Amir Degani

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Technion
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CEAR
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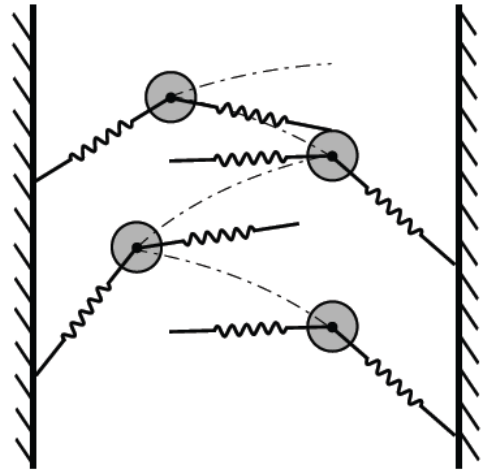
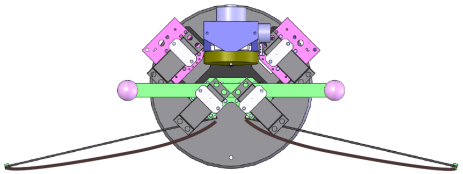
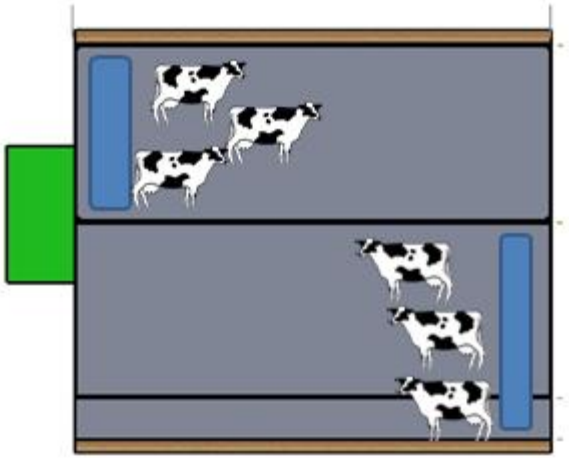


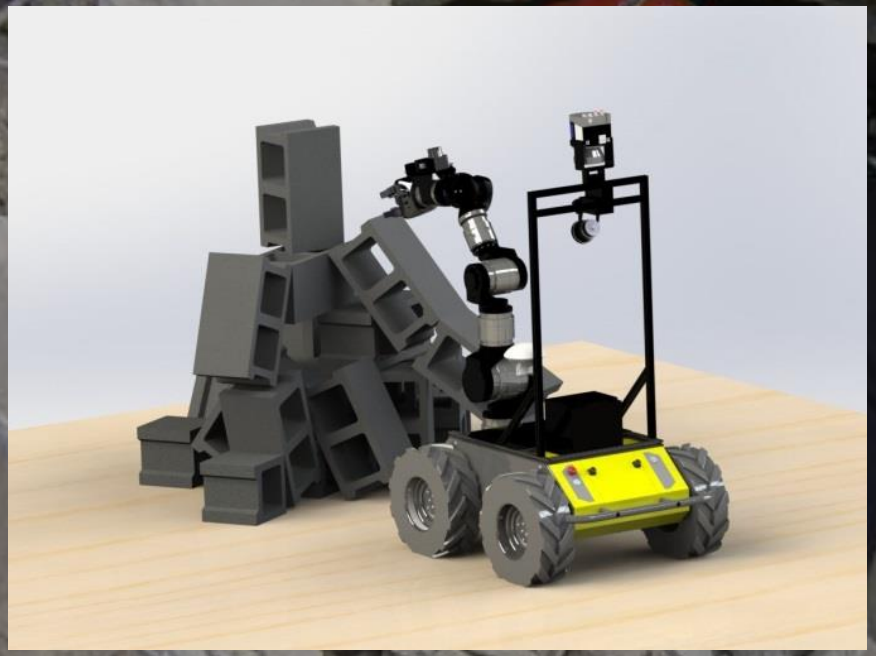




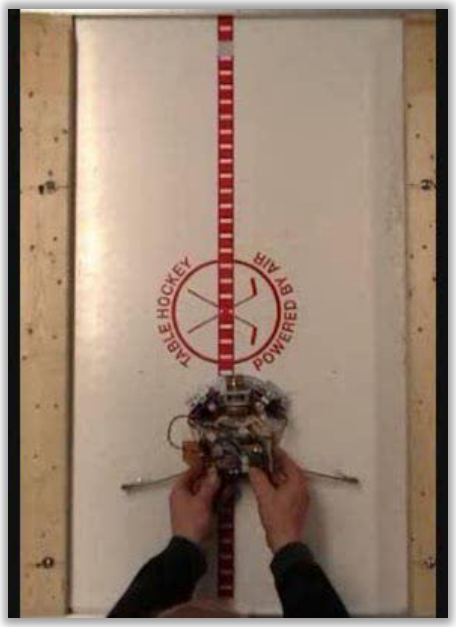
Dynamic Locomotion

Agriculture

Civil Applications



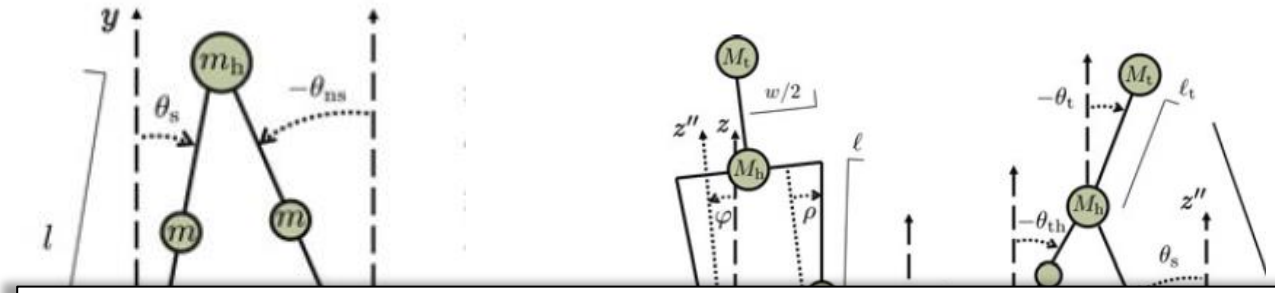
Dynamic Climbing



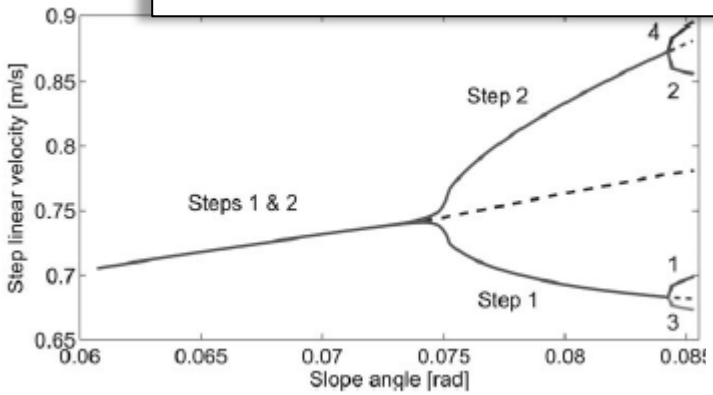
1mm

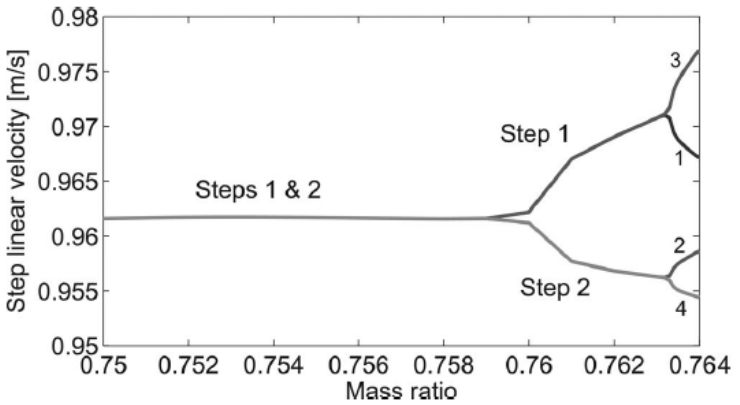
On the Mechanics of Functional Asymmetry in Bipedal Walking

Robert D. Gregg*, *Member, IEEE*, Yasin Y. Dhaher, *Senior Member, IEEE*, Amir Degani, *Member, IEEE*, and Kevin M. Lynch, *Fellow, IEEE*

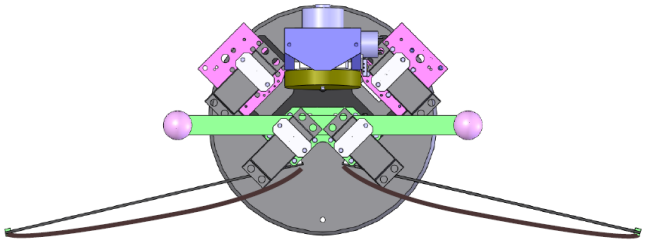


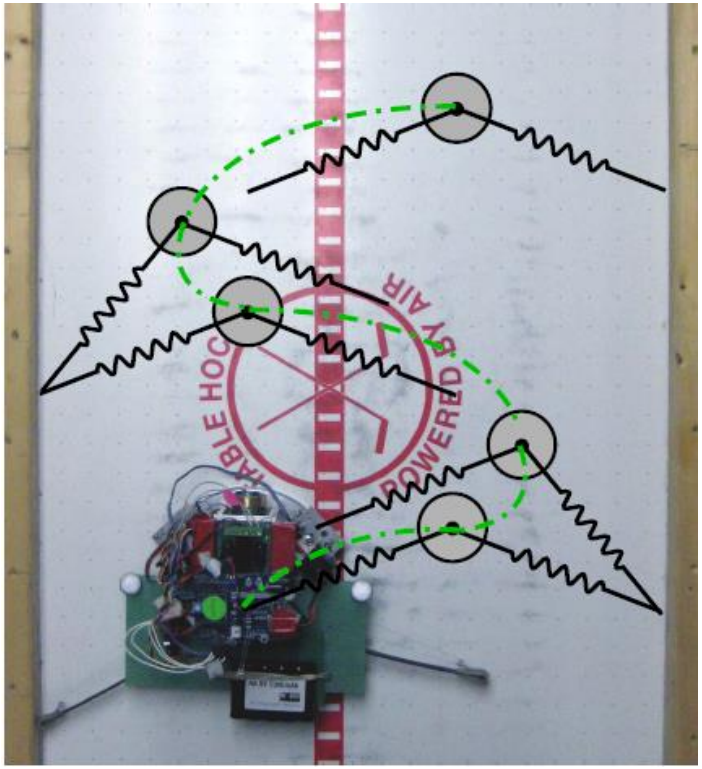
Body mechanics, independent of neurophysiological mechanisms such as leg dominance, may contribute to able-bodied gait asymmetry.





The ParkourBot





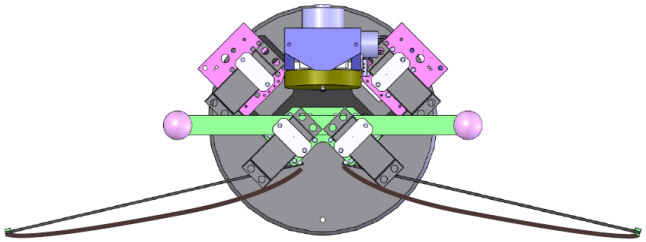
Planar Bow Leg Hopper
Passive Stability Demonstration

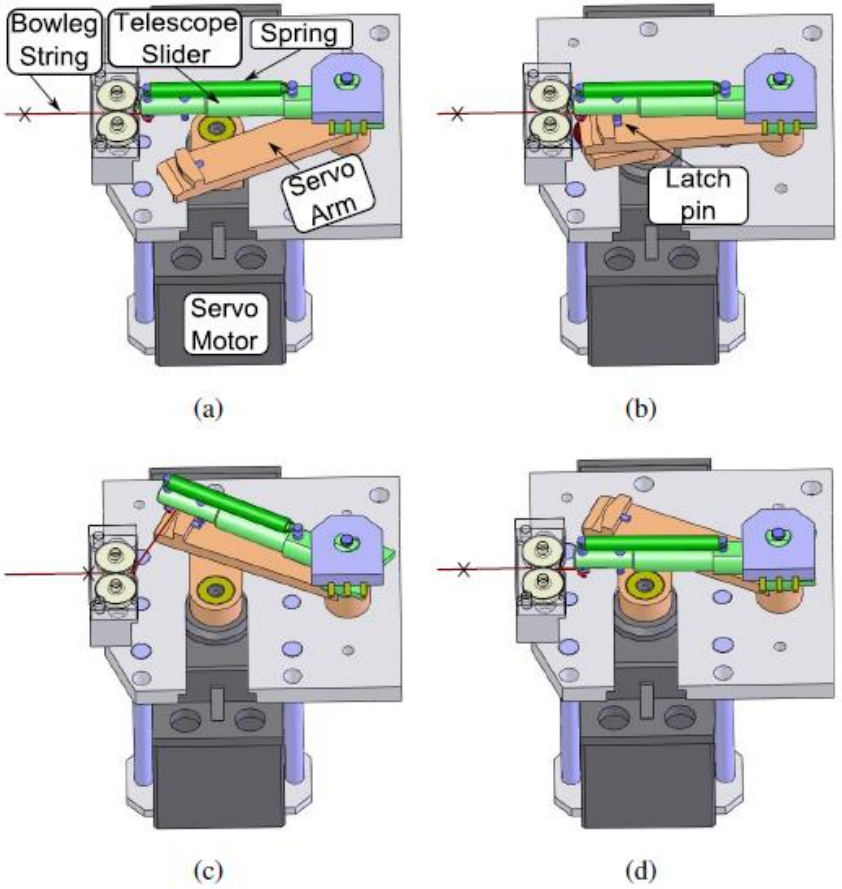
H. Benjamin Brown, Jr.
Garth Zeglin

Carnegie Mellon University
Robotics Institute

Carnegie Mellon
THE ROBOTICS INSTITUTE

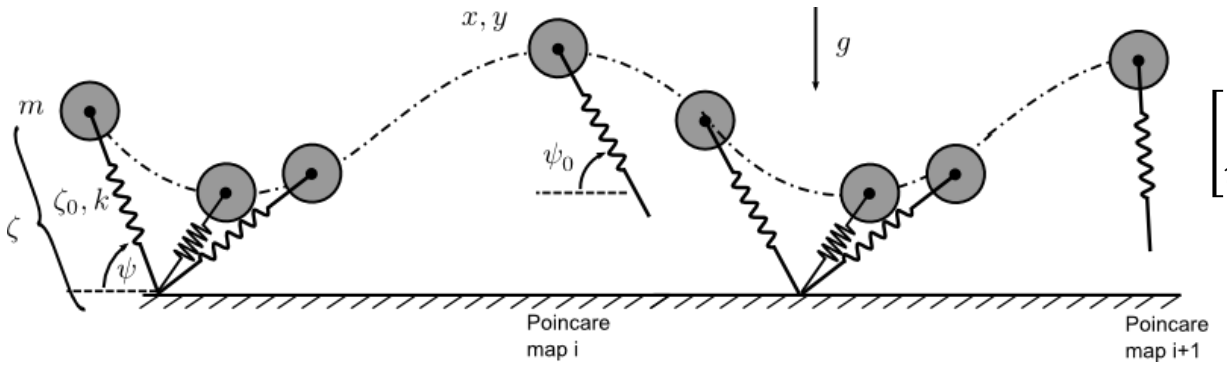
The ParkourBot





Horizontal Running Model

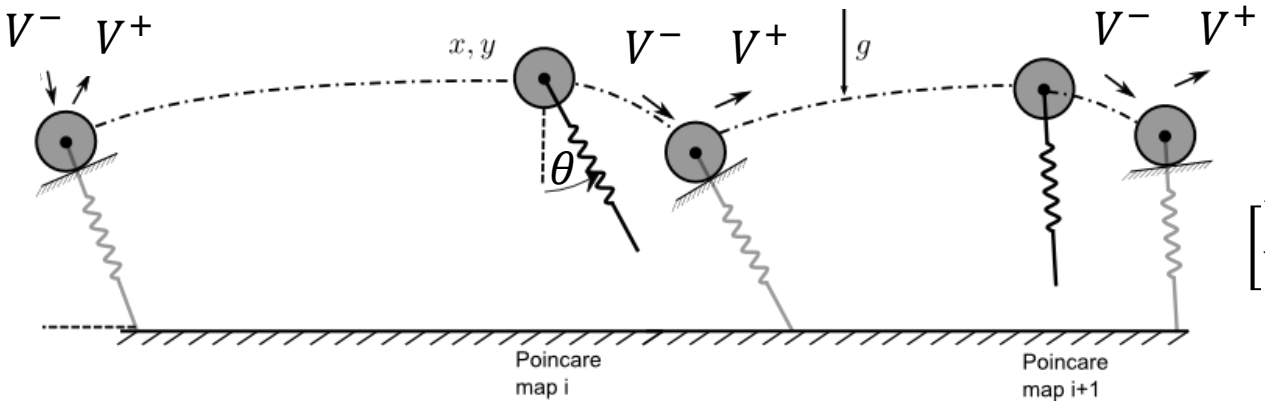
SLIP – Spring Loaded Inverted Pendulum



Stance:

$$\begin{bmatrix} \ddot{\zeta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} -\frac{m}{k}(\zeta - \zeta_0 - g\cos(\psi) + \zeta\dot{\psi}^2 \\ -\frac{2\dot{\zeta}}{\zeta}\psi - \frac{g}{\zeta}\sin(\psi) \end{bmatrix}$$

Horizontal "SPM" – Simplest Parkour Model*

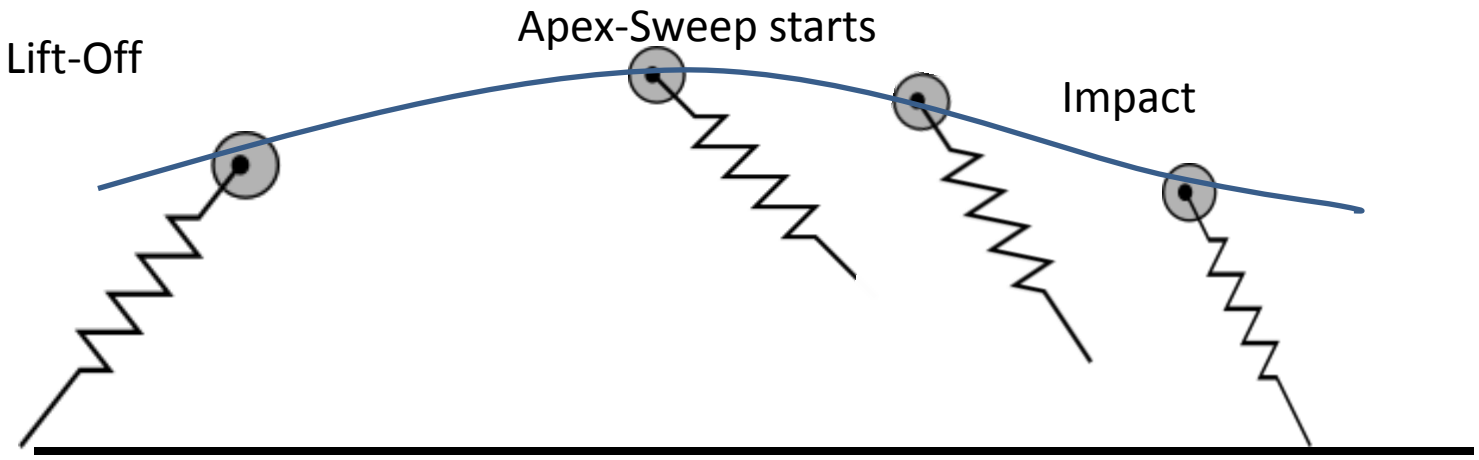


Impact:

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix}^+ = \begin{bmatrix} V_x^- \cos(2\theta) + V_y^- \sin(2\theta) \\ V_x^- \sin(2\theta) - V_y^- \cos(2\theta) \end{bmatrix}$$

* Simplified model similar to: Zeglin, and Brown, 1998; Arslan and Sranli, 2012

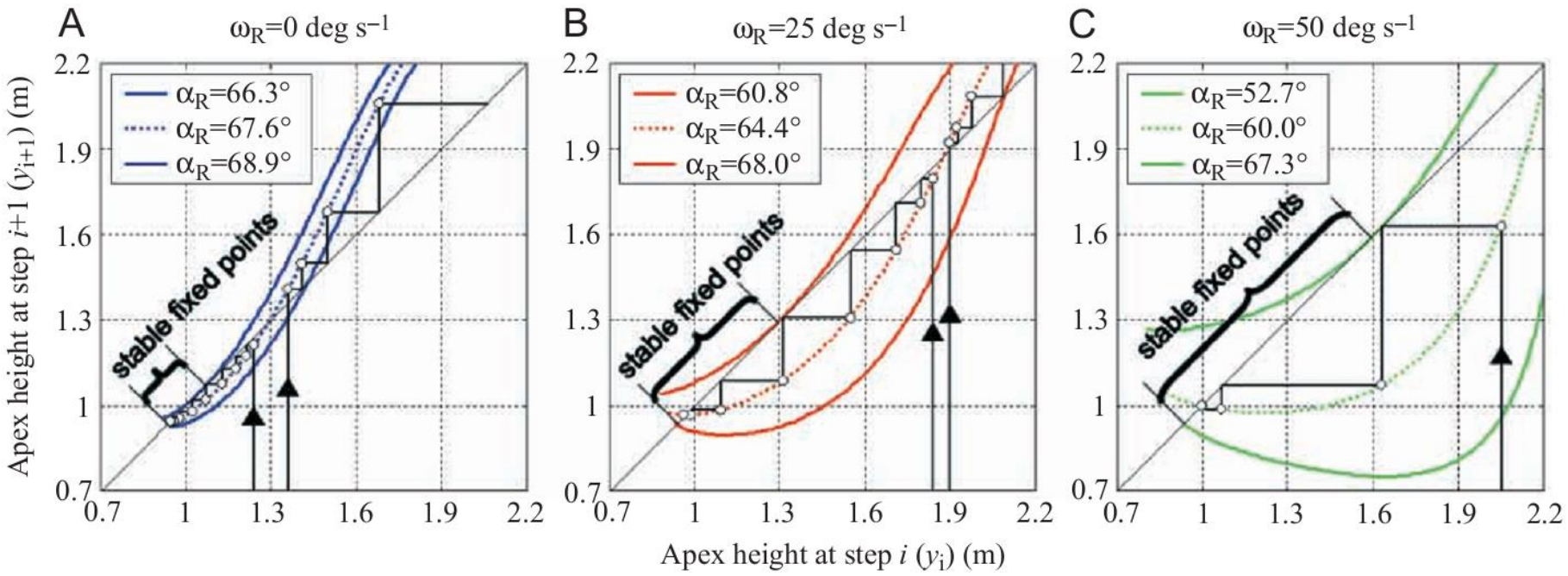
Swing-leg retraction



Taken from H. Geyer Website

Swing-leg retraction: a simple control model for stable running, Seyfarth, Geyer, and Herr; J. Exp. Biol. 2003

Swing-leg retraction

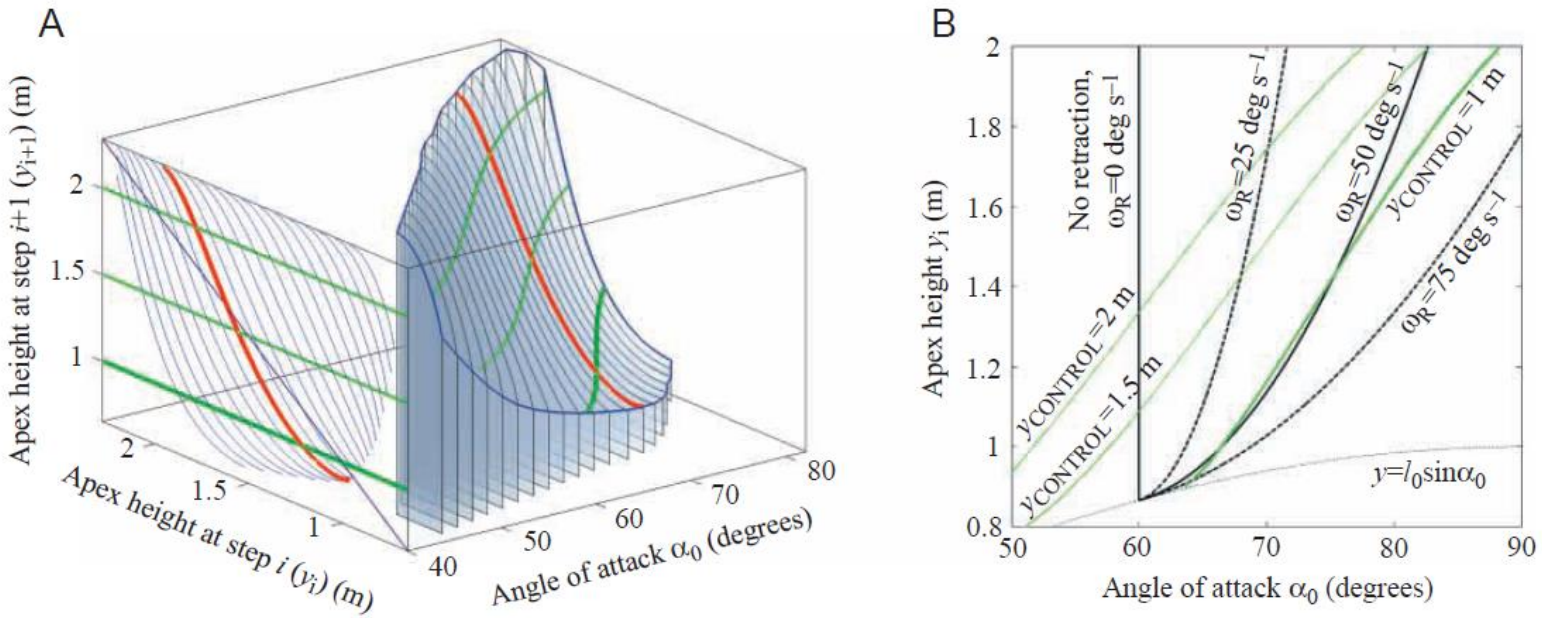


System Values:

$$m = 80kg; \zeta_0 = 1m; k = \frac{20kN}{m}; E = 1784J$$

Swing-leg retraction: a simple control model for stable running, Seyfarth, Geyer, and Herr; J. Exp. Biol. 2003

Sweep-Dead Beat Controller



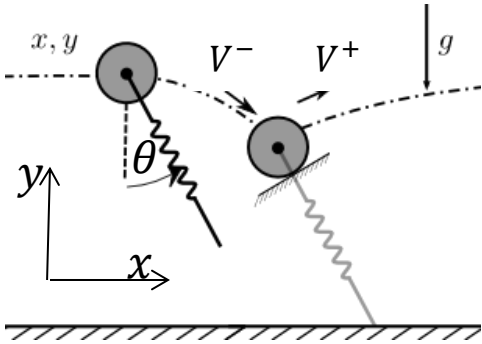
System Parameters: $E = 1784J, corrsepends\ to\ V_{x_0} = 5\frac{m}{s}, m = 80kg, l_0 = 1m, K = \frac{20kN}{m}$

Green lines- Constant y_{i+1}

Red lines- $\alpha = 68°$

Swing-leg retraction: a simple control model for stable running, Seyfarth, Geyer, and Herr; J. Exp. Biol. 2003

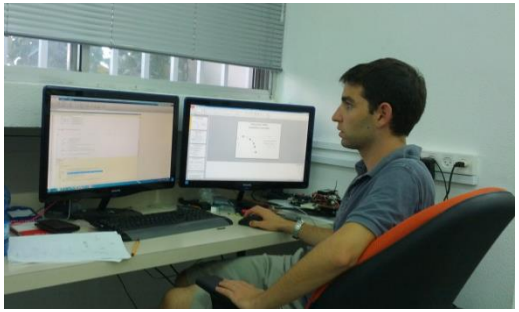
Horizontal "SPM"



- Closed form solution for stance phase:

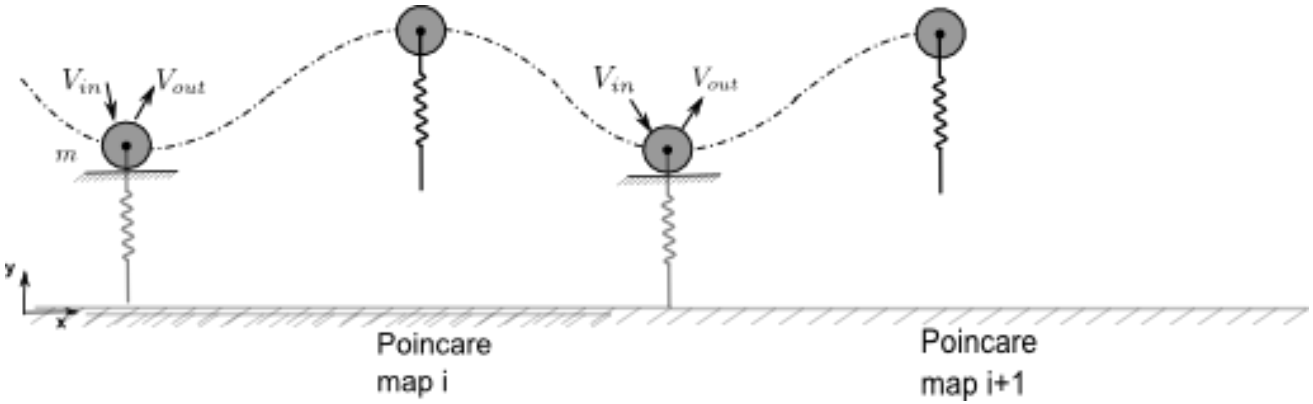
$$\begin{bmatrix} V_x \\ V_y \end{bmatrix}^+ = \begin{bmatrix} V_x^- \cos(2\theta) + V_y^- \sin(2\theta) \\ V_x^- \sin(2\theta) - V_y^- \cos(2\theta) \end{bmatrix}$$

- Fixed point is at $\theta = 0$



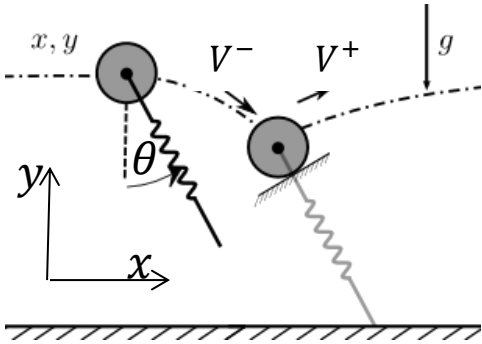
Naty Shemer – MSc Student

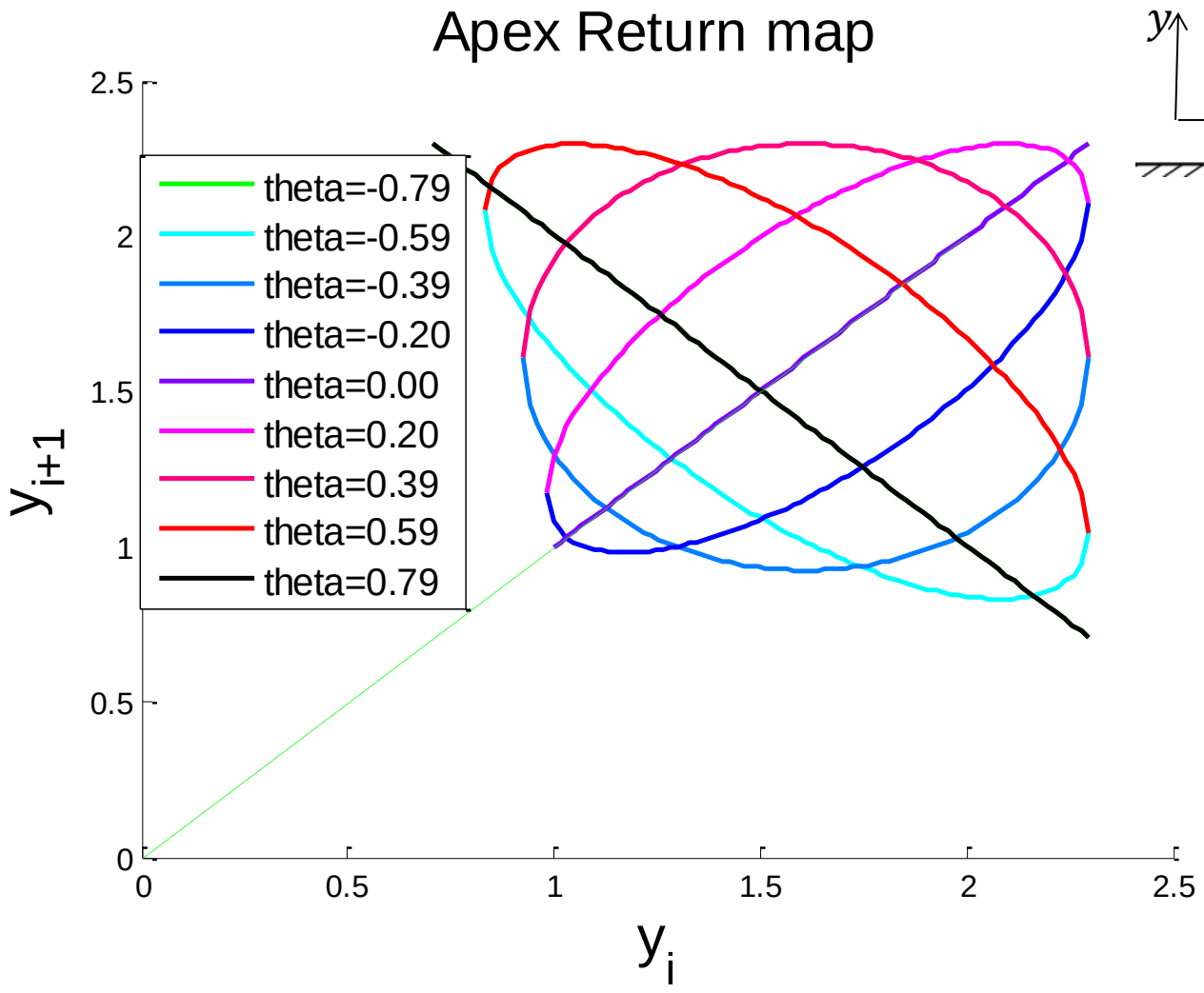
- Eigenvalue of the solution is 1 – Marginally stable



Horizontal “SPM” without sweep

$$\omega = 0$$





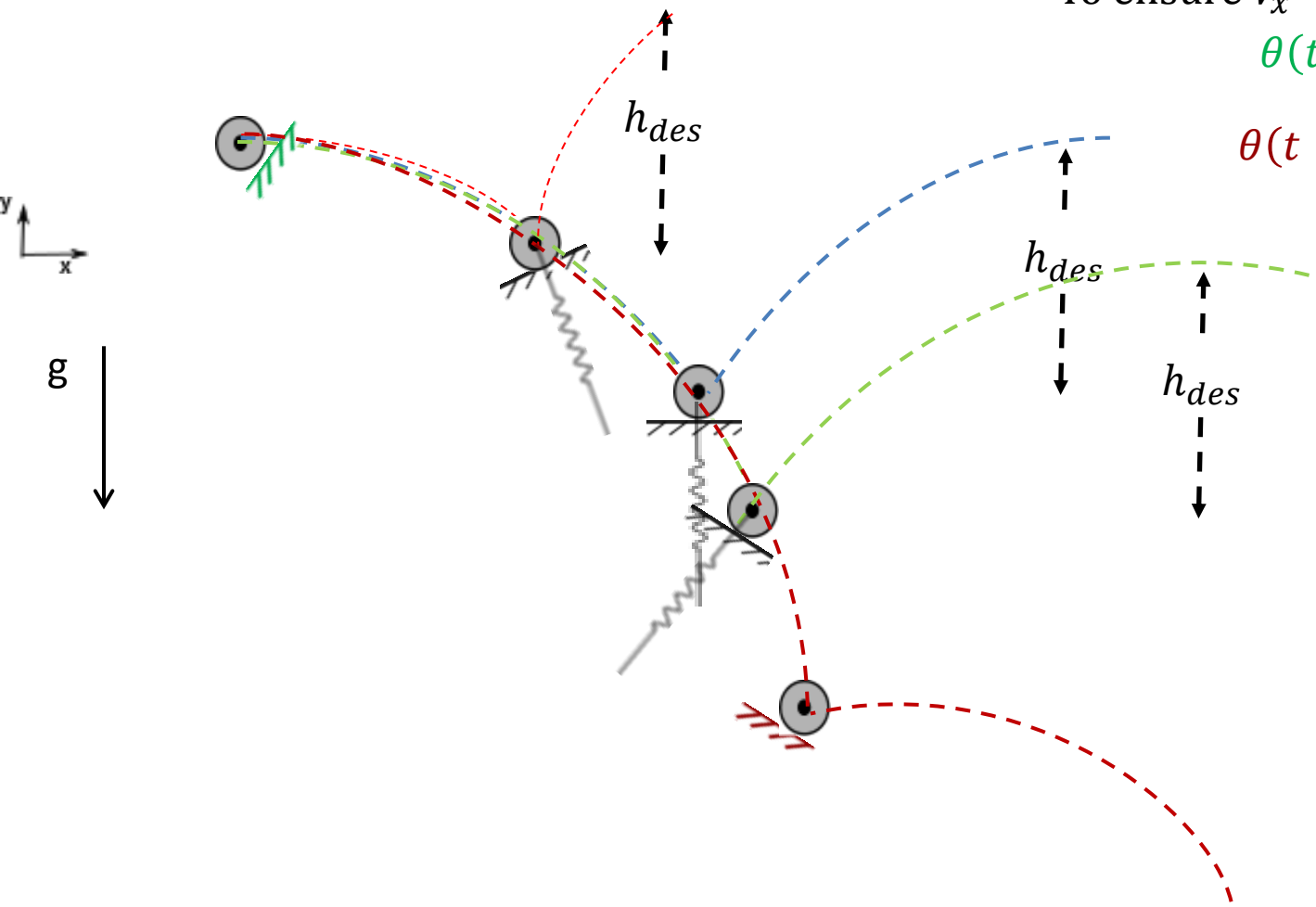
Horizontal “SPM” Dead-Beat Controller

Finding impact angle bounds:

To ensure $V_x^+ > 0$ & $V_y^+ < 0$

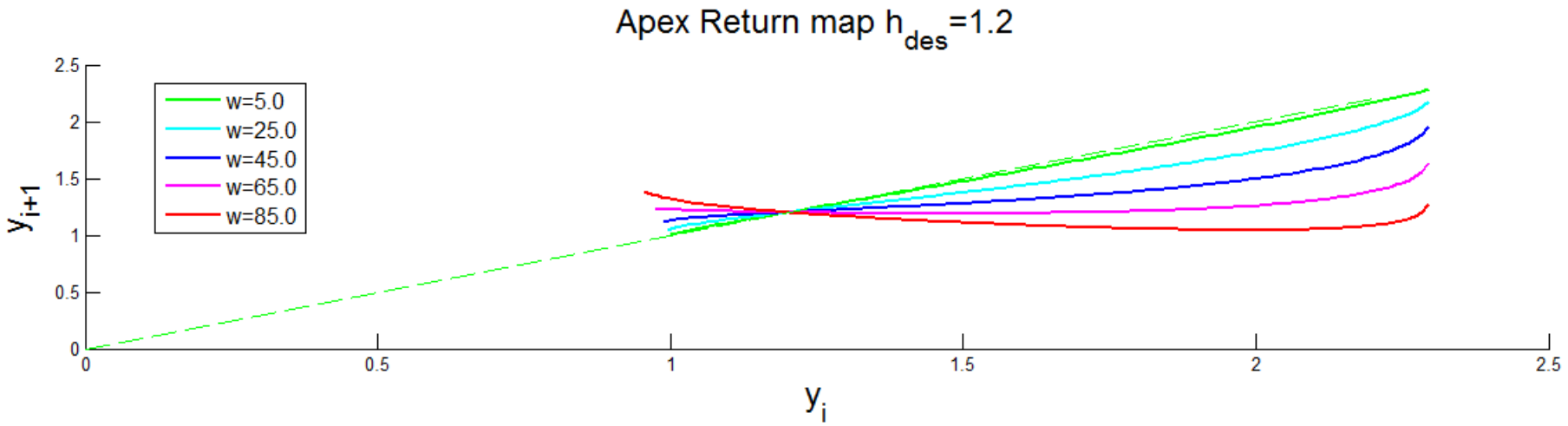
$\theta(t = 0) < \frac{\pi}{4}$

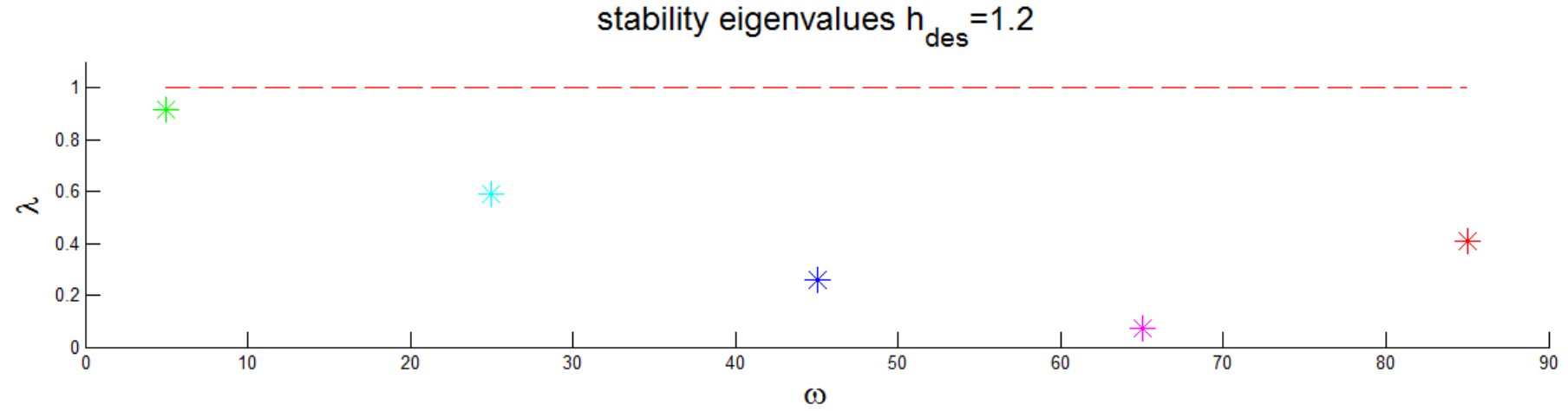
$\theta(t = \infty) > \frac{3\pi}{4}$



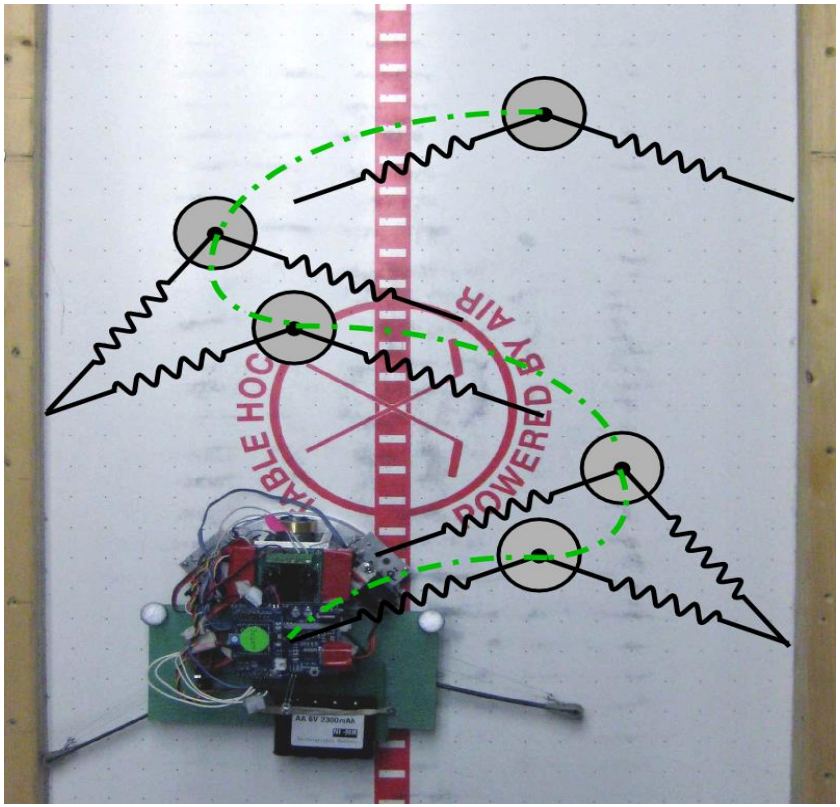
Horizontal "SPM" **with** Swing-Leg

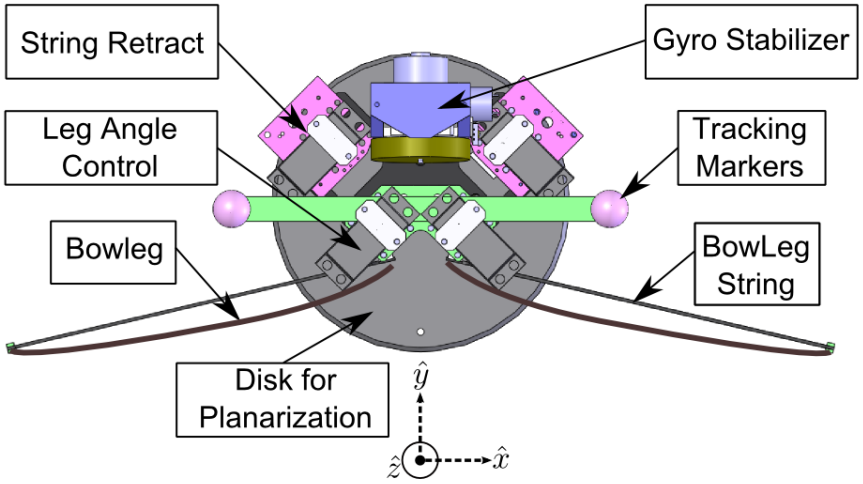
$$\omega \neq 0$$

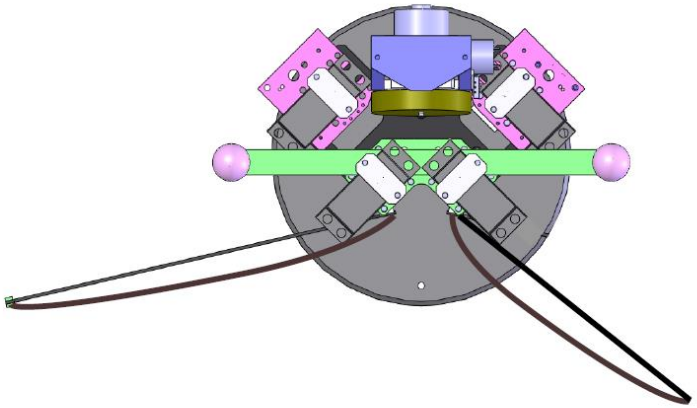




The ParkourBot



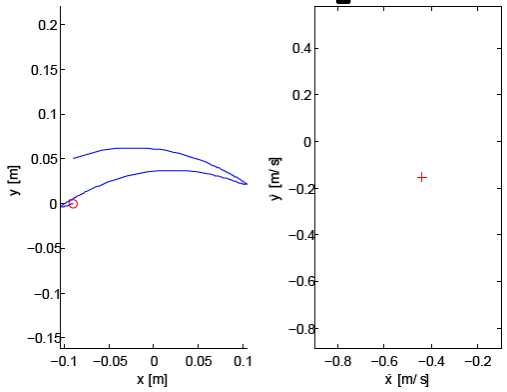




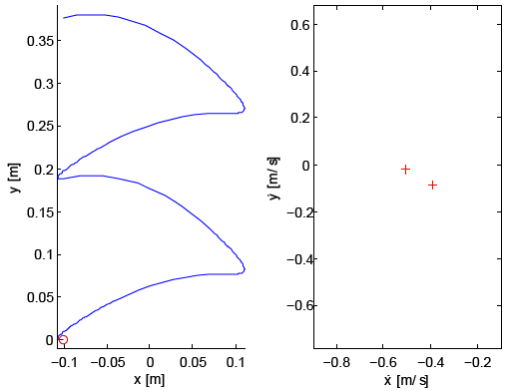
With Howie Choset, Matt Mason, Ben Brown (CMU) and Kevin Lynch (NU)

ParkourBot – Previous **open loop**

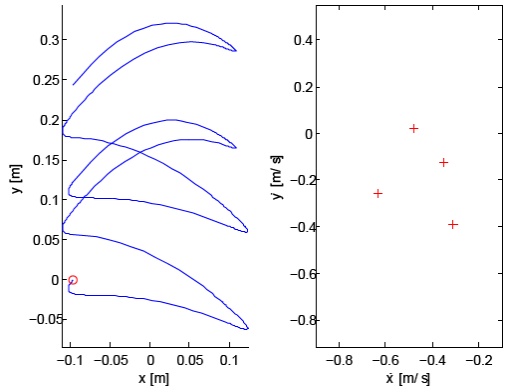
Period-1



Period-2



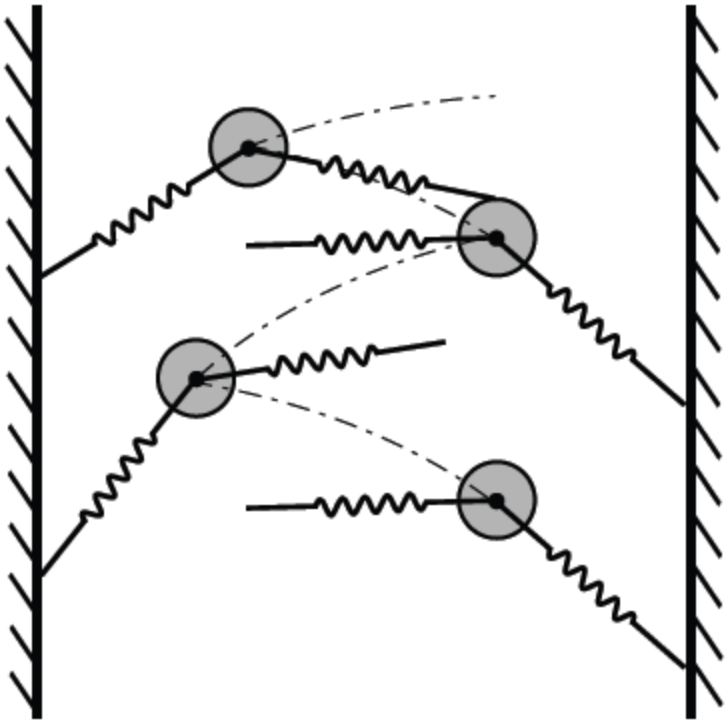
Period-4



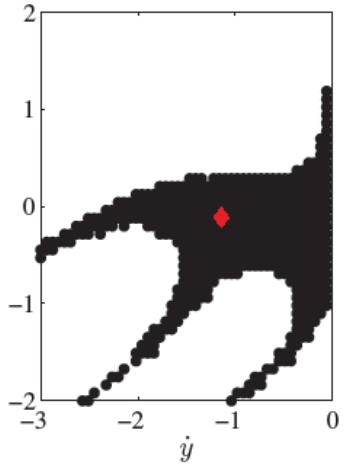
ParkourBot – Previous **open loop**

Vertical Movement Complications:

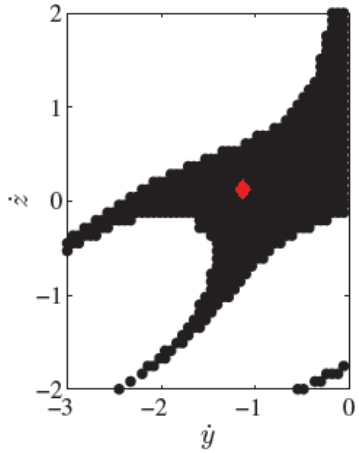
1. Apex doesn't always happen
2. Movement on the same axis as gravity
3. Poincare map is 2D



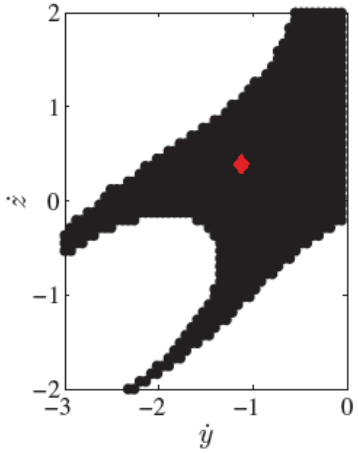
(a) Maximum eigenvalue vs. energy input.



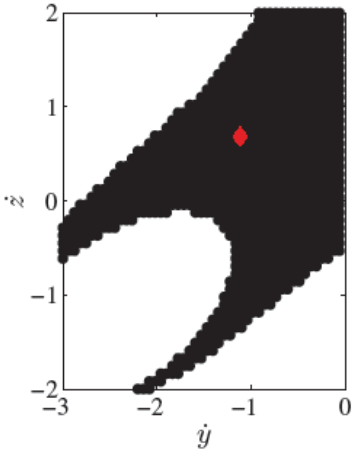
(b) $\zeta_0 = 0.8$



(c) $\zeta_0 = 0.75$



(d) $\zeta_0 = 0.7$

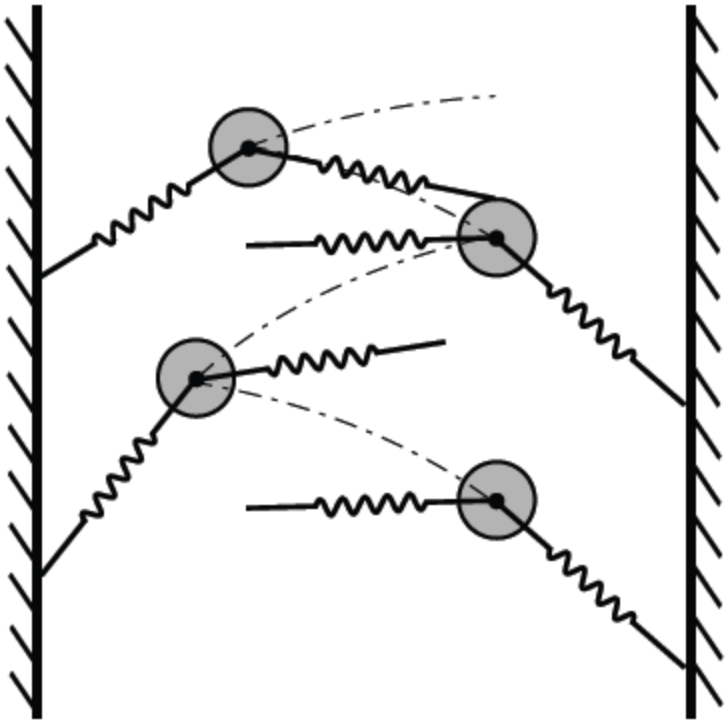


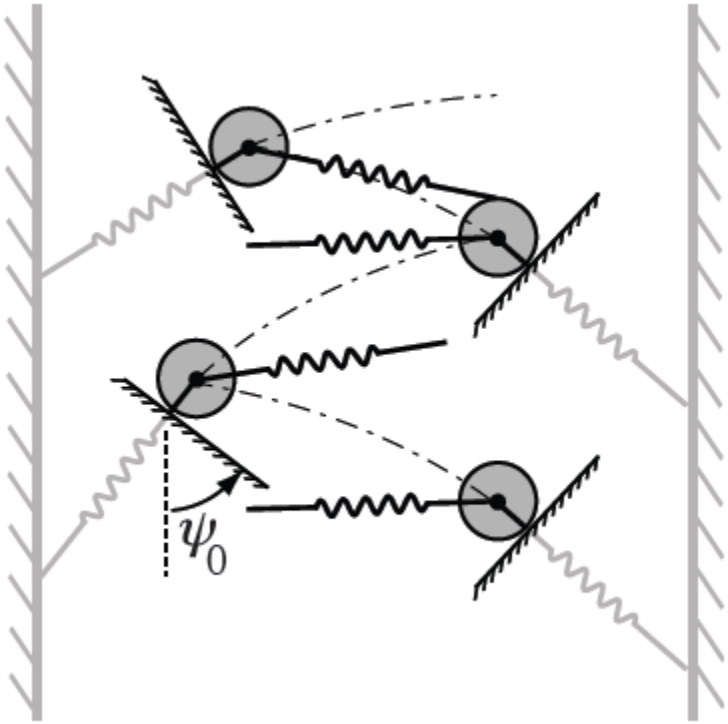
(e) $\zeta_0 = 0.65$

Vertical SPM

$$\begin{aligned}\ddot{\zeta} &= k - k\zeta + \zeta\dot{\psi}^2 - \sin\psi - c_\zeta\dot{\zeta} \\ \ddot{\psi} &= -\frac{1}{\zeta}(\cos(\psi) - 2\dot{\zeta}\dot{\psi}) - c_\psi\dot{\psi}\end{aligned}$$

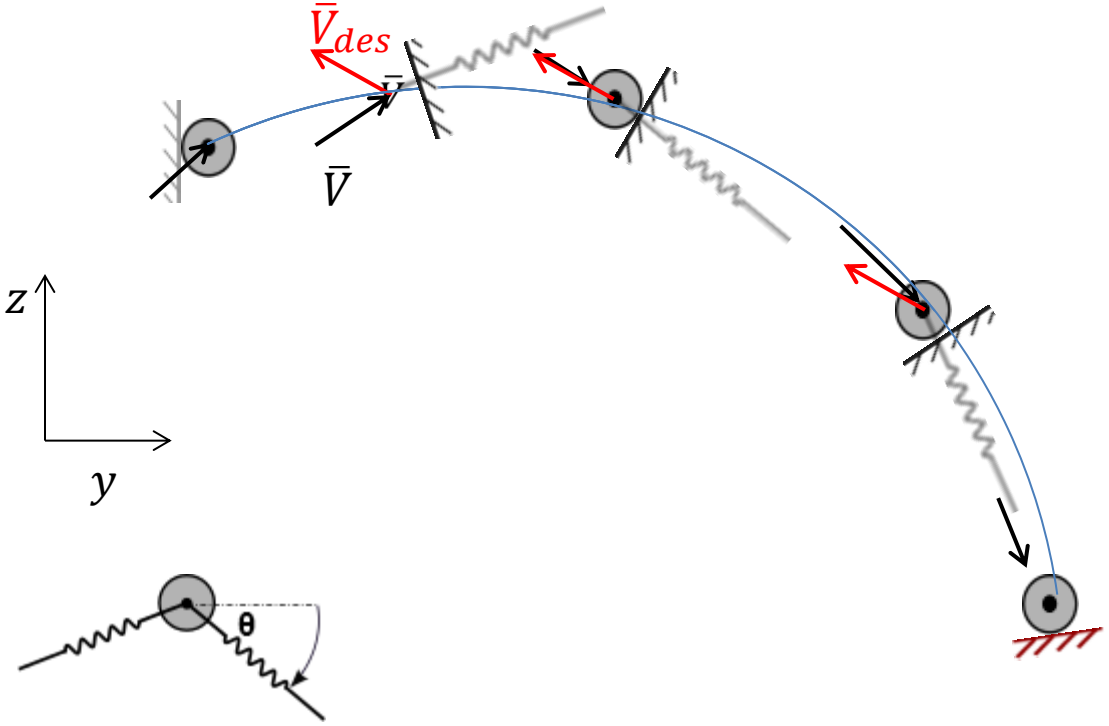
$$\begin{bmatrix} V_y \\ V_z \end{bmatrix}^+ = \begin{bmatrix} V_z^- \sin(2\theta) - V_y^- \cos(2\theta) \\ V_y^- \sin(2\theta) + V_z^- \cos(2\theta) \end{bmatrix}$$





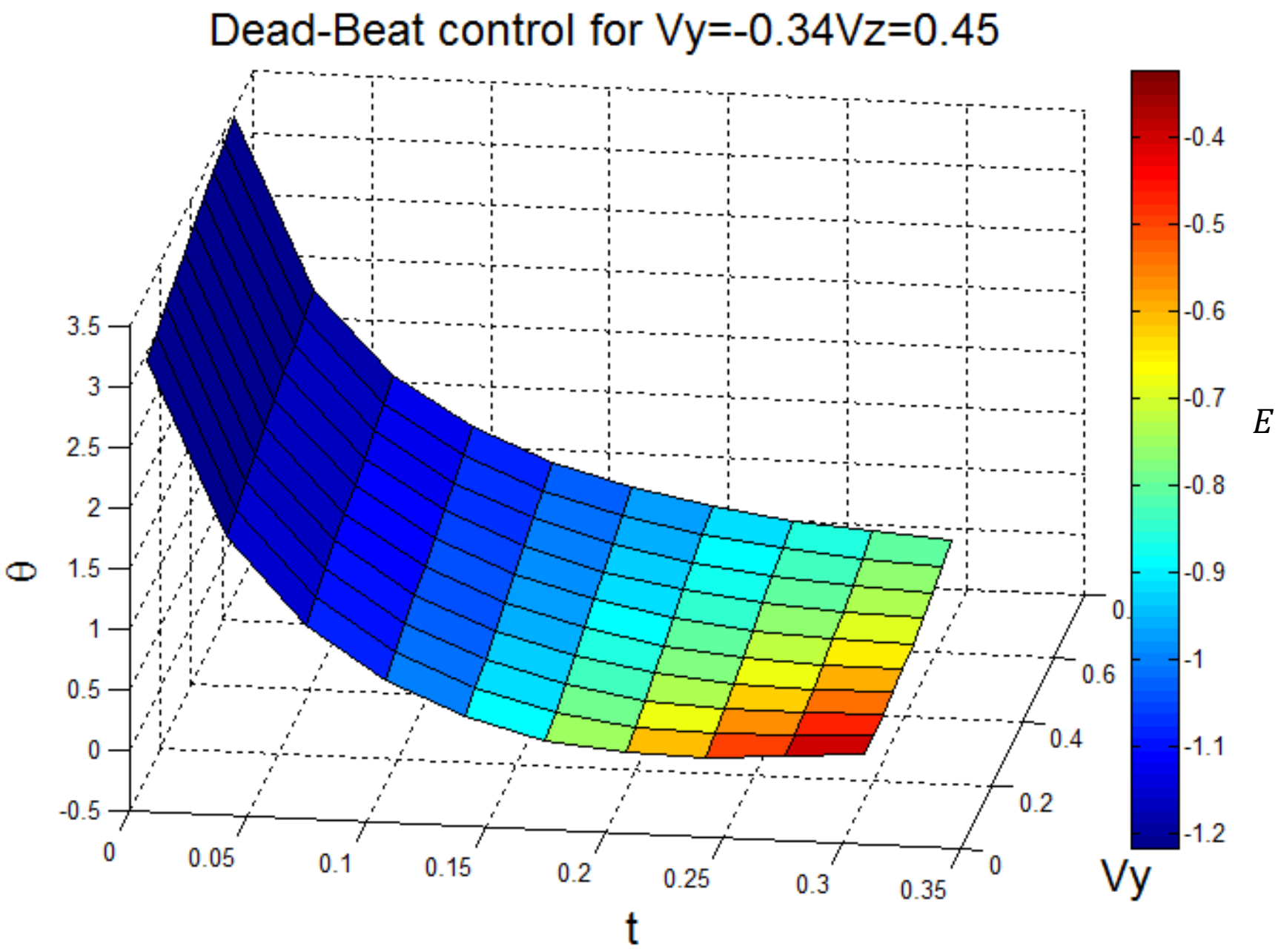
Steady State Solution

$$\begin{bmatrix} V_y \\ V_z \end{bmatrix}^+ = \begin{bmatrix} V_z^- \sin(2\theta) - V_y^- \cos(2\theta) \\ V_y^- \sin(2\theta) + V_z^- \cos(2\theta) \end{bmatrix}$$



In order to ensure
$V_y^+ < 0$;

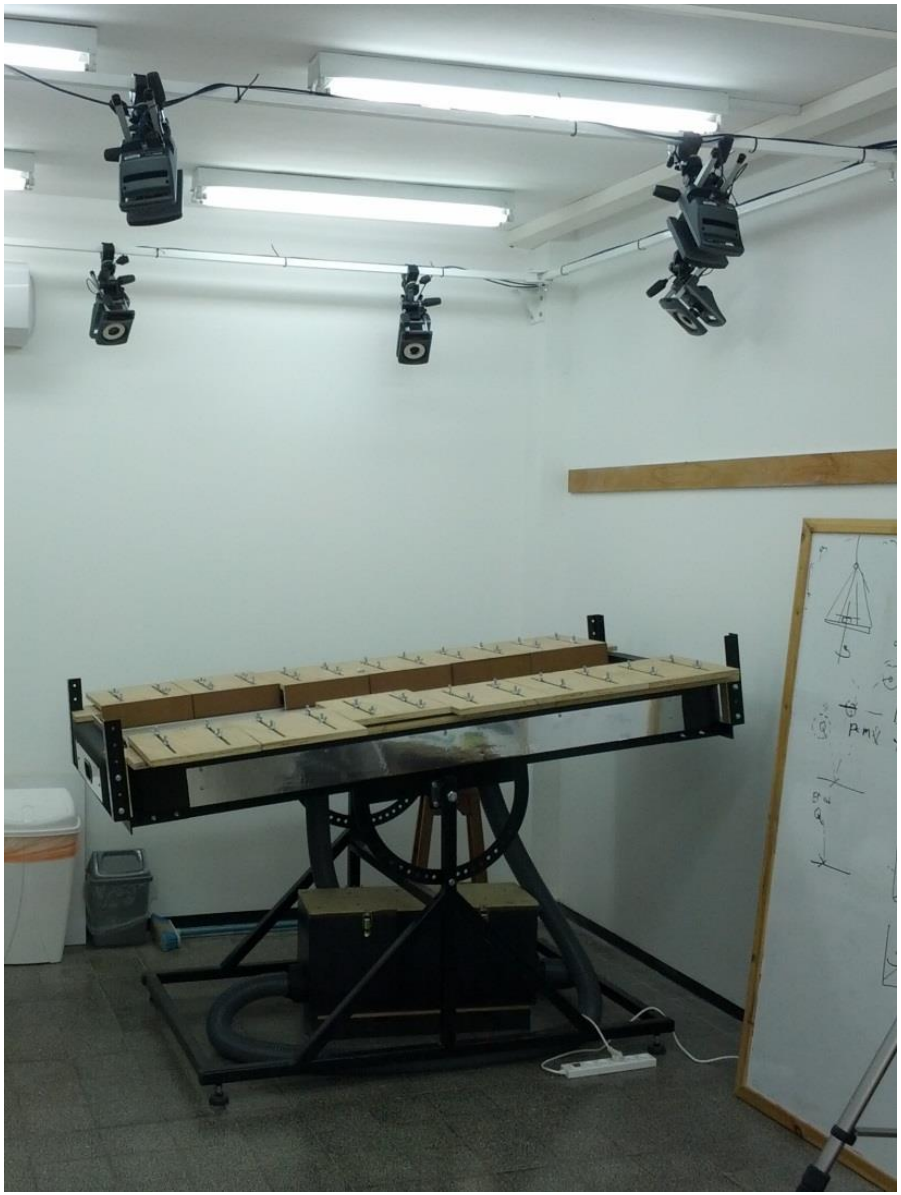
$\theta(t = \infty) > 0$



Model Values: $V_{z0} = 0.45$;g=1.47;$\epsilon = 0.7$

Non-Dimension

Experimental Setup

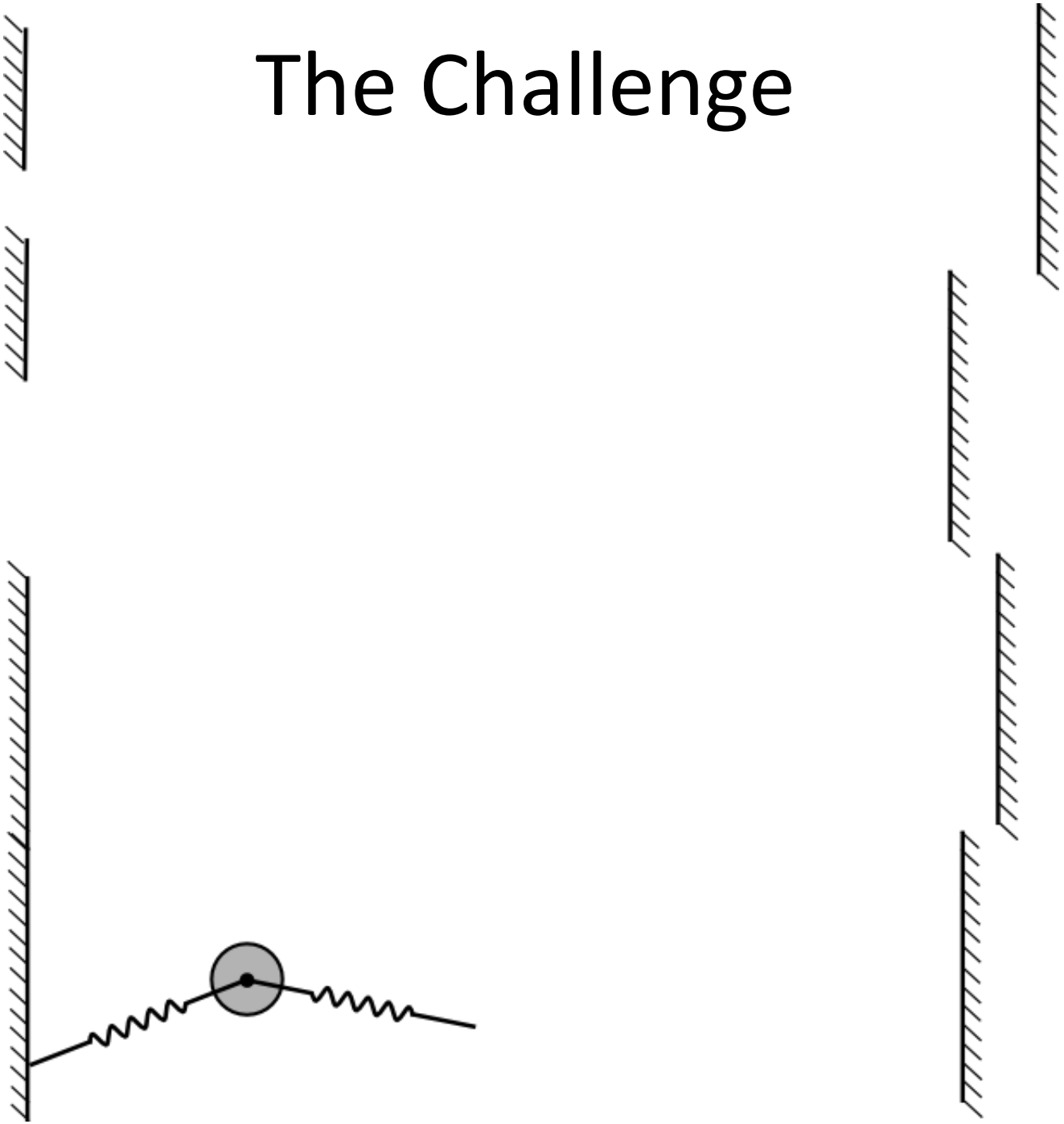


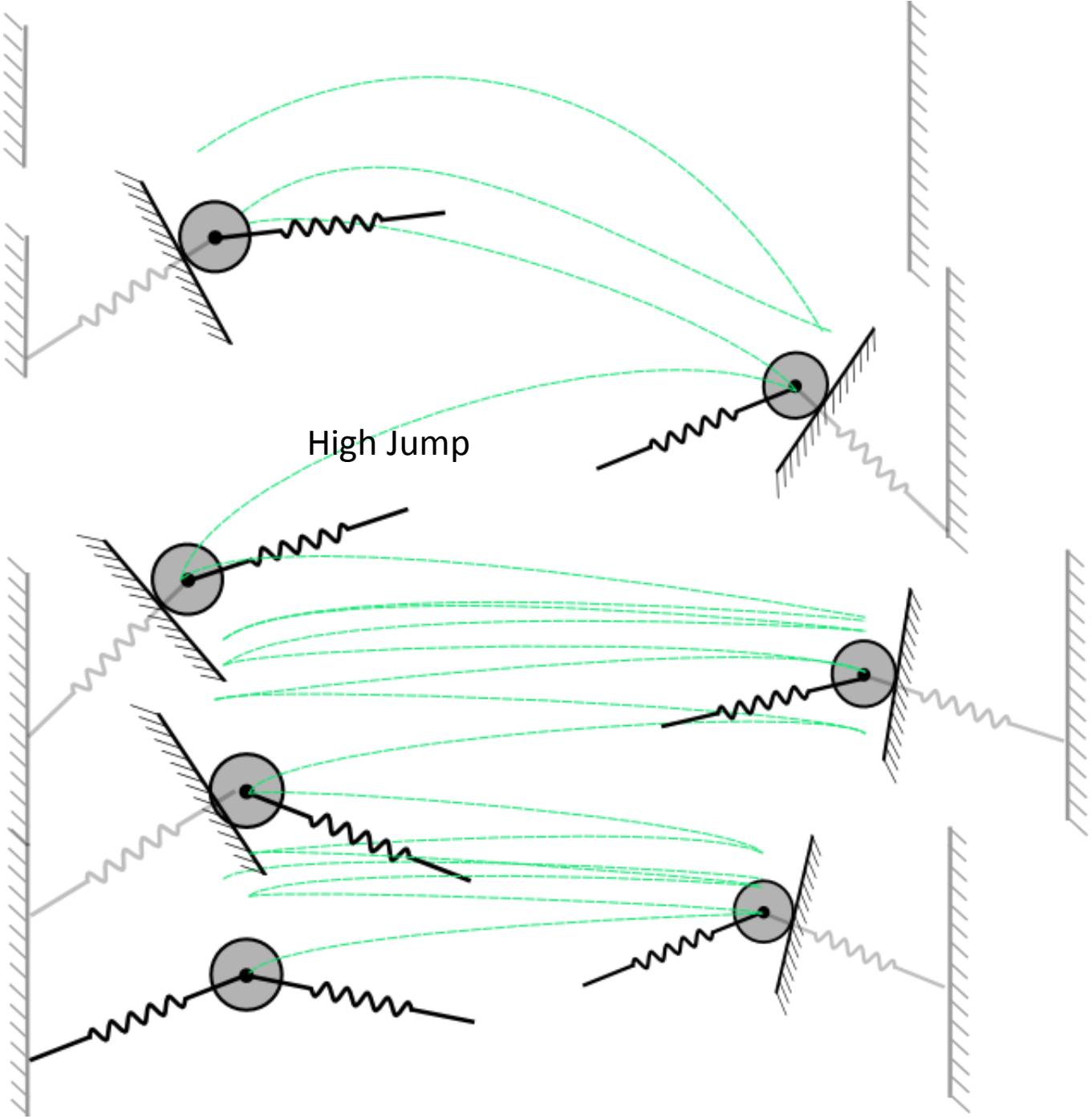
No Swing-Leg

Swing-Leg

Motion Planning and Control

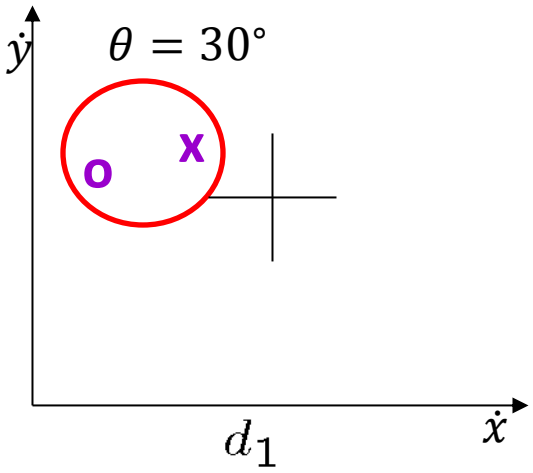
The Challenge

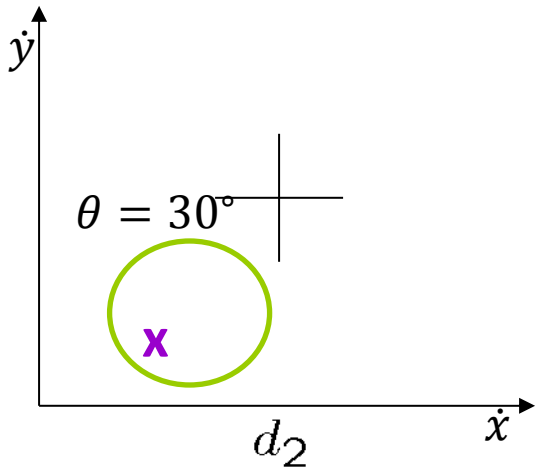


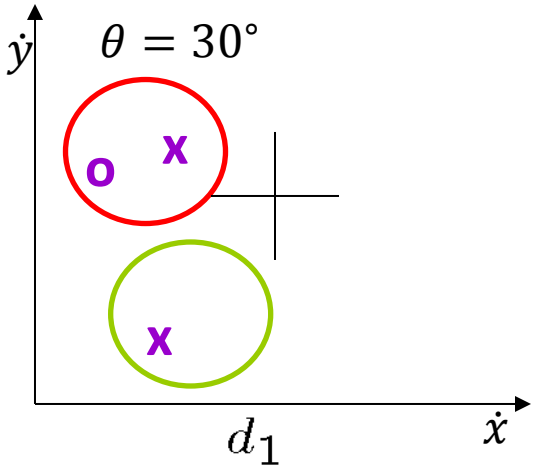

High Jump
Long Jump
Increase Velocity

Closed-loop

Chaining passive basins of attractions

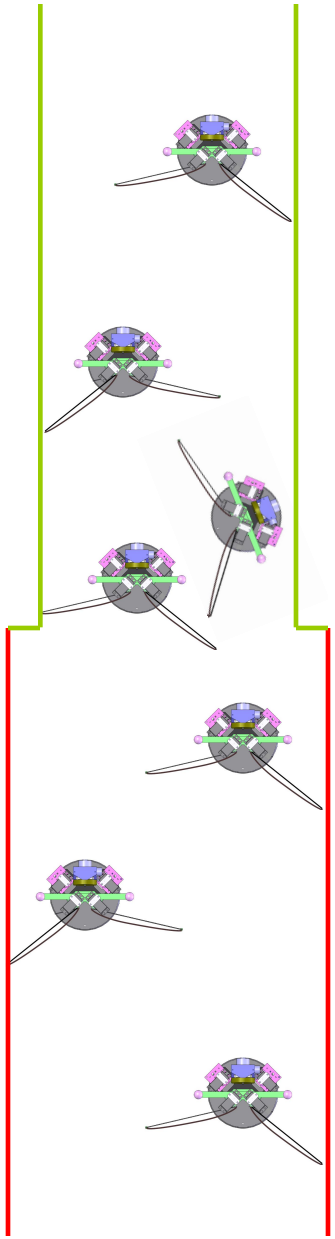






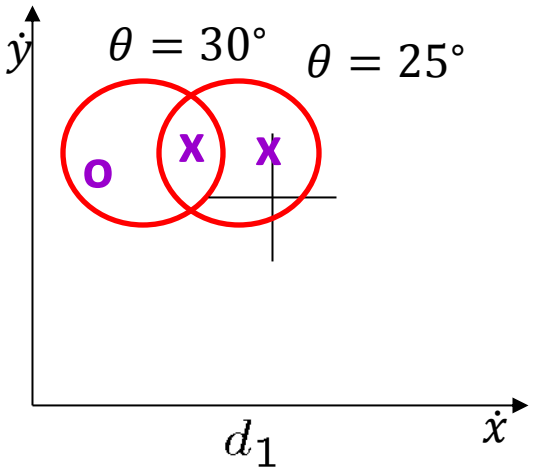
O – init. cond

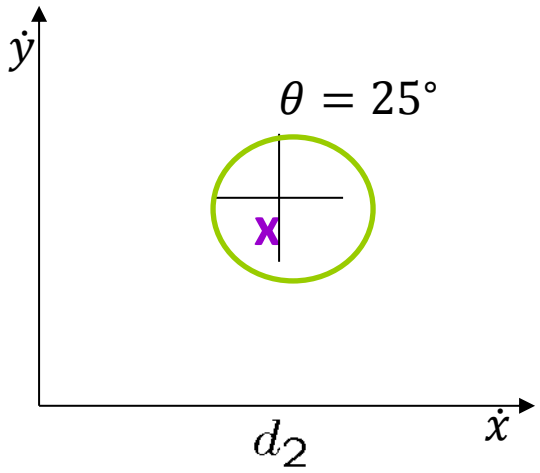
X - attractor



Closed-loop

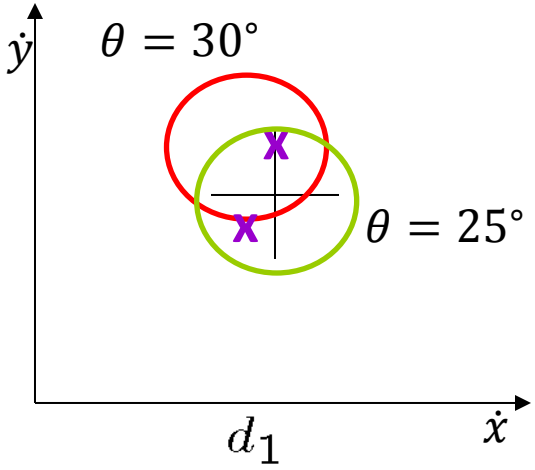
Chaining passive basins of attractions

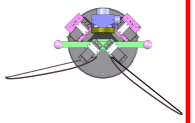




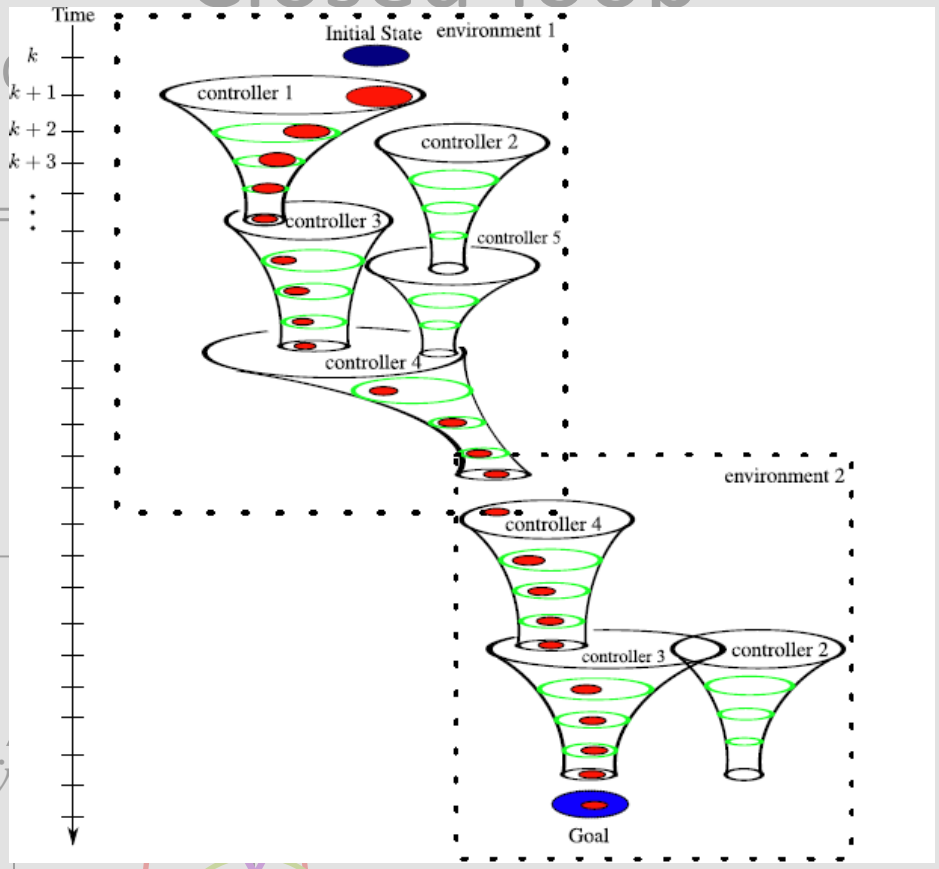
O – init. cond

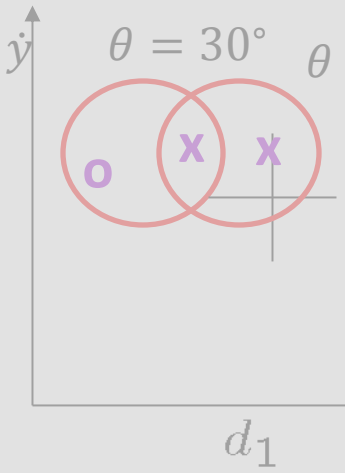
X - attractor

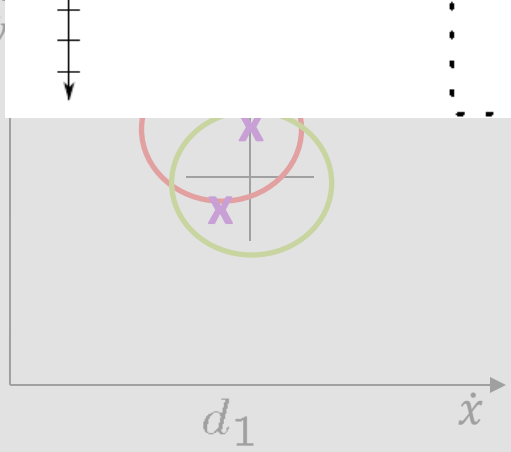




Closed-loop





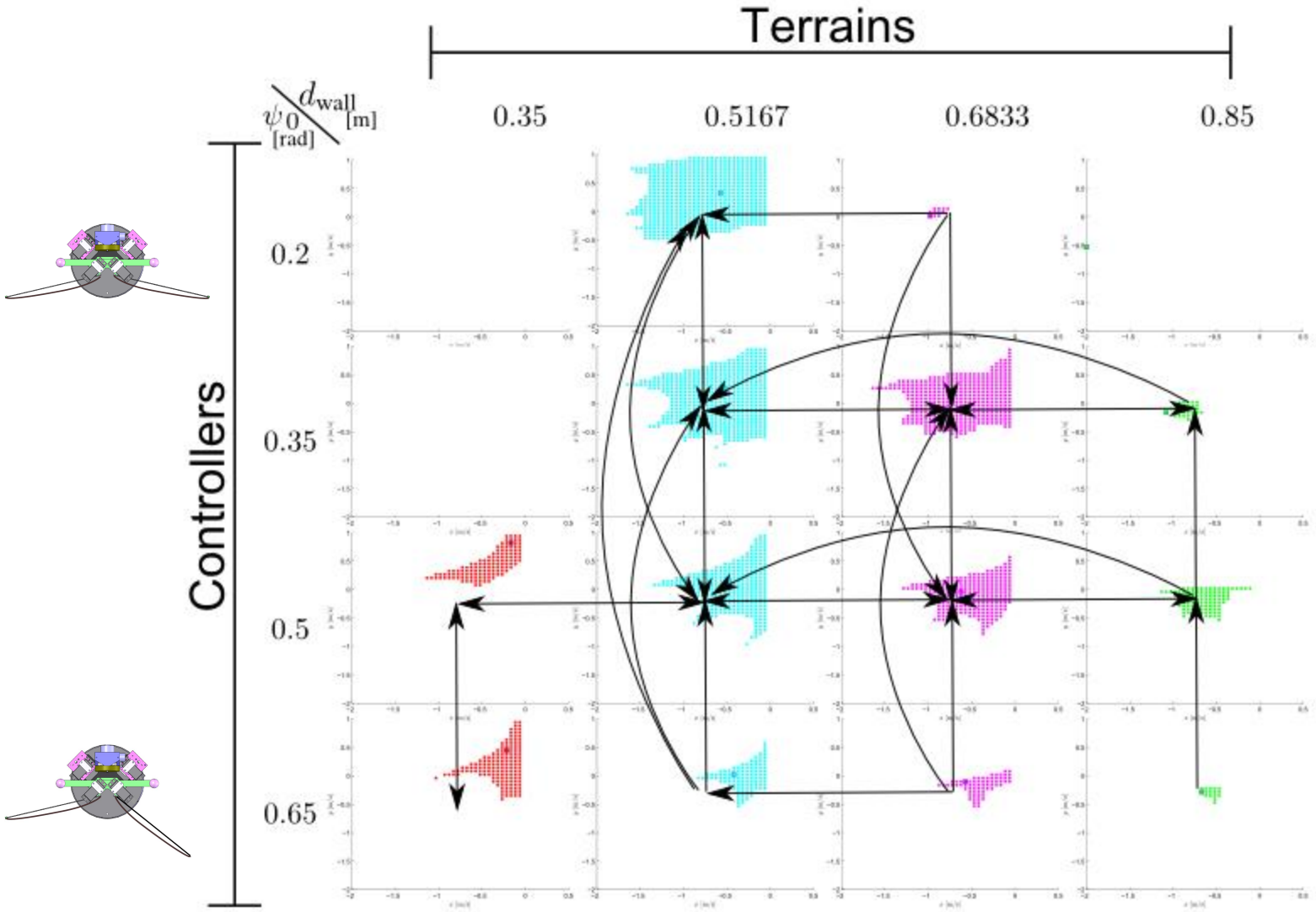


O – init. cond

X - attractor

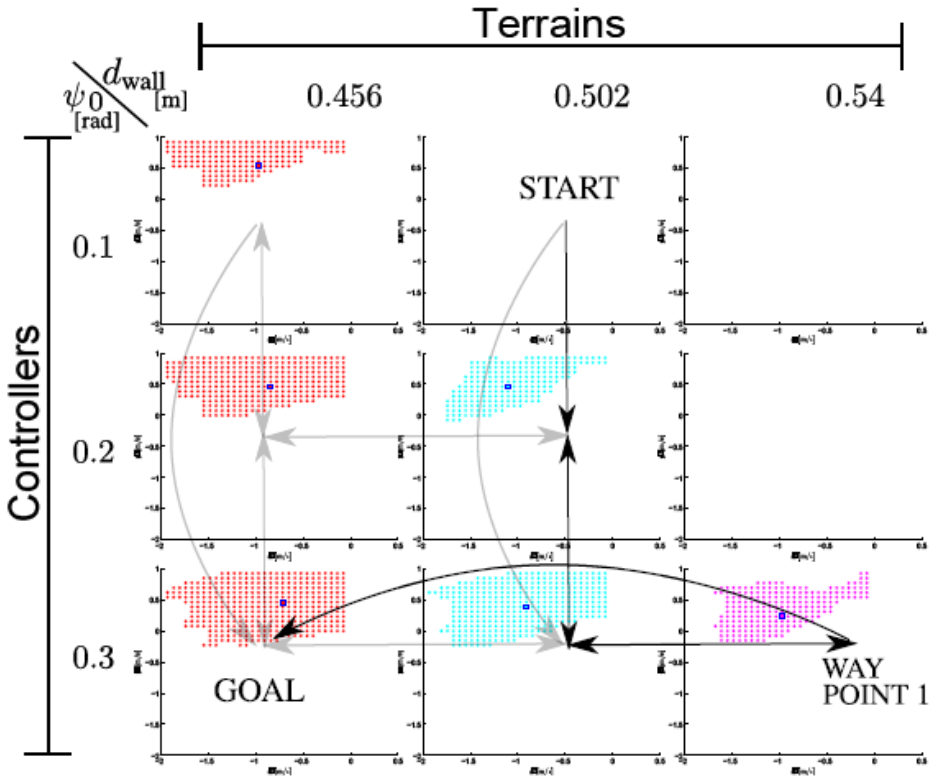
Closed-loop

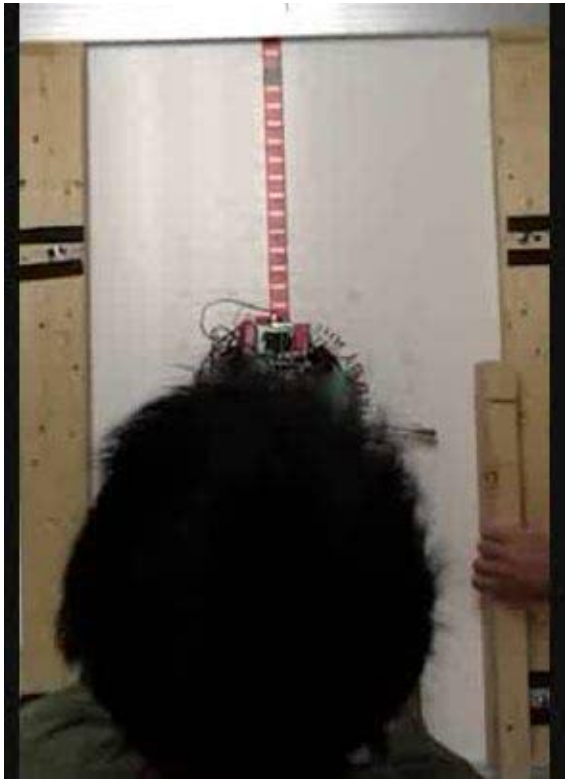
Chaining passive basins of attractions



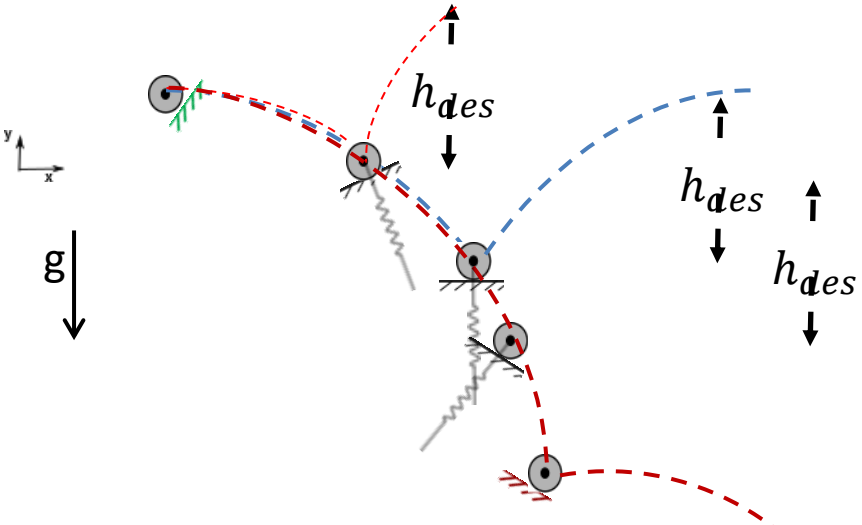
Closed-loop

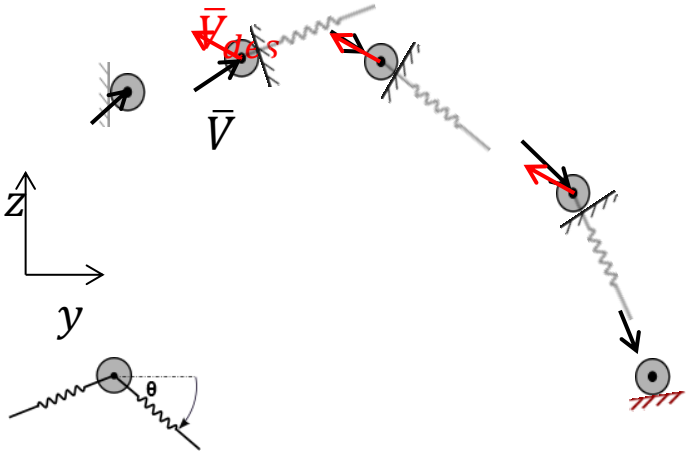
Chaining passive basins of attractions

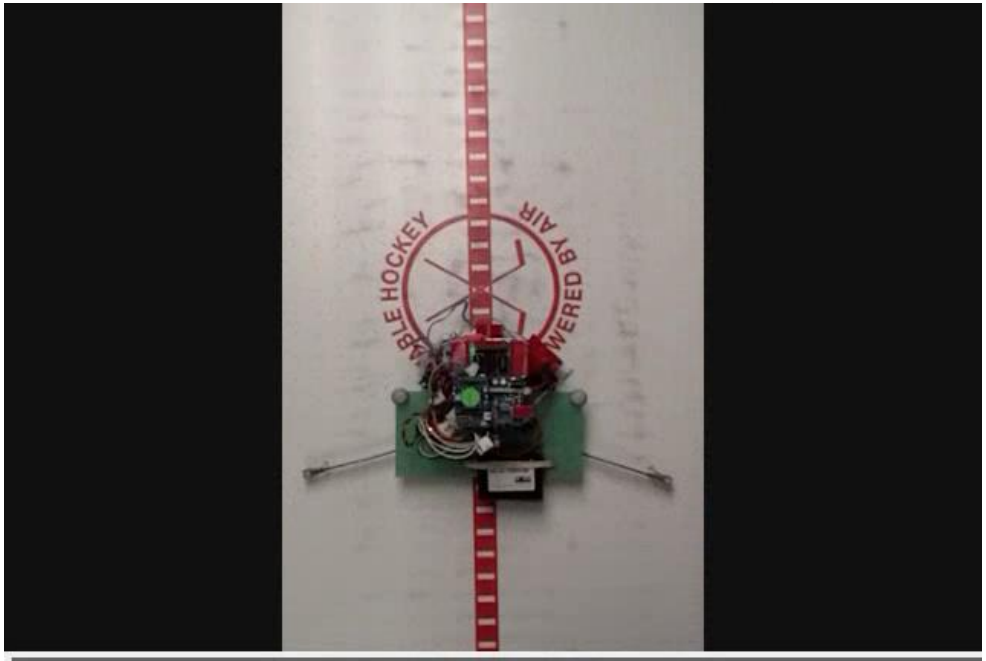




Discussion - Questions







Mechanism Design