Some Bipedal Control

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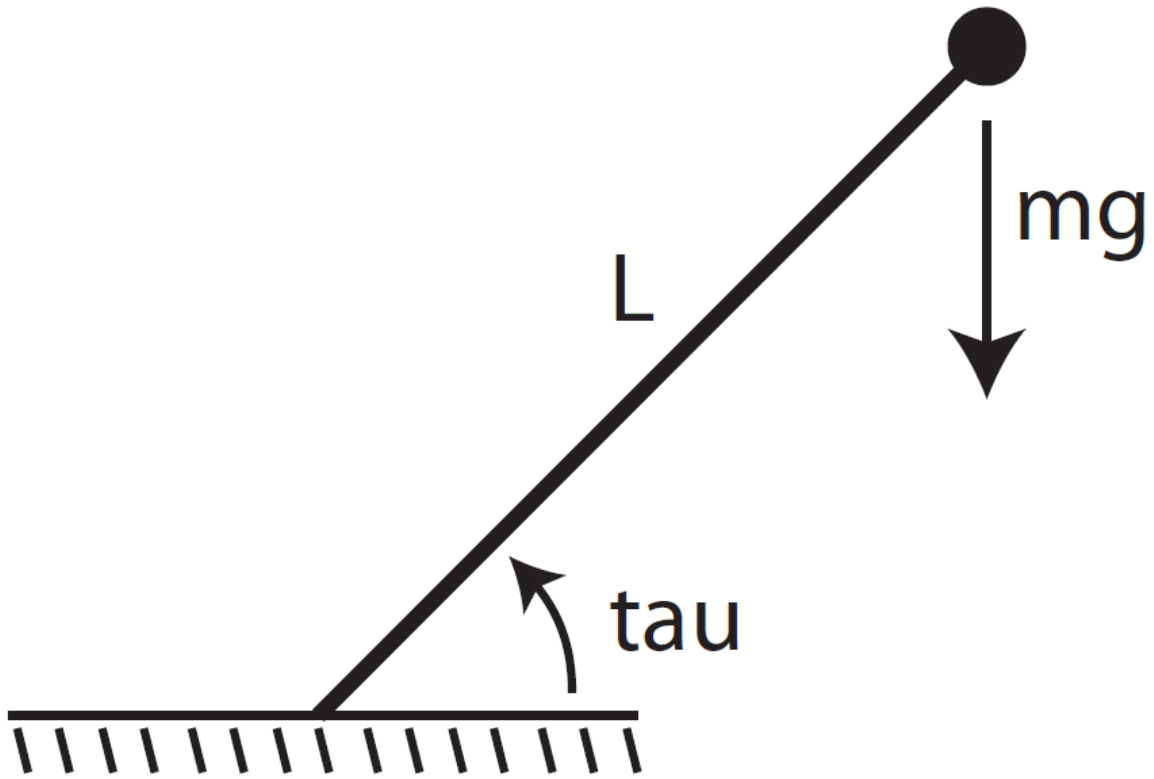
Introduction to Robotics 2016
March 7

Controlling nonlinear systems

- Use tools you already know to solve interesting nonlinear problems
- For example, bipedal systems are:
  - Nonlinear (as are all real systems)
  - Underactuated
  - Hybrid Dynamic

Problems with Pendulums:



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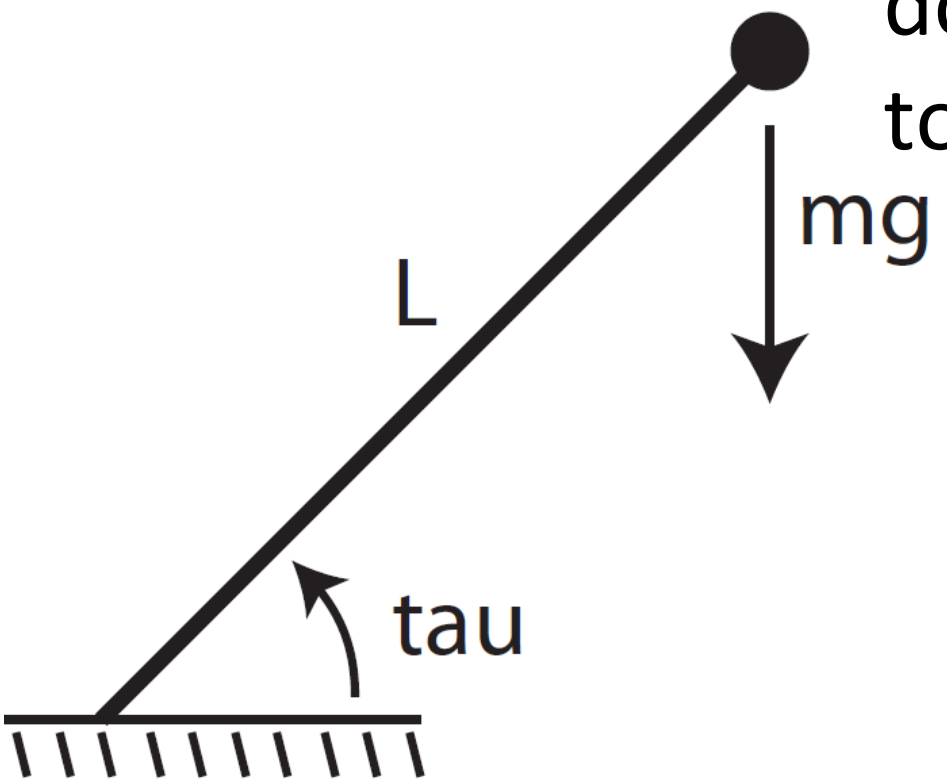

How much torque do we need to get to top?

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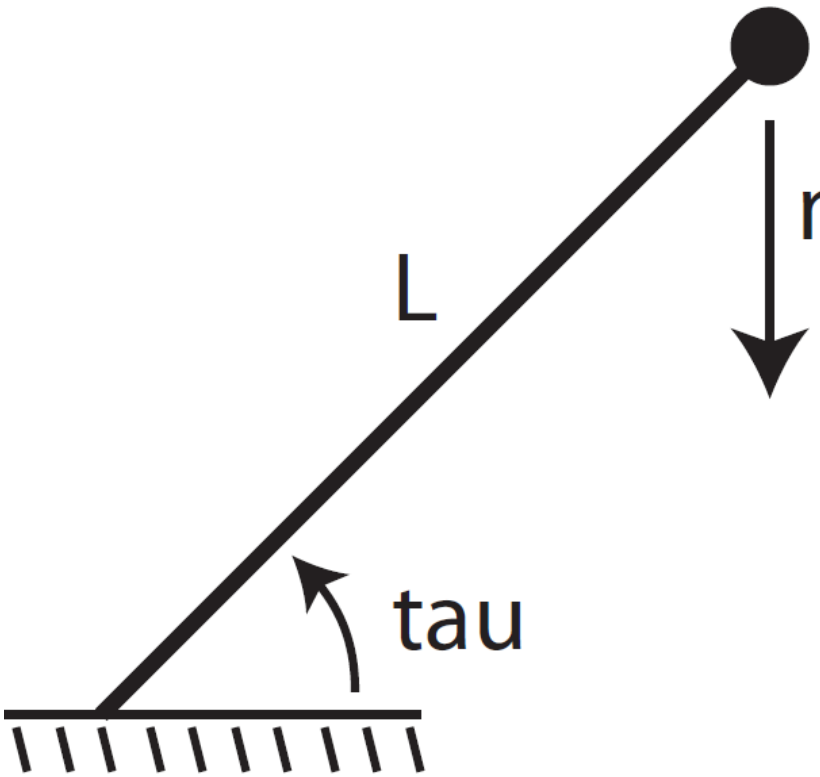

How much torque do we need to get to top?

Can we get to the top with less torque?

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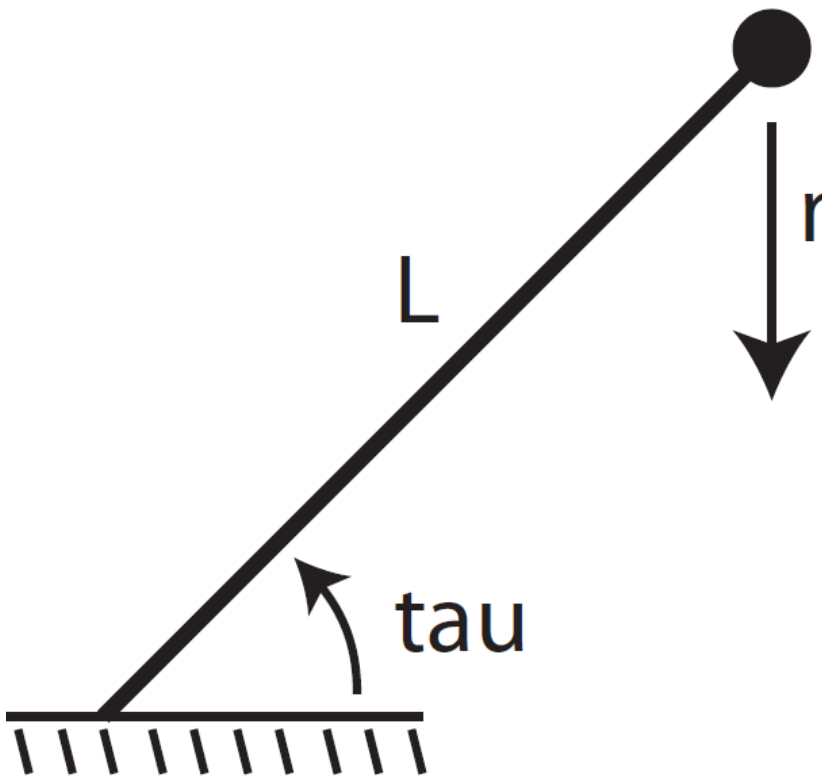

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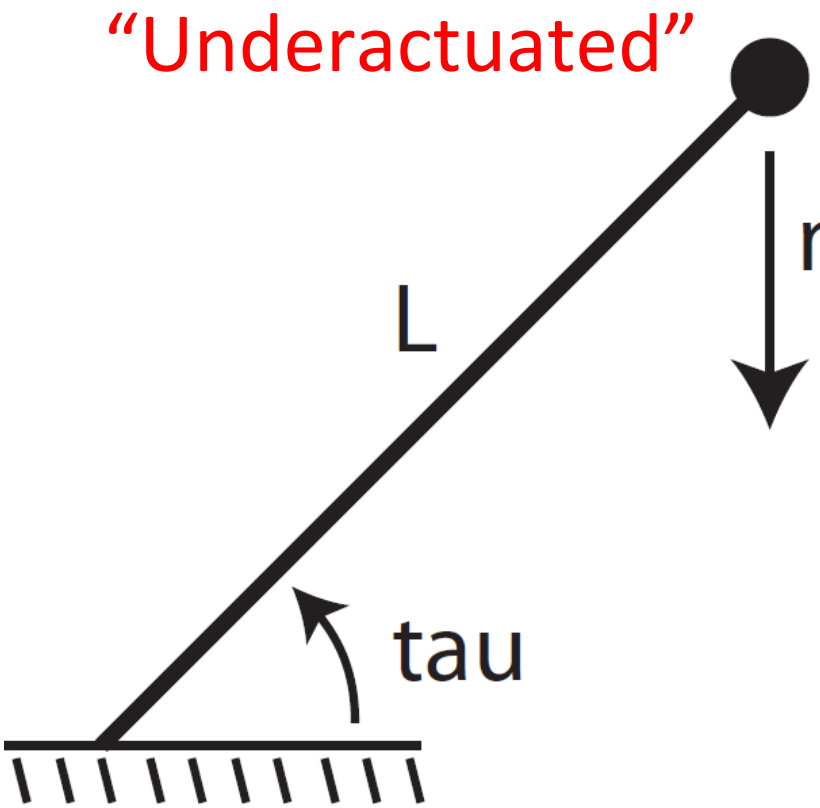
Sometimes we need to think about trajectories

Problems with Pendulums:



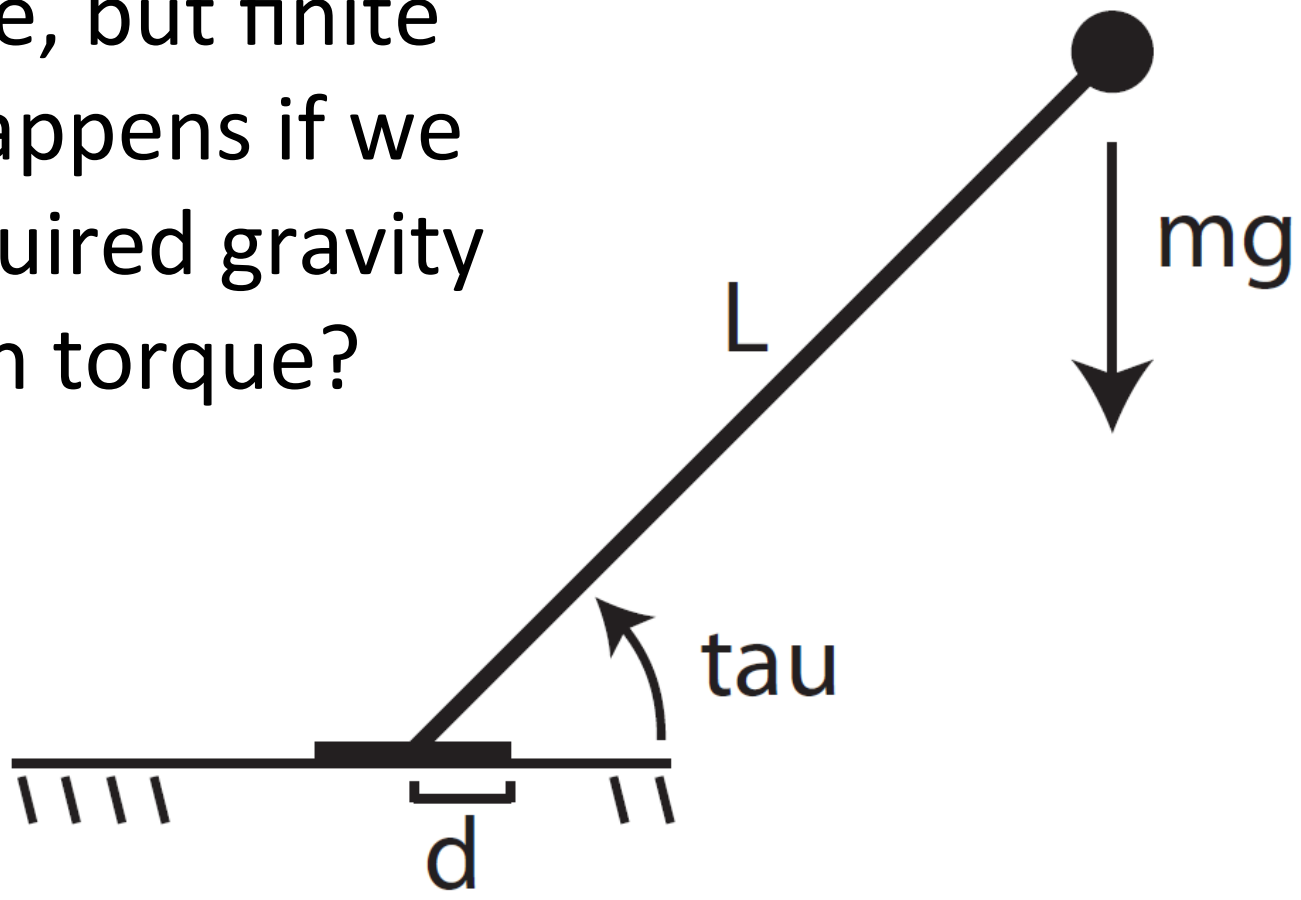
How much torque do we need to get to top?

Can we get to the top with less torque?

Sometimes we need to think about trajectories

Problems with Pendulums:

Now, assume we have infinite torque, but finite foot. What happens if we apply the required gravity compensation torque?

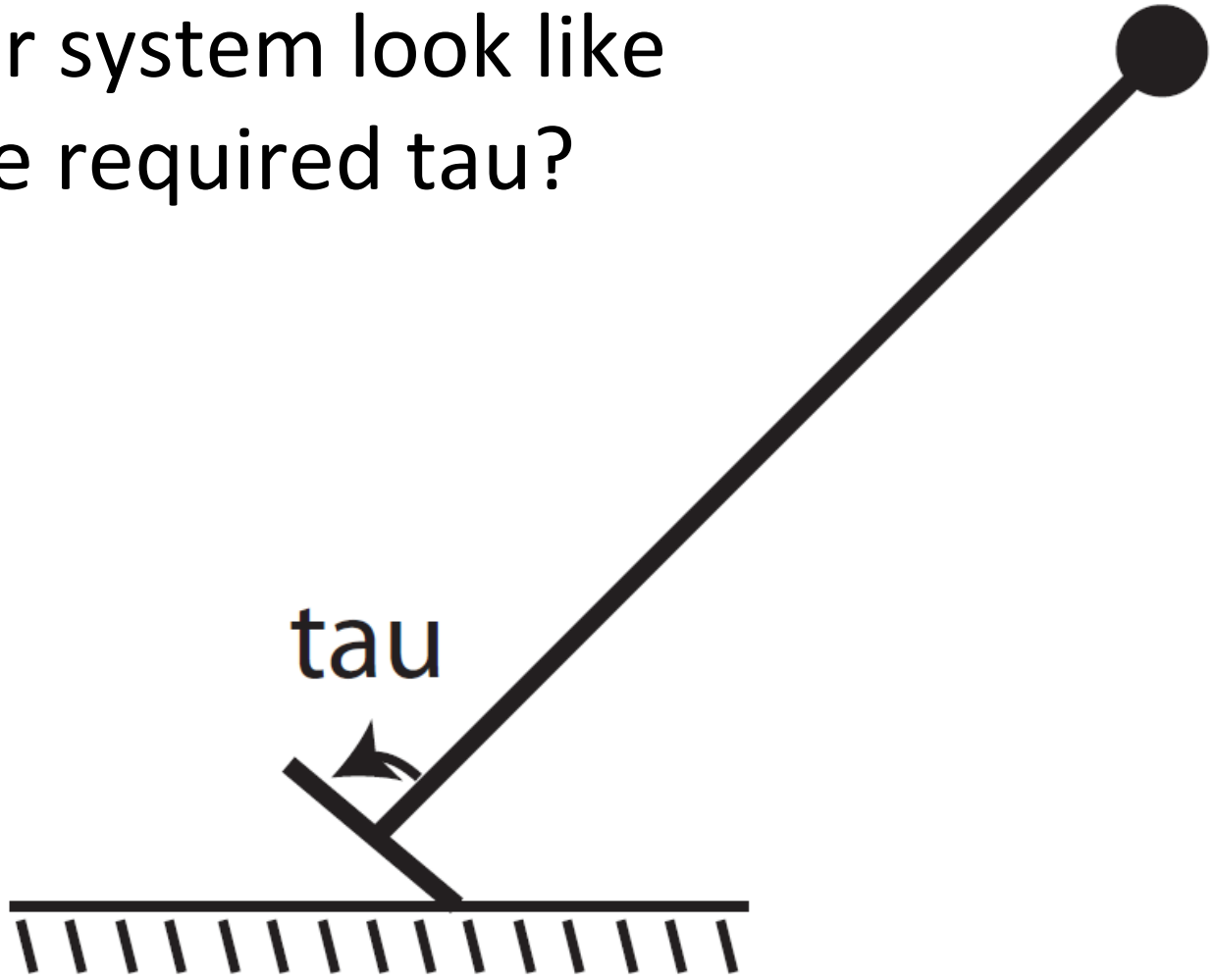


Problems with Pendulums:

What does our system look like
if we apply the required gravity
compensation torque?

Problems with Pendulums:

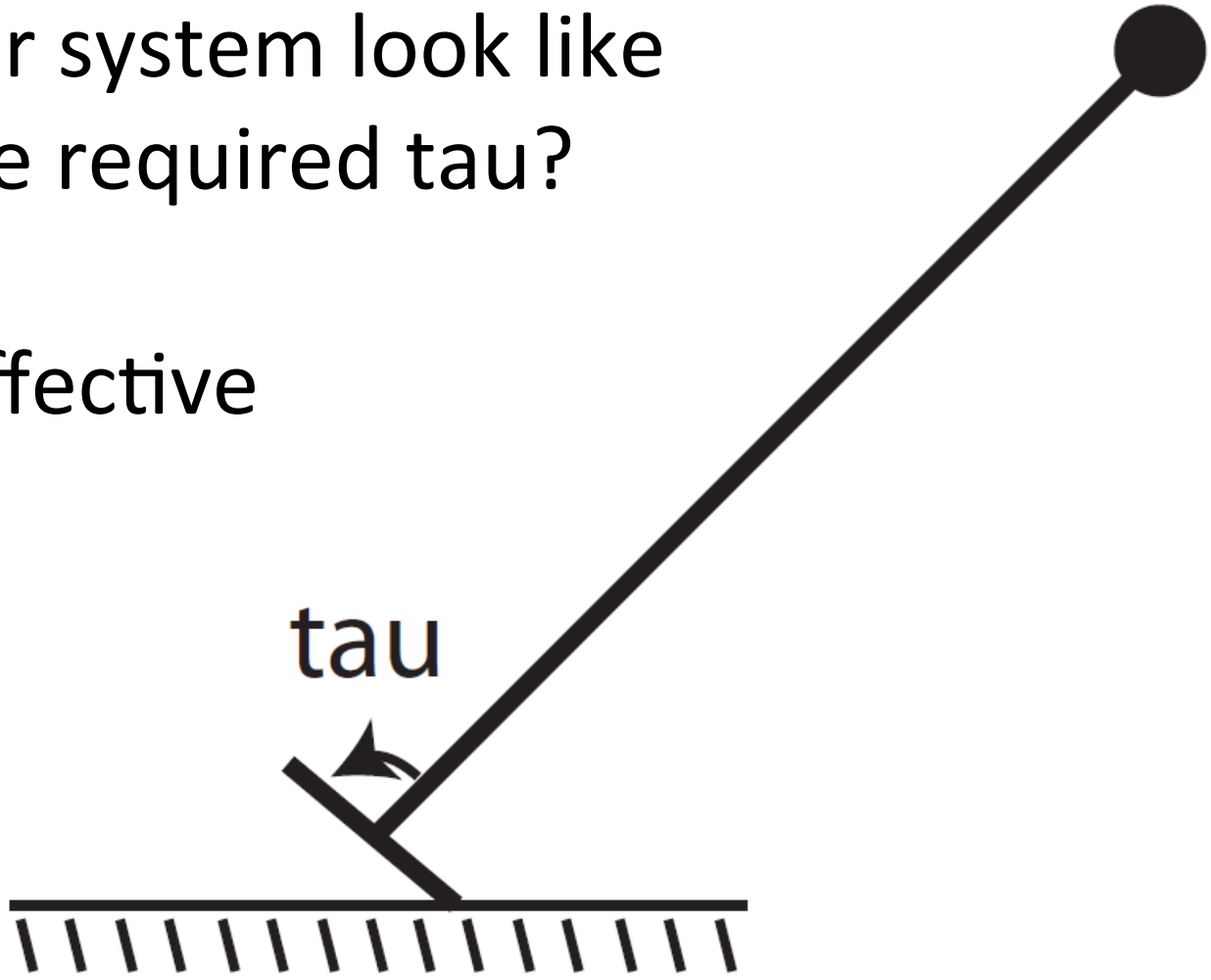
What does our system look like
if we apply the required tau?



Problems with Pendulums:

What does our system look like
if we apply the required tau?

What is the effective
max torque?



Problems with Pendulums:

What does our system look like
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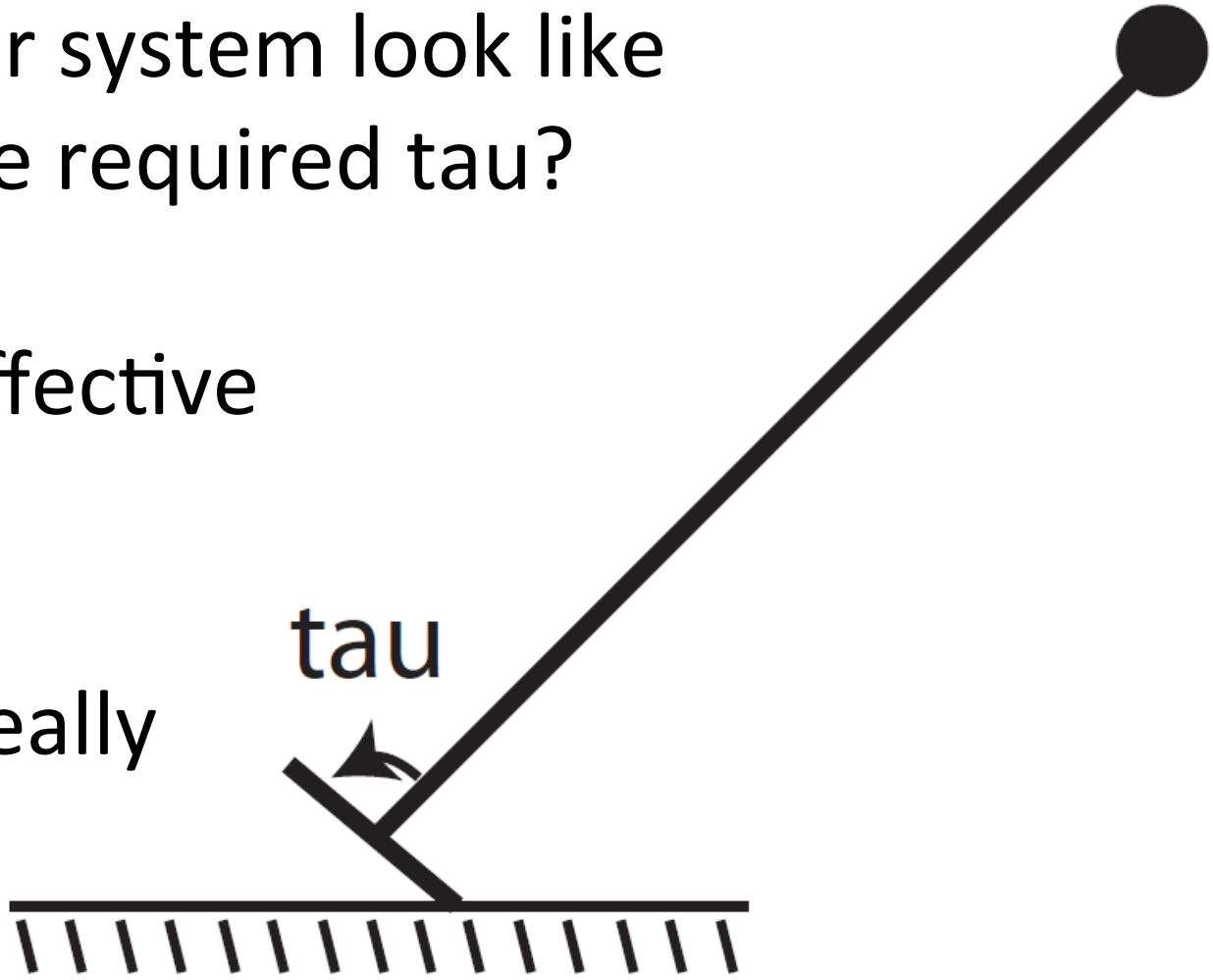
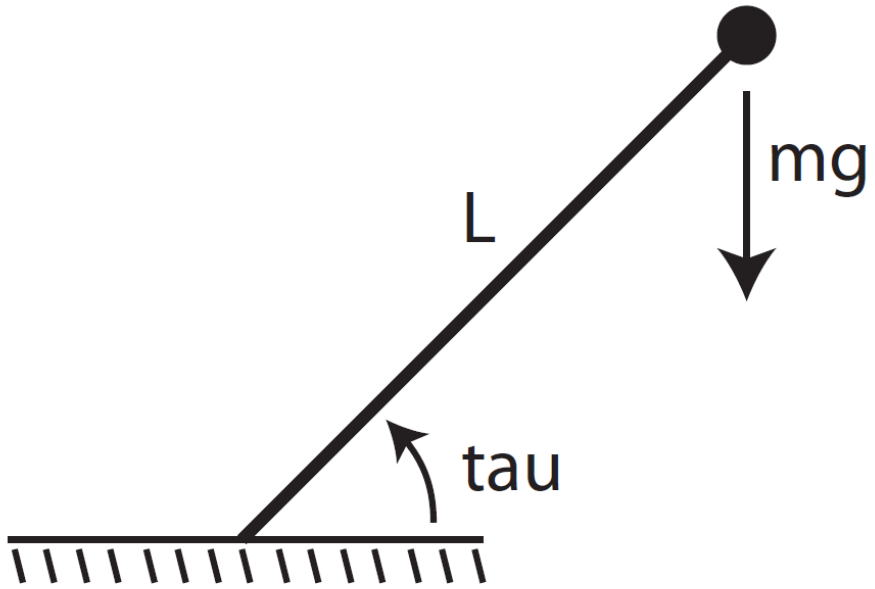
What is the effective
max torque?

What about really
Large tau?



Problems with Pendulums:

Interesting systems might require path planning (or you might be doing exactly the wrong thing)



Problems with Pendulums:

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Envelopes of operation

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Envelopes of operation

Can find ways to apply our nice linear methods in some cases

A walking system that requires no sensing, control, computer, etc.

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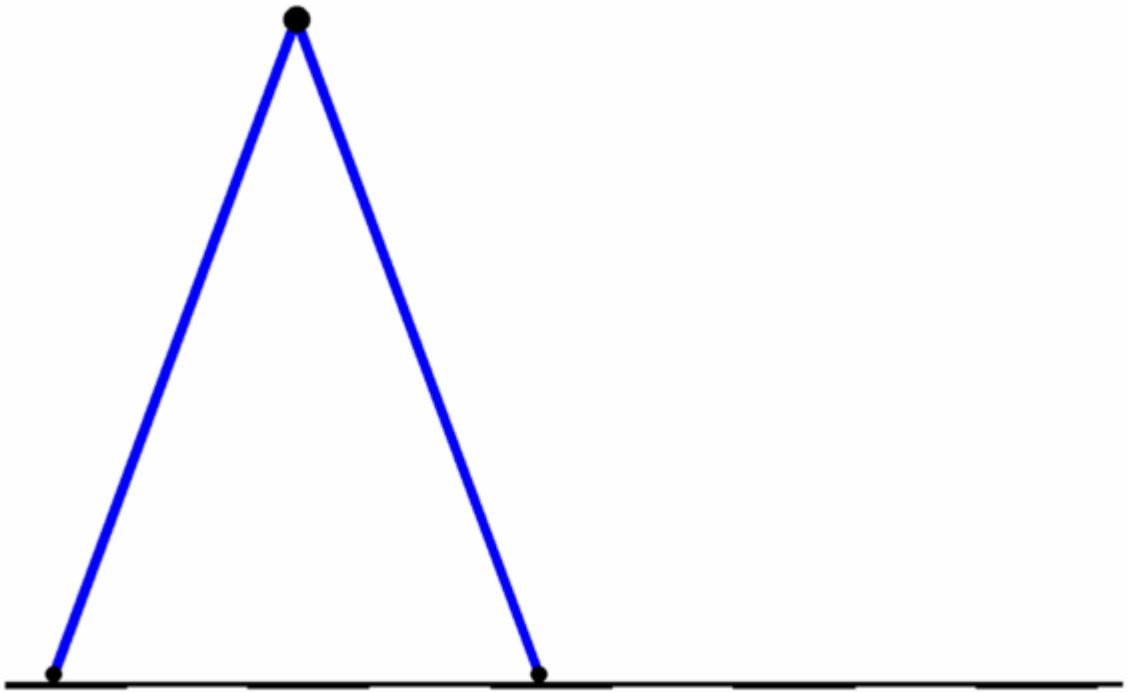

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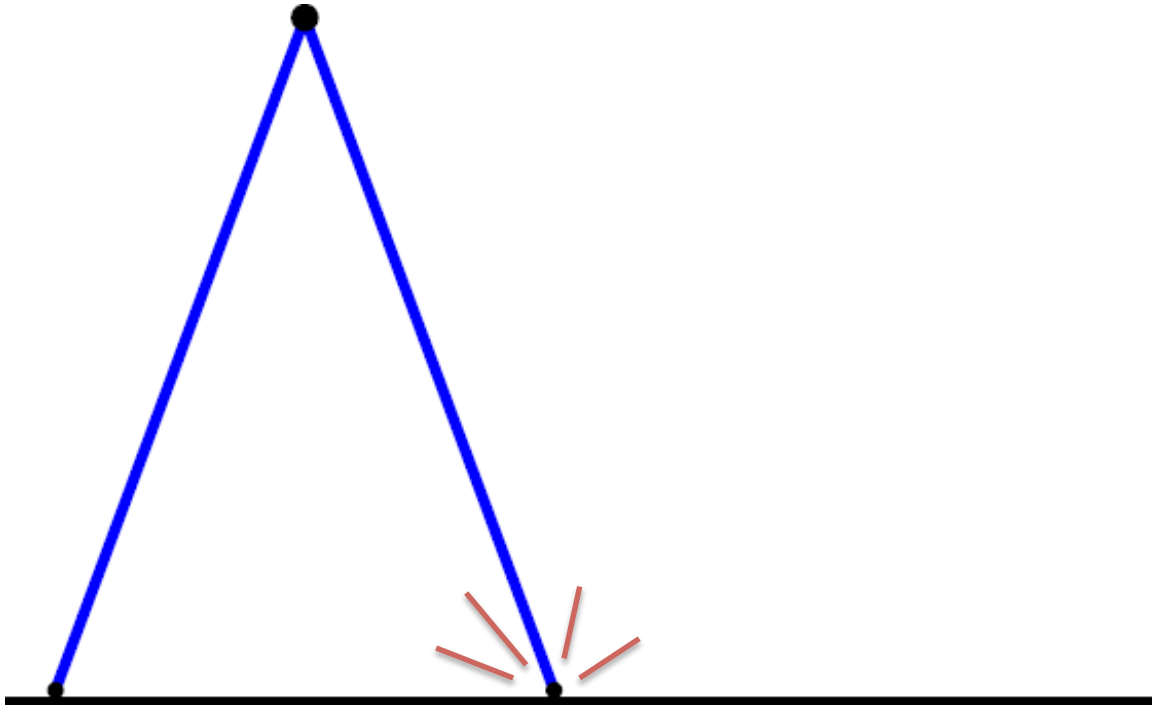

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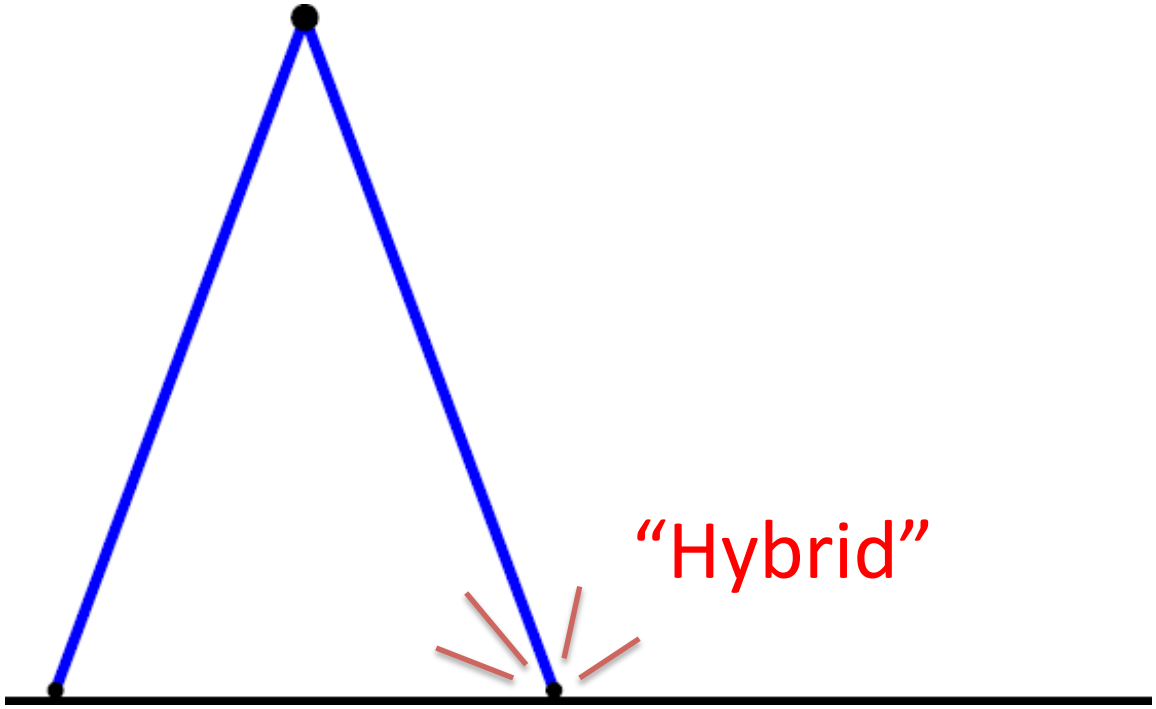
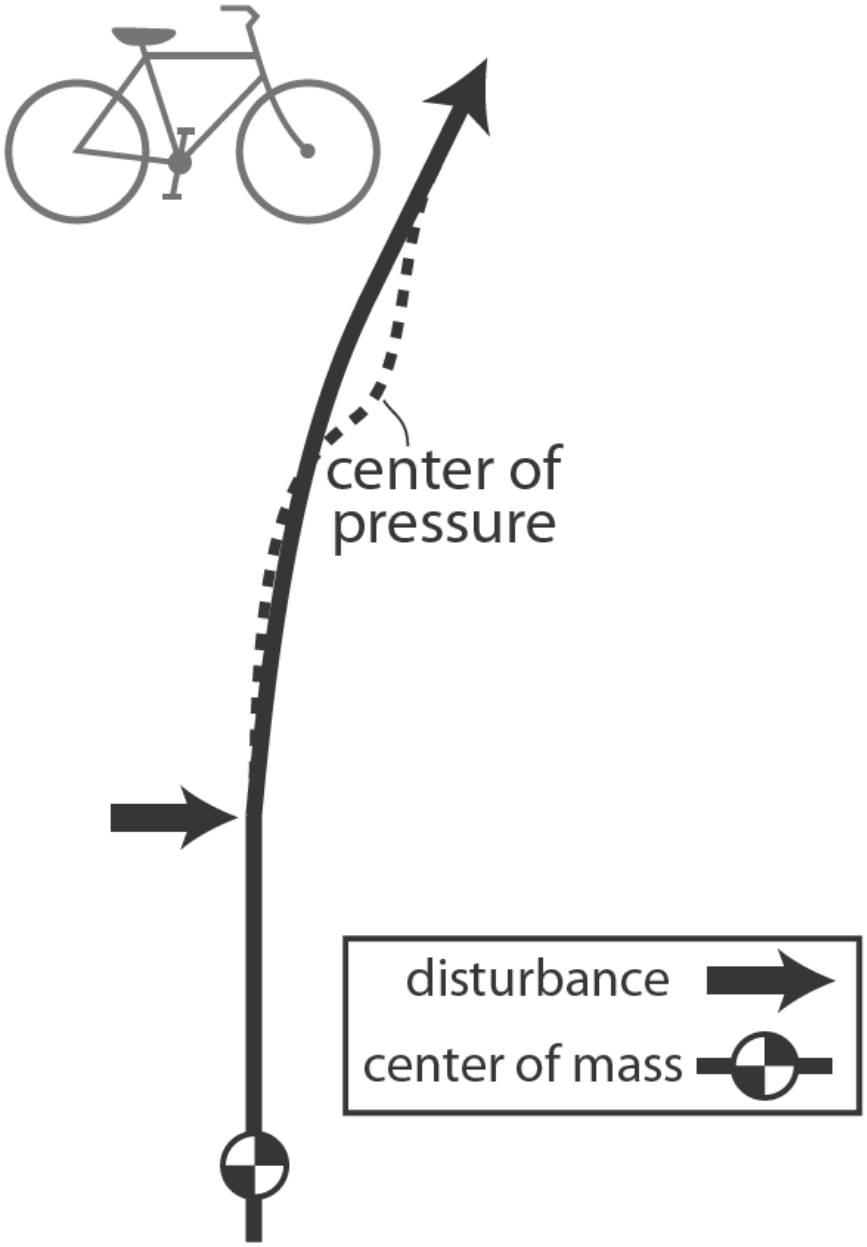


Another walking system

https://www.youtube.com/watch?v=dl7KUUVHC-M

One way to control walking stability

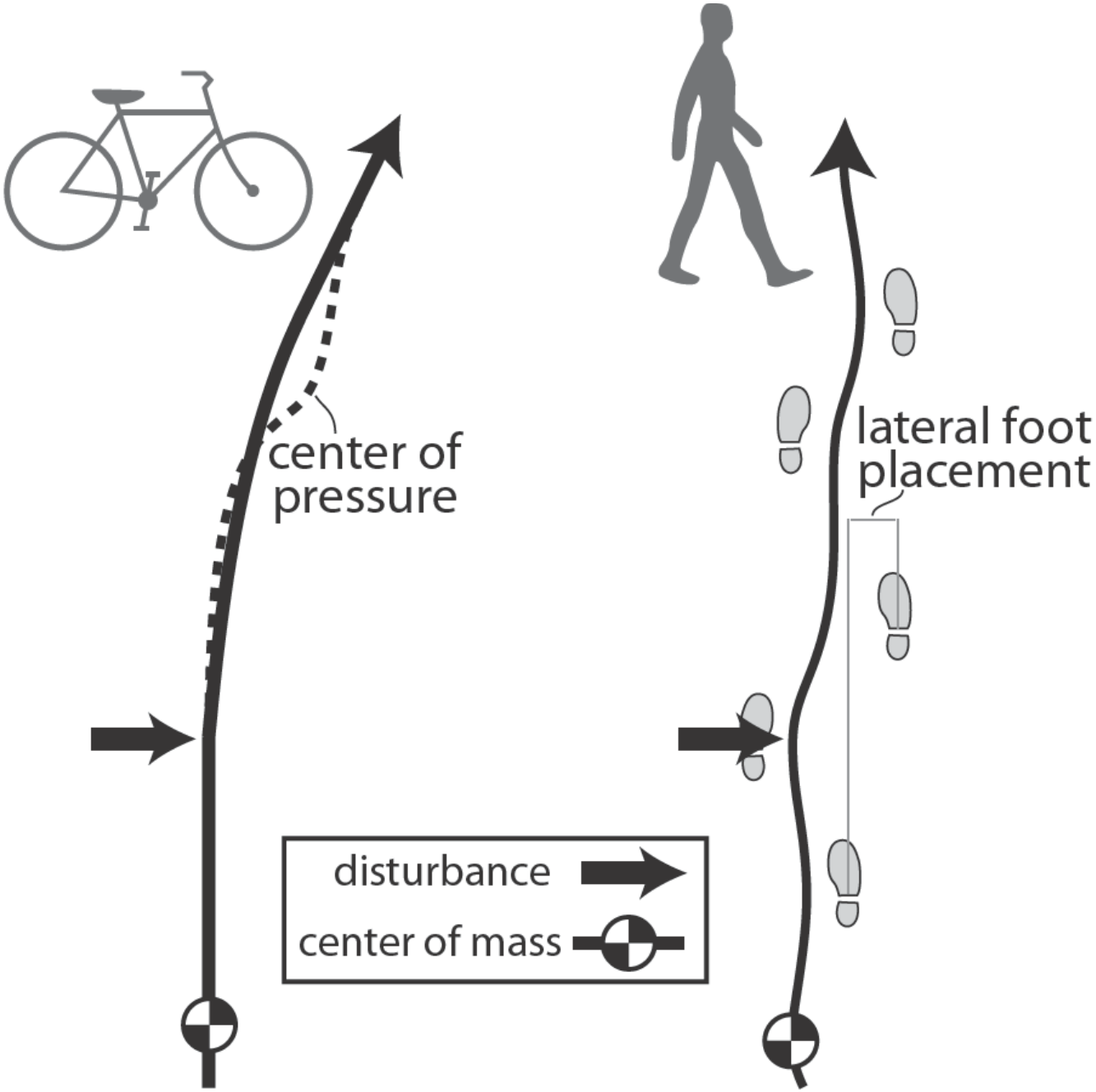
For more detail, a draft of a paper on this project is available at https://dl.dropboxusercontent.com/u/19827221/2014-footYawStabilityPaperV3.pdf



(Wisse 2005)

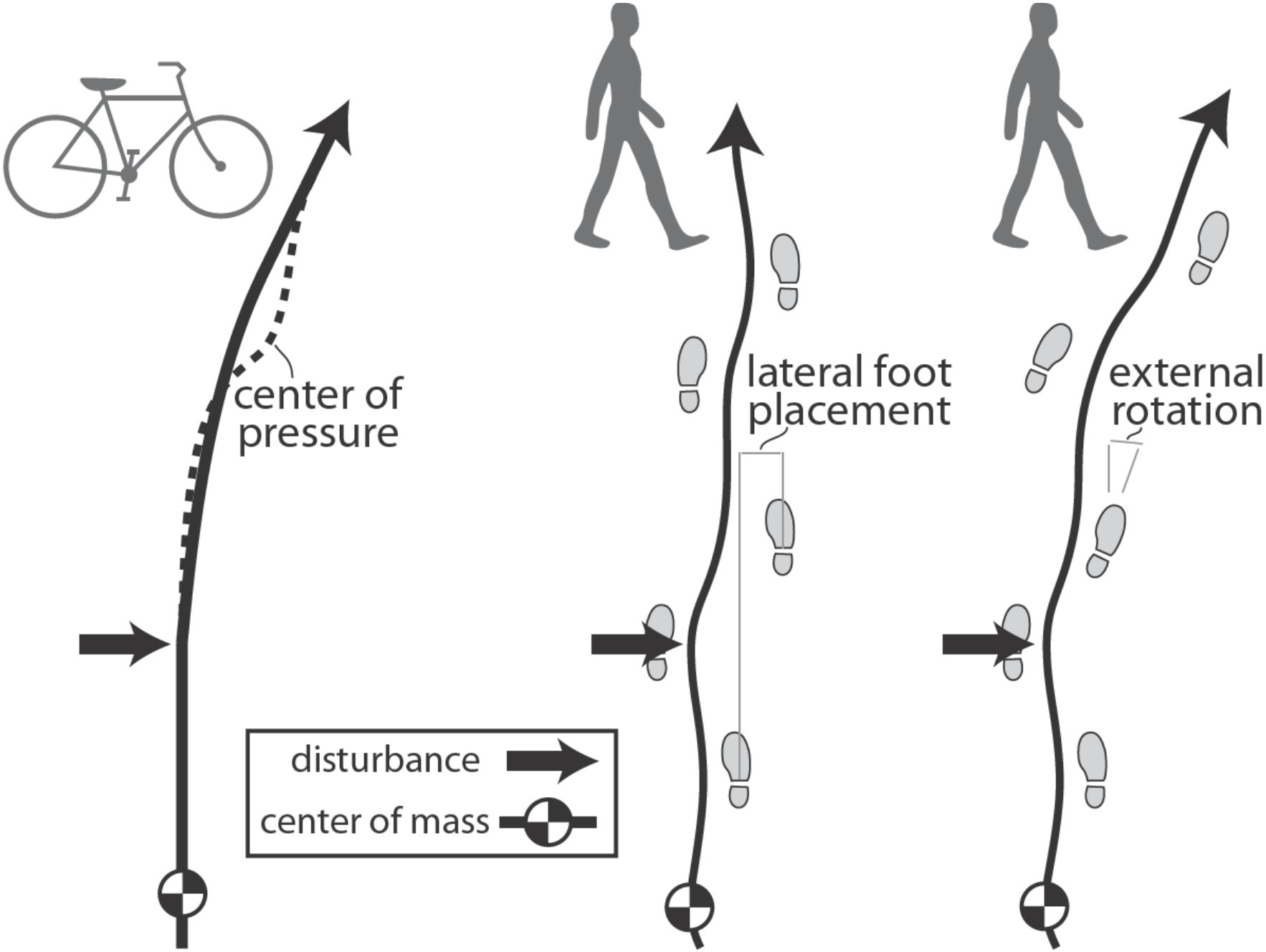
More info on bicycle stability:
http://ruina.tam.cornell.edu/research/topics/bicycle_mechanics/papers.php

In particular, a very interesting bicycle that stabilizes without gyroscopic or caster effects (it uses mass distribution to couple lean with steering)
http://ruina.tam.cornell.edu/research/topics/bicycle_mechanics/stablebicycle/index.htm



(Wisse 2005)

(Kuo 1999)



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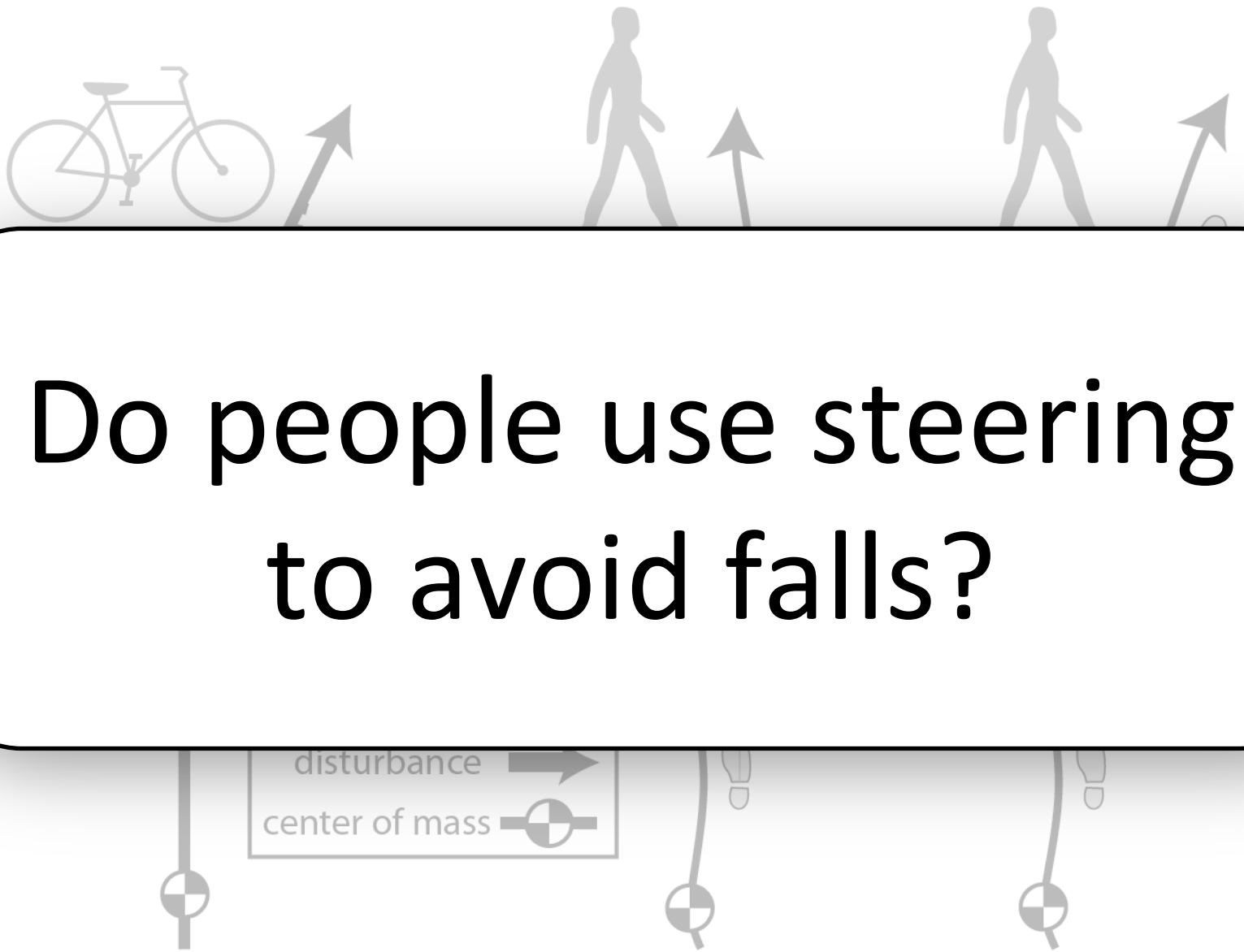

Do people use steering to avoid falls?

[Ref]

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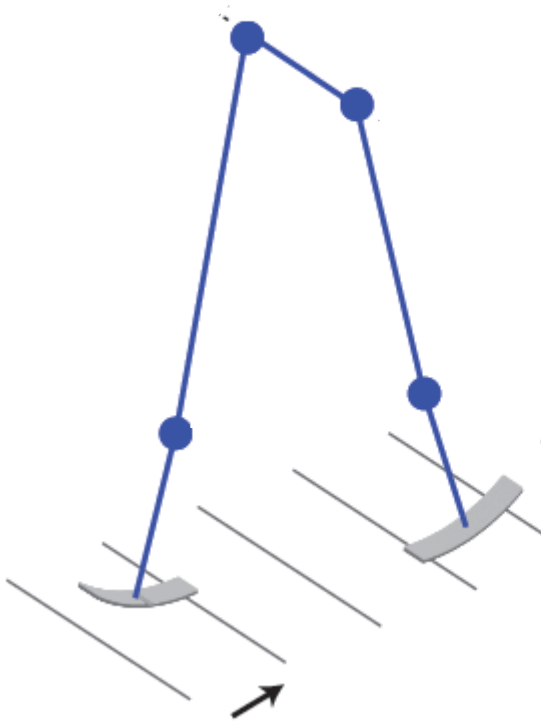
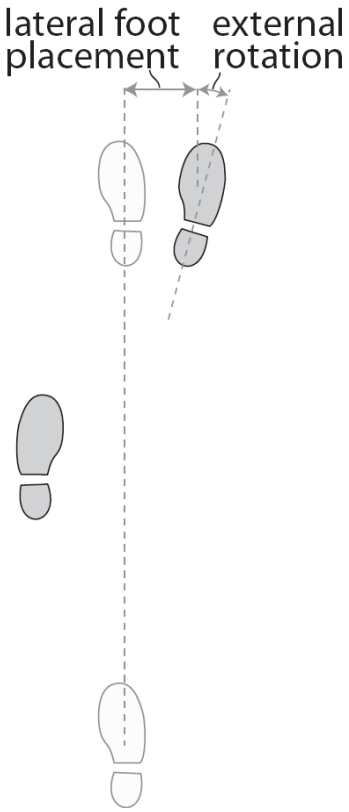
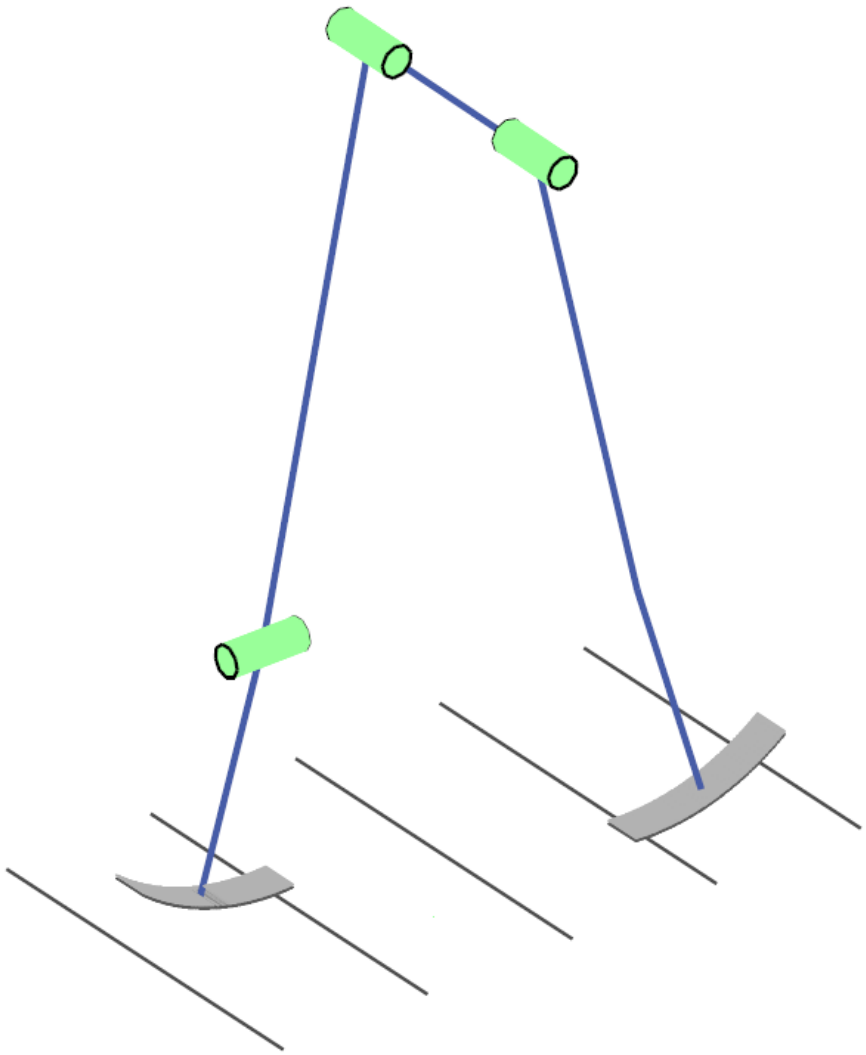
Model



Human Experiment



Walking Model



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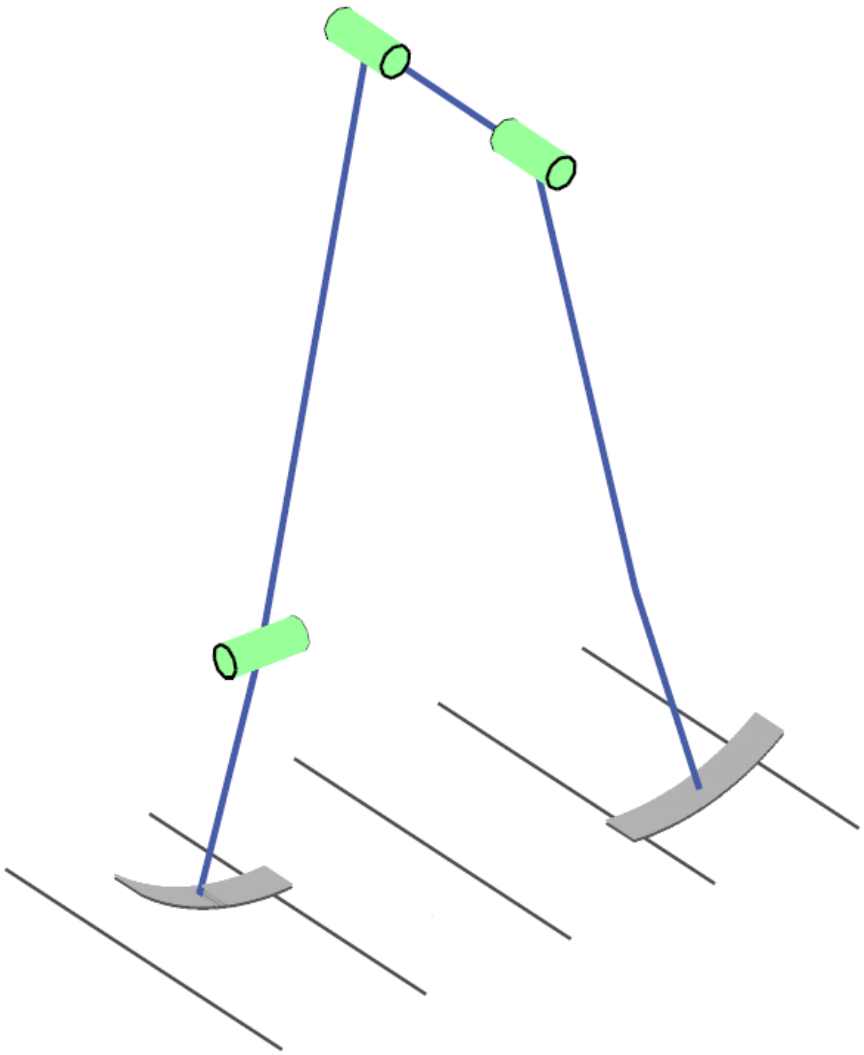
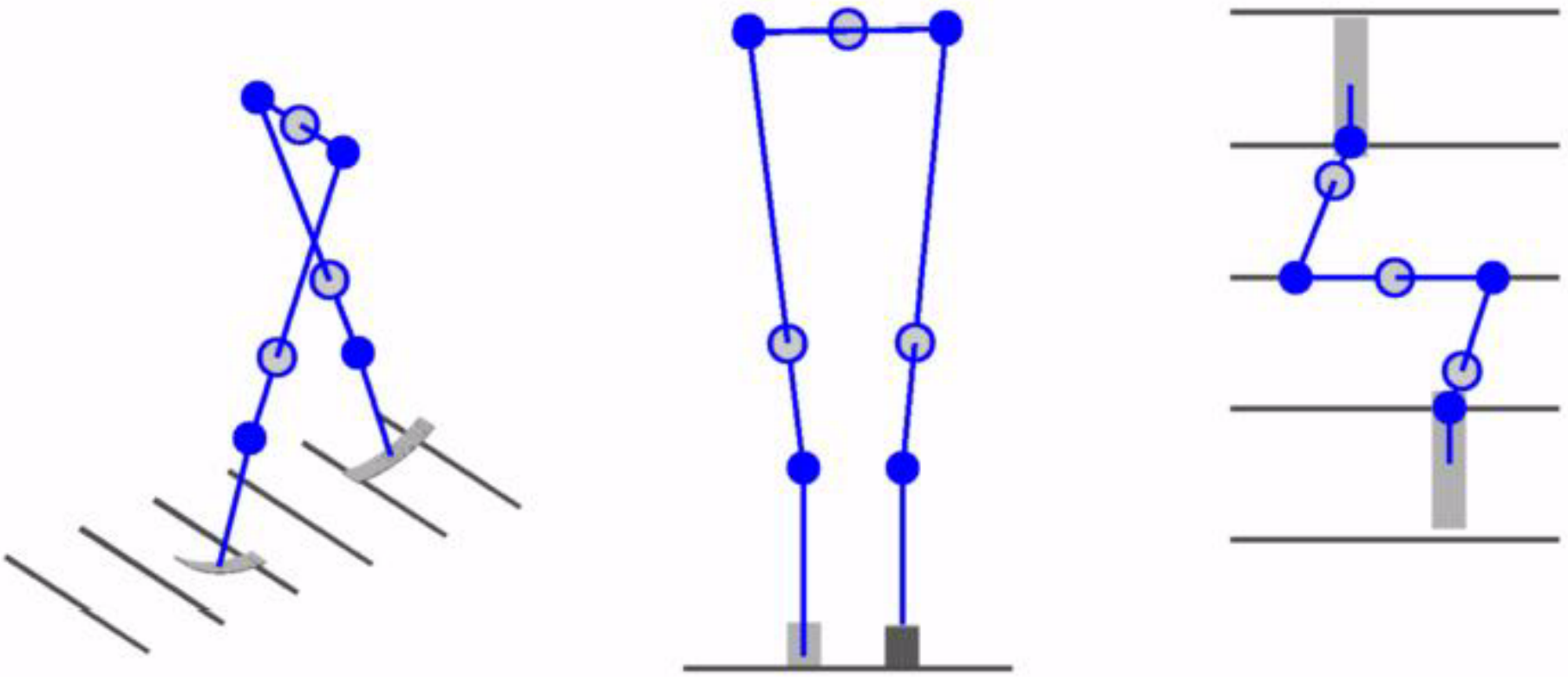
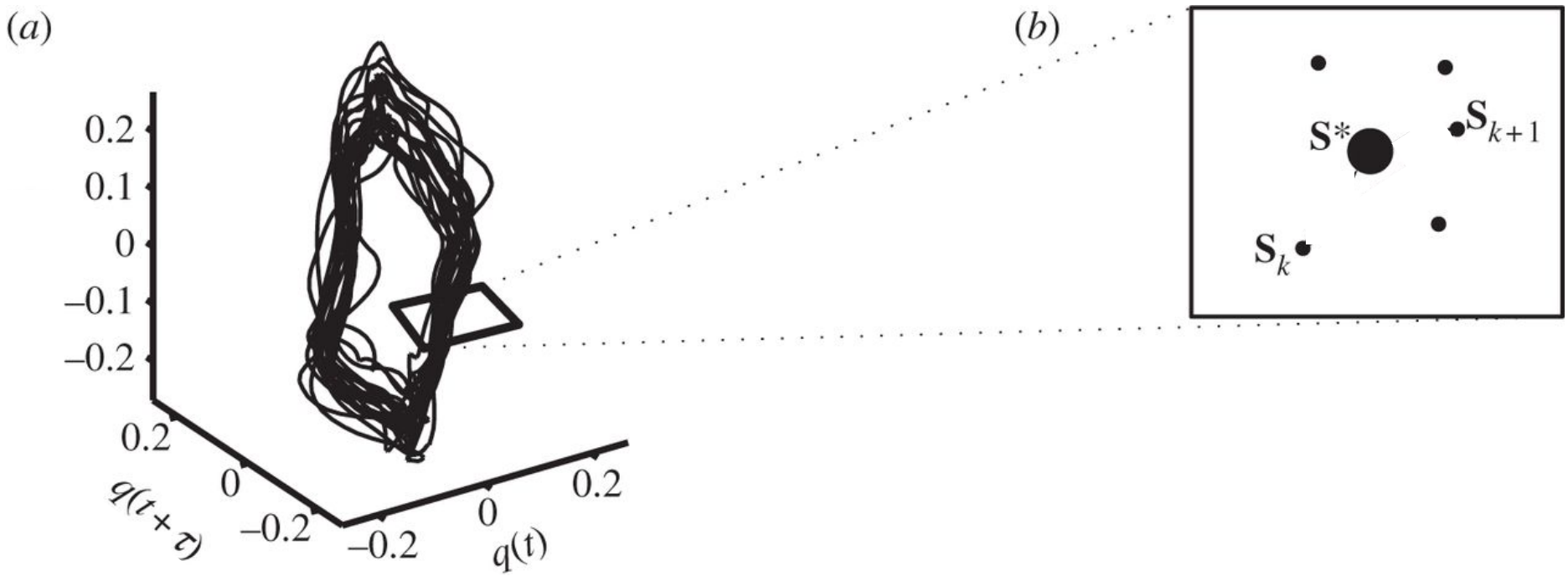


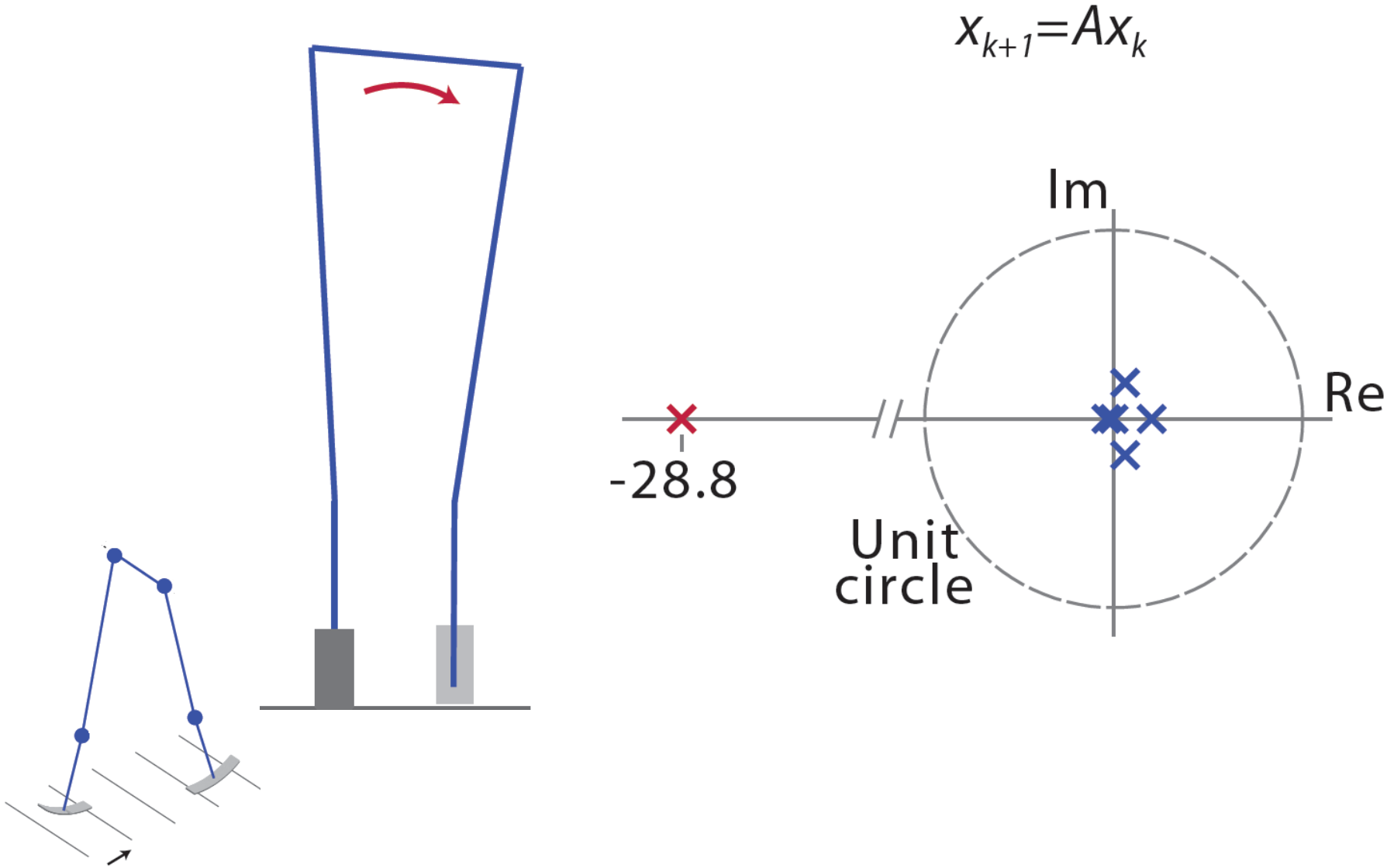
Analytical EOMs
Hybrid dynamics
Inelastic collisions
Constraint jacobians
SQP → Limit cycle
Passive, down slope



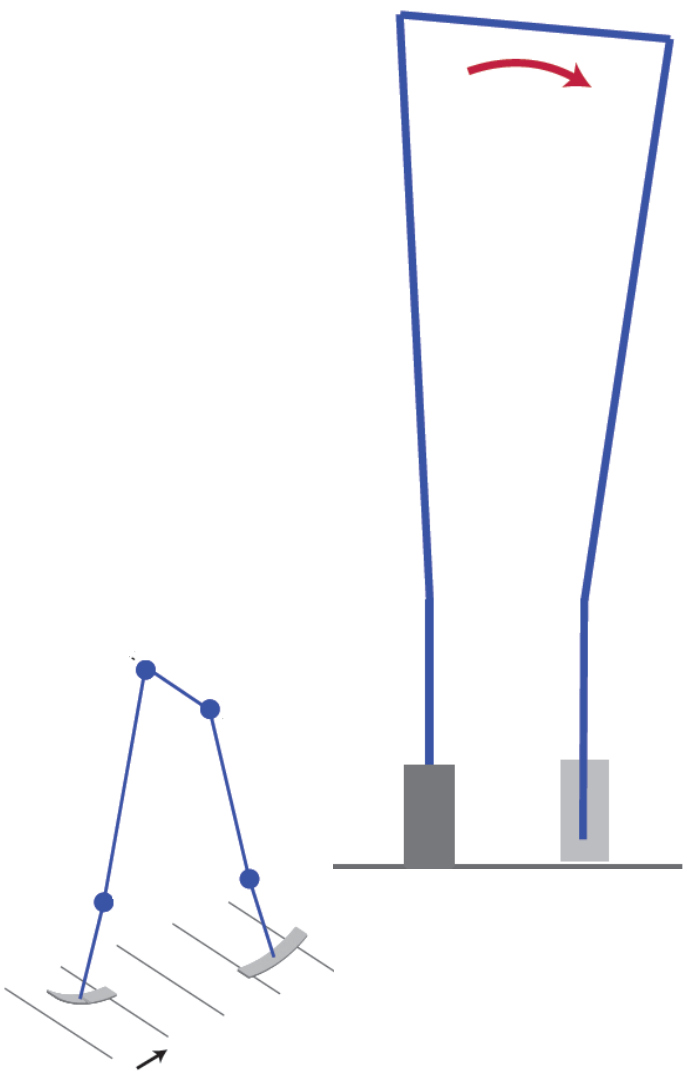
Linearize Cyclic Dynamics



Unstable Lateral Falling Mode

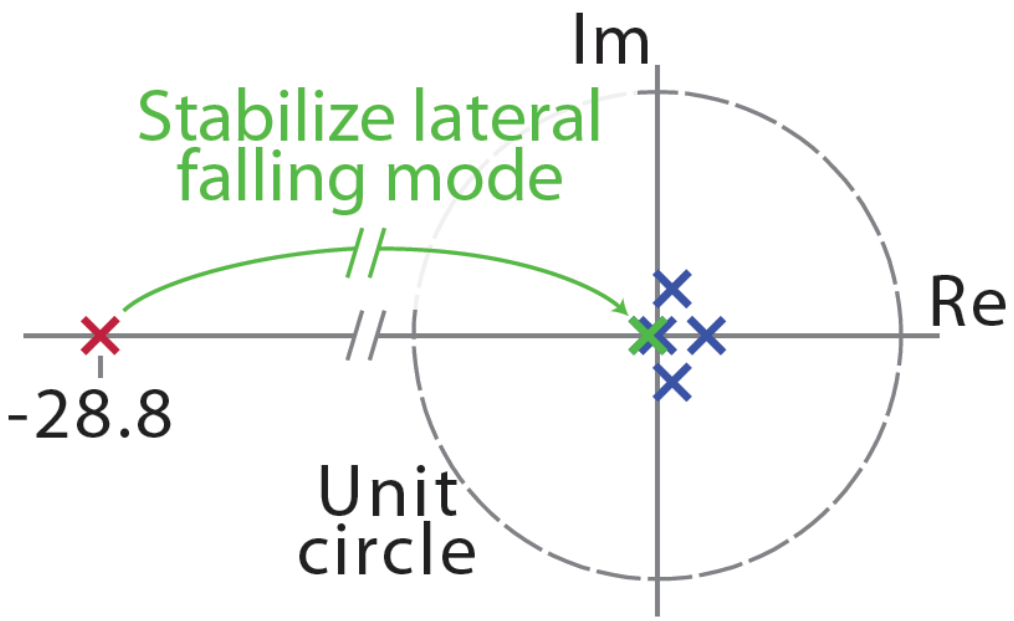


Control to Stabilize Lateral Falling

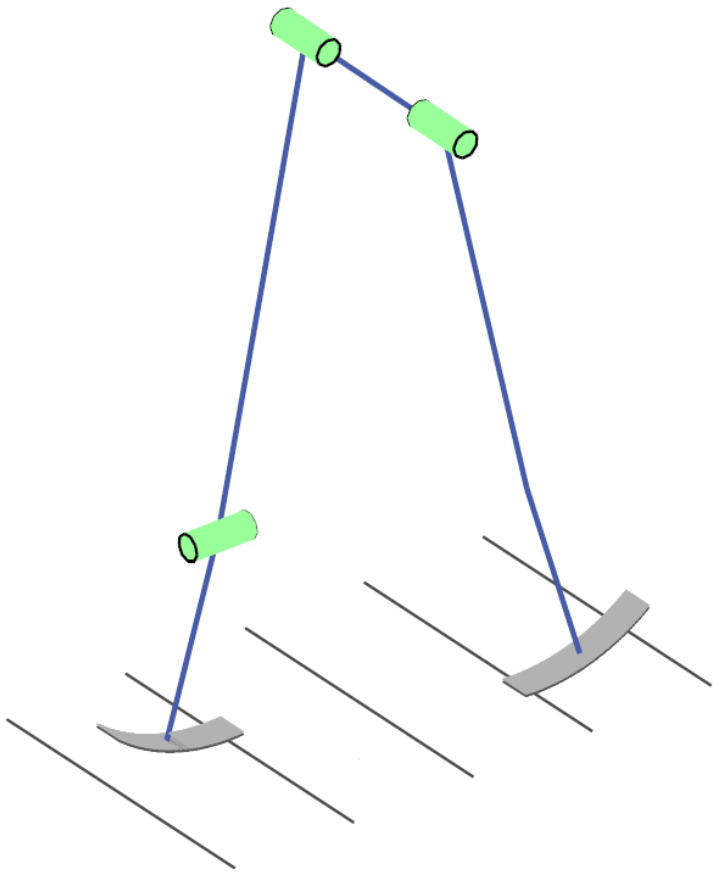


$$x_{k+1}=Ax_k+Bu$$

$$u_k=-Kx_k$$



Stabilizing the Walking Model



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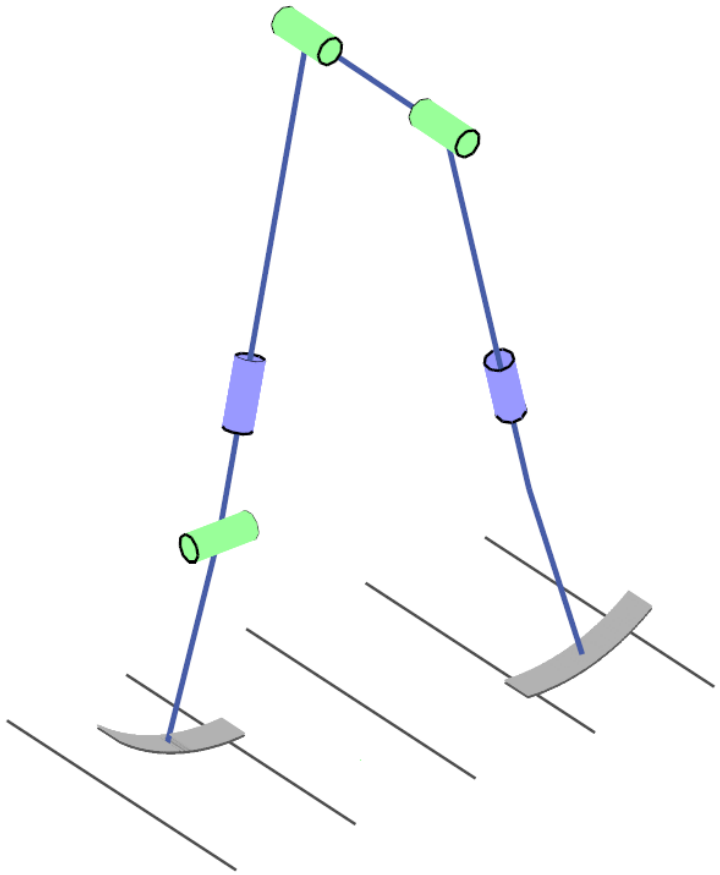

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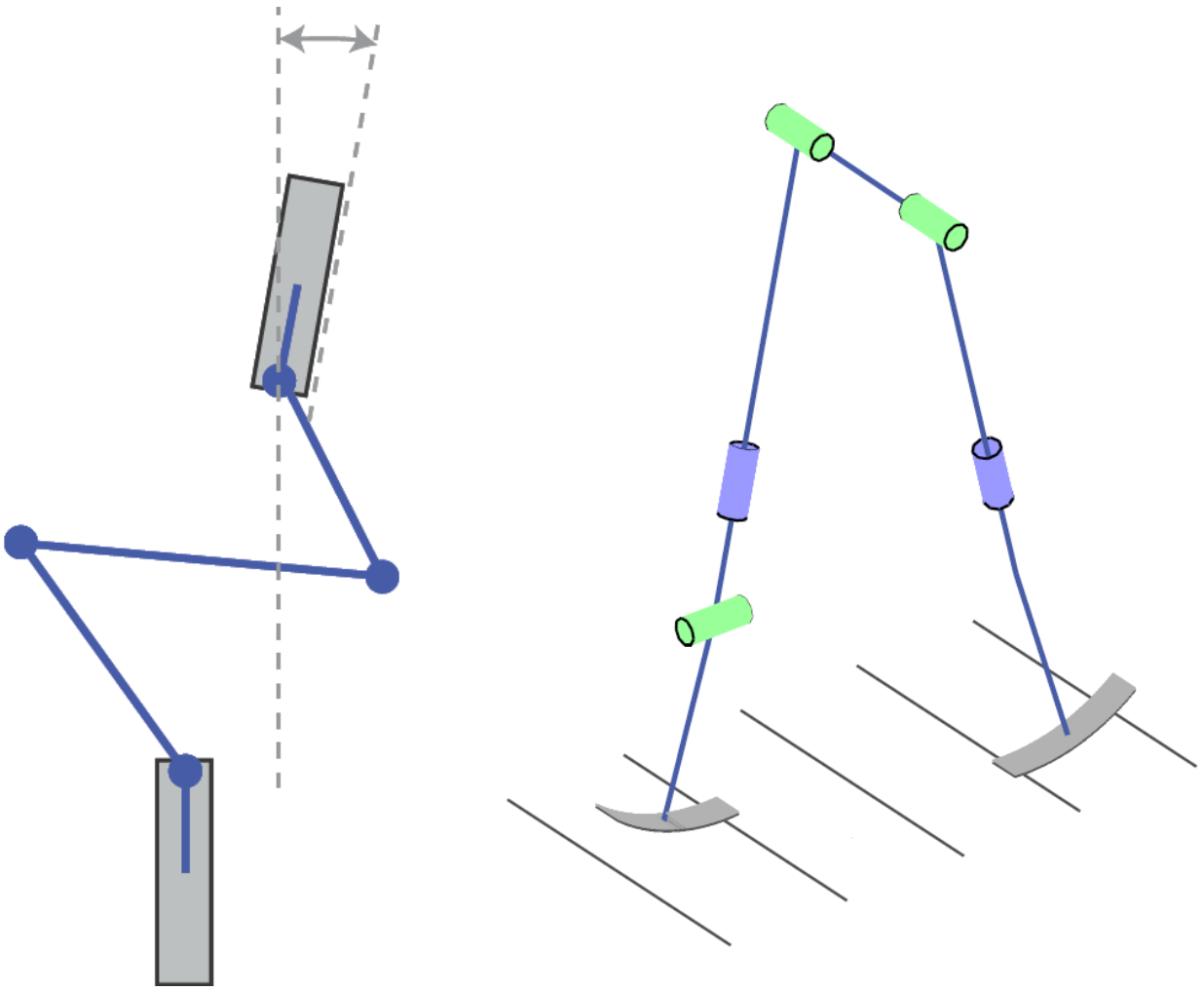

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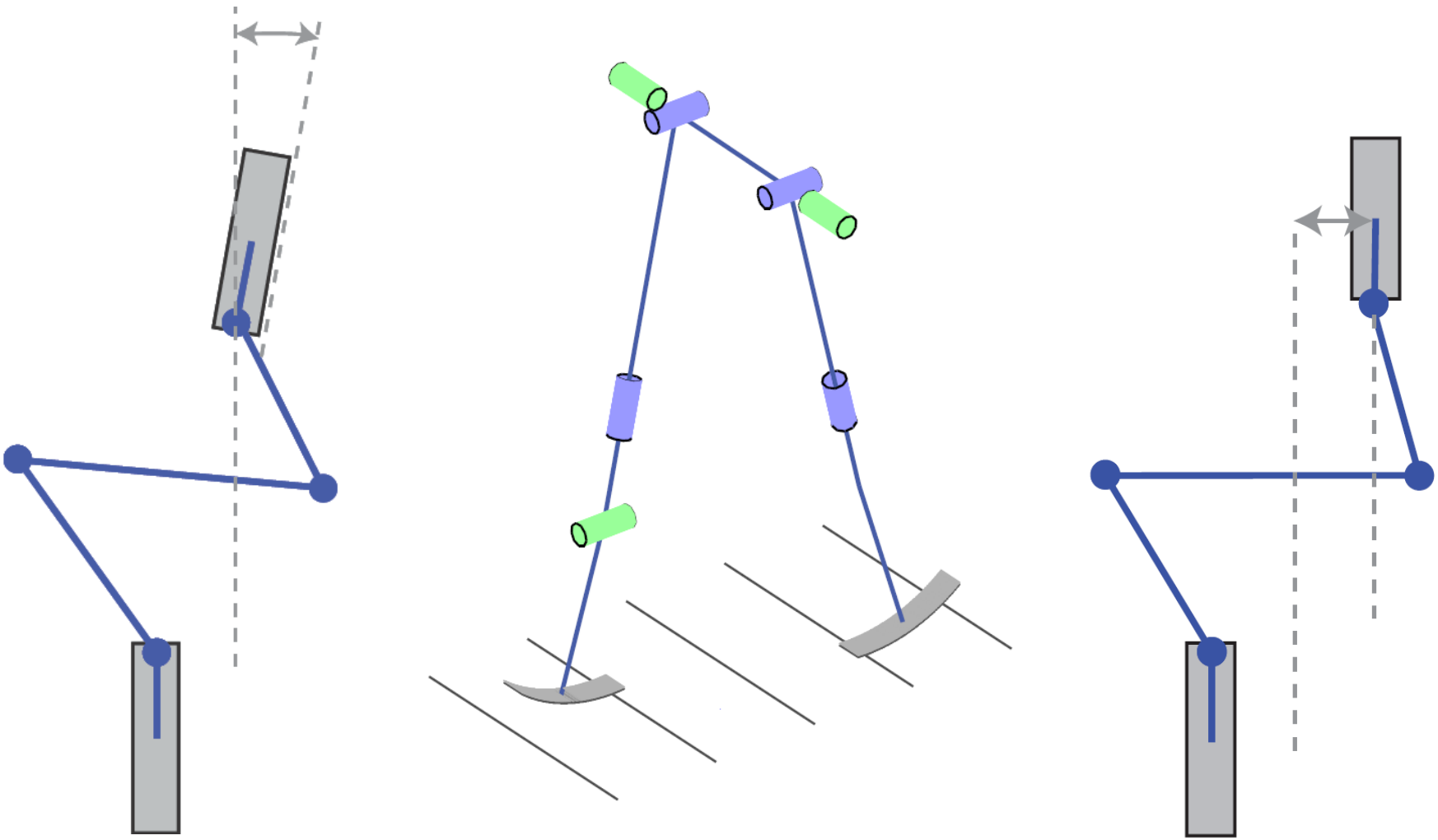
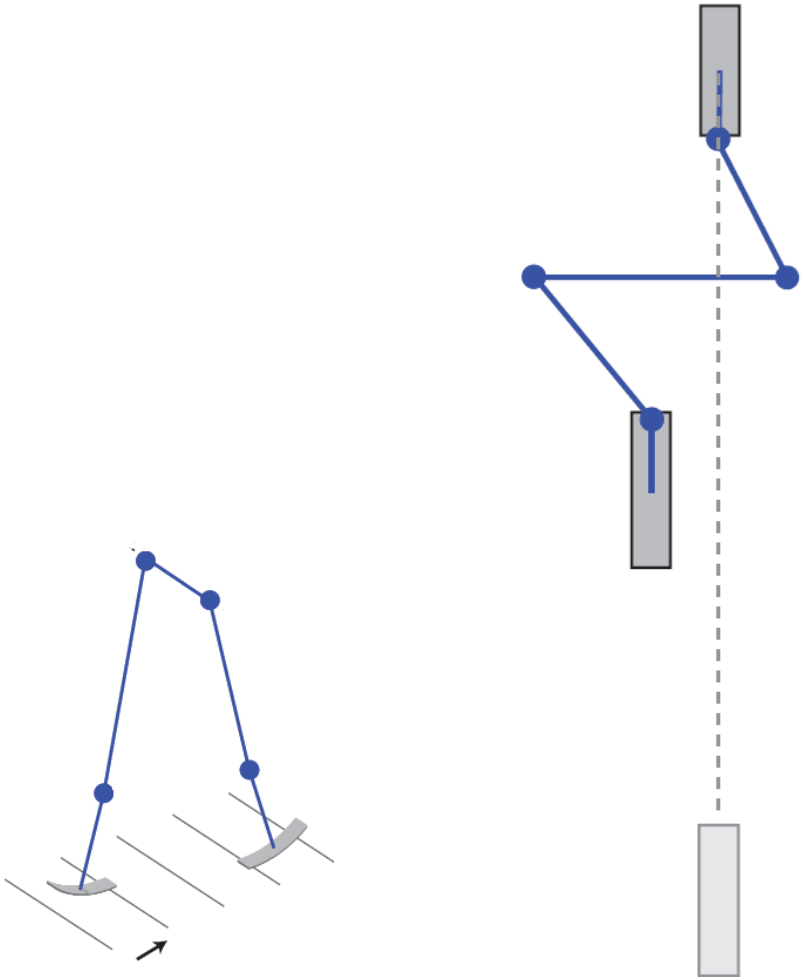


Stabilizing the Walking Model

Foot placement control



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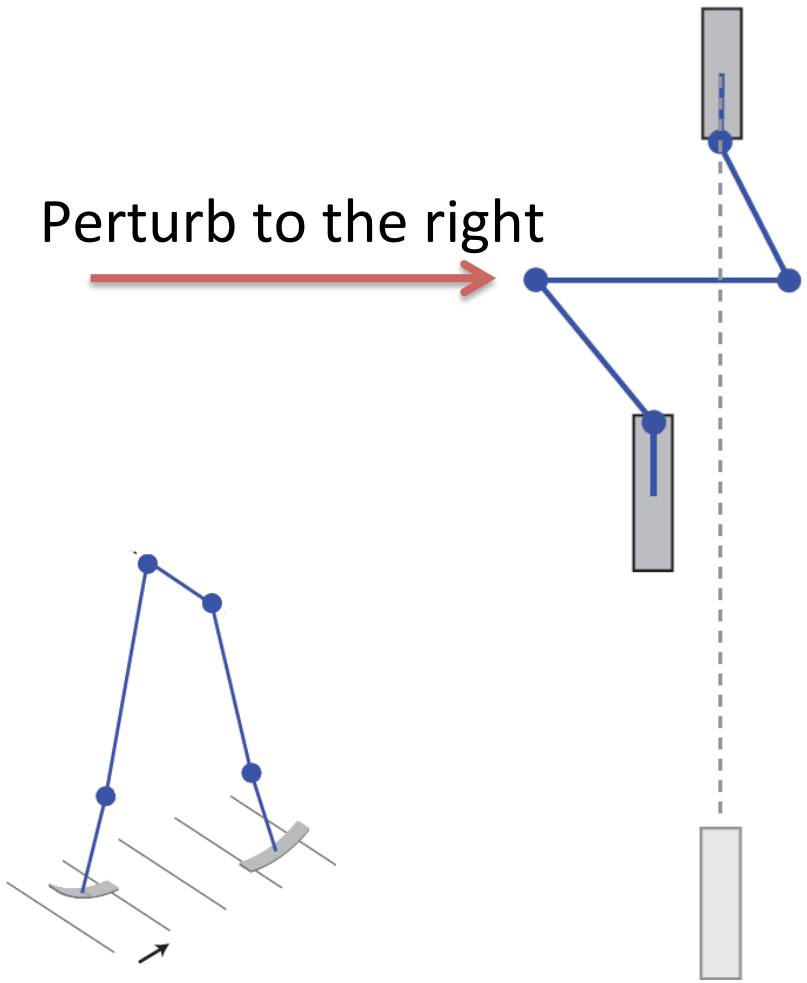

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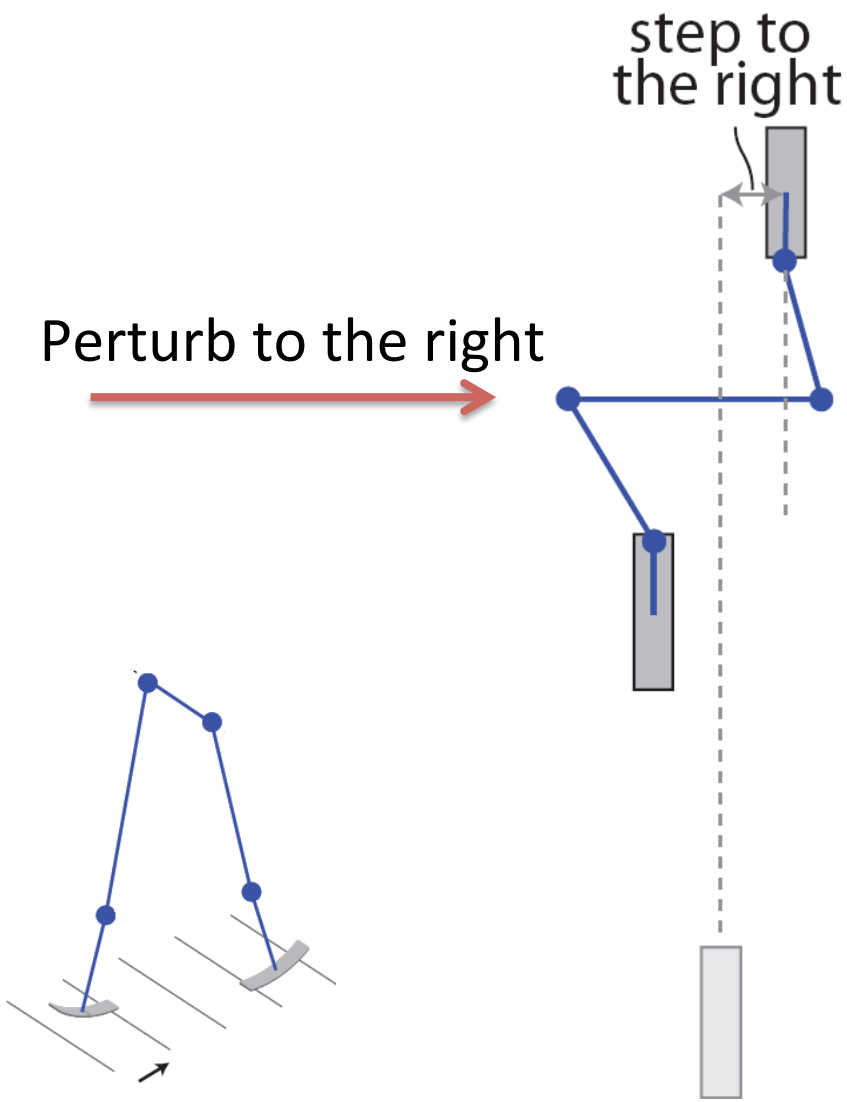
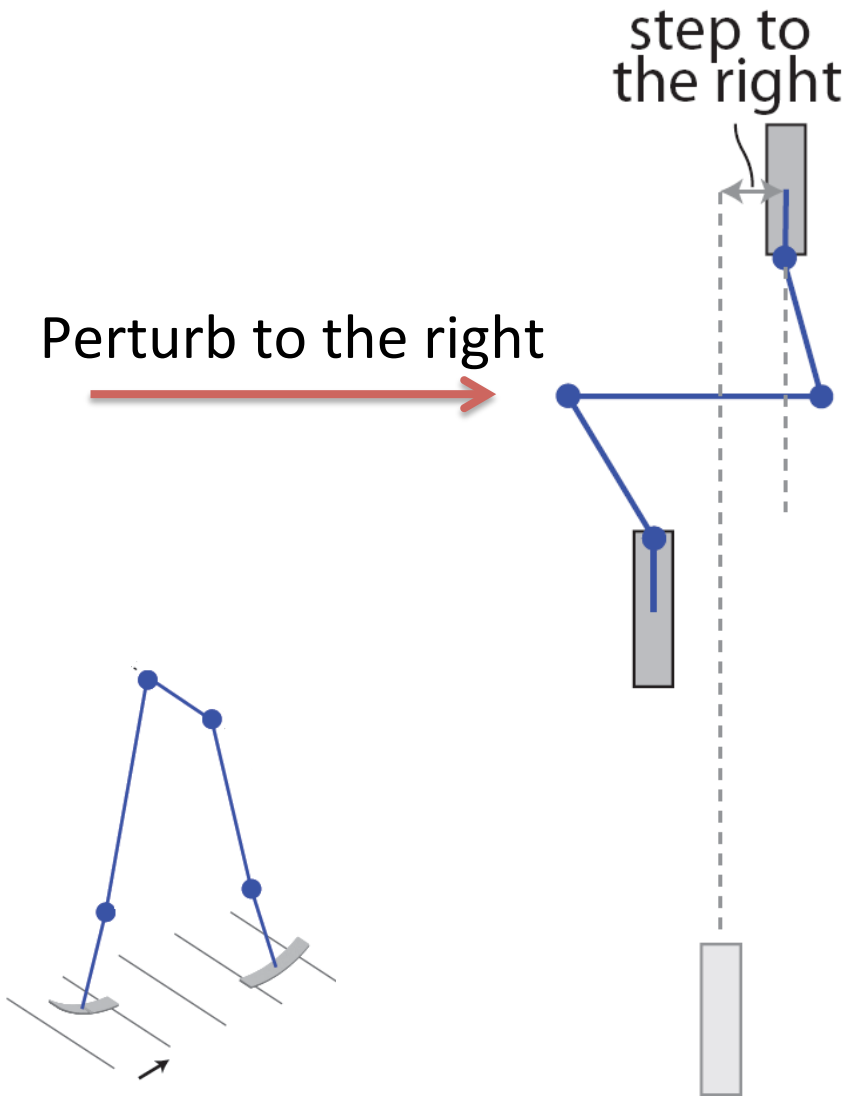


Stabilizing the Walking Model

Foot placement control

External rotation control



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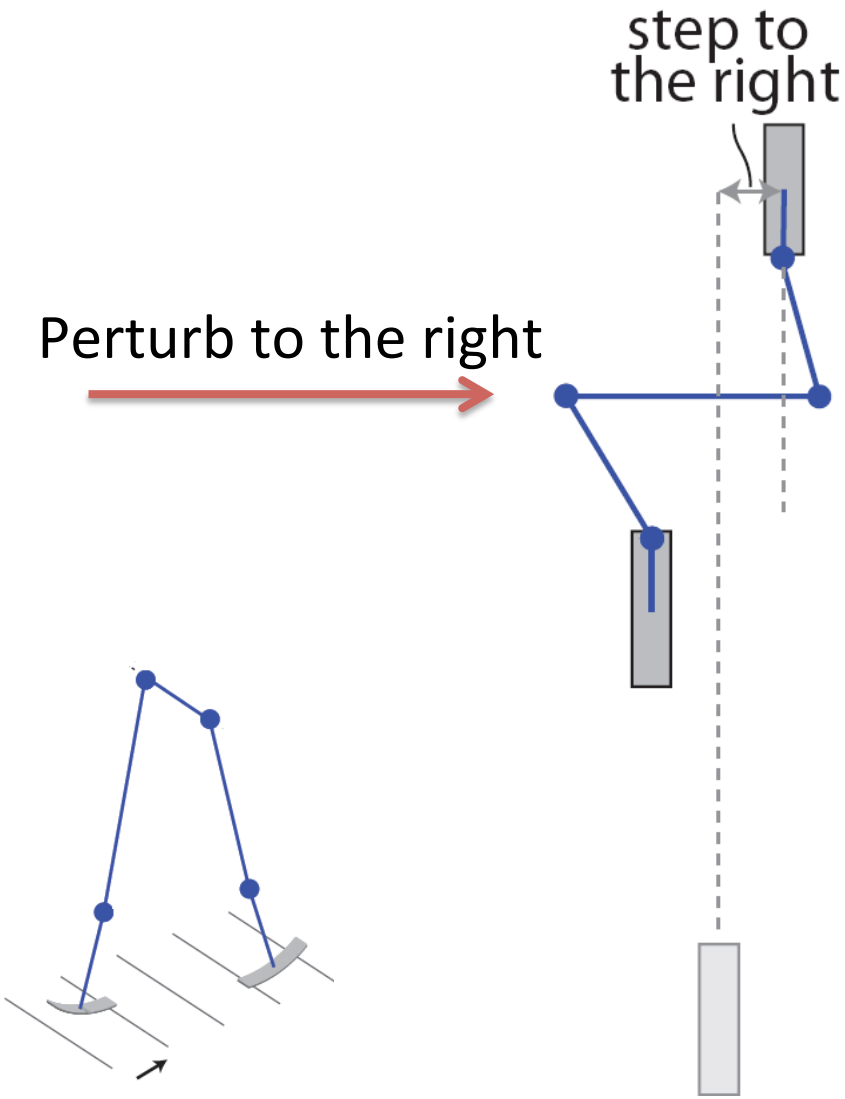

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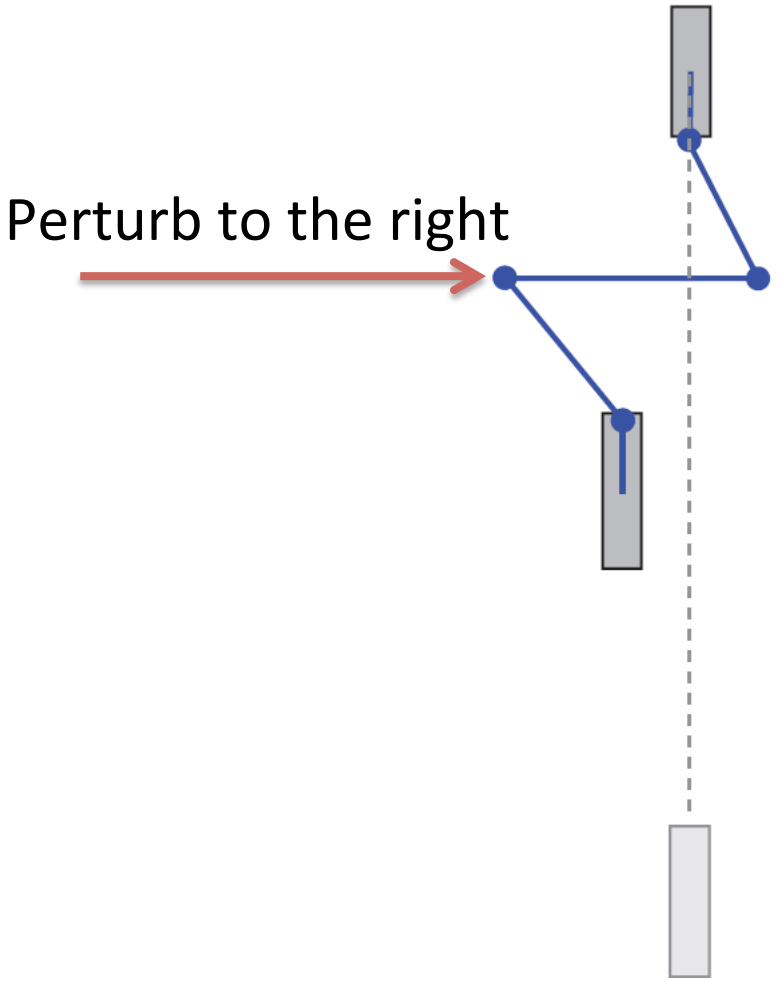

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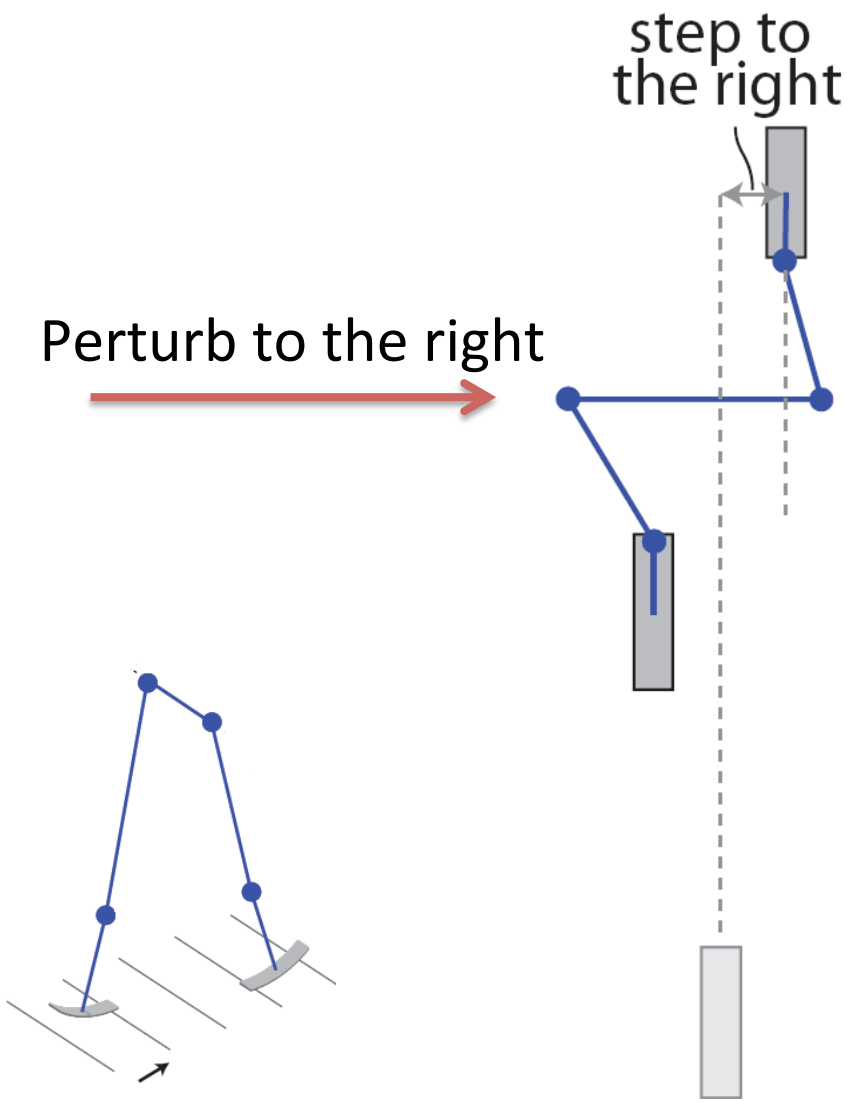

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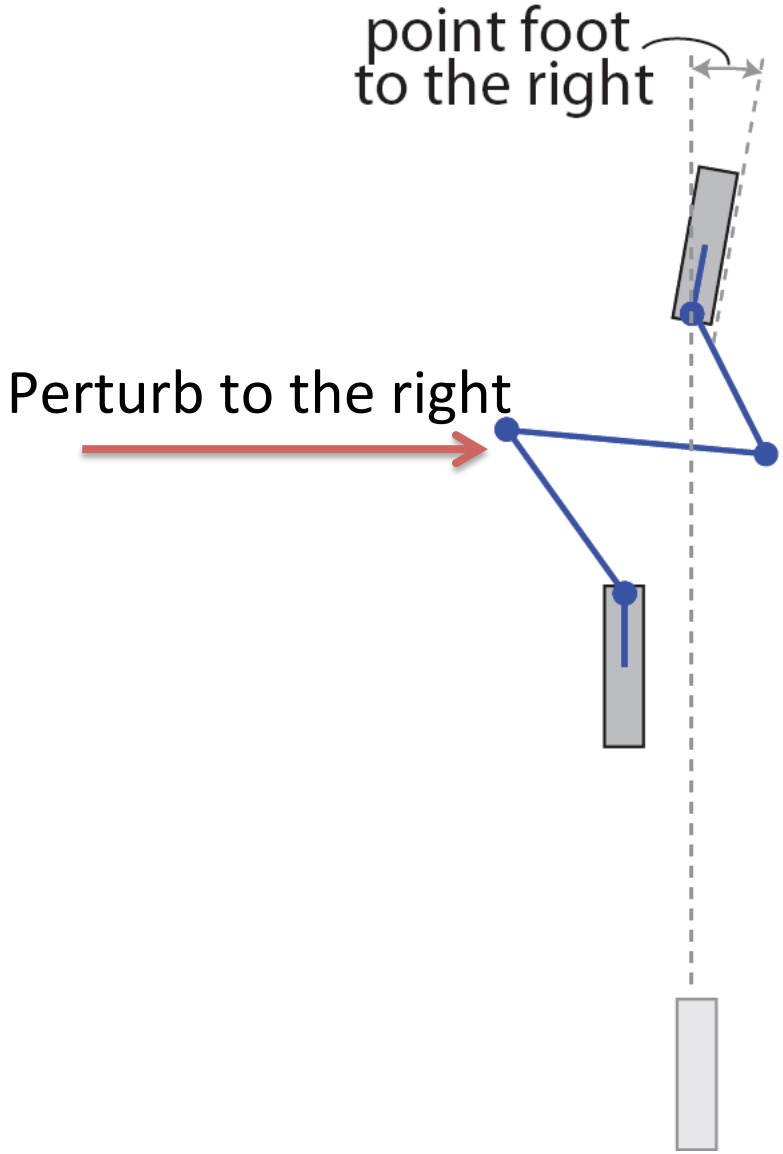
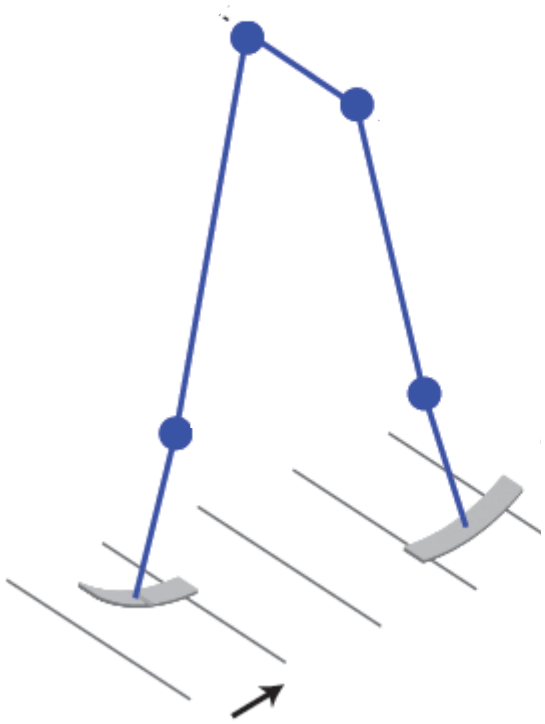


Do people use steering to avoid falls?

Model



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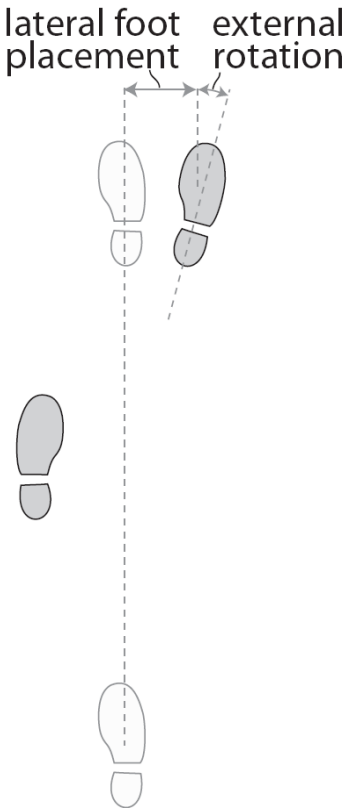
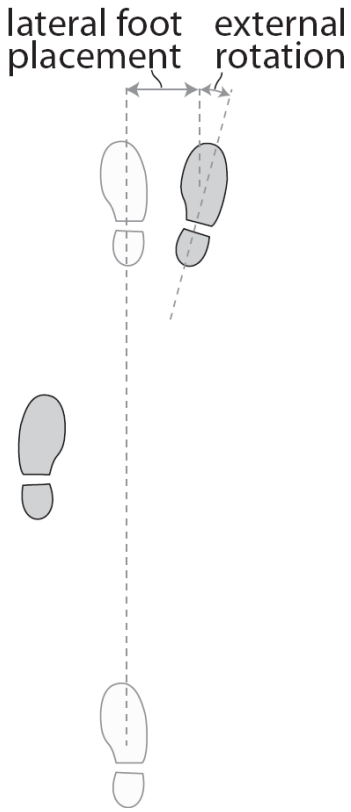


Do people use steering to avoid falls?

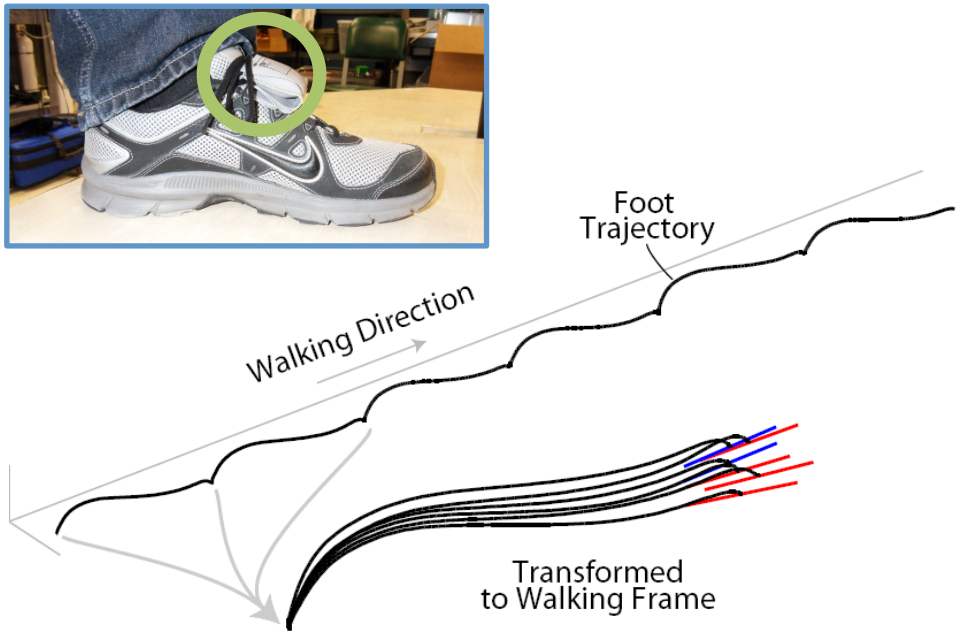
Model

Steering stabilizes mechanical model

Human Experiment



Normal Walking



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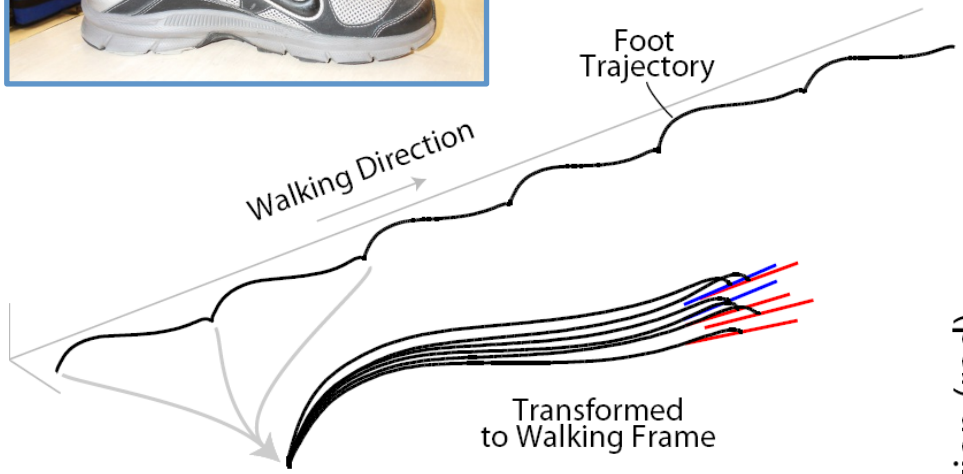
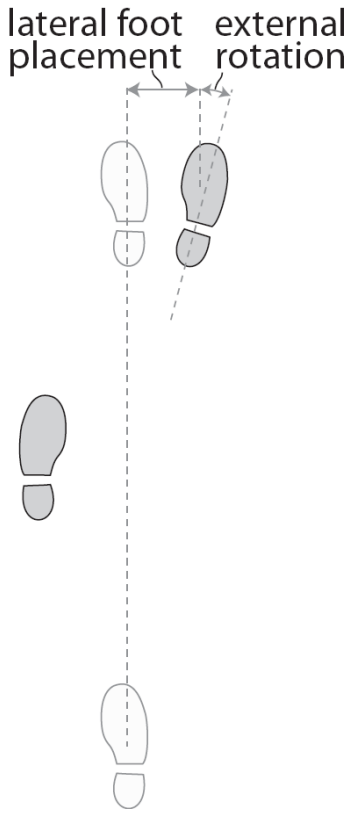
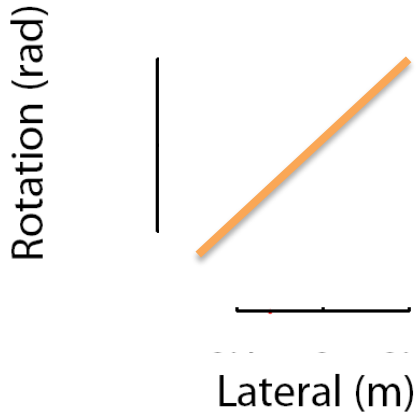
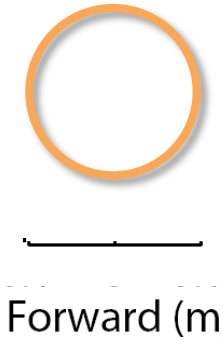
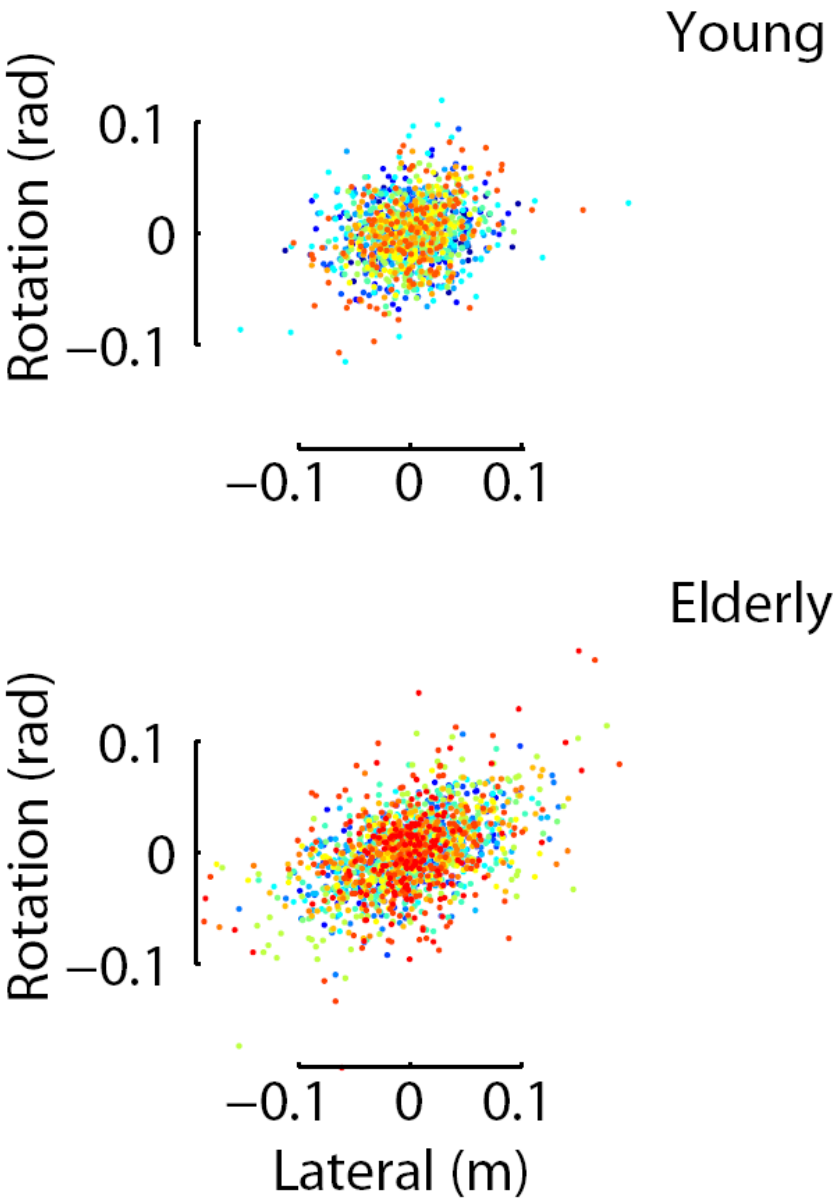








All Stride Correlations



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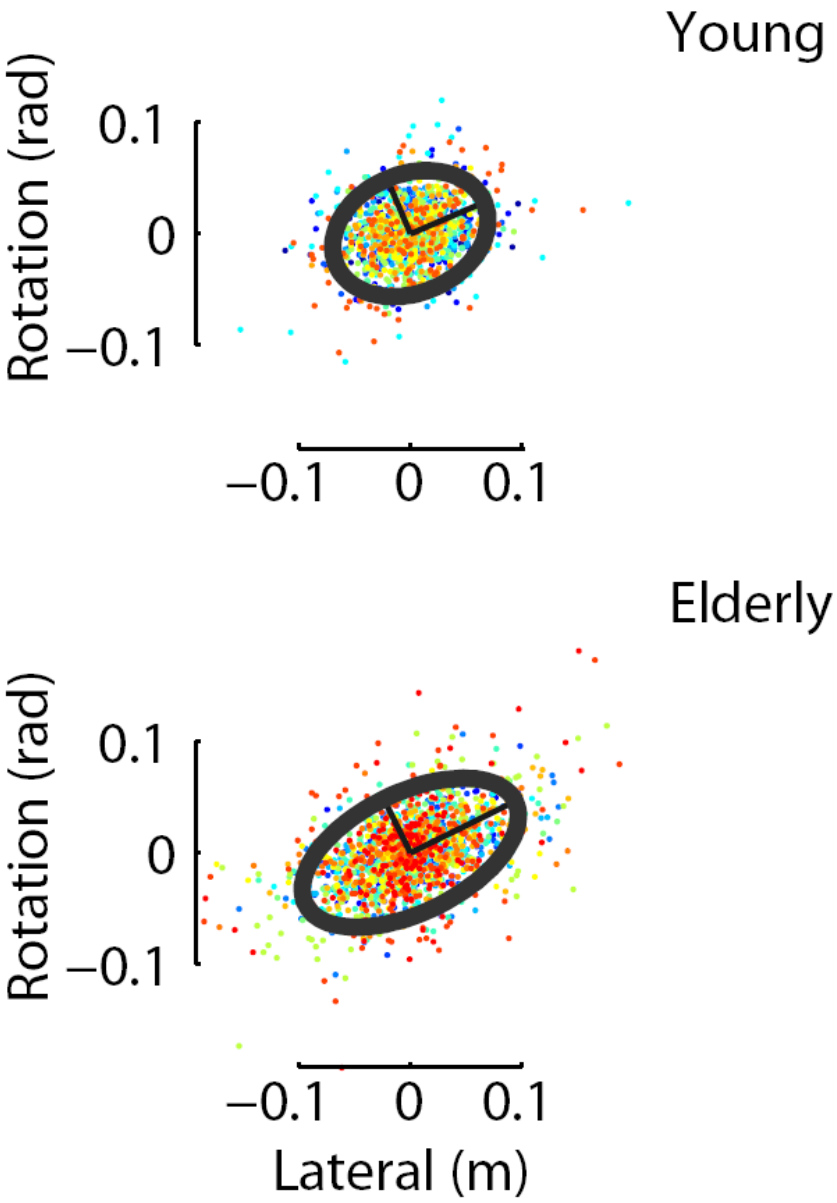

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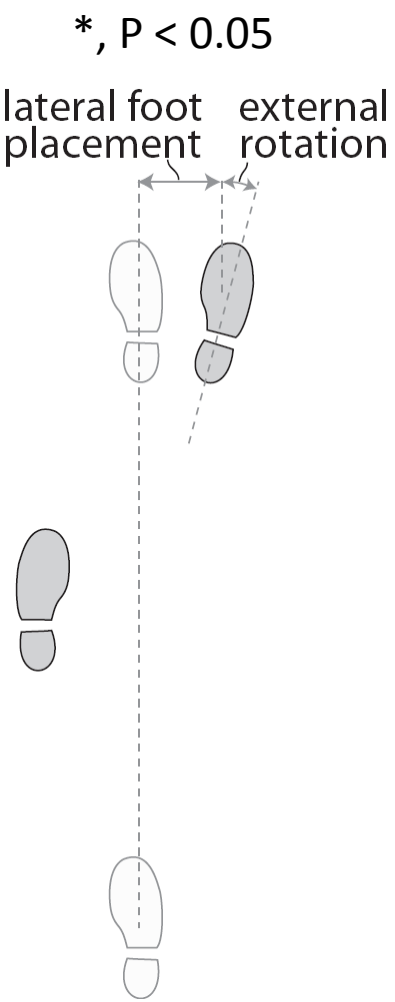

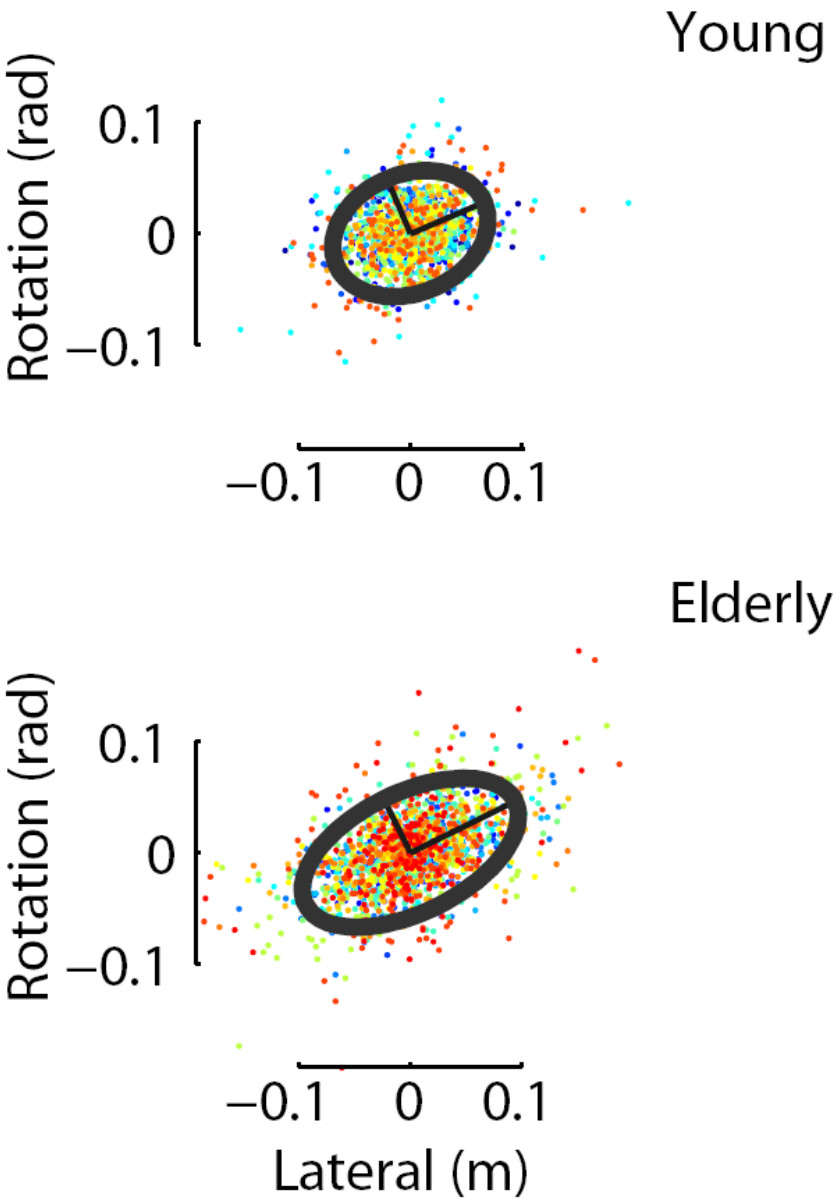

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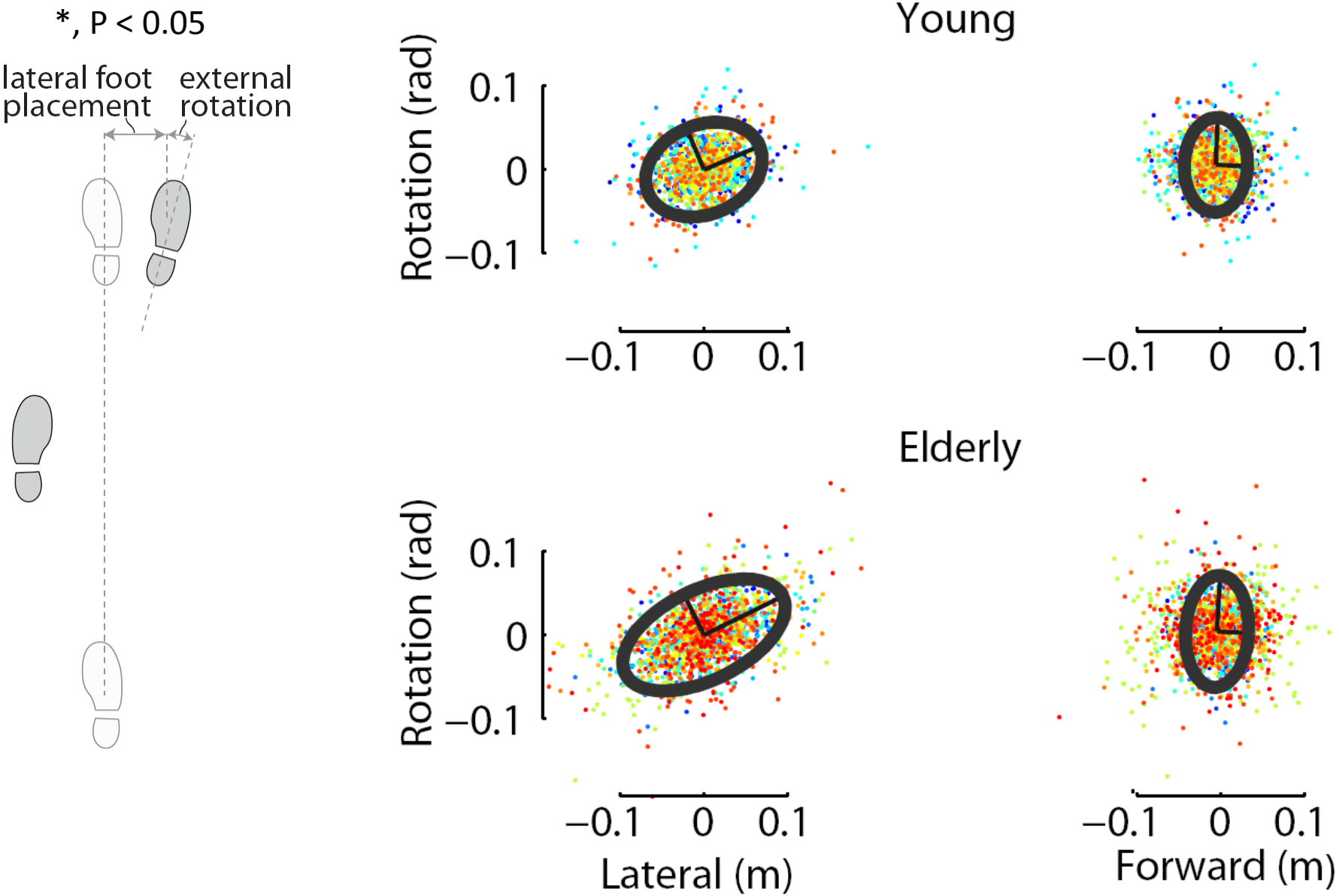
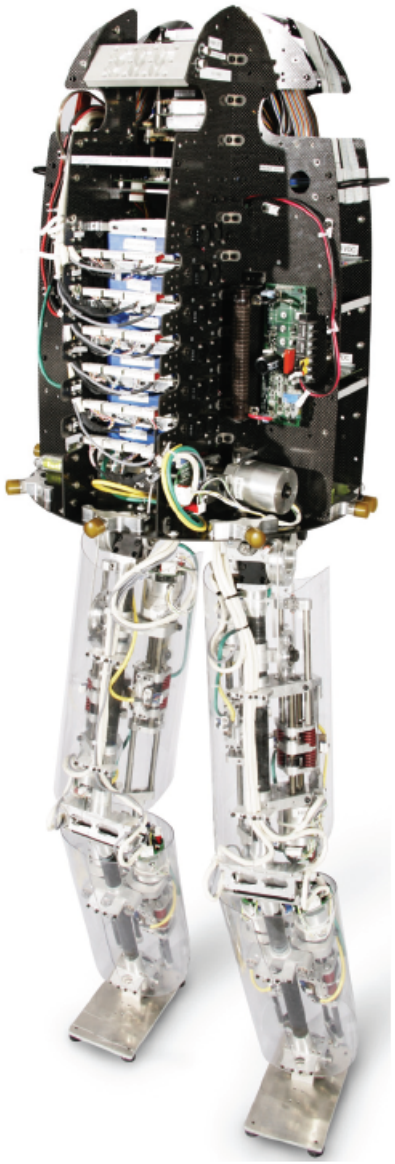
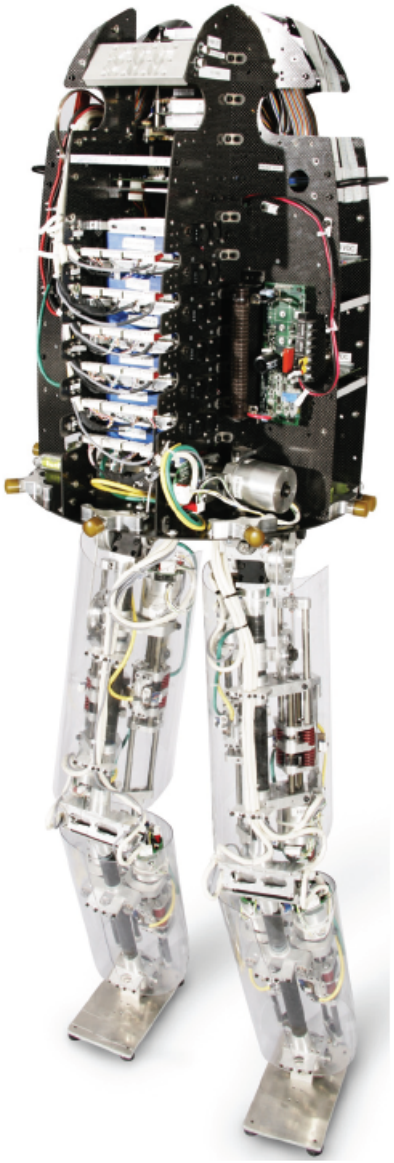
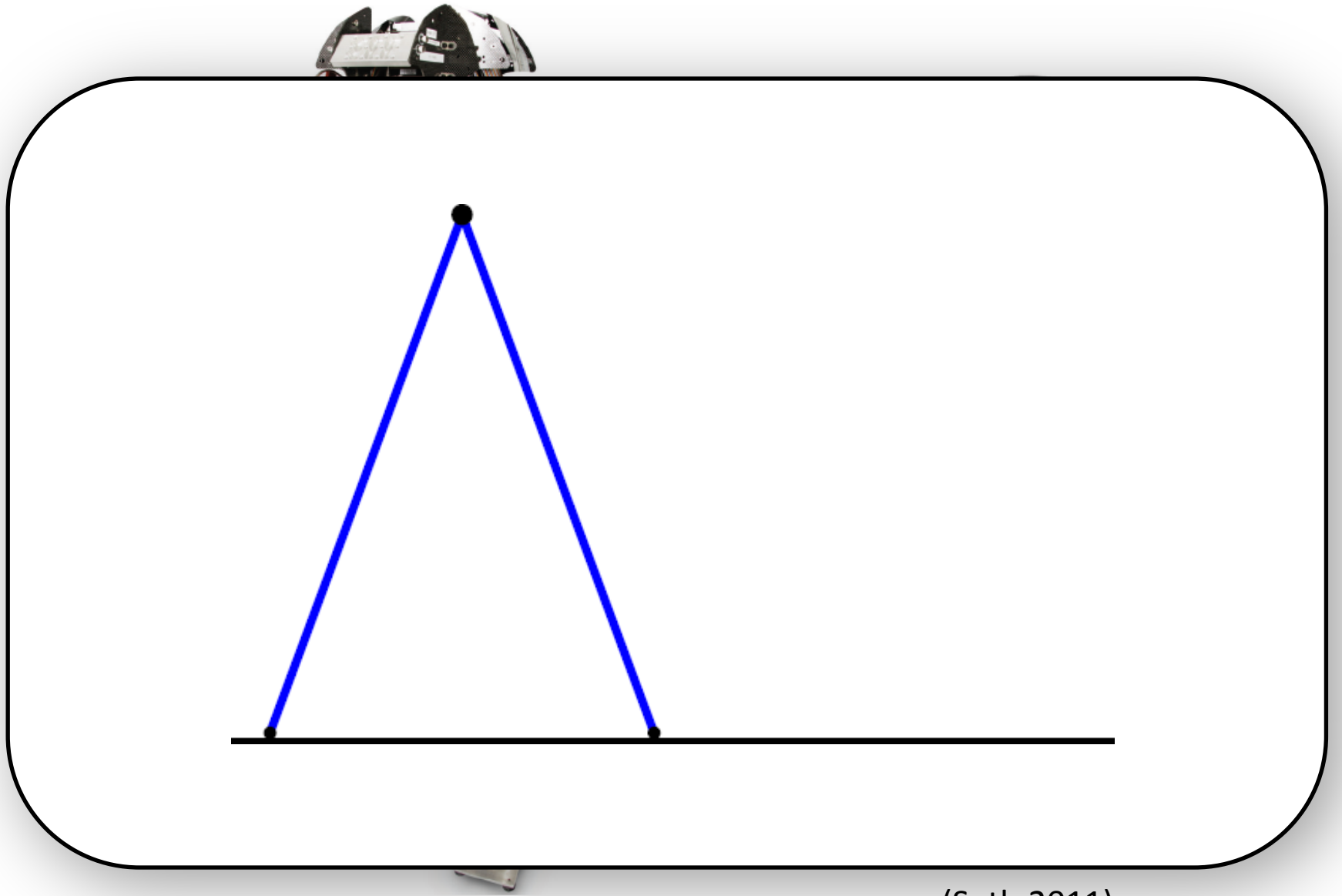


Simple models could be used for planning trajectories

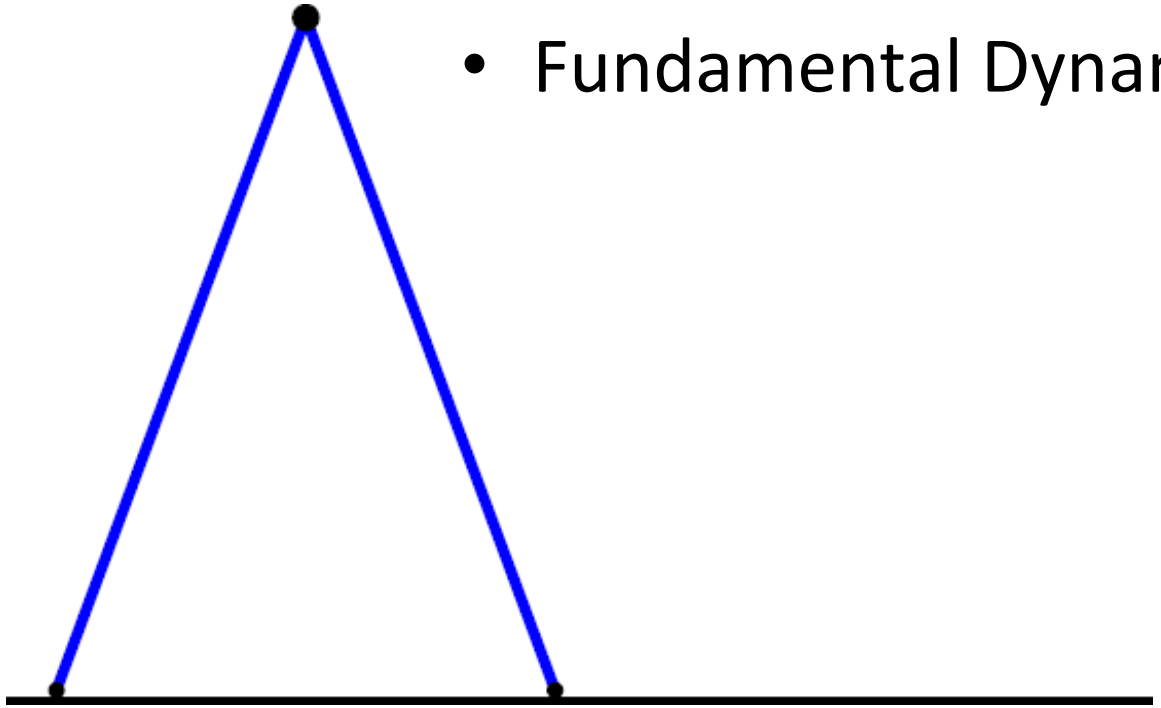




(Seth 2011)

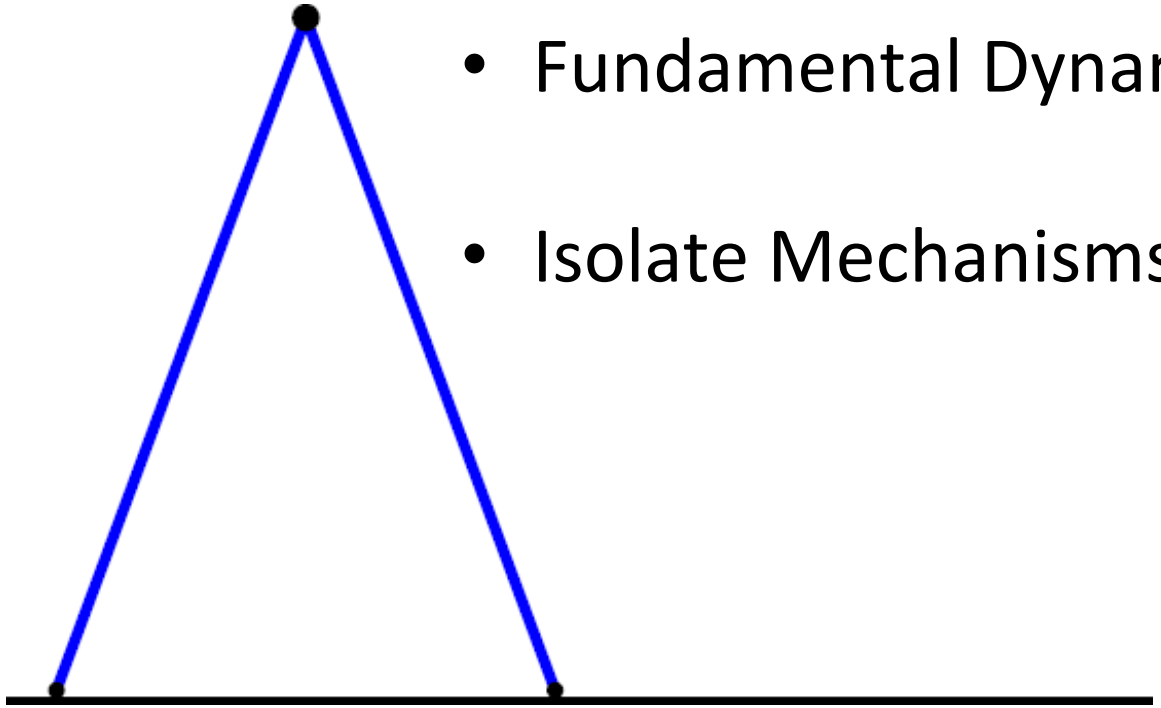


(Seth 2011)



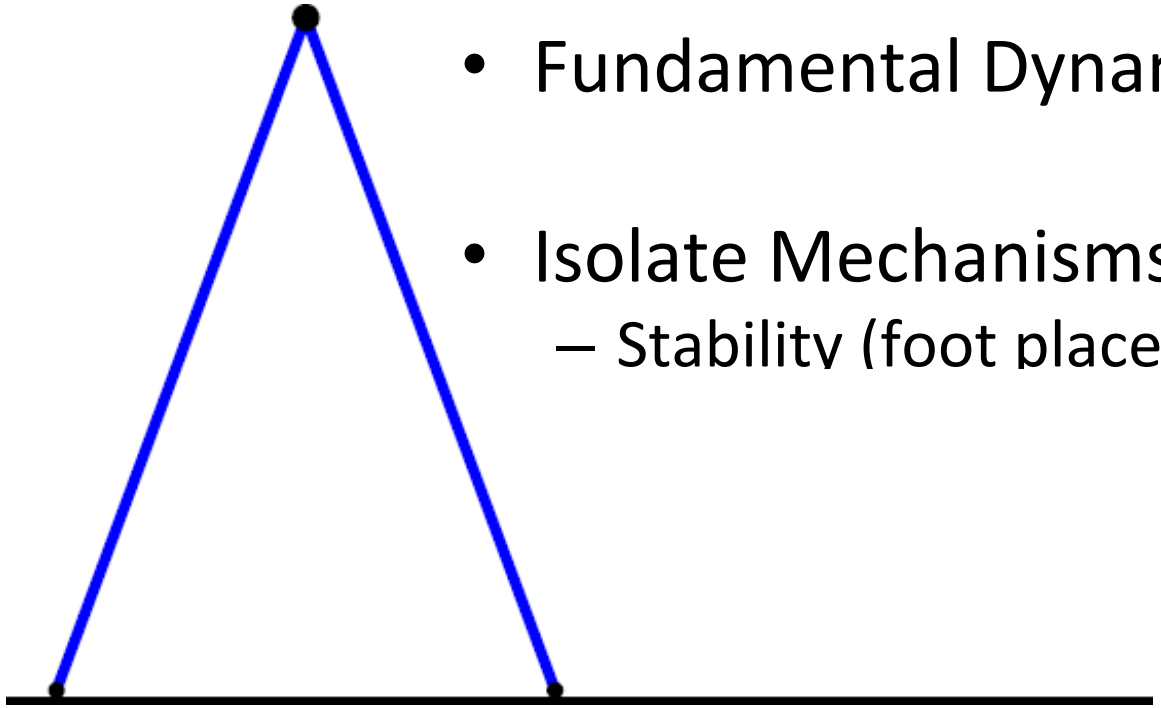
- Fundamental Dynamics

(Seth 2011)



- Fundamental Dynamics
- Isolate Mechanisms

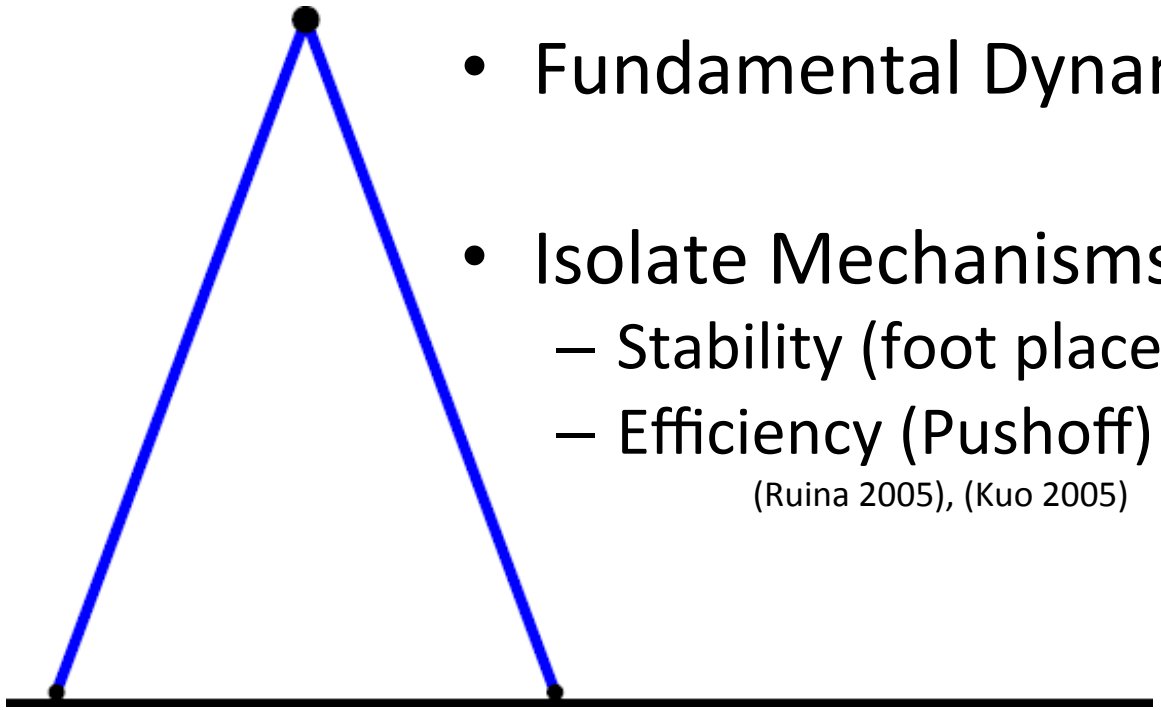
(Seth 2011)



- Fundamental Dynamics
- Isolate Mechanisms
  - Stability (foot placement)

(Kuo 1999)

(Seth 2011)



- Fundamental Dynamics
- Isolate Mechanisms
  - Stability (foot placement) (Kuo 1999)
  - Efficiency (Pushoff) (Ruina 2005), (Kuo 2005)

(Seth 2011)