Order Matters ! ?
The Choice of Gait and Contact Sequence

C. David Remy

April 3rd, 2015
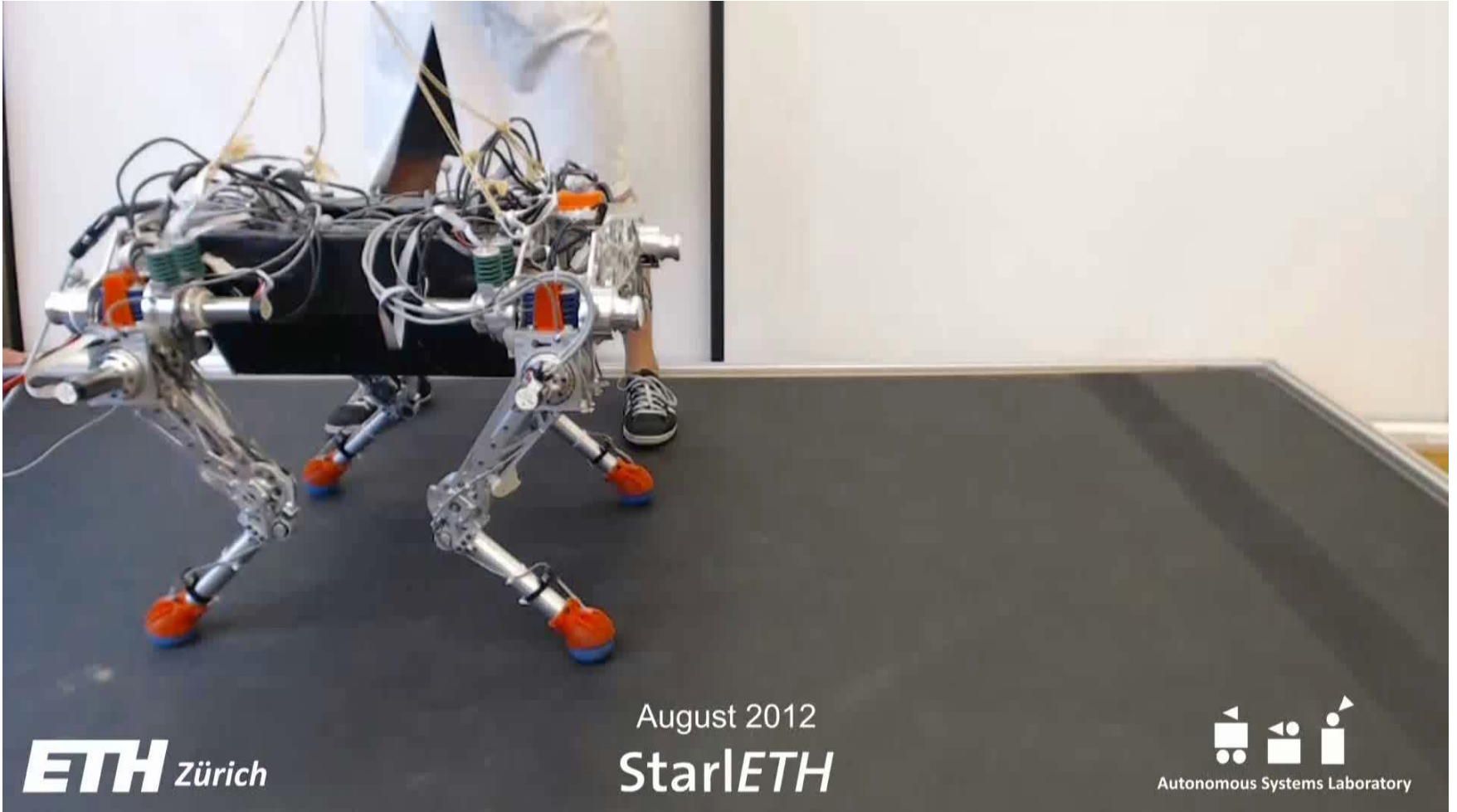
RAMlab

Robotics and Motion Laboratory

The great divide of locopulation
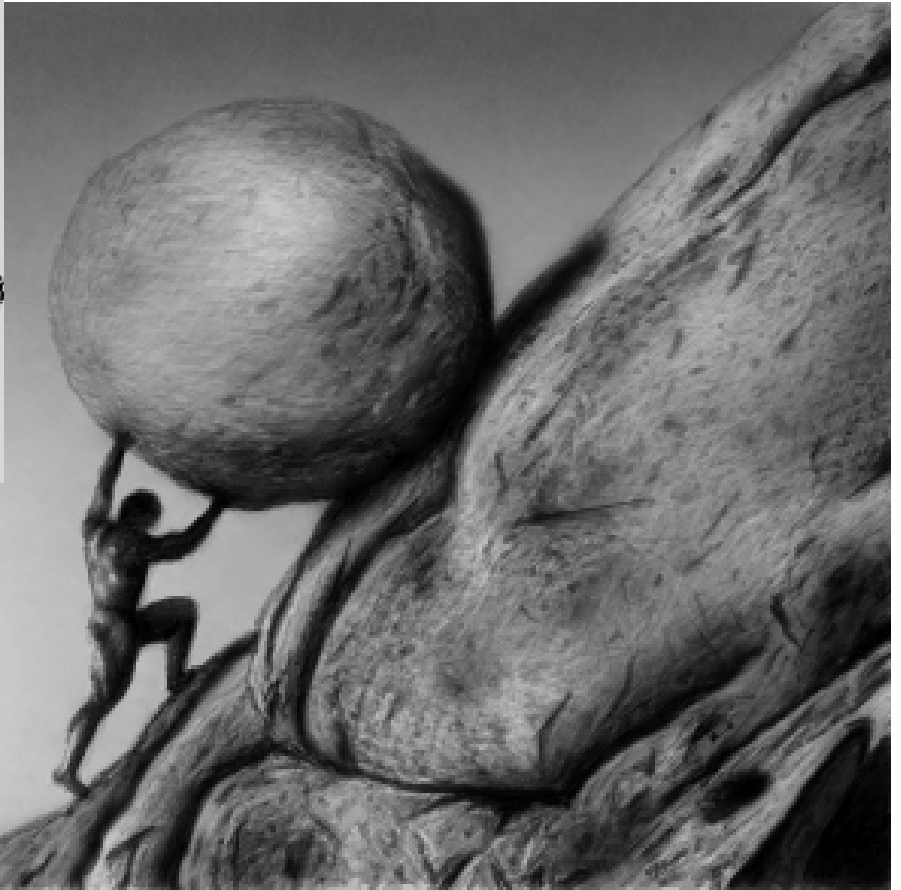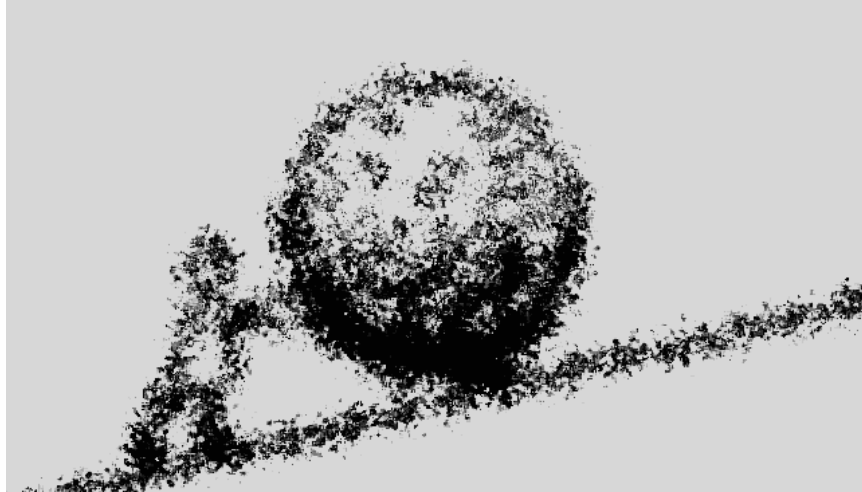
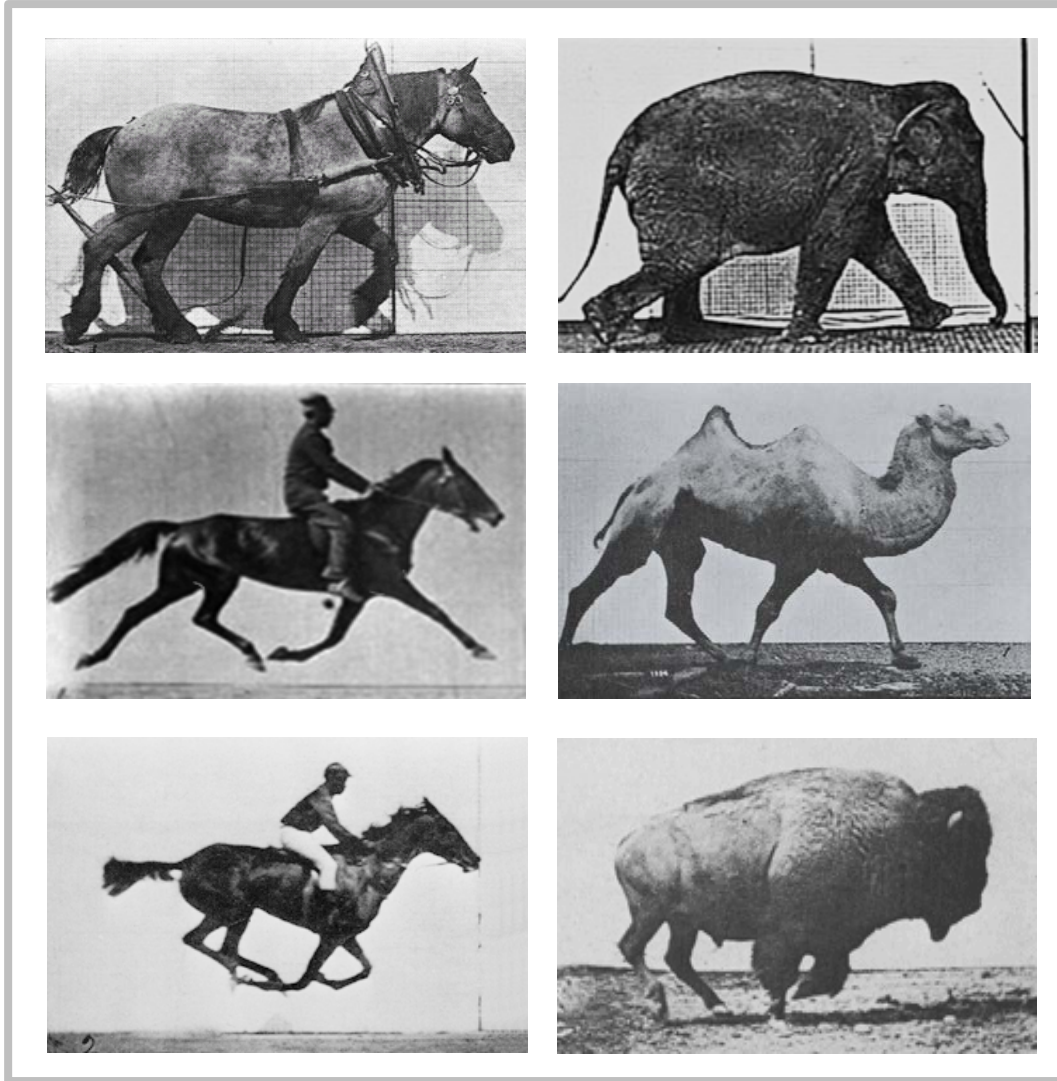[Homer, 1260BC]

Starl*ETH*

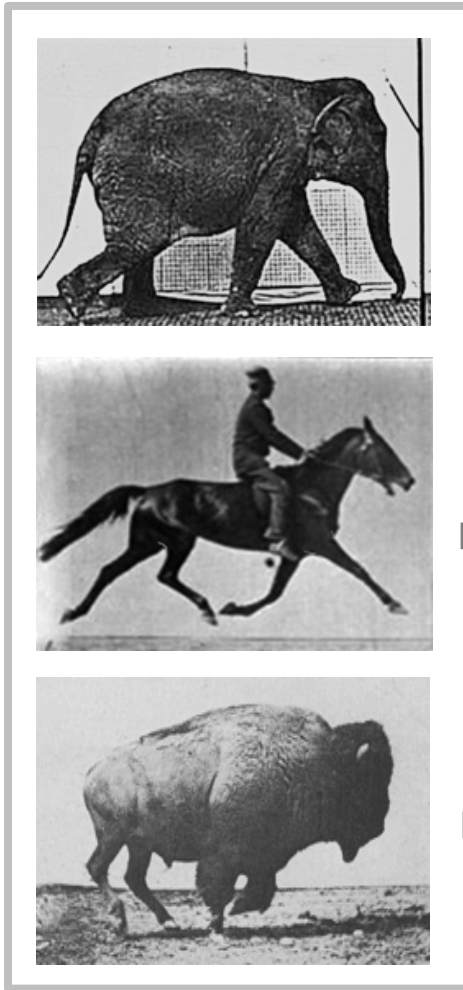August 2012
Starl*ETH*

ETH Zürich

Autonomous Systems Laboratory

Locomotion comes in a variety of ways

[Eadweard Muybridge, 1887]

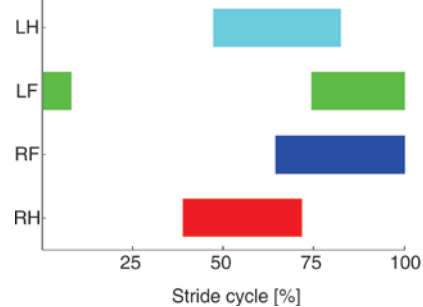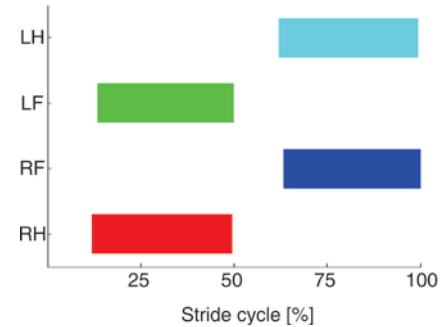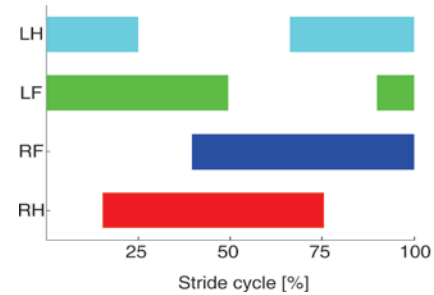# Different gaits → different footfall patterns

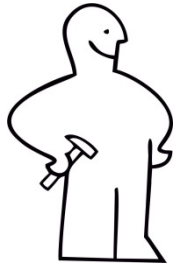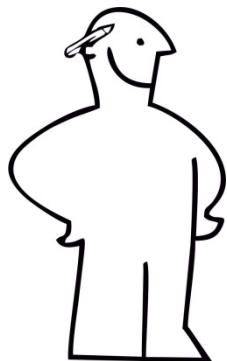**Footfall patterns**
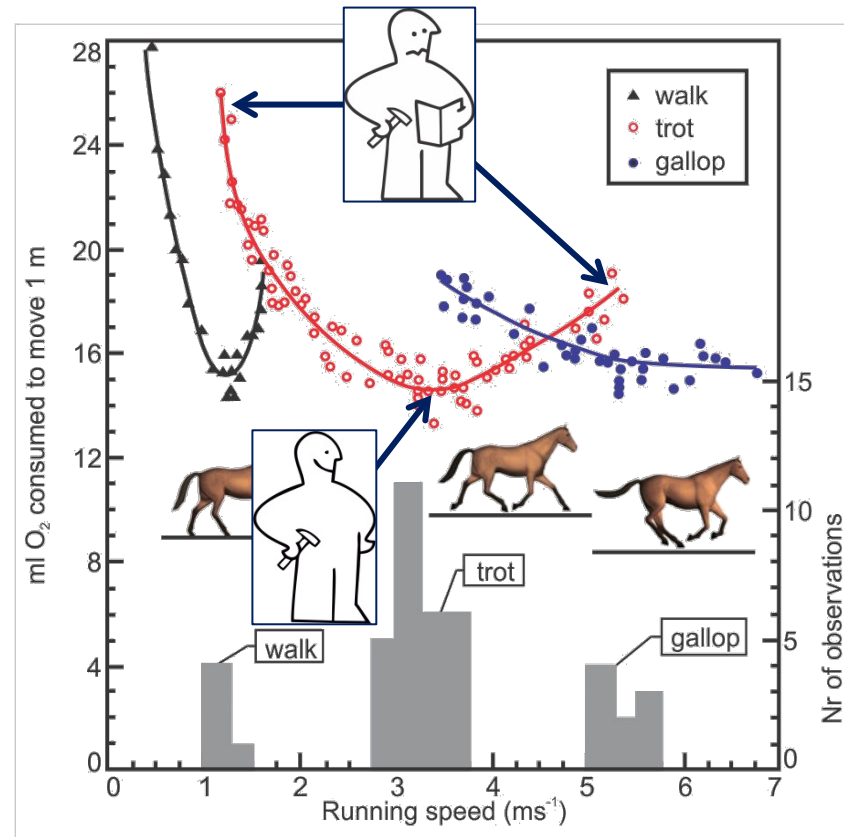
Walk

Trot

Gallop

Velocity and energy in nature

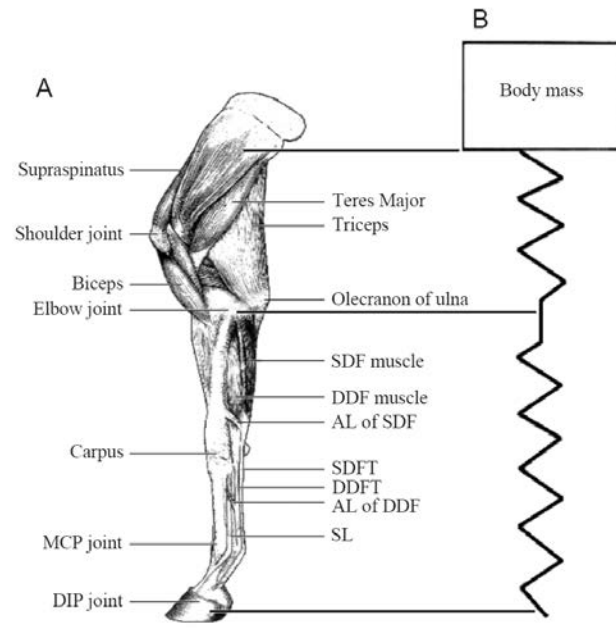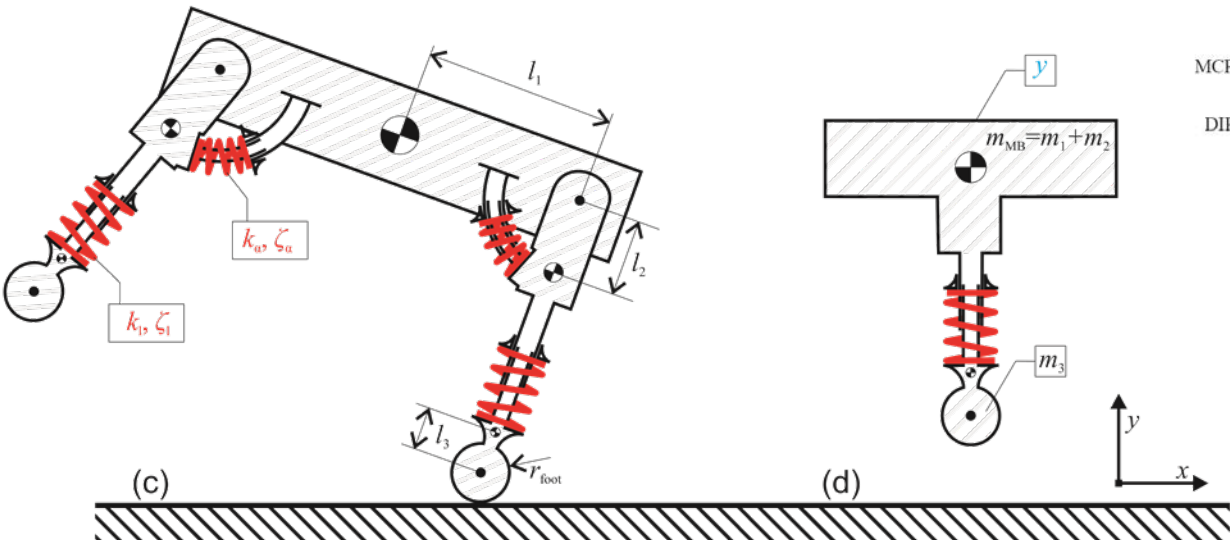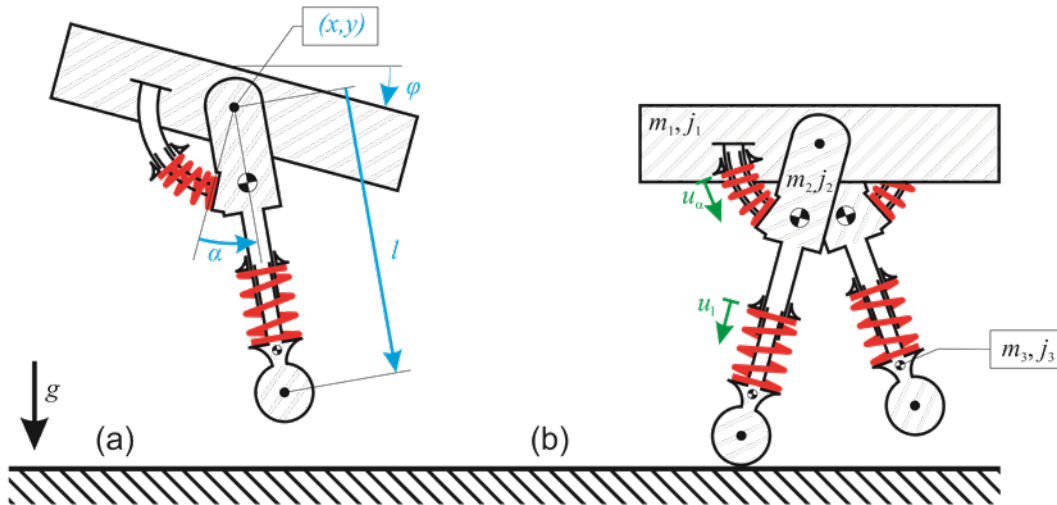Each gait as an optimal velocity

Moving at other velocities increases energy consumption

Switching from one gait to another enables energy efficient locomotion over a wide range of velocities
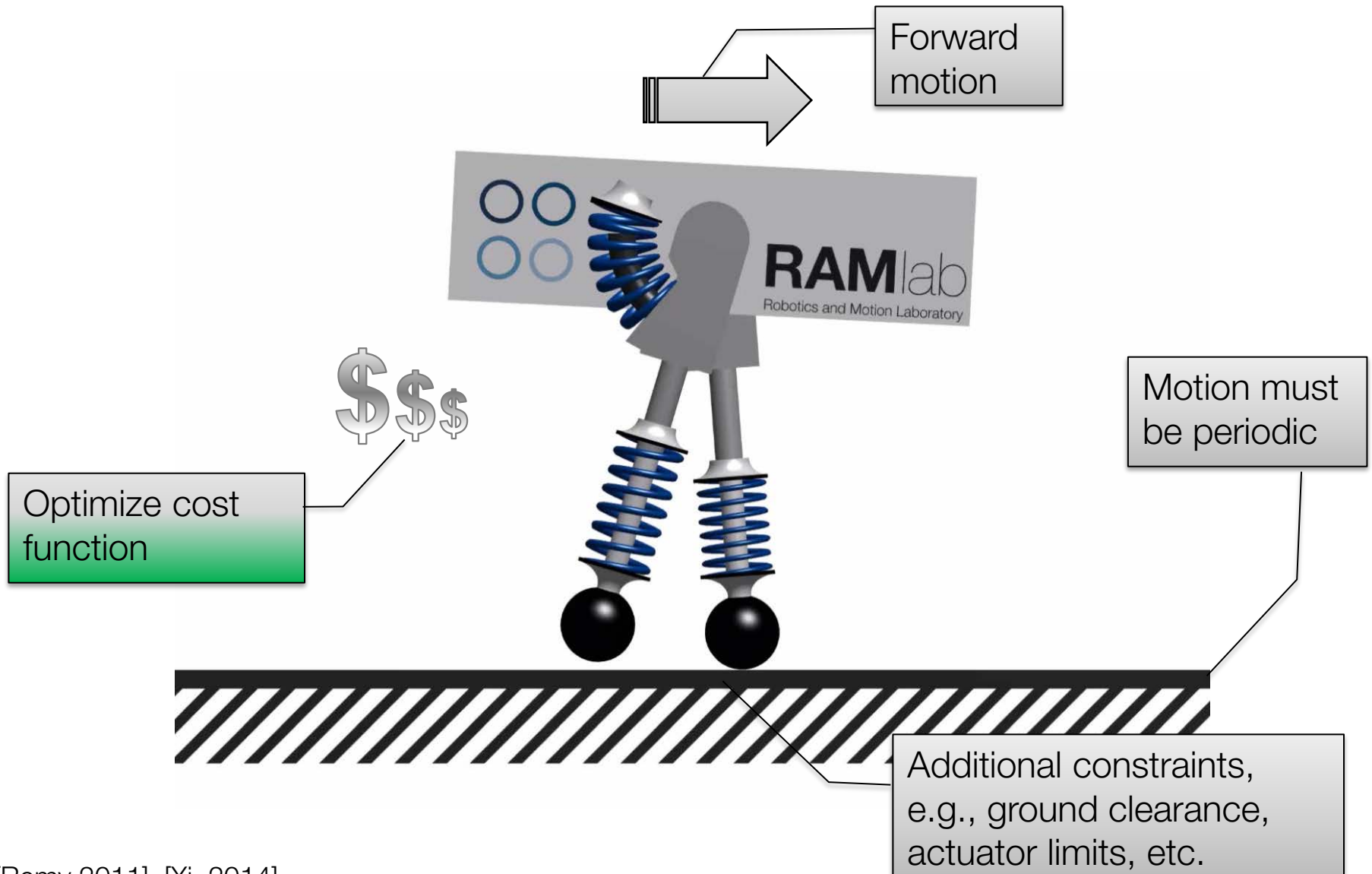
Springs Help Store Energy

[McGuigan & Wilson 2003]

Optimal control for motion creation

Forward motion

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Motion must be periodic

$$$

Optimize cost function

Additional constraints, e.g., ground clearance, actuator limits, etc.

[Remy 2011], [Xi, 2014]
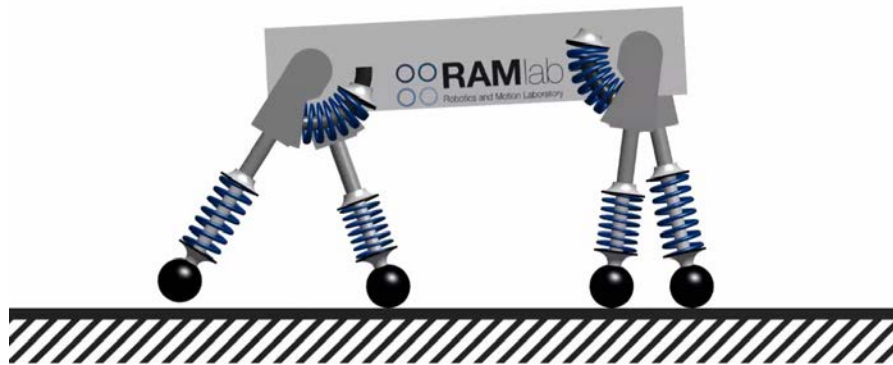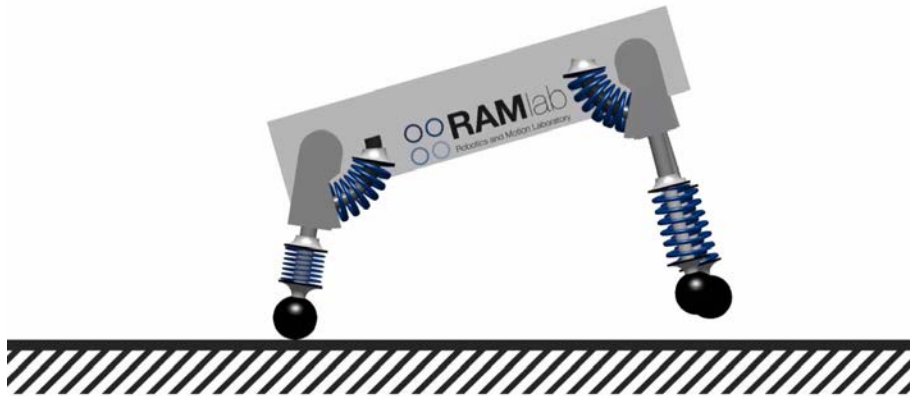
Optimal motions
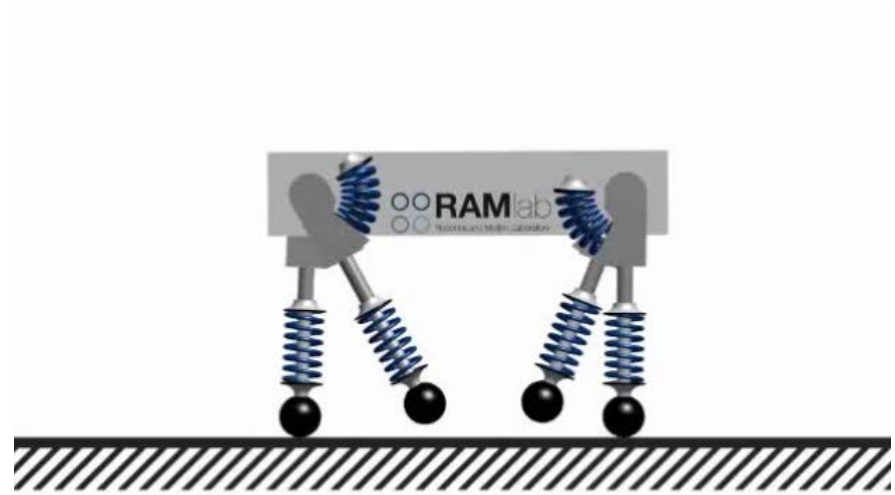

Walking
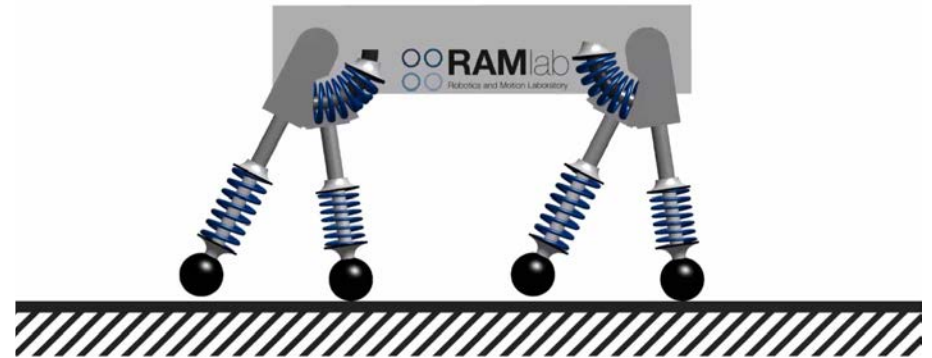
2-Beat Walking

Optimal motions
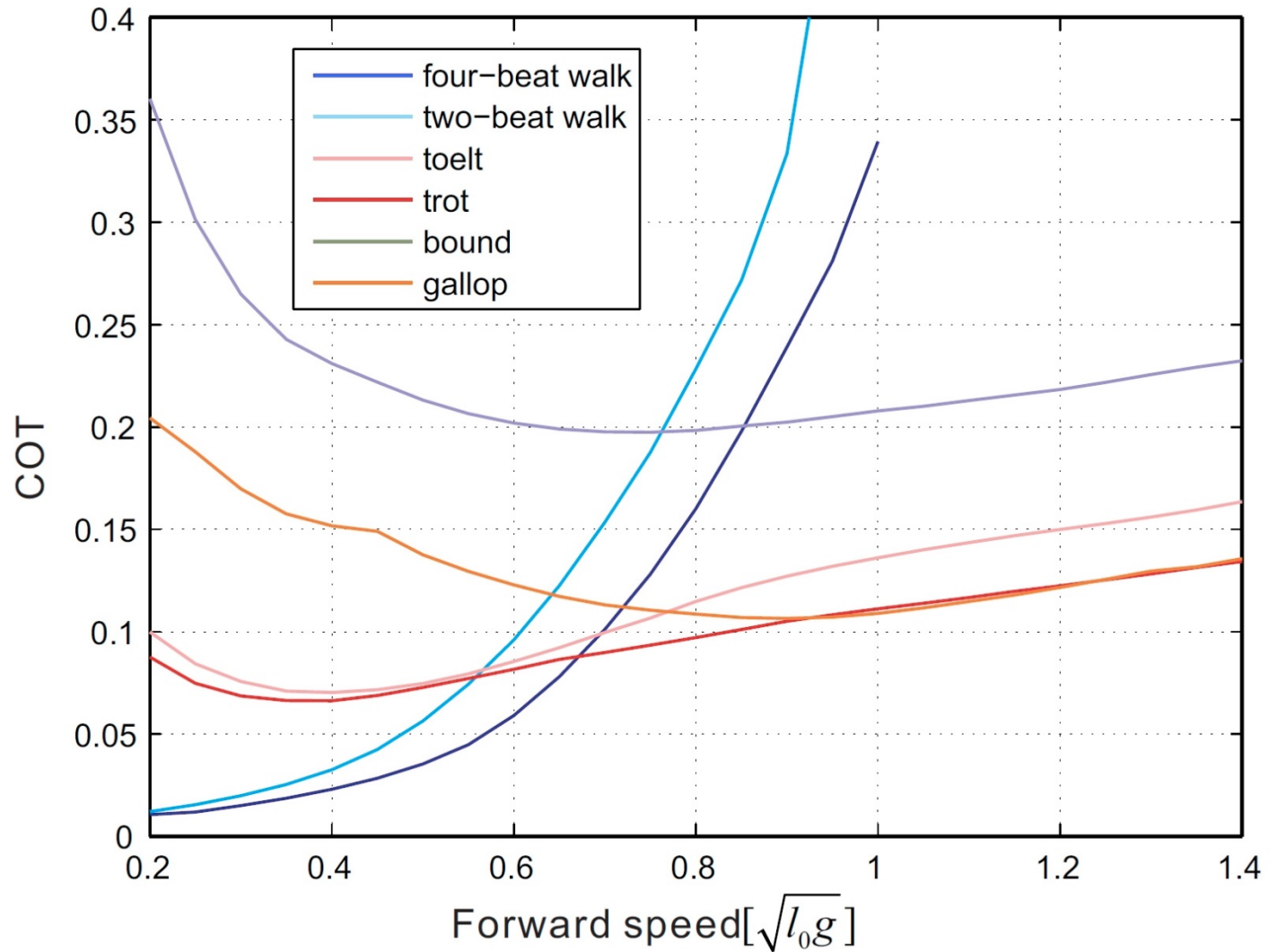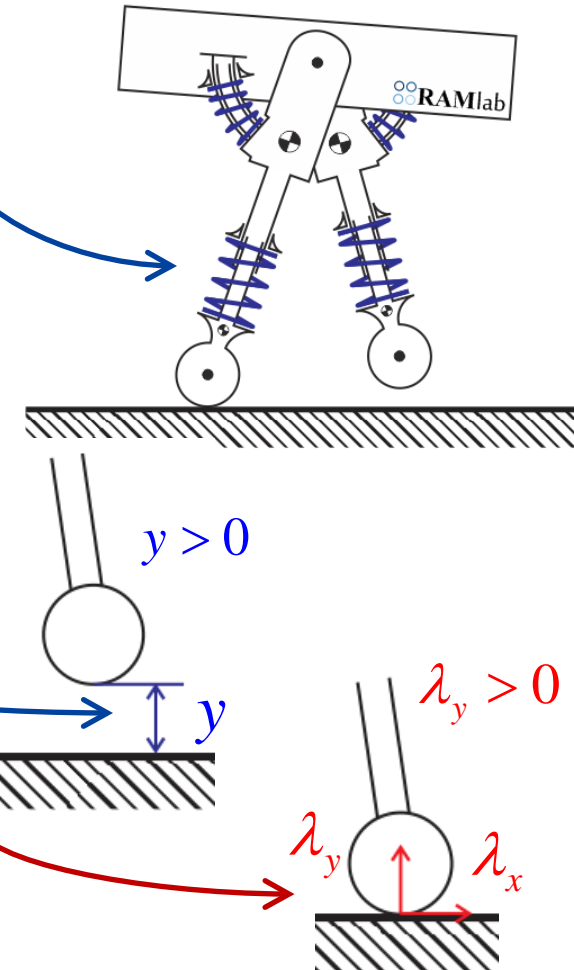

Toelting

Trotting

Optimal motions

Bounding


Galloping

Resulting Energetics

Optimizing w/o defining contact a-priory

○ **Goal:** Find optimal motions for the model of a bipedal robot.

○ **Idea:** Make the contact forces part of the free variable vector

○ **Allows us to:** Use direct collocation without a predefined contact sequence

○ **Use as constraints:** Complementarity conditions:

$y \geq 0$, feet cannot penetrate the ground

$\lambda_y \geq 0$, vertical ground reaction force cannot be negative

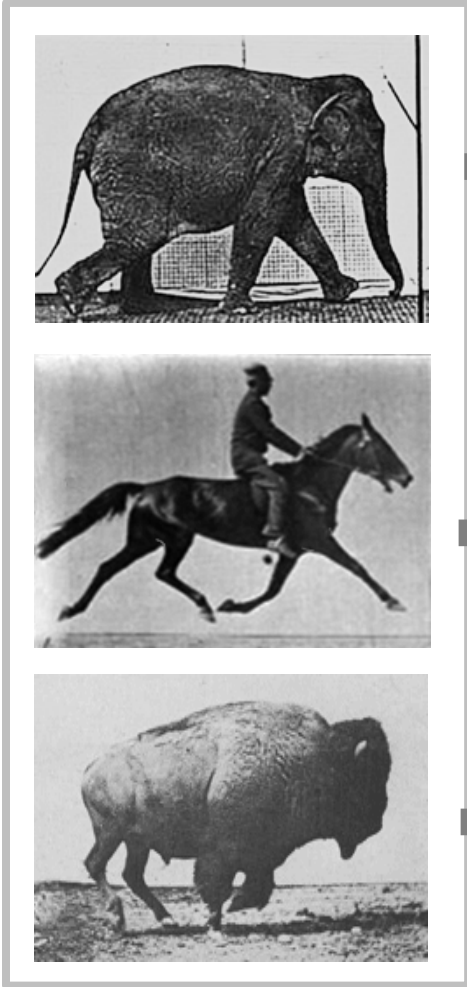$y \cdot \lambda_y = 0$, forces only allowed if foot is on the ground

$y > 0$

y

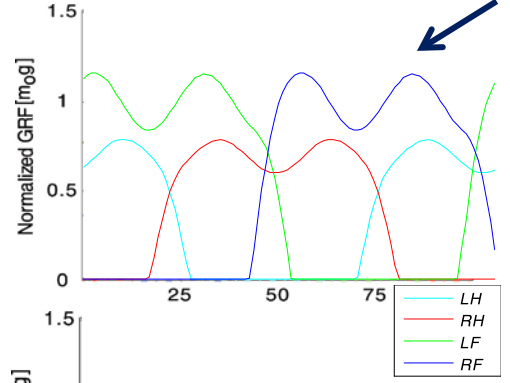$\lambda_y > 0$

λ_y λ_x

[M. Posa and R. Tedrake, 2013]
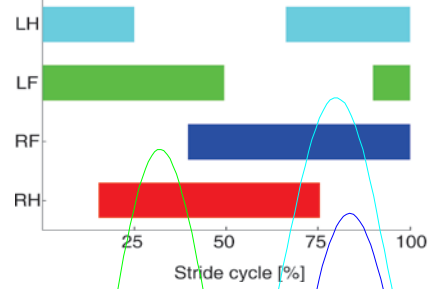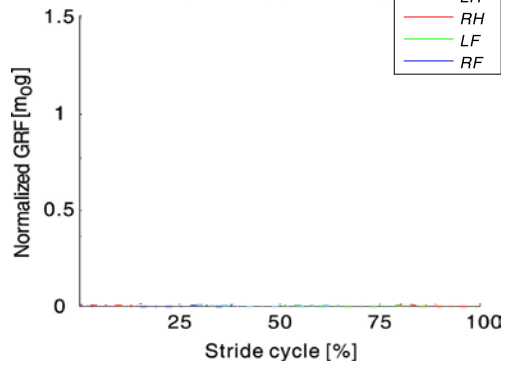
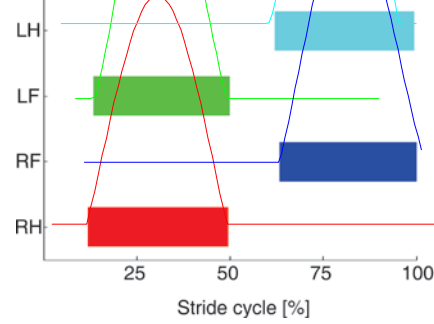# Resulting Energetics
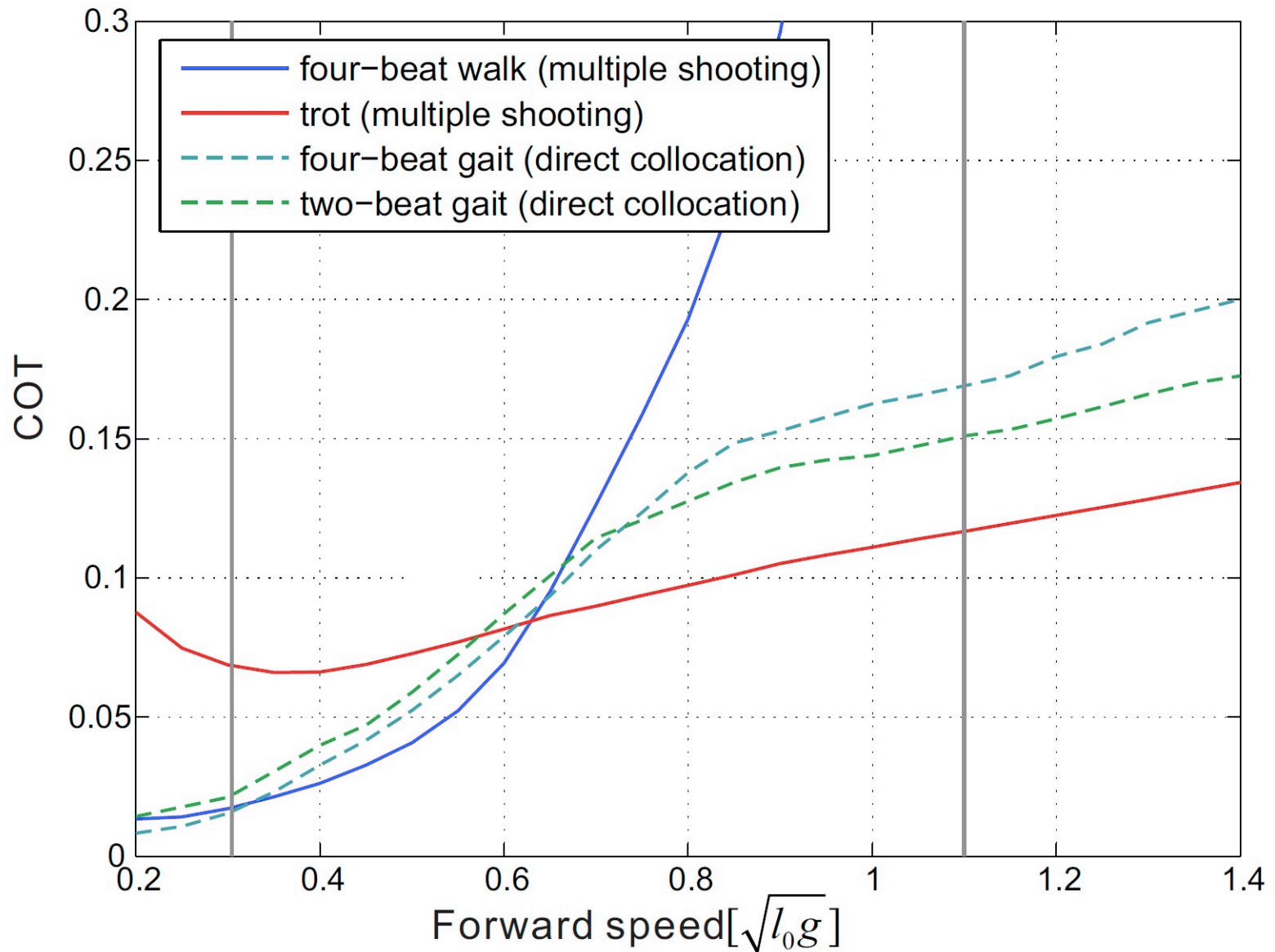
Different gaits → different contact fo

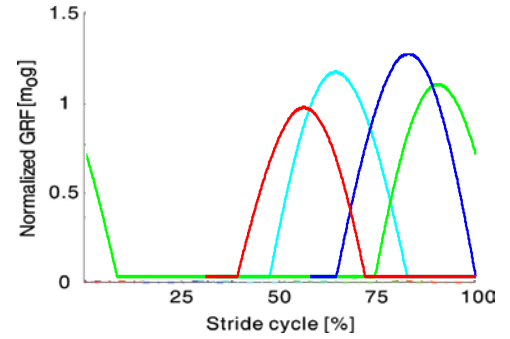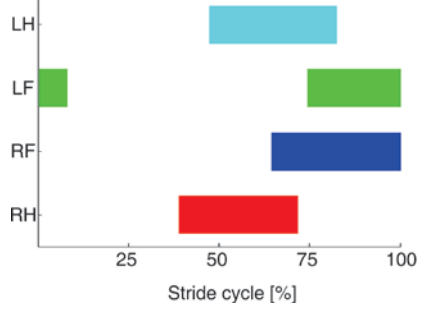**Footfall patterns**　　　**Vertical Ground Rea**

Walk

Trot

Gallop

[Data from VetSuisse]

(a) four-beat walking: speed=$0.2\sqrt{l_o g}$

(b) two-beat walking: speed=$0.2\sqrt{l_o g}$

(c) toelting: speed=$0.8\sqrt{l_o g}$

(d) trotting: speed=$0.8\sqrt{l_o g}$

(e) bounding: speed=$0.8\sqrt{l_o g}$

(f) galloping: speed=$0.8\sqrt{l_o g}$
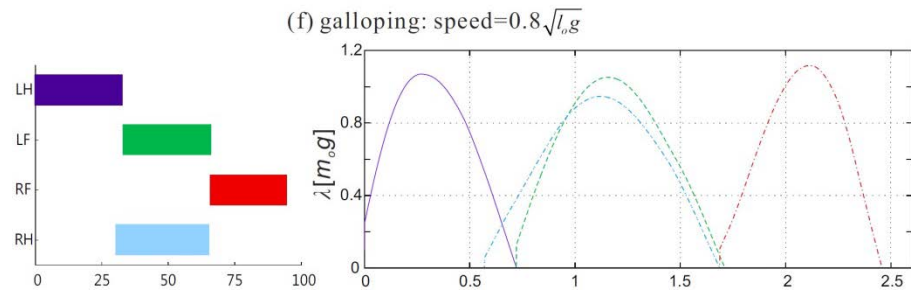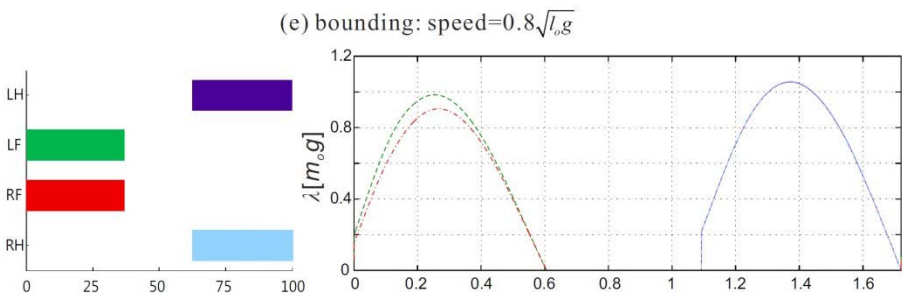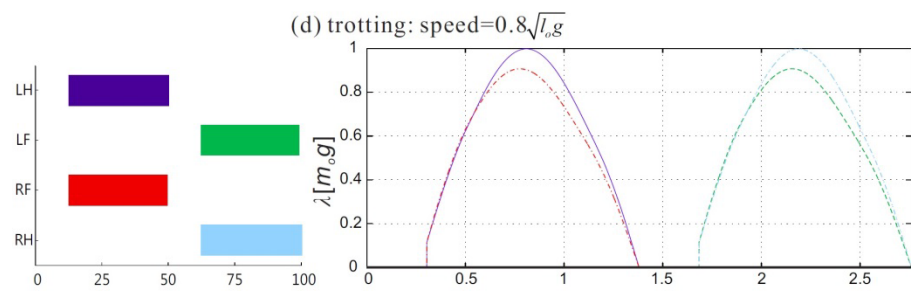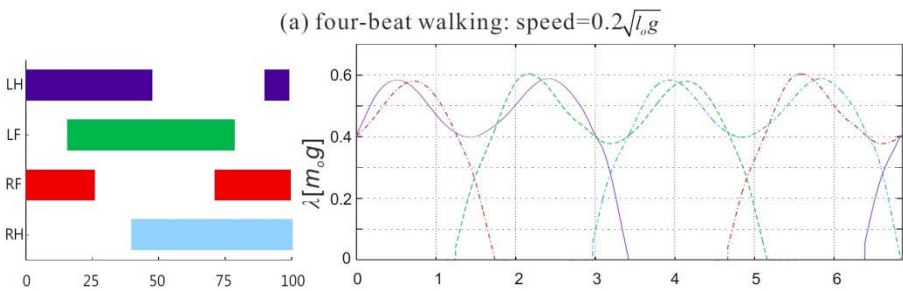
Here's a really simple model:
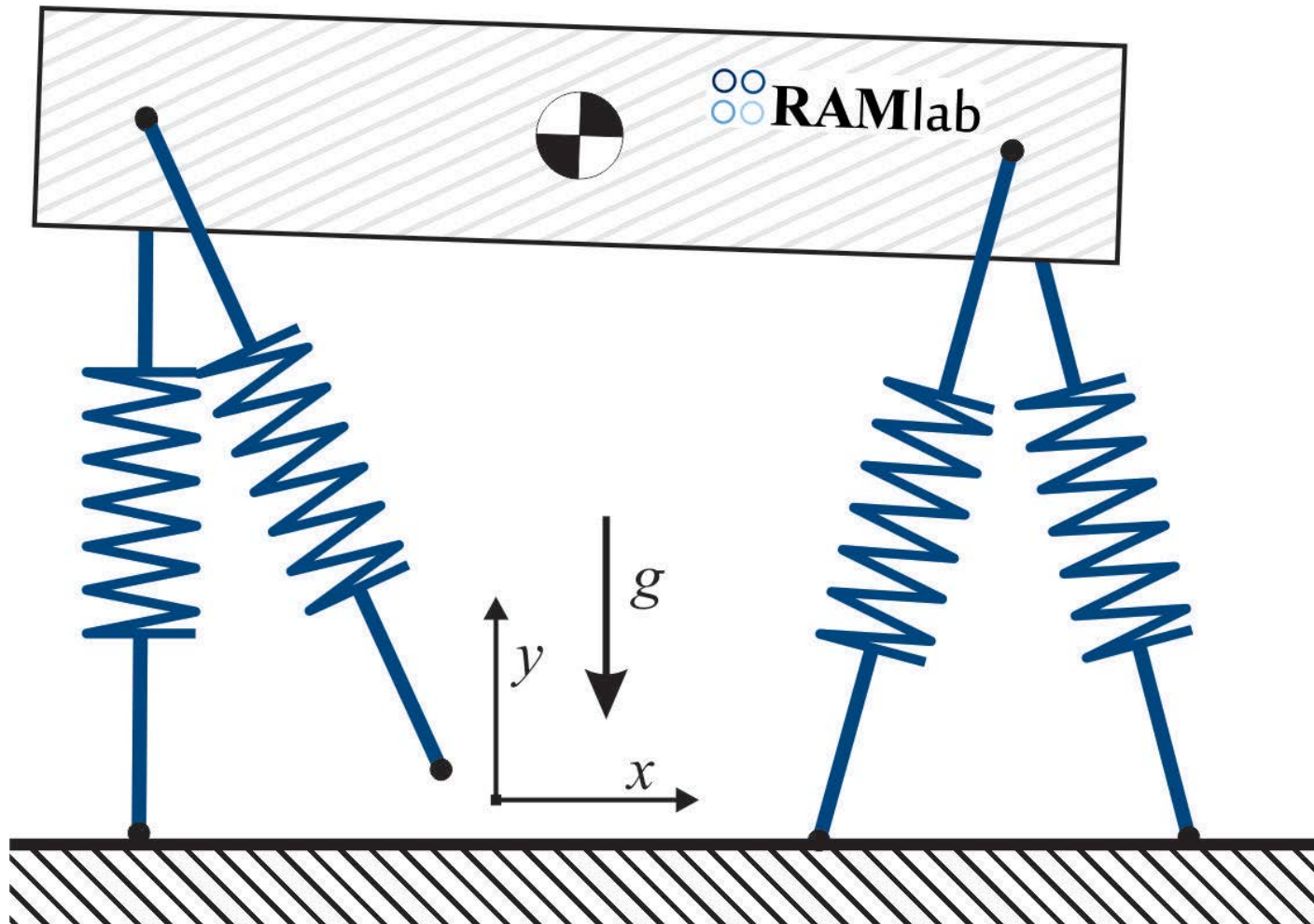
Passive gait variations
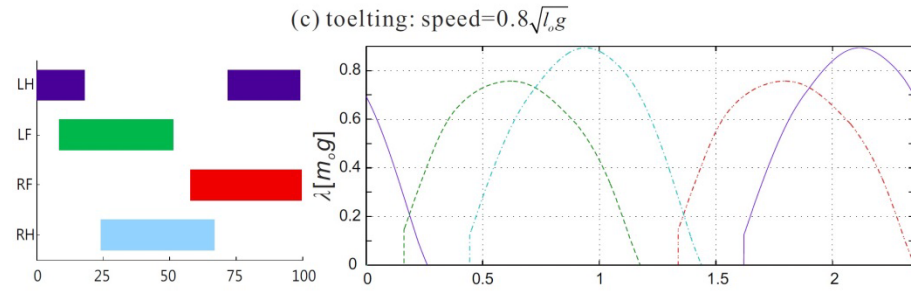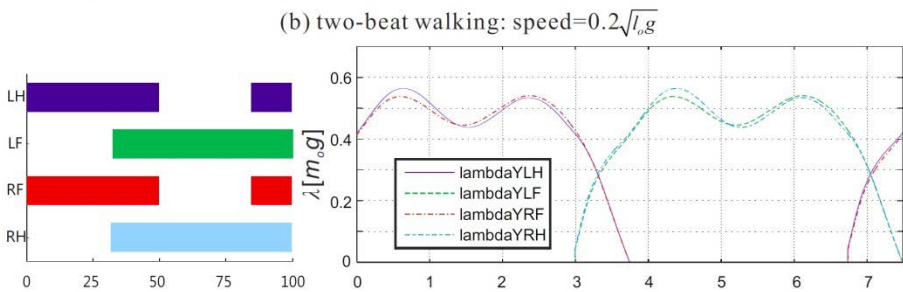

Toelt

Walk
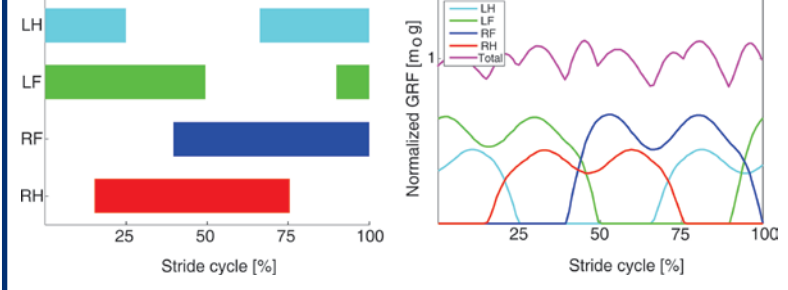
Comparing the forces to nature
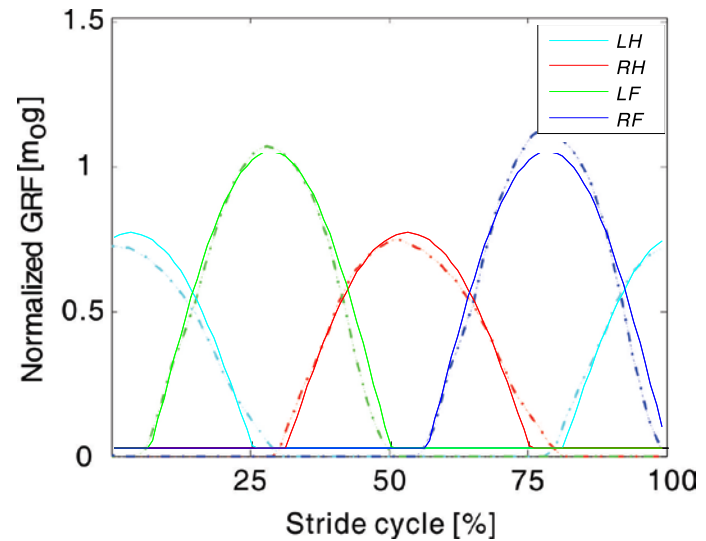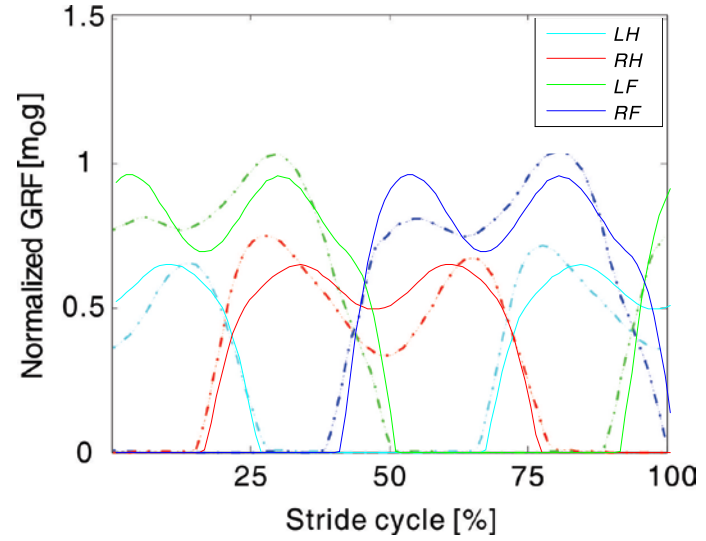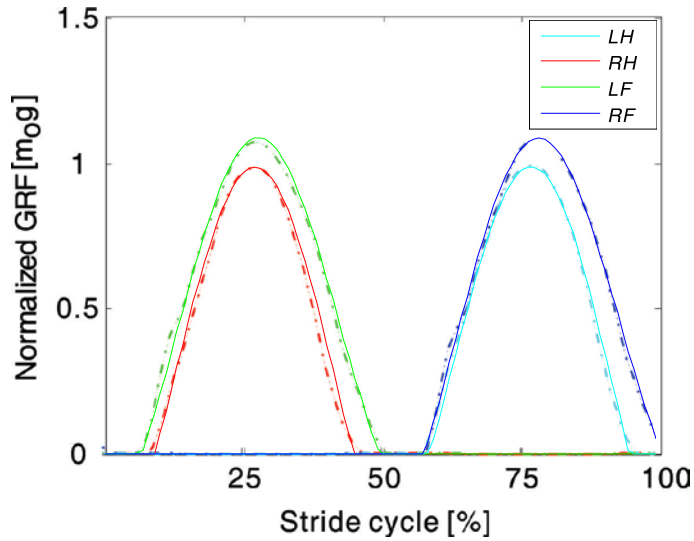
Finding asymmetrical gaits

Bound
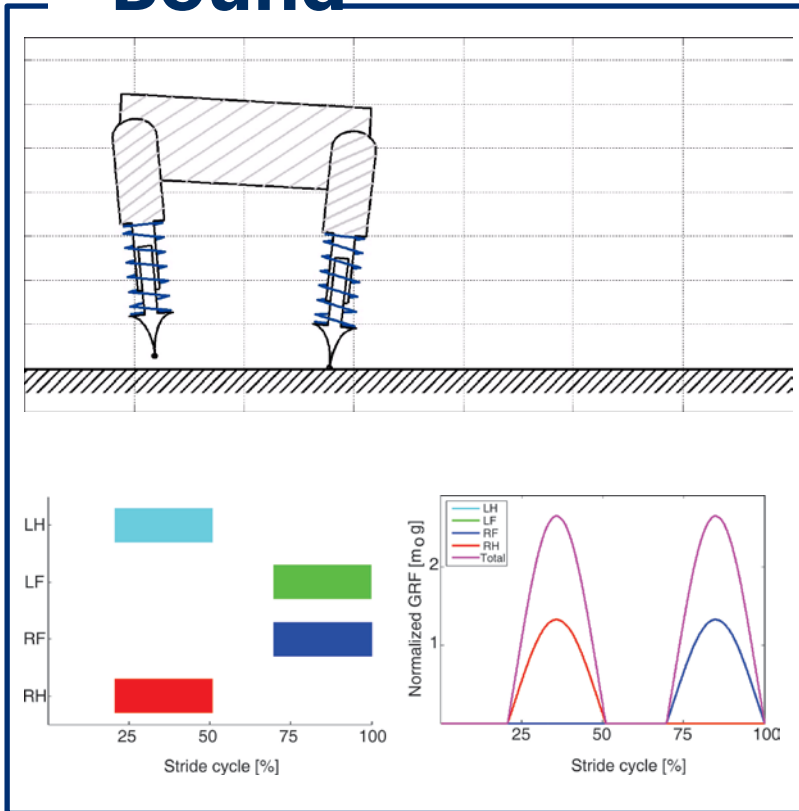
Gallop
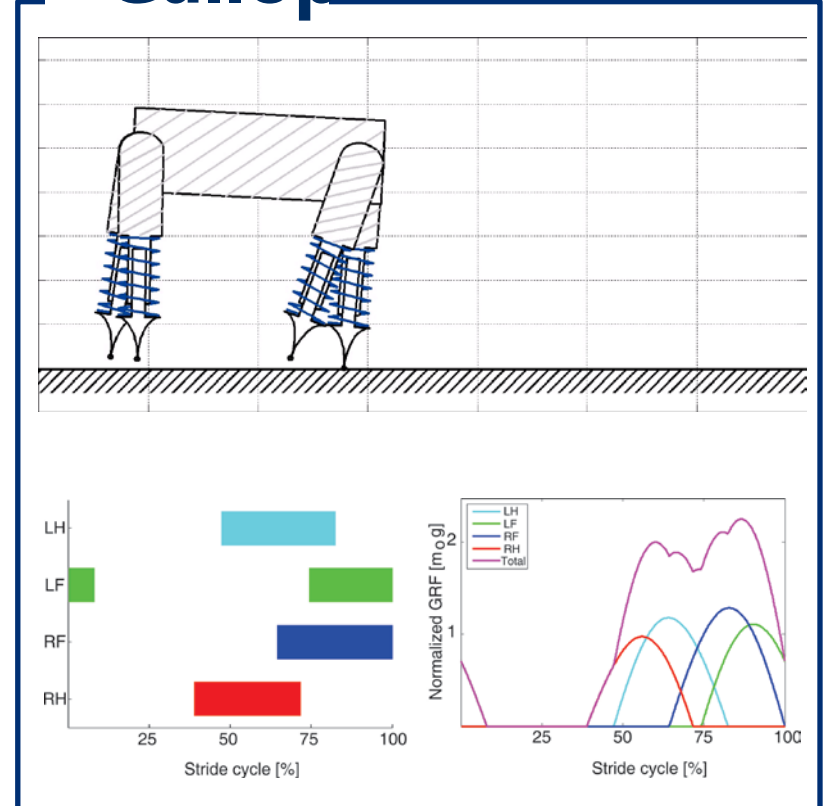
Different modes of the same oscillator

Walk
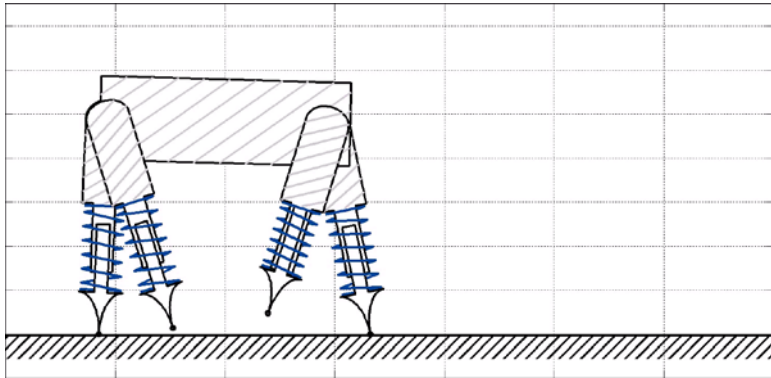
Trot
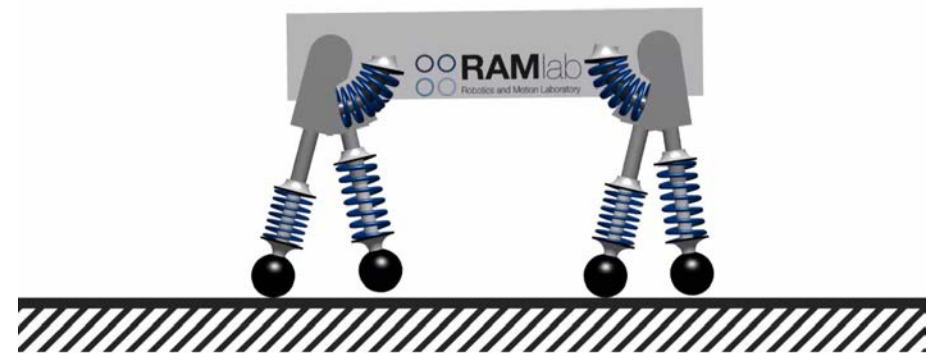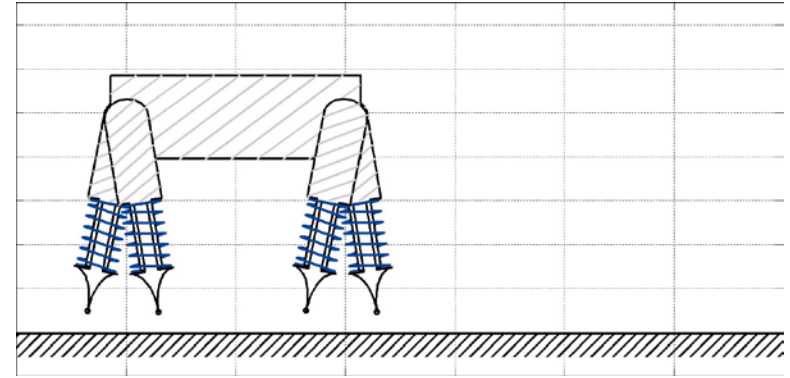
Conclusions

○ Gaits are useful

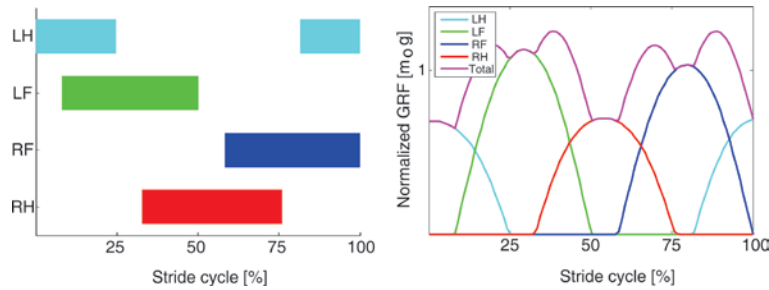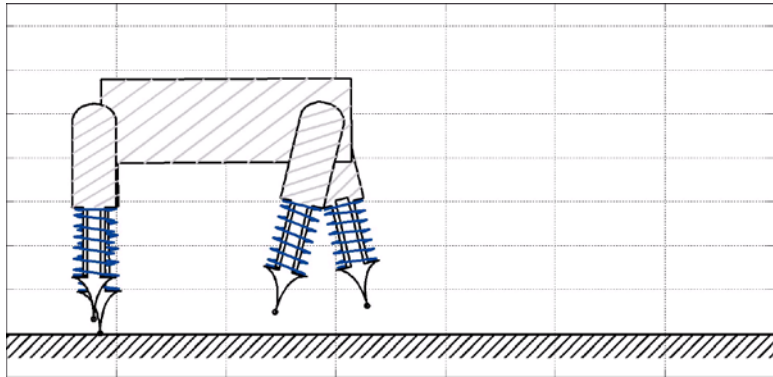○ Contact sequence is important…

○ (Optimization through contact is desirable)

○ … but not the only thing that matters

○ Dynamics of the 'manipulator' are crucial
   ○ → This is a *design* problem
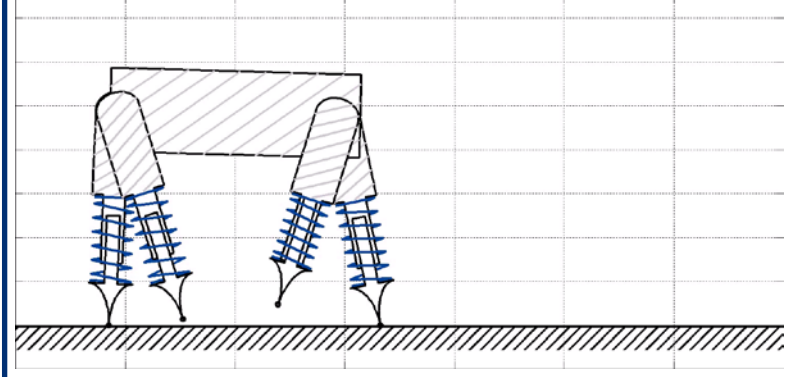

○ Different gaits are just different modes of on single nonlinear oscillator

References

○ M. P. McGuigan and A. M. Wilson. "*The effect of gait and digital flexor muscle activation on limb compliance in the forelimb of the horse equus caballus".* Journal of Experimental Biology, 2003.

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○ D. F. Hoyt and C. R. Taylor. *«Gait and the energetics of locomotion in horses».* Nature, 1981.

○ C. D. Remy, "*Optimal Exploitation of Natural Dynamics in Legged Locomotion"*, PhD Thesis, 2011.

○ M. Posa, C. Cantu, and R. Tedrake. "*A direct method for trajectory optimization of rigid bodies through contact".* The International Journal of Robotics Research, 2013.

○ Xi, Weitao and Remy, C.D., "*Optimal Gaits and Motions for Legged Robots*", IROS 2014.

○ *Gan, Zhenyu and Remy, C.D., "A Passive Dynamic Quadruped that Moves in a Large Variety of Gaits",* IROS 2014.

Questions and Acknowledgements
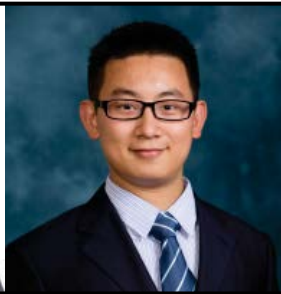
Weitao Xi   Zhenyu Gan   Yevgeniy Yesilevskiy   Rodney Gleason   Wyatt Felt   Jeff Koller