

Low-Profile Crawling for Humanoid Motion in Tight Spaces

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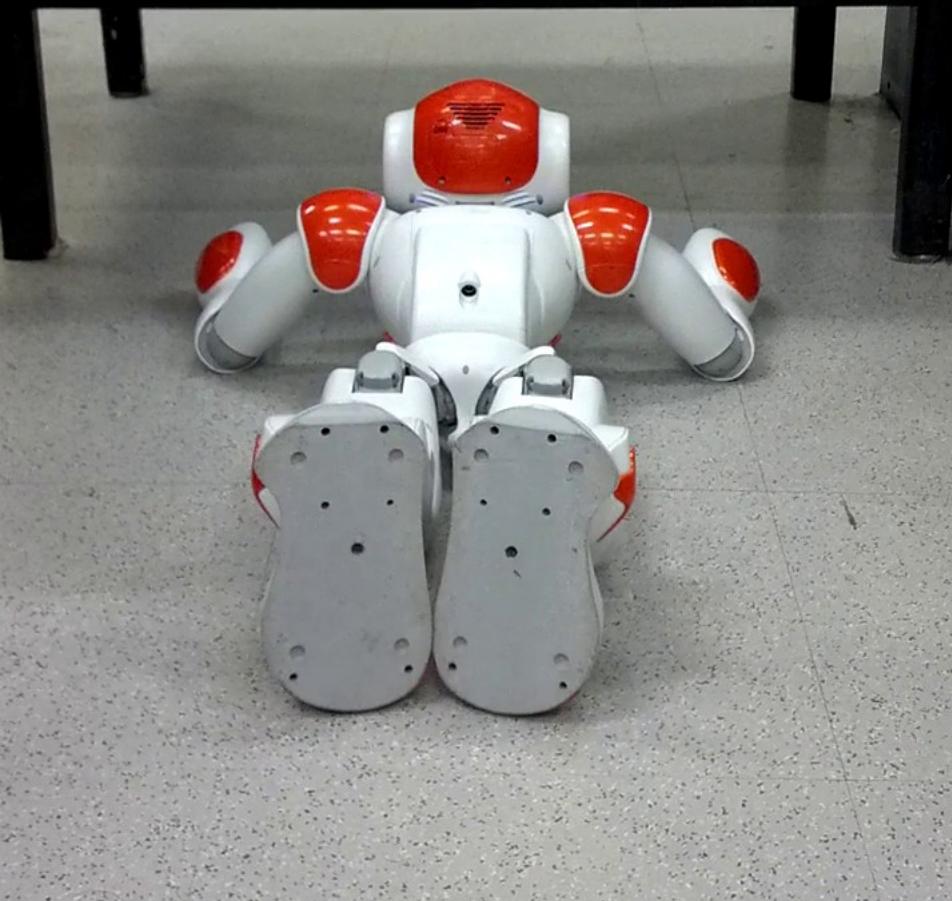
Presentation Outline

Where are we going?

Introduction

Nao Platform
Crawl Gait Formulation
Gait Optimization

Conclusion



Introduction

What are we going to talk about?

Expand Set of Humanoid Gaits

Statically Stable Gait

Low Vertical Clearance





Nao Platform

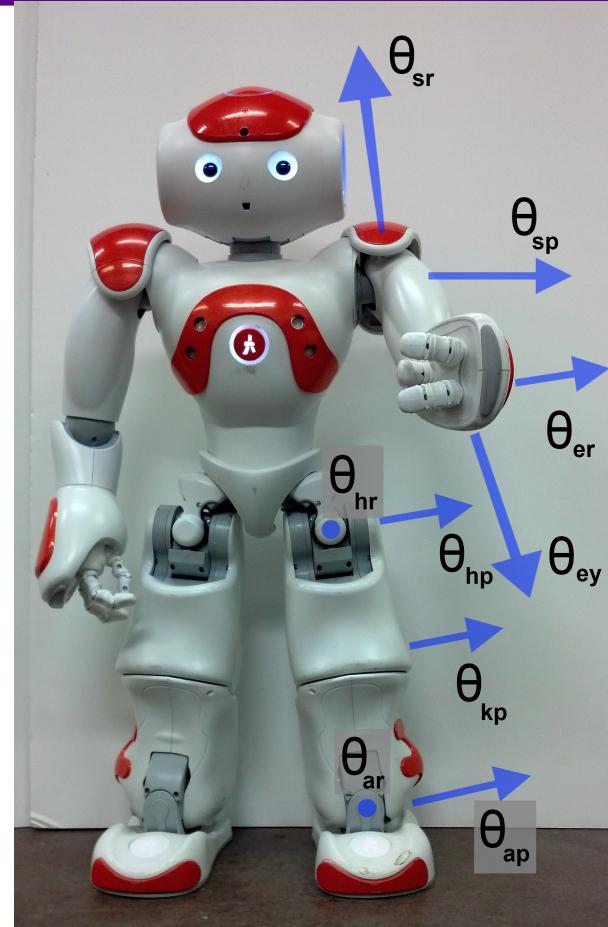
Hardware Review

Aldebaran Robotics

25 DoF humanoid, 58 cm, 4.3 kg

Atom processor, cameras, sonars, IMU

Laterally symmetric, no back joint





Crawl Gait

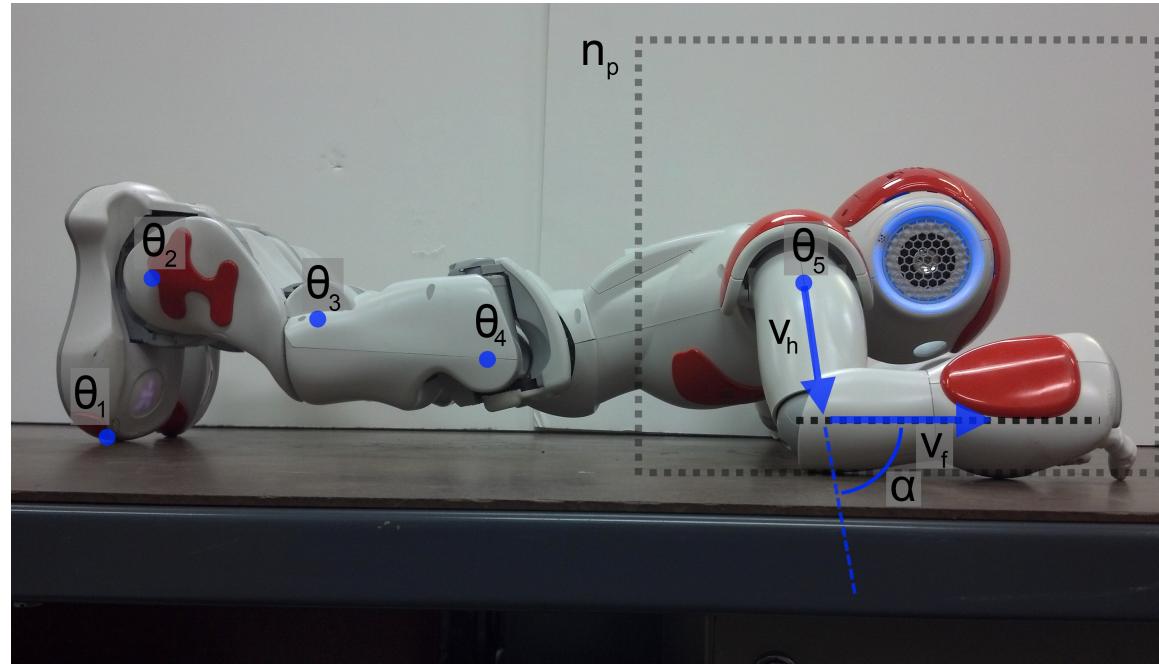
How does it move?

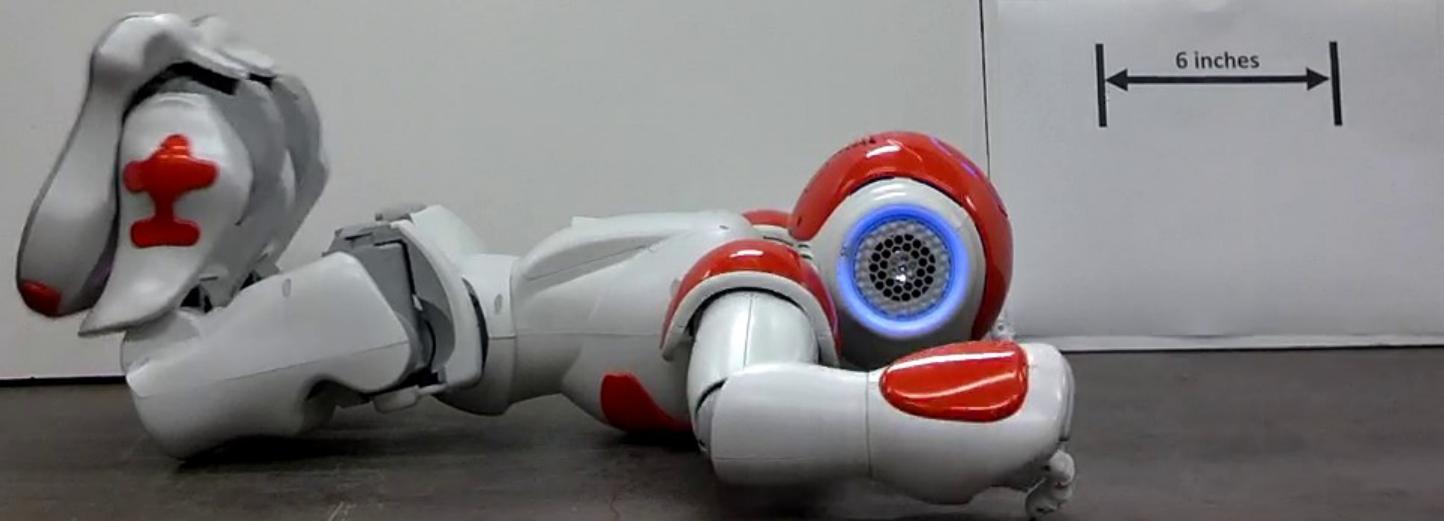
Projected Profile

- Sagittal Plane Projection
- 25 DoF to 6 DoF

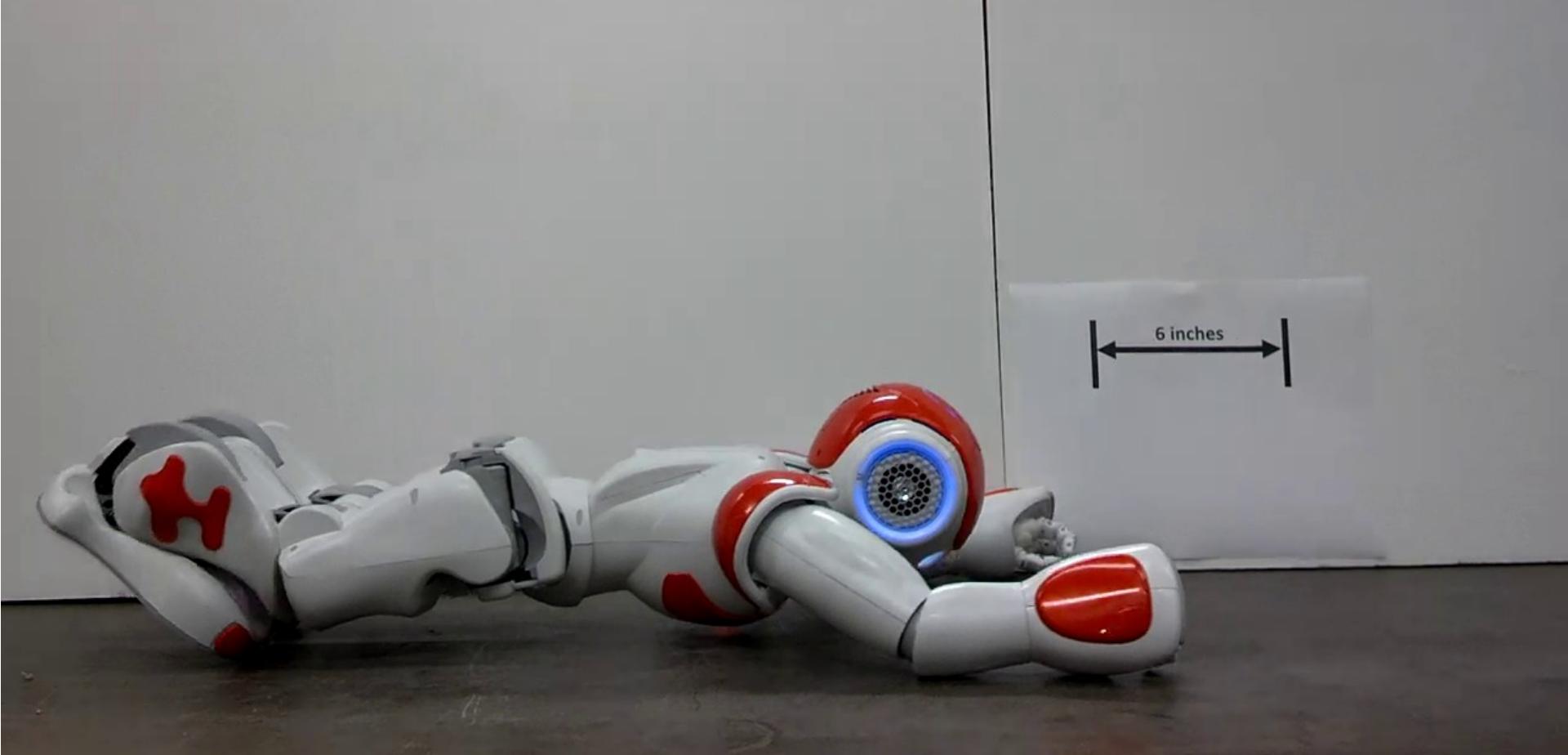
Dual Mode

- Open Chain
 - Move end effectors
- Closed Chain
 - Move CoM

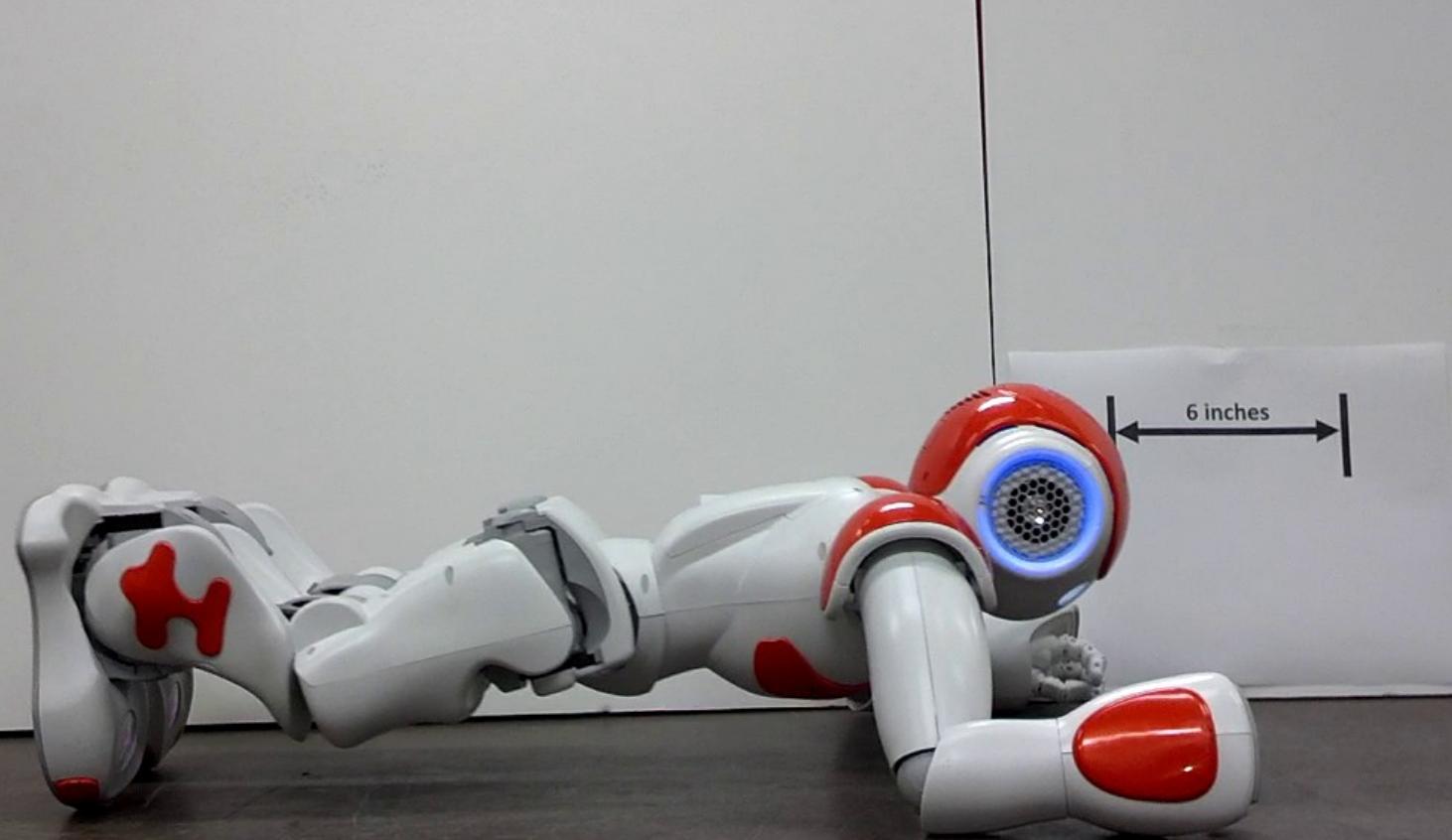




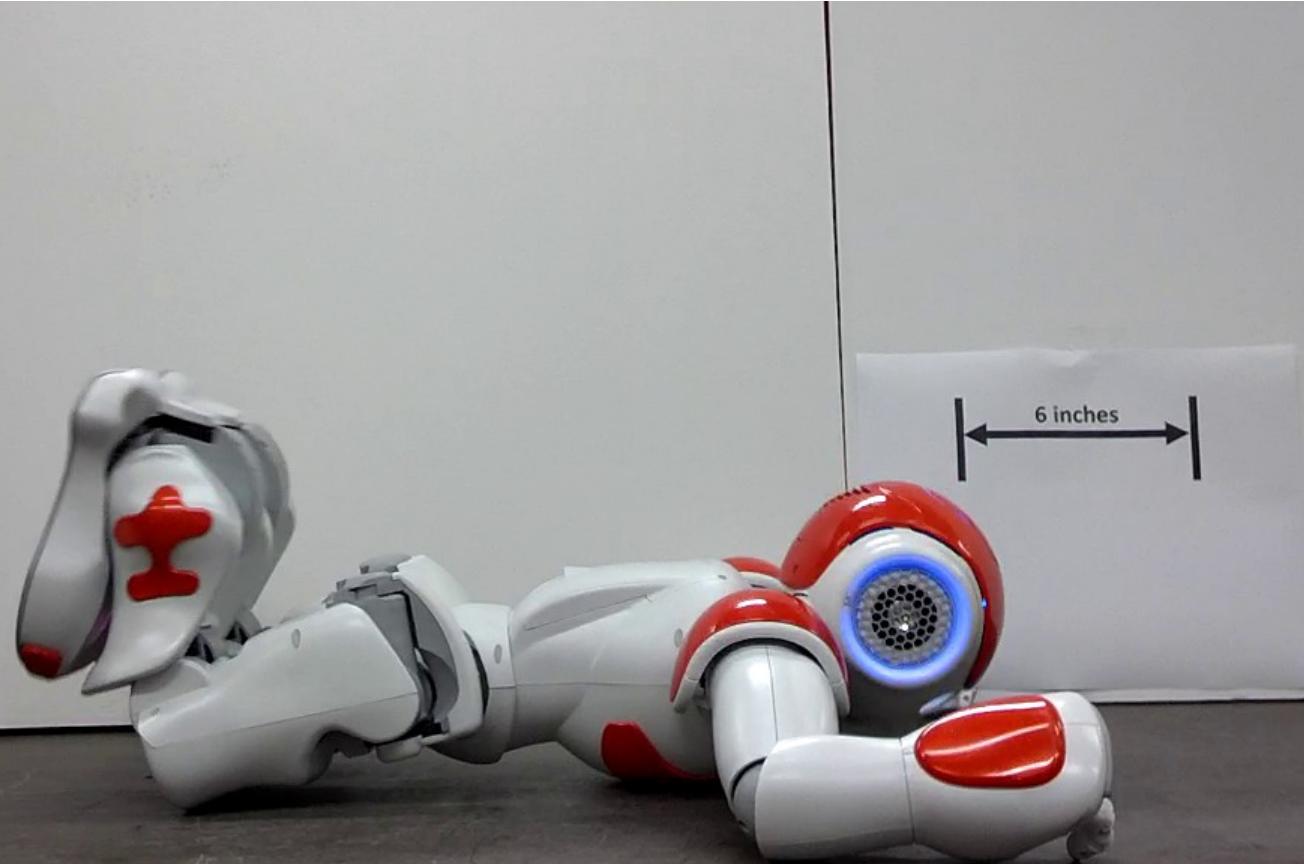
Crawl Gait: Extension



Crawl Gait: Compression



Crawl Gait: Open Chain



$$d_e = \sum_{i=1}^5 l_i \cos(\sum_{j=1}^i \theta_j)$$

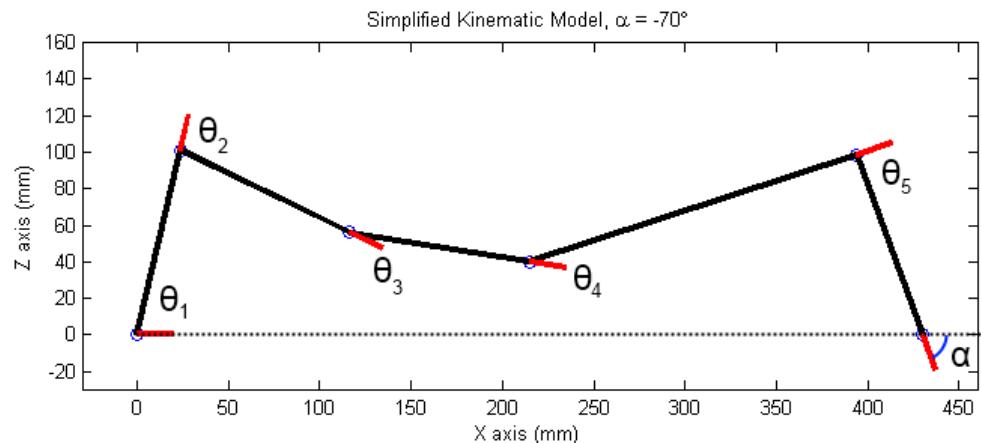
$$0 = \sum_{i=1}^5 l_i \sin(\sum_{j=1}^i \theta_j)$$

$$\alpha = \sum_{i=1}^5 \theta_i$$

Foot “joint” is not actuated

Knee and Hip as free variables

Remaining joints function of Elbow



Solving for Ankle Joint

- Squared sum

$$2l_1K_1 \cos(\theta_2) + 2l_1K_2 \sin(\theta_2) = \\ [d_e - l_5 \cos(\alpha)]^2 + [l_5 \sin(\alpha)]^2 - l_1^2 - K_1^2 - K_2^2$$

Solving for Ankle Joint

$$K_1 \triangleq l_2 + l_3 \cos(\theta_3) + l_4 \cos(\theta_3 + \theta_4)$$

$$K_2 \triangleq -l_3 \sin(\theta_3) - l_4 \sin(\theta_3 + \theta_4)$$

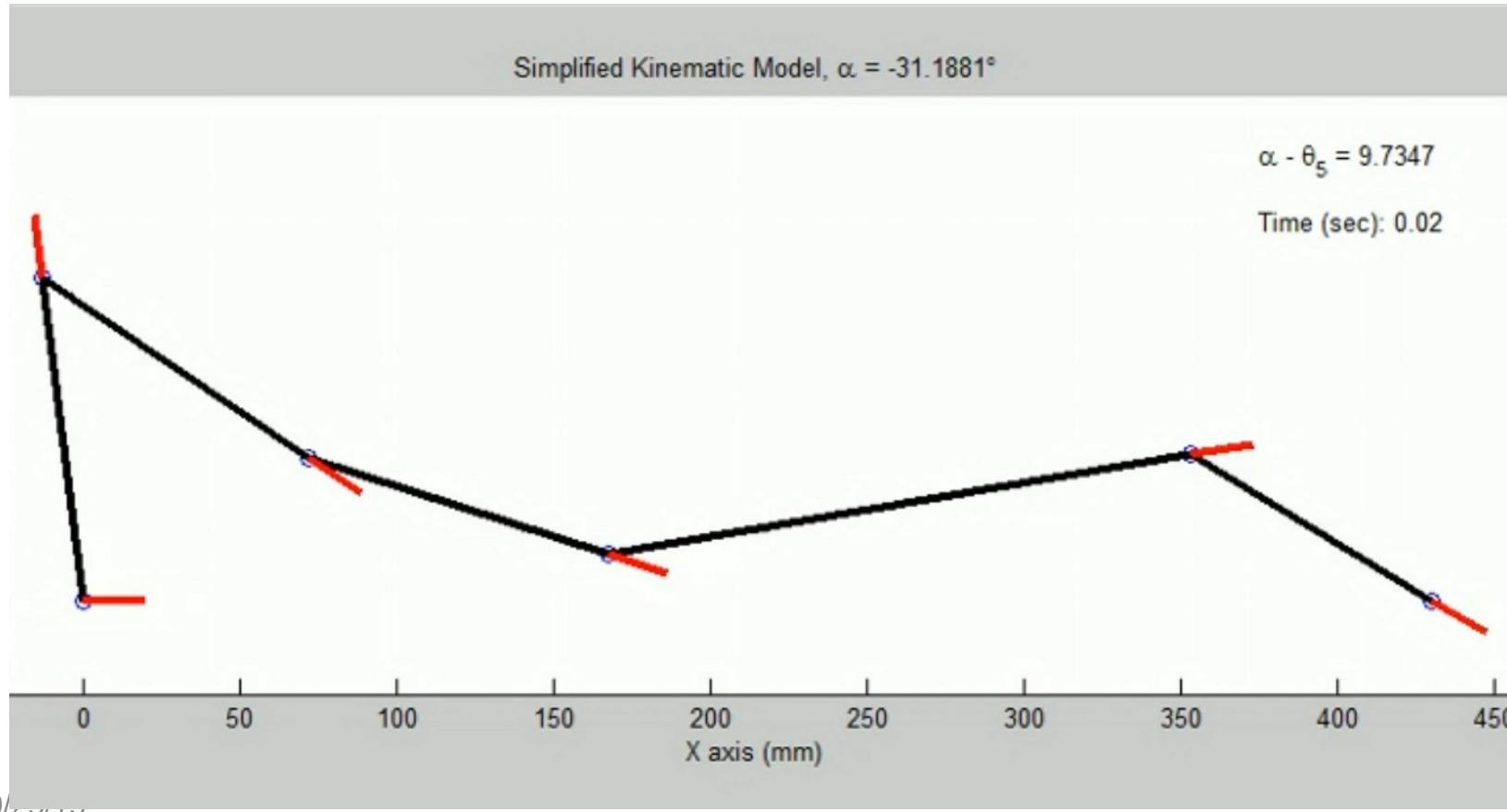
Yields two solutions for Ankle

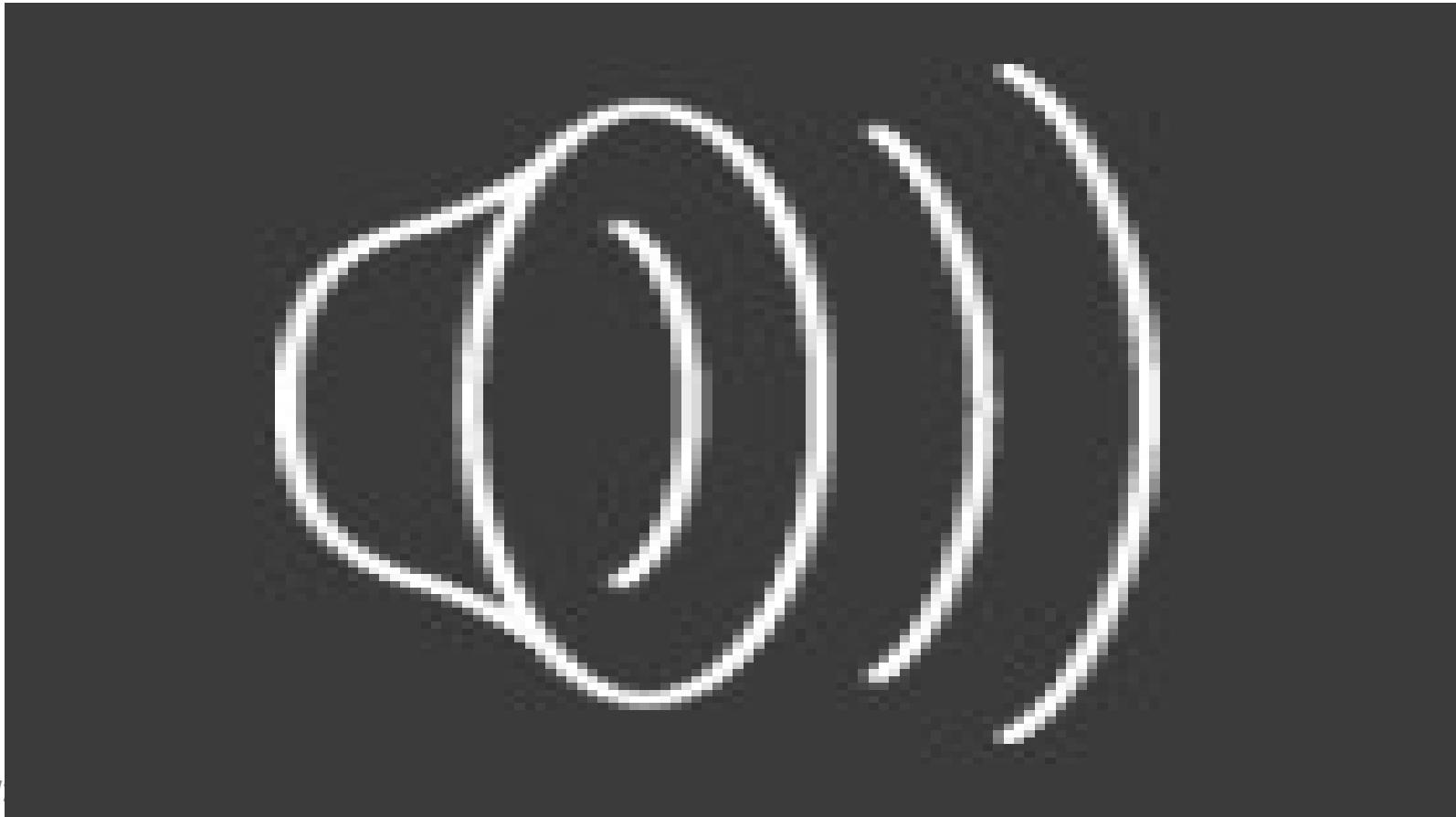
- One is kinematically infeasible

Foot joint follows from Ankle

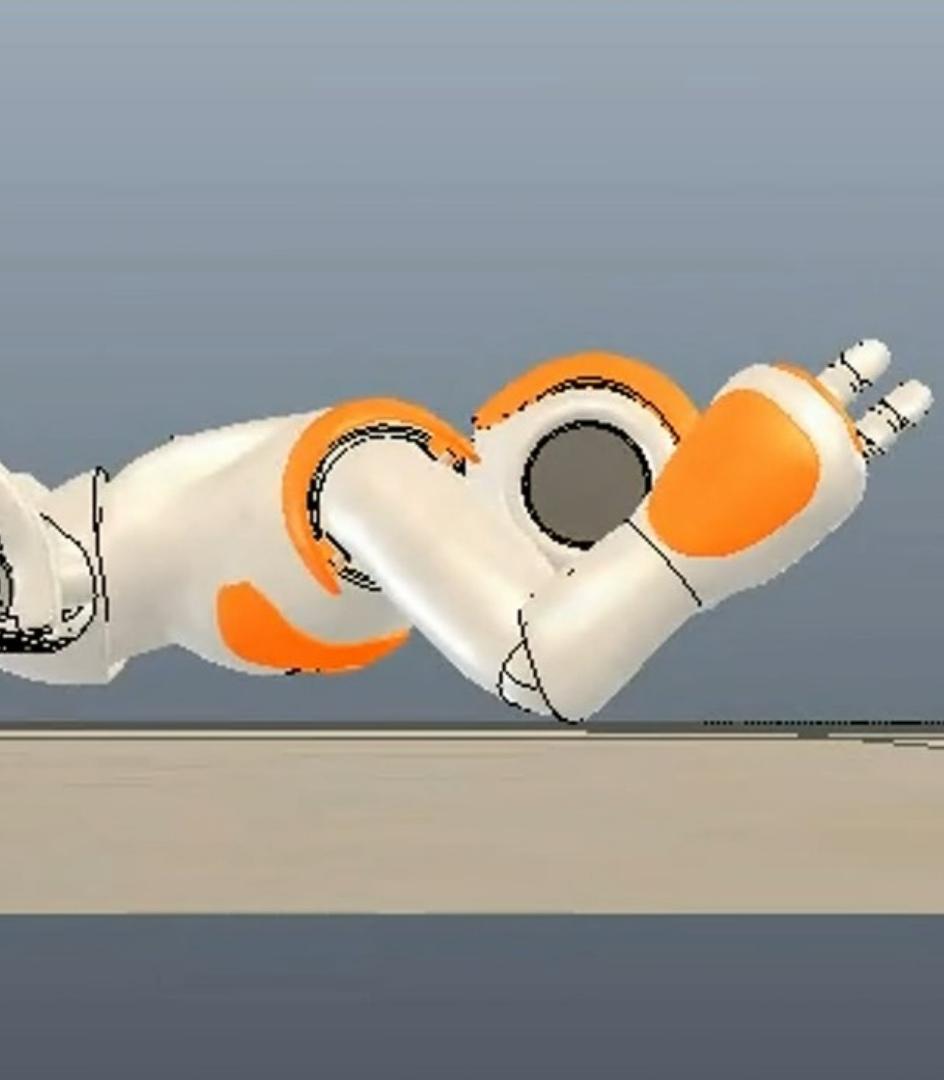
Shoulder joint is given by:

$$\theta_5 = \alpha - \sum_{i=1}^4 \theta_i$$









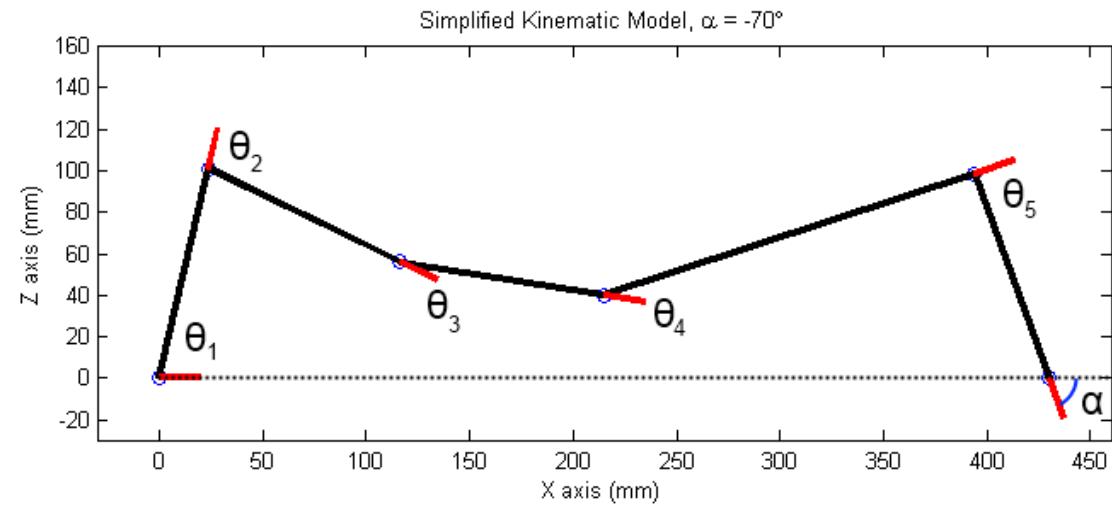
Gait Optimization

How should it move?

Knee and hip as free variables

Optimize wrt torques

Pseudo-static formulation

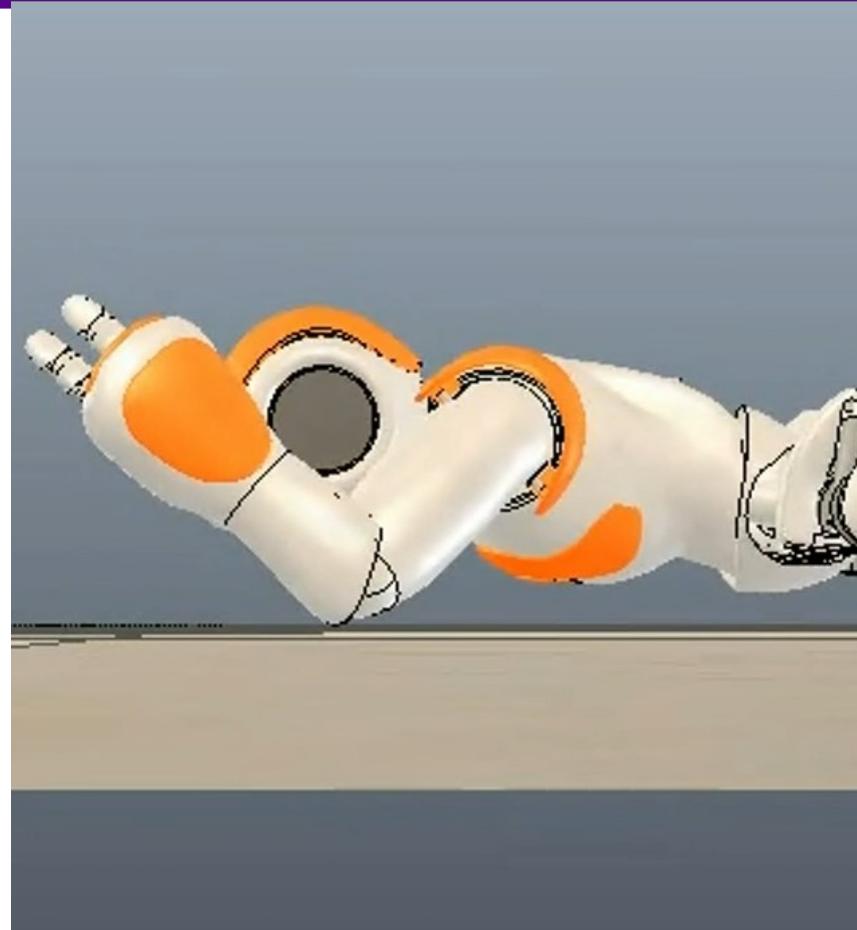


V-REP simulation

Table of joint angles to torques

- 2.5° resolution
- $\pm 30^\circ$ about initial pose
- Linear interpolation

Genetic algorithm for optimization



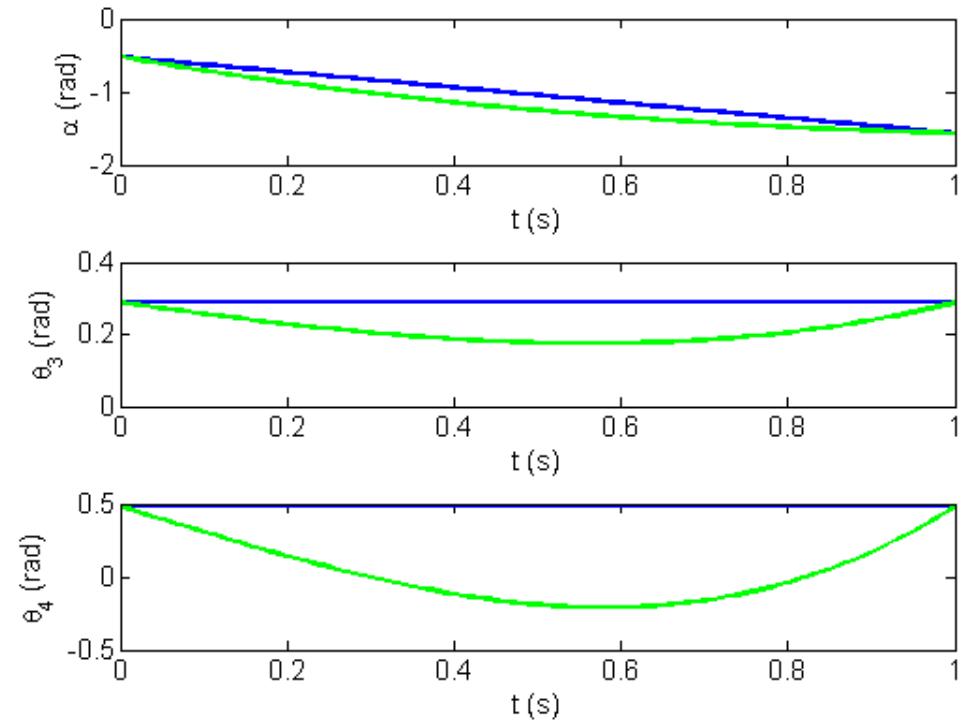
$$\int_0^T \sum_{i=1}^4 w_i \tau_i^2(t) dt$$

Cost Function

- Shoulder weighted more to minimize use
- Terms to prevent backtracking and use feasible joint range

Cubic splines

5.8x reduction in cost





Conclusion

What happened?

Nao Humanoid Projected Profile Optimizing free params

Generality
Heading control
Back orientation control

