Optimal Reduced-order Modeling of Bipedal Locomotion

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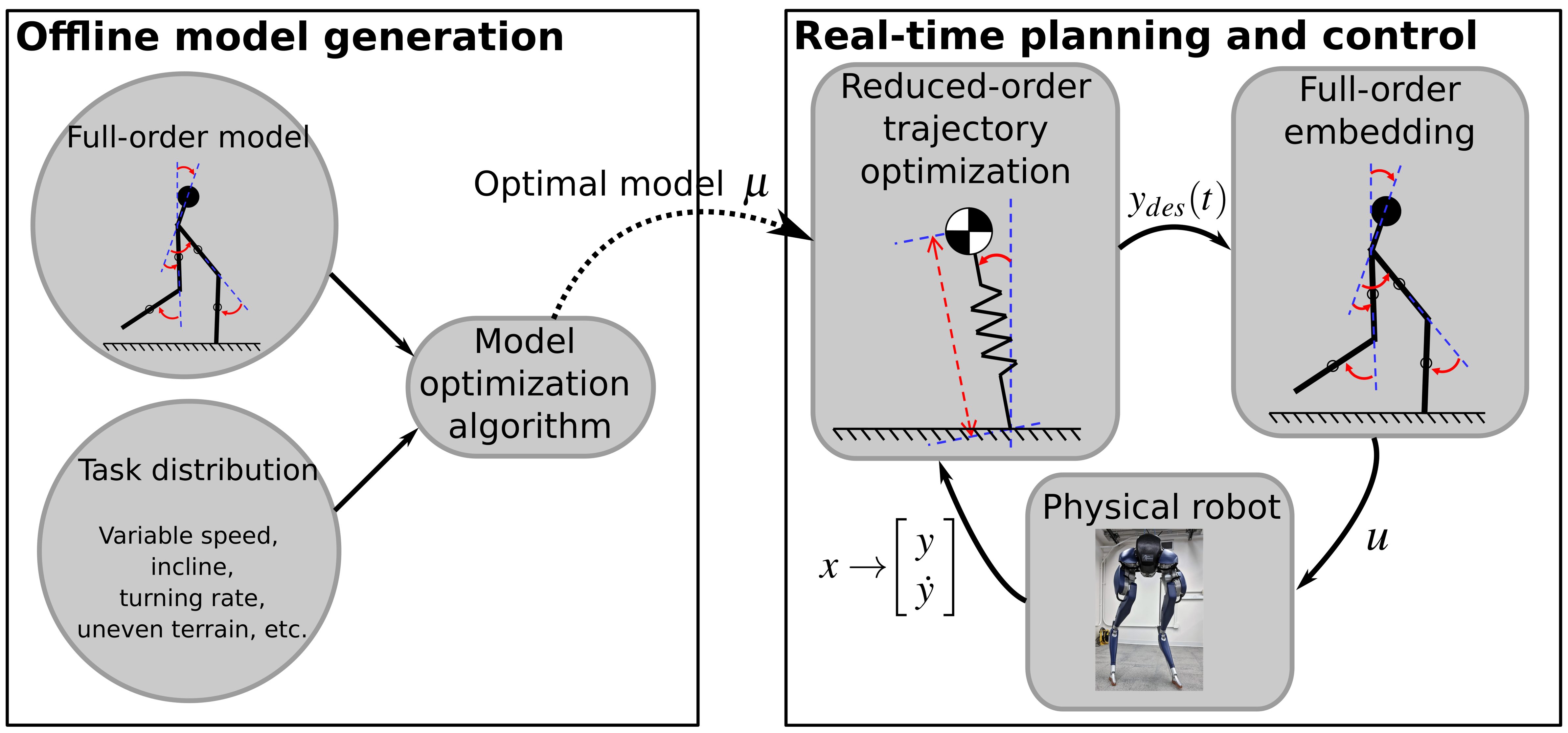
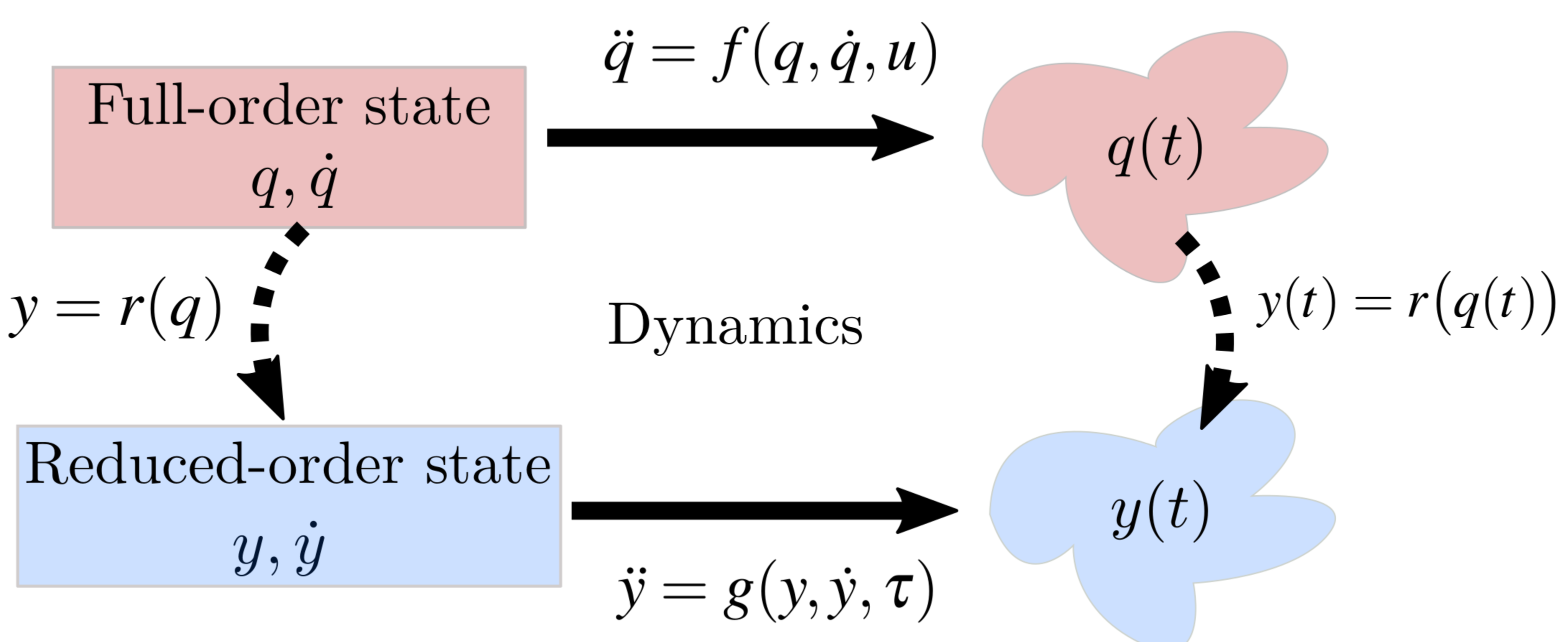
Introduction

Question: What is the best reduced-order model for a walking robot? How do we find it in a principled fashion?



Definition of Reduced-order Models



We define a reduced-order model to be $\mu \triangleq (r, g)$ with

$$y = r(q),$$
$$\ddot{y} = g(y, \dot{y}, \tau),$$

where $\dim y < \dim q$
$\dim \tau \leq \dim u$.

Problem Statement

Goal: find a reduced-order model μ^* that enables low-cost motion given a distribution Γ for the tasks

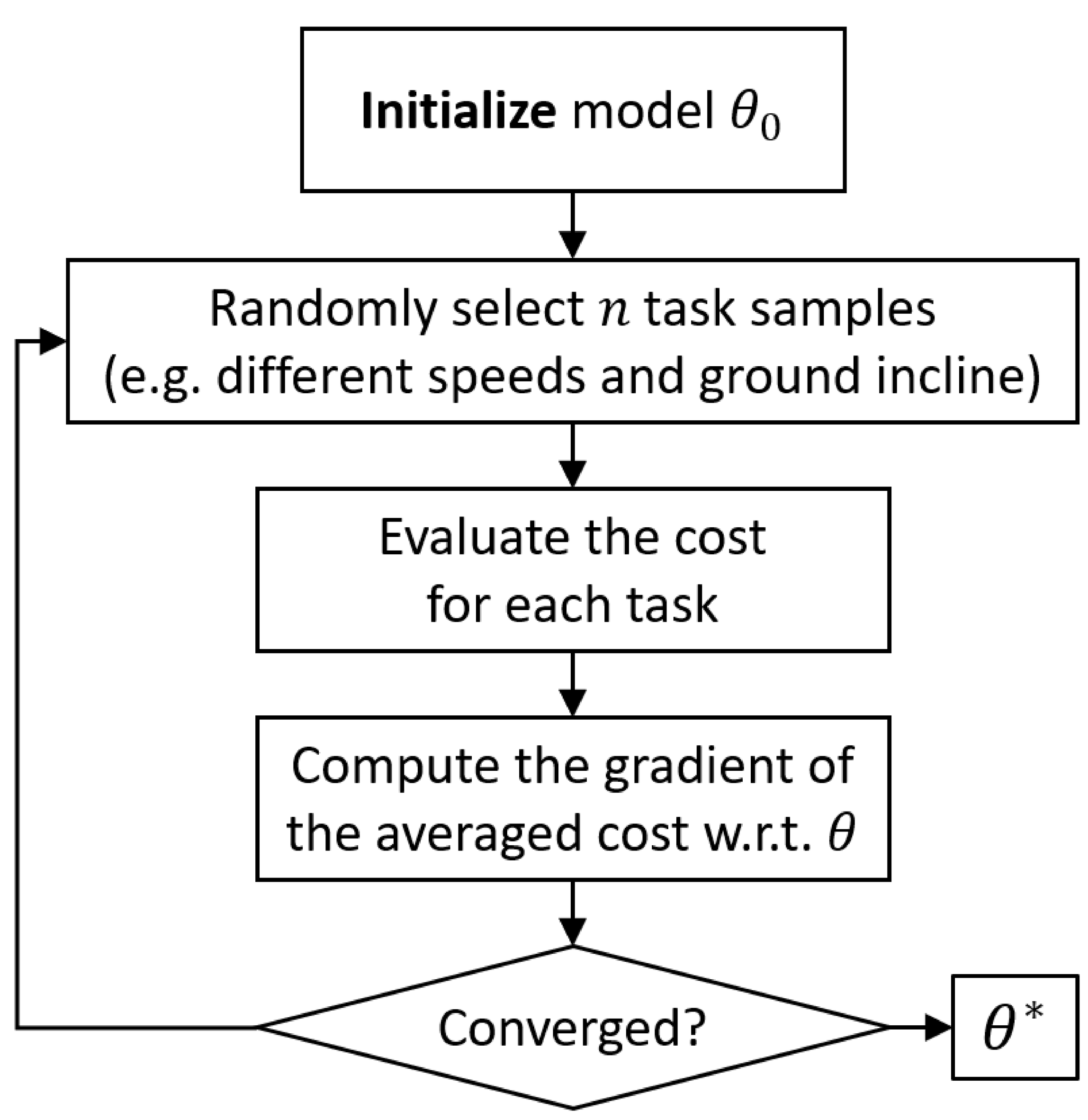
$$\mu^* = \underset{\mu \in M}{\text{argmin}}\ \mathbb{E}_\gamma \left[\mathcal{J}_\gamma(\mu) \right],$$

M	model space
γ	random variable $\sim \Gamma$
$\mathcal{J}_\gamma(\mu)$	cost required to achieve a task γ while the robot is restricted to a particular model μ

Problem simplification

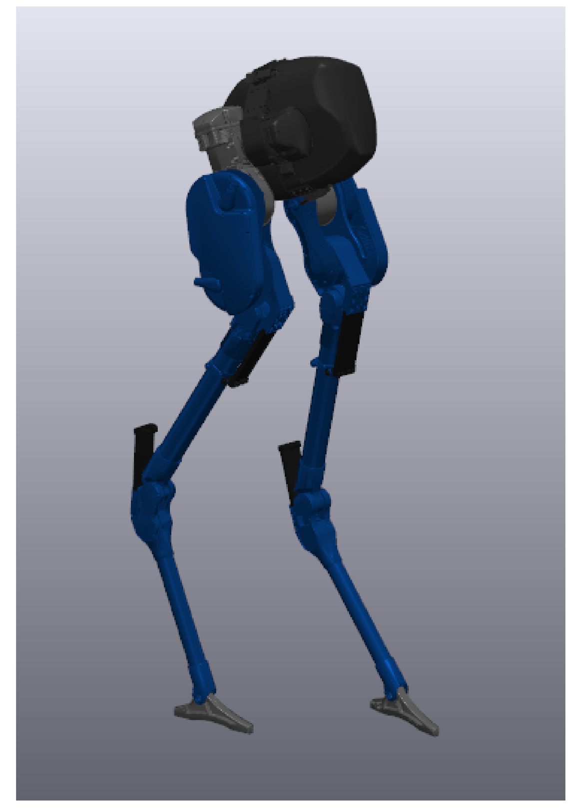
- parametrize the subspace of M with specified feature functions
- search for the parameter θ^*

Optimization Algorithm

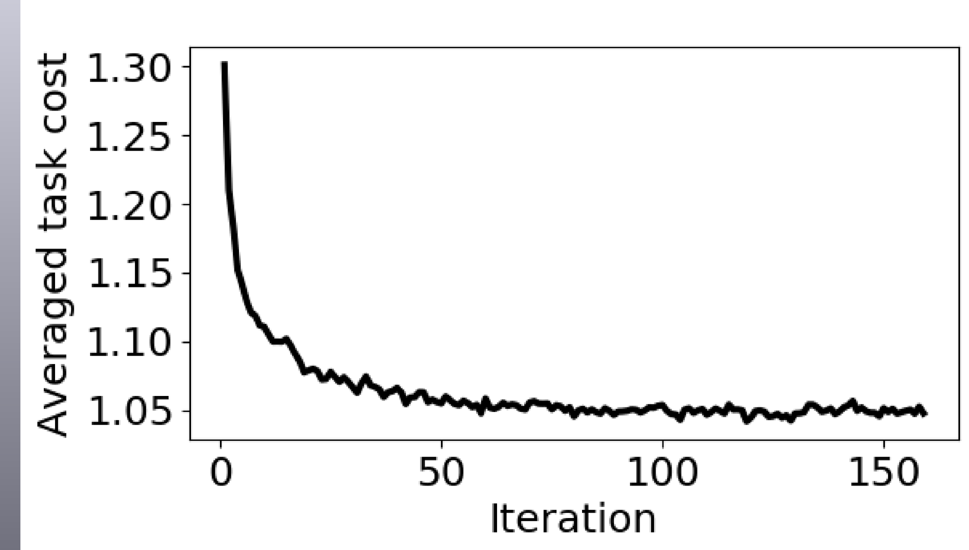


Examples

Robots:	the five-link planar robot and the robot Cassie from Agility Robotics
Tasks:	walking at different speeds (0.25 ~ 0.75 m/s) and on different ground inclines -0.08 ~ 0.08 radians
Initial models:	linear inverted pendulum (LIP), LIP with an actuated point-mass swing foot, etc



3D model embedded in Cassie

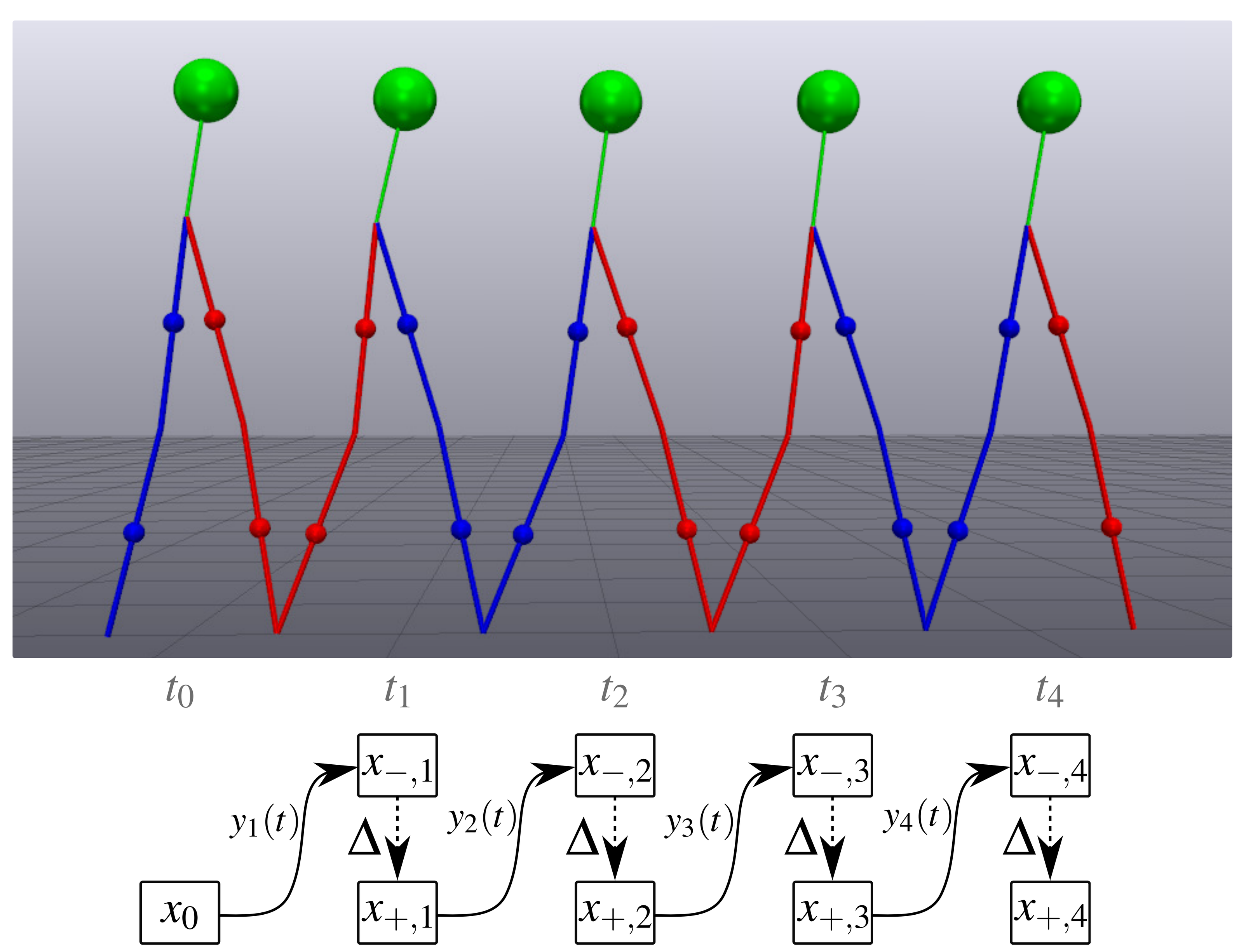


Planning with Reduced-order Models

The reduced-order model only captures the continuous dynamics, and perfect embedding of a reduced-order hybrid model is often impossible

$\Downarrow$

We mix the reduced-order model with the discrete dynamics from the full-order model.



Results

Tasks	Runtime
walk 0.5 m in 1 stride	0.2 seconds (vs. tens of seconds for full model)

Yu-Ming Chen and Michael Posa. Optimal reduced-order modeling of bipedal locomotion. *To appear in ICRA*, 2020. `https://dair.seas.upenn.edu/publications/` (video included)