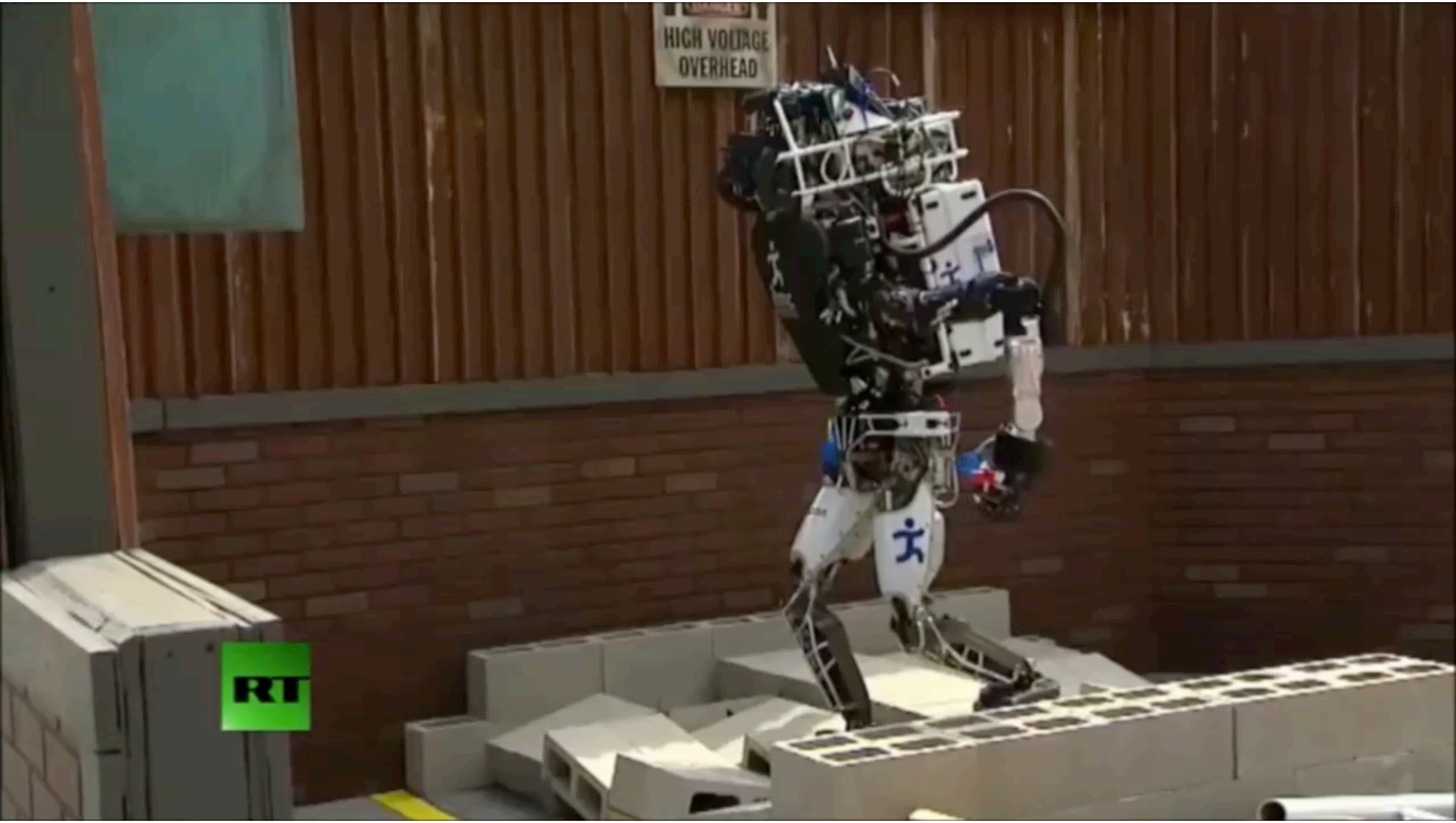
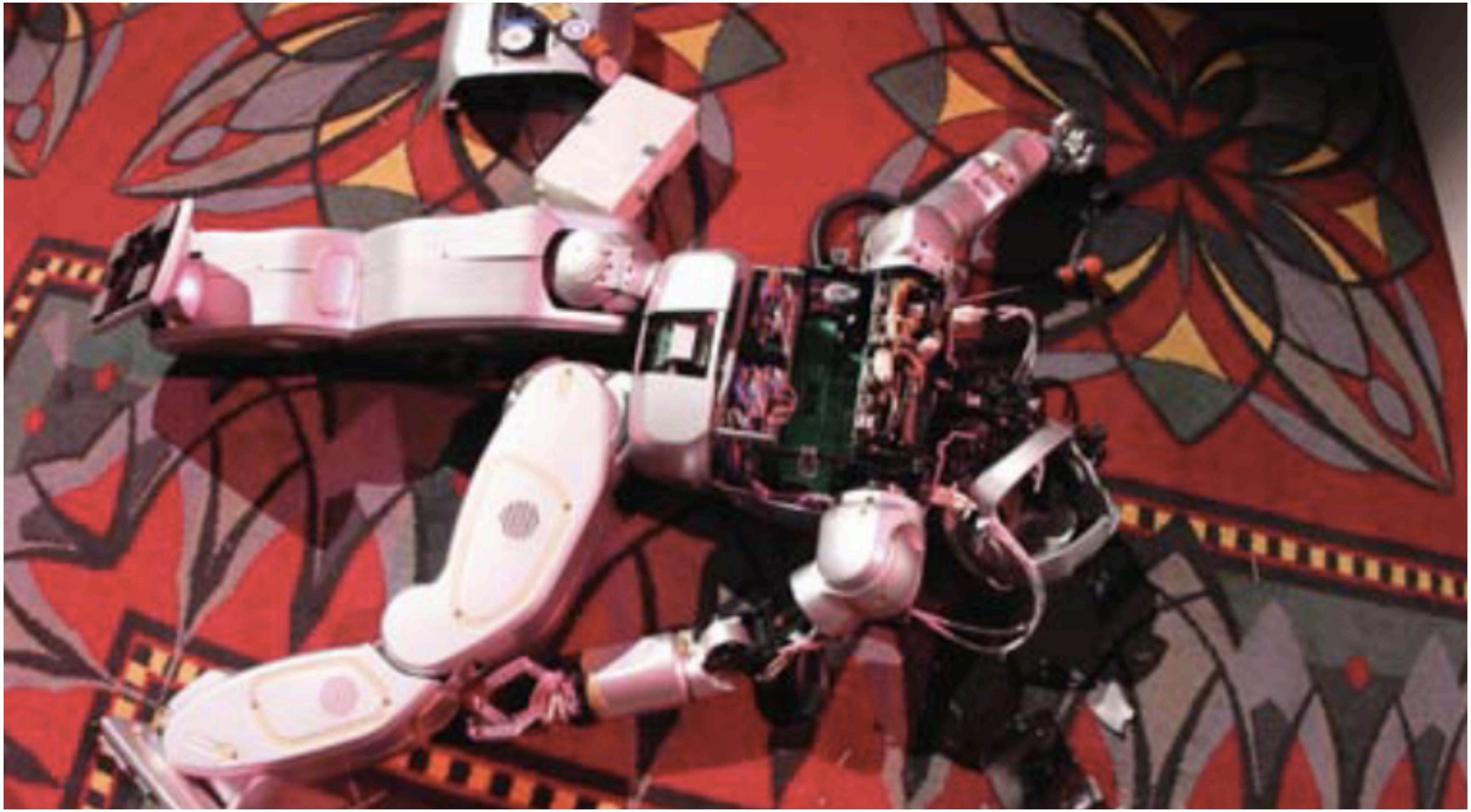
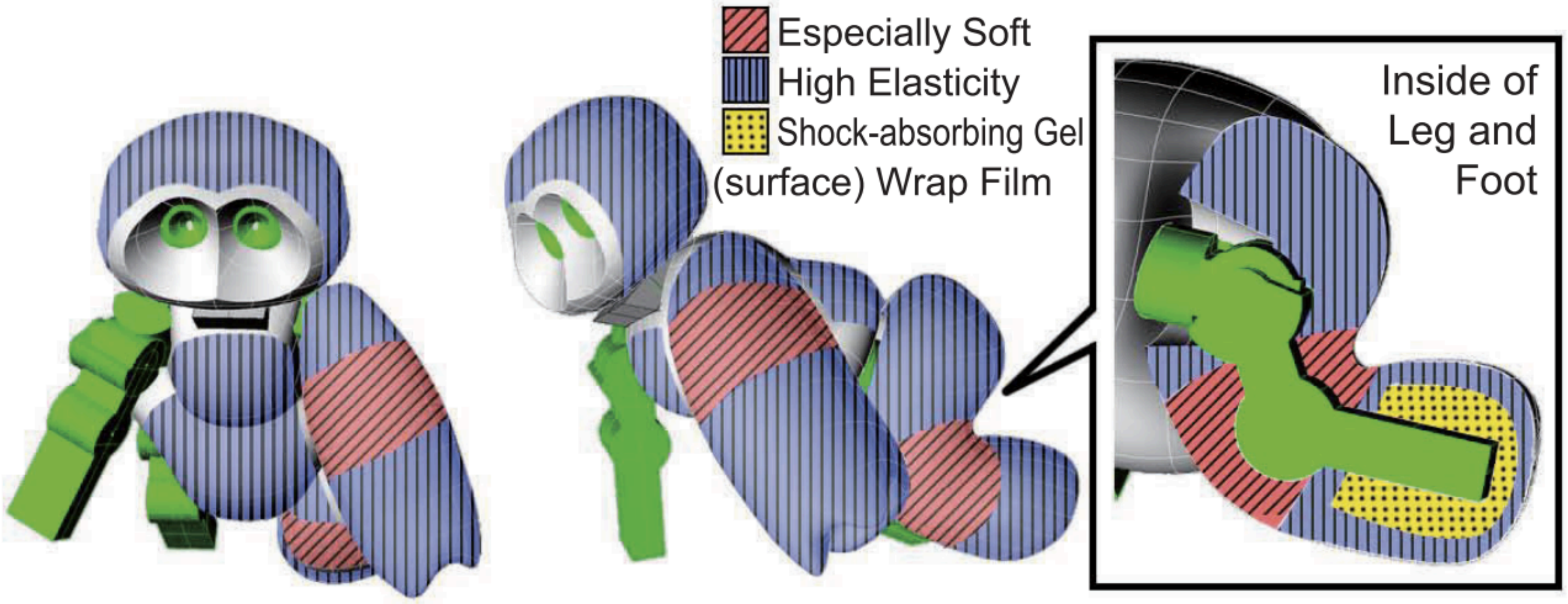
Multiple Contact Planning for Minimizing Damage of Humanoid Falls

Sehoon Ha and C. Karen Liu
Georgia Institute of Technology


HIGH VOLTAGE
OVERHEAD





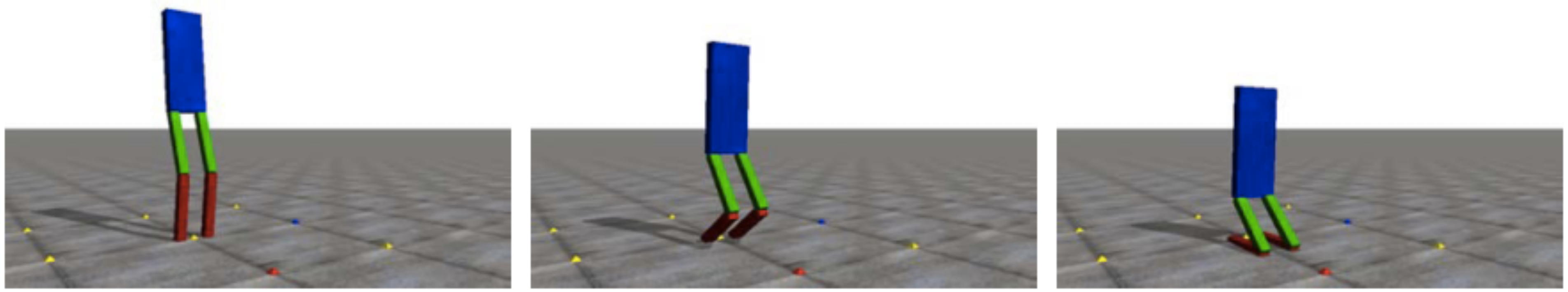
Kobayashi et al.

Learn how to fall safely

Existing falling strategies

Execute a specific contact sequence for a set of scenarios.

Knee-first strategy

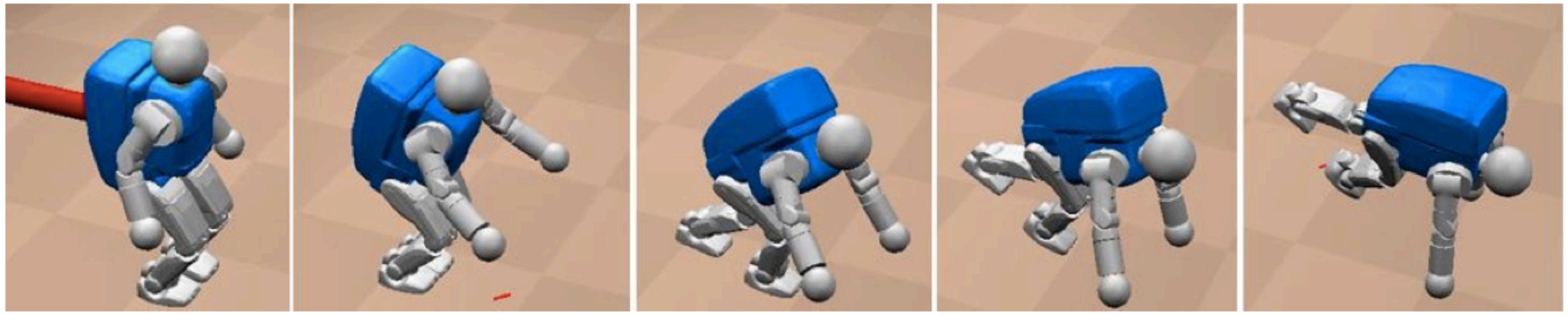


Wang et al. 2011

Existing falling strategies

Execute a specific contact sequence for a set of scenarios.

Tripod strategy

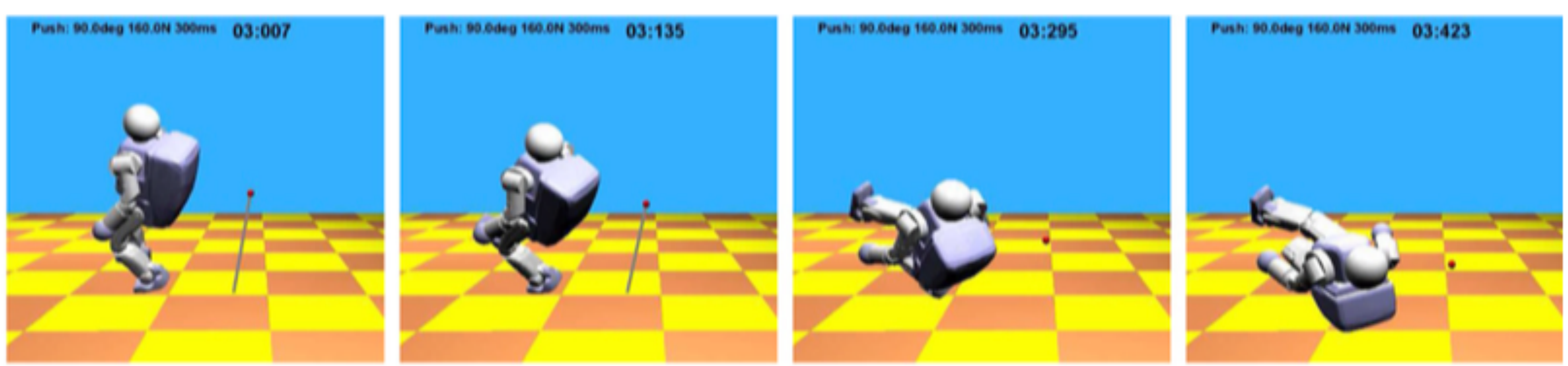


Yun and Goswami 2014

Existing falling strategies

Execute a specific contact sequence for a set of scenarios.

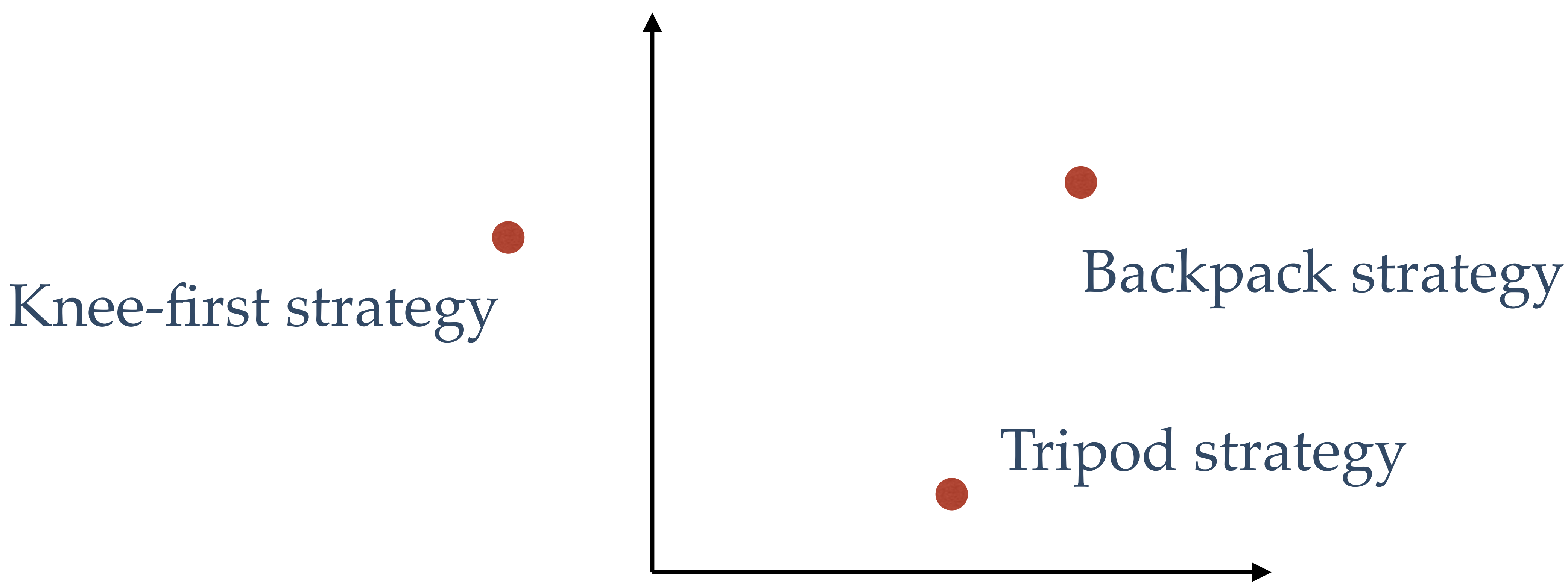
Backpack strategy

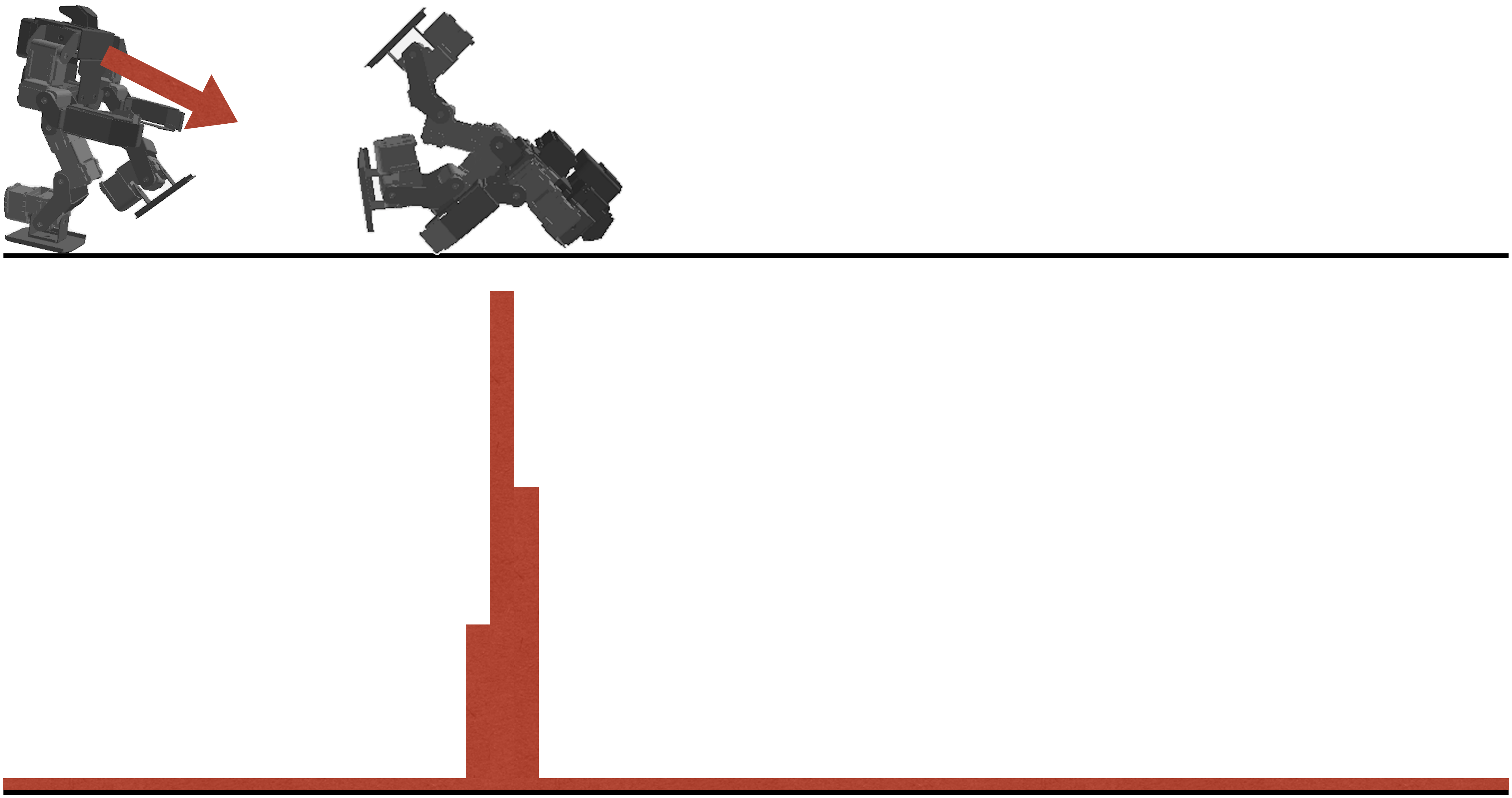


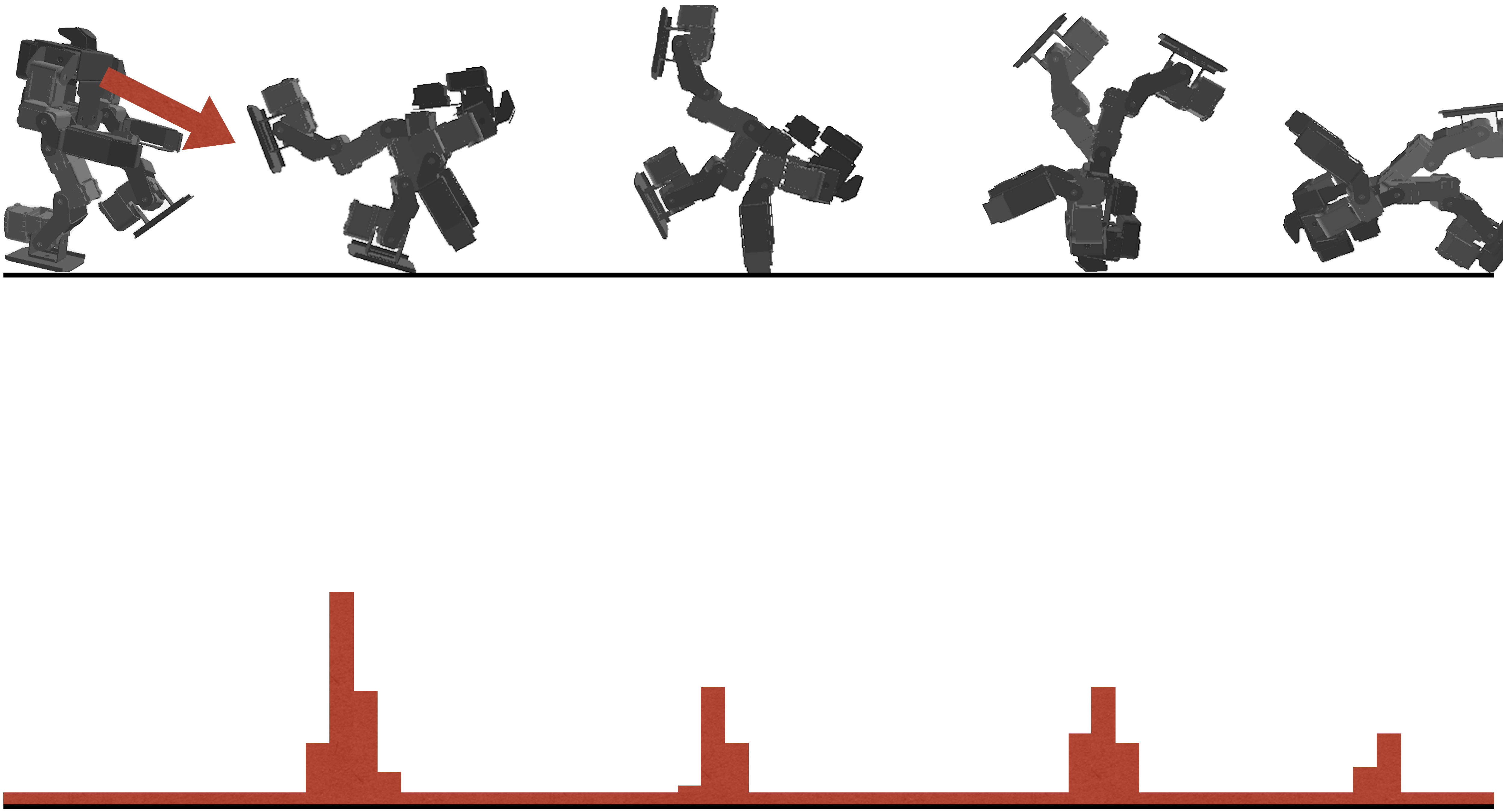
Lee and Goswami 2012

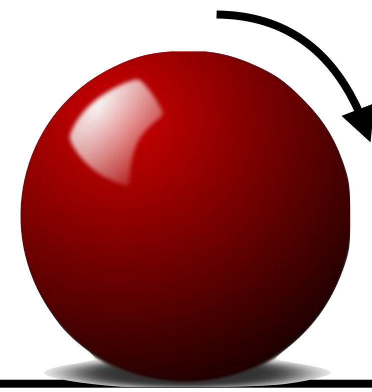
Space of falling strategies

each point in this space is a particular contact sequence

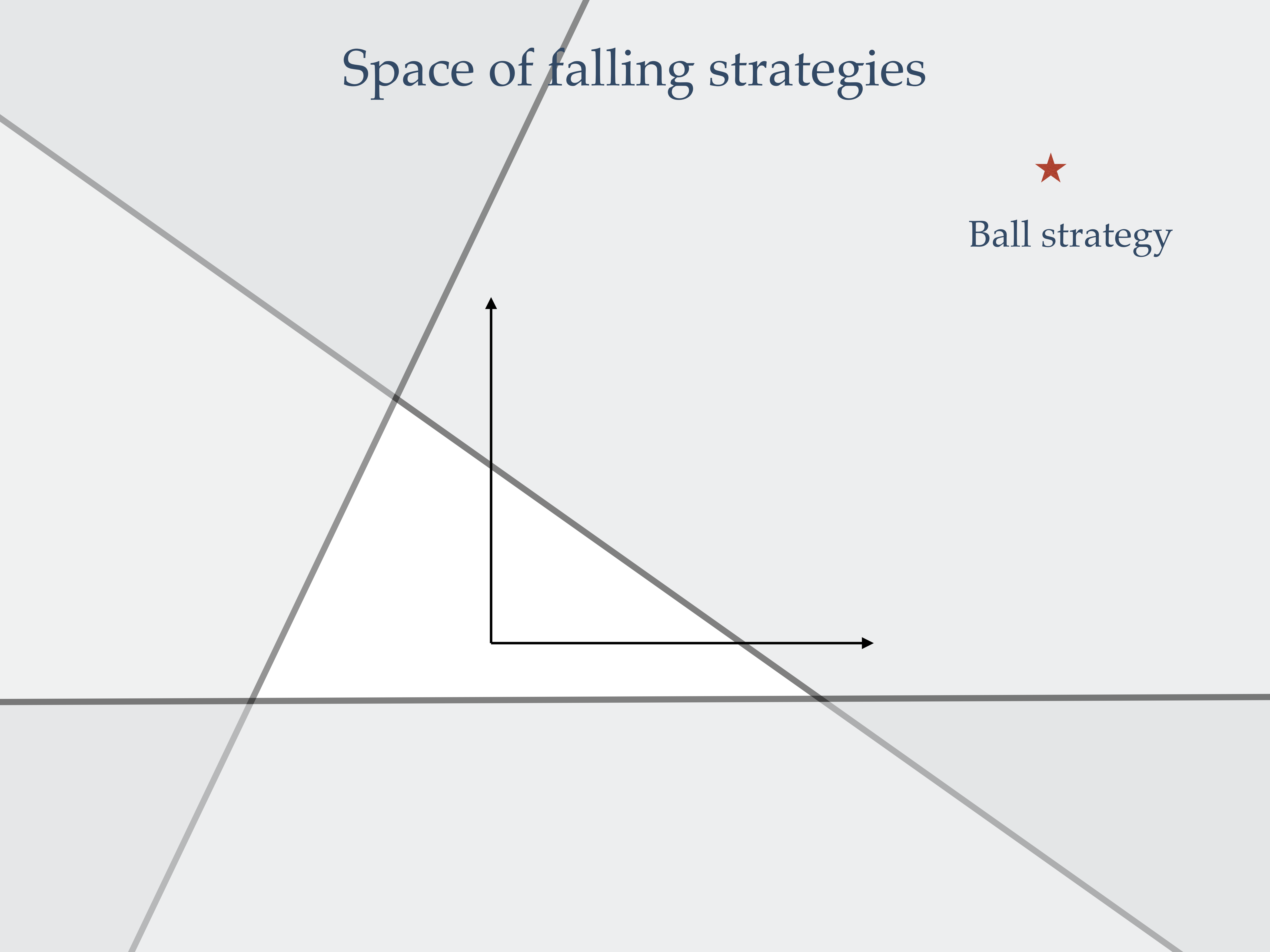








Space of falling strategies

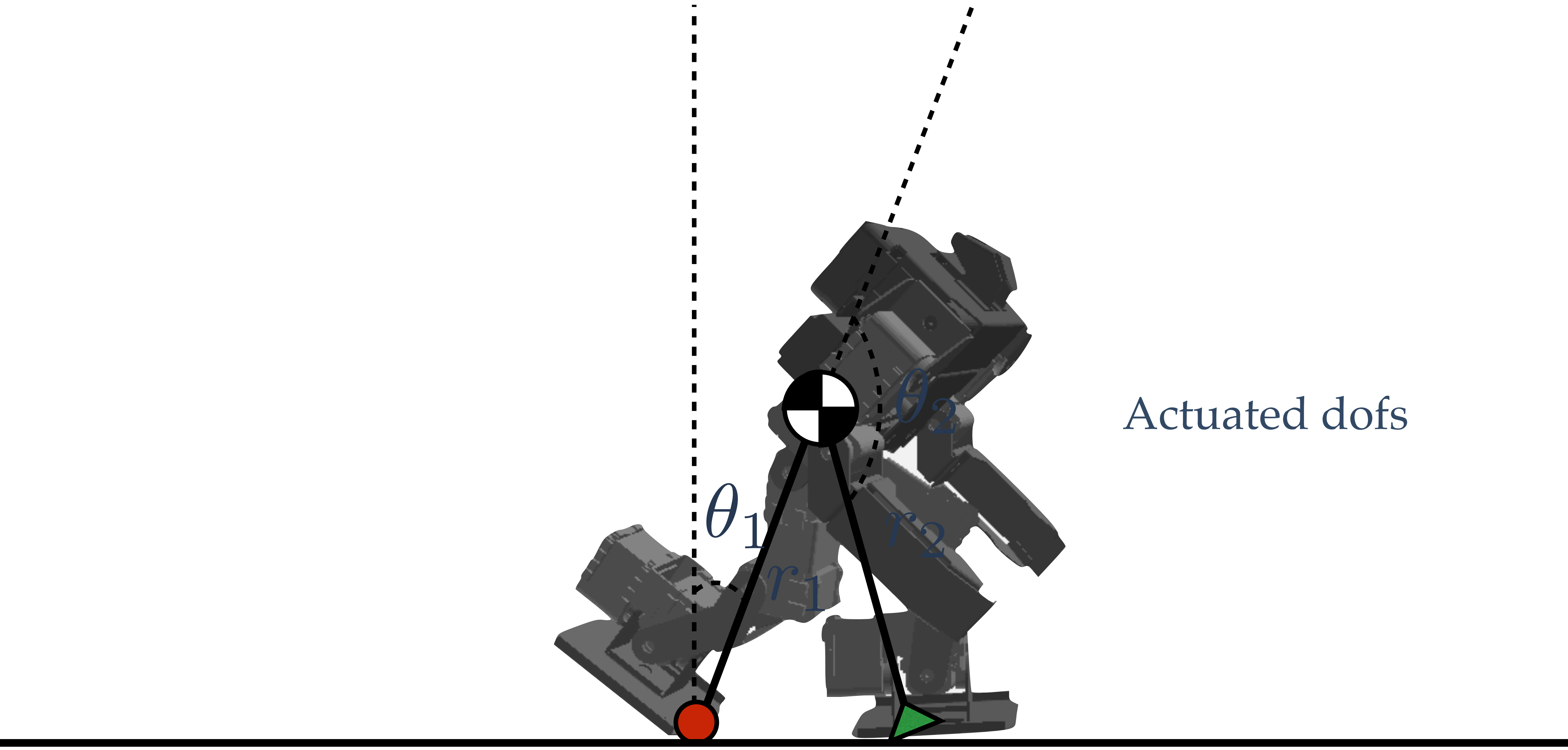


The problem

Given robot hardware constraints and an unbalanced initial state of the robot, compute the optimal contact sequence to dissipate the kinetic energy.

minimize the maximum impulse

total number of contacts
order of contacts
position of contacts
timing of the contacts



θ_1
r_1
θ_2
r_2
Actuated dofs

$$P_y^+ = m\dot{y}_1{}^+ = m\dot{y}_1{}^- + j$$

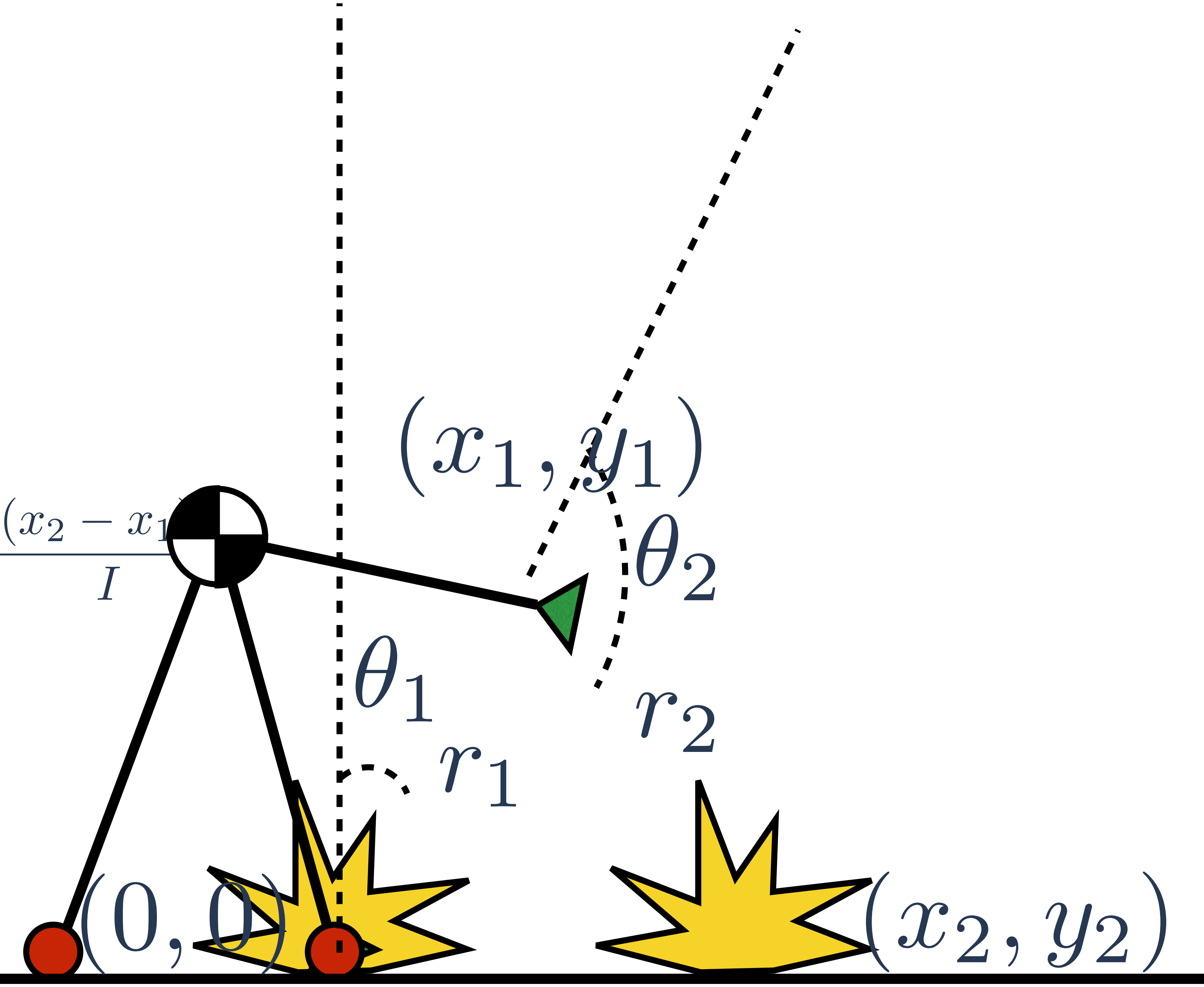
$$L^+ = I\dot{\theta}_1{}^+ = I\dot{\theta}_1{}^- - (x_2 - x_1)j$$

$$0 = \dot{y}_2^+$$

$$= \dot{y}_1^+ - (x_2 - x_1)\dot{\theta}_1^+$$

$$= (\dot{y}_1^- + \frac{j}{m}) - (x_2 - x_1)(\dot{\theta}_1^- - \frac{(x_2 - x_1}{I}$$

$$= (\frac{1}{m} + \frac{1}{I}(x_2 - x_1)^2)j + \dot{y}_2^-$$

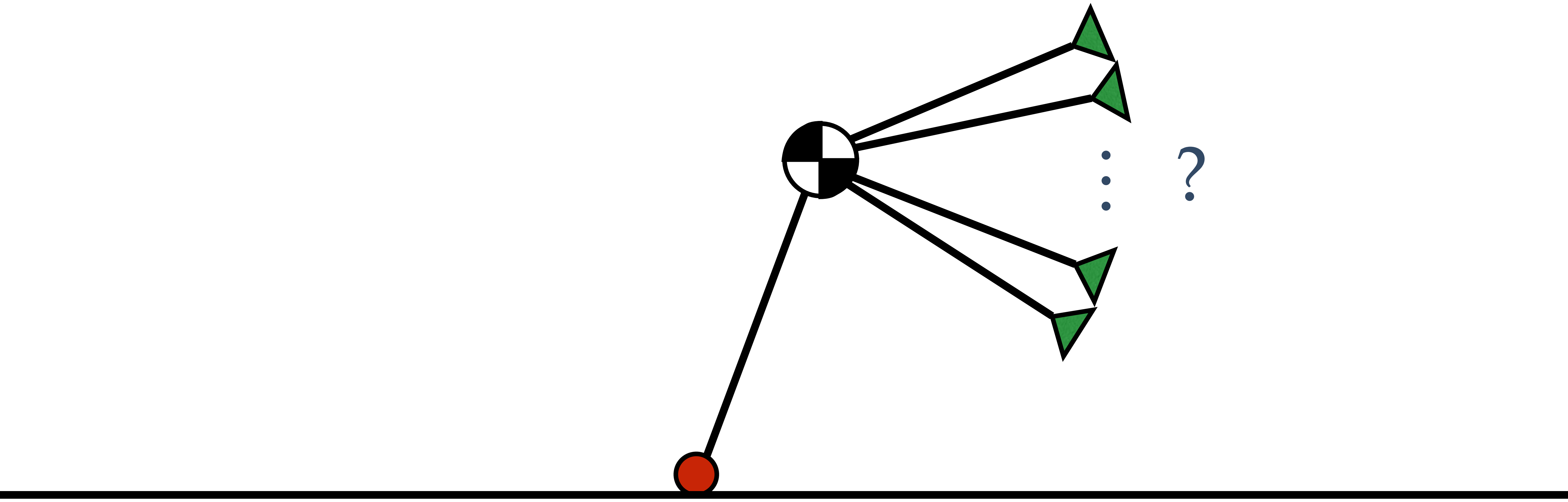


$$j = -\frac{\dot{y}_2^-}{\frac{1}{m} + \frac{1}{I}(x_2 - x_1)^2}$$

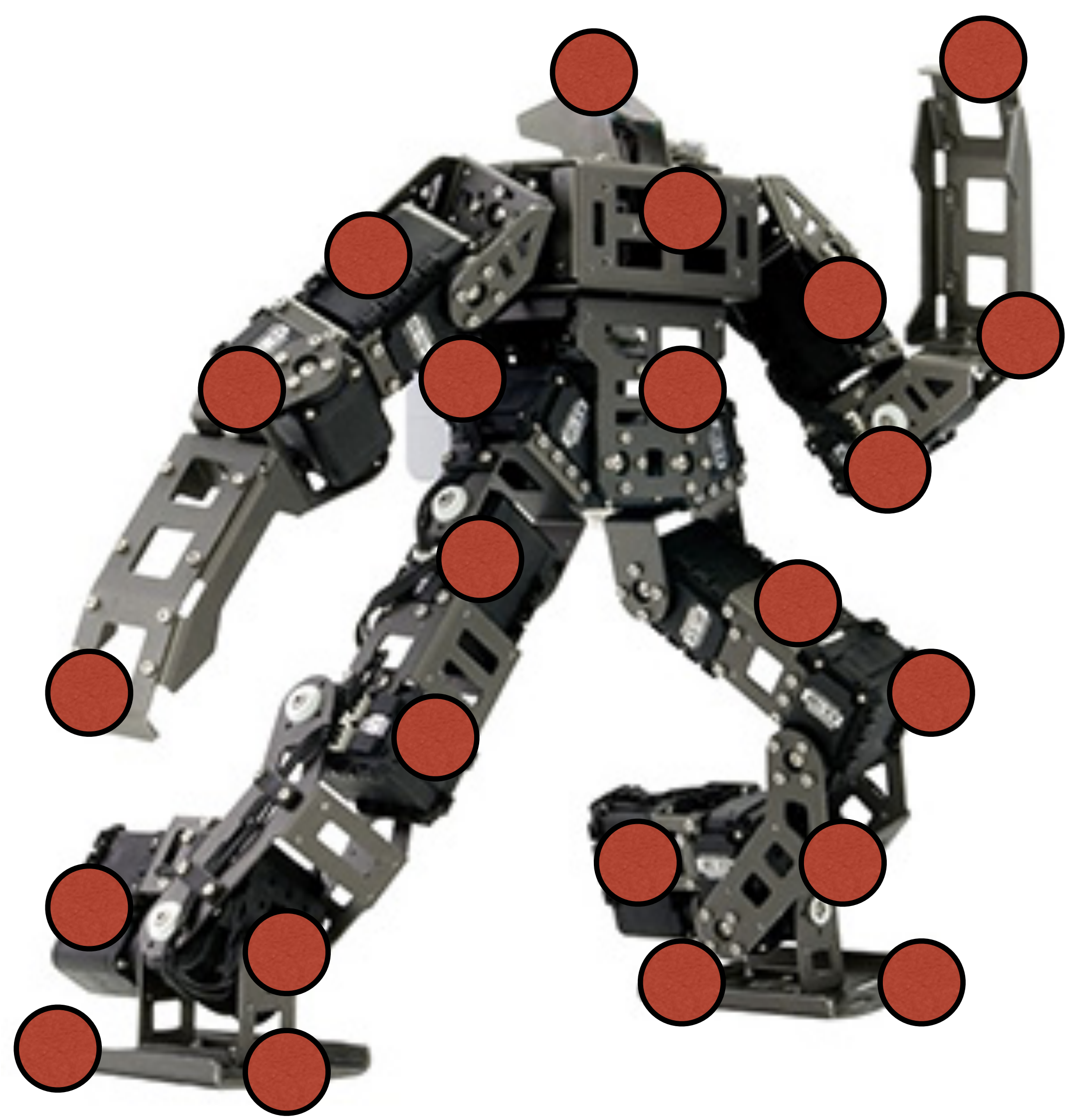
$$r_1\ddot{\theta}_1 + 2\dot{r}_1\dot{\theta}_1 - g\sin\theta_1 = 0$$

$$m\ddot{r}_1 - mr_1\dot{\theta}_1^2 + mg\cos\theta_1 = \tau_{r_1}$$

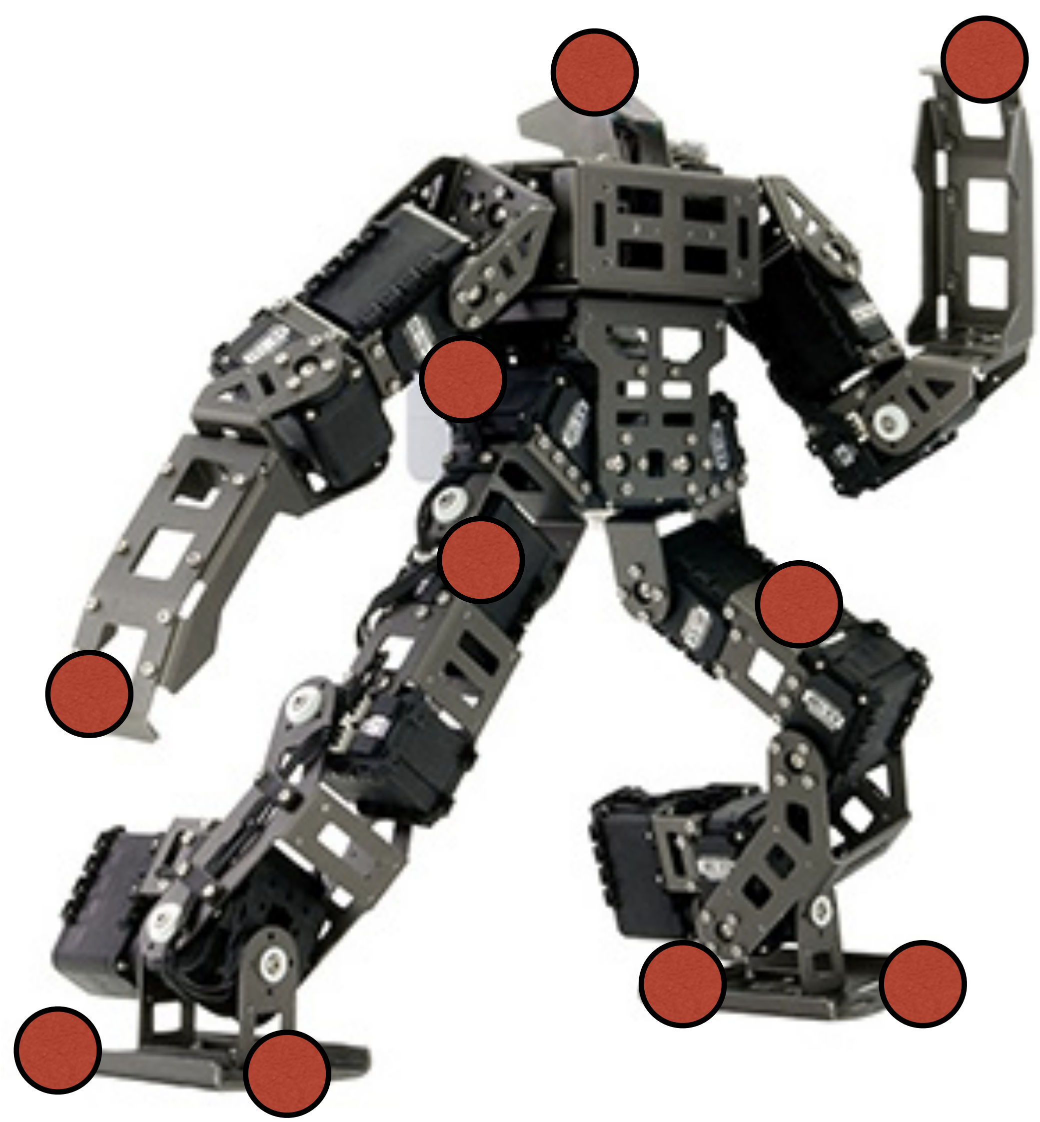
Abstract model



Multiple contact candidates



Multiple contact candidates

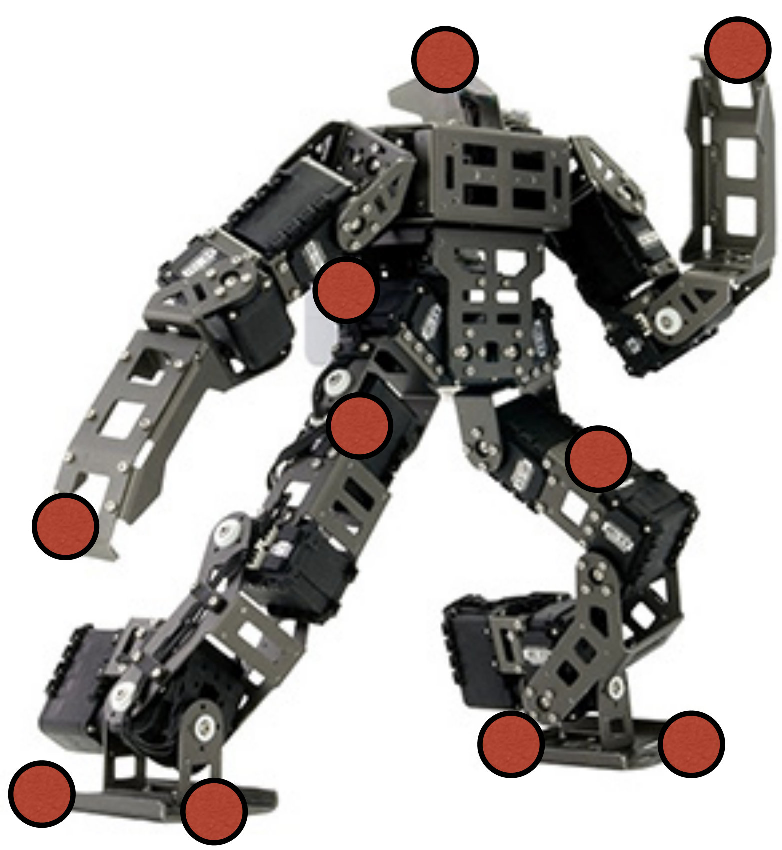


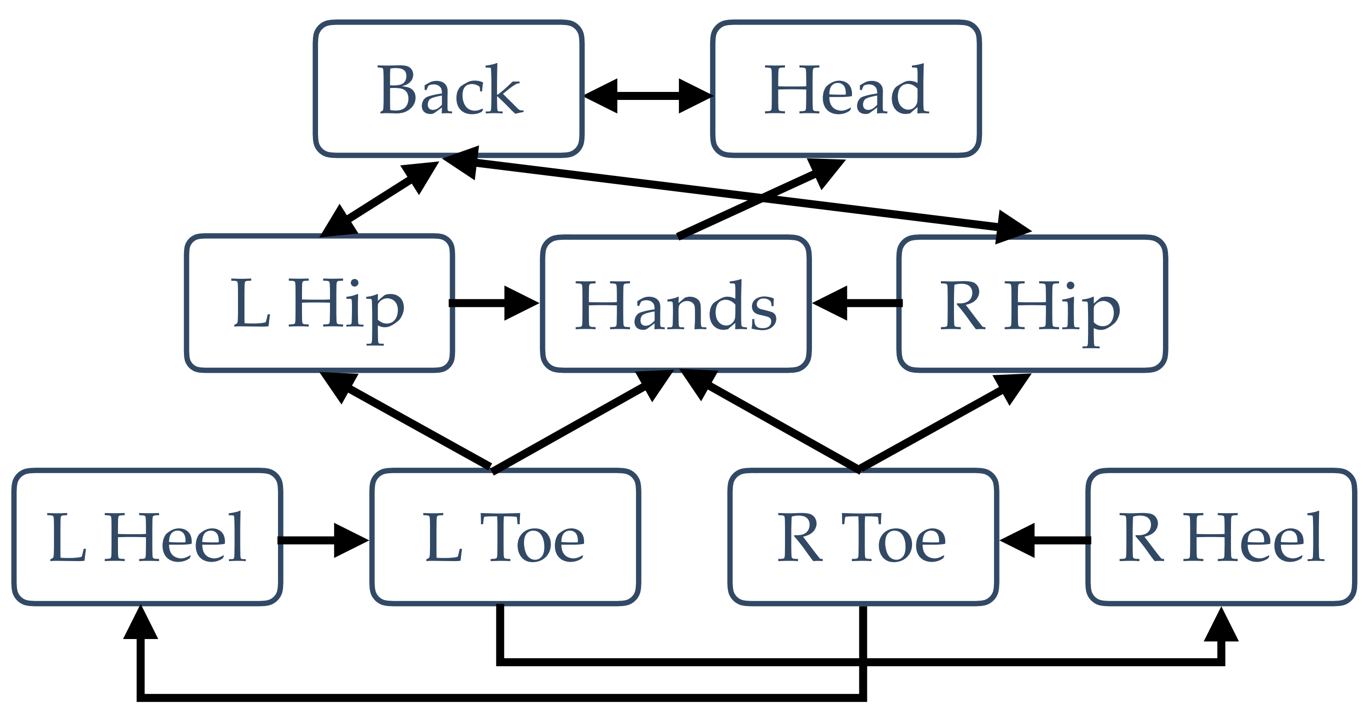
Contact graph

A representation for all possible falling strategies a robot can employ.

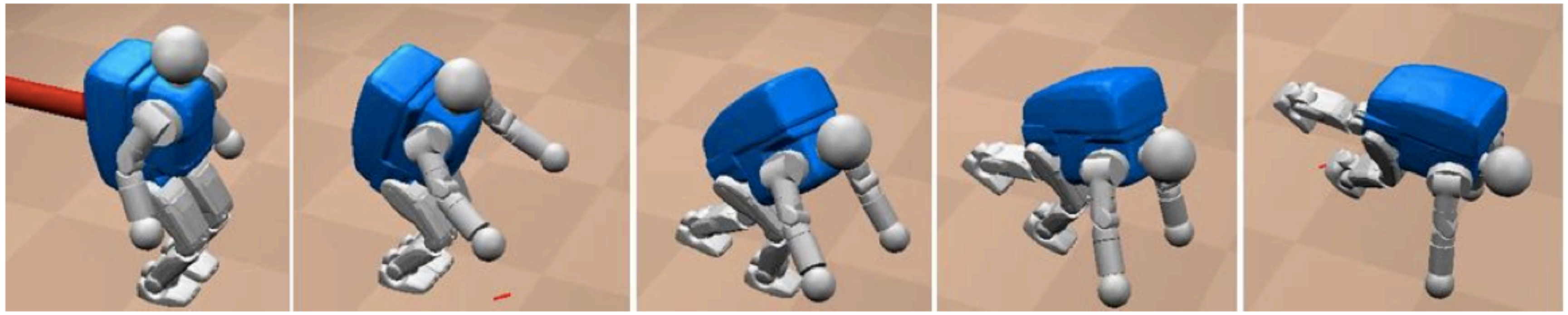
vertex: preferred contact points

edge: preferred contact transitions

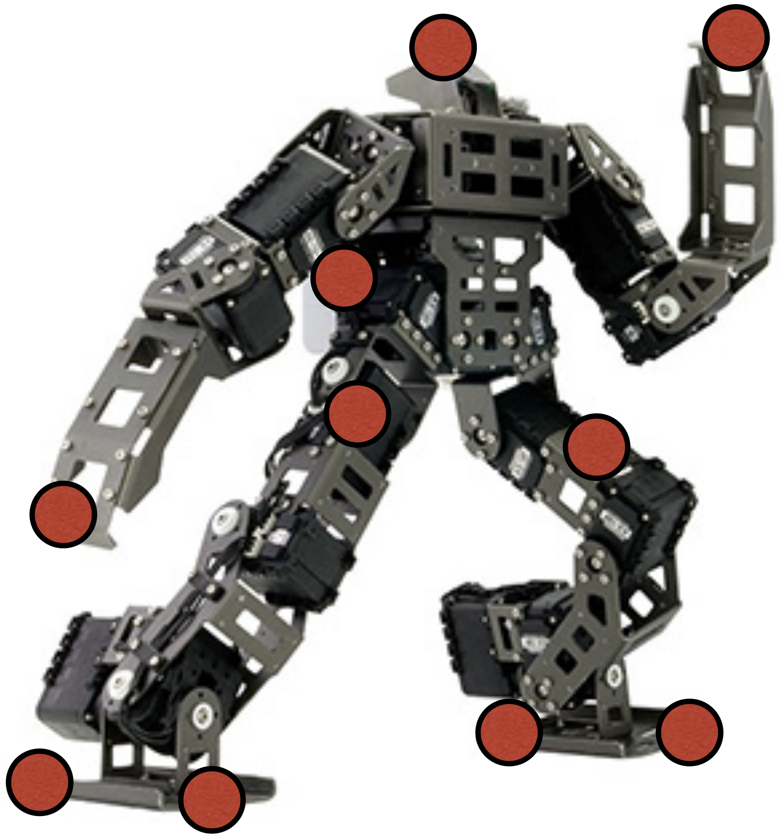


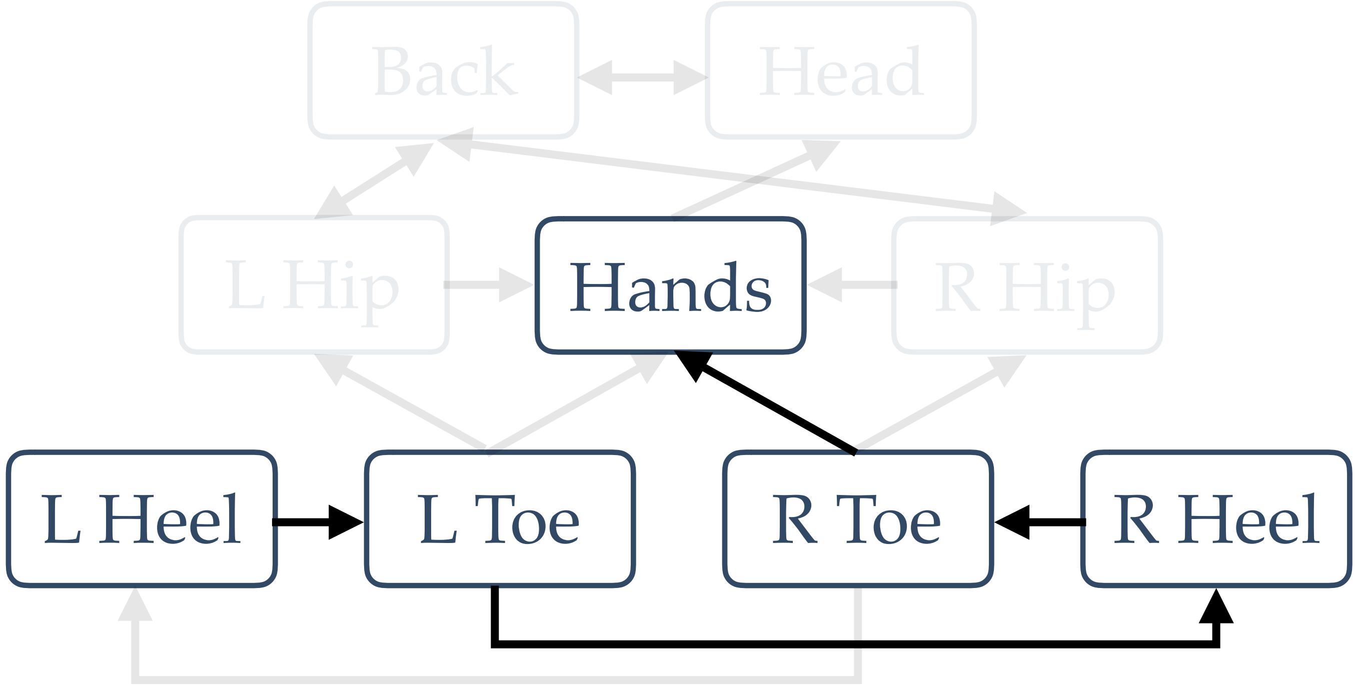


Contact graph

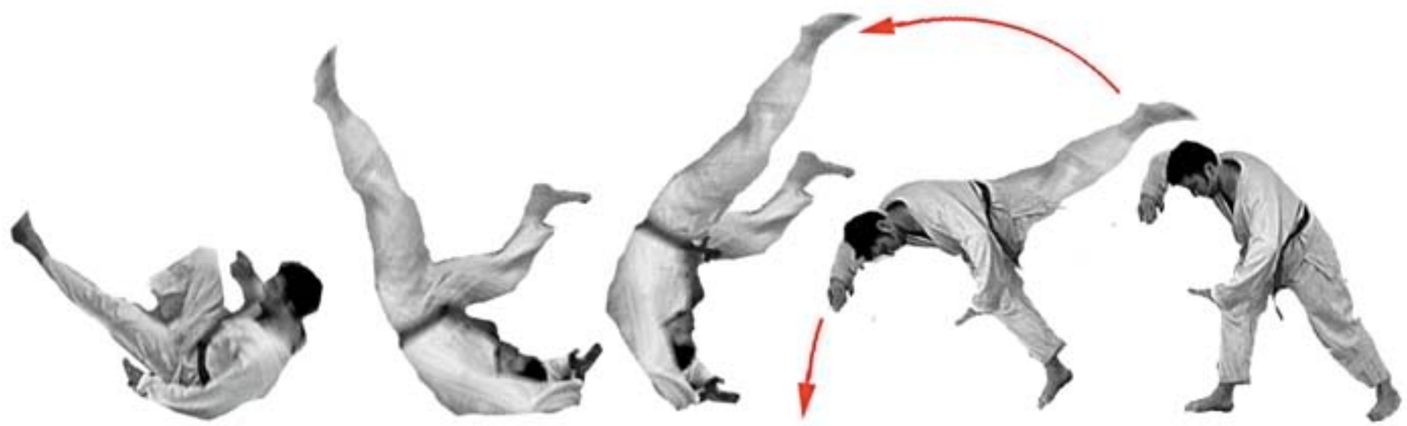


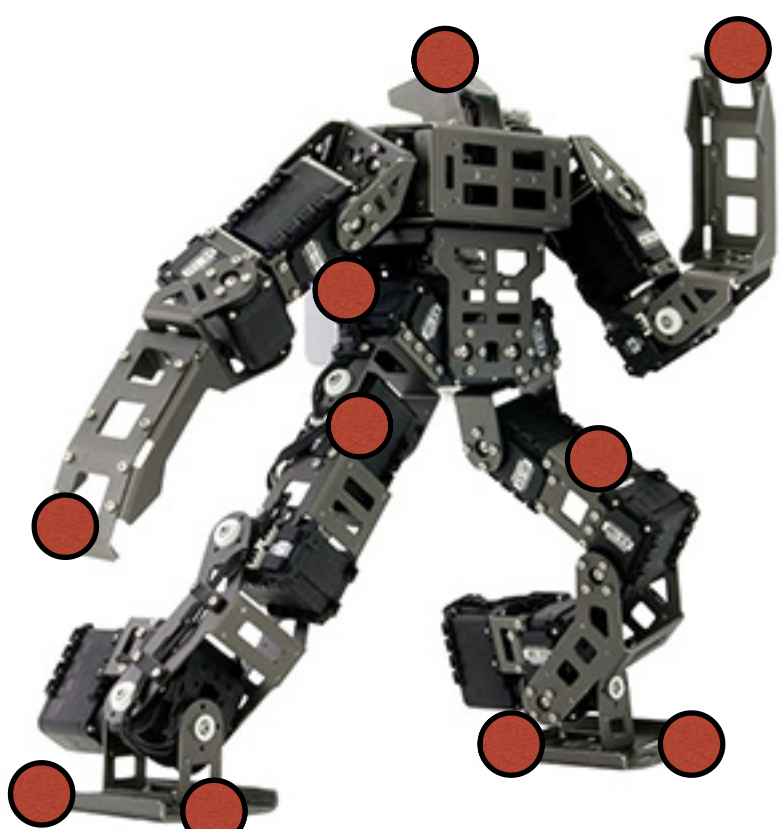
Tripod strategy

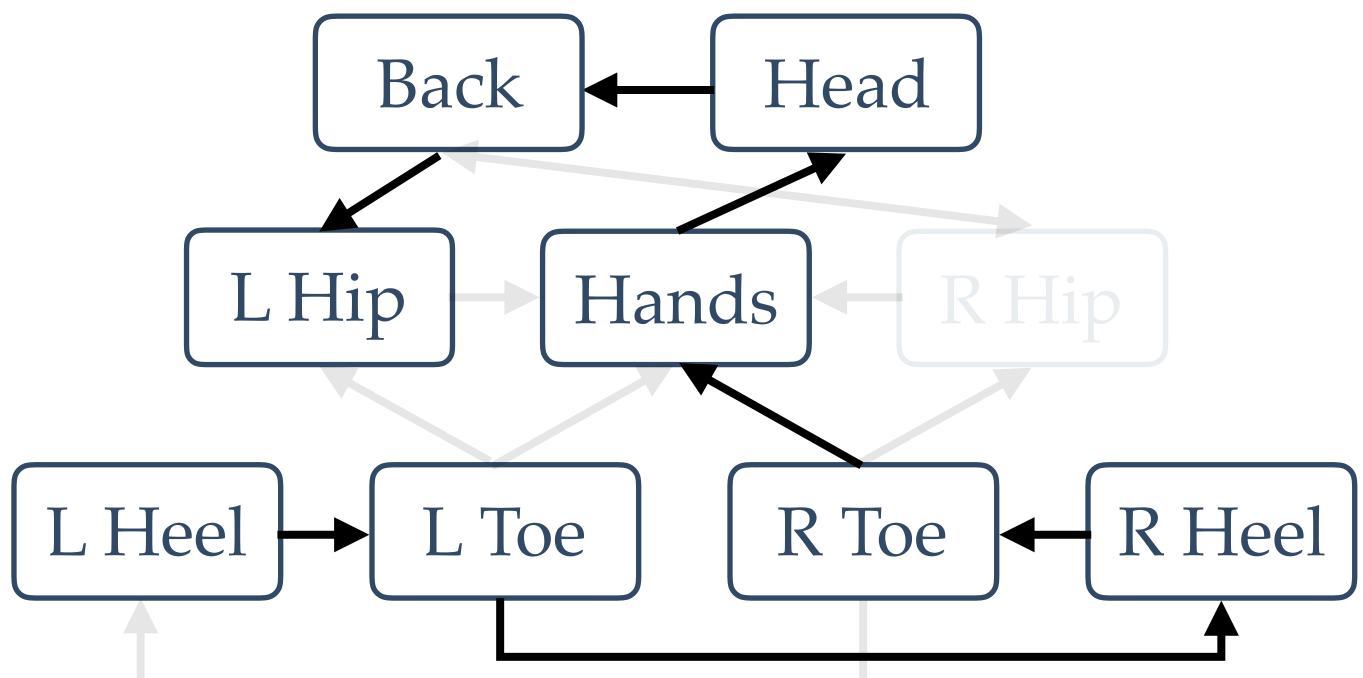




Contact graph



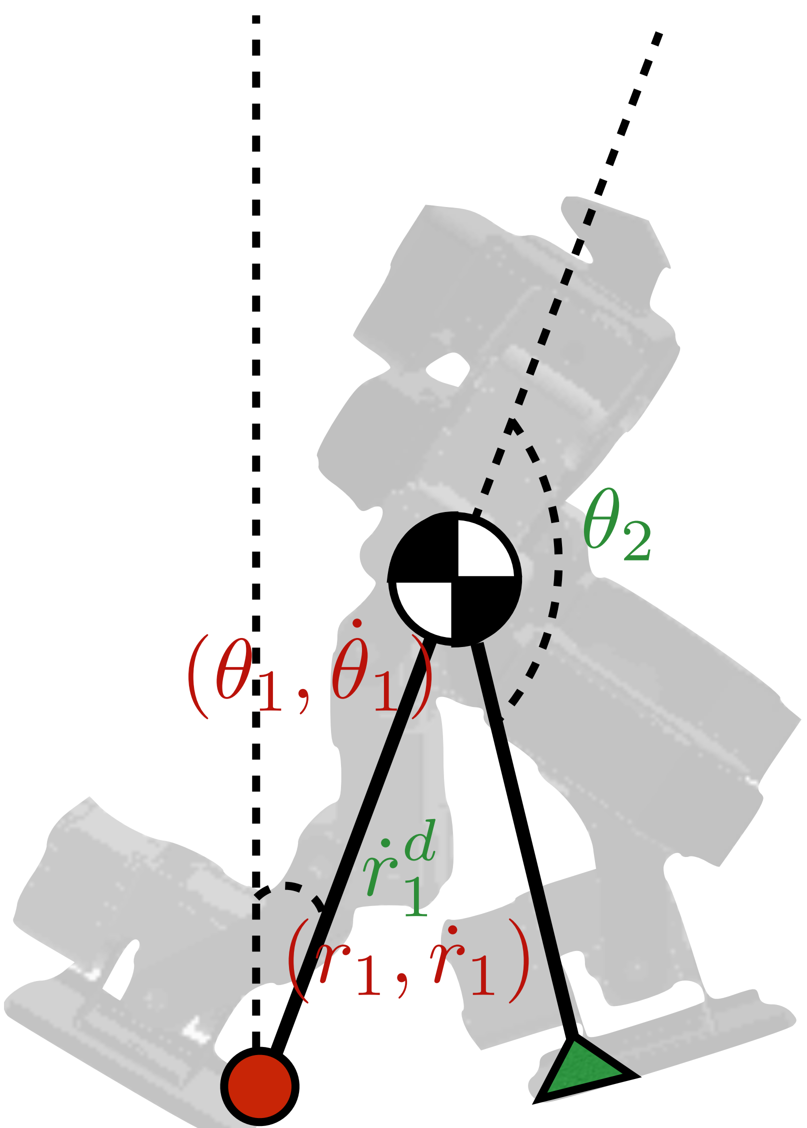




Markov Decision Process

State: $\mathbf{x} = \{c_1, \hat{t}, \theta_1, r_1, \dot{\theta}_1, \dot{r}_1\}$

Action: $\mathbf{a} = \{c_2, \theta_2, \Delta t, \dot{r}_1^d\}$



Cost for action **a** taken at state **x**:

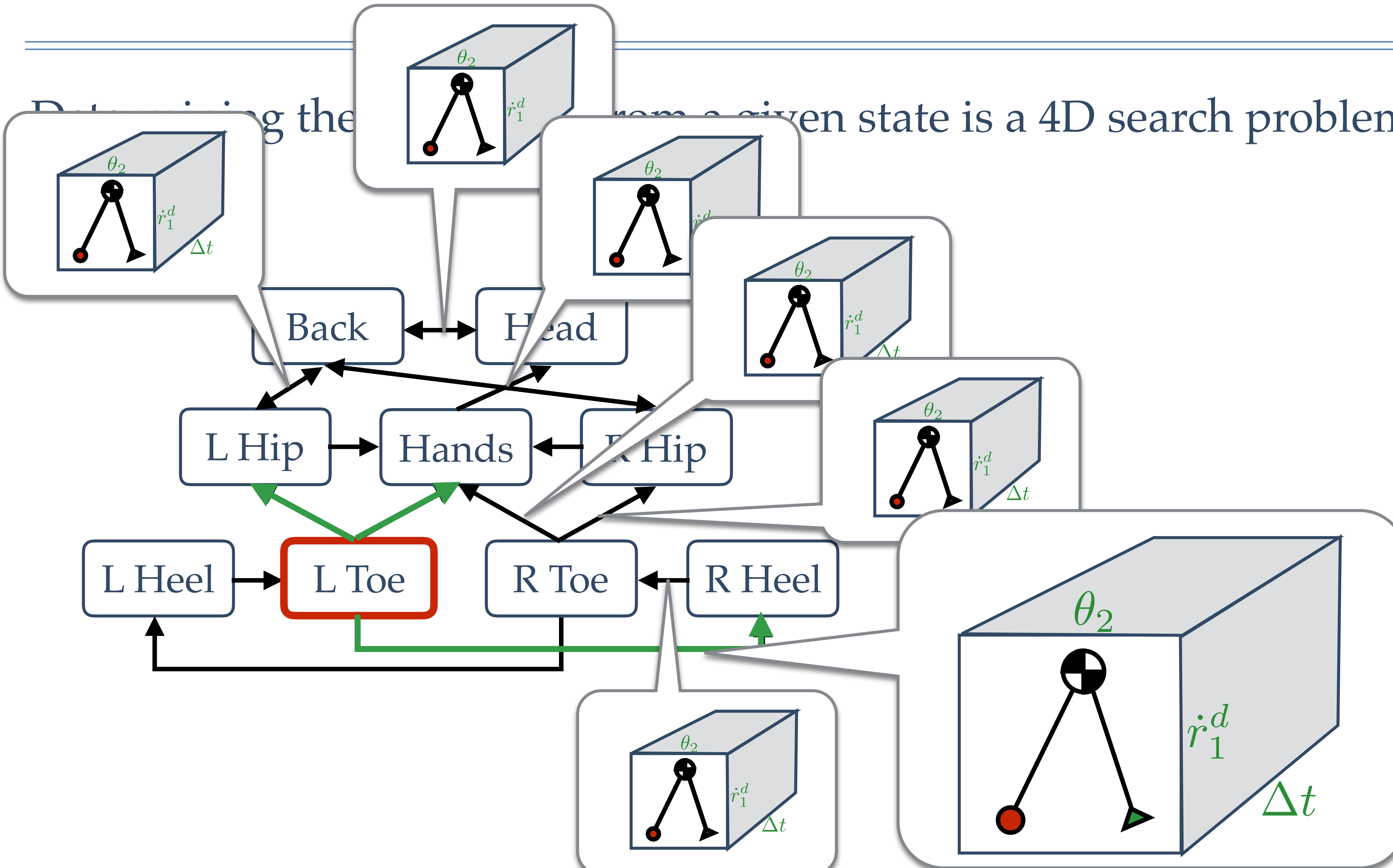
$$\max\left(\underline{g(\mathbf{x}, \mathbf{a})}, v(\underline{f(\mathbf{x}, \mathbf{a})})\right)$$

Optimal value function:

$$\underline{v(\mathbf{x})} = \min_{\mathbf{a}} \max(g(\mathbf{x}, \mathbf{a}), \underline{v(f(\mathbf{x}, \mathbf{a}))})$$

Dynamic programming

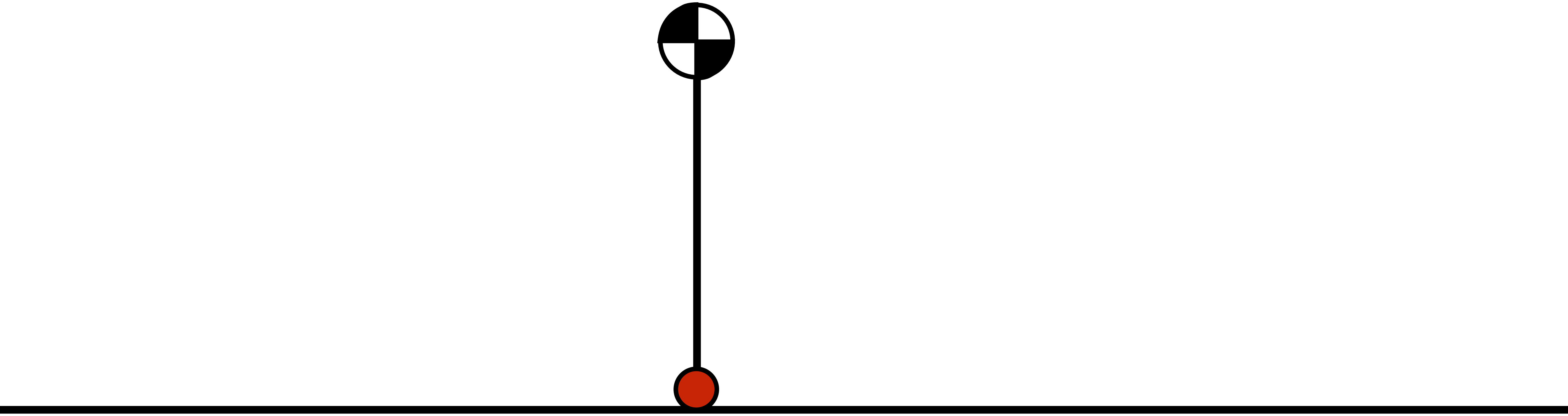
Determining the [illegible] from a given state is a 4D search problem



Dynamic programming

Determining the best action from a given state is a 4D search problem

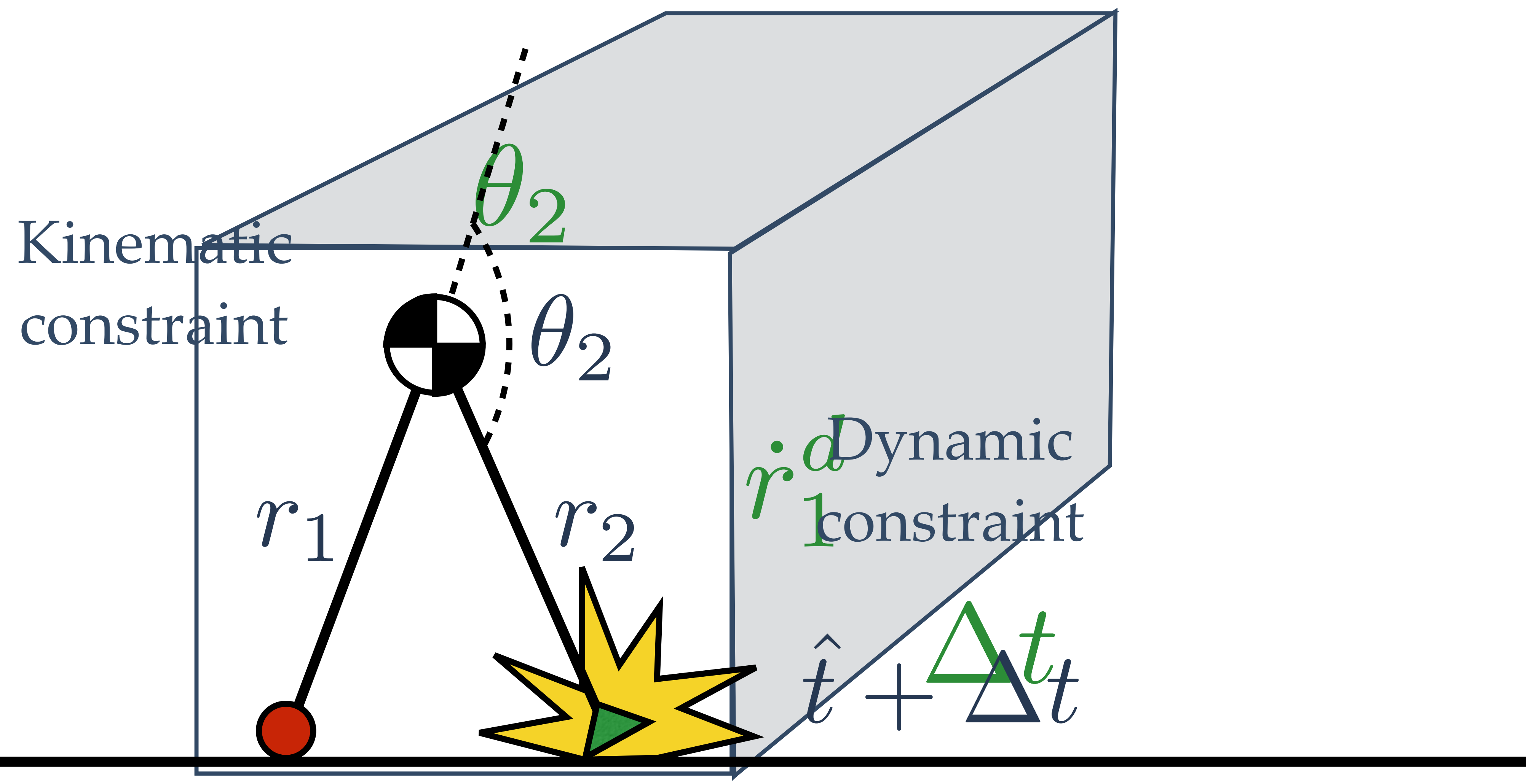
- Use KNN to reduce evaluation of repeated states



Dynamic programming

Determining the best action from a given state is a 4D search problem

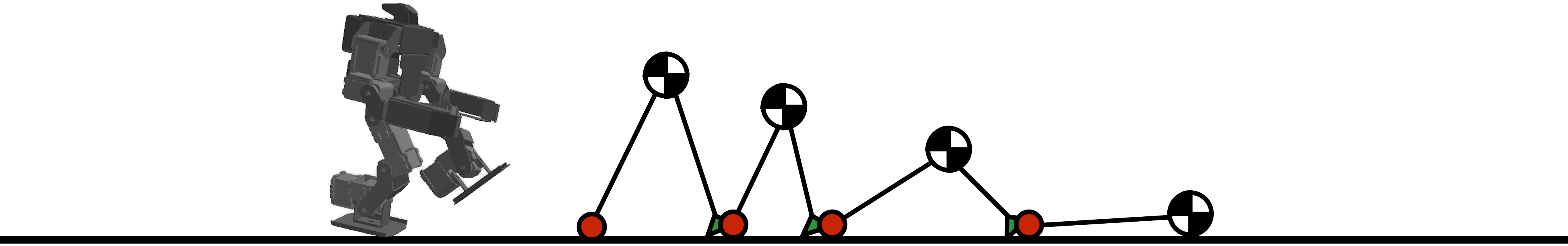
Use KNN to reduce evaluation of repeated states



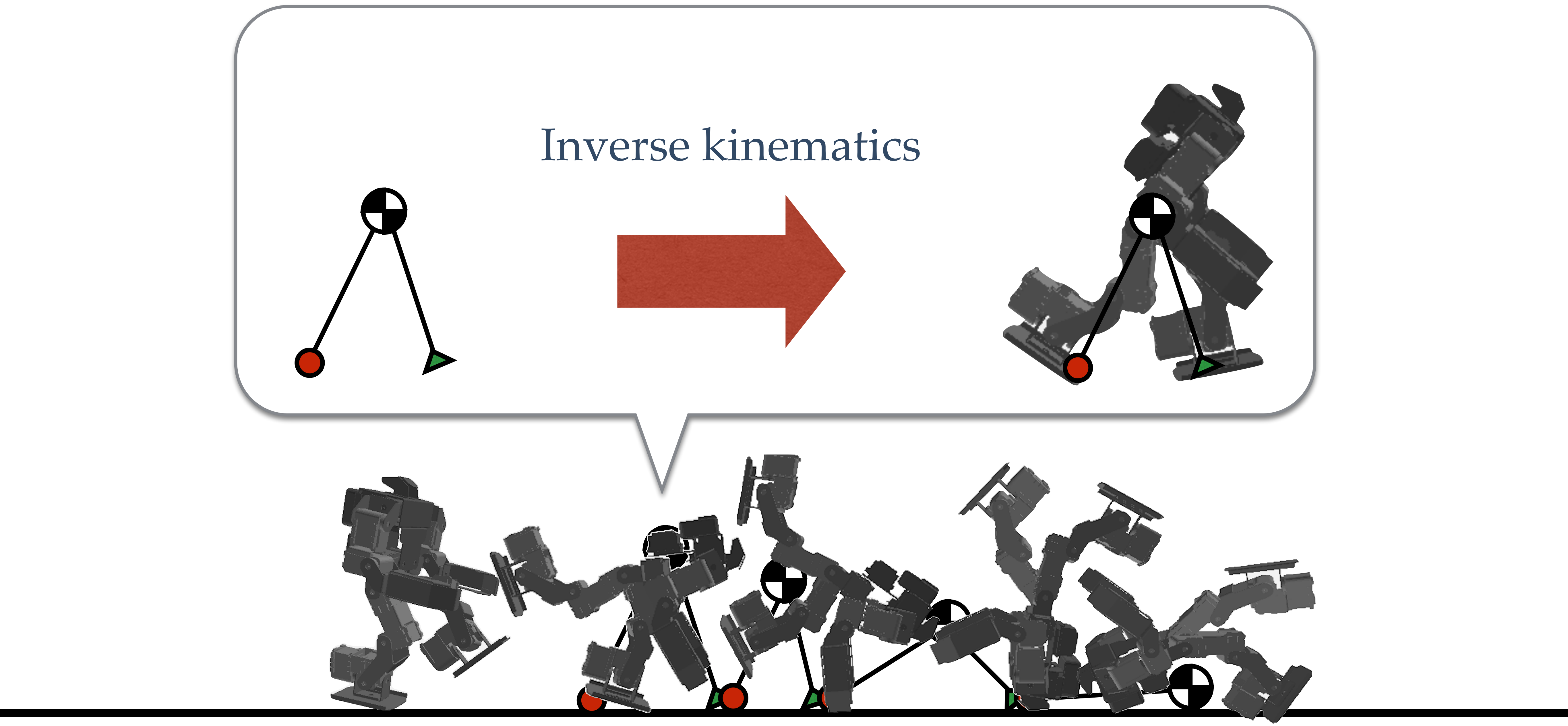
Dynamic programming

Determining the best action from a given state is a 4D search problem

- Use KNN to reduce evaluation of repeated states
- Use kinematic and dynamic constraints to reduce the search space



Whole body motion



Results

Limitations

Real-time planning:

- Take a few seconds to compute.
- Can precompute a set of contact plans for a range of initial conditions.

Non-planar falls:

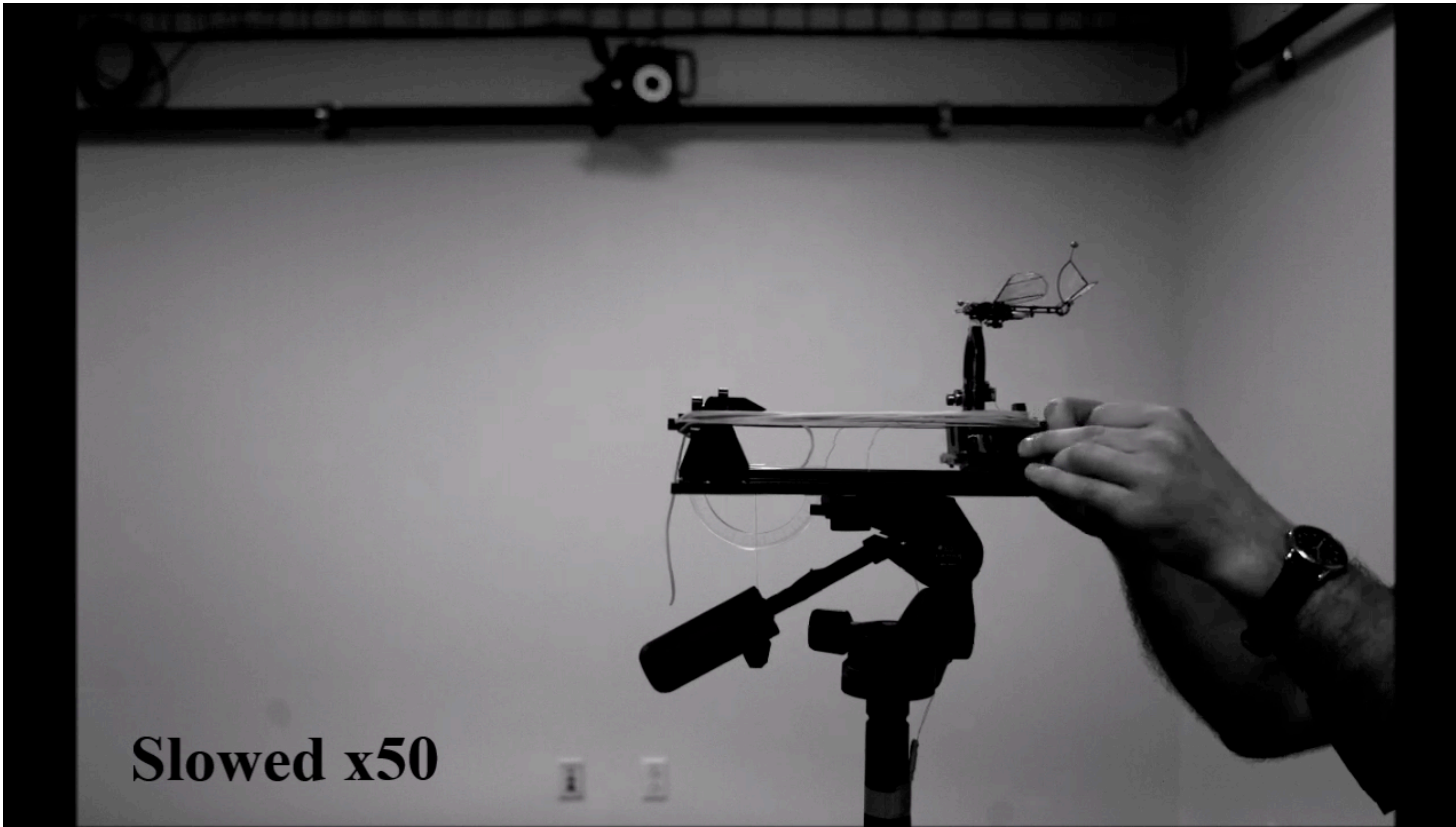
- Do not apply to falls with non-planar initial momentum.
- Can use more complex models to include non-planar motion.

Future work

UIUC bat bot


System overview:
Attitude control @ 100 Hz (roll & pitch)
Manual throttle command
IMU sampled @ 300 Hz
Body encoders sampled @ 100 Hz
Coordinated Science Lab, UIUC

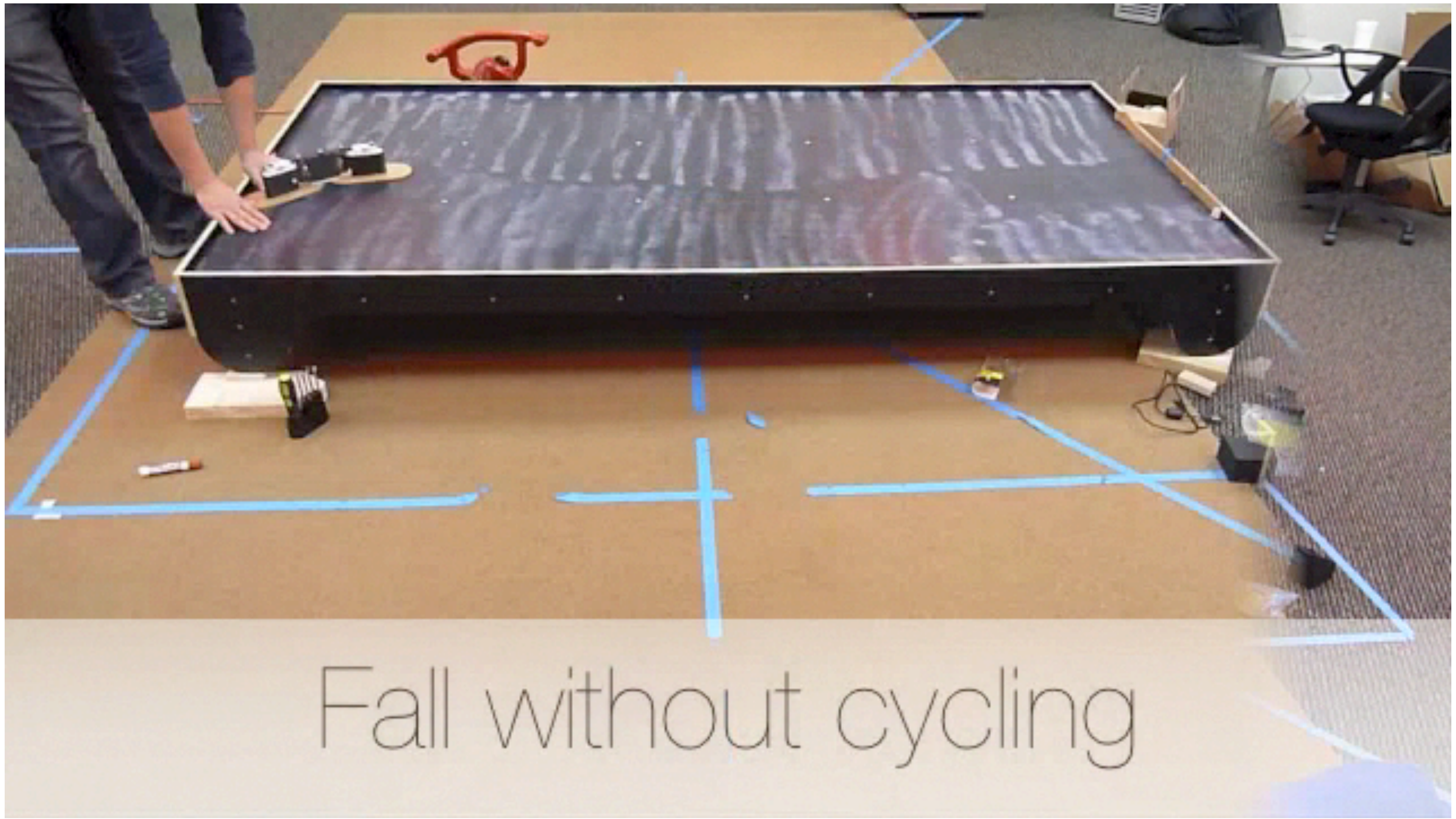
Harvard meso-scale flier



Self-righting

Rolling

Near-zero angular momentum



Bingham et al. IROS 2014

NSF

NATIONAL INSTITUTES OF HEALTH

DARPA

ALFRED P. SLOAN FOUNDATION 1934

Adobe

Georgia Tech Robotics & Intelligent Machines

GVU GEORGIA TECH

Open Source Robotics Foundation