Adding leg mass to the SLIP: The M-SLIP model

Frank Peuker

Locomorph Summer School 2012
Odense, Denmark

RUNNING

KINEMATICS
orientation of runner

DYNAMICS
ground reaction forces (GRF)

Two phases per cycle:

flight phase:
falling

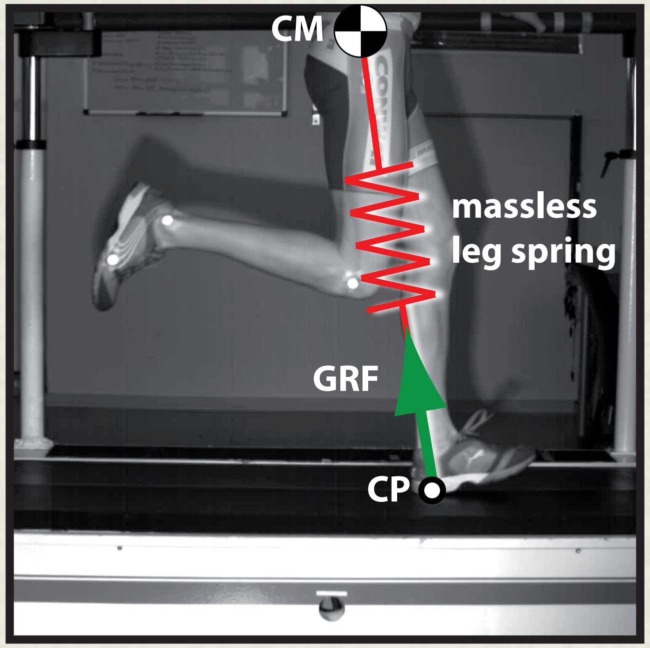
stance phase:
redirect fall motion by leg-ground interaction

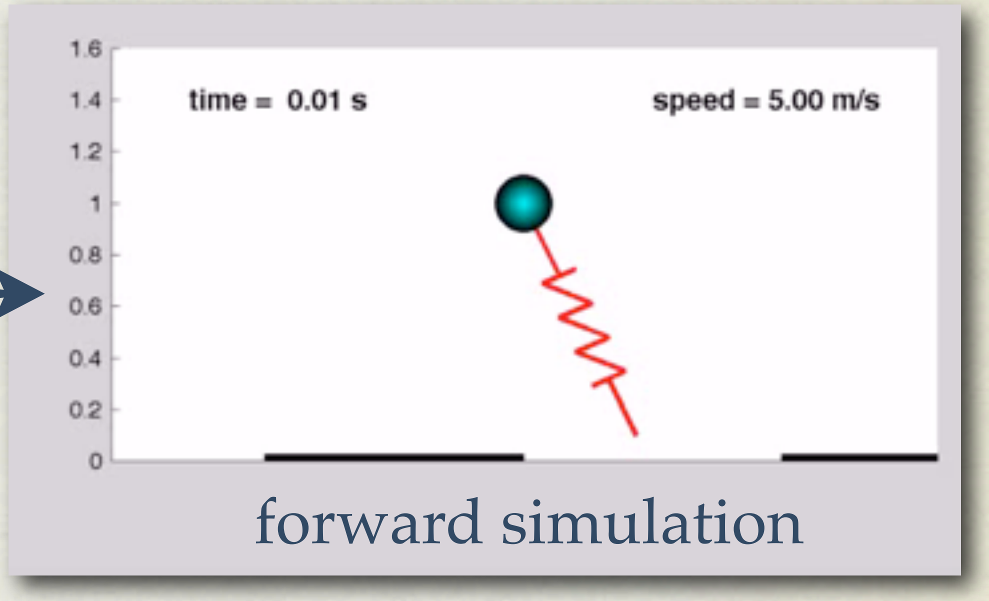
CAPTURING RUNNING BEHAVIOR IN MODEL

behavior

pick major features

find template model





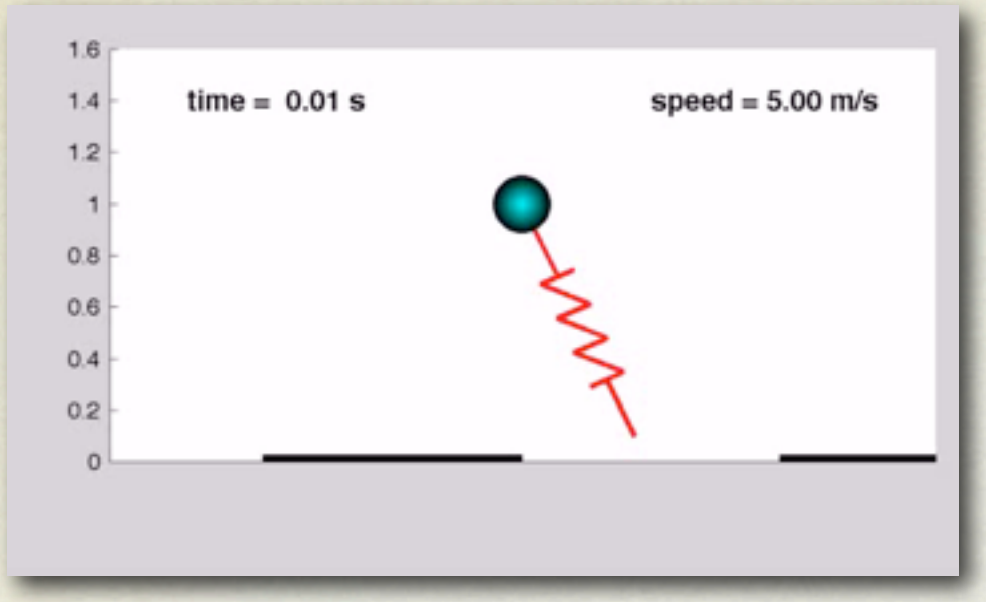
forward simulation

running

center of mass (CM)
(and GRF)

SLIP model:
1 point mass +
1 massless spring

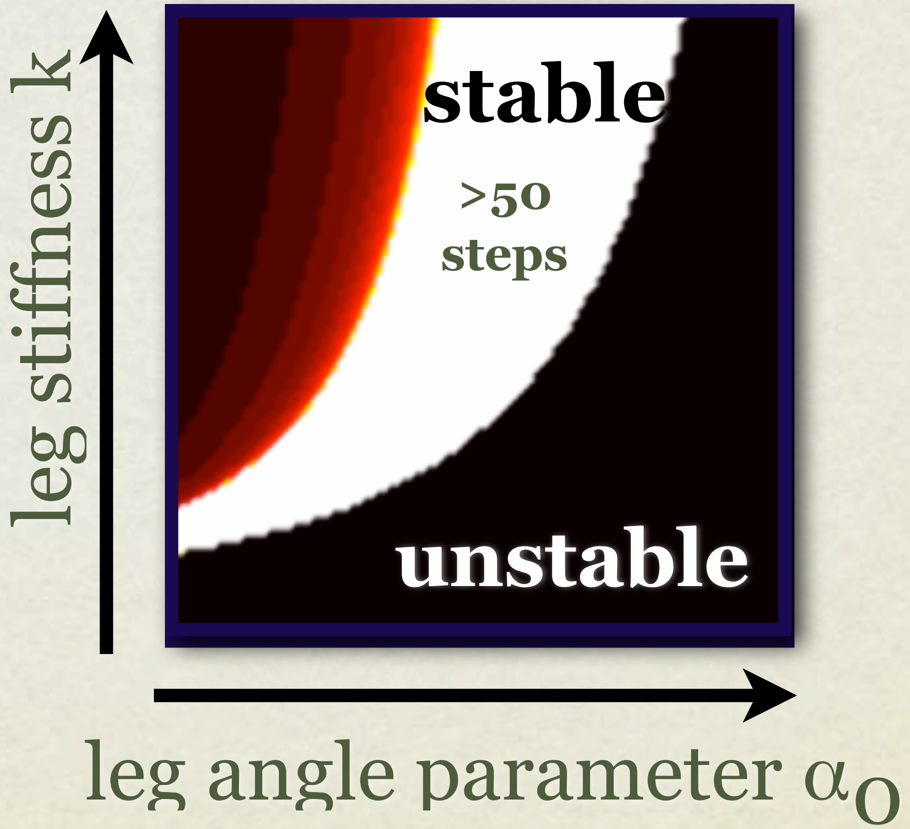
SLIP MODEL



SLIP = spring-loaded inverted pendulum

SLIP reproduces GRF and CM motion of running humans and animals

steps-to-fall map



Is stable in forward simulations !!

Powerful idea:

evolution developed towards intelligent mechanics

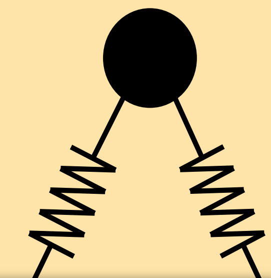
TRANSFER TO ROBOTS

realistic models
(e.g. **Peuker** 2010-2012)

?

keep stability

simplistic model (SLIP)
(Blickhan ´89, Seyfarth ´02, Geyer ´05)

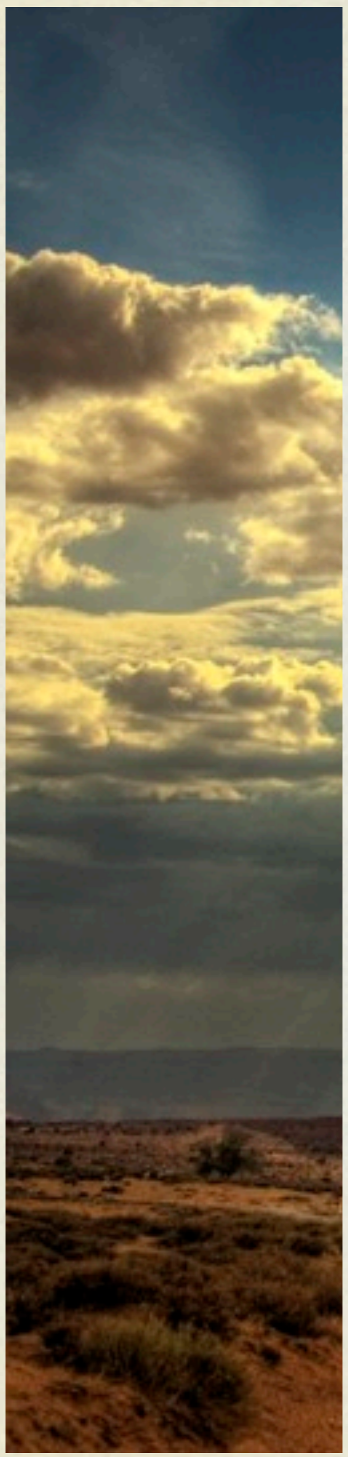


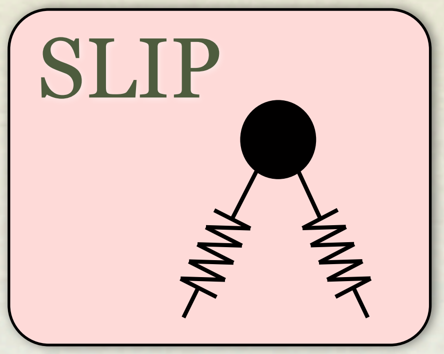
simplified transfer

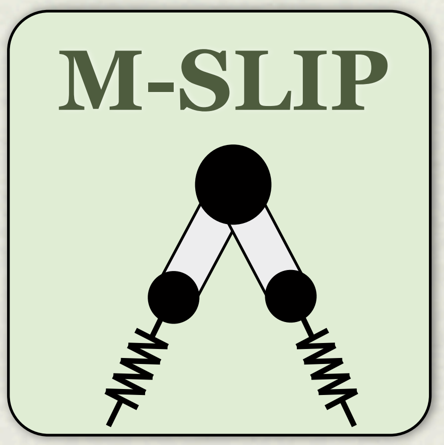
capture behavior

concurrent approaches

WHAT FEATURE TO ADD?







leg mass

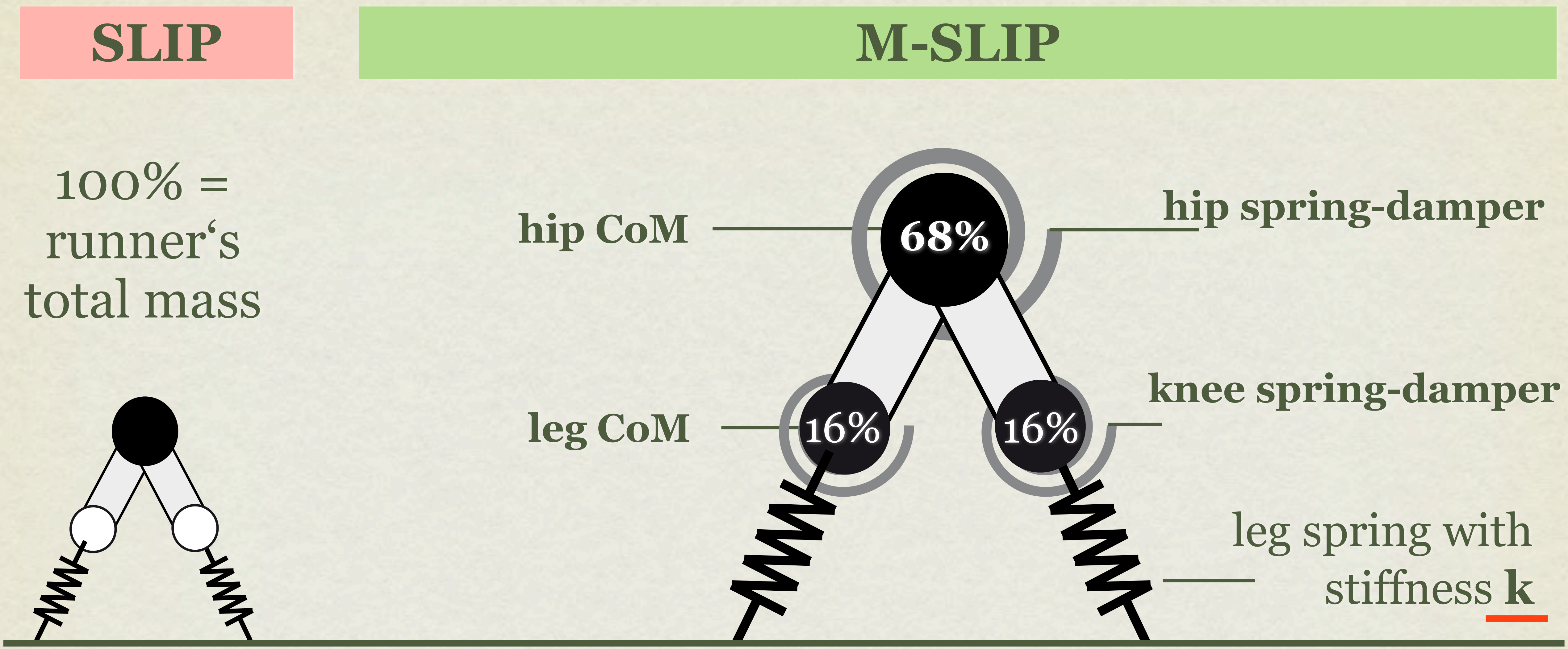
Human legs are made by

1/3 of total body mass

Clauser et al., 1969

! Owaki, 2008 use leg mass to predict PDR gaits

MECHANICS

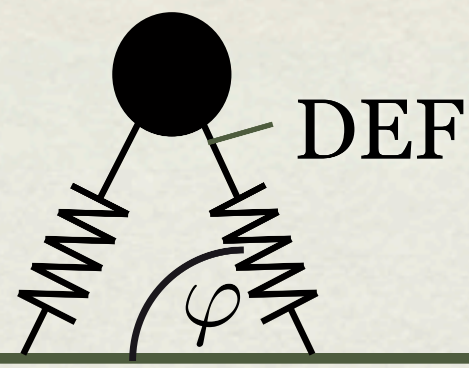
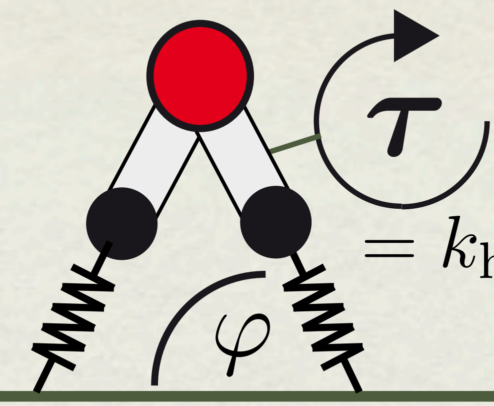


Two follow-up features of adding leg mass:

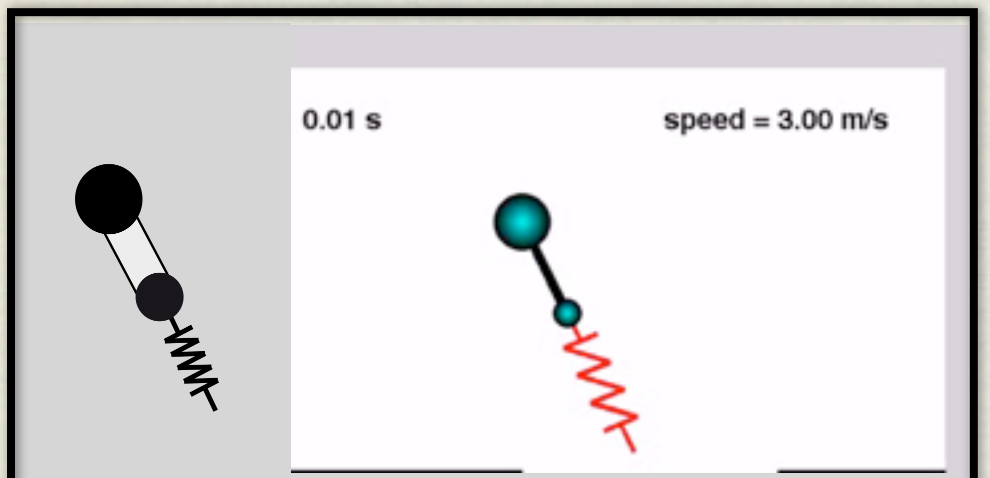
1 ENERGY CHANGES

2 SWING-LEG DYNAMICS

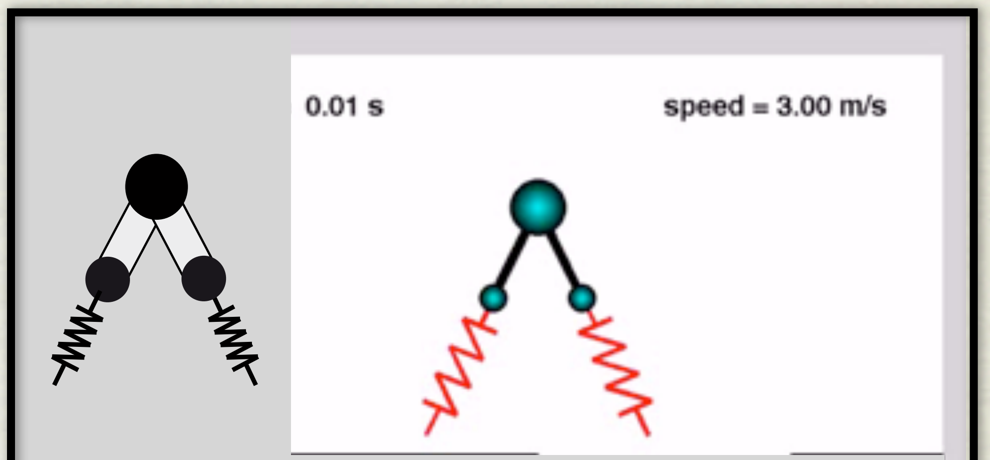
CONTROL

	SLIP	vs.	M-SLIP
hip control to approach leg angle φ_0			 $= k_{\text{hip}} \cdot (\varphi - \varphi_0)$
swing phase	**leg retraction** $\varphi_0 = \underline{\alpha_0} + \omega(t - t_{\text{apex}})$		
stance phase	no control		compensate damping losses $\varphi_0 = 120\ \text{deg}$

SOLUTIONS



single-legged

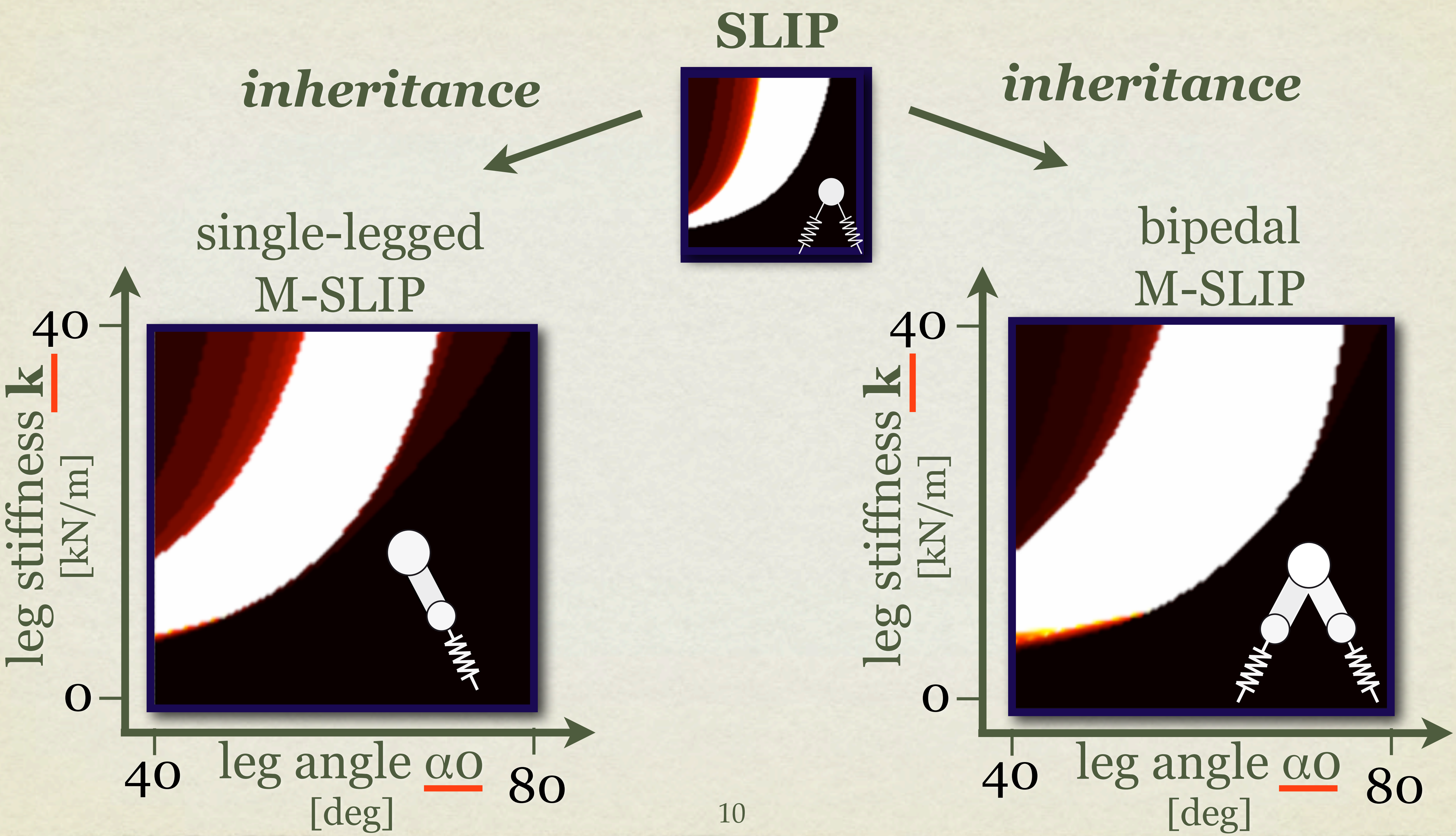


bipedal

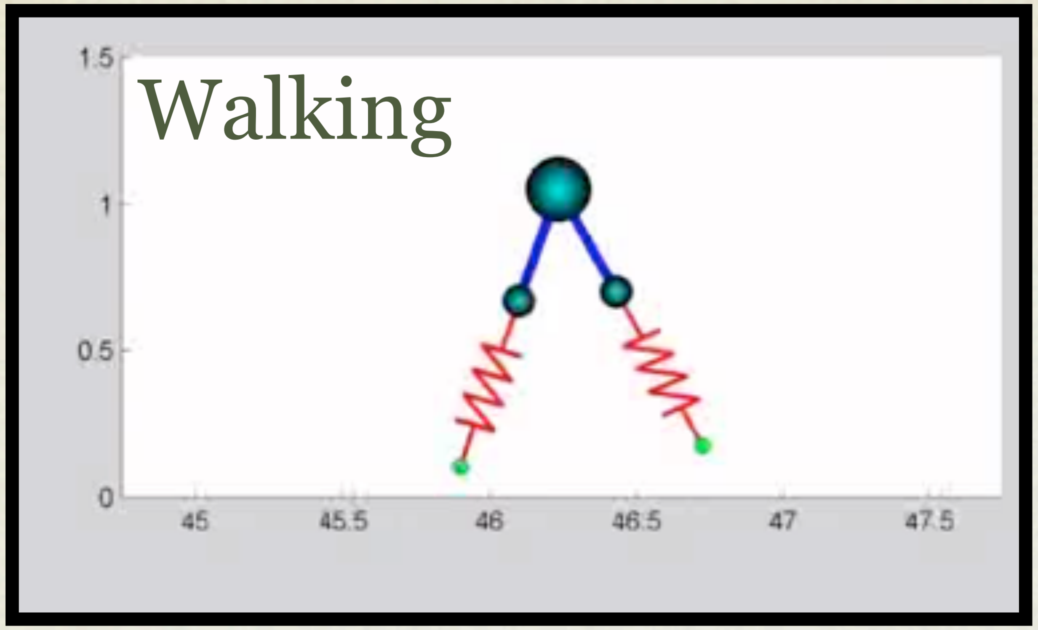
human reference: 80 kg, 20 kN/m, initial 3 m/s, ω=50 m/s

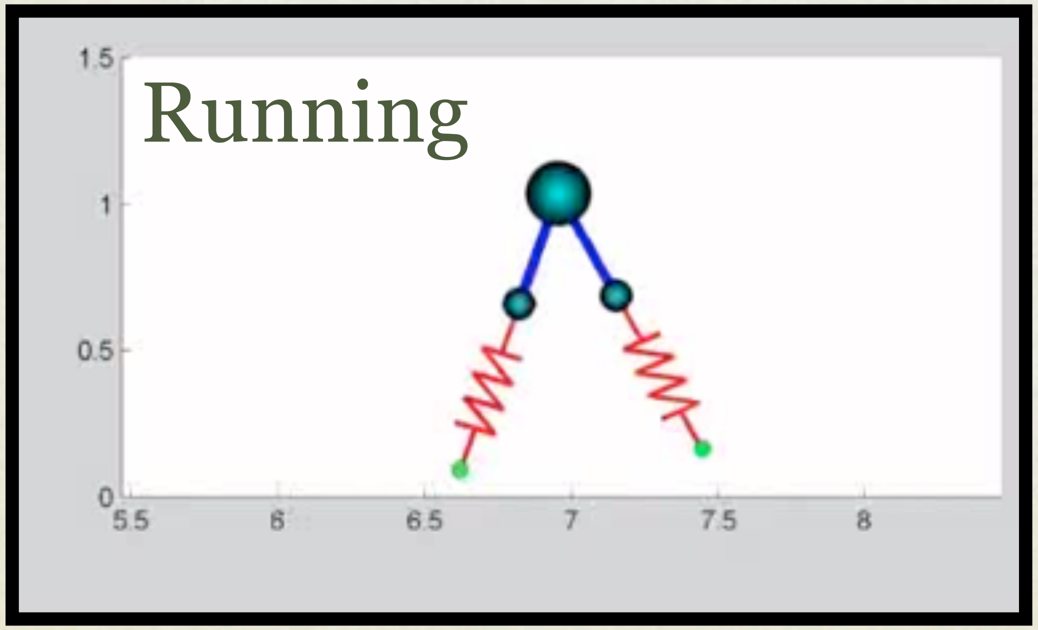
systematic search: 0.75 kNm/rad (hip), 1 kNm/rad (knee), critical damping

INHERITANCE OF SLIP RUNNING STABILITY



BONUS MATERIAL





<u>Bipedal M-SLIP model can do many things:</u>

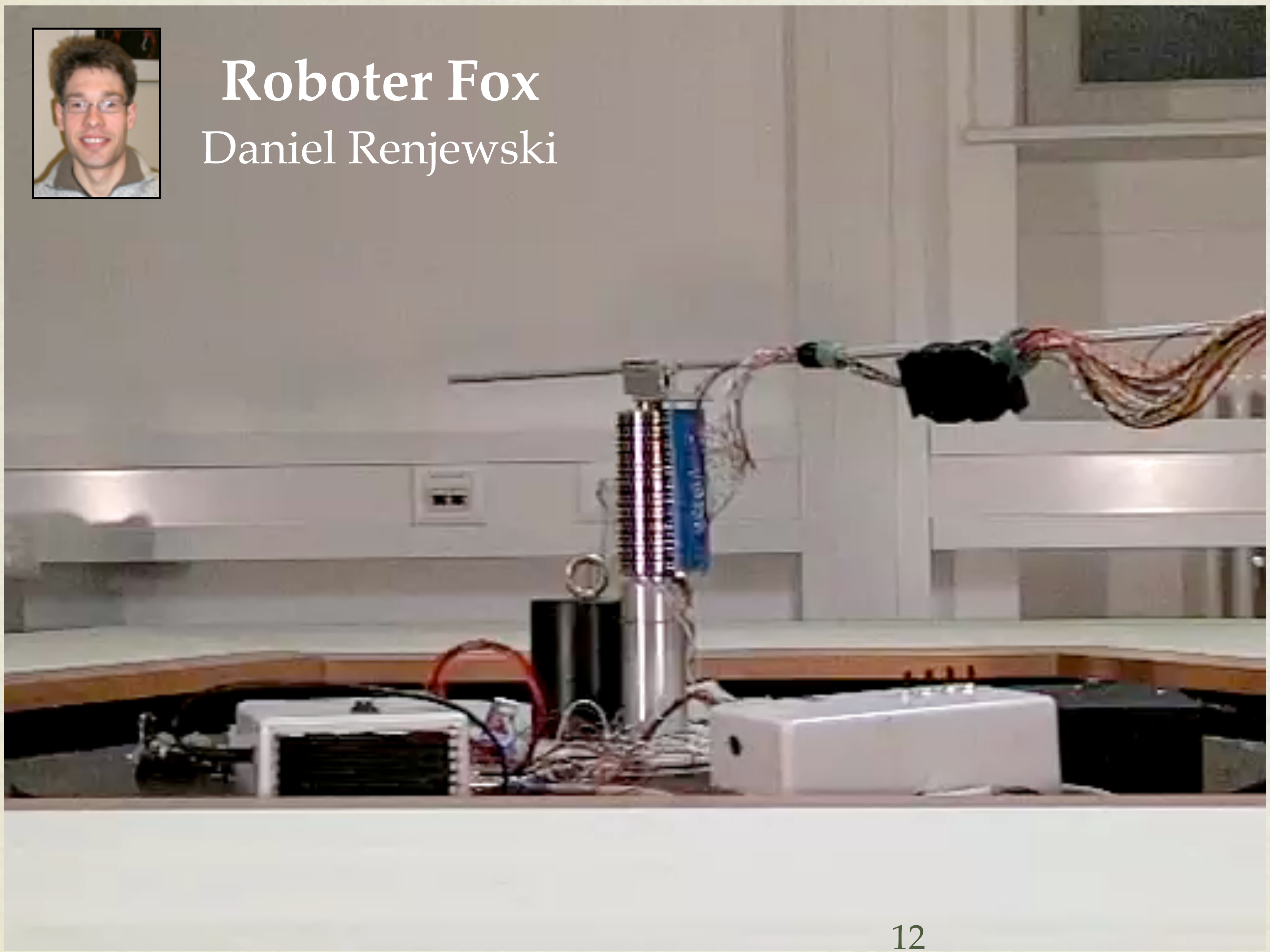
External perturbations:
Up and down stairs without adjustment

Run-walk transitions:
by changing rest angle of hip spring in stance

FUTURE WORK

Gerrit Kollegger (LL)
Marc Deisenroth (IAS)
Zi Yun Zhon (LL+IAS)

Implementation of M-SLIP model



Currently:

Already snaps to stable walking !

Goal:

Behavior predictable by model

M-SLIP GUI

- Playing around with parameters in Matlab
- Unfortunately: You have to compile the M-SLIP kernel:

  `> mex -setup` (in Matlab 2012a the flag is different)

  `> mex mslip.c`
- Picked only some of them:

  (1) Stiffness values (Hip, knee and leg)

  (2) Leg axial damping

  (3) Control, i.e.: Rest angle of hip spring in stance and flight

  (4) Initial values (height and speed)