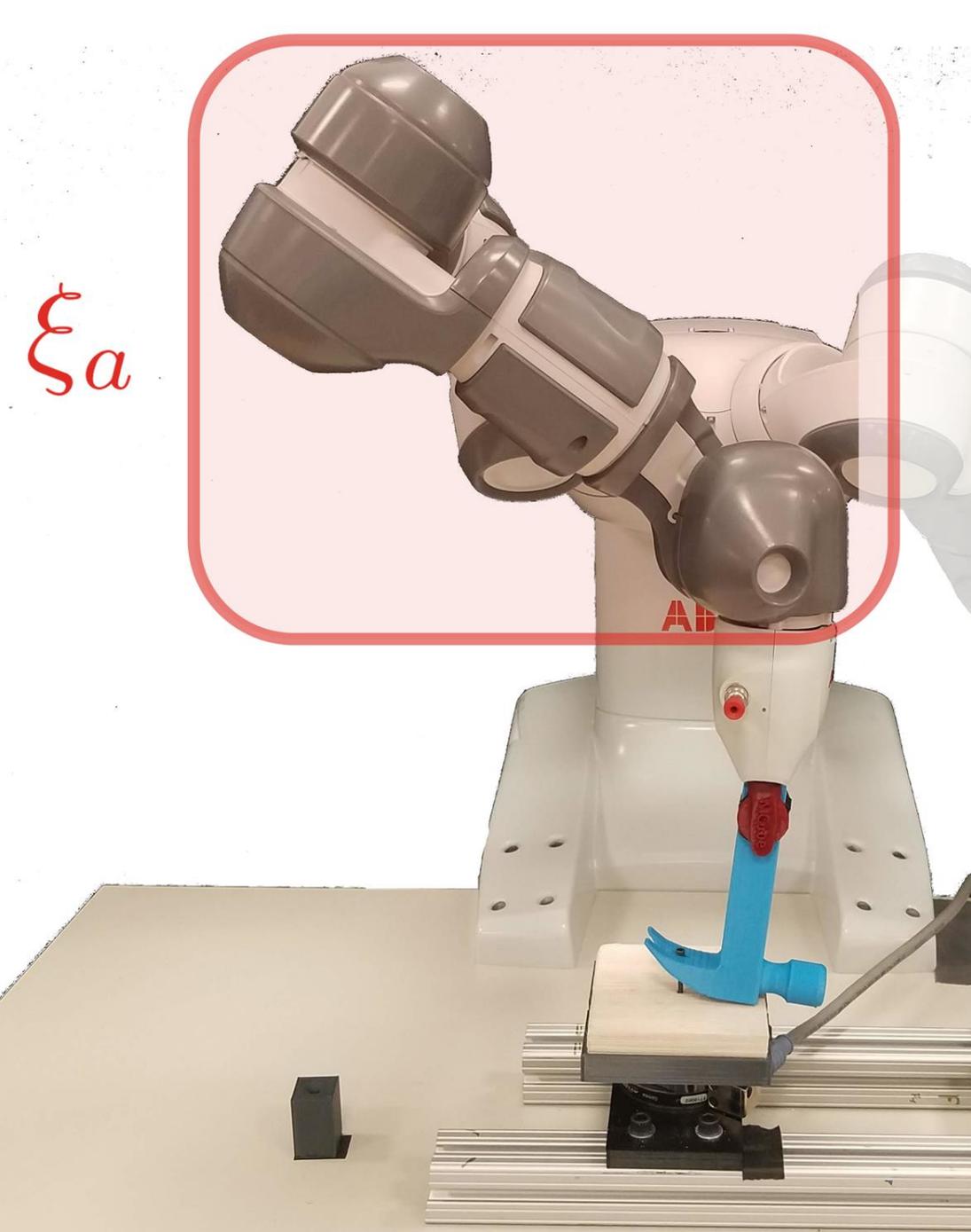
ξ_m







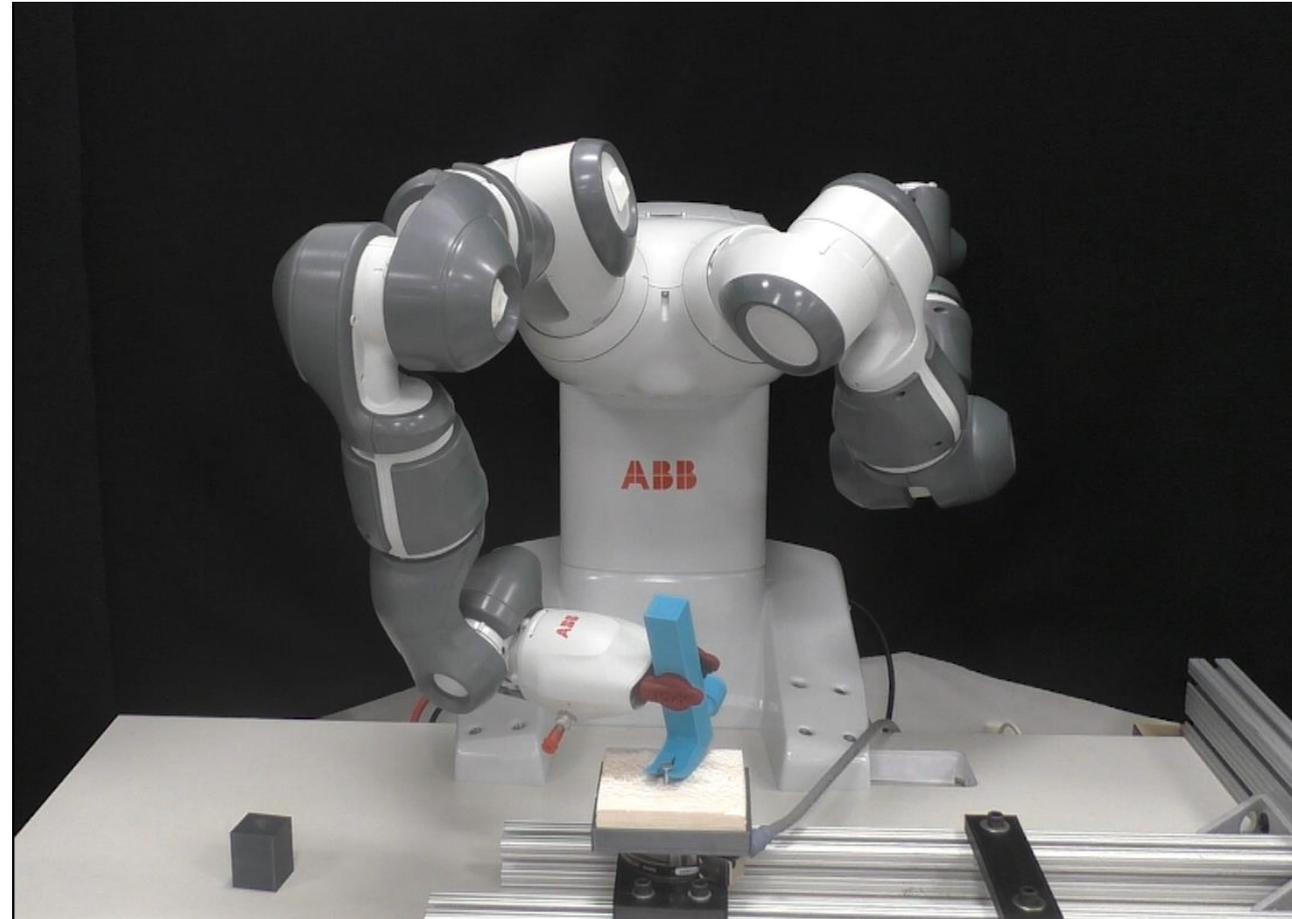
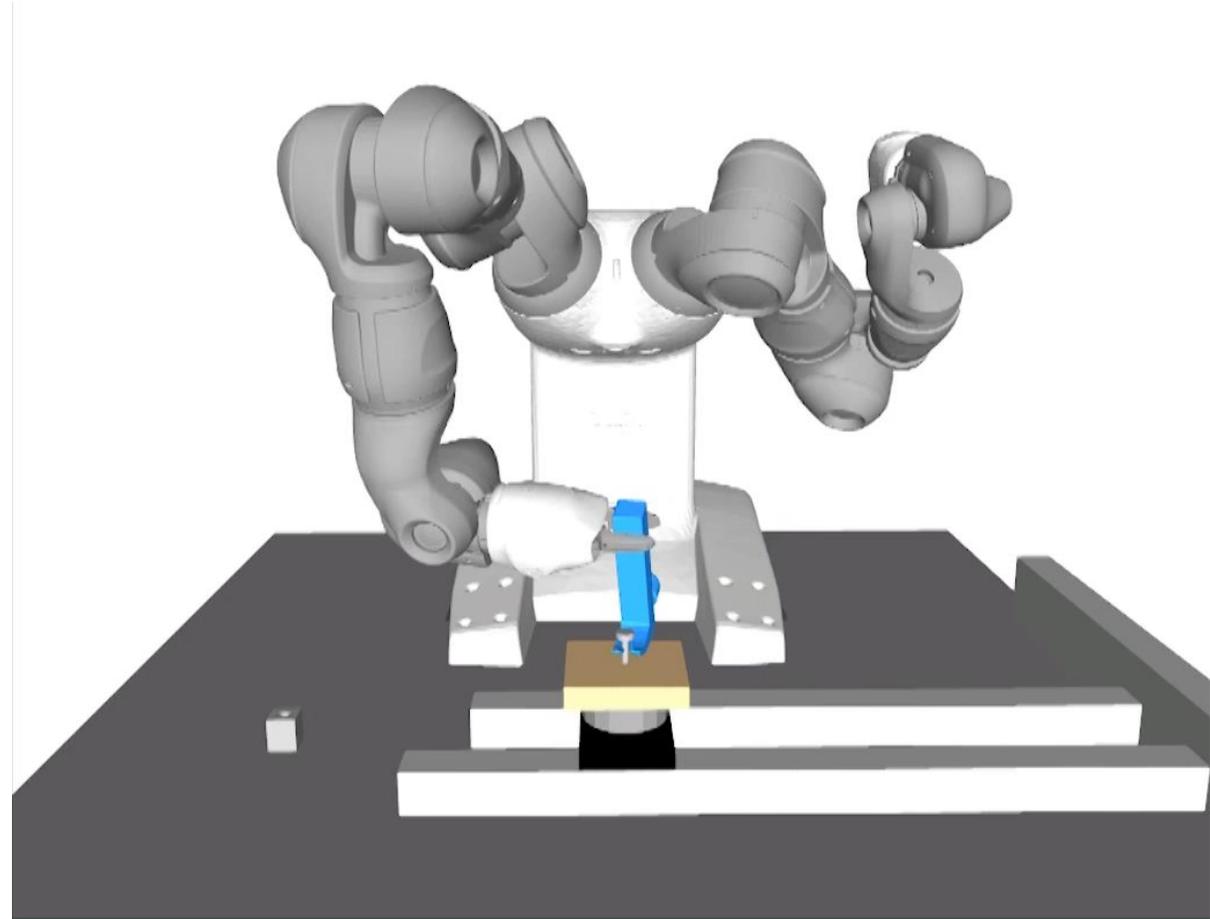




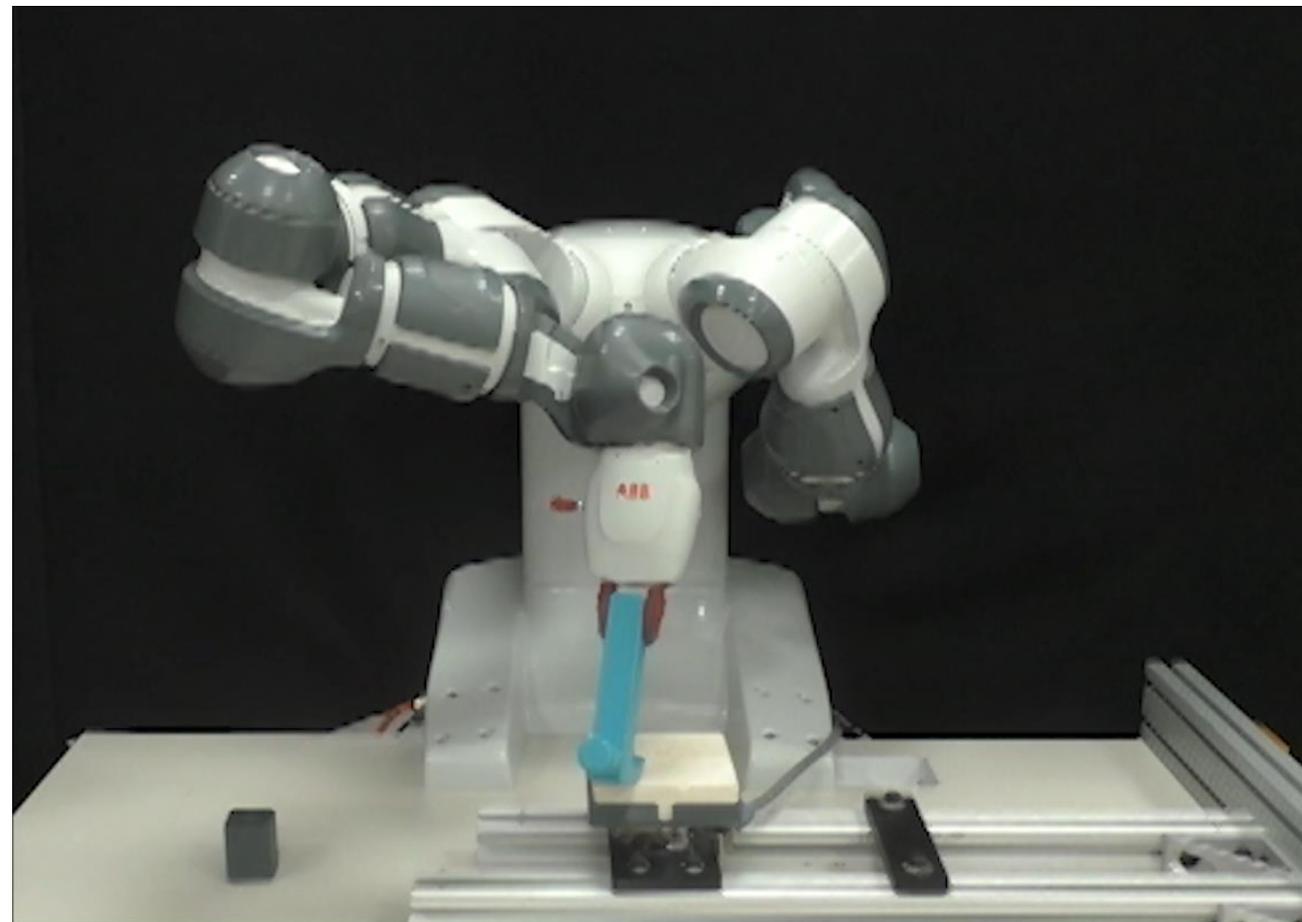
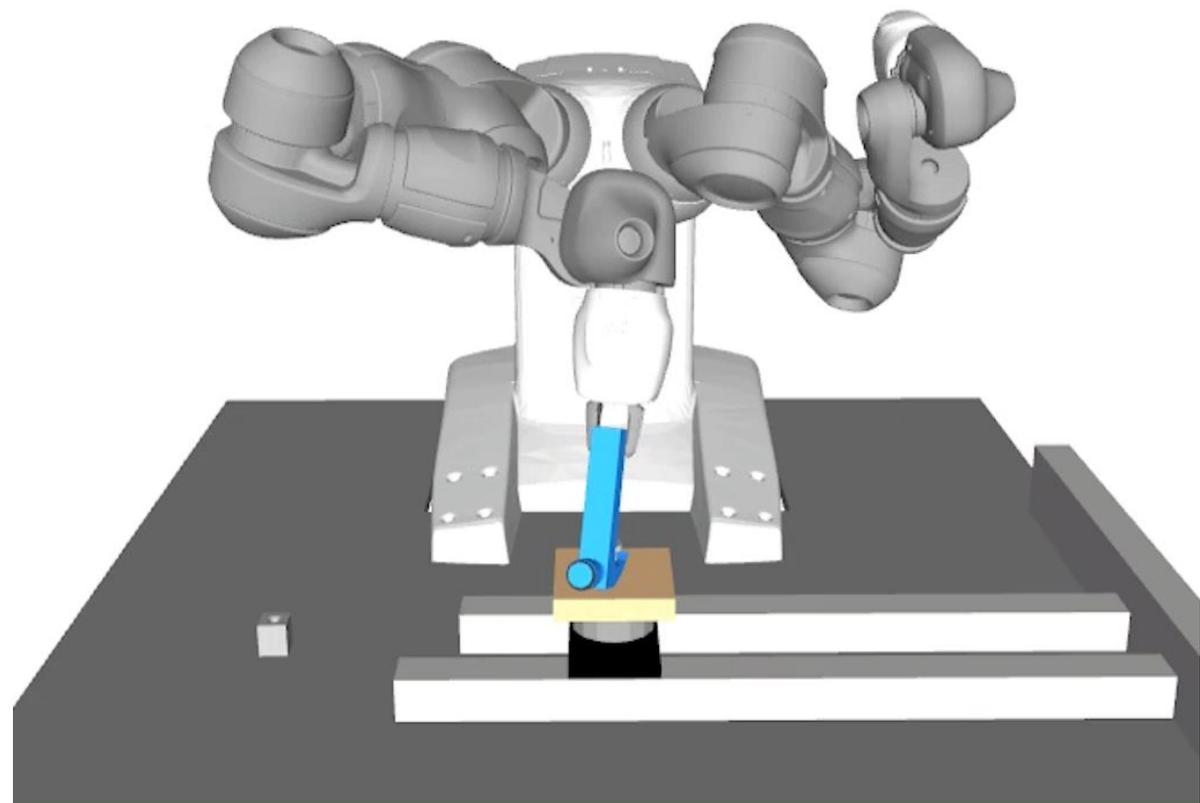
$$\tau_{ext} = J^T(q) f_{ext}$$

$$\tau_{lim} > \tau_{ext} = J^T(q) f_{ext}$$

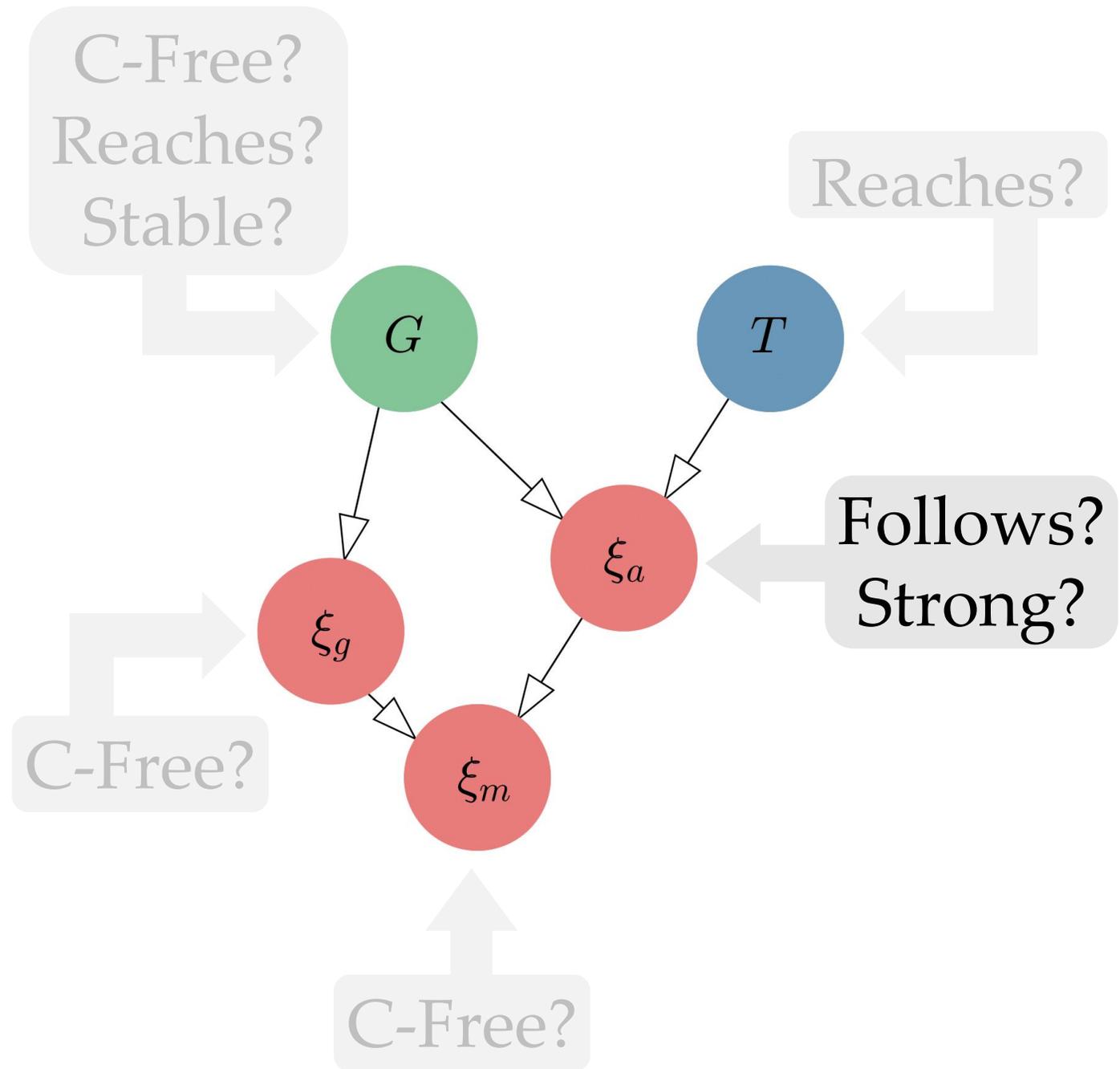
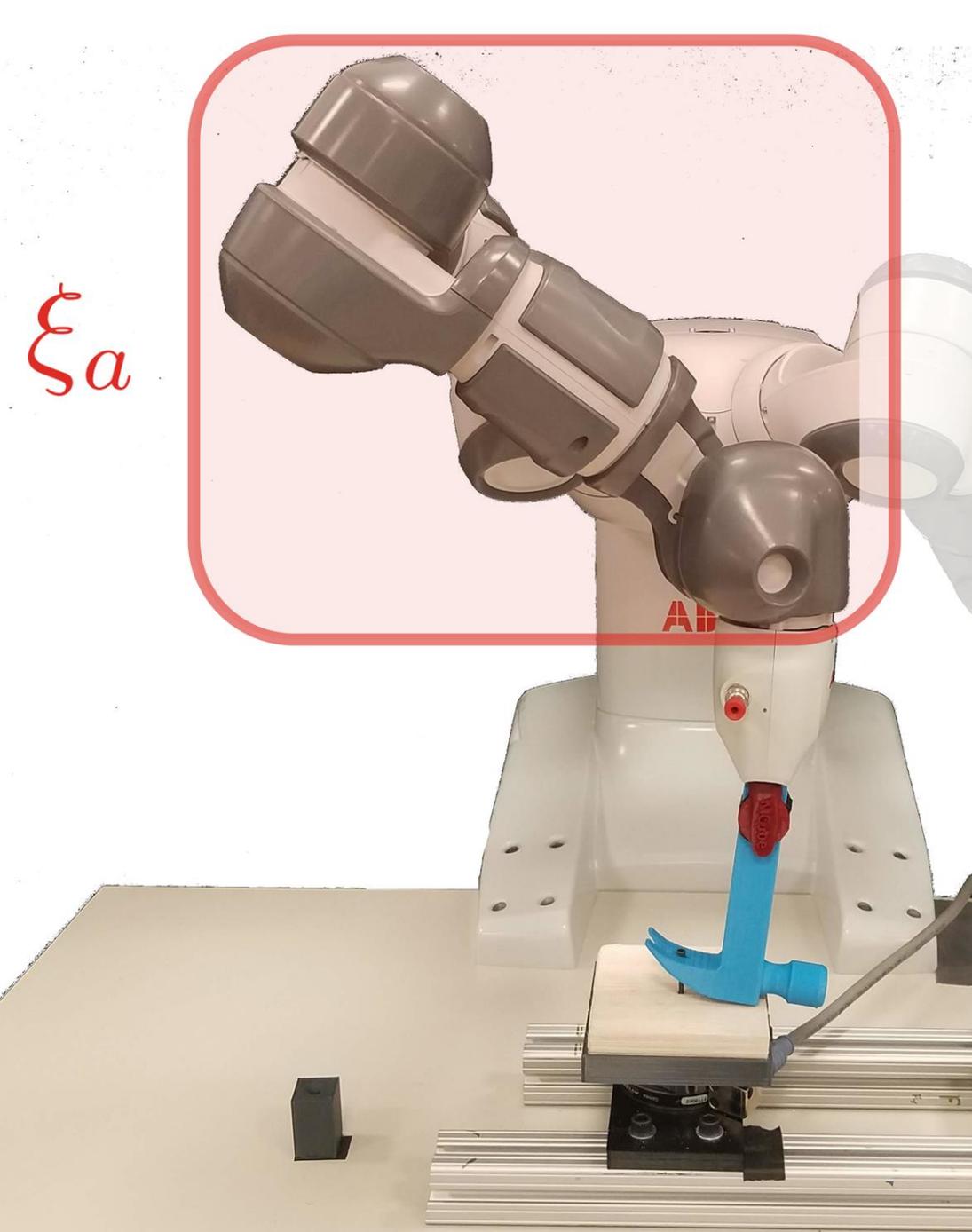
What if we violate these constraints?

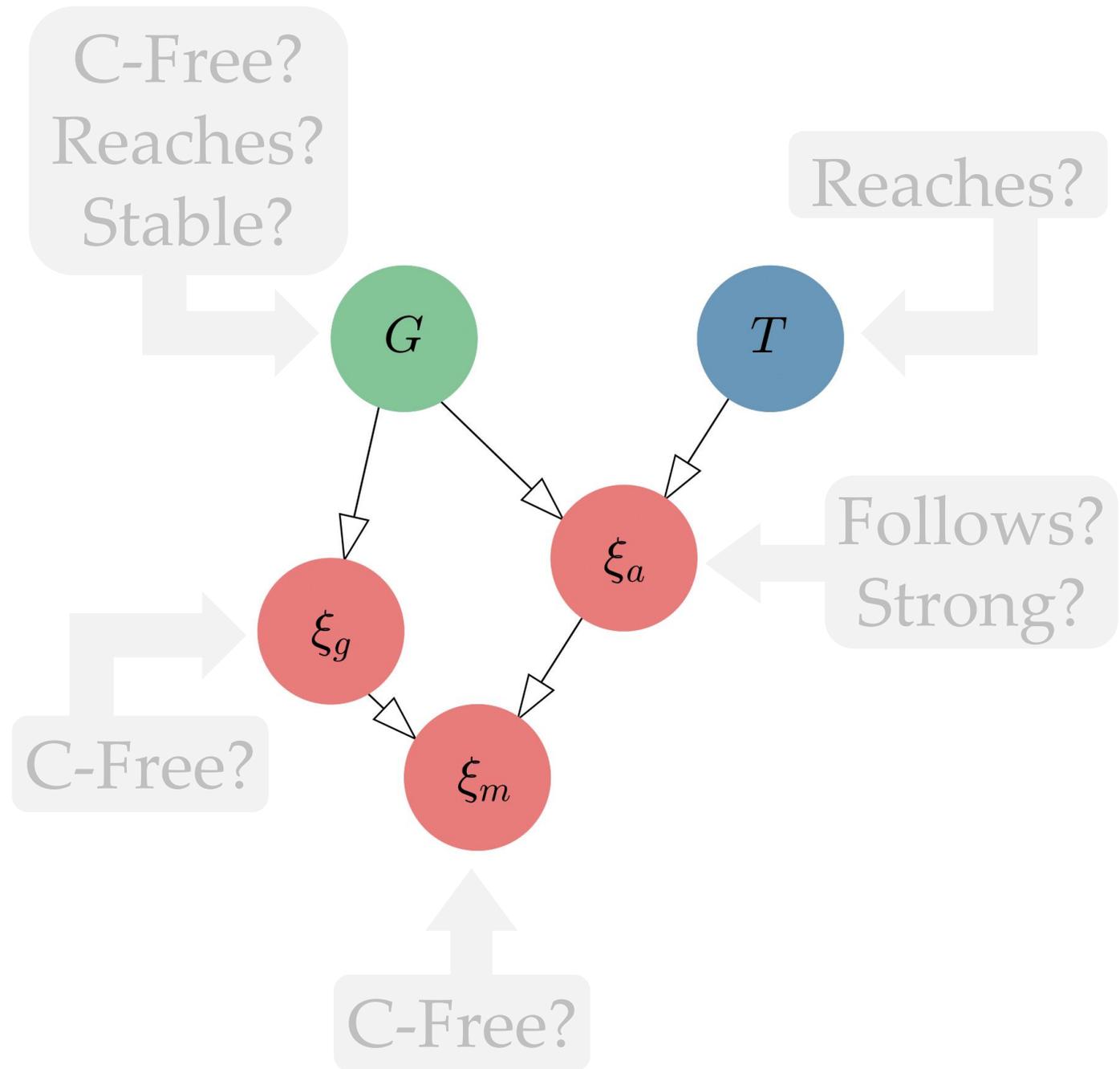
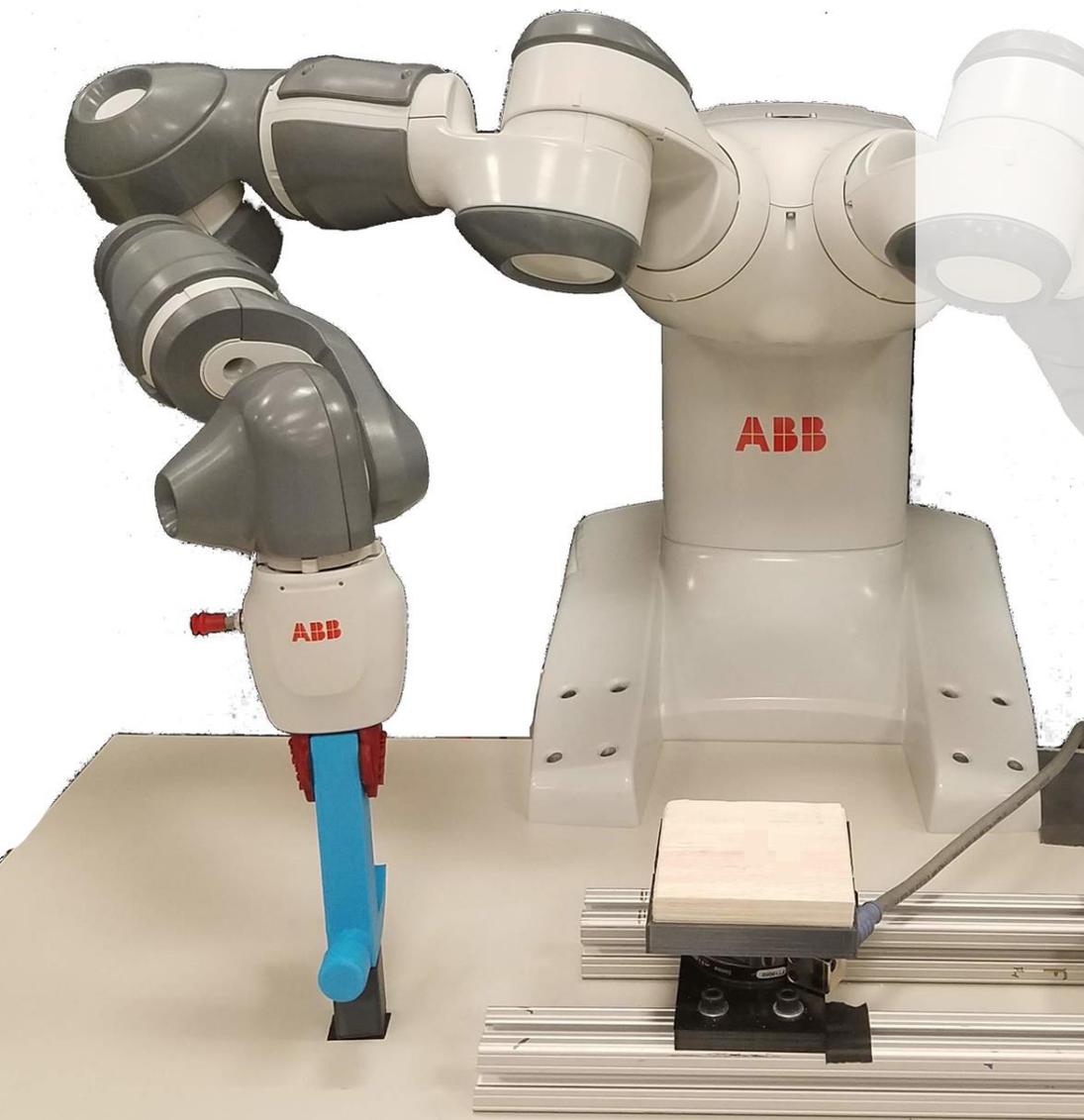


Torque Fault!

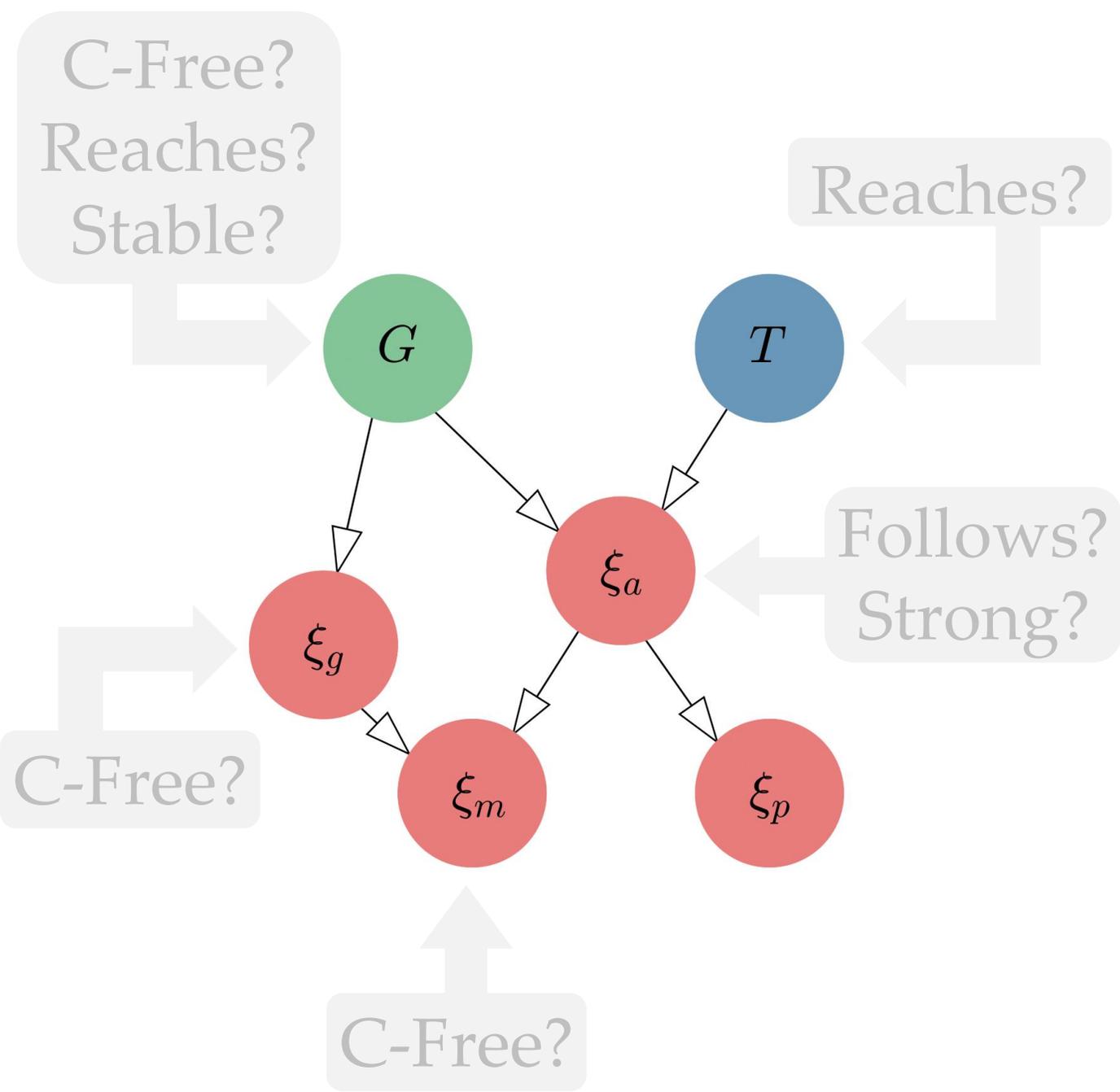
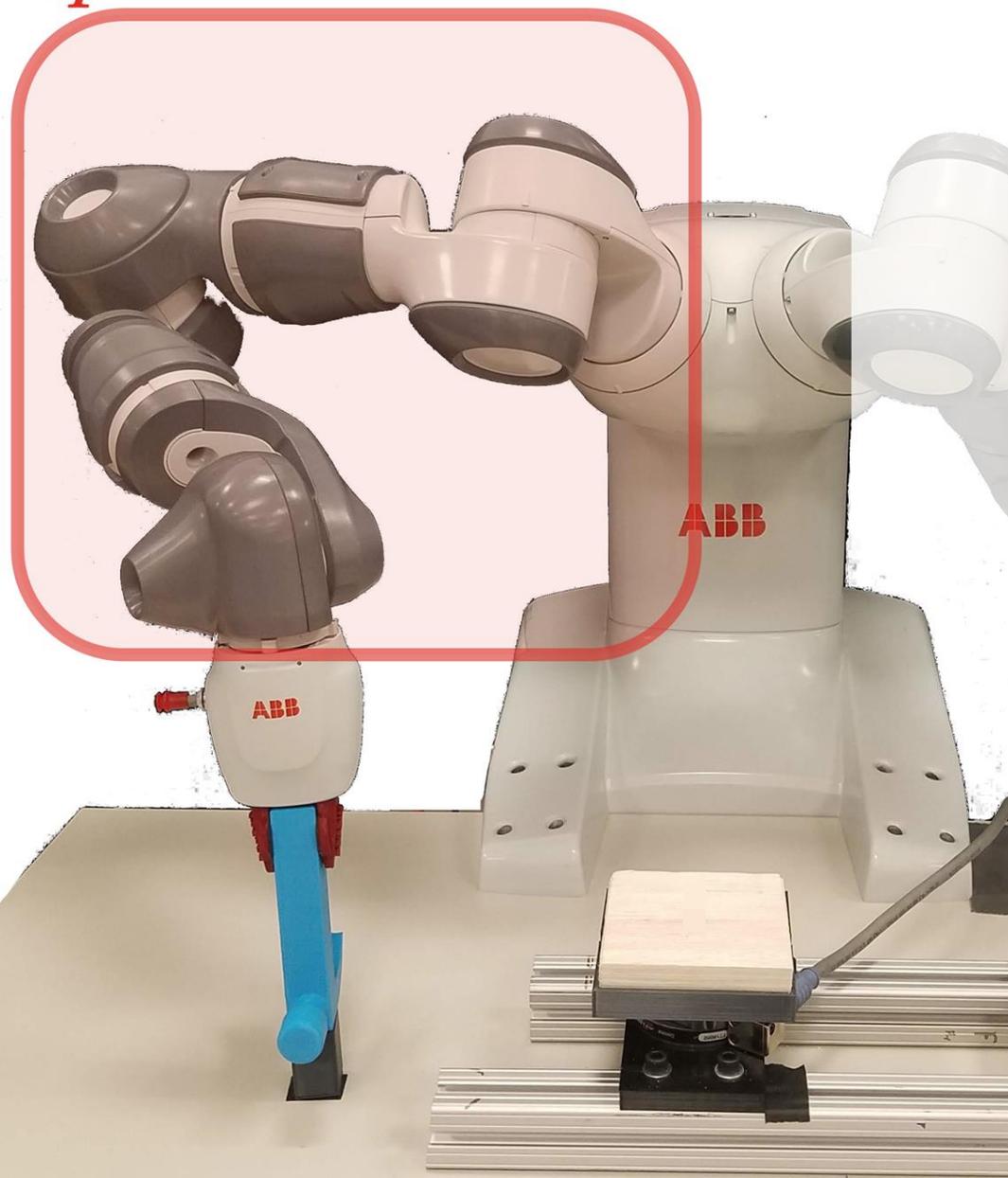


Success!

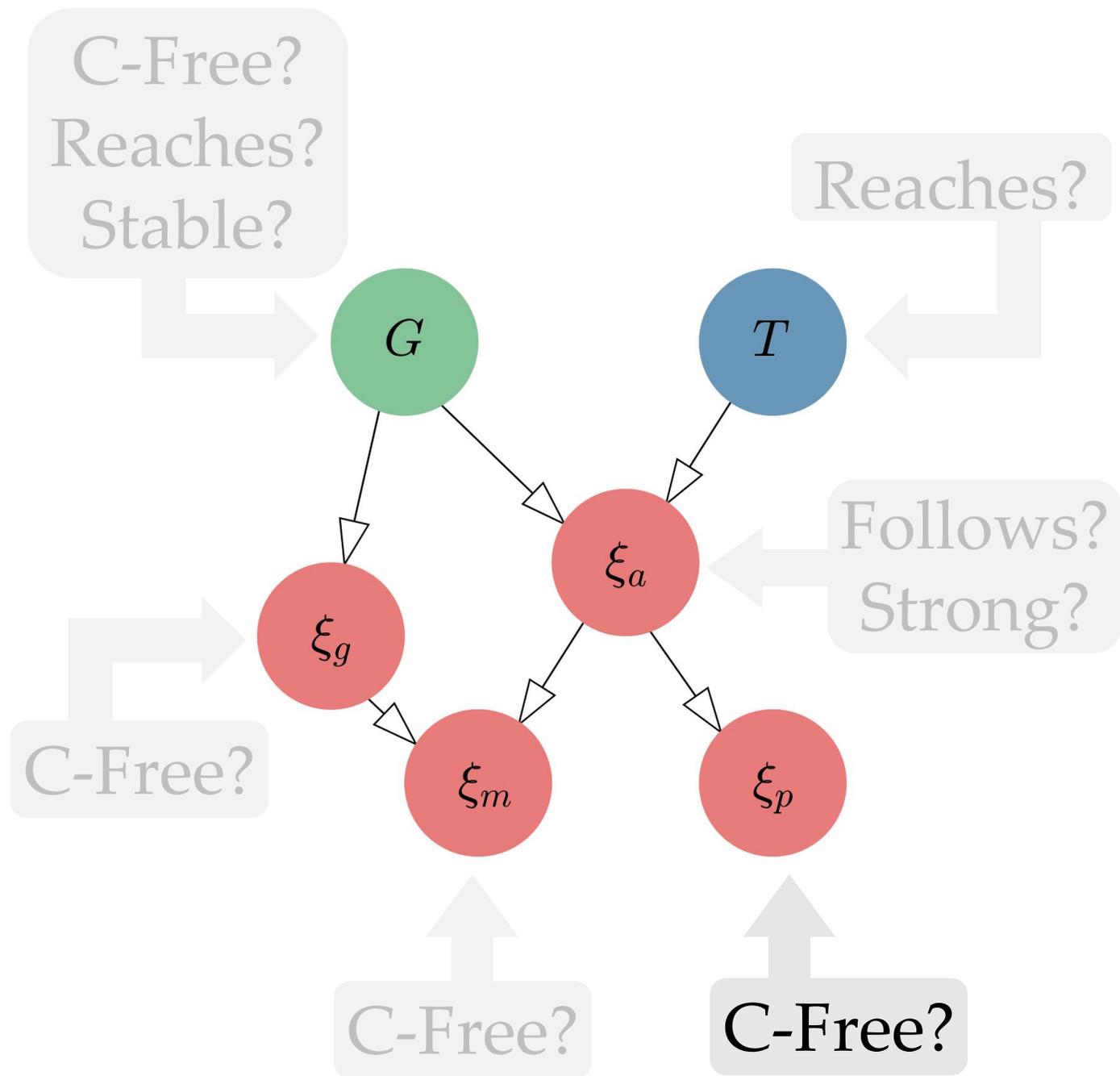
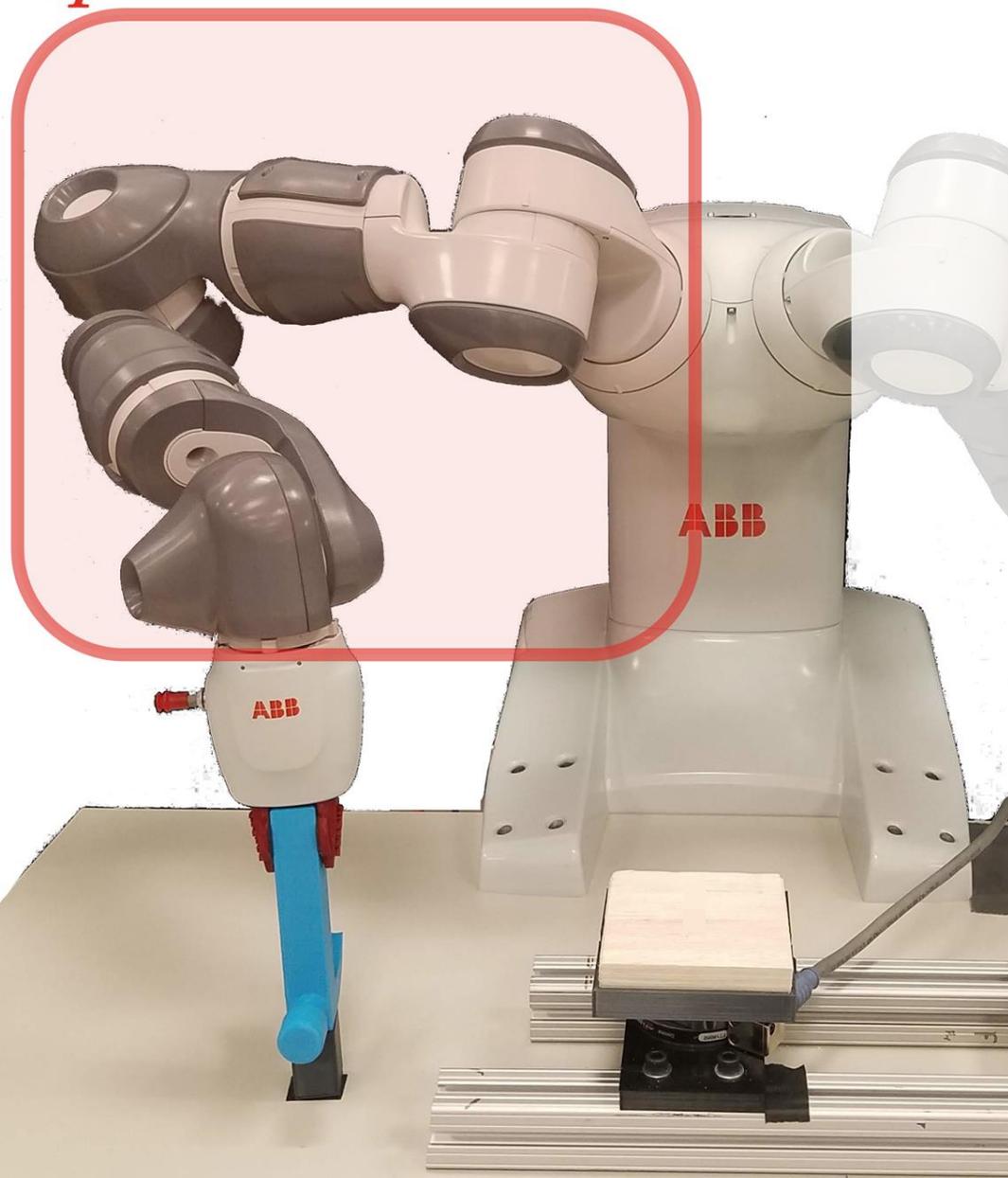


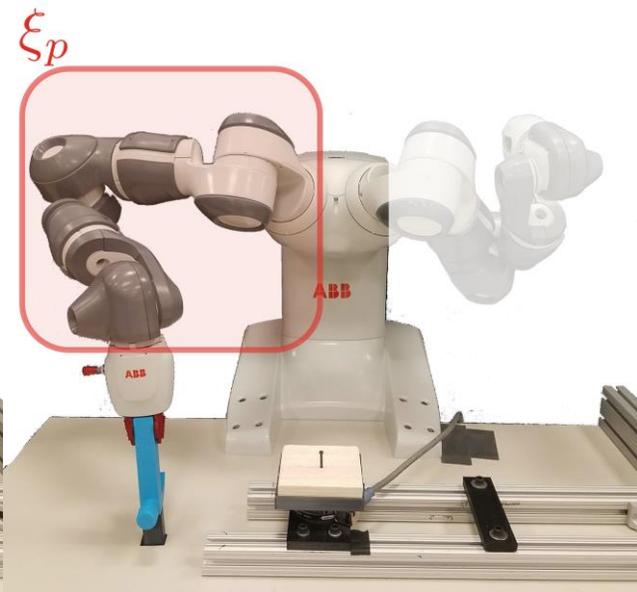
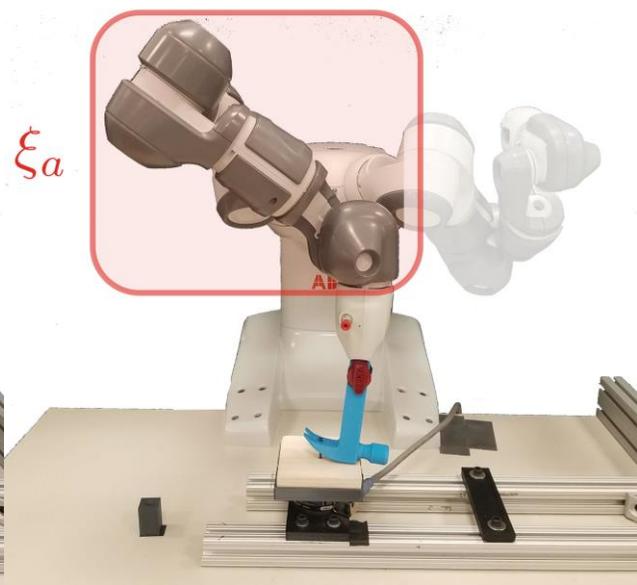
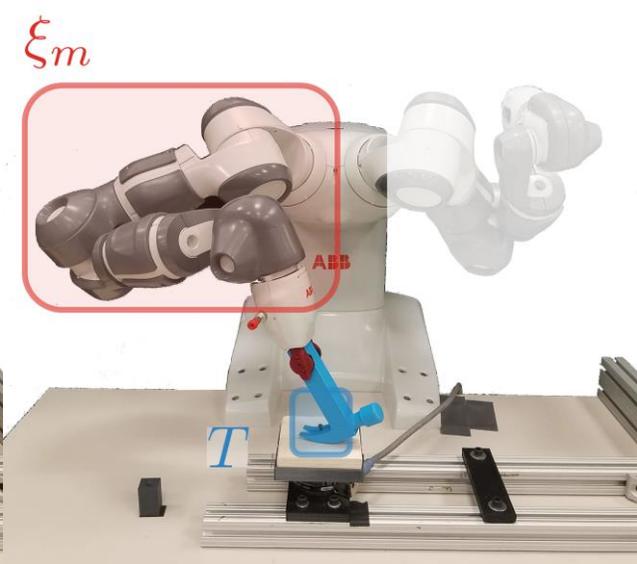
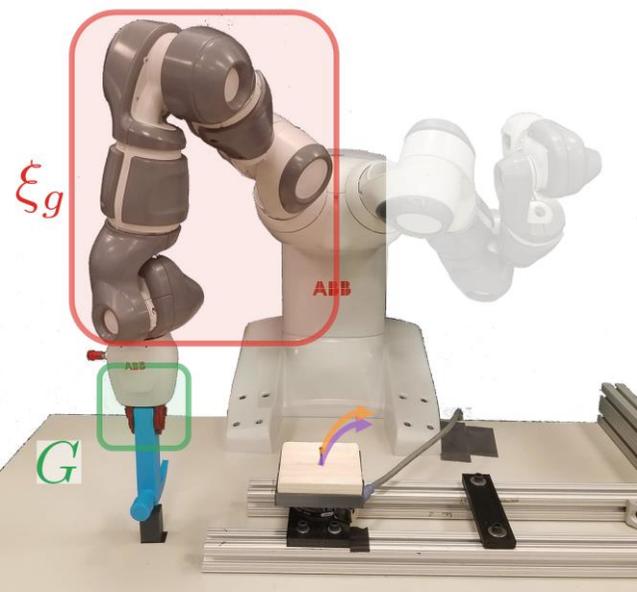


ξ_p

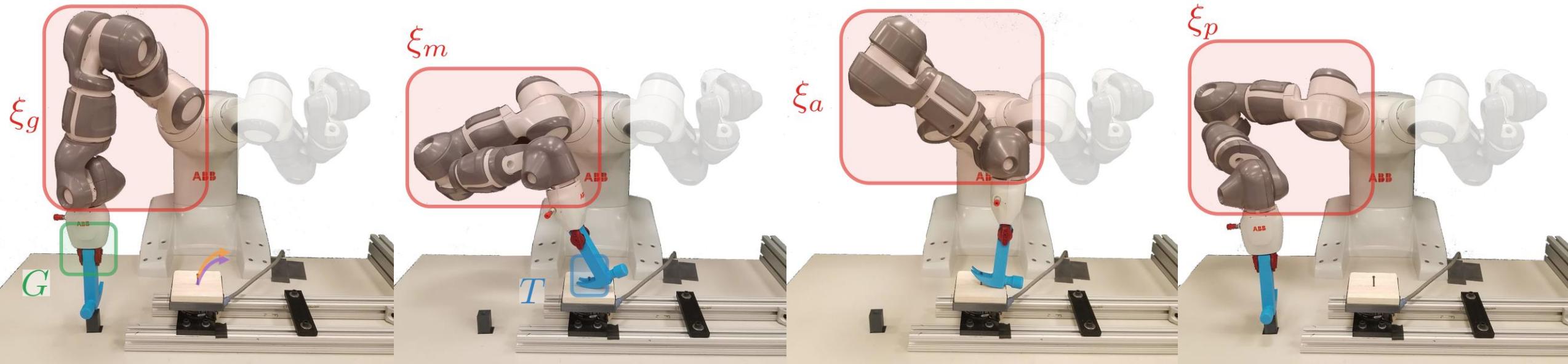


ξ_p



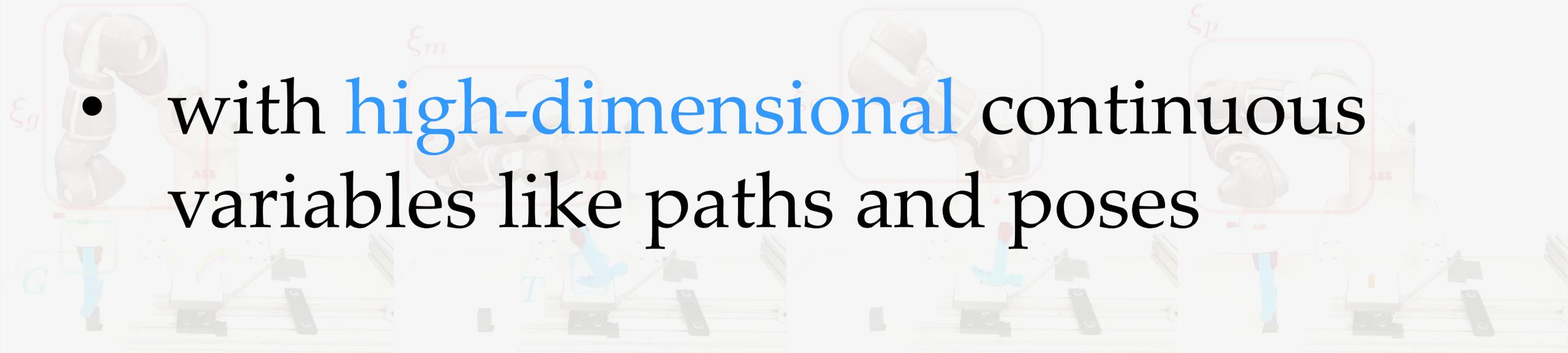


Tool Use as a *constraint satisfaction* problem



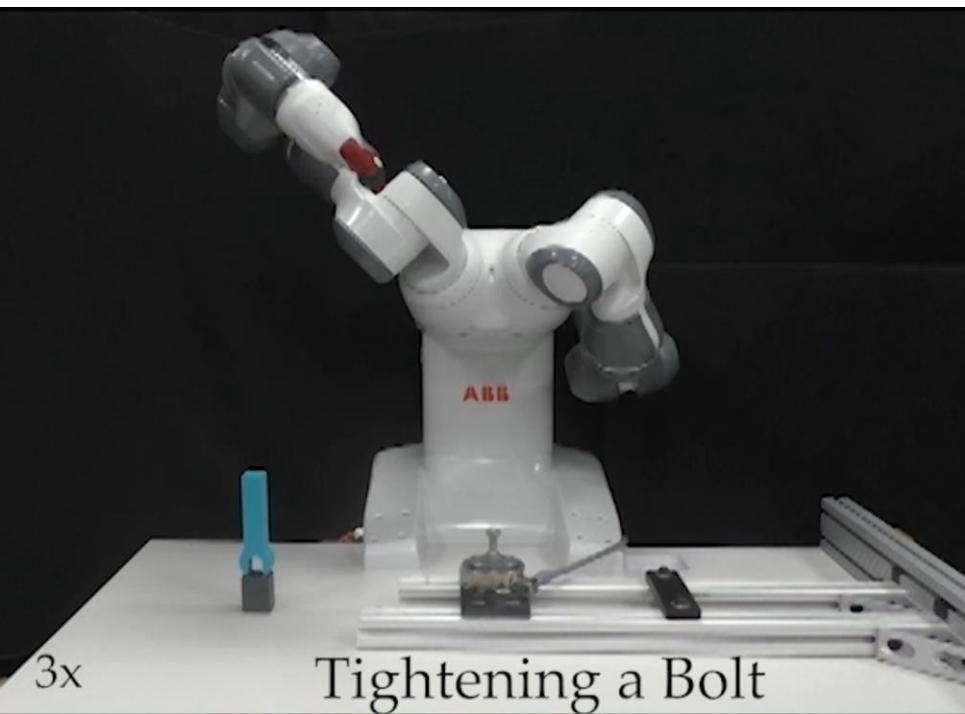
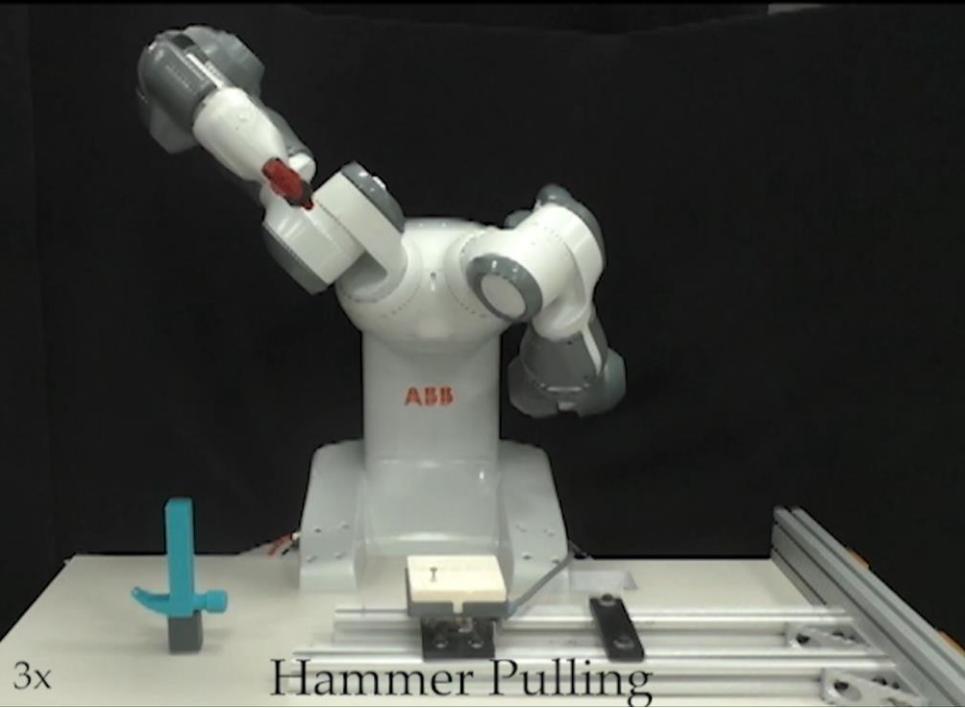
Tool Use as a *constraint satisfaction* problem

- with **high-dimensional** continuous variables like paths and poses

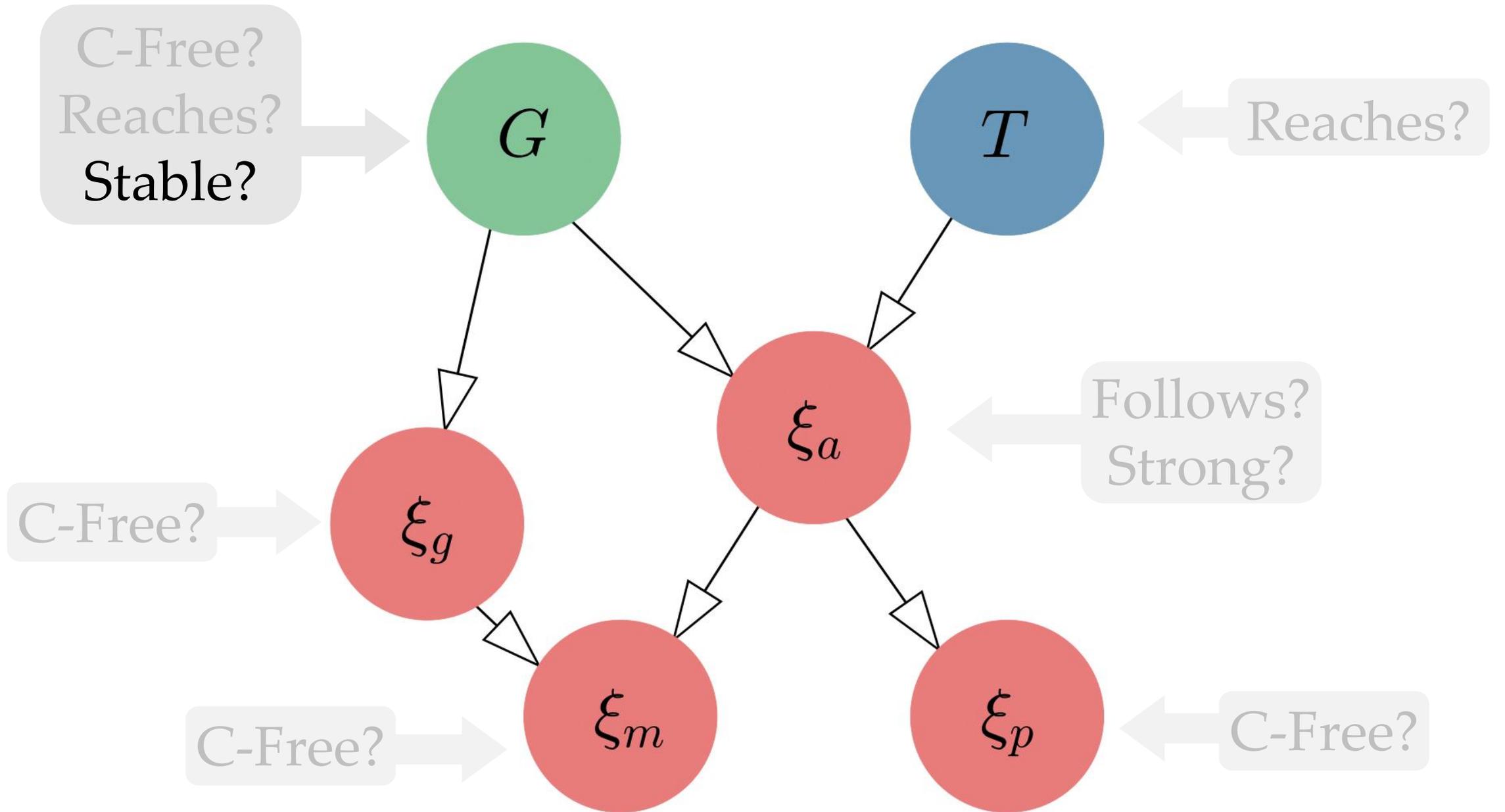


Tool Use as a *constraint satisfaction* problem

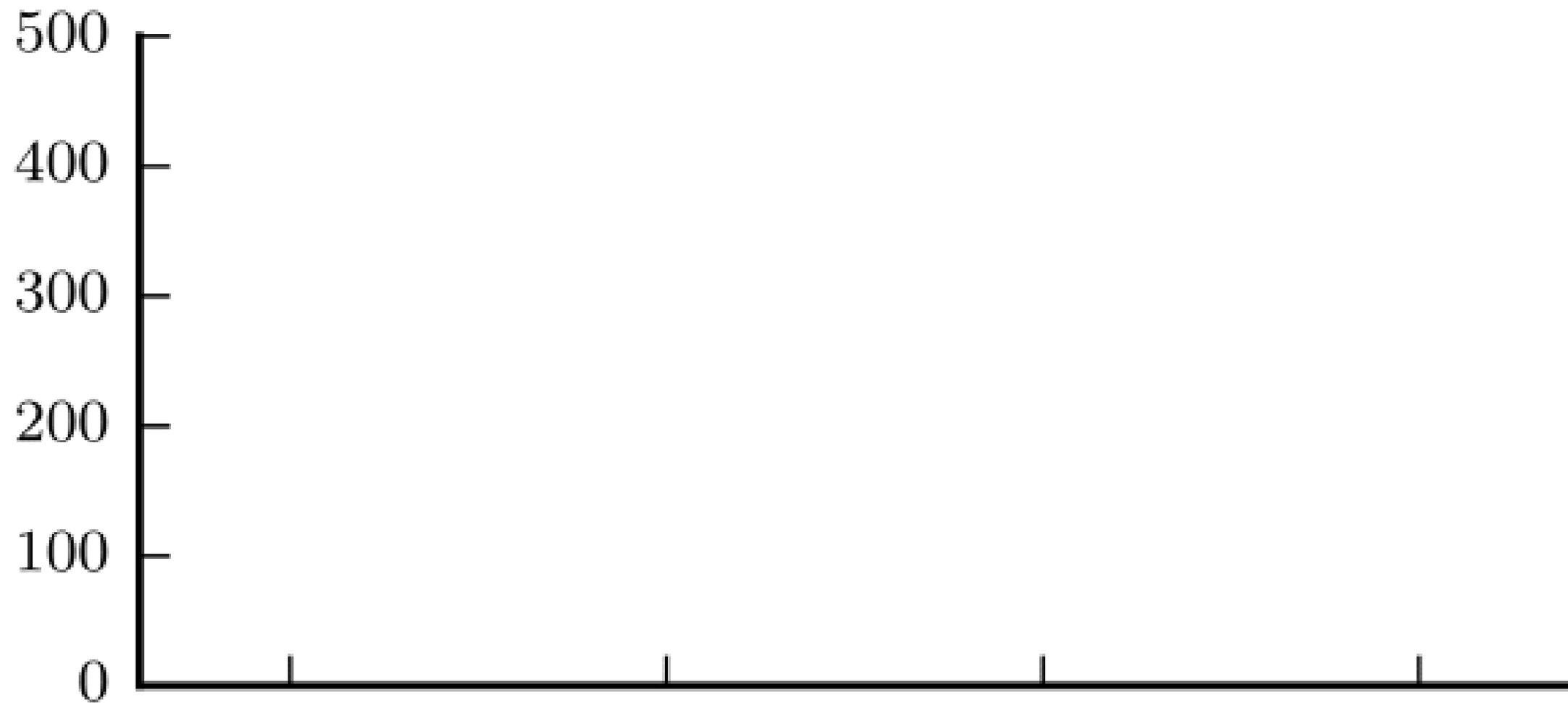
- with **high-dimensional** continuous variables like paths and poses
- a variety of kinematic, actuation, friction and environment **constraints**

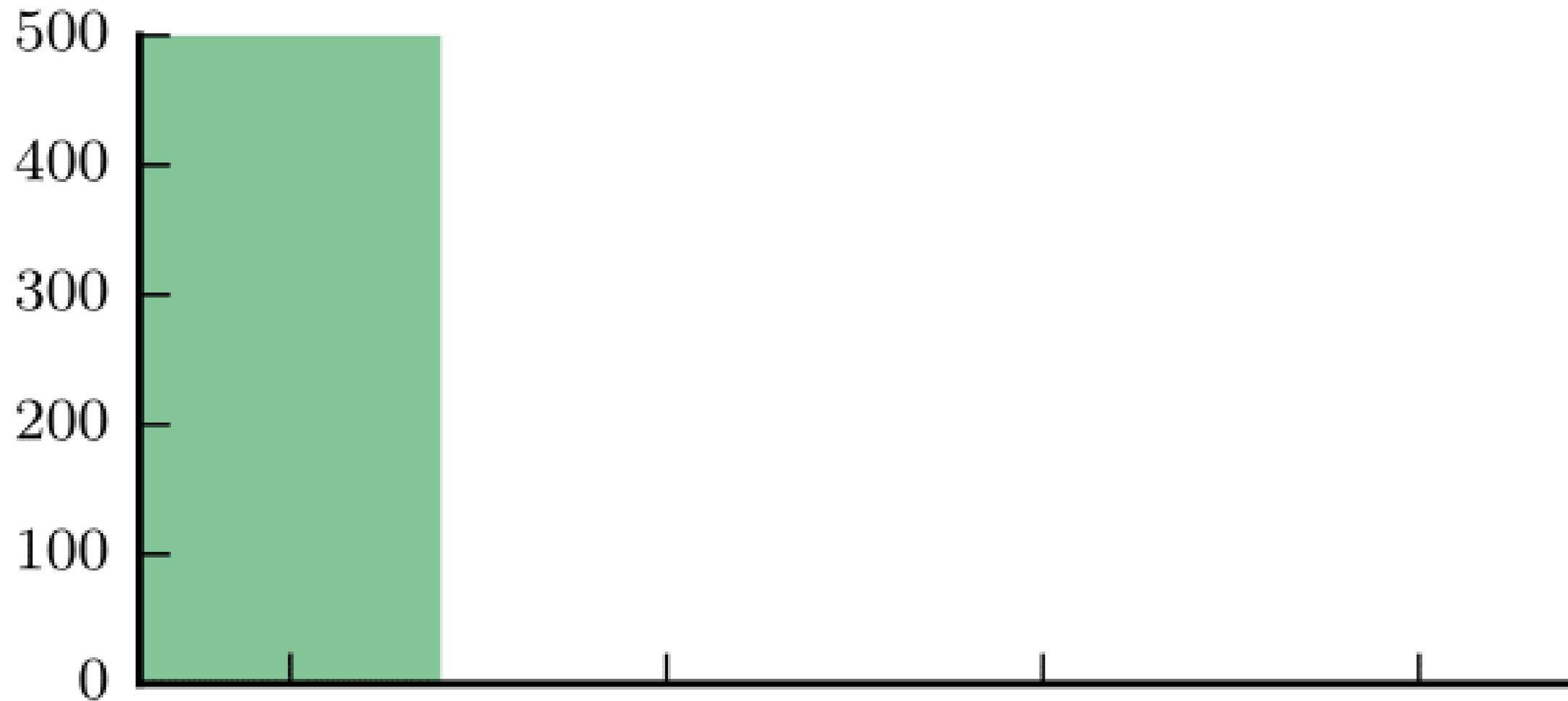


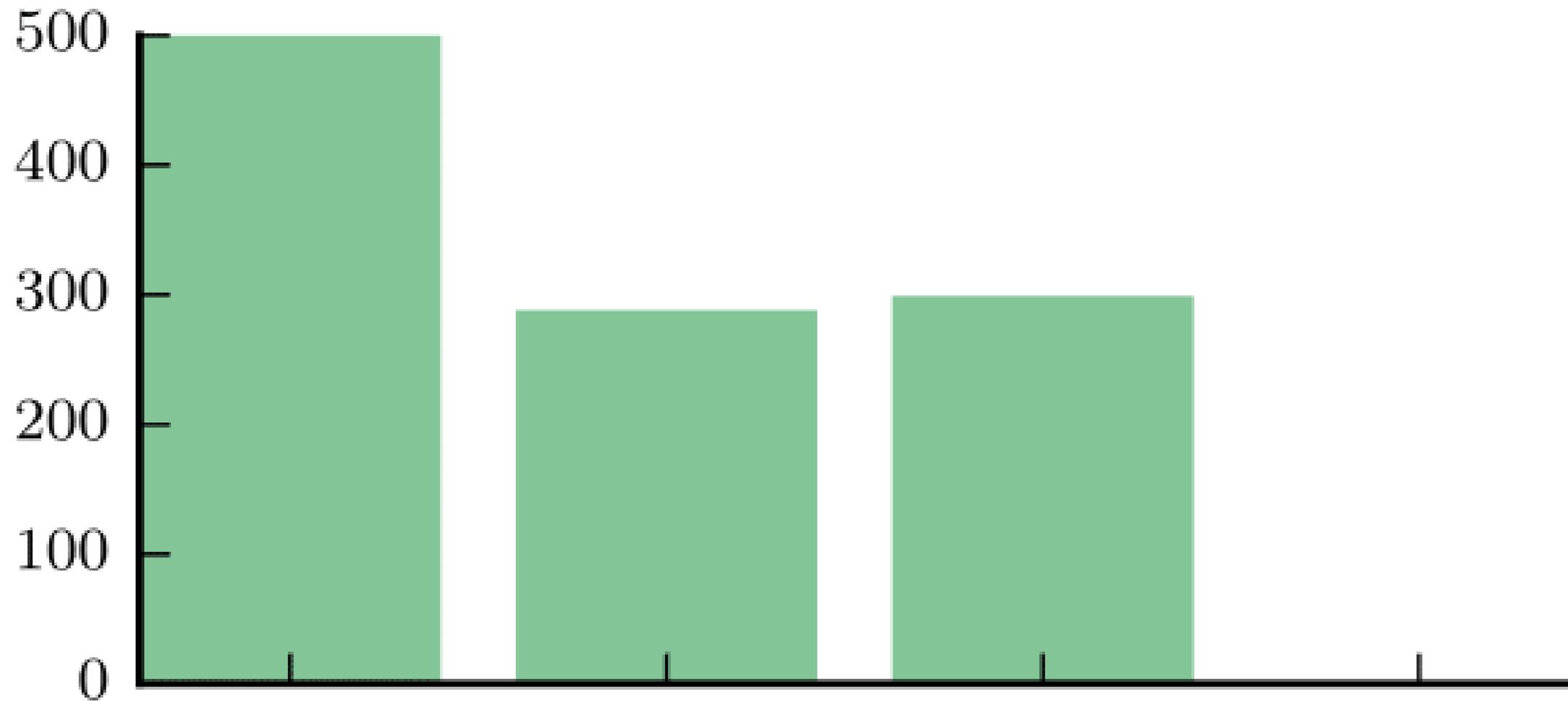
Applied
to four
tasks

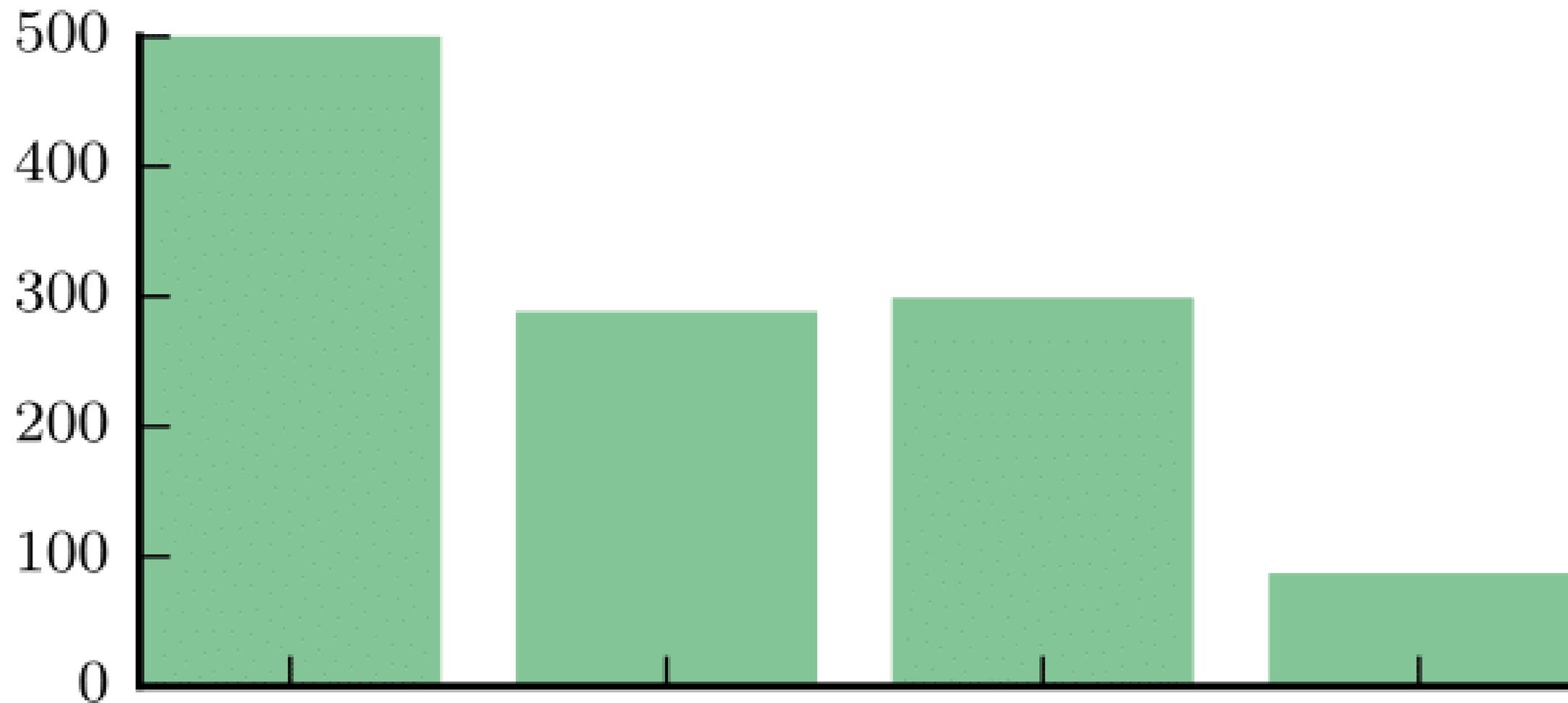


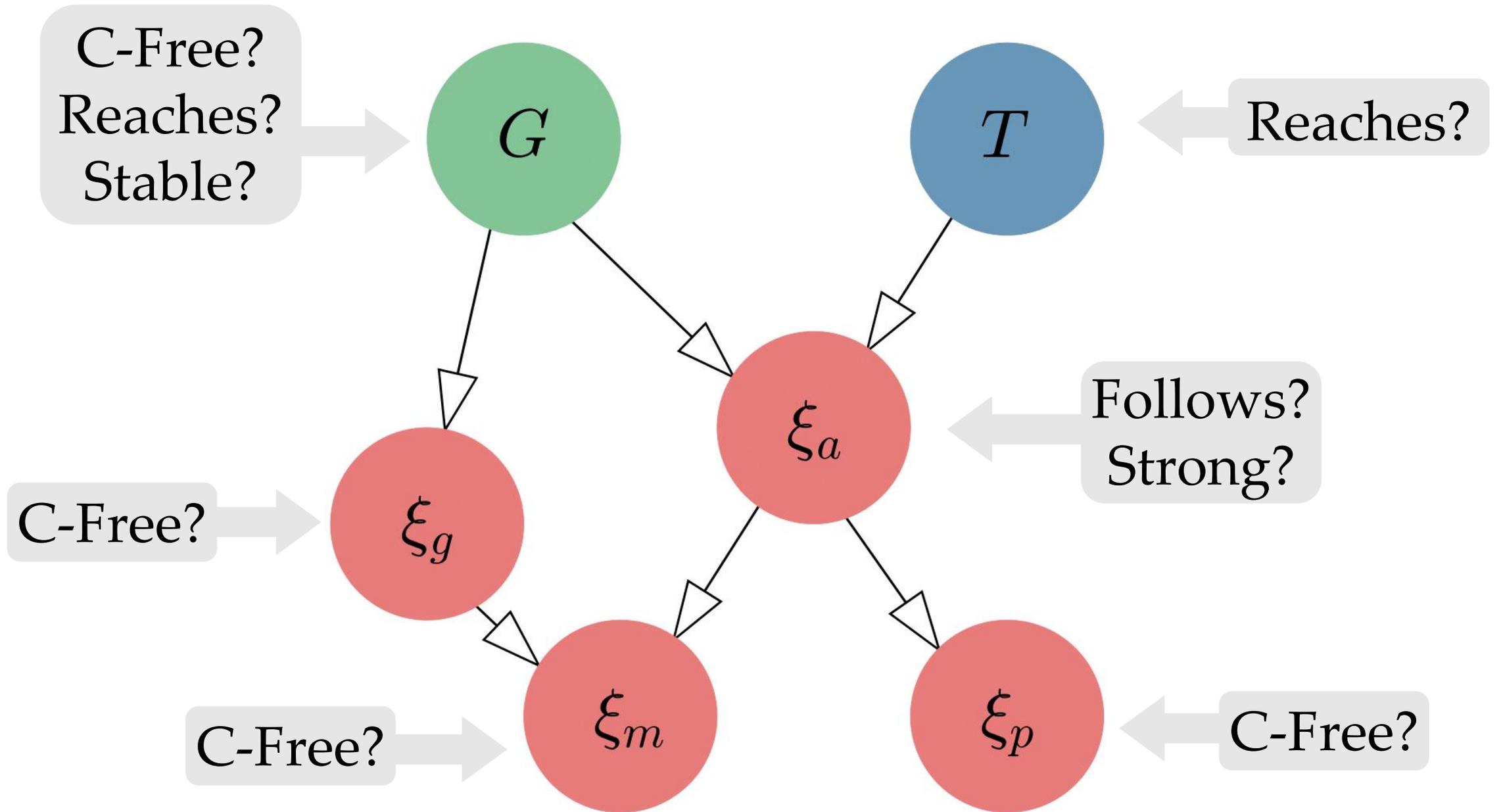


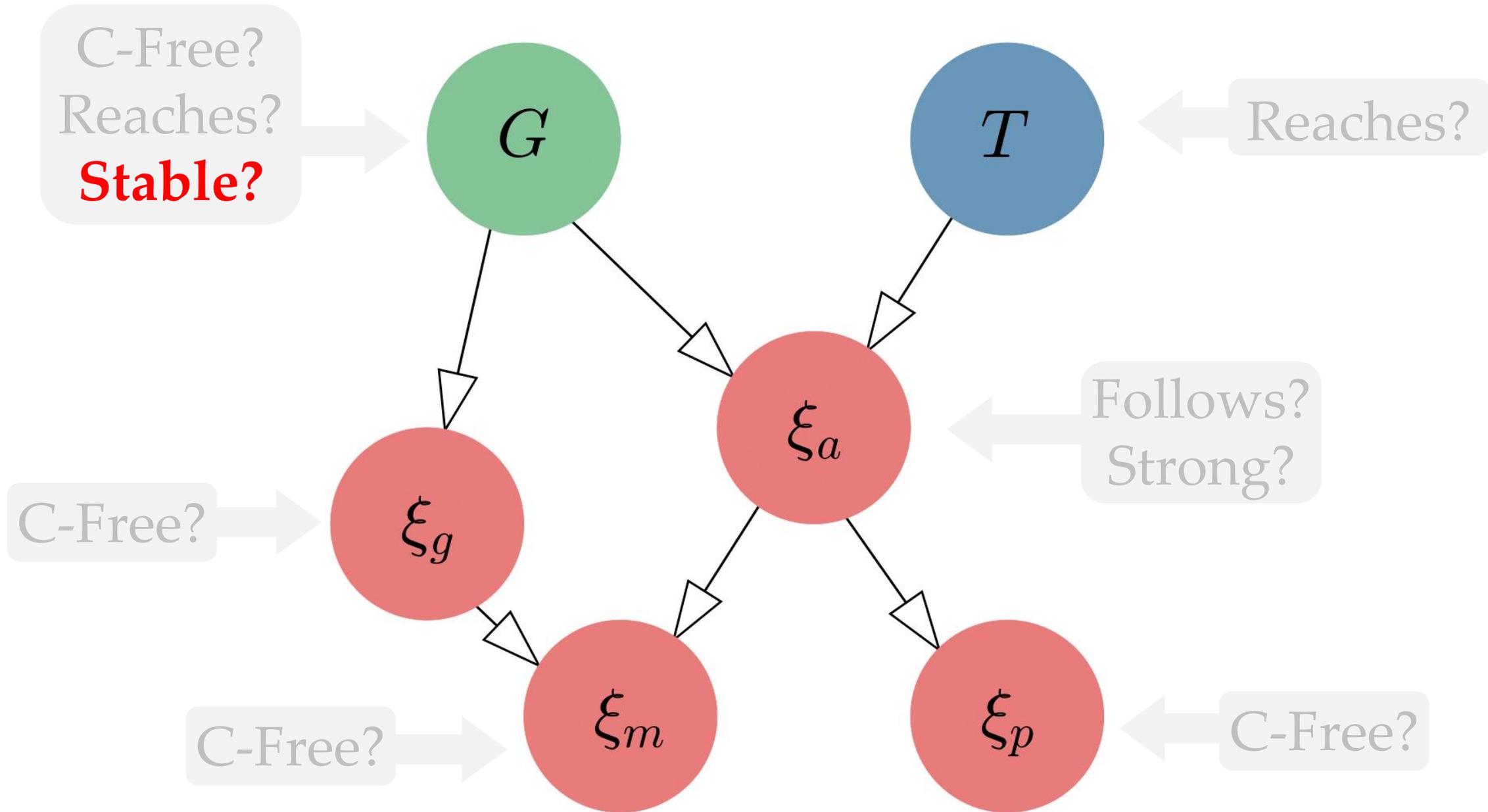


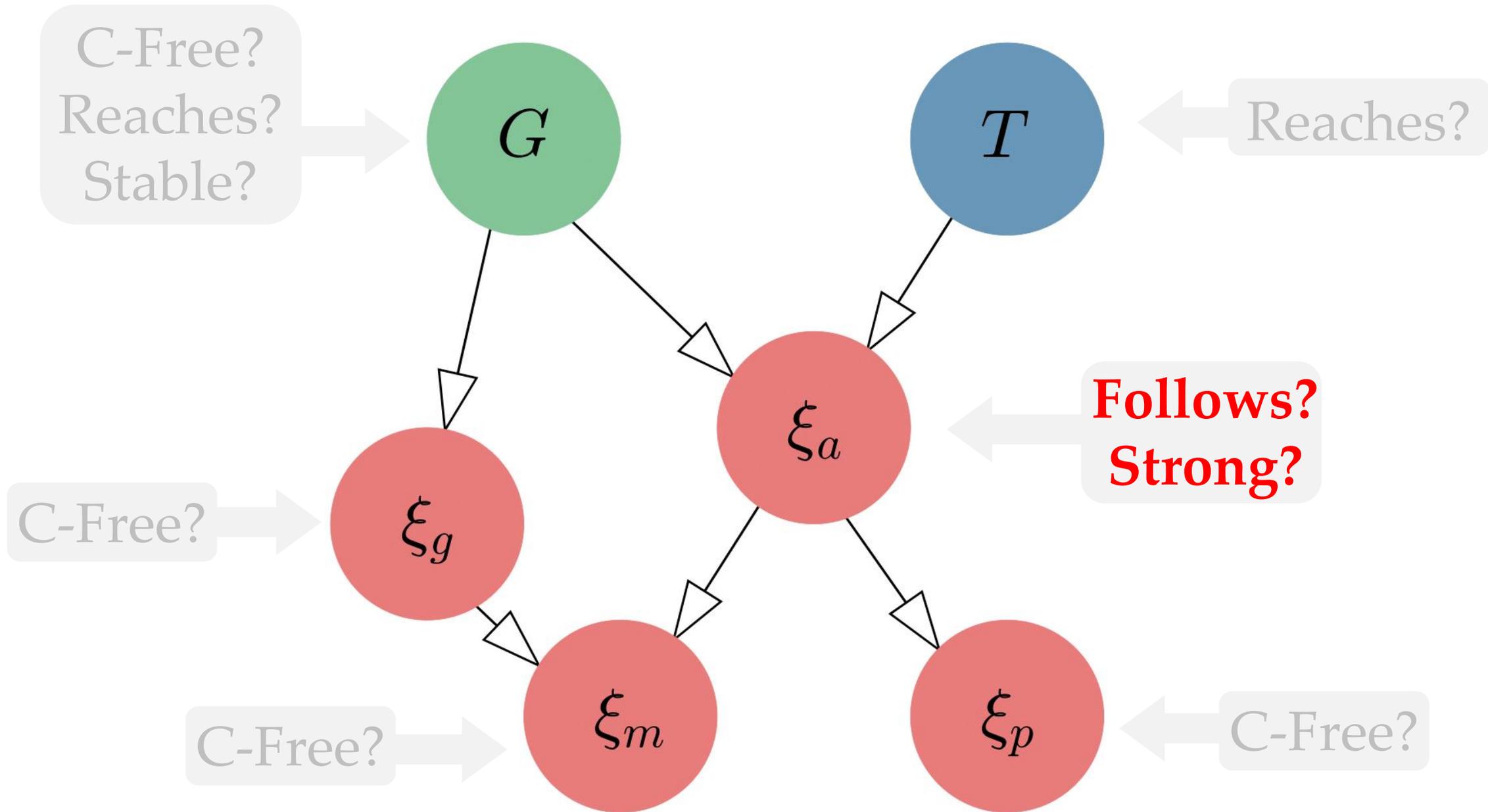
















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mcube.mit.edu/tool-use/

