Simplifying Control Through Active Tail Use

Motivation

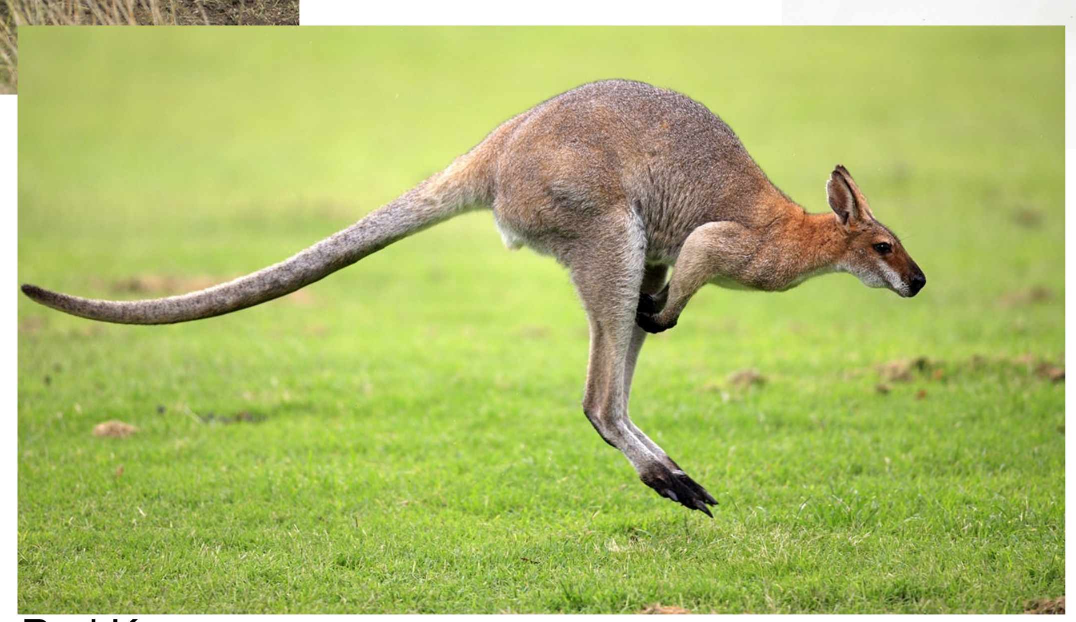
- Aquatic vertebrates use tails for propulsion, but...
- Most terrestrial vertebrates have repurposed their tails for roles other than locomotion.
  Why?
- There are some notable exceptions!
  Why do tails work for these animals?

Cheetah
courtesy
CheetahsAlive.org

Turning?

Agama Lizard & co.
courtesy ciber.berkeley.edu

Body-pitch righting



Red Kangaroo
courtesy http://www.hdNewWallpapers.com/

Steady-State Locomotion?

Our Approach:
Rebuild the solution!

Through modeling, simulation and robots, we focus on the use of tails during steady-state locomotion in the sagittal plane.

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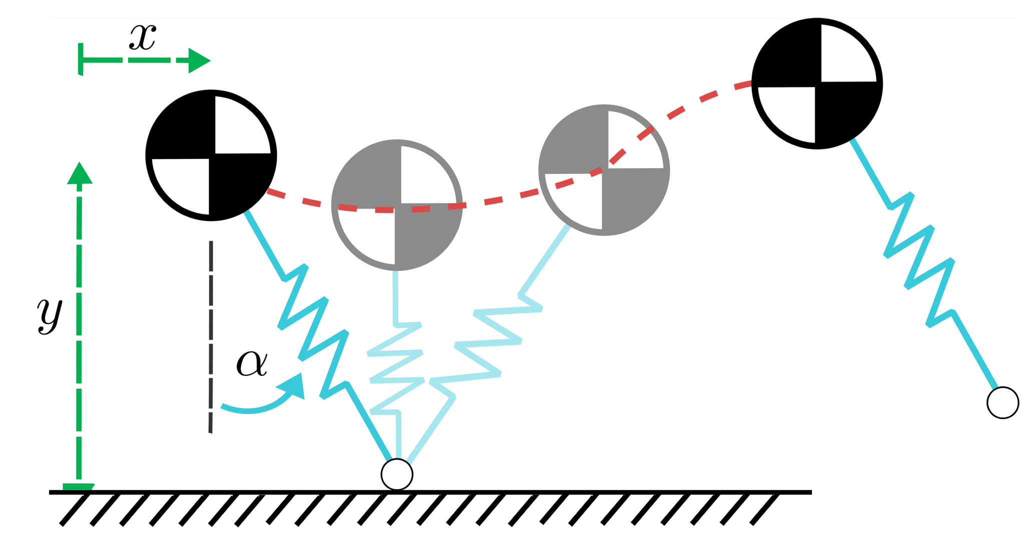
Mathematical Model: SLIP & Flywheel

Our models are based on the spring-loaded inverted pendulum (SLIP) Model.
We fully model body and leg dynamics, and add a joint for the tail.
Our simplest model uses a flywheel centered at the body center of mass.

These simple models reveal an important advantage: minimizing tail-mass greatly simplifies control and *decouples body-pitch stabilization from energy-input*.



SLIP-Model

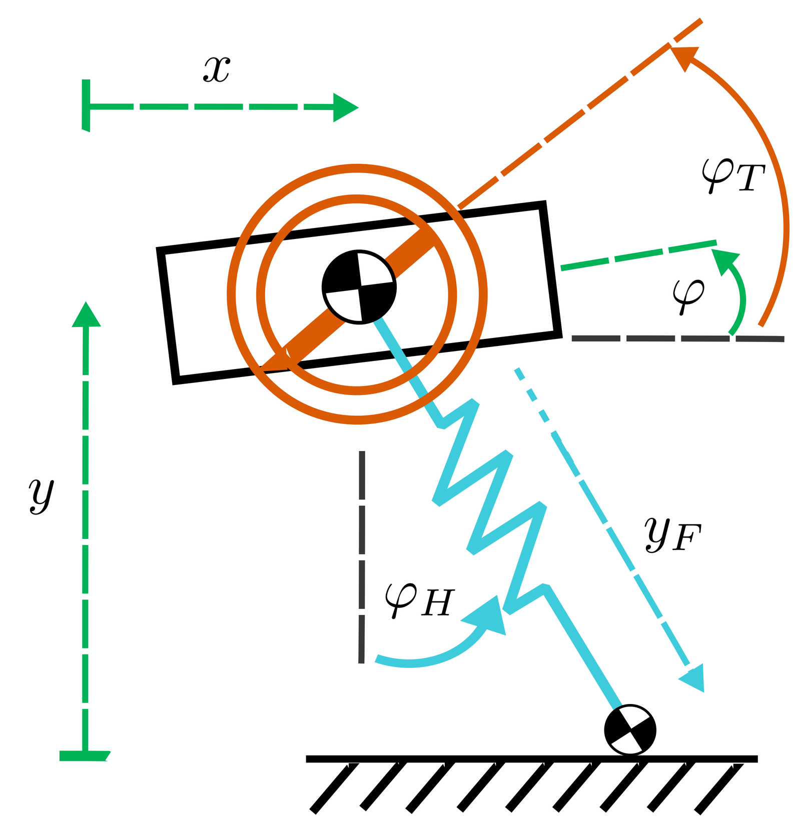
Coupled Control in a Nutshell

Imagine you have a faucet and you want to control the water *temperature* as well as *flow*.

Decoupled Control:
Lifting the lever affects only flow, and turning the lever affects only temperature.

Coupled Control:
Turning either knob affects both the flow as well as temperature.

courtesy heatAndPlumb.com

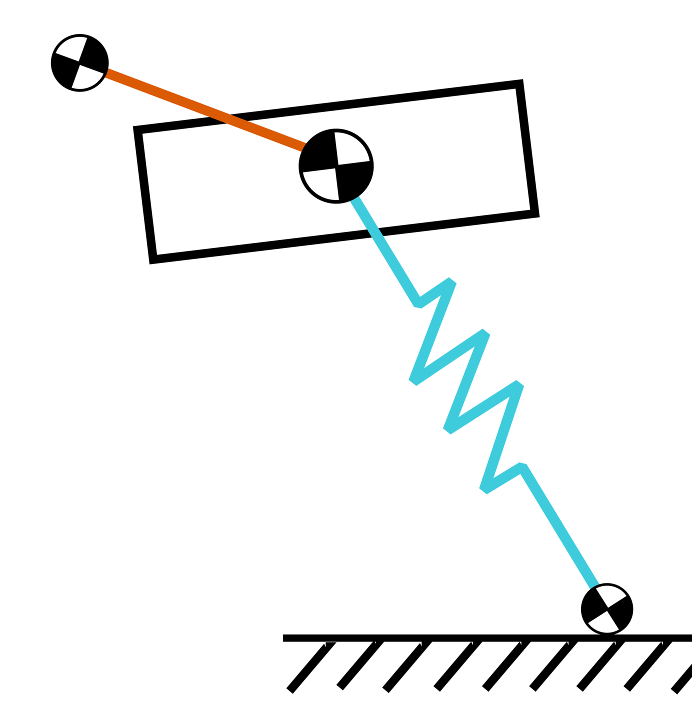


Template Model with Flywheel

Decoupled Control for the Template Model with Flywheel

$$\begin{pmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{\varphi} \\ \ddot{y}_F \\ \ddot{\varphi}_H \\ \ddot{\varphi}_T \end{pmatrix} = H_{(q,\dot{q})} + \begin{pmatrix} \frac{\sin(\varphi_H)}{m_s} & \frac{y_F \cos(\varphi_H)}{J_F + m_S y_F^2} & 0 \\ -\frac{\cos(\varphi_H)}{m_s} & \frac{y_F \sin(\varphi_H)}{J_F + m_S y_F^2} & 0 \\ 0 & -\frac{1}{J_S} & -\frac{1}{J_S} \\ \frac{1}{m_S} & 0 & 0 \\ 0 & \frac{1}{J_F + m_S y_F^2} & 0 \\ 0 & 0 & \frac{1}{J_T} \end{pmatrix} \begin{pmatrix} \tau_F \\ \tau_H \\ \tau_T \end{pmatrix}$$

Accelerations — Natural Dynamics — Control Matrix for the Flywheel model: Sparse! — Control Inputs



Extended Model with Tail