Skippy: A Versatile 3D Hopper

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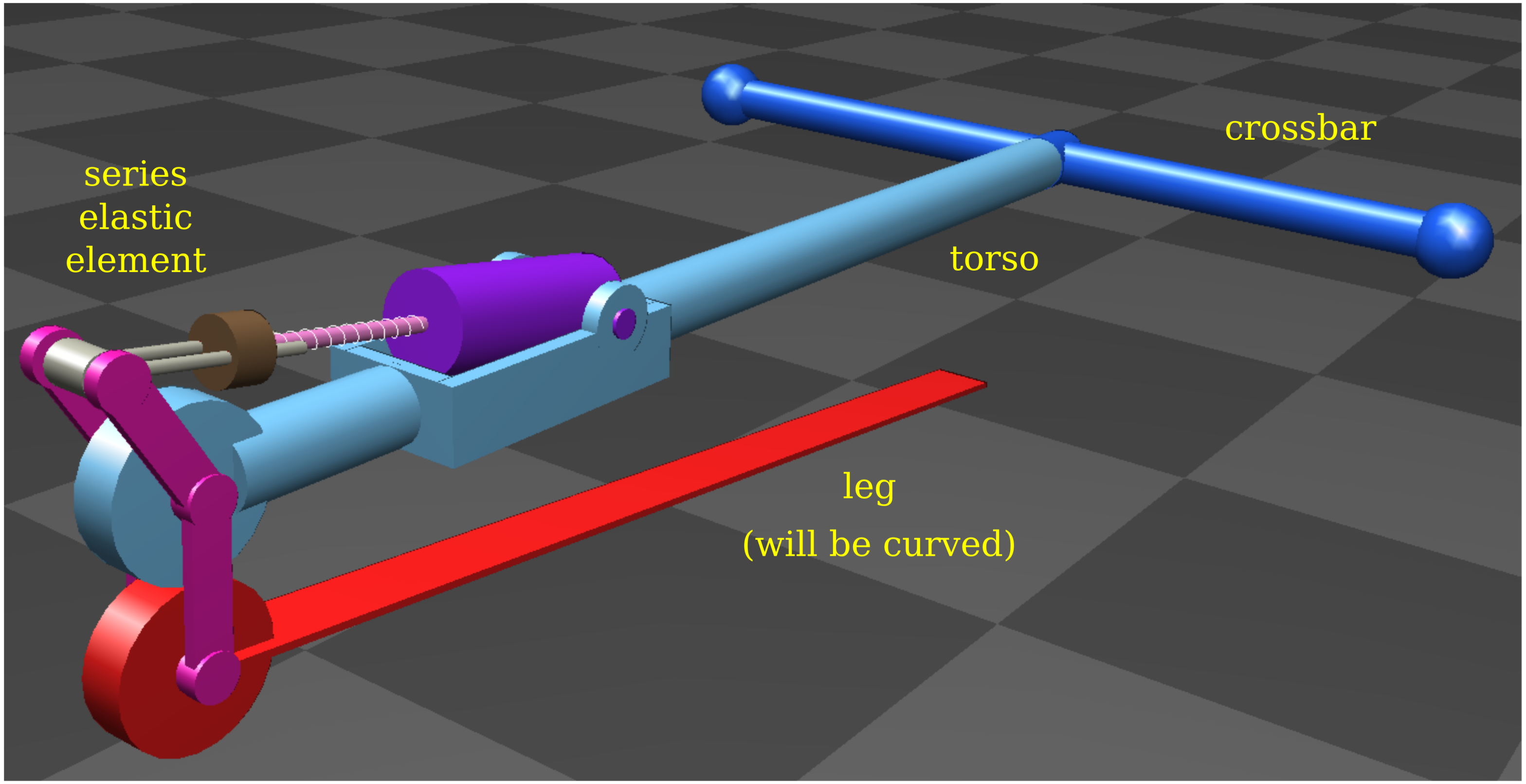


Skippy --- The Motivation

Normal Robotics Research

Step 1: create a robot that is
- very complex
- very expensive
- very fragile/self-destructive
- very heavy
- barely strong enough

Step 2: perform experiments
- very cautiously
- at low speeds
- hampered by risk management and the feebleness of the robot

The Skippy Approach

Step 1: create a robot that is
- maximally simple
- relatively cheap
- robust/non self-destructive
- light
- strong

Step 2: perform experiments
- aggressively
- safely at high speeds
- making rapid progress and discovering new things

Skippy --- The Idea

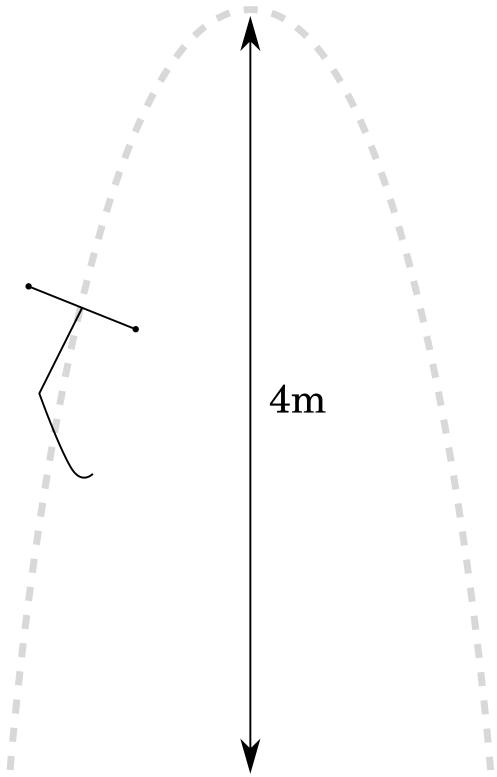
A robot that is/has/can do

- fully autonomous
- full 3D motion
- only 2 actuators – maximally simple
- light – ~2kg
- energetic – 4m hop
- versatile – balance, bow, pirouette, somersault, climb stairs, fall over and get back up, ...

Hopping – needs explosive power

Balancing – needs exquisite control

Hopping

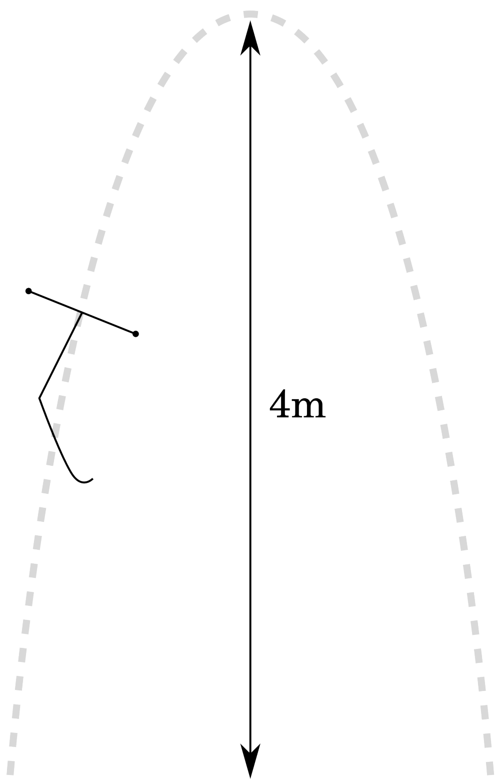


Skippy must hop high and land on its foot, or crash without damage

Why 4 metres?

- because it's outrageous
- because it's spectacular
- because it's possible
- because it pushes the limits
- because the numbers are easy

Hopping



Some easy numbers:

- 2kg @ 4m = 80J
- 4m hop → 9m/s launch velocity
- 9m/s → 1.8s flight phase
- 9m/s @ 0.5m stroke
  → 0.2s stance phase (10% duty cycle)
  → 10g average stance acceleration
  → 200N thrust
- assuming 40J from previous hop
  → 200W average stance power

A 120W Maxon motor weighs 175g and can be pulsed at >200W.
The only real problem is the maximum speed of the ball screw.

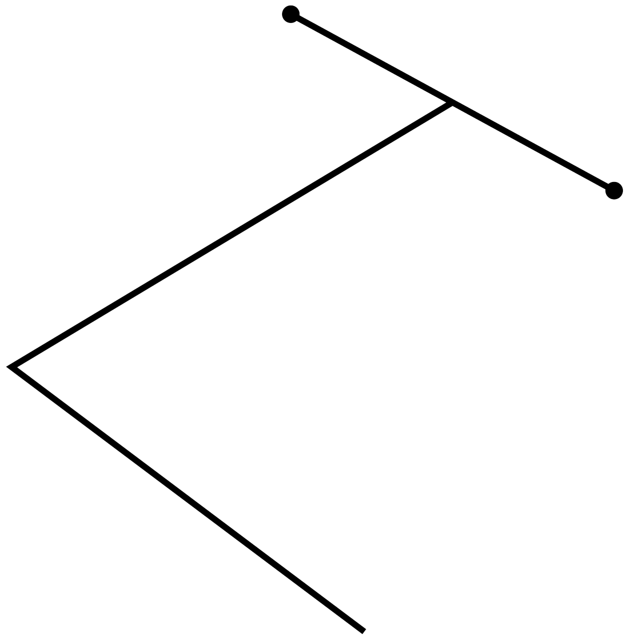
Balancing

Balancing alone is not enough. If Skippy is to be genuinely versatile then it must be able to

- balance while simultaneously executing motion trajectories
- deliberately tip itself off balance in preparation for a hop

(Of course, there is also in-flight attitude control....)

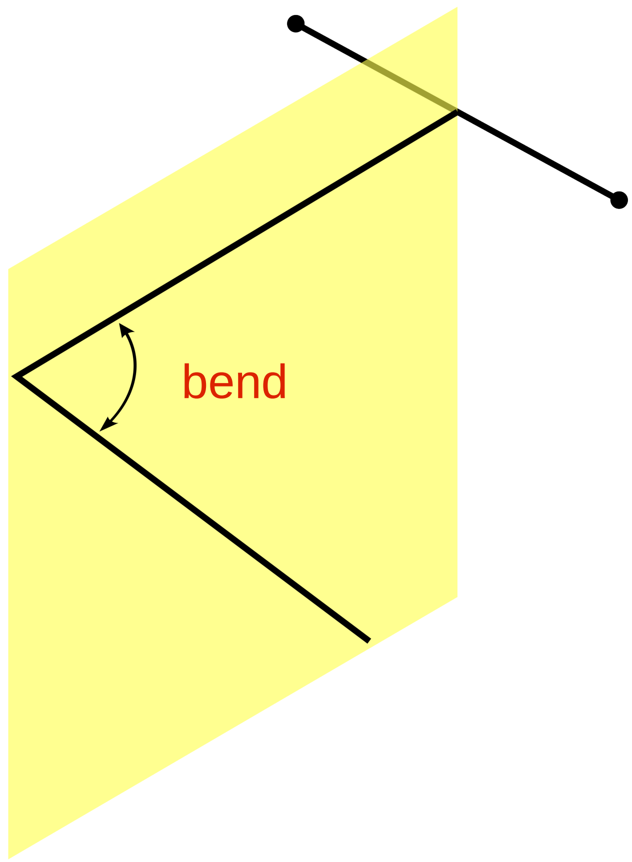
Balancing



Balancing in 3D can be decomposed into two subtasks:

- balancing in the plane, and
- keeping the plane vertical

Balancing

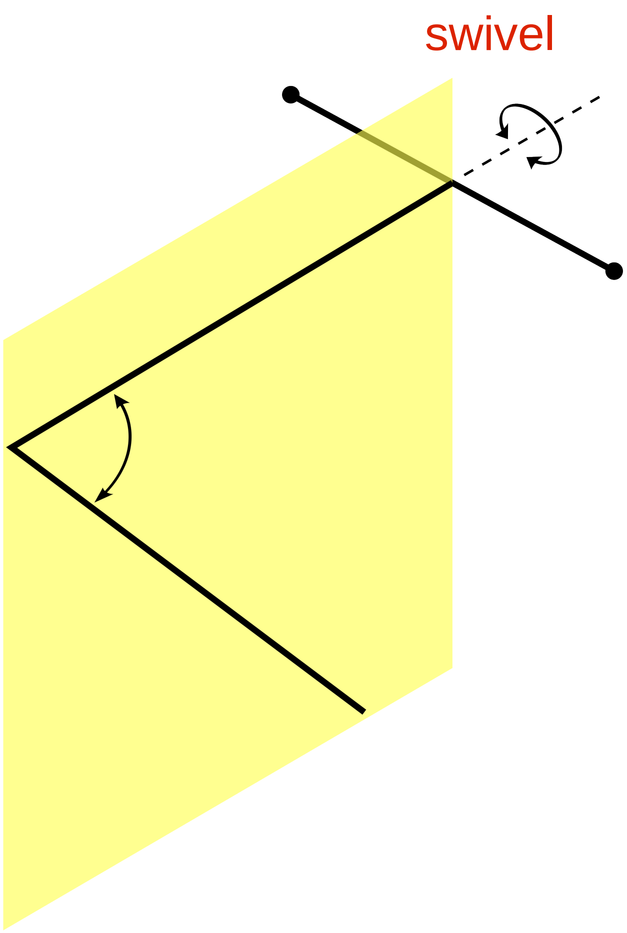


Balancing in the plane is accomplished by varying the *bend angle*.

In addition to balancing the robot, the bend controller can also

- follow a given bend-angle trajectory
- deliberately tip the robot backwards or forwards

Balancing

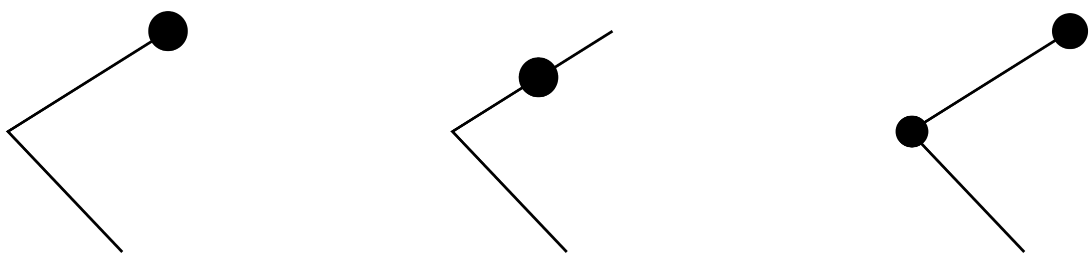


Keeping the balance plane vertical is accomplished by *rotating the crossbar*. In addition to keeping the balance plane vertical, this *'swivel'* controller can also

- deliberately tip the balance plane, causing it to rotate
- control the robot's heading via this rotation

Design Issues --- Mass Distribution

Even if the total mass is fixed, the *mass distribution* makes a big difference to performance



good hopper
bad balancer

OK hopper
bad balancer

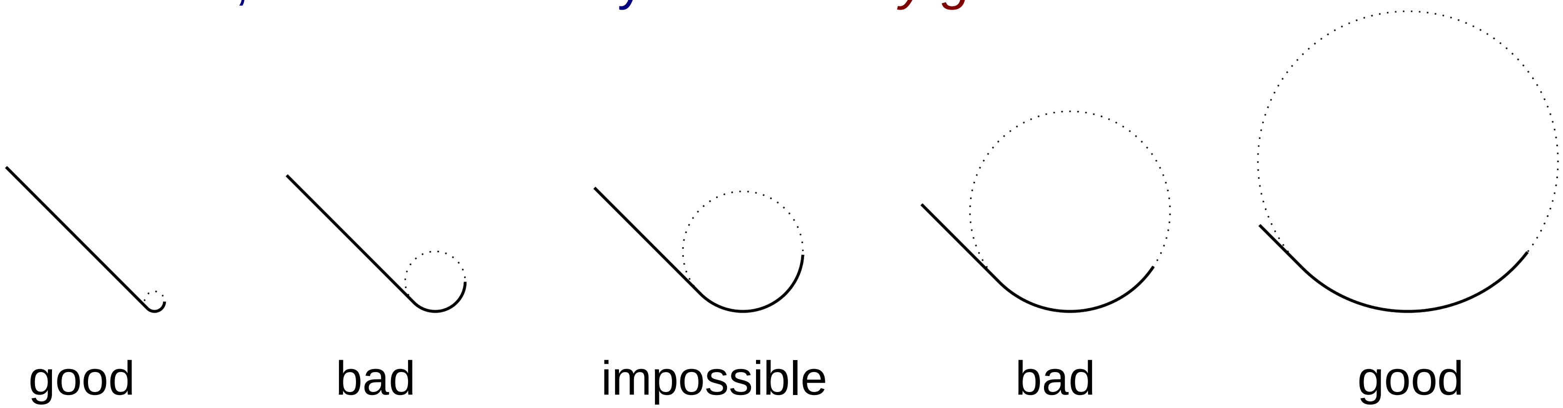
OK hopper
OK balancer

heavier toe → more energy lost at landing

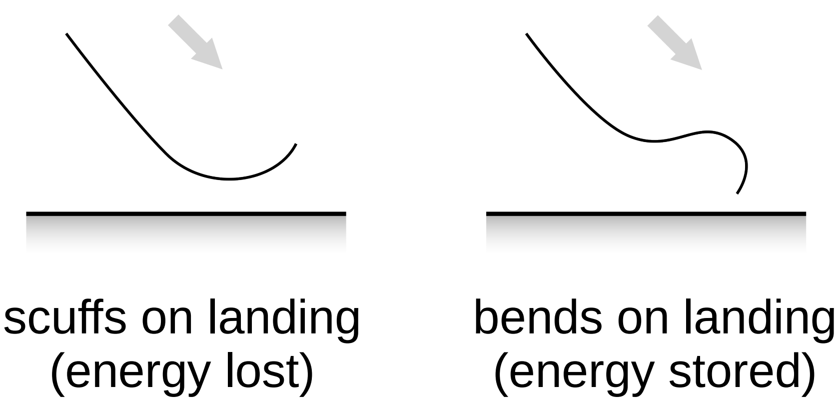
lighter toe → less manoeuvrable in flight

Design Issues --- The Shape of the Foot

The curvature of the foot strongly affects the robot's ability to balance, as measured by the *velocity gain*.



Something else
to think about:



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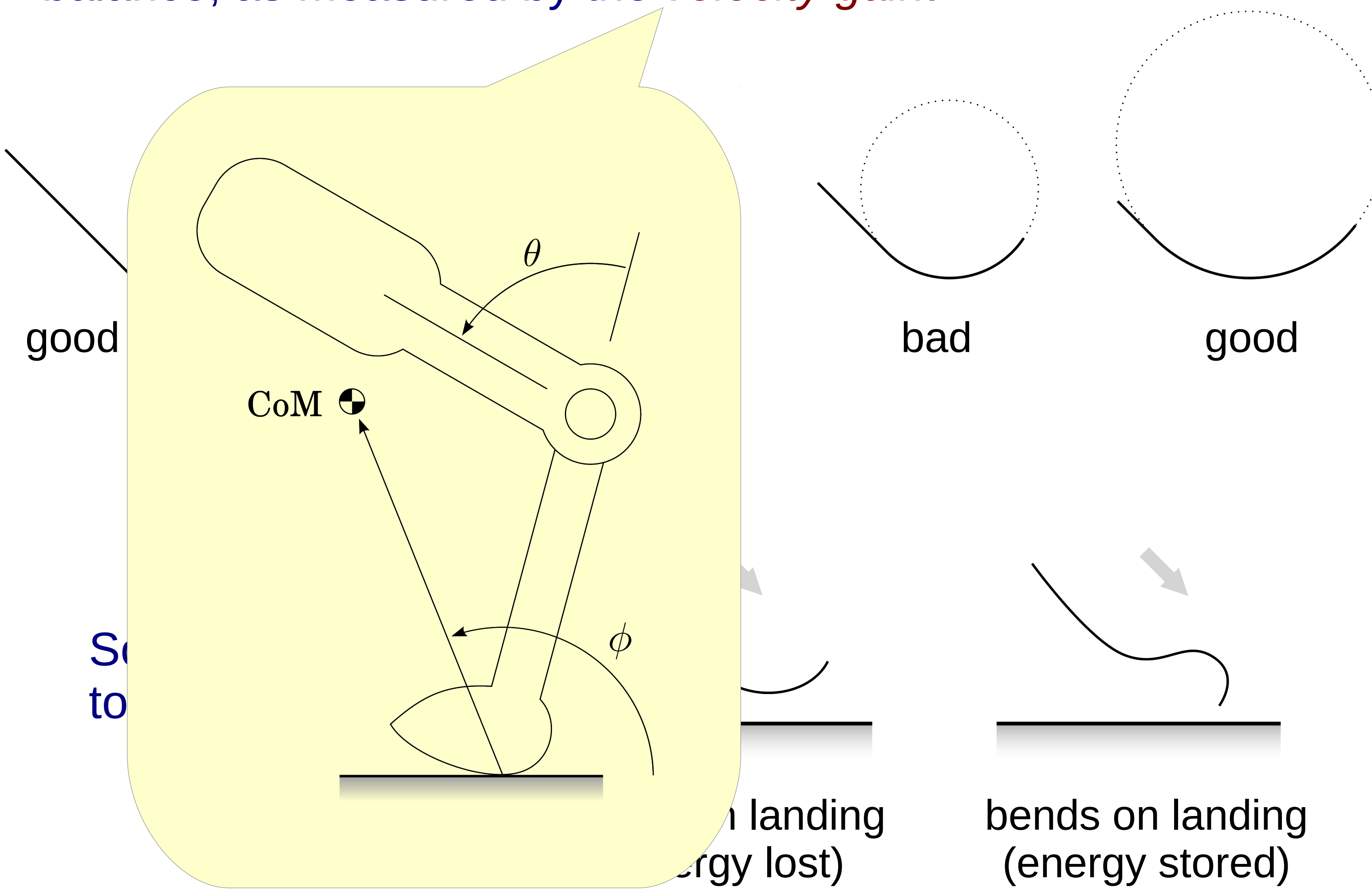

Sc
to

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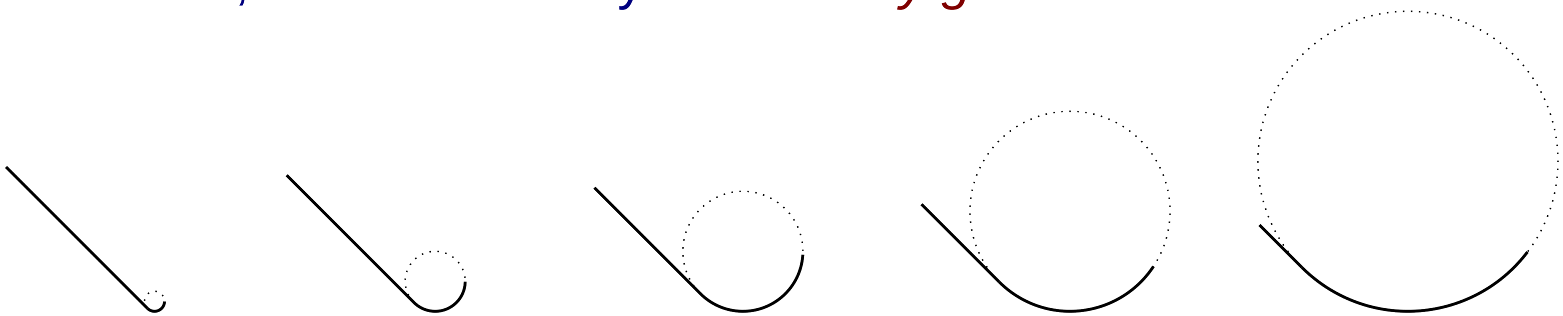
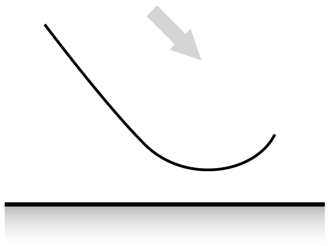
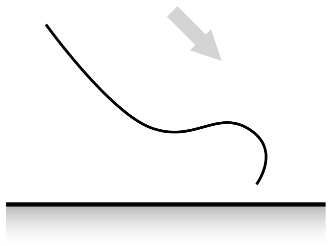


good   bad   impossible   bad   good

Something else to think about:



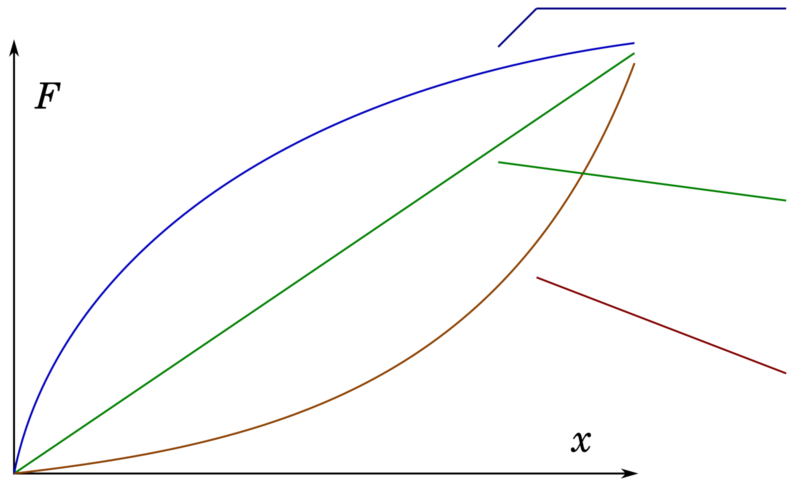
scuffs on landing (energy lost)



bends on landing (energy stored)

Design Issues --- Exploiting Nonlinearity

(Aren't we a bit too fond of linearity?)



Weakening spring – good for energy storage

Linear spring – good for teaching students

Strengthening spring – good for end stops/shock absorbers

The transmission mechanism is nonlinear too ….