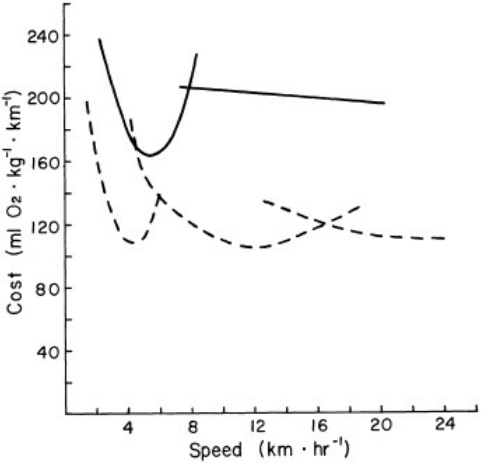
Structural changes for bipedalism

- Orthograde (upright posture)
- Muscles for core support
- Mechanisms for endurance
    - Carrier et al. [1984]: "Carrier's constraint"

The reptilian idea of fun
Is to bask all day in the sun.
A physiological barrier,
Discovered by Carrier,
Says they can't breathe, if they run.

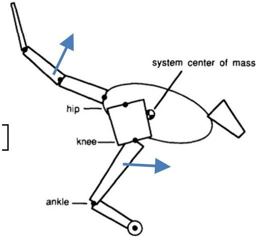
—Richard Cowen



- Flat running CoT
- Bigger stores; better dissipation

Tails in nature's bipeds

From Raibert and Hodgins [1993]



Counterbalance legs

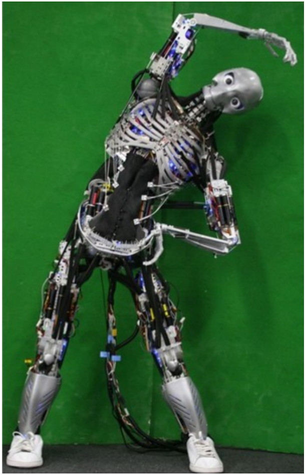
Power walking at slow speeds

https://www.youtube.com/watch?v=yZ4_7051rEE

https://www.youtube.com/watch?v=bgWJ9DN1Qak

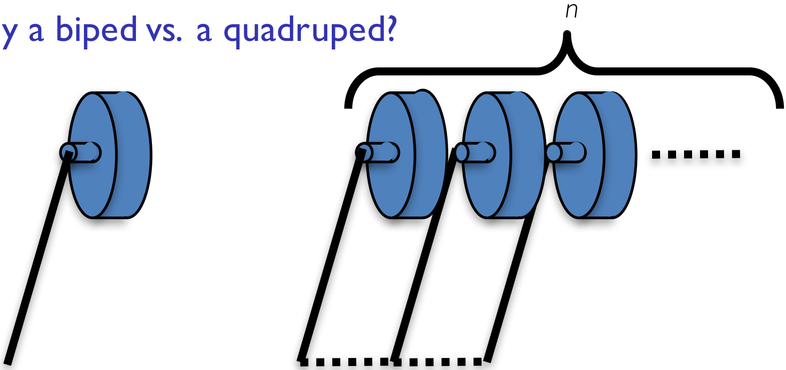
Some robotic bipeds

Kenshiro—Nakanishi et al. [2012] (~100 actuated DOF)



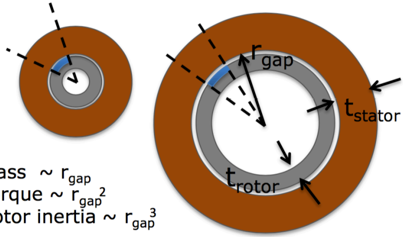
ATRIAS (6 actuated DOF)

Why a biped vs. a quadruped?



- Framing costs—Kenneally et al. [2015]
- "Parallel motors" as in multiple legs, not multiple DOFs/leg

- Torque/motor: $\tau/n \sim r^2$
  Mass/motor: $m/n \sim r$ (Seok et al [2012])
- $\tau/n \sim (m/n)^2$, so $\tau \sim n^{-1}$ (fix total mass budget m)

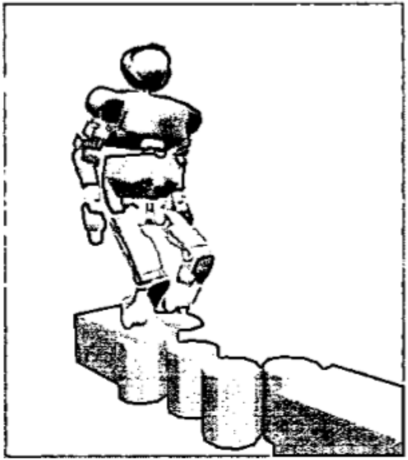


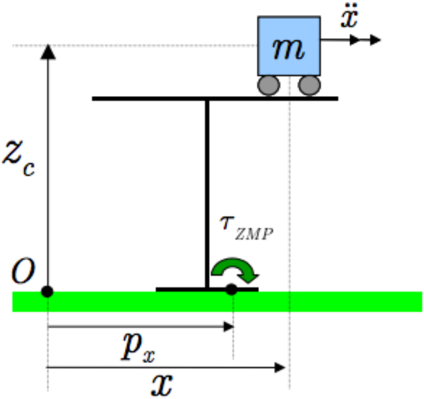
Mass $\sim r_{gap}$
Torque $\sim r_{gap}^2$
Rotor inertia $\sim r_{gap}^3$

Torque density $\sim r_{gap}$
Torque/inertia $\sim 1/ r_{gap}$

Balance with feet

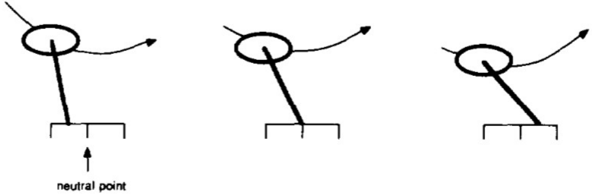
ZMP—e.g. in Kajita et al. [2003]



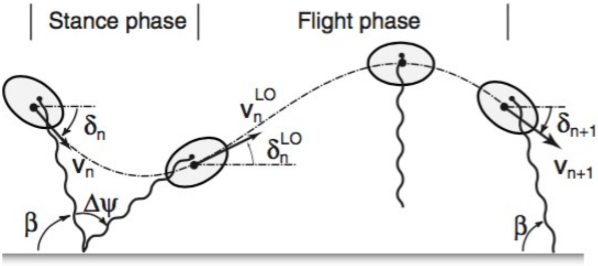


Dynamic balance

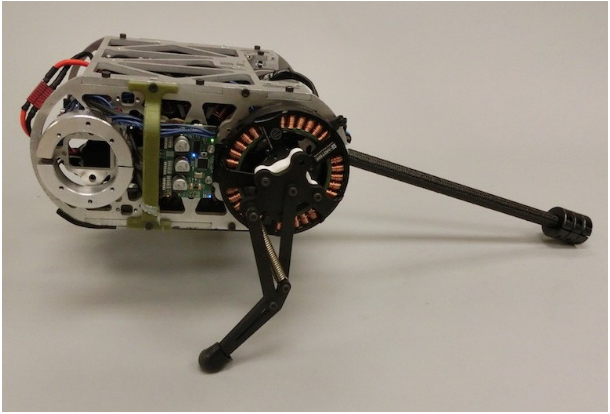
- Leg modelled as sprung mass
- Neutral point Raibert [1986] (recall from 2.1)



- "Simply stabilized" Ghigliazza et al. [2005]

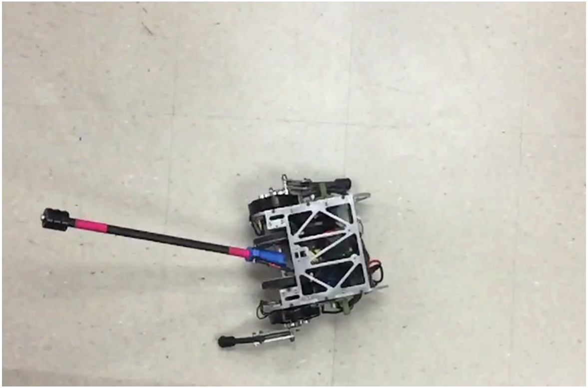


Jerboa design



- Direct drive—Kenneally et al. [2015]
- Springy legs; passive extension—De and Koditschek [2015c]
- 2DOF actuated tail
- Leg+tail vs. 2DOF leg

Some uses of a robotic tail



- Turning
- Reorientation
- More in next segment

Lessons from bipedal animals and robots

Biomechanists tell us

- Animals went bipedal for physiological reasons—Carrier et al. [1984]

Roboticists learn

- Build robots with as few actuated DOFs as possible
- Tails can be used to inertially to control body orientation (and more!)